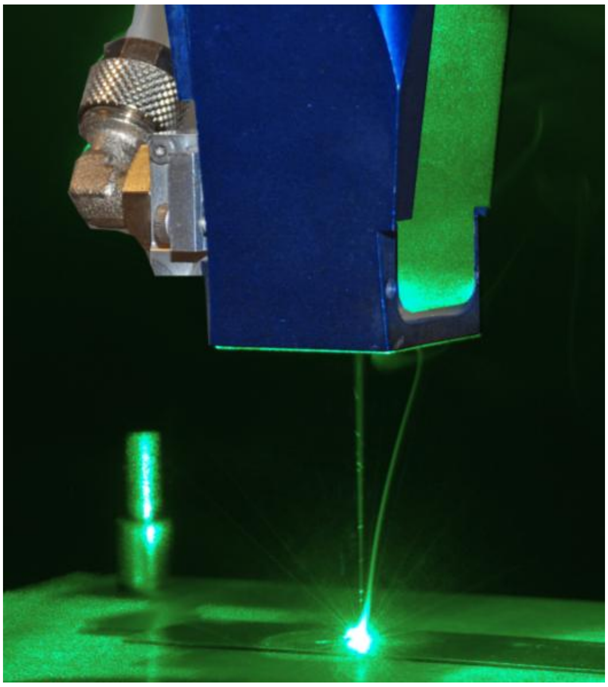
Wissenschaftliche Gesellschaft Lasertechnik e.V.

WLT LiM 2015

LASERS IN MANUFACTURING 2015

Timetable + Abstracts



Munich ICM
Internationales Congress
Center München, Germany

June 22-25, 2015

www.wlt.de/lim

WORLD OF PHOTONICS CONGRESS

www.photonics-congress.com

Preface

Within the International Year of Light and Light-based Technologies, proclaimed by the UN General Assembly, it is worthwhile to take a look at the contribution of laser technologies to our daily life and to actual developments. At the World of Photonics congress this will be done with respect to many different aspects. The use of lasers in production technology will be addressed by the LiM conference. Compared to the situation a few years ago, the role of lasers in manufacturing has changed or, more precisely, has become twofold: One is the continued extension of the influence of lasers by enabling new processes or process variants. The second is the laser as an established tool in industrial processes, where high power lasers are no more an exotic experiment but just a commodity. Despite the fact that the laser-based processes are well accepted and adapted in industrial daily life, there are still significant efforts ongoing to enhance precision, reliability and effectivity. In the first mentioned category of processes there still has to be fundamental research and development to implement new ideas also in production. As an example new materials like press hardened steel have to be joined and laser technology brings a very important prerequisite of low line energy in brazing and welding. In tool making, new materials, especially surface coatings and structures for extreme mechanical and tribological loads and high number of process cycles are needed to realize dry metal forming. Dry metal forming omits lubricants to protect the environment, but the stress on the forming tools increases. Process developments for such applications long for new high-power lasers such as ultrafast lasers with pulse widths of some ps at average powers exceeding 1 kW. Using those and other new developments, new processes can be worked out. The 3D printing of metallic components is another example for a process, which is nowadays at the threshold to industrial use. Applications in medical and biological fields are maybe the next areas which will come up.

The WLT – Wissenschaftliche Gesellschaft Lasertechnik – is the German association of scientists who are leading the larger institutes working on laser technology in Germany. The association promotes collaboration between the scientists linked to the WLT and their institutes, foster education in summer schools and classes, develops new research programs, and last but not least organizes the LiM.

The LiM– International Conference on Lasers in Manufacturing – is the platform for discussing scientific and application oriented contributions from research and development in universities, institutes and industry. It brings together young scientist, experienced researchers and people from industry. The mutual exchange opens chances for the application of new ideas to solve actual problems and gives impulses for new research work. In more than 230 contributions – the largest number since the launch of the LiM conference series in 2001 – from 28 countries all over the world actual results will be presented and discussed.

Such a conference cannot run without the help of a large number of unresting helping hands. We therefore like to express our gratitude to all members of the Organizing Committee and the Scientific Committee for their valuable support of the preparation of the LiM. Special thanks for the organization of the conference reception is due to our colleague Prof. M. Zäh.

We hope that the conference venue, the reception, the proceedings and especially the contents meet your demands and are helpful for your further work in research, development or application of laser technology!

Munich, June 2015

On behalf of the WLT: The Chairmen of LiM 2015

Prof. Thomas Graf - Prof. Claus Emmelmann - Prof.Ludger Overmeyer - Prof. Frank Vollertsen

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F. Vollertsen, BIAS Bremen, Germany
K. Wegener, ETH Zurich, Switzerland
M. Zäh, TU Munich, Germany

Chairs

General Chair: **Prof. Dr. phil. nat. Thomas Graf**, University of Stuttgart, Germany

Chair Macro Materials Processing: **Prof. Dr.-Ing. Frank Vollertsen**, BIAS Bremen, Germany

Chair Micro Materials Processing: **Prof. Dr.-Ing. Ludger Overmeyer**, LZH, Germany

Chair Joint Sessions with ECLEO (for LiM):**Prof. Dr.-Ing. Ludger Overmeyer**, LZH, Germany

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Organizer

WLT Wissenschaftliche Gesellschaft Lasertechnik e.V.

The German Scientific Laser Society (www.wlt.de)

in cooperation with

Institut für Strahlwerkzeuge

University of Stuttgart, Germany

IFSW UNIVERSITÄT STUTTGART INSTITUT FÜR STRAHLWERKZEUGE STUTTGART LASER TECHNOLOGIES

Universität Stuttgart

and

Applied Laser Technologies

Ruhr-Universität Bochum, Germany

LAT

RUHR UNIVERSITÄT BOCHUM RUB

We wish to sincerely thank Messe München GmbH and our partners

AILU the association of laser users · ELI European Laser Institute · JLPS · LIA Laser Institute of America Laser Applications and Safety · SLN

LiM2015 Get-Together-Evening

at Augustiner Keller in Munich

WLT is very pleased to invite you to a Get-Together-Evening at the Augustiner Keller in Munich. The restaurant is one of the most popular meeting places for locals and guests from all over the world who value the charm of Bavarian tradition.
The evening is organized by Prof. M. Zäh, TU München.

Date: Tuesday, 23. June 2015

Time: 7 to 11 pm

Venue: Augustiner Keller, Arnulfstr. 52, 80335 München

http:// www.augustinerkeller.de/

LiM2015 Advance Program, Monday, 22.6.2015

08:00 - 09:00	**Registration**	

	ICM Ground Floor/1st Floor, Room 1	
	WoP Opening and Plenary Session	
09:00 - 11:00	WoP-Opening Ceremony and Plenary Session	*WoP*

Coffee break

	ICM 1st Floor, Room 13b	
	LiM Plenary Session and WLT ceremony, Chair A. Ostendorf & T. Graf	
11:15 - 11:30	Welcome to LiM	*Andreas Ostendorf* *Thomas Graf*
11:30 - 12:00	The Extreme Light Infrastructure (ELI)	*Wolfgang Sandner*
12:00 - 12:30	Laser-sintering: laser-based industrial 3D printing	*Tobias Abeln*
12:30 - 12:45	WLT Award Ceremony	*Andreas Ostendorf*
12:45 - 13:15	Price Winning Topic	*Price Winner*

Lunch

LiM2015 Advance Program, Monday, 22.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Macro Processing: Joining (Welding, Brazing) (Mo_A2_1), Chair U. Reisgen

Time	Title	Authors
14:30 - 14:45 14:45 - 15:00	Flow and bead formation characteristics in high power laser welding at different welding positions (Invited)	*Suck-Joo Na* *Sang-Woo Han, Sohail Muhammad, Linjie Zhang, Andrey Gumenyuk, Michael Rethmeier, Miikka Karhu, Veli Kujanpaa*
15:00 - 15:15	Energy-Efficient Industrial Production with High-Power Disk- and Direct Diode-Lasers	*Matthias Koitzsch* *Volker Rominger*
15:15 - 15:30	Yb:fiber laser joining of Ti-6Al-4V and AA6013 dissimilar metals	*Aline Capella Oliveira* *Rudimar Riva, Natalia Maria Antonangelo Athanazio*
15:30 - 15:45	Influence of different zinc coatings on laser brazing of aluminum to steel	*Tim Radel* *Marius Gatzen, Peer Woizeschke, Claus Thomy*
15:45 - 16:00	Laser Beam Welding of press hardened ultra-high strength 22MnB5 steel	*Benjamin Gerhards* *Uwe Reisgen, Simon Olschok, Oliver Engels*

Coffee break

Macro Processing: Joining (Welding, Brazing) (Mo_A2_2), Chair J. Powell

Time	Title	Authors
16:30 - 16:45	3D-capable Coaxial Laser Brazing Head	*Alexander Gatej* *Markus Kogel-Hollacher, David Blázquez-Sánchez, Andreas Bobrowski, Andreas Niete, Nicholas Blundell, Kevin Withers*
16:45 - 17:00	Robust false friend detection via thermographic imaging	*Karin Heller* *Steffen Kessler, Friedhelm Dorsch, Peter Berger, Thomas Graf*
17:00 - 17:15	Correlation of keyhole dynamics and pore formation	*Joerg Volpp* *Frank Vollertsen*
17:15 - 17:30	Properties of steel-aluminum joints generated by combining continuous and pulsed laser radiation	*Sascha Frank*
17:30 - 17:45	Laser-GMA-Hybrid Welding of high strength multi-material joints	*Felix Möller* *Helge Kügler, Sven-F. Goecke, Frank Vollertsen*
17:45 - 18:00	Laser cleaning of Aluminium alloy for automotive component welding (Invited)	*Lin Li*

LiM2015 Advance Program, Monday, 22.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Micro Processing: Surface Functionalization (Mo_A32_1), Chair A. Conzelmann

Time	Title	Authors
14:30 - 14:45 14:45 - 15:00	Laser based surface structuring for lightweight design (Invited)	*Max Kahmann* *Ulf Quentin, Marc Kirchhoff, Rüdiger Brockmann, Klaus Löffler*
15:00 - 15:15	Investigation and application of laser induced surface functionalization with pulse delays between 40ns and 50µs on silicon and steel foils	*Viktor Schütz* *Jürgen Koch, Oliver Suttmann, Ludger Overmeyer*
15:15 - 15:30	One-Step Generation of Ultrahydrophobic Aluminum Surface Patterns by Nanosecond Lasers	*José L. Ocaña* *Radhakrishnan Jagdheesh, Juan J. García-Ballesteros*
15:30 - 15:45	Structuring of injection moulding tools with ultrashort laser pulses for surface functionalization after casting	*Felix Dreisow* *Sebastian Wächter, Sabine Sändig*
15:45 - 16:00	Laser beam propagation and energy deposition in particulate PEEK layers	*Hendrik Sändker* *Jochen Stollenwerk, Johannes Hofmann, Peter Loosen*

Coffee break

Micro Processing: Surface Functionalization (Mo_A32_2), Chair A. Conzelmann

Time	Title	Authors
16:30 - 16:45	Use of high-energy laser radiation for surface preparation of magnesium for adhesive applications	*Norbert Schneider* *Christian Wrobel, Jens Dr. Holtmannspoetter, Guenther Prof. Dr. Loewisch*
16:45 - 17:00	Nanostructures fabricated by laser interference lithography and their potential applications	*Evaldas Stankevičius* *Mantas Garliauskas, Gediminas Račiukaitis*
17:00 - 17:15	Investigation of the influence of laser surface modifications on the adhesive wear behavior in dry cold extrusion of aluminum	*Ingo Roß* *André Temmler, Edgar Willenborg, Marco Teller*
17:15 - 17:30	Fabrication of graphene-chitosan electrodes for sensing applications by laser induced modification of the composite film	*Romualdas Trusovas* *Raimonda Celiešiūtė, Rasa Pauliukaite, Gediminas Račiukaitis*
17:30 - 17:45	Influence of laser marking on stainless steel surface and corrosion resistance	*Martin Kucera*
17:45 - 18:00	High velocity laser printing of conductive tracks	*Philippe Delaporte* *Daniel Puerto, Emeric Biver, Catalin Constantinescu, Dimitris Karnakis, Anne-Patricia Alloncle*

LiM2015 Advance Program, Monday, 22.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Micro Processing: Micro Joining (Welding and Brazing) (Mo_A31_1), Chair M. Kogel-Hollacher

Time	Title	Authors
14:30 - 14:45	Sputter-free and Reproducible Laser Welding of Electric or Electronic Copper Contacts with a Green Laser	*Elke Kaiser* *Rudolf Huber, Christian Stolzenburg, Alexander Killi*
14:45 - 15:00	Energy efficiency in laser rod end melting	*Heiko Brüning* *Frank Vollertsen*
15:00 - 15:15	Laserwelding of transparent polymer films	*Maximilian Brosda* *Viktor Mamuschkin*
15:15 - 15:30	High precise welding of transparent polymers	*Frederick Vinzent* *Michael Schwalme, Tobias Jaus, Manuel Sieben*
15:30 - 15:45	Direct bonding of transparent PMMA using an ultrafast fiber CPA laser system	*Annalisa Volpe* *Caterina Gaudiuso, Andrea De Rosa, Rebeca Martínez Vázquez, Antonio Ancona, Pietro Mario Lugarà, Roberto Osellame*
15:45 - 16:00	Influence of Welding Parameters and Stack Configuration on Pore Formation of Laser Welded Aluminum Foil Stacks	*Thomas Engelhardt*

Coffee break

Micro Processing: Micro Joining (Welding and Brazing) (Mo_A31_2), Chair M. Kogel-Hollacher

Time	Title	Authors
16:30 - 16:45	Camera based closed-loop control of laser micro-welding processes by observation of the full penetration hole	*Andreas Blug* *Volker Jetter, Daniel Carl, Simon Gutscher, Jan Nekarda*
16:45 - 17:00	Laser welding simulation of microfluidic devices	*Arnaud Francois* *Anne Henrotin, Jose A. Ramos*
17:00 - 17:15	Thermal analysis of Laser Transmission Welding of thermoplastics: Indicators of weld seam quality	*Adhish Majumdar* *Benjamin Lecroc, Laurent D'Alvise*
17:15 - 17:30	Effect of processing parameters in welding of biocompatible polymer film to metal sheet using an infrared laser source	*Guijun Bi* *Hui-Chi Chen, Juan Carlos Hernandez Castaneda, Hong Xie*
17:30 - 17:45	Adjustment and Impact of the Thermoplastic Microstructure of the Melting Layer in Laser-based Joining of Polymers to Metals	*Klaus Schricker* *Martin Stambke, Jean Pierre Bergmann*
17:45 - 18:00	Laser hybrid joining of plastic and metal components for lightweight assemblies	*Jens Rauschenberger* *Asier Cenigaonaindia, Jan Keseberg, Ulrich Gubler, Fernando Liébana*

LiM2015 Advance Program, Tuesday, 23.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Macro Processing: Joining (Welding, Brazing) (Tu_A2_1), Chair W. Behr

Time	Title	Authors
08:30 - 08:45	Laser welding inspection on aeronautic material with non-contact real-time optical beam deflection sensor	*João Marcos Salvi Sakamoto* *Renan Borges Marques, Rudimar Riva, Cláudio Kitano, Gefeson Mendes Pacheco*
08:45 - 09:00	Three-dimensional, multi-factor monitoring and control of laser keyhole welding by inline coherent imaging	*Paul J. L. Webster* *Christopher M. Galbraith, Cole Van Vlack, Daniel R. Buckley, James M. Fraser*
09:00 - 09:15	3D weld seam characterization based on optical coherence tomography for laser-based thermal joining of thermoplastics to metals	*Philippe Ackermann* *Guilherme Mallmann, Robert Schmitt, Jean Pierre Bergmann, Klaus Schricker, Martin Stambke*
09:15 - 09:30	Influence of a second heat source on the distortion behaviour during laser beam welding	*Falk Nagel* *Jean Pierre Bergmann*
09:30 - 09:45	Controlled metal transfer from wire by a laser-induced boiling front	*Alexander Kaplan* *Mohammad Javad Torkamany, F. Malek Ghaini, Mikko Vänskka, Antti Salminen, Karl Fahlström, Joakim Hedegård*
09:45 - 10:00	Capillary geometries during welding of metals observed with X-ray technique and calculated using a ray-tracing tool and a finite volume program treating heat diffusion and fluid flow	*Peter Wolfgang Berger* *Andreas Heider, Meiko Boley*

Coffee break

Macro Processing: Joining (Welding, Brazing) (Tu_A2_2), Chair S. Olschok

Time	Title	Authors
10:30 - 10:45	Influence of residual stresses induced by forming on the hot cracking sensitivity of laser welding processes of AlMgSi aluminum alloy	*Peter Stritt* *Christian Hagenlocher, Rudolf Weber, Thomas Graf*
10:45 - 11:00	Fundamental analyses of hot cracks in remote laser welded aluminium fillet welds	*Hans Langrieger* *Frank Krafft, Martin Mensinger, Florian Oefele*
11:00 - 11:15	Analysing Hot Crack Formation in Laser Welding of Tempered Steel	*Marcel Schaefer* *Nicolai Speker, Rudolf Weber, Thomas Graf, Thomas Harrer*
11:15 - 11:30	Online crack detection during laser welding using passive thermography	*Daniel Weller* *Peter Stritt, Florian Fetzer, Rudolf Weber, Thomas Graf, Cyrille Bezençon, Jörg Simon, Corrado Bassi*
11:30 - 11:45	Influence of filler wire and focus diameter on crack formation in laser beam welding of high strength aluminum alloys	*Matthias Holzer* *Fabian Hoppe, Vincent Mann, Konstantin Hofmann, Florian Hugger, Stephan Roth, Michael Schmidt*
11:45 - 12:00		

Lunch

LiM2015 Advance Program, Tuesday, 23.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Micro Processing: Surface Functionalization (Tu_A32_1), Chair S. Marzenell

Time	Title	Authors
08:30 - 08:45	Adjustment of surface energy on steel surfaces due to CLP generation by picosecond laser processing	*Tom Häfner* *Johannes Heberle, Daniel Holder, Michael Schmidt*
08:45 - 09:00	Tribological surface functionalization via femtosecond laser-induced periodic surface structures on metals	*Sandra Höhm* *Jörn Bonse, Robert Koter, Manfred Hartelt, Dirk Spaltmann, Simone Pentzien, Stephan Marschner, Alexandre Mermillod-Blondin, Arkadi Rosenfeld, Jörg Krüger*
09:00 - 09:15	Studies on Laser Surface Texturing of Titanium Alloy (Ti-6Al-4V)	*Jyotsna Dutta Majumdar* *Renu Kumary, Heino Besser, Tim Scharnweber, Wilhelm Pfleging*
09:15 - 09:30	Non-uniform micro-texturing of tribological steel surfaces by femtosecond laser ablation	*Antonio Ancona* *Giuseppe Carbone, Michele Scaraggi, Annalisa Volpe, Michele De Filippis, Pietro Mario Lugarà*
09:30 - 09:45	Generation of low-spatial frequency Laser Induced Periodic Surface Structures Driven by Surface Finish	*Stefan Rung* *Florian Preusch, Ralf Hellmann*
09:45 - 10:00	Selective Femtosecond-Laser Structuring of Dielectric Thin Films with Different Band Gaps: A Time-Resolved Study of Ablation Mechanisms	*Stephan Rapp* *Gerrit Heinrich, Heinz P. Huber, Michael Schmidt*

Coffee break

Micro Processing: Processing of Transparent Materials (Tu_A32_2), Chair O. Suttmann

Time	Title	Authors
10:30 - 11:00	Pulsed laser induced photo ablation of diamond (Invited)	*Vitaly Ivanovich Konov* *Vitali Viktorovich Kononenko, Maxim Sergeevich Komlenok*
11:00 - 11:15	Nanosecond laser processing of diamonds	*Jan-Patrick Hermani*
11:15 - 11:30	Laser Induced Micro-Dot Generation Inside Transparent Materials: A) Formation Dynamics, Refractive Character and Internal Stress	*Alexandre Mermillod-Blondin* *Arkadi Rosenfeld, David Ashkenasi*
11:30 - 11:45	Laser Induced Micro-Dot Generation Inside Transparent Materials: B) Process Implementation, Optimization and Utilization	*David Ashkenasi* *Manuela Schwagmeier, Alexandre Mermillod-Blondin, Arkadi Rosenfeld*
11:45 - 12:00	Tuning the Energy Deposition of Ultrashort Pulses inside Transparent Materials for Laser Cutting Applications	*Malte Kumkar* *Klaus Bergner, Daniel Flamm, Daniel Grossmann, Myriam Kaiser, Jonas Kleiner, Stefan Nolte*

Lunch

LiM2015 Advance Program, Tuesday, 23.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Macro Processing: CFRP (Tu_A31_1), Chair A. Gillner

Joint session with ECLEO., Room 13a

Time	Title	Authors
08:30 - 08:45		
08:45 - 09:00	Laser Cutting and Joining in a Novel Process Chain for Fibre Reinforced Plastics	*Frank Schneider* *Christoph Engelmann, Norbert Wolf, Wolfgang Moll, Dirk Petring*
09:00 - 09:15	Analytical Model for Laser Cutting of Carbon Fiber Fabrics: Maximum Cutting Speed and Heat Affected Zone	*Alexander N. Fuchs* *Thomas Woldrich, K. Manfred Heimhilger, Michael F. Zaeh*
09:15 - 09:30	Ultrafast Lasers Jump to Macro Applications	*Martin Griebel* *Jan Langebach*
09:30 - 09:45	Effect of several gas ambiences on HAZ suppression in CFRP cutting with nanosecond laser	*Yuji Sato* *Masahiro Tsukamoto, Fumihiro Matsuoka, Kensuke Yamashita, Kenjiro Takahashi, Shinichiro Masuno*
09:45 - 10:00	Analysis of potentially hazardous substances emitted during laser processing of carbon fiber reinforced plastics	*Jürgen Walter* *Christian Hennigs, Michael Huse, Michael Hustedt, Stefan Kaierle, Ludger Overmeyer*

Coffee break

Macro Processing: CFRP (Tu_A31_2), Chair A. Gillner

Time	Title	Authors
10:30 - 10:45	High Power UV Laser Processing of CFRP with Short ns Pulses and Pulse Splitting	*Masayuki Fujita* *Hiroshi Ohkawa, Toshihiro Somekawa, Takaomi Matsutani, Yoshinobu Maeda, Jim Bovatsek, Rajesh Patel, Noriaki Miyanaga*
10:45 - 11:00	Theoretical and experimental determination of the polarization dependent absorptance of laser radiation in carbon fibers and CFRP	*Christian Wilhelm Freitag* *Lukas Alter, Rudolf Weber, Thomas Graf*
11:00 - 11:15	Metal meets Composite - Hybrid Joining for Automotive Applications	*Christoph Engelmann* *Daniel Meier, Alexander Olowinsky, Mathieu Kielwasser*
11:15 - 11:30	Temperature monitoring independent of laser-beam-position during laser transmission welding of fibre reinforced thermoplastics	*Oliver Suttmann* *Hagen Dittmar, Verena Wippo, Peter Jaeschke, Helmut Kriz, Chris Beaver, Ludger Overmeyer*
11:30 - 11:45	Cutting of CFRP with short-pulsed lasers at 1 µm and 10 µm wavelength and average powers of more than 1 kW	*Margit Wiedenmann* *Christian Freitag, Matthias Haug, Volkher Onuseit, Rudolf Weber, Thomas Graf*
11:45 - 12:00		

Lunch

LiM2015 Advance Program, Tuesday, 23.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Macro Processing: Joining (Welding, Brazing) (Tu_A2_3), Chair M. Rethmeier

Time	Title	Authors
14:00 - 14:15	Fundamental Research of 100 kW Fiber Laser Welding Technology (Invited)	*Seiji Katayama* *Masami Mizutani, Yousuke Kawahito, Shingo Ito, Daichi Sumimori*
14:15 - 14:30		
14:30 - 14:45	Influence of Ambient Pressure on Spatter Formation during Laser Welding of Copper	*Andreas Heider* *Thomas Engelhardt, Rudolf Weber, Thomas Graf*
14:45 - 15:00	Laser Beam Welding in Vacuum – Overview of Thick-Plate Steel Application and Beyond	*Stefan Jakobs* *Uwe Reisgen, Simon Olschok, Christoph Turner*
15:00 - 15:15	Multispot laser welding to improve process stability	*Klaus Schütt Hansen* *Flemming O. Olsen, Morten Kristiansen, Ole Madsen*
15:15 - 15:30	Online Detection of Pore Formation during Laser Deep-Penetration Welding	*Meiko Boley* *Rudolf Weber, Thomas Graf*

Coffee break

Macro Processing: Joining (Welding, Brazing) (Tu_A2_4), Chair R. Holtz

Time	Title	Authors
16:00 - 16:15	Influence of laser power modulation on the time-resolved temperature distribution in the weld pool during laser welding of copper to aluminum	*Michael Jarwitz* *Florian Fetzer, Peter Stritt, Rudolf Weber, Thomas Graf*
16:15 - 16:30	Simulation of Laser Welding of Dissimilar Metals	*Rodrigo Gómez Vázquez* *Andreas Otto, Gerhard Liedl, Robert Feichtenschlager*
16:30 - 16:45	Laser Power Modulation to Minimize the Electrical Resistance of Auminum-Copper Welds	*Florian Fetzer* *Michael Jarwitz, Rudolf Weber, Thomas Graf*
16:45 - 17:00	Influence of filler wires on weld seam properties of laser beam welded dissimilar copper connections	*Vincent Mann* *Matthias Holzer, Fabian Gärtner, Florian Hugger, Stephan Roth, Michael Schmidt*
17:00 - 17:15	Comparison of Mechanical and Microstructural Characteristics in Maraging 300 Steel Welded by three different processes: LASER, PLASMA and TIG.	*Antonio Jorge Abdalla* *Milton Sérgio Fernandes Lima, Leonardo Fanton, Cecília Vieira Gomes, Sandro Lombardo, Deivid Ferreira Silva, Paulo Roberto Sakai*
17:15 - 17:30	Keyhole shape and element loss in laser beam welding of brass alloys	*Florian Hugger* *Vincent Mann, Matthias Holzer, Stephan Roth, Michael Schmidt*
17:30 - 17:45	Experimental Studies of Fiber Laser Welding of a Range of Dissimilar Material Combinations	*Mohammed Naeem*
19:00 - 23:00	**LiM Get together**	**Augustiner Bier Keller**

LiM2015 Advance Program, Tuesday, 23.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Micro Processing: Processing of Transparent Materials (Tu_A32_3), Chair O. Suttmann

Time	Title	Authors
14:00 - 14:15	Laser-Induced Subsurface Modification of Silicon Wafers (Invited)	*Paul Christiaan Verburg* *Lachlan Smillie, Gert-Willem Römer, Bianca Haberl, Jodie Bradby, Jim Williams, Bert Huis in 't Veld*
14:15 - 14:30		
14:30 - 14:45	Investigation on Bragg grating formation in a perfluorinated polymer optical fiber	*Simon Kibben* *Michael Koerdt, Frank Vollertsen*
14:45 - 15:00	New approach for laser processing of transparent materials	*Michael Grimm* *Michael Werner, Robin Zimny*
15:00 - 15:15	Straightforward Laser Machining of Thin Glass	*David Ashkenasi* *Tristan Kaszemeikat, Norbert Mueller*
15:15 - 15:30	Influence of Pulse Duration on the Glass Cutting Process	*Lara Bauer* *Uwe Keller, Simone Russ, Malte Kumkar, Birgit Faisst, Thomas Graf*

Coffee break

Micro Processing: Processing of Transparent Materials (Tu_A32_4), Chair O. Suttmann

Time	Title	Authors
16:00 - 16:15	Laser controlled ion exchange process and its applications	*Xinghua Li* *Garner Sean*
16:15 - 16:30	Fabrication of micropump device with mixing functionality in fused silica with ultrashort laser pulses	*Valdemar Stankevič* *Gediminas Račiukaitis*
16:30 - 16:45	Laser line etching technique using the nozzle-induced bubble jet impact for glass	*Chwan-Huei Tsai* *Di-Wen Chiue*
16:45 - 17:00	Rear Side Processing of Soda-Lime Glass Using DPSS Nanosecond Laser	*Juozas Dudutis* *Paulius Gečys, Gediminas Račiukaitis*
17:00 - 17:15	Glass Processing with High Power Q-Switch CO2 Laser Radiation	*Sebastian Heidrich* *Christian Weingarten, Edgar Willenborg, Reinhart Poprawe*
17:15 - 17:30	Precise structuring by 2-photon absorption in positive photoresist materials	*Gordon Zyla* *Andreas Aumann, Sarah Isabelle Ksouri, Evgeny Gurevich, Andreas Ostendorf*
17:30 - 17:45	Thermal simulation of confined SiO2/Si laser ablation	*Regina Moser* *Niko Burkard, Jürgen Sotrop, Heinz P. Huber, Gerd Marowsky*
19:00 - 23:00	**LiM Get together**	**Augustiner Bier Keller**

LiM2015 Advance Program, Tuesday, 23.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Macro Processing: CFRP (Tu_A31_3), Chair M. Zäh

Joint session with ECLEO.. Room 13a

Time	Title	Authors
14:00 - 14:15	Experimental and analytical description of the multi-wavelength remote-laser ablation process at fiber reinforced polymers	*Michael Rose* *Andreas Fürst, Dominik Hipp, Annett Klotzbach, Jan Hauptmann, Andreas Wetzig, Eckhard Beyer*
14:15 - 14:30	Remote Laser Cutting of CFRP: Increased Fatigue Strength as a Consequence of the Heat Affected Zone	*Johannes Wolfgang Stock* *Michael F. Zaeh*
14:30 - 14:45	Correlation between temperature field and heat affected zone during laser cutting of CFRP	*Marten Canisius* *Max Oberlander, Dirk Herzog, Matthias Schmidt-Lehr, Petter Ploog, Claus Emmelmann*
14:45 - 15:00	Laser-remote-cutting of large-scale semi-finished carbon-fibre products using a solid state laser	*Max Oberlander* *Matthias Schmidt-Lehr, Dirk Herzog, Marten Canisius, Claus Emmelmann*
15:00 - 15:15	Productive Laser Processing of CFRP	*Volkher Onuseit* *Torben Prieß, Christian Freitag, Margit Wiedenmann, Birgit Faisst, Roswitha Giedl-Wagner, Thomas Rettich, Rudolf Weber, Peter Middendorf, Thomas Graf*
15:15 - 15:30		

Coffee break

(Tu_A31_4),

Joint session with ECLEO.. Room 13a

Time	Title	Authors
16:00 - 16:15		
16:15 - 16:30		
16:30 - 16:45		
16:45 - 17:00		
17:00 - 17:15		
17:15 - 17:30		
17:30 - 17:45		
19:00 - 23:00	**LiM Get together**	**Augustiner Bier Keller**

LiM2015 Advance Program, Wednesday, 24.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Time	Macro Processing: Joining (Welding, Brazing) (We_A2_1), Chair J.-P. Bergmann	
08:30 - 08:45	Influence of Laser Power and Wavelength on the Resonant Interaction between Laser Radiation and TIG Welding Arc	*Jörg Hermsdorf* *Benjamin Emde, Michael Huse, Stefan Kaierle, Volker Wesling, Ludger Overmeyer*
08:45 - 09:00	Crack-Free autogenous one-side laser welding of a 6013 aluminium alloy-joint for aircraft applications	*Rudimar Riva* *Rafael Humberto Mota de Siqueira, Milton Sérgio Fernandes de Lima*
09:00 - 09:15	Laser Beam Welding of WASPALOY for Aeronautic Engine Application	*Reza Shoja Razavi*
09:15 - 09:30	Modeling of powder consolidation coupled with heat transfer at selective laser melting of fused silica	*Andrey V. Gusarov* *Roman S. Khmyrov, Cyrill E. Protasov*
09:30 - 09:45	Properties of large 3D parts made from Stellite 21 through direct powder deposition	*Hannes Freiße* *Pavel Khazan, Malte Stroth, Henry Köhler*
09:45 - 10:00	High Strength Al-Cu Alloys Processed Using 400W Selective Laser Melting	*Daniel Koutny* *David Palousek, Ondrej Koukal, Tomas Zikmund, Libor Pantelejev, Filip Dokoupil*

Coffee break

Time	Micro Processing: Ablation, Drilling and Micro-Cutting (We_A2_2), Chair A. Ostendorf	
10:30 - 10:45 10:45 - 11:00	Multi parallel ultrashort pulse laser processing (Invited)	*Arnold Gillner* *M. Jüngst, P. Gretzki*
11:00 - 11:15	Investigation of Femtosecond Laser Texturing in Cemented Carbide Cutting Tools	*Wagner de Rossi* *Patrícia Alves Barbosa, Marcelo Bertolete, Ricardo Elgul Samad, Nilson Dias Vieira Júnior, Izabel Fernanda Machado, Álisson Rocha Machado, Rui Vilar*
11:15 - 11:30	Shorter than short: How does the pulse duration influence the process efficiency and the quality of conductive materials?	*Simone Russ* *Uwe Keller, Lara Bauer, Tilo Meyer, Raphael Gebs, Birgit Faisst, Jörg Roller, Benjamin Führa*
11:30 - 11:45	Laser micro structuring using adaptive mirror for extra-cavity beam-shaping of high-power ultra-short laser pulses	*Marco Smarra* *Johannes Neyer, Klaus Dickmann, Jean Pierre Bergmann*
11:45 - 12:00	Cutting diamond tools using the Laser MicroJet® technology on a 5 axis machine	*Annika Richmann* *Sébastien Kurzen, Benjamin Carron, Bernold Richerzhagen*

Lunch

LiM2015 Advance Program, Wednesday, 24.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Time	Macro Processing: Surface Treatment and Cladding (We_A32_1), Chair T. Seefeld	
08:30 - 08:45	Additive manufacturing of a deep drawing tool	*Hannes Freiße* *Jochen Vorholt, Thomas Seefeld, Frank Vollertsen*
08:45 - 09:00	Influence of a short time heat treatment on the formability and aging characteristics of aluminum profiles	*Matthias Graser* *Marion Merklein, Michael Lechner*
09:00 - 09:15	Laser Surface Treatment of electroless Ni–P-SiC coating on Al356 alloy	*Reza Shoja Razavi* *Sayed Hamid Hashemi*
09:15 - 09:30	Characterization of the effect of laser scribing on the isolation coating of electrical steel	*Peter Rauscher* *Jan Hauptmann, Jörg Kaspar, Andreas Wetzig, Eckhard Beyer*
09:30 - 09:45	Reconditioning of lamellar graphite cast iron parts by means of Laser-Cladding and heuristic-based process parameter adaption	*Dipl.-Ing. Mauritz Möller* *Prof. Dr.-Ing. Claus Emmelmann*
09:45 - 10:00	Surface structuring by laser remelting of Inconel 718	*André Temmler* *Tobias Schmickler, Edgar Willenborg, Konrad Wissenbach*

Coffee break

Time	Macro Processing: Surface Treatment and Cladding (We_A32_2), Chair T. Seefeld	
10:30 - 10:45 10:45 - 11:00	Reconditioning of HPT Blade Tips (Invited)	*Knut Partes*
11:00 - 11:15	High Speed Quasi-CW Fibre Laser Drilling of Aerospace Alloys	*Sundar Marimuthu* *Mohammad Antar, Dimitrios Chantzis*
11:15 - 11:30	Developments on Laser Drilling in Gas Turbine Blades	*Thomas Beck* *Jens Dietrich*
11:30 - 11:45	Development of a wire based laser alloying process for highly stressed surfaces of hot forming steel tools	*Konstantin Hofmann* *Matthias Holzer, Stefan Lutz, Steffen Schmitt, Vincent Mann, Florian Hugger, Stephan Roth, Michael Schmidt*
11:45 - 12:00	Inner walls laser cladding of WC reinforced Ni coatings	*Josu Leunda* *Carlos Soriano, Carmen Sanz*

Lunch

LiM2015 Advance Program, Wednesday, 24.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Time	Macro Processing: Cutting (We_A31_1), Chair A. Lüdi	
08:30 - 08:45	Theoretical Analysis of Laser Cutting of Metals at 1 and 10 micrometer wavelength	*Michael Heinrich Brügmann*
08:45 - 09:00	Performance and efficiency of an industrial direct diode source with an extremely low BPP in laser cutting of Fe-based and reflective alloys	*Barbara Previtali* *Giovanni Riva, Erica Librera, Maurizio Sbetti, Mattia Vanin, Giacomo Biscaglia, Francesco Villa, Bien Chann, Bryan Lockman*
09:00 - 09:15	Effect of the laser beam polarization state on the laser cut surface quality	*Alexander Golyshev* *Victor Shulyatyev, Anatoly Orishich*
09:15 - 09:30	Multiple Wavelength Laser Processing Technology for Flexible Manufacturing	*Joe Hillman* *Yefim Sukhman, Chris Risser*
09:30 - 09:45	Remote laser cutting of composites with a fibre guided thin-disk nanosecond high power laser	*Sven Bluemel* *Veit Angrick, Stefan Bastick, Peter Jaeschke, Oliver Suttmann, Ludger Overmeyer*
09:45 - 10:00	F-Theta at Jenoptik - a holistic approach	*Tim Baldsiefen*

Coffee break

Time	Macro Processing: Cutting (We_A31_2), Chair A. Wetzig	
10:30 - 10:45 10:45 - 11:00	Laser or Plasma Cutting – Is there a Choice? (Invited)	*Volker Krink* *Thomas Dr. Rümenapp, Michael Dr. Schnick, Nicole Dönicke*
11:00 - 11:15	Laser Micro-Cutting of Thick Tungsten Sheets	*Ramūnas Šniaukas* *Gediminas Račiukaitis*
11:15 - 11:30	The influences of pulse overlap on cut quality during fiber laser cutting of electrodes for Lithium-ion batteries	*Tobias Reincke* *Stefan Kreling, Klaus Dilger*
11:30 - 11:45	Basic imaging and modelling analysis of the processing front in laser remote fusion cutting	*Ramiz .S. Matti* *Alexander F.H. Kaplan*
11:45 - 12:00	Temporally and spatially resolved measurement of the cut front geometry while cutting with a solid-state laser	*Oliver Bocksrocker* *Tim Hesse, Peter Berger, Meiko Boley, Thomas Graf*

Lunch

LiM2015 Advance Program, Wednesday, 24.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Micro Processing: Ablation, Drilling and Micro-Cutting (We_A2_3), Chair C. Esen

Time	Title	Authors
14:00 - 14:15	Influence of coaxial cw laser heating on the ablation of silicon with ultra-fast lasers	*Christian Fornaroli* *Arnold Gillner*
14:15 - 14:30	Effects of ultrashort laser ablation in copper and stainless steel	*Wagner de Rossi* *Denilson de Camargo Mirim, Nilson Dias Vieira Júnior, Ricardo Elgul Samad*
14:30 - 14:45	Direct Laser Beam Interference Patterning for Fabrication of Plasmonic Hole Arrays	*Simonas Indrisiunas* *Bogdan Voisiat, Gediminas Raciukaitis*
14:45 - 15:00	Temporal evolution of hole-geometry and influences of energy deposition during ultra-short pulses helical drilling	*Chao He* *Claudia Hartmann, Christian Fornaroli, Frank Zibner, Arnold Gillner*
15:00 - 15:15	Laser Micro-drilling of Multi-layered Artificial Skin	*Yasuhiro Okamoto* *Kiichi Asako, Akira OKADA, Shogo Minagi, Naoto Maeda, Qiuyue Pan, Keiji Jin, Goro Nishigawa*
15:15 - 15:30	Energy transfer mechanisms during laser pulsed processing of metals	*Daniel Johannes Förster* *Volkher Onuseit, Rudolf Weber, Thomas Graf*

Coffee break

Micro Processing: Ablation, Drilling and Micro-Cutting (We_A2_4), Chair Y. Okamoto

Time	Title	Authors
16:00 - 16:15	Highly reproducible laser micro drilling of titanium-based HLFC sections	*Hamza Messaoudi* *Salar Mehrafsun, Geza Schrauf, Frank Vollertsen*
16:15 - 16:30	Calculating the optimal combination of pulse-to-pulse distance and fluence for scribing and patterning with ultrashort pulsed lasers	*Matthias Domke* *Giovanni Piredda*
16:30 - 16:45	Laser ablation of SiCp/Al composite	*Huanzhen Zhang* *Ting Huang, Rongshi Xiao*
16:45 - 17:00	Computational Study on the Effect of the Pulse Length on Laser Ablation Processes	*Stefan Tatra* *Rodrigo Gómez Vázquez, Andreas Otto*
17:00 - 17:15	Scaling of ablation rates. Ablation efficiency and quality aspects of “Burstmode”-micromachining of metals.	*Marc Sailer* *Jonas Kleiner, Myriam Kaiser, Simone Russ*
17:15 - 17:30	Analysis of shape geometry of Ti6Al4V parts fabricated by nanosecond laser ablation	*Sabina Luisa Campanelli* *Nicola Contuzzi, Fulvio Lavecchia, Gianluca Percoco*
17:30 - 17:45	Crater shape dependence on pulse duration in crystalline silicon generated using an IR Gaussian laser beam: from femtosecond to microsecond regime	*Stefano Buratin* *Carol Kong*

LiM2015 Advance Program, Wednesday, 24.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Macro Processing: Surface Treatment and Cladding (We_A32_3), Chair K. Partes

Time	Title	Authors
14:00 - 14:30	Sensors, modelling, real time process control and monitoring of laser cladding (Invited)	*Pascal Aubry*
14:30 - 14:45	Deposition of Corrosion Resistant Alloy on to Low Alloyed Steel using LAAM for Oil & Gas Applications	*Guijun Bi* *Hui-chi Chen, Bing Yang Lee, Beng Siong Lim*
14:45 - 15:00	High speed micro cladding using a high-power single-mode continuous-wave fiber laser and a polygon scanning system	*Martin Erler* *Robby Ebert, Stefan Gronau, Matthias Horn, Sachsa Klötzer, Horst Exner*
15:00 - 15:15	Selective Copper Plating on Polymers Induced by Laser Activated Fillers	*Karolis Ratautas* *Mindaugas Gedvilas, Ina Stankevičienė, Aldona Jagminienė, Eugenijus Norkus, Nello Li Pira, Stefano Sinopoli, Umberto Emanuele, Gediminas Račiukaitis*
15:15 - 15:30	Free-form fabrication of steel parts by multi-layer laser cladding	*Carmine Signorile* *Sabina Luisa Campanelli, Andrea Angelastro, Giuseppe Casalino, Antonio Domenico Ludovico*

Coffee break

Macro Processing: Surface Treatment and Cladding (We_A32_4), Chair K. Partes

Time	Title	Authors
16:00 - 16:30	Industrial Laser Technologies for Shipbuilding (Invited)	*Valeriy M. Levshakov* *Aleksandr N. Aleshkin, Natalia A. Steshenkova, Gleb A. Turichin, Nikolay A. Nosyrev*
16:30 - 16:45	Laser direct metal deposition for alloy development: use of nominal composition alloy powder as compared to mixed powder feeding with matched composition	*Javier Montero* *Maria Jose Tobar, Jose Manuel Amado, Eva Díaz, Armando Yáñez*
16:45 - 17:00	Effect of Sensitization on Pitting Corrosion Resistance of Laser Melting 304 Stainless Steel	*sami Ibrahim Al-rubaiey* *Mohammed Jasim Kadhim Al-Tameemi, Zaman abdualrazaq abdualwahab*
17:00 - 17:15	Influence of particle size on heat affected zone in laser cladding	*Daichi Tanigawa* *Nobuyuki Abe, Masahiro Tsukamoto, Yoshihiko Hayashi, Hiroyuki Yamazaki, Yoshihiro Tatsumi, Mikio Yoneyama*
17:15 - 17:30	Analysis and optimization of process parameters in Al-SiCp laser cladding	*Ainhoa Riquelme Aguado*
17:30 - 17:45	Strategies for high deposition rate additive manufacturing by Laser Metal Deposition	*Antonio Candel Ruiz* *Oliver Müllerschön, Simon Abt*

LiM2015 Advance Program, Wednesday, 24.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Macro Processing: Cutting (We_A31_3), Chair L.D. Scintilla

Time	Title	Authors
14:00 - 14:15	Optical cutting tear detection system for industrial fiber laser based cutting machines	*Benedikt Adelmann* *Benedikt Neumeier, Max Schleier, Eugen Wilmann, Ralf Hellmann*
14:15 - 14:30	Modeling of Transport Phenomena in Metal Fusion Cutting Using High Power Laser	*Karim Kheloufi* *El Hachemi Amara*
14:30 - 14:45	Dynamic beam shaping for laser fusion cutting	*Cindy Goppold* *Thomas Pinder, Patrick Herwig, Achim Mahrle, Andreas Wetzig, Eckhard Beyer*
14:45 - 15:00	Flow diagnostice produced by SLM laser cutting nozzles	*Stefan Ulrich* *Simon Jahn, Sabine Sändig, Burkhardt Fleck*
15:00 - 15:15	Innovative distance control for laser cutting based on inline low coherence interferometry	*Guilherme Mallmann* *Robert Schmitt, Timo Kosanke*
15:15 - 15:30	Areas of application for TEA CO2-Laser induced shock waves	*Stefan Veenaas* *Frank Vollertsen*

Coffee break

Macro Processing: Process Monitoring and Control (We_A31_4), Chair S. Katayama

Time	Title	Authors
16:00 - 16:15	Use of inline coherent imaging for laser welding processes: Process control and beyond	*Thibault Bautze* *Markus Kogel-Hollacher*
16:15 - 16:30	Seam tracking for fillet welds with scanner optics	*Friedhelm Dorsch* *Holger Braun, Dieter Pfitzner*
16:30 - 16:45	Using optical measuring techniques to investigate the hot cracking susceptibility of laser welded joints	*Nasim Bakir* *Andrey Gumenyuk, Michael Rethmeier*
16:45 - 17:00	How fast is fast enough in the monitoring and controlling of laser welding?	*Felix Tenner* *Florian Klämpfl, Michael Schmidt*
17:00 - 17:15	Autocorrelation analysis of plasma plume oscillations in deep penetration laser welding	*Libor Mrňa* *Martin Šarbort*
17:15 - 17:30	On the detection of defects and of incorrect actuator settings in laser machining	*Ralph Hohenstein*
17:30 - 17:45		

LiM2015 Advance Program, Thursday, 25.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Micro Processing: Ablation, Drilling and Micro-Cutting (Th_A2_1), Chair A. Gillner

Time	Title	Authors
08:30 - 08:45	Nanoparticles fabricated by laser ablation in liquids for biomedical and energy applications	*Stephan Barcikowski*
08:45 - 09:00	Production of silver nanoparticles in liquid by CW and pulsed lasers	*Juan Pou Mohamed Boutinguiza, Rafael Comesaña, Fernando Lusquiños, Antonio Riveiro, Jesús del Val*
09:00 - 09:15	Bioactive glass nanofibers produced by Laser Spinning for biomedical applications	*Felix Quintero Martinez Joaquin Penide Duran, Antonio Riveiro Rodriguez, Jesus del Val Garcia, Rafael Comesaña Piñeiro, Fernando Lusquiños Rodríguez, Juan Pou Saracho*
09:15 - 09:30	Femtosecond laser ablation in liquids of iron-based nanoparticles	*Alexander Kanitz Jan Hoppius, M'Barek Chakif, Evgeny Gurevich, Andreas Ostendorf*
09:30 - 09:45	Formation of a periodically distributed inverted pyramid structure on silicon using direct laser interference ablation and surface etching processes	*Airidas Žukauskas Bogdan Voisiat, Martynas Gavutis, Gediminas Račiukaitis*
09:45 - 10:00	Direct laser patterning as alternative method for production of THz components and plasmonic structures	*Bogdan Voisiat Aidas Petryla, Gediminas Račiukaitis, Irmantas Kašalynas, Linas Minkevičius*

Coffee break

Micro Processing: Ablation, Drilling and Micro-Cutting (Th_A2_2), Chair W. de Rossi

Time	Title	Authors
10:30 - 10:45	Evaluation of picosecond laser induced shunt resistance in CIGS thin-film solar cells	*Edgaras Markauskas Paulius Gečys, Gediminas Račiukaitis*
10:45 - 11:00	Picosecond laser modification of thin-film CIGS solar cell absorber layer for P2 micro-welding process	*Andius Žemaitis Paulius Gečys, Gediminas Račiukaitis*
11:00 - 11:15	Material modification of reinforcing glass fibers through pulsed laser radiation	*Niels Schilling Benjamin Krupop, Udo Klotzbach, Scott White, Raj Patel*
11:15 - 11:30	Laser Processing of Lithium Iron Phosphate Battery Electrodes	*Adrian Hugh Alexander Lutey Alessandro Fortunato, Maurizio Fiorini, Simone Carmignato, Alessandro Ascari*
11:30 - 11:45	Fabrication of microchannels by picosecond laser pulses spatially shaped with cylindrical lens	*Ehsan Zahedi Daniel Förster, Volkher Onuseit, Rudolf Weber, Thomas Graf*
11:45 - 12:00	Experimental study on laser marking of alumina	*Joaquín Penide Félix Quintero, Felipe Arias-González, Antonio Fernández, Jesús del Val, Rafael Comesaña, Antonio Riveiro, Fernando Lusquiños, Juan Pou*

Lunch

LiM2015 Advance Program, Thursday, 25.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Macro Processing: Additive Manufacturing (Th_A32_1), Chair D. Drummer

Time	Title	Authors
08:30 - 08:45	Hybrid lightweight design by laser additive manufacturing and laser welding processes	*Frank Beckmann Claus Emmelmann*
08:45 - 09:00	Effect of process conditions on mechanical behavior of Aluminium Wrought Alloy EN AW-2618 additively manufactured by Laser Beam Melting in powder bed	*Michael Cornelius Hermann Karg Bhrigu Ahuja, Adam Schaub, Jochen Schmidt, Marius Sachs, Alexander Mahr, Sebastian Wiesenmayer, Leon Wigner, Karl-Ernst Wirth, Wolfgang Peukert, Marion*
09:00 - 09:15	The role of powder properties on the process-ability of Aluminium alloys in selective laser melting	*Nesma T. Aboulkhair Ian Maskery, Ian Ashcroft, Chris Tuck, Nicola M. Everitt*
09:15 - 09:30	Hydrodynamic instabilities and ablation phenomena under the laser melting of powder layers	*Yuri Chivel*
09:30 - 09:45	Influence of local dependencies in additive layered manufacturing on serial process design for aerospace applications	*Kai Schimanski Daniel Tolksdorf, Thorsten Schroeder, Bernhard Bahlmann*
09:45 - 10:00	Selective deposition of polymer powder by vibrating nozzles for laser beam melting	*Thomas Stichel Tobias Laumer, Philipp Amend, Stephan Roth*

Coffee break

Macro Processing: Additive Manufacturing (Th_A32_2), Chair D. Drummer

Time	Title	Authors
10:30 - 11:00	Additive Manufacturing – an introduction to the activities of Collaborative Research Center CRC 814 (Invited)	*Dietmar Drummer*
11:00 - 11:15	Application of CO2 laser for 3D printing utilizing thermal assisted polymerization of PVC plastic	*Mohammadreza Riahi Dehkordi*
11:15 - 11:30	Additive manufacturing based on laser cladding of cp-Ti for dental implants	*Felipe Arias-González Jesús del Val, Rafael Comesaña, Joaquín Penide, Fernando Lusquiños, Félix Quintero, Antonio Riveiro, Mohamed Boutinguiza, Juan Pou*
11:30 - 11:45	Additive process chain using selective laser melting and laser metal deposition	*Benjamin Graf Michael Schuch, Robert Kersting, Andrey Gumenyuk, Michael Rethmeier*
11:45 - 12:00		

Lunch

LiM2015 Advance Program, Thursday, 25.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Macro Processing: System Technology (Th_A31_1), Chair A. Fuchs

Time	Title	Authors
08:30 - 08:45	Laser Fumes at fs Laser Processes – Product, Process and Environment Considerations	*Stefan Jakschik*
08:45 - 09:00	System Technology for High Speed Laser Welding	*Peter Hoffmann Bernd Pögel, Roland Dierken*
09:00 - 09:15	Latest trends in high power disk laser technology	*Volker Rominger Marco Holzer, Matthias Koitzsch, Tracey Ryba*
09:15 - 09:30	Creation of system for studying of optical materials and coatings for their damage threshold, mastering of measuring methodic.	*Elena Krehova Alexander Ignatov, Vasily Kurakin, Anatoliy Pozdnyakov, Yuri Kalinin, Boris Krayev, Andrey Skrynnik, Michael Filipov, Vladimir Serebryakov*
09:30 - 09:45	Laser joining of glass and metal	*Thomas Schmidt Benjamin Kipker, Ronny Bauer, Daniel Eilenberger, Sabine Sändig*
09:45 - 10:00	Identification of process phenomena in DMLS by optical in-process monitoring.	*Robert Domröse Thomas Grünberger*

Coffee break

Macro Processing: System Technology (Th_A31_2), Chair A. Fuchs

Time	Title	Authors
10:30 - 11:00	New Approaches for seam tracked laser beam brazing and welding (Invited)	*Daniel Reitemeyer Stefan Liebl, Florian Albert*
11:00 - 11:15	Statistical distributions of the protection time of passive laser safety barriers – Normal distribution or is there a better description?	*Florian Peter Lugauer Florian Moosbauer, Michael Friedrich Zäh*
11:15 - 11:30	Development and integration of an adaptive focus position control system for a new high-performance laser remote welding head	*Georg Cerwenka PD Dr.-Ing. habil. Jörg Wollnack, Prof. Dr.-Ing. Claus Emmelmann*
11:30 - 11:45	Sub-100µs latency feedback control of laser machining using FPGA-powered inline coherent imaging	*Ethan Jenkins Cole Van Vlack, Paul J. L. Webster, James M. Fraser*
11:45 - 12:00	Reinventing thermal laser power measurements	*Susanne Dröscher Michele Zahner, Etienne Schwyter, Thomas Helbling*

Lunch

LiM 2015

LiM2015 Advance Program, Thursday, 25.6.2015

Room "Edison", 1st Floor, Exhibition Hall A2 (A21/A22)

Time	Micro Processing: Ablation, Drilling and Micro-Cutting (Th_A2_3), Chair S. Barcikowski	
14:00 - 14:15	On line evaluation of femtosecond laser ablation efficiency on copper structures	*Jan Stefan Hoppius* *Alexander Kanitz, Benjamin Schöps, Evgeny Gurevich, Andreas Ostendorf*
14:15 - 14:30	Reducing the roughness of the kerf for brass sheet cutting with the Laser MicroJet® by a systematic parameter study	*Yixin Bai* *Annika Richmann, Jamie Paik, Bernold Richerzhagen*
14:30 - 14:45	3D laser micro-machining for targets manufacturing	*Remy Bourdenet*
14:45 - 15:00	Mechanical properties of ultrafast-laser cut polylactic acid films	*Giovanni Piredda* *Rein Andreas, Johann Zehetner, Victor Matylitsky*
15:00 - 15:15	Effect of the pulse duration on the surface roughness and the heat affected zone in laser micro polishing processes	*Mikel Gomez-Aranzadi* *Antonio Dias, Miguel Martinez-Calderon, Ainara Rodriguez, Santiago Miguel Olaizola*
15:15 - 15:30	Scanned Mask Imaging: The economical approach to high resolution micro-machining using UV solid state lasers	*David Milne* *Zoe Knill*

Coffee break

Time	Micro Processing: Surface Functionalization (Th_A2_4), Chair S. Marzenell	
16:00 - 16:15	Improving a Finite Element thermal simulation of the nanosecond laser ablation on silicon targets	*Germano Galasso*
16:15 - 16:30	Improvement of the adhesion between CoCr and dental ceramics by laser surface structuring	*Sina Hallmann* *René Nodop, Christian Daniel, Martin Weppler, Jügen Geis-Gerstorfer, Claus Emmelmann*
16:30 - 16:45	Pulsed Laser Surface Pre-Treatment of Aluminium to Join Aluminium-Thermoplastic Hybrid Parts	*Andre Heckert* *Christian Singer, Michael F. Zaeh*
16:45 - 17:00	Surface conditioning of copper to improve the continuous wave laser micro welding	*Nerea Otero* *Pablo Romero, Christian Hoff, Jörg Hermsdorf*
17:00 - 17:15	Femtosecond laser manufacturing of highly hydrophobic hierarchical structures fabricated by combining surface microstructures and LIPSS	*Miguel Martínez-Calderon* *Ainara Rodríguez, Antonio Dias, Mikel Gómez-Aranzadi, Santiago Miguel Olaizola*
17:15 - 17:30	Comparison of UV- to M-IR laser for surface pre-treatment based on the ILSS-test	*David Blass* *Stefan Kreling, Klaus Dilger*
17:30 - 17:45		

LiM2015 Advance Program, Thursday, 25.6.2015

Room "Newton 2", 1st Floor, Exhibition Hall A3 (A32)

Time	Macro Processing: Additive Manufacturing (Th_A32_3), Chair M. Karg	
14:00 - 14:15	Experimental and theoretical study of residual deformations and stresses at additive manufacturing by fusion	*Andrey V. Gusarov* *Victor Saphronov*
14:15 - 14:30	Influence of process parameters on deposition dimensions in laser engineered net shaping	*Fangyong Niu* *Guangyi Ma, Dongsheng Chai, Siyu Zhou, Dongjiang Wu*
14:30 - 14:45	Build-up strategies for generating components of cylindrical shape with Laser Metal Deposition	*Torsten Petrat* *Benjamin Graf, Andrey Gumenyuk, Michael Rethmeier*
14:45 - 15:00	Influence of temperature gradients on the part properties for the simultaneous laser beam melting of polymers	*Tobias Laumer* *Thomas Stichel, Philipp Amend, Michael Schmidt*
15:00 - 15:15	Laser sintering of silver filled conductive adhesive for generation of embedded electronic circuits in stereolithography parts	*Bernd Niese* *Philipp Amend, Uwe Urmoneit, Stephan Roth, Michael Schmidt*
15:15 - 15:30	Reliable Beam Positioning for Metal-based Additive Manufacturing by Means of Focal Shift Reduction	*Christiane Thiel* *Martin Stubenvoll, Bernd Schäfer, Toni Krol*

Coffee break

Time	Macro Processing: Additive Manufacturing (Th_A32_4), Chair B. Ahuja	
16:00 - 16:15	Hybridization of semiconductor micro particles with plasmonic nanoparticles during additive manufacturing	*Marcus Lau* *Ralf Niemann, Mathias Bartsch, William O'Neill, Stephan Barcikowski*
16:15 - 16:30	Simulation of the effect of different laser beam intensity profiles on the productivity of the Selective Laser Melting process	*Tim Marten Wischeropp* *Raul Salazar, Dirk Herzog, Claus Emmelmann*
16:30 - 16:45	Some optimization strategies for tool path generation in 3D laser metal deposition	*Angel Rodríguez* *Maria Jose Tobar, Jose Manuel Amado, Javier Montero, Armando Yáñez*
16:45 - 17:00	Laser printing and curing/sintering of silver paste lines for solar cell metallization	*David Munoz-Martin* *Chen Yu, Andres Márquez, Miguel Morales, Carlos Molpeceres*
17:00 - 17:15	TRIZ-based Biomimetic Part Design for Laser Additive Manufacturing	*Tobias Kamps* *Christopher Muenzberg, Lukas Stacheder, Reinhart Gunther, Udo Lindemann*
17:15 - 17:30		
17:30 - 17:45		

LiM2015 Advance Program, Thursday, 25.6.2015

Room "Newton 1", 1st Floor, Exhibition Hall A3 (A31)

Time	(Th_A31_3),	
14:00 - 14:15		
14:15 - 14:30		
14:30 - 14:45		
14:45 - 15:00		
15:00 - 15:15		
15:15 - 15:30		

Coffee break

Time	(Th_A31_4),	
16:00 - 16:15		
16:15 - 16:30		
16:30 - 16:45		
16:45 - 17:00		
17:00 - 17:15		
17:15 - 17:30		
17:30 - 17:45		

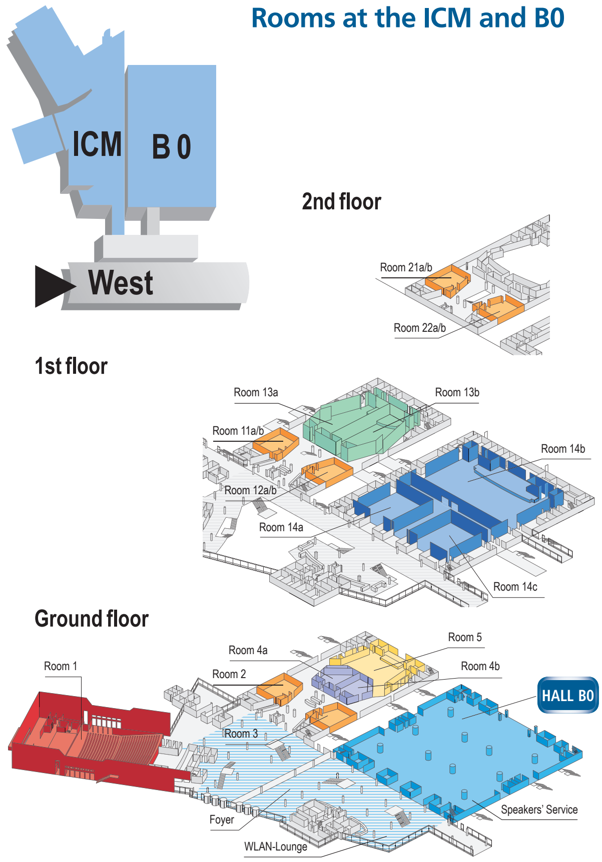
Joint Sessions with ECLEO

LiM2015 Advance Program, Tuesday, 23.6.2015		
	ICM 1st Floor, Room 13a, Joint Session with ECLEO	
	JSL: Diagnostics and Control (only Invited) (Tu_13a_1), Chair L. Overmeyer	
08:30 - 09:00	Laser Process Monitoring and Control of Real Process Features (Invited)	*Stefan Kaierle*
09:00 - 09:30	Control of Femtosecond Pulsed Laser Deposition by Temporal Pulse Shaping (Invited)	*Florence Garrelie*
09:30 - 10:00	Ship-in-a-bottle Fabrication of Functional Biochips by Hybrid Femtosecond Laser Processing (Invited)	*Koji Sugioka*
	Coffee break	

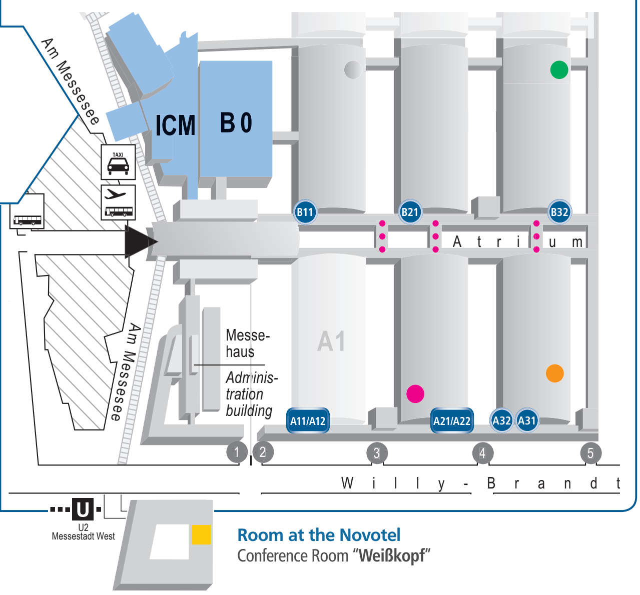
LiM2015 Advance Program, Tuesday, 23.6.2015		
	ICM 1st Floor, Room 13a, Tech Focus Sessions with ECLEO	
	TFI: Ultrafast Solid-State and Fibre Lasers (only Invited) (Tu_13a_3), Chair L. Overmeyer	
14:00 - 14:30	Micromachining and Materials Processing with High Energy Ultrafast Fiber Lasers (Invited)	*Tim Gerke*
14:30 - 15:00	Mid IR Fiber Frequency Combs and Applications (Invited)	*Martin Fermann*
15:00 - 15:30	Industrial Ultrafast Lasers for Advanced Manufacturing Applications (Invited)	*Eric Mottay*
	Coffee break	
	TFII: Materials Structuring Using Short Laser Pulses (only Invited) (Tu_13a_4), Chair L. Overmeyer	
16:00 - 16:30	Surface functionalization	*Rainer Kling*
16:30 - 17:00	Ultrafast Burst-Mode Fiber Lasers: Source Development and Material Processing (Invited)	*F. Oemer Ilday*
17:00 - 17:30	Additive and Subtractive 3D-Microfabrication of Micro/Nanostructures (Invited)	*Yongfeng Lu*

CONFERENCE ROOM OVERVIEW

Rooms at the ICM and B0



Rooms at the Exhibition Halls



Room at the Novotel
Conference Room "**Weißkopf**"

ICM – Internationales Congress Center München

- **B11** Room "**Einstein**", 1st Floor, Exhibition Hall B1 (B11)
- **B21** Room "**Hertz**", 1st Floor, Exhibition Hall B2 (B21)
- **B32** Room "**Maiman**", 1st Floor, Exhibition Hall B3 (B32)
- **A11/A12** Room "**Curie**", 1st Floor, Exhibition Hall A1 (A11/A12)
- **A21/A22** Room "**Edison**", 1st Floor, Exhibition Hall A2 (A21/A22)
- **A32** Room "**Newton 2**", 1st Floor, Exhibition Hall A3 (A32)
- **A31** Room "**Newton 1**", 1st Floor, Exhibition Hall A3 (A31)
- **HALL B0** World of Photonics Congress **Poster Show**

Also visit our Forums

- **A2** Photonics Forum Hall A2 "**Optical Metrology and Imaging**"
- **A3** Photonics Forum Hall A3 **"Industrial Laser Applications"**
- **B3** Photonics Forum Hall B3 **"Biophotonics and Medical Applications/Lasers and Optics"**

Sessions

The Extreme Light Infrastructure ELI

Europe on its way to build the world's first international laser user facility

Prof. Dr. Wolfgang Sandner

Director General and CEO, ELI-DC International Association AISBL
The "Extreme Light Infrastructure" ELI
Berlin office: c/o DESY – Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany

Abstract

Roughly five decades after invention of the laser the international scientific community has joined forces to build the world's most powerful lasers for scientific research, the "Extreme Light Infrastructure" ELI.
Technically, ELI's high-power lasers will push the present frontiers in power, intensity and repetition rate by at least a factor of ten. Scientifically, due to the highly non-linear nature of ultra-intense light matter-interactions, a wealth of new research opportunities in basic science and applications arises. They include novel laser-plasma particle acceleration schemes, secondary radiation generation from THz to Gamma rays and their applications in science, life sciences and engineering, ultra-short radiation pulses in the atto-second regime, laser-based nuclear physics and nuclear photo-physics, up to pioneering exploration of QED effects in ultra-intense laser fields. ELI is presently being constructed as a distributed research infrastructure in the Czech Republic, Hungary and Romania, and will start operations in 2018.

Laser-sintering: laser-based industrial 3D printing

Tobias Abeln

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Abstract

„3D printing“ has generated a lot of attention over the last few years. Looking behind the hype, we see an assortment of technologies with very different performance levels and applications. At the high end, these technologies indeed start to change several paradigms of industrial manufacturing: Geometric complexity almost comes for free, personalisation is not expensive, design alterations of new products can be fast and cheap. These changes are evolutionary in nature rather than revolutionary, meshing nicely with existing manufacturing technologies and emerging design capabilities. And suiting the global trends of customised product designs, shortened life cycles and limited resource availability. This presentation will show where industrial 3D printing is today and which way it is heading.

Flow and bead formation characteristics in high power laser welding at different welding positions (invited talk)

S.-J. Na[a,d], S.-W. Han[a], S. Muhammad[a], L. Zhang[b], A. Gumenyuk[c], M. Rethmeier[c], M. Karhu[d], V. Kujanpaa[d]

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Abstract

The numerical simulations of high power laser keyhole welding at different welding positions are performed by using Volume-Of-Fluid (VOF) method. The main material is SS400. The multi-physics phenomenon is considered using several models, such as the heat flux of Gaussian heat source, the recoil pressure with Clausisus-Clapeyron equation, the Marangoni flow considering temperature gradient, the buoyancy force with Boussinesq approximation, the additional shear stress and heat source due to metallic vapor ejected through keyhole entrance, the bubble formation assumed as adiabatic bubble, and the multiple-reflection by solving proper discriminant, are used. To analyze the fluid flow pattern, the concept of streamline formed by reconstructing the value of the velocity vector is applied.

Partial and full penetration cases at different welding positions are considered. The welding position seems to have only a minor influence on bead formation characteristics in both cases. This is probably due to the fact that the recoil pressure has a major influence when compared to other driving forces. The flow characteristics and fluid velocity in weld pool are analyzed to compare the gravity direction effect at different welding positions. It is observed that the clockwise flow pattern is mainly formed by the recoil pressure on the keyhole surface in the case of partial penetration. The laser energy can't maintain the whole weld pool when the weld pool size becomes too large. And then the solidification starts from the middle part of weld pool and a necked weld pool shape is formed. In the full penetration welding, the weld pool flow patterns are affected by the leakage of laser power through the full penetration keyhole and also by surface tension. Furthermore, the numerical simulation of full penetration welding with AISI316L is also performed to analyze the effect of material properties. The weld bead shapes obtained by simulations were compared with the corresponding experimental results to confirm the validity of the process models adopted and the CFD simulation tool.

Energy-efficient production with high-power disk- and diode-lasers

M. Koitzsch, V. Rominger

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Abstract

This paper presents and discusses two main aspects of energy-efficient production using laser technology: First, the laser as a tool and the evolution of important laser characteristics; second, potential improvements in design and novel approaches in production due to the use of lasers are discussed.

Yb:fiber laser joining of Ti-6Al-4V and AA6013 dissimilar metals

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[c]*Instituto Tecnológico de Aeronáutica, Praça Mal.Eduardo Gomes 50, Vila das Acácias, São José dos Campos – SP, 12228-900, Brazil*

Abstract

Titanium and aluminum alloys have been considered to applications instructural components of aircrafts. A common phenomenon in Al/Ti joints is the presence of brittle intermetallic compound (IMC) in the junction interface region. Laser beamjoiningof dissimilar metals can generate acceptable limits of IMC in this region. In the present work, Ti-6Al-4V and AA6013 sheets (1.0 mm and 1.6 mm thick, respectively) were joined by anYb:fiber laser. Butt joints were conducted by varying the relative positioning of laser beam toward Al alloy, from0 (interface joint) up to 0.5 mm. The welding speed and the laser average powerwerefixed , 3.0 m/min and 1000 W, respectively. Metallographic analyses were performed on the joint cross-section by optical microscopy. The positioning of laser beam has a pronounced influence on the quality of the joints. Between 0.2 and 0.4 mm, the Ti alloy was not melted, promoting a joint with no severe defects. On other hand, when the laser beam was positioned near of the interface area, a melted region containing a mixture of titanium and aluminum was formed with the presence of some defects. EDS line scanning in the junction interfaceshowed a decreasing of IMC layer in the joints without melted titanium alloy, i.e., with laser beam positioned toward Al alloy between 0.2 and 0.4 mm. The thickness of interfacial IMC layer was about 15-30 times lower than the interfacial IMC layer forthe melted Ti alloy condition, reaching the mean value of 15 µm.

Influence of different zinc coatings on laser brazing of aluminum to steel

T. Radel, M. Gatzen, P. Woizeschke, C. Thomy

BIAS - Bremer Institut für angewandte Strahltechnik GmbH, Klagenfurter Str. 2, 28359 Bremen, Germany

Abstract

Joining of aluminum to steel is a common challenge in light-weight structures. In case the steel is zinc-coated, aluminum can be joined to steel using laser processes without the use of flux. However, this is not yet fully understood.

In this paper, the influence of type and thickness of the zinc coating on the wetting behavior of molten aluminum on steel sheets was investigated in bead-on-plate laser brazing. Two hot-dip and two electro galvanized zinc coatings with thicknesses between 6 µm and 10.5 µm were analyzed. Appropriate wetting was observed for all four coatings in the experiments. The results show that the solidification time, the spreading time and the final wetting length decrease with increasing coating thickness. Aluminum seams on hot-dip galvanized steel sheets appear smoother than seams on electro galvanized steel sheets.

Laser beam welding of press hardened ultra-high strength 22MnB5 steel

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Abstract

Lightweight design is the most challenging topic for OEMs worldwide of this and the following decades. Thus ultra-high strength steels like the press hardenable 22MnB5 Boron steel gain further importance as construction materials.

Through the press hardening process where the parts are heated up to 900 °C and then quenched in a die, the 22MnB5 steel gains a fully martensitic structure with an ultimate strength of 1500 MPa. To prevent scaling, the steel sheets are usually protected by an aluminum-silicon layer which remains on the parts after the press hardening process.

As good as the press hardened 22MnB5 steel is as construction material, there are some issues when it comes to joining. Each heat input into the material harms the costly adjusted material properties. Thus, each welding process reduces the strength in the heat affected zone considerably. Furthermore, each fusion welding process brings the aluminum-silicon layer into the weld pool.

The effect is a primary problem of laser beam welding. Due to the high welding speed and the missing filler material there is only little weld pool movement. Especially in the case of welding overlap joints this leads to precipitation of aluminum at the fusion line, causing a strong metallurgical notch.

This means there are two weaknesses of laser welded 22MnB5 seams: the heat affected zone where the strength is reduced and the precipitation of aluminum at the fusion line. The latter usually bears the failure during lap shear tests. Removing the aluminum-silicon layer can shift the crack from the fusion line to the heat affected zone.

3D-capable coaxial laser brazing head

A. Gatej[a], M. Kogel-Hollacher[a,b], D. Blázquez-Sánchez[a], A. Bobrowski[a], A. Niete[a], N. Blundell[c], K. Withers[c]

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Abstract

Laser processing heads for brazing applications still operate with lateral wire feed suffering from two major disadvantages: the reorientation and the low joint strength. The head's reorientation becomes very complex if small radii are to be processed. Moreover, the joint strength is limited due to shadowing effects of the laser beam by the filler wire. Thus, the preheating of the wire and the base material are inhomogeneous and lead to a reduced wetting ability and thus to reduced strength of the joint.

In order to overcome these limitations, the optical system design, which is developed for diode and solid-state laser applications, enables the generation of a donut shaped laser intensity distribution with a concentric and obscuration-free wire feed. Thus, it provides a full-3D-processing capability without lateral interference contours. Despite of the current design still operating with an external seam tracking system, the optical design is already prepared for an internal, coaxial tracking.

Despite of the design aiming on the brazing industry, applications in the area of aluminum welding or cladding are also conceivable and currently under investigation. Particularly cladding is of great interest, since the 3D-capability is of major value.

Robust “false friend” detection via thermographic imaging

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[b]IFSW Institut fuer Strahlwerkzeuge, Pfaffenwaldring 43, 70569 Stuttgart, Germany

Abstract

During the laser deep penetration welding process several weld faults may occur in the solidified material and exert influence on the thermal state. The online detection of an insufficient bonding during overlap welding (commonly referred to as “false friend”) is a specific challenge, because the welding result at the upper and lower seam seems to be satisfactory, but there is no fusion between the two parts.

The experimental sensor setup provides a coaxial thermographic image of the process, which allows conclusions about changes inside the material, if they disturb the surface temperature sufficiently enough. This is the case, when a false friend prevents the heat flow to the lower part of the workpiece and a defined attribute of the thermal image is changed.

To obtain a better scientific understanding of the experimental thermographic results, the behavior of the thermal attribute is fundamentally analyzed within the scope of a simple laser welding model for which the temperature field can be computed analytically. To this case the model of Rosenthal, 1946 (reprocessed by Rykalin, 1957 and Carslaw and Jaeger, 1986) with a moving point source on the surface is adapted to a plate with finite thickness. The thermal information flow from the inside to the top surface is influenced by the processing parameters, laser power and feed rate, by the plate thickness and the material properties. The characteristics in the bulk of the material affects the top surface temperature. This becomes visible in the thermal image. Where and how this influence is detectable is investigated by taking the reflections on the bottom side of the workpiece into account.

A robust detection of a loss of fusion during an overlap welding is predicted by the analytical approach and validated by experiments.

Correlation of keyhole dynamics and pore formation

J. Volpp[a] and F.Vollertsen[a,b]

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[b]University of Bremen, Germany

Abstract

Imperfections like pores occurring due to high process dynamics during laser deep penetration welding reduce the weld quality and the strength of welded joints. It is assumed that keyhole instabilities are responsible for the high process dynamics. In order to better understand the correlation between pore formation and keyhole dynamics an analytical process model has been developed describing keyhole radius fluctuations in different depths depending on the process parameters. Modelled radius oscillation frequencies have been compared to experimentally measured process emissions. Frequency spectrums of acoustic process emission observations show similar tendencies of keyhole dynamics compared to the calculations. For pore detection x-ray photography has been used while pore percentage and pore number in the weld seams have been evaluated. The pore formation in the solidified weld seam is compared to the observed dynamic characteristics during the process. Higher keyhole frequencies tend to correlate with increased pore numbers at reduced pore sizes.

Properties of steel-aluminum joints generated by combining continuous and pulsed laser radiation

S. Frank, K. Arntz, F. Klocke

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Abstract

The combination of a continuous and a pulsed laser beam in a common process zone makes it possible to join aluminum and galvanized steel. This method does not require the use of chemical fluxes. It can be applied to different joint geometries such as double-flanged joints and lap joints. The basic microstructure of these joints is discussed using metallographic cross-sections. The properties of the intermetallic iron-aluminum compounds are examined in greater detail using methods such asenergy-dispersive X-ray spectroscopy (EDS) and transmission electron microscopy (TEM). The results from these measurements indicate that the use of wire material alloys containing silicon leads to the formation of ternary phases. The joints exhibit a high strength in mechanical tests even when cyclic loads are applied.

Laser-GMA-hybrid welding of high strength multi-material joints

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[b]*Fachhochschule Brandenburg, Magdeburger Strße 50, 14770 Brandenburg an der Havel*

Abstract

A particular challenge for welding 22MnB5 and DP800 are the coatings of each steel sheet. As a prevention of oxidation during press-hardening 22MnB5 sheets are protected with an aluminum silicon coating. The dual phase steel DP800 is zinc coated in many cases. In this described case the steel sheets are hot-dip galvanized. The evaporation temperature of zinc is below the melting temperature of steel. For that reason a zinc degassing gap between the sheets is necessary for welding in overlap configuration.

At BIAS a laser-GMA-hybrid welding process was established for welding 22MnB5 to DP800. With this process combination weld seams reach a strength exceeding the strength of the heat affected DP800. Tensile tests prove yield strength of 800 N/mm² with failure location in the heat affected zone of DP800.

The laser beam was oscillated 0.7 mm transverse to the feed direction with a frequency of 200 Hz. A feed rate of 3 m/min was realized. The laser beam was able to vaporize zinc 5 mm ahead of the GMA-process which was carried out with a wire feed rate of 14 m/min. For this hybrid welding process a 1 mm thick G3Si1 wire was used.

Occurrence of pores and spatters could be avoided by a gap of 0.4 mm between overlapping sheets. The aluminum silicon coating of 22MnB5 accumulates at the seam tip.

Laser cleaning and welding of aluminium alloys for automotive manufacture

L. Li[a], A.W. AlShaer[a], A.Mistry[b]

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[b]*Advanced Manufacturing Engineering, Jaguar and Land Rover, Banbury Road, Badon, Warwick, CV35 0RR, UK*

Abstract

Laser welding of aluminium alloys typically results in porosity in the fusion zones leading to poor mechanical and corrosion performances. Porosity can be formed from a number of reasons including surface contamination, H2 trapping and keyhole instability. This work investigates various factors affecting porosity formation and the the effects of short pulsed laser surface cleaning on the porosity formation in laser welding of AC-170PX (AA6014) aluminium sheets (coated with titanium and zirconium and lubricated using a dry lubricant AlO70) using several filler wires including AlSi5 (AA4043). Porosity, weld fusion zone geometry were examined before and after laser cleaning. Nanosecond pulsed Nd:YAG laser cleaning at 1.06 μm wavelength was found to reduce porosity significantly in the weld fusion zones. For fillet edge welds, porosity was reduced to less than 0.5% compared with 10-85% without laser cleaning. This has been found due to the elimination of contaminations and oxide layers that contribute to the porosity formation. The laser cleaning is based on thermal ablation. The work was carried out in collaboration with an automobile manufacturer and the technology has now been applied for lightweight transportation vehicle production.

Laser welding inspection on aeronautic material with non-contact real-time optical beam deflection sensor

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[c]Universidade Estadual Paulista (UNESP), Av. Professor José Carlos Rossi 1370 Campus III, Ilha SolteiraSP 15385-000, Brazil
[d]Instituto Tecnológico de Aeronáutica (ITA),Praça Mal. Eduardo Gomes 50, São José dos Campos SP 12228-900, Brazil

Abstract

In this work we show the application of an optical beam deflection sensor for detection of airborne thermal and acoustic waves generated by laser welding of aeronautical aluminum (AA 6013), and the sensor's potential for process inspection and control. The principle of working of the sensor is based in the measurement of the refractive index variation (of the surrounding medium) induced by temperature or pressure variation. The laser welding conditions generates the index variation which, in turn, deflects the optical beam, modulating the optical intensity. Therefore, the sensor is able to perform non-contact, non-destructive and surface roughness independent measurements.

Three-dimensional, multi-factor monitoring and control of laser keyhole welding by inline coherent imaging

P. J. L. Webster, C. M. Galbraith, C. Van Vlack, D. R. Buckley, J. M. Fraser

Laser Depth Dynamics, 2 Gore St. Kingston ON, K7L 2L1, pwebster@laserdepth.com

Abstract

Direct measurements of keyhole geometry such as those provided by inline coherent imaging (ICI) are expanding options for process monitoring for industrial laser keyhole welding. ICI has been used to demonstrate real-time closed loop weld depth control. However, practical processing conditions demand a more robust registration of tool-path to workpiece than the position of the process optics alone can provide. Combining ICI with a beam directing system at the camera port of a commercial, fixed-optic laser head, we gain the ability to dynamically steer the ICI beam across the sample surface at millisecond timescales. Here we show how this 3D capability can be used to implement multiple process monitoring and control threads quasi-simultaneously. By sampling data from multiple points in and around the phase change region, we are able to implement autofocus and continuously correct motion error and distortion in the measured keyhole depth. In addition, transverse measurement sweeps of the leading region in common joint configurations enable seam-tracking for closed-loop correction of imperfect part geometry. We present results demonstrating seam-tracking and autofocus update rates on the order of kHz while simultaneously providing weld monitoring for quality control. The combined realization of these capabilities makes ICI a more robust and versatile weld process control and quality control solution.

3D weld seam characterization based on optical coherence tomography for laser-based thermal joining of thermoplastics to metals

R. Schmitt[a,b], G. Mallmann[a] , P. Ackermann[a], J. P. Bergmann[c], M. Stambke[c], K. Schricker[c]

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[c] *Technische Universität Ilmenau, Department of Production Technology, Gustav-Kirchhoff-Platz 2, Ilmenau, Germany*

Abstract

Laser-based thermal joining of metals to plastics shows a great potential for functional constructions especially in terms of light weight design. Thereby, the process strategy and time-temperature regime affects the resulting joint zone; hence process monitoring is a central issue. State of the art monitoring and quality assurance systems for this technology are limited as no direct information about the joining zone itself is given. Within this paper, a new method for the quality assurance in metal-plastic hybrids is presented using optical coherence tomography (OCT). This approach enables the measurement of the joint geometry as well as bubbles, imperfections and the wetted bonding area.

Influence of a second heat source on the distortion behaviour during laser beam welding

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Abstract

Due to its several advantages like low heat input, high flexibility and welding speed, laser welding is an established process within numerous industrial fields such as automotive but also food and pharmacy industry.
A restricting phenomenon during laser welding of thin sheets is distortion, which can result in a change of the gap width between the welded parts and hence, highly affect the process performance itself and lead to reduced joint and component quality. The distortion is caused by thermally induced strains and the shrinkage in the weld, respectively.
By applying a second heat source positioned in a defined distance behind the main heat source, the shrinkage can be counteracted, hence optimizing the welding process. For this investigation, austenitic stainless steel 1.4301 sheets were welded with a CO_2 laser, and as a second heat source a diode laser was employed. Several parameters such as travel speed, power and position of the second heat source were varied to evaluate their effect on the process and the joint properties.
The influence of the second heat source on the welding process and the welding result is described. The application of a second heat source allows lower demands on the dimension accuracy and clamping devices in order to realize good welding results.

Controlled metal transfer from a wire by a laser-induced boiling front

A. F. H. Kaplan[a], M. J. Torkamany[a,b], F. M. Ghaini[b], M. Vänskä[c], A. Salminen[c], K. Fahlström[d], J. Hedegård[d]

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Abstract

The addition of wire is an option during laser welding, laser cladding or laser additive manufacturing. By high speed imaging of leading wire addition during fibre laser keyhole welding it was observed that for the 40 experiments under consideration the wire tip always established a concave boiling front. The front appears similar to a keyhole front and is sort of a continuation of the keyhole, owing to the leading wire employment. For most of the parameters the melt is transferred downwards from the wire tip into the melt pool surrounding the keyhole front. In other words, hardly any uncontrolled spatter to the sides was observed. A trailing wire would normally tend to a completely different behaviour. Typical as well as limiting phenomena of the wire melt transfer mechanism are presented and discussed. Controlled vertical melt transfer of the wire through the ablation pressure from a laser-induced boiling front, either in contact with the workpiece surface or positioned higher above, can be a desirable mechanism of metal deposition for the different techniques, namely welding, surface treatment or LAM. By suitable choice of the laser power density above the boiling threshold, the here observed mechanism can be applied in a controllable manner. An interesting technique option is lateral beam oscillation for example by a galvanometer optics which shears off the melt in a manner similar to remote fusion cutting. The process limits become different to the static technique. The wire melt transfer technique has the potential to be developed further towards a highly controllable remote drop transfer, e.g. in terms of direction.

Capillary geometries during welding of metals observed with X-ray technique and calculated using a ray-tracing tool and a finite volume program treating heat diffusion and fluid flow

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Abstract

To understand and to predict the seam properties in deep-penetration laser welding, it is important to know the shape of the capillary. High-speed X-ray videography is an adequate technique to observe the average shape and the temporal development of the capillary. Other observation methods use transparent materials in front of the workpiece or instead of the metallic workpiece. Capillary features, which are observed by X-ray technique and which are typical for different materials, will be compared. The investigated materials have in common, that the lower part of the capillary often shows a different behavior compared to the upper part. For example the lower part shows more fluctuations can be more inclined or more often exhabits bulging on the rear side.

To understand the observed phenomena better, calculations can be performed. The calculations presented here use a model which combines a ray-tracing module with a finite volume program treating heat conduction and fluid flow. In this model the surface of the capillary is defined by a large number of triangles which are rearranged after each time step in order to fulfill mass, momentum, and energy balance. The structure of this surface is perfectly suited for fast ray tracing. With this model some interesting features of the capillary shape and of the temporal behavior observed during the experiments could be described although momentum transfer within the vapour was not included in the model.

Influence of residual stresses induced by forming on the hot cracking sensitivity of laser welding processes of AlMgSi aluminum alloy

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Abstract

In industrial production forming processes are often followed by joining processes such as laser welding. In most cases forming processes like deep drawing create residual stresses in the work piece. The influence of those residual stresses on laser welding processes in terms of hot crack formation and the resultant weld quality are major outcomes of the presented paper.

Cups of 6080 aluminum alloy were produced by deep drawing and the resultant residual stresses were determined by experiment and simulation. Knowing the local stresses, welding experiments were performed on the formed part and compared with welding experiments on flat aluminum sheets, which were stress free before welding.

Several known publications related the hot cracking sensitivity to the local stresses during the dendritic solidification of the melt. The experiments showed that the addition of residual bending stresses caused by forming increased the hot cracking sensitivity. This can be derived from analysis of high-speed images during the welding process and the metallographic analysis of the weld seam after the welding process. Finally these results were evaluated in the context of existing theories on hot crack formation.

Fundamental analysis of hot cracks in remote laser welded aluminium fillet welds

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Abstract

Remote laser welding is a highly efficient technology for the automotive body in white series production. However, the application of remote laser welding to high strength aluminium alloys is restricted due to hot cracking. Recent research activities mainly focus on centerline hot cracks in welds in close-edge position. Crack-free welds can be created within an edge distance of smaller than 2 mm. In this study remote laser welded fillet joints of high strength EN AW-6082 T6 alloy were analyzed experimentally concerning their hot cracking behavior. This type of joint design can avoid centerline cracks. Yet, cracks in transverse direction on a microscopic scale were found along the weld seam by x-ray radiography. Scanning electron microscope images confirmed that the cracks formed in semi-solid-state. In order to investigate the influence of welding parameters on the formation of transverse hot cracks a full factorial study regarding the welding speed, the laser power, the sheet thickness, the protrusion of the lower sheet and the beam position was conducted. In this study the welding speed and laser power were found to have a major effect on hot crack formation. Additionally high-speed imaging was used to observe the exact moment and the location of hot crack formation. It can be seen that transverse hot cracks arise not at the end of the weld pool but beside the weld pool between the weld centerline and the seam edge. As the solidification behavior during the welding process is a key factor in hot crack formation the influence of melt pool geometry on hot crack formation was investigated by high-speed imaging. Based on these results a beam oscillation method was developed to control the melt pool morphology leading to reduced hot cracks in fillet joints.

Analysing hot crack formation in laser welding of tempered steel

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Abstract

Tempered steel is used in many automotive and aviation parts due to its beneficial material properties such as the combination of high tensile and fatigue strength. Therefore, steel grades like e.g. 42CrMoS4 are used for steering knuckles, axles, connecting rods, drive shafts, pinions, gearwheels, pistons and other highly stressed components (Key to Steel, 2007). Laser welding such parts has the advantage of high welding speed, low heat input, low distortion and high weld seam quality (Huegel and Graf, 2014).
However, seam defects may occur which reduce weld seam strength. In that respect, hot cracks are severe weld defects which are not tolerated, according to ISO 13919-1. In general hot crack formation depends on three factors affecting each other (Cross, 2005): energy deposition into the part (heat input; welding parameters), part design (geometry; restraining conditions) and material properties (solidification temperature range).
To separate the influence of the above-mentioned factors welding experiments were conducted with varying parameters including beam focusing, beam quality and laser power for partial or full penetration depth. Examining the welding process was done by means of 2D x-ray inspection and longitudinal respective transversal cross sections.
In this paper the analysis of continuous crack formation within laser welds in tempered steel will be presented. Additionally, possibilities to reduce and even avoid such severe seam defects will be discussed. Moreover, a new approach of explanation for the formation mechanism of transverse hot cracks will be presented.

Online crack detection during laser welding using passive thermography

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Abstract

The non-destructive testing of laser welds within the process chain of industrial production is of prime importance for the quality assurance. In this paper passive thermography was used to detect centerline cracks. These hot cracks are likely to occur when welding car body sheets in an overlap configuration close to the edge. Welding at this position leads to a strong heat accumulation. This results in a non-symmetric temperature field causing a heat flow from the edge into the body across the weld seam. If the weld seam is split due to a centerline crack this heat flow is significantly disturbed.
It was found that this characteristic change of the heat flow is clearly measurable and can be utilized to detect hot cracking during welding using an infrared camera.

Influence of filler wire and focus diameter on crack formation in laser beam welding of high strength aluminum alloys

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Abstract

Light weight components for automotive industry become more important with increasing demand for electronic driven vehicles. Up to now, high strength aluminum alloys have a wide use in aerospace sector. To establish these alloys also in automotive sector, the development of improved welding techniques are required. However, due to its alloying elements magnesium, zinc, silicon and copper which increase solidification interval, the weldability of high strength aluminum alloys of 5xxx, 6xxx and 7xxx series is limited by hot crack formation. Hence, metallurgical as well as systemic approaches are needed to enable weldability of these alloys. The present paper discusses the influence of different filler wire materials and spot diameters on hot cracking. Therefore a disc laser is used to weld aluminum alloys without and with filler wire. Mechanical and metallographic analysis display quality of welds. In particular, tensile tests, microhardness measurements and cross sections are shown in order to compare welds of 5xxx, 6xxx and 7xxx. It results that a small focus diameter of 340 µm by trend reduce hot crack formation for AA 6082-T6 and AA 7075-T6 due to low heat input. Moreover, the use of filler material decreases also hot cracking, while AlSi5 can be identified to have highest influence with respect to avoid hot crack formation for the hardenable alloys.

Fundamental research of 100 kW fiber laser welding technology

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Abstract

Recently 100 kW fiber laser is commercially available, and so the development of welding technology with 100 kW fiber laser is mostly expected for the utilization of a high power laser. First a focusing optic, a welding nozzle and a power meter were designed and manufactured for such a high power laser, and laser welding was performed under various conditions. The penetrations of laser weld beads were investigated and welding phenomena were observed. Consequently deeply penetrated laser weld beads of more than 40 mm in depth could be produced at 100 kW and 2 m/min, and a sound full-penetration weld bead could be made in a stainless steel plate of 70 mm in thickness with two passes from both surface sides. Moreover, it was confirmed that laser weld beads of about 100 mm to 125 mm in depth were formed under the welding conditions of the high laser power of 50 to 70 kW, the low speed of 0.3 m/min and the low vacuum of 1 kPa.

Influence of ambient pressure on spatter formation during laser welding of copper

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Abstract

Due to its high electrical and thermal conductivity, copper has a wide range of applications. Many of those require an efficient and reliable welding process most preferably using a remote laser technique. However, the low absorptivity of copper at the wavelength of 1 µm together with its high heat conductivity makes remote laser welding of copper a challenging task. Welding speeds below 10 m/min are required to obtain penetration depths of several millimeters in copper when using laser sources with average powers below about 8 kW. Such welds suffer from numerous defects such as melt ejections and pores. As these weld defects degrade both, the mechanical and electrical properties of the weld seam, it is important to reduce or even avoid such weld defects especially for industrial applications.

For the present paper the influence of the ambient pressure on defect formation was investigated. High-speed X-ray imaging of the welding process was used to analyze keyhole stability. It was seen that spatter formation was strongly reduced for reduced ambient pressure. Simultaneously, the penetration depth was decreased of up to 40% using identical laser parameters. It was seen that changing the ambient pressure directly correlates with a change of both, the shape and the stability of the keyhole.

Laser Beam Welding in Vacuum – Overview of Thick-Plate Steel Application and Beyond

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Abstract

Laser Beam Welding (LBW) and Electron Beam Welding (EBW) are both processes that are well established in industry. EBW has its main application fields in thick-plate joining as well as in manufacturing automotive drive train components in small indexing vacuum machines. LBW is widely used in thin-plate welding (6 mm and below) as a stand-alone process or as part of hybrid processes with arc welding variants. Despite the continuous development of laser beam sources regarding output power and beam quality, the LBW process remains behind the EBW process in terms of achievable weld-in depths and inner weld seam quality. The process variant of LBW in low to medium vacuum (LaVa) as investigated and developed by the Welding and Joining Institute (ISF) closes the gap between the two beam-welding processes and opens up new application fields for the Laser. This includes the joining of thick-walled structures beyond the possibilities of the common LBW process as well as the energy and quality optimized joining with small weld-in depths. The following paper will give a brief overview of the LaVa process, the results achieved on unalloyed steel and a comparison with EBW. Additionally, a brief glimpse of what is possible with LaVa beyond unalloyed steel is given.

Multispot laser welding to improve process stability

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Abstract

Two studies about laser welding applying multiple spots in the process zone are presented. The first study aims to investigate how to control the dimensions of a weld pool by applying multiple spots on a row perpendicular to the welding direction. Examinations were performed as bead on plate experiments. The methods' ability to increase bridging and sensitivity to alignment tolerances were tested in a butt joint configuration with up to four parts in a single pass. The results showed that both the width and the depth could be controlled independently. The ability to bridge a gap was increased, and tolerances against alignment errors were good.

The second study was from a real production in which failures in form of impurities leads to blow outs, and failure in the final product. A study of the ability to perform inline repair welding with multiple spots was performed on specimens where an exaggerated blow out was caused by zinc powder. Results showed large improvements. Porosities were present after the welding which is concluded to originate from the heavy turbulence during the blow out.

Spot patterns were produced by splitting the beam from a single mode fiber laser into several spots with diffractive optics.

Online detection of pore formation during laser deep-penetration welding

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Abstract

Pore formation during laser welding still presents a serious problem. Today, inspection of the weld quality is performed after the welding process. The detection of pores requires non-destructive methods such as computer tomography and ultrasonic testing or destructive methods such as cross-section analysis. The non-destructive methods require expensive equipment and trained staff to perform and analyze the inspection, whereas destructive testing often is not an option when welding only few parts.
In this contribution, a novel online method to detect pore formation is presented. Laser deep penetration welding was observed coaxially using the In-Process Depth Meter (IDM) of Precitec. The IDM is an optical coherence tomography system, which is capable of measuring optical path lengths. The IDM was operated in the IFSW-X-ray system which allows simultaneous time-resolved determination of the depth and shape of the keyhole. It was seen, that in many processes the keyhole is instable. The strong fluctuations in depth and shape often result in the formation of pores. It will be shown, that the keyhole changes its shape in a very specific manner before, while and after a pore is generated. By comparing the X-ray videos and the simultaneously recorded depth data, a signature was found in the measured depth signal, which indicates the generation of a pore.

Influence of laser power modulation on the time-resolved temperature distribution in the weld pool during laser welding of copper to aluminum

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Abstract

Temperatures were measured with high temporal resolution of 0.1 ms at two positions on the weld pool surface simultaneously at distances of 1 mm and 2 mm behind the keyhole during disk laser welding of Cu-OF to Al99.5 in overlap configuration. The cw welding process shows inherent instabilities resulting in large periodic oscillations of the temperature signals at a rather broad frequency bandwidth between 15 Hz to 30 Hz. These instabilities can be suppressed when laser power modulation is applied at modulation frequencies between 100 Hz and 300 Hz. Thus, the welding process is dominated by the laser power modulation. This leads to a significantly reduced temperature fluctuation range (up to 70%) in this frequency range and the temperature signals as well as the temperature gradient oscillate mainly with the respective frequency of the laser power modulation. The influence of the laser power modulation is reduced at higher modulation frequencies and the characteristic instabilities of the cw welding process appear again but are still superimposed by the laser power modulation.

Simulation of laser welding of dissimilar metals

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Abstract

Welding of dissimilar metals in general is a complicated task that involves many difficulties. Currently one of the most challenging problems is the formation of inter-metallic phases in the joining interface. In this paper we introduce a simulation model aimed to support the study of laser dissimilar welding by providing useful information on the process characteristics (e.g thermal distribution, species mixing) including inter-metallics formation. The introduced model is based on our existing multi-physical solver for simulation of laser processes within OpenFOAM's environment. The simulation capabilities were extended with new physics for the study of dissimilar welding processes. Multi-species diffusion and a simplified growth model for the intermetallic layer were included. Implemented diffusion includes temperature dependency and allows simultaneous mixing of different species. The formation of inter-metallic phases is calculated by a species reaction model coupled with both species and energy transport models. The thickness of the inter-metallic layer predicted by the simulations is finally compared with experimental data for aluminum and steel.

Laser power modulation to minimize the electrical resistance of aluminum-copper welds

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Abstract

Power modulated overlap-welding of Cu-OF to Al99.5 was investigated with the aim of minimizing the welds electrical resistance. In-situ X-ray videography was used to measure the intrusion depth of copper into the aluminum sheet with acquisition rates of up to 5 kHz. Temperatures in the weld pool were measured synchronously and a concurrence of both signals is found. It is shown that laser power modulation at frequencies from 100 Hz to 400 Hz can increase the process stability, whereas its influence on the electrical resistance of the joints is negligible. Beside, an influence of the top material on this resistance was found and we claim the aluminum-top configuration to be superior.

Influence of filler wires on weld seam properties of laser beam welded dissimilar copper connections

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Abstract

Due to its high thermal conductivity and corrosion resistance, copper and its alloys are often used for components of heat exchangers and pipe applications. These material properties results in a need of high energy densities for fusion welding which are provided by laser beam welding, for example. Here the small focal diameters lead to high energy densities and high thermal gradients. This offers the chance for a locally limited heat input and high welding velocities. However, a disadvantage of laser beam welding is the low gap bridging capability due to the small focal diameters.
A solution for this problem which is already applied for laser beam welding of aluminum and stainless steels is the use of filler wire. Thus this paper investigates the influence of copper filler wires on resulting weld seam properties of laser beam welded dissimilar copper alloy connections. At first the influence of welding velocities on weld seam properties for different gap sizes is investigated. Moreover the effect of different diameters of filler wires on weld seam geometries is determined. Here the resulting weld seam properties as geometrical shape and surface structure of the weld seams are analyzed. Besides this the mechanical and electrical properties of the welded connections are determined by means of tensile tests and four-point resistance measurements. According to the obtained results, the use of pure copper filler wire avoids seam and root collapse of the welded joints, decreases the electrical resistance of the welded components and improves the tensile strength and strain of the welded connections.

Comparison of mechanical and microstructural characteristics in maraging 300 steel welded by three different processes: LASER, PLASMA and TIG

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Abstract

The maraging steel are considered ultra high strength due to its yield strength greater than 1400 MPa and are part of a set of advanced materials of interest for technological development, mainly for aeronautics and aerospace industry. For this purpose should submit good toughness, fatigue resistance and acceptable weldability. These steels are used in the aerospace industry as high-strength fasteners, engine casings and missiles, landing gear structures, among others.

There are few studies of the process of laser welding of this material, making it important to study the feasibility of welding these steels. A comparison between the traditional welding processes (TIG-Tungsten Inert Gas and PAW-Weldding Plasma Arc) and the laser welding process (LBW - Laser Beam Welding) was performed.

To evaluate the mechanical properties were used tensile and hardness tests by microindentation, showing that the maraging steel can be welded with little loss in mechanical properties, with advantages for the laser welding process.

Microstructural characterization was performed by optic and scanning electron microscopy, showing that the fused and heat affected area in the process LBW is about 10 times lower than that affected by TIG and PAW process.

Keyhole shape and element loss in laser beam welding of brass alloys

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Abstract

Deep penetration laser beam welding is characterized by a keyhole where evaporation of the material takes place. Welding alloys with a significant difference of evaporation temperature of base material and alloying elements leads to disproportionately high evaporation of the volatile element. This leads to elongation of the keyhole and loss of the volatile element in the weld.

In this paper full penetration welds of brass alloys of 10%, 20% and 37% zinc by mass are carried out using a solid state laser. The welding process is detected by high-speed imaging by which vapor capillary elongation as well as capillary shape is observed for different parameters. Furthermore alloy composition is analyzed and element loss depending upon alloy composition and feed rate is detected by EDX measurement.

Experimental studies of fiber laser welding of a range of dissimilar material combinations

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Abstract

The capacity to produce a product utilizing various diverse metals and alloys greatly increases flexibility in design and production. Various properties such as corrosion, wear and heat of the product can be optimized, and cost saving in production are often gained. Joining of dissimilar material combinations, however, presents challenges owing to the big differences in physical, mechanical and electrical properties which are present and this can lead to premature failure of the welded joint due to the formation of intermetallic brittle phases.

In principle, a laser can weld any material, which can be joined by conventional processes. In the welding of dissimilar metals, good solid solubility is essential for sound weld properties. A sound weld between dissimilar materials is one that is as strong as the weaker of the two metals being joined, i.e., having sufficient mechanical properties i.e. tensile strength and ductility so that the joint will not fail in the weld.

At Prima Power Laserdyne detailed experimental studies have been carried to weld a range of different material combinations used in aerospace, electronics and medical industries with continuous wave (CW) and Quasi Continuous Wave (QCW) fiber lasers. Investigations including metallurgical and mechanical examinations were carried out by means of varying laser and processing parameters, such as laser power i.e. continuous wave or pulsed, power density, welding speed, etc.

Influence of laser power and wavelength on the resonant interaction between laser radiation and TIG welding arc

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Abstract

The combination of a laser beam with several kW and an electric arc for laser hybrid welding has already been known for over 30 years for its beneficial properties in deep penetration welding, for instance for its increased speed or its gap bridging capabilities. More recent studies have drawn attention towards the role of the laser´s wavelength, especially when using lasers with power less than 1 kW. Choosing the wavelength close to a resonance wavelength of the argon shielding gas allows for an additional increase of the welding speed. This paper presents investigations on the resonant interaction between a low-power laser beam and a TIG welding arc, and discusses the effect of resonant atomic absorption at 810.4 nm and 811.5 nm, respectively.

Crack-free autogeneous one-sided laser welding of a 6013 aluminum alloy T-joint for aircraft applications

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Abstract

T-joined laser beam welded stringer–skin panels are of common use on aluminum aircraft structures. Usually, the aircraft stringer-skin joints are manufactured by simultaneously welding on both sides of the T-joint and by using of a Si-rich aluminum alloy filler. Recently, we had shown a simpler welding geometry in which T-joints of the 1.6 mm thick AA6013 sheets were welded with a Yb:fiber laser by only one side without any filler material. In this welding configuration, the presence of micro-cracks limits the weld joint tensile strength up to 70-80 % of base material. For an AlMgSi alloy (6XXX) the cracking susceptibility is usually reduced by introducing in the weld pool a Si-rich filler material or by modifying the welding heating and cooling rates. These rates can be modified by introducing a secondary heating source or by changing the laser beam interaction time T_L which depends on the welding speed V and the laser beam diameter D_L ($T_L = D_L/V$). In this work, we investigated the influence of these process parameters on the welding solidification crack susceptibility using two different beam diameters, 100 µm and 190 µm. Crack-free weld T-joints were obtained for a 100 µm beam diameter only for 17 mm/s welding speed. The same condition was obtained for a beam diameter of 190µm, but with welding speed increased to 50 mm/s. The results indicate the crack-free welding conditions are obtained when T_L is greater than 3-4 ms. In such crack-free condition, the ultimate tensile stresses for Hoop and T-pull tests were 300 MPa and 260 MPa respectively, which approach the mechanical strength of the base material.

Laser beam welding of WASPALOY for aeronautic engine application

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Abstract

WASPALOY is a precipitation-strengthened wrought nickel-base superalloy extensively used as a blade and disk material in jet engines. Although WASPALOY has good resistance to corrosion and high temperature oxidation due to the presence of chromium and aluminum alloying elements, however, this alloy is not readily weldable using conventional joining technologies for manufacturing of new components or for repair of worn or damaged parts. In this research, laser beam welding (LBW) of WASPALOY was conducted using a 700W Nd:YAG pulsed laser. The influences of LBW parameters, such as laser scan rate, laser average power and defocusing distance were investigated. Microstructure of the welded seam was characterized by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD) and energy dispersive spectrometer (EDS). Microhardnesses across the welded seam were, also, measured. Hot corrosion studies were conducted on samples in the molten salt environment (Na_2SO_4-60%V_2O_5) at 900˚C for 50 hours. The results indicated that the microstructure of weld zone was mainly dendritic grown epitaxially in the direction perpendicular to the weld boundary and heat transfer. Moreover, the Ti-Mo carbide particles were observed in the structure of the weld zone and base metal. The average size of carbides formed in the base metal (2.97±0.5 µm) was larger than that of the weld zone (0.95±0.2 µm). XRD patterns of the weld zone and base metal showed that the laser welding did not alter the phase structure of the weld zone, being in γ-Ni(Cr) single phase. Microhardness profile showed that the hardness values of the weld zone (210-261 HV) were lower than that of the base metal (323-330 HV). Hot corrosion tests indicated that the corrosion resistance of the weld metal was greater than the base metal.

Modeling of powder consolidation coupled with heat transfer at selective laser melting of fused silica

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Abstract

Fused silica is perspective for obtaining crack-free parts by selective laser melting because of extremely low thermal expansion. However, the parts often suffer from excessive porosity because this material is very viscous, even at high temperatures. The model of powder consolidation is proposed, which can be used to optimise the process parameters. It takes into account viscous coalescence of particles and heat transfer through necks between particles and through the gas phase and radiative thermal conduction. The calculation results correlate with the experimental micrographs of the cross-sections and correctly predict a good contact between the bead and the substrate at the thickness of the powder layer of 100 μm and a bad contact at the thickness of 200 μm. The calculations show that full consolidation of powder corresponds to zones where the temperature attains 2000 K at laser treatment.

Properties of large 3D parts made from Stellite 21 through direct powder deposition

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Abstract

The mechanical properties of macroscopic laser deposited three-dimensional tensile test specimens out of Stellite® 21 are presented in this work. A modified software enabled the additive manufacturing of tensile test specimens through direct metal deposition using the widespread laser cladding process and hardware. The additive manufacturing set-up included a 3-axis-CNC-machine and a laser cladding processing head with coaxial powder feed. The software VisCAM RP4.0 from Marcam Engineering usually used for selective laser melting (SLM) devices was adapted within this work to translate the data of the CAD-Model into the G-Code to realise the trajectory of the CNC-machine. Three different exposure strategies were applied for the build up of tensile test specimens. The influence of the path orientation on the mechanical properties under unidirectional tensile load was investigated. It was found out that the properties of the laser generated parts were competitive to as-cast parts regarding ultimate tensile strength and Young's modulus.

Processing of high strength Al-Cu alloy using 400W selective laser melting – Initial study

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Abstract

The proposed paper deals with development of production parameters of high strength Aluminium (Al–Cu–Mg–Fe–Ni) alloy using 400W selective laser melting system. The AW2618 high-strength aluminium alloy is typically used in aerospace and military components, engine pistons, parts of turbochargers due to its ability to work in higher temperature applications. The advantage is the stability of mechanical properties after heating even over 100 °C due to the Ni and Fe content. Due to high energy input of SLM, high heating and cooling rates are induced during the melting/solidification process which gives the ability to process this typically difficult to weld material. First stage of experiments with different values of laser power (LP) and laser scanning speed (LS) were conducted to describe the processing window. Single track scans (STS) with LP 100-400W and LS 200-1400mm/s were processed to find the optimal energy density for Al-Cu alloy. Layer thickness and other parameters stayed unchanged. Continuity and quality of STS were analyzed with non-contact 3D optical profilometer. Second stage of experiments was aimed on processing of multiple layers and homogeneity of the material. The µCT scanning of the samples was used in order to obtain qualitative and quantitative information about the sample porosity. Results show, that with the higher laser power (400W) a relative density higher than 99% can be reached, however with large amount of cracks. To reach the fully dense material free of cracks further experiments are necessary.

Theoretical analysis of laser cutting of metals at 1 and 10 μm wavelength

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Abstract

We present a theoretical analysis of laser cutting of metals based on a model originally proposed by Nizievand an extension which includes heat conduction. Specifically, we investigate the dependence of relevant parameters, such as maximum cutting speed, shape of the cutting front et cetera, on wavelength, polarization, and laser beam properties. A special emphasis is on the comparison between results obtained for lasers around 1 µm and CO_2 lasers at 10 µm wavelength, respectively. To test the model we compare the numerical solutions for a cold-work steel work-piece to experimental results presented elsewhere. We find good agreement between theoretical and experimental observations. The main differences between laser cutting with 1 and 10 µm lasers arise from the different absorptivity profiles and absorbed intensities. In most of the analysed cases the computed mean absorbed intensities as well as the absorbed intensity profiles show that the energy transfer is more efficient for laser cutting with1 µm lasers.

Performance and efficiency of an industrial direct diode source with an extremely low BPP in laser cutting of Fe-based and reflective alloys

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Abstract

The performance and efficiency of a 2kW industrial direct diode laser source with an extremely low BPP are investigated when carbon and stainless steels as well as aluminium and brass sheetsare laser cut. The results confirm the industrial feasibility and robustness of the direct diode laser source as tool for laser processes. In particular in the oxidation laser cutting of iron-based alloys the low BPP together with relative larger transport fiber diameter allows quality and cutting speed equivalentto the active fiber and disk laser sources in a very large range of thickness (up to 15 mm). When higher power densities are required, because inert laser fusion cutting of structural steel is carried out or because high reflective alloys need to be cut, the low BPP and the shorter wavelength are favorable figures and produce comparable performances with the mentioned laser sources.

Effect of the laser beam polarization state on the laser cut surface quality

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Abstract

It is well-known that laser cut characteristics highly depend on the polarization state of laser beam. The works on laser cutting deal mainly with the effect of the polarization on the cutting speed, whereas the effect on the cut surface quality was almost neglected. This paper presents the experimental investigation of the effect of the laser beam polarization state on the laser cut surface roughness. The CO_2 laser was used to cut steel sheets of 3, 5, 8 and 10 mm. The cut surface roughness and maximal cutting speed were measured in the cases of the circular polarization of the laser beam, and plane polarization at various angles between the polarization plane and cutting speed direction. For all thicknesses, the roughness is minimal when the cutting speed direction is perpendicular to the polarization plane. The cutting speed and cut surface quality of the samples, cut by the CO_2 laser at various polarization states, were compared with the respective parameters of the samples cut by the fiber laser.

Multiple wavelength laser processing technology for flexible manufacturing

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Abstract

Multiple wavelength laser processing technology allows laser beams of several different wavelengths to be combined to form a single, coaxial beam. This hybrid laser beam is capable of cutting composite materials, which are composed of matrix and reinforcing materials that have different optical and physical characteristics. For example, carbon fiber reinforced polymer can be cut using a combination of a 1.06 micron laser beam, which cuts thought the carbon fibers, and a 10.6 micron laser beam, which simultaneously vaporizes the polymer matrix material. This technology not only allows two or more wavelengths to be combined, but also allows for seamless switching from one laser wavelength to another. This capability enables flexible manufacturing processes for many applications.

Remote laser cutting of composites with a fibre guided thin-disk nanosecond high power laser

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Abstract

Carbon fibre reinforced plastics (CFRP) are of high interest for lightweight construction within many industrial sectors. The automotive industry shows already an increasing demand for CFRP parts, but the implementation of CFRP parts is limited by the lack of automatable, reliable and cost efficient processes. In the field of laser cutting of CFRP materials, there are also different scientific approaches such as the use of nanosecond lasers with high average power. At this point, the German research project HolQueSt 3D starts dealing with 3-dimensional high power laser processing of lightweight CFRP structures in enhancing quality and quantity.

Within this paper, the authors will describe the first results achieved with a newly developed fibre-guided high power nanosecond laser. The laser emits at a wavelength of $\lambda = 1030$ nm with a pulse duration of $t_p = 30$ ns. The laser has an average power of $P_{avg} = 1.5$ kW with a maximum pulse energy of $E_{p,max} = 80$ mJ. The laser beam was deflected by a 3D programmable focusing optic with a focal length of $l_f = 255$ mm. CFRP based on an epoxy resin with two different reinforcements was used for the investigations. The gained results were analysed concerning the achieved heat affected zone and the optical quality of the cutting edges. The average HAZ width b could be minimized to a value below b <40 µm for both materials. Furthermore, the maximum effective cutting velocity for selected laser parameters was determined. The maximum effective cutting speed achieved within this investigation is$v_{eff} = 1.8$ m/min. The results of the investigation revealed the potential of the fibre-guided nanosecond laser for industrial applications. This is in particular the case for 3D applications due to the possibility of robot based remote processes.

F-Theta at Jenoptik – A holistic approach

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Abstract

The continuing development in laser technology and laser applications drives the development of suitable optical systems and components. E.g. both trends to higher laser power as well as shorter laser pulses pose different new challenges for the design, manufacturing, and testing of F-Theta lenses. This contribution will present how Jenoptik Optical Systems GmbH addresses these challenges, employing experiences as a manufacturer for customized optical systems for both laser as well as high-NA UV applications.

Laser or plasma cutting – Is there a choice?

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Abstract

There are various methods that can be used for cutting metals. Depending on the type of material as well as economic and quality-related aspects, each technology has its own strengths and thus its justification.
On the one hand, there is the versatile laser cutting; on the other hand there is the constantly improved plasma cutting technology. Thus, new areas of application for cutting metallic work-pieces with plasma could be opened up over the past years and process variants have been developed which cover even non-conductive or interrupted materials in a wide performance range and a wide range of material thicknesses.
Today, some plasma cutting systems achieve in many areas cut qualities which are equal or almost equal to laser cutting. Due to the significantly lower investment costs compared to laser, the costs per cutting metre for plasma cutting are considerably lower. The achieved performance increase of the plasma cutting units with regard to thick mild steel sheets is also increasingly competing with gas cutting methods.
But which cutting method is the right one? This contribution shows the strengths and weaknesses, which every user should consider. It does not always have to be a laser, because laser cutting also has its limits, or there are areas of application where other methods, like plasma cutting, can be more economic and/or achieve high quality.

Laser micro-cutting of thick tungsten sheets

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Abstract

In recent years, laser-based technologies become important or even dominant in industrial applications such as welding or cutting. Further possibilities and innovations are still in progress concerning the area of laser micro processing. Laser technologies enables to manufacture materials with micrometeraccuracy, however, there are obstacles to reaching desirable speeds when cutting thick materials (>200 µm).
Different cutting strategies were investigated to achieve the high cutting speed and quality at the same time in a 300 µm thick tungsten with picosecond lasers. A parametric study of laser cutting was performed taking into account trade-offs between precision and cutting speed. Experimental results proved that picosecond lasers are suitable to process quite thick tungsten sheets with micrometeraccuracy. Furthermore, improvements in overall performance were achieved by optimizing the beam guiding approach over the full size of the component to cut.

The influences of pulse overlap on cut quality during fiber laser cutting of electrodes for Lithium-ion batteries

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Abstract

Concerning e-mobility and the research of highly developed battery technologies within the automotive sector the quality improvement and cost reduction of Lithium-ion batteries is an important challenge. Therefore the Battery LabFactoryBraunschweig (BLB) examines the entire production chain with the objective of improving the energy density, quality and reliability of these traction batteries.

Within this development programme the cutting of the electrodes represents a significant challenge for the production of Lithium-ion batteries. Compared to die cutting the approach of contactless laser cutting offers a higher flexibility and reduced tool costs. Furthermore the decreased edge quality due to the tool wear can be prevented by using laser cutting.

Referring to laser cutting of thin metal and composite sheets by using a fiber laser a particular challenge is the improvement of the cut quality as well as the reduction of the heat affected zone leading to a degradation of properties. This comparative study investigates different process parameters such as pulse frequency or cutting speed and focuses on the influence of pulse overlap or respectively yielded energy to minimize the heat affected zone and thus improve the quality of the cut. The influences of the pulse overlap on the delamination width which is defined as the delamination of the coated layer of the metal substrate at the laser cut kerf are examined.

Basic imaging and modelling analysis of the processing front in laser remote fusion cutting

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Abstract

The nature of the front surface in laser welding and laser remote fusion cutting is of importance. Both processes have in common that their front is governed by the ablation pressure from laser-induced surface boiling. The geometry of the front is calculated by a simplified analytical model, through local calculation of an energy balance between the absorbed laser beam and heat losses, neglected multiple beam scattering. From high speed imaging of the front a pattern can be seen, moving downwards. The pattern is interpreted as mass movement of topology along with temperature variations. In combination with modelling of the front shape, applying simplifying assumptions the greyscale variation of the images were converted to a three-dimensional wavy surface of the front in remote fusion cutting. This modelled geometry including the topology enabled sophisticated analysis regarding the distribution of the angles of beam incidence, absorptivity and absorption in combination with beam projection. The analysis enabled to study sub-trends like roughness sensitivity, shadow regimes, time dependence and separation or combination of peaks and valleys. Statistical analysis by frequency polygons enabled to clearly identify certain trends, despite the very complex front topology and movement. When correlating the angle dependent Fresnel-absorptivity characteristics with the steep main inclination angle of the processing front, conclusions on the sensitivity of the front with respect to a wavy topology can be made. For remote cutting of stainless steel with a fibre laser, in one studied case about 25% of the surface were shadow domains, 15% of the surface had so glancing angles of incidence that the absorptivity became strongly modulated between 0-35%, while most of the surface, namely 60% remained in a narrow absorptivity window of 35-43%. This very robust behaviour is likely to take place for most parameter combinations, demonstrating a very typical and predictable absorption behaviour of lasers with about 1 µm wavelength.

Measurement of the laser cut front geometry

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Abstract

Solid-state lasers at the wavelength of about 1 µm have gained a rapidly increasing importance in the last few years for cutting metal sheets. As known from numerous investigations, the spatial distribution of the absorbed laser power is a key factor for the efficiency and the quality of the cutting process. Therefore, the exact cut front geometry is one major input parameter in order to investigate the influence of the absorption process.

In the present paper, measurements of the cut front geometry while cutting mild steel will be presented. A novel monitoring system, a so called quotient goniometer, enables recording temporally and spatially resolved measurements of the cut front geometry. The quotient goniometer exploits the angular- and polarization-dependent thermal emission of hot surfaces in order to measure the angle of the cutting front. The study shows that the cut front has a characteristic, straight profile while cutting with standard parameters. In addition the dynamic behavior of the molten material can be visualized with the quotient goniometer. It will be shown, that there is a high fluctuation of the cut front profile near the bottom of the cut front, while the shape in the upper half of the cut front typically remains constant over time. The measurements are compared to longitudinal sections to investigate the cut front geometry in the cutting direction.

Optical cutting tear detection system for industrial fiber laser based cutting machines

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Abstract

In this study, we demonstrate an optical cutting tear detection and evaluation system affixed to a 4 kW fiber laser cutting machine. The sensor is mounted between the cutting head and collimator and collects the thermal radiation from the process zone. The process radiation is detected by a stacked silicon and InGaAs photodiode combination and digitalized with 20 kHz sample rate. The acquired signal for two exemplarily chosen cuts in 2 mm stainless steel which one of them include cutting tears are shown wherein the piercing, the waiting time and laser switch on/off are clearly be resolved. These signals are high pass filtered and the fluctuation range is calculated. In the resulting signal, a cutting tear is indicated by the fluctuation range of the Si diode exceeding the fluctuation range of the InGaAs diode multiplied with a correction factor. With this characteristic signature, 193 cuts including 83 cutting tears were analyzed revealing 96.4 % detection rate (alpha error 3.6 %) and 0 % beta errors. The easy integration in existing cutting systems, the direction independent signal and the high detection rate highlight the systems potential for cutting tear detection in industrial cutting machines.

Modeling of transport phenomena in metal fusion cutting using high power laser

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Abstract

In the present study, a three-dimensional transient numerical model was developed to study the temperature field and cutting kerf shape during laser fusion cutting. The finite volume model has been constructed, based on the Navier–Stokes equations and energy conservation equation for the description of momentum and heat transport phenomena, and the Volume of Fluid (VOF) method for free surface tracking. The Fresnel absorption model is used to handle the absorption of the incident wave by the surface of the liquid metal and the enthalpy-porosity technique is employed to account for the latent heat during melting and solidification of the material. To model the Physical phenomena occurring at the liquid film/gas interface, including momentum/heat transfer, a new approach is proposed which consists of treating friction force, pressure force applied by the gas jet and the heat absorbed by the cutting front surface as source terms incorporated into the governing equations. All these physics are coupled and solved simultaneously in Fluent CFD®. The main objective of using a transient phase change model in the current case is to simulate the dynamics and geometry of a growing laser-cutting generated kerf until it becomes fully developed. The model is used to investigate the effect of some process parameters on temperature fields and the formed kerf geometry.

Beam oscillation – Periodic modification of the geometrical beam properties

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Abstract

Sheet metal with thicknesses above 8 mm has a distinct cutting performance. The optical configuration, composed of fiber diameter, collimation and focal length, allows for many opportunities to influence the stationary beam geometry. Previous analysis points out the limits of this method in the thick section area. The achieved cut quality of a stationary beam shape is restricted by the laser power. Most operators would like to improve the cutting results without changing their available laser sources, even for thicker materials. To overcome some limits, new approaches are desired. Within the present study an experimental investigation of fiber laser fusion cutting of thick section stainless steel was performed, by means of dynamical beam oscillation. The aim is to compare stationary and dynamical beam shaping, through evaluation of the cut quality, the kerf geometry, and the applied process parameters. The investigation emphasizes promising procedural possibilities for improvements of cutting performance in fiber laser cutting of thick stainless steel.

Flow diagnostics produced by selective laser melting of cutting nozzles

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Abstract

The increasing spread of laser technology in materials processing leads inter alia increasingly individual solution strategies in order to cope with the growing demands on the process control. The focus of this work is the fluidic analysis of the cutting nozzles, which were usually produced either by selective laser melting or conventional methods. The Schlieren measurement was utilized in order to visualize flows. Through the adjustment of optical components, the Schlieren-Aufnahmegerät 80 was coupled with a high speed camera. Based on these measurement results, the influence of manufacturing technology has been evaluated on the flow behaviour. With the help of cutting tests a direct proof of the achievable quality of the cutting edge has been evaluated. The results from both research methods provide a statement on the quality of the gas stream and the achievable cutting quality of manufacturing technology.

Innovative distance control for laser cutting based on inline low coherence interferometry

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Abstract

Laser based cutting processes are present today in a large number of industrial applications, processing different materials from micro to macro-ranges with high flexibility and automation levels. Modern systems use different sensor units to monitor and consequently enable a robustness enhancement through a controlled process. In the case of a distance control, e.g. an integrated capacitive sensor monitors the distance between laser cutting head and workpiece, with the aim of maintaining the workpiece within the system's allowed parameter window.
The application of this technique is however just possible on conductive materials, not covering several carbon fiber reinforced plastic (CFRP), plastic or glass workpieces. Additionally the measurement spots of capacitive sensors are very large, in the range of some millimeters, limiting its usage next to workpiece discontinuities.
Within this paper, the integration of a low coherence interferometer in the optical path of a laser cutting head is presented for inline distance measurements. This solution presents a promising alternative to the state of the art, enabling a material and surface independent monitoring / control. Furthermore the dimensions of the measurement spot in the range of micrometers (same range of the laser spot) also enables the monitoring / control next to workpiece discontinuities. The achieved results validate its usage for inline distance measurement in different parameter scenarios.

Areas of application for TEA CO_2-Laser induced shock waves

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Abstract

Increasing batch size and shorter lifecycle in micro manufacturing is a challenge for production processes. Conventional processes have limits regarding the technical feasibility for producing micro parts, due to so-called size effects. Therefore, a new flexible production approach using TEA-CO_2-laser induced shock waves for manufacturing micro parts is presented in this paper. For thin sheet in the range of 15 µm to 100 µm materials there are some technical challenges using a conventional mechanical process. The right tool alignment, for forming, punching and blanking processes, between punch and die is an increasing challenge when the process dimensions are decreasing. Additionally, in a punching process the clearance between punch and die is such a critical parameter. The size of a suitable cutting clearance correlates with the sheet thickness, e.g. for a fine blanking process 0.5 % of the material thickness, which results for 20 µm in clearance dimension of just 0.1 µm. Therefore, it is shown how a laser shock process in micro range can replace conventional forming, punching and blanking processes. For thermal joining processes, there are restrictions due to the principle of joining, especially for the use in clean rooms or regarding the creation of intermetallic phases for hybrid joints. Therefore, laser induced shock waves can be used to join different sheets by a plastic forming process. This technology enables the joining of different sheet materials with thicknesses between 20 µm and 300 µm. The manufacturing of these joints is an incremental process where several laser induced shock waves are needed to form an undercut, which presents the joint itself. The joining of aluminum/steel and aluminum/copper joints is shown in this paper. For different thicknesses ranging from 15 µm to 100 µm of Al99.5-sheet perforations were successfully generated. The punching geometry is also not limited to circular holes. Rectangular perforations were proved to be applicable as well. Methods and approaches to use a laser as a flexible tool for forming, cutting and joining processes for the micro range are presented in this work.

Additive manufacturing of a deep drawing tool

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Abstract

A new approach to establish sustainable production technology in metal forming is to avoid lubricants. This new green technology is called dry metal forming. In this work laser surface technology by means of laser cladding and remelting was used to assess the surface properties by varying process parameters. Furthermore, the cladding process was applied for additive manufacturing. The target was the generation of a deep drawing tool to form circular cups out of 1.4301 high alloy steel with an inner diameter of 30 mm. Different build-up strategies were tested to realize the near net shape geometry of the tool. Parameter set for the deposition process was investigated. The generated forming tool was successfully deployed to form circular cups.

Influence of a short-term heat treatment on the formability and ageing characteristics of aluminum profiles

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Abstract

Aluminum and its corresponding semi-finished products are widely used in the automotive industry. However, their formability is low in comparison to conventional steel materials. At the LFT a new approach to enhance the forming limits of precipitation hardenable aluminum alloys was invented. By performing a partial short term heat treatment a local softening of the material and the adaption of the material flow is possible. Due to this, critical forming areas are relieved and premature failure is prevented. After already been investigated in detail for blank material the adaption to aluminum profiles is preferable, because they are increasingly used in car space frames. For a better understanding of the mechanisms of this technology a comprehensive material characterization will be induced. Furthermore, the influence on the different subsequent aging processes (natural, artificial) is analysed. Based on the results, a process window and design rules for the implementation of a local short-term heat treatment on profiles of the precipitation hardenable aluminum alloy EN AW 6060 will be derived.

Laser surface treatment of electroless Ni–P-SiC coating on Al356 alloy

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Abstract

Electroless Ni-P–SiC coatings are recognized for their hardness and wear resistance. In the present study, electroless Ni–P coatings containing SiC particles were co-deposited on Al356 substrate. Laser surface heat treatment was performed using 700W Nd:YAG pulsed laser. Effects of different laser operating parameters, such as laser scan rate, laser average power and defocusing distance on microstructures were investigated by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD) and energy dispersive spectrometer (EDS). The results of microstructural characterization indicated that the laser treatment under different operating conditions produced composite coating contained nanocrystallined Ni-based matrix with SiC particles Ni3P, Ni12P5, Ni5P2, Ni8P3 precipitates. The microhardness measurements showed that the hardness of the coating was increased up to 60 percent, due to laser heat treatment, without effect on base metal.

Characterization of the effect of laser scribing on the isolation coating of electrical steel

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Abstract

The demand for high energy efficiency leads to an ongoing development of better material grades of grain oriented electrical steel, which is used as core material in power or distribution transformers. In order to reduce the core losses of the silicon steel after the process of rolling different methods can be used, such as mechanical scratching, plasma irradiation, spark ablation and laser scribing. All these techniques induce mechanical or thermal stress that refines the magnetic domains. Due to the no-contact nature and the ease of integration laser scribing is the most commonly used technology, but with the drawback of laser-induced damage of the isolation layer [1], [2].

In this study the material ablation of the isolation layer due to high power continuous wave CO_2 (10.6 µm) and fiber laser beam sources (1.07 µm) was investigated in order to evaluate the damage threshold of the coating with respect to the treatment parameters. The study was performed with the so-called LMDR (Laser Magnetic Domain Refinement) test system to realize industry-related process parameters with spot velocities up to 300 m/s and laser output powers up to 4000 W. The experimental results are combined with material studies to characterize the ablation process related to the difference in the absorption behavior of the material based on the difference in wavelength [3].

Reconditioning of lamellar graphite cast iron parts by means of laser cladding and heuristic-based process parameter adaption

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Abstract

Clad layer based on a two-stage experimental study of laser cladding on grey cast iron, a heuristic approach for the prediction of the process parameters is presented. Different repairing strategies using two Ni-based alloy powders are analyzed in an experimental design. Along this results the correlation of dilution, aspect ratio and the weld seam quality is investigated. The mathematical description of cladding quality under the condition of different dilutions and aspect ratios is used to define the repair requirement. The aim is the identification of the process parameters necessary to produce a good quality weld. Since the clad layer quality depends on various influence factors the direct way of determining the suitable parameters is not a possible solution in many repair applications because of the complex free-form geometries of the damaged areas, the various material conditions, differing part thicknesses and many more. The influence of the differing part thickness and along with this the different thermal situations in the part are chosen exemplary to show the capability of process parameter prediction by the usage of neural networks.

Surface structuring by laser remelting of Inconel 718

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Abstract

A new approach of structuring metallic surfaces is structuring by remelting with laser radiation (WaveShape). In this process no material is removed but reallocated while molten. This structuring process is based on the new active principle of remelting. The surface structure and the micro roughness result from a laser-controlled self-organization of the melt pool due to surface tension. Up to now basic research has been focused on hot work steel 1.2343 (AISI: H11) and titanium alloy Ti6Al4V, and promising results have been achieved for this materials. Current research and development is now seeking to expand the spectrum of processable materials. Since remelting is a thermally driven process, significant differences between metals are expected due to their thermos-physical properties such as thermal conductivity, absorption coefficient, viscosity, heat capacity etc.

The nickel based super alloy Inconel 718 has a wide range of industrial applications, especially for turbine components in aviation and aerospace. The innovative WaveShape process for this material will be investigated within this paper. The procedural principle of the WaveShape process is based upon a sinusoidal modulation of laser power while the laser beam is moved over the surface. We used metallographic cross sections to measure the dimensions of melt pool depth and width as they depend on processing parameters, such as laser beam diameter, scanning velocity and laser power. We also investigated basic interdependencies between structural characteristics (e.g. height) and processing parameters used, such as laser beam diameter, laser power, wavelength of modulation and scanning velocity.

The results show that surface structuring by remelting is well suited to process the nickel based super alloy Inconel 718 since structures and process velocities achieved are higher than for the previously investigated hot work steel 1.2343 (H11).

Reconditioning of HPT blade tips

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Abstract

High pressure turbine blades are exposed to high thermal, corrosive and mechanical load. Todays HPT blades consist of superalloys, commonly nickel base. In order to increase the resistance against oxidation attack, the blades have a corrosion coating and an optional thermal barrier coating. Moreover, cooling holes realize a film cooling for further protection. However, after flight operation the blades don't have the length as a new part. Due to the wear between shroud and the blade the blades got shorter and a welding buildup is mandatory in a repair shop visit.

In order to rebuild the blade tips near net shape an automated laser cladding process can be used. Laser cladding is an overlay welding process in order to build up wall like structures or volumetric bodies. The energy for welding the filler material is delivered by a laser beam. The filler material (commonly consisting of powder) is delivered by a coaxial nozzle. The coaxial nozzle realizes the same quality independent of motion direction. Due to the usage of a laser beam the heat can be introduced highly spatial resolved. Hence, a welding process with comparably low heat input is possible. That allows low thermal distortion combined with highly net shaped structures and a high overall process efficiency.

The requirement to repair welding is an adaptive process that reacts on the individual blade distortion coming out of the flight operation. Therefore, in production every blade is individually measured in the laser cell. Afterwards the program is rotatory and translative matched. This allows an individual automated treatment of every blade.

The materials of turbine blades have been further developed towards higher creep resistance. The first blades consisted of polycrystalline material. Afterwards, directionally solidified (DS) materials have been developed. Most of todays high pressure turbine blades consist of single crystal (SX) super alloys. The requirement of welding DS and SX materials make the welding process more difficult. Time temperature regimes and spatial motion control have to be more precise in order to match an even smaller process window. By controlling the laser system it could even be possible to generate SX epitaxial solidification. Hence, the solidifying material has the same crystallographic orientation as the base material.

High speed quasi-cwfibre laser drilling of aerospace alloys

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Abstract

Laser drilling of metals and alloys are extensively used across various sectors to produce holes of various size and shape. Currently, most laser drilling of aerospace alloys are performed using Nd:YAG laser and over the years many attempts were made to increase the productivity of Nd:YAG lasers drilling process, but with little success. This paper investigates the use of recently developed millisecond-pulsed-Quasi-CW-fibre-laser for high speed drilling of aerospace grade nickel super-alloy. The main investigation concentrates on the effects of proportional increase in laser drilling speed and power on hole quality. Various hole characteristic were examined using trepanning drilling process. The principal findings are based on reducing the recast laser. Results show that the beam characteristic/profile of the fibre laser is more uniform over the range of investigated laser power levels, compared to a lamp pumped Nd:YAG laser. The uniform beam profile of the fibre laser enables proportional increase in speed and power without undermining the drilling quality. The results demonstrate that fibre laser drilling can produce step change in drilling speed and quality, which may not be feasible with the free-space Nd:YAG laser. The fibre laser drilling process shows around four times increase in productivity on a flat plate compared to the traditional Nd:YAG drilling process.

Developments on laser drilling in gas turbine blades

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Abstract

Drilling applications represent about 5 % of the industrial laser materials processing applications. Cooling holes in gas turbines for aircrafts as well as for power plants are one of the main applications. The improvement of productivity has led to several drilling strategies with respect to laser sources (thermal drilling and ablation drilling), the beam handling, beam distribution, and handling of the work piece, all of which contribute to the over-all efficiency of the process and a high productivity. We present the successful development and implementation of a combination of laser systems with different pulse durations for drilling complex 3D geometries. Additionally an overview on actual fields of development is presented.

Development of wire based laser alloying process for highly stressed surfaces of hot forming steel tools

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Abstract

The machining of high strength steels for vehicle parts in press hardening processes requires high process temperatures which lead to high tool stresses with huge wear. In order to reduce mechanical wear, a local laser alloying process is developed to increase tool-endurance. Therefore, filler material in form of a compact filler wire is used which ensures higher material utilization as well as an avoidance of decomposition problems in comparison to powder based alloying processes. Moreover a dynamic laser beam deflection is necessary to enable a turbulent flow of melt for a homogeneous distribution of alloying elements. To ensure homogeneous dispersion of the alloying elements in the alloying area as well as uniform mechanical properties of the surface, a process development for wire based alloying processes, like different parameters with oscillating laser beam and compositions of alloying elements is necessary.
The development of different beam oscillation frequencies in combination with various wire feed velocities enables a suitable process for an adaption of the surface properties. To reach the material-specific element concentrations for hot forming tool steels, which typically lead to an improvement of mechanical and thermo-mechanical properties and increase the wear resistance, the base material is alloyed with nickel and chromium. Oscillation frequencies between 50 and 400 Hz and oscillation amplitudes of the double wire diameter enable the reentry of the oscillating laser beam into still existing melt pools and a stable alloying process.

Inner walls laser cladding of WC reinforced Ni coatings

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Abstract

Thick and hard coatings are widely applied in a substantial number of heavy-duty industrial applications to improve wear and corrosion resistance. The techniques that allow producing depositions of metallic, ceramic or metallic-ceramic mixtures in zones with difficult access, like inner walls of a cylinder, are quite limited. Methods like spin casting, for instance, are successfully applied in parts with cylindrical symmetry. Nevertheless, when parts with more complex geometries have to be coated, new solutions must be applied.

The use of laser cladding as a possible alternative for these applications is studied in the present work. Coatings of a NiCr matrix reinforced with hard tungsten carbide particles were produced in internal walls. Carbides with different shape and size were employed in order to find the most suitable candidate for producing defect free coatings with maximum thickness. In order to achieve this goal, the effect of different processing parameters had to be investigated, and the use of preheating and a soft buffer layer was also considered for minimizing the residual stresses produced during the rapid cooling of the coating, from the melting point to the solid state.

Liquid penetrant tests were used for detecting eventual cracks of the coatings and optical and electron scanning microscopy, as well as microhardness tests were used for characterizing crack-free samples.

Laser-induced subsurface modification of silicon wafers

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Abstract

In addition to the processing of transparent dielectric materials, pulsed lasers can be used to produce subsurface modifications inside silicon by employing near- to mid-infrared light. An application of these modifications is laser-induced subsurface separation, which is a method to separate wafers into individual dies. We investigated the subsurface modification process using a combination of numerical simulations and experiments. Different wavelengths, pulse durations and pulse energies were tested. We found that subsurface melting of silicon followed by rapid resolidification is the primary material modification mechanism. Lattice defects and transformations to both amorphous silicon and pressure-induced high density silicon phases occurred as a result of the laser irradiation.

Deposition of corrosion resistant alloy onto low alloyed steel using LAAM for oil & gas applications

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Abstract

In the oil & gas industry, a large number of components are designed with corrosion resistant cladding in order to prevent premature failures, rapid degradation and chemical induced cracking. Most of the surface components are made of carbon steel. However, in order to protect the inner-surface from erosion and corrosion, they are clad with corrosion resistant alloys including stainless steel and Ni-base alloys. Currently TIG/MIG cladding has been widely adopted in the oil & gas industry. However, there are several issues for TIG/MIG cladding. These include low conformance of the clad, lengthy pre-heating and post-weld heat treatment, as well as excessive post-machining time due to undesirable built up of clad material at intersecting holes. Laser aided additive manufacturing (LAAM) has advantages over traditional arc cladding processes for surface modification and repair. The key advantages include lower distortion due to lower heat input to the base material, higher conformance and clad integrity, less materials, manpower and energy needed.
In this paper, deposition of corrosion resistant alloy (CRA) onto low alloyed steel using LAAM was studied. Post heat treatment was investigated to achieve required mechanical properties. The results showed that the quality of the clad CRA can be significantly improved. Pre-heating is not necessary and the post heat treatment time can be reduced 50%. The tensile properties of the deposited material can meet the specifications for oil & gas applications.

High speed micro cladding using a high-power single-mode continuous-wave fiber laser and a polygon scanning system

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Abstract

High speed micro cladding is a new field of research at the Laserinstitut Hochschule Mittweida (LHM). So far, the investigations have been focused on high rate micro cladding with high power short pulse lasers and fast galvanometer scanner systems. Thereby, a high build-up rate of more than 3,500 mm^3/h and a structural resolution of 50 µm have been achieved [1, 2]. Laser micro processing e.g. welding and cutting by applying high brilliance laser radiation of continuous wave (cw) lasers in combination with ultrafast beam deflection systems has been successfully applied at LHM [3, 4]. Therefore, the current investigations deal with the potential of high speed micro cladding of µm-sized metal powder using a cw laser. For the experiments, a cw fiber laser with an output power up to 3 kW and a polygon scanning system for fast laser beam deflection with a scan speed up to 500 m/s are used. Furthermore, to switch the laser irradiation during the scan line, an acousto-optic modulator with a maximum frequency up to 2 MHz is applied. Generated micro-walls and the results of the rapid surface coating with layer thicknesses in the micron range are presented depending on the various laser parameters. Also, the influence of process limits of the high speed micro cladding are shown and discussed.

Selective copper plating on polymers induced by laser activated fillers

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Abstract

Selective plating of metals on polymers has many applications from decorations of artworks to building's engineering. However, the best prospects of this technology are for electronics application: making conductive tracks for integrated circuits. There are two basic techniques of laser writing for selective plating on plastics: the laser-induced selective activation (LISA) and laser direct structuring (LDS). In the LISA method, pure plastics without any filler can be used. In the LDS method, special fillers are mixed into the polymer matrix. Laser writing for selective plating is fast and cheap for prototyping. Moreover, there is material saving because it works selectively. However, the biggest merit of this technology is the potential to produce moulded interconnect devices, enabling to create electronics in the 3D structure, thus saving space, materials and cost of production. There are some commercial materials available on the market, but mostly they are based on expensive fillers, usually palladium.

In this work, both methods of the laser writing for the selective plating of polymers were investigated and compared. We present the LDS results on polymeric materials with new carbon-based additives, and the laser processing has been studied using picosecond and nanosecond laser pulses.

Free-form fabrication of steel parts by multi-layer laser cladding

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Abstract

Laser Cladding (LC) is actually one of the most attractive techniques in the group of Material Accretion Manufacturing (MAM) processes. As a surface coating technique, laser cladding has been developed for improving wear, corrosion and fatigue properties of mechanical components. Multilayer laser cladding (MLC) can be used also for high performance part repair and as a rapid manufacturing process. Thus, the application of laser cladding technology is nowadays widely extended in several industrial sectors due to its advantages for high added value parts direct manufacturing and repairing.

Multilayer laser cladding (MLC) combines powder metallurgy, solidification metallurgy, laser, CAD/CAM, CNC, rapid prototyping and sensors technologies. This process allows to produce metal components ready to use, in a single step, without the need for molds or tools and using a wide variety of metals, including those very difficult to work with conventional techniques.

The aim of this work was to manufacture MLC steel parts using a CO_2 laser with a maximum power of 3kW. The effect of the main process parameters (laser power, travel speed, powder flow rate, degree of overlapping) on the properties of built parts was investigated. A Taguchi experimental plane was used to reduce the number of experiments and a mathematical model was applied in order to obtain an optimized degree of overlapping between adjacent layers and between tracks. Performance of the MLC samples were analyzed in terms of density, macro structure, adhesion to the substrate and microhardness. The powder material chosen for experiments had a composition close to a maraging steel (grade 300). Experimental results showed that high density parts could be produced with a limited number of tests.

Industrial laser technologies for shipbuilding

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Abstract

Laser welding technologies are widely applied for welding of thin-wall constructions. The shipbuilding industry requires high-performance production technologies for the heavy gauges. A hybrid laser-arc welding technology which provides higher productivity, improvement of production effectiveness and reliable quality of welded joints is the most promising technology for this task.
JSC "Shipbuilding & Shiprepair Technology Center" (JSC SSTC) jointly with Saint-Petersburg Polytechnic University performed a complex of studies, including modeling and full-scale experiments, for the purpose of development of industrial hybrid laser-arc welding technologies. The dynamic model of the deep penetration hybrid laser-arc welding process, based on variational principle, was designed. This model specifies the dynamic processes (including self-oscillating) effect on the welding seam formation. Designed model takes into account melt flow, waves traveling on the melted pool surface, viscosity of the melted metal, capillary tension, return pressure and laser radiation parameters. Experimental researches were carried out on the preproduction models of technological complexes developed by JSC SSTC and equipped with 16 kW and 25 kW fiber lasers.
At the present time JSC SSTC is developing the technology for vertical position hybrid welding for high-strength steel over 40 mm thickness. Industrial hybrid laser-arc welding technology for butt-welded and T-joints up to 20 mm thickness was approved by Russian Maritime Register of Shipping (RMRS).

Laser direct metal deposition for alloy development: Use of nominal composition alloy powder as compared to mixed powder feeding with matched composition

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Abstract

In this work we test the feasibility of using the Laser Metal Deposition Process in the field of alloy development. Two powder blends are included in the powder feeding system, in independent hoppers, and mixed on-fly with weight mixing ratios as set by the user. Two mixtures were tested, Tribaloy 800+Ni and Tribaloy800+Ni20Cr, in proportions equivalent to the Tribaloy 900 composition. The microstructre of the mixed deposited material was compared with that of the nominal blend. Promising results were obtained with the first mixture (T800+Ni), while the second one (T800+Ni20Cr) rised questions to be considered about the entalphy of formation of the respective alloys and the relevance of using similar powder sized.

Effect of sensitization on pitting corrosion resistance of laser melting 304 stainless steel

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Abstract

The present paper presents an attempt to improve the corrosion resistance of sensitized 304 stainless steel by pulsed laser surface melting. Tafel extrapolation technique was used to determine the corrosion rates in 3.5% NaCl in four conditions. These conditions are as-received, sensitized, laser treatment for as received stainless steel and laser treatments after sensitization. The results obtained are expressed in terms of corrosion parameters through electrochemical behavior namely, E^o, I^o, $E_{Corr.}$, E_P, I_P, $E_{Pit.}$ And I_{Pit}. Detailed analysis found that these parameters are strongly dependent on the microstructures of the stainless steel. The results reveal when the potentials increase means the microstructure becomes thermodynamically more stable and has good corrosion resistance. The above electrochemical parameters for sensitized 304 stainless steel show that the localized corrosion rate increases which affected the phases. The laser surface melting treatment shifts the potential toward noble direction. The corrosion current densities values shift to lower values. The comparison of anodic polarization curves indicates that the corrosion rates for laser treated samples are reduced. Increasing the corrosion resistance means that the most inclusions at the surface have been dissolved in the structure due to melting. An interesting feature is the systematic shift of the pitting potential in the noble region with a laser melting. This results confirms that the laser treatment can be used successfully to improve the localized corrosion resistance.

Influence of particle size on heat affected zone in laser cladding

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Abstract

Laser cladding is one of the useful surface coating methods for improving the quality of wear and corrosion resistance of material surfaces. Compared with other conventional surface coating methods, such as plasma thermal spray and transferred arc welding, laser cladding can produce much better coatings with minimum dilution and well bond to the substrate. When cladding layer is produced, heat affected zone (HAZ) is formed in the substrate. In order to reduce the area of HAZ, heat input needs to be reduced. In this study, influence of particle size on HAZ was investigated. The cladding layers were produced at various heat input and particle size. Ni-Cr-Si-B alloy powder with the average particle size were 30, 40 and 55 µm were deposited on the C45 carbon steel substrate. The area of HAZ was measured with optical microscope. The results showed that the cladding layers with well attached to the substrate were produced at smaller heat input by using smaller powder material. The area of HAZ with 30 µm powder was about 30% smaller than that with 55 µm powder

Analysis and optimization of process parameters in Al-SiCp laser cladding

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Abstract

The process parameters of the laser cladding have great effect on the clad geometry and dilution of the single and multi-pass coatings of an aluminum matrix composite reinforced with SiC particles (Al/SiCp) on ZE41 magnesium alloys using a high-power diode laser (HPLD). The influence of the laser power (500-700W), scanning speed (3-17mm/s) and focal position of the laser beam (focus, positive and negative defocus) on the shape factor, the cladding-bead geometry, the cladding-bead microstructure including the presence of pores and cracks, and mechanical properties such as hardness has been evaluated. From the measured values, different contour maps were produced, which show the correlation of these process parameters and their influence on the properties and ultimately, with the feasibility of the cladding process. The importance of the focal position is demonstrated. The different energy distribution of the cross section of the laser beam in focus, positive and negative defocus affects on the cladding-bead properties.

Strategies for high deposition rate additive manufacturing by laser metal deposition

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Abstract

To increase the integration of laser based additive manufacturing in the series production major challenges related to the production costs and deposition rates still need to be overcome. Laser Metal Deposition (abbr. LMD), also known as Laser Cladding or Direct Metal Deposition, is regarded as an established technology for repairing components and producing coating systems with defined properties in the petrochemical and heavy duty industry, as well as in medical engineering and aerospace. A novel promising application field for LMD is the use of the process as additive manufacturing technique.

By contrast with the powder bed technology, by means of LMD it is possible not only to generate complete parts but also to deposit defined 3D structures on existing components. In this way, an alternative to additive manufacturing from scratch is given: a combination between conventional processing and advanced laser additive manufacturing can be applied to reduce the production costs. Also geometrical modifications as well as the production of local reinforcements to adapt a basis design to different requirements can be achieved. Nevertheless, with a view to the utilization of the process in the series production, efforts have to be made to increase the cost effectiveness of the process. The present work focuses on the possibilities of LMD as additive manufacturing technology, novel strategies for the improvement of deposition rates and process efficiency being presented.

Hybrid lightweight design by laser additive manufacturing and laser welding processes

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Abstract

This paper deals with the design and production of hybrid components as a combination of laser additive and conventional manufactured segments by laser welding. Hereby the economic and technological limits of the LAM process can be overcome. The study goes into the weldability of the material with the focus on the cast alloy AlSi12 and evaluates static strength of the hybrid connection.

Effect of process conditions on mechanical behavior of aluminium wrought alloy EN AW-2618A additively manufactured by Laser Beam Melting in powder bed

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Abstract

Additive Manufacturing offers geometric freedom excellently suited for topology optimized light weight designs. Ideally these should be built from materials of high strength to weight ratio and high plastic formability- such as aluminium-copper wrought alloys. Al-Cu wrought alloys are considered much less suitable for welding without cracks, so processing them in Laser Beam Melting of Metals in powder bed (LBM) can be considered challenging. Today, the only class of aluminium alloys widely processed by LBM is that of aluminium-silicon cast alloys which are easily weldable. In this contribution, mechanical characteristics of LBM samples are presented and discussed. Tensile tests were conducted under variation of load direction relative to build-up direction and heat treatment Pronounced anisotropy was observed. Remarkably, elongation at break of T6 heat treated samples pulled in build-up direction exceeds values from literature for conventionally manufactured EN AW-2618A. The chemical constitutions of both the powder and the LBM samples were analyzed and shown to be similar to the expected EN AW-2618A. For further interpretation, boundary conditions of sample production, metallographic microsections and fracture surfaces were considered.

The role of powder properties on the processability of aluminium alloys in selective laser melting

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Abstract

Selective laser melting is used to manufacture complex structures using an additive manufacturing approach with metal powders. It is generally supposed that the quality of the powder plays an important role in the success of the manufacturing process. This is because the powder morphology alongside its size distribution governs the formation of gas pores and controls the flowability. This is important as the process requires successive deposition of uniform layers of powder, which is hindered if the powder does not flow well. In this work, two batches of AlSi10Mg powder with different specifications were characterized in terms of morphology, composition, size distribution, flowability, and apparent density. Bulk samples were created from the powders using selective laser melting and the relative densities were compared. One of the metal powders, which is specially produced for additive manufacturing was found to provide higher quality parts than those fabricated using the other powder, which is not specifically manufactured for that aim. In this paper, we report a successful approach to avoid defects and porosity induced by powder quality by altering the scan strategy, namely scanning each layer twice with different laser powers per scan. The approach could pave the way for successfully overcoming poor quality powder effects.

Hydrodynamic instabilities and ablation phenomena under the laser melting of powder layer

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Abstract

Process of melting of the thick metal powder layers was investigated under temperature control. Ejection of dispersed particles from the overheated melt has been observed and investigated. Mechanisms of the melt penetration into loose powder bed have been determined. Instability of the contact surface between the melt and powder revealed by in experiment has been studied. Numerical simulation of the Rayleigh - Taylor instability suggest that instability develops starting from small scale passing to the large-scale structure

Influence of local dependencies in additive layered manufacturing on serial process design for aerospace applications

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Abstract

The technology of additive layered manufacturing (ALM) achieves more and more industrial applications. The win of freedom in design powered by this technology, makes it to an important technology for aerospace applications due to the high potential on weight savings. And it is also interesting in view of ecological aspects. But therefore a holistic view and understanding on the ALM process and its attended pre- and post processing is important.

Varel plant of Premium AEROTEC is able to provide nearly all required pre- and post processes and in consequence a machine for the additive laser manufacturing was installed in June 2014. Among other things running projects investigate the local dependencies within the cross section of the ALM process regarding the distortion behavior, microstructure and the mechanical properties within the process chain. The knowledge of those influences on the manufactured parts will be used for the design of an efficient process.

The contribution describes the dimensional and shape deviations, the microstructure and the mechanical properties along the process chain for additive manufacture parts. Depending on the process parameters dimensional deviations up to 0.1 mm occurred for the ALM process. Due to the required high performance of parts within the aerospace industry methods for compensation of these deviations will be pointed out to achieve the required accuracy.

Selective deposition of polymer powder by vibrating nozzles for laser beam melting

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Abstract

In this report, the delivery of polyamide 12 (PA 12) powder and powder layer preparation by vibrating steel nozzles is investigated and discussed with respect to its application for laser beam melting. Therefore, a setup was realized which includes a steel nozzle attached to a piezo actor as well as a positioning system. In order to investigate the mass flow characteristics in dependency on the applied vibration state, a weighing cell is used enabling time-resolved mass flow measurements. Moreover, single-layer patterns consisting of colored and uncolored polyamide 12 were created and characterized regarding surface homogeneity and selectivity before as well as after the melting of the powder layers by a hot plate.

Additive manufacturing – An introduction to the activities of Collaborative Research Centre CRC 814

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Abstract

With almost unlimited freedom of design, additive manufacturing technologies open up new perspectives to achieve individual solutions. These types of manufacturing techniques barely set any limits to the spirit of innovation. Due to this fact additive manufacturing techniques follow the trend towards customized products and will allow for serial production in the future. Especially powder and beam based polymer and metal processing are certified to have a high suitability for achieving industrial requirements. Despite the high potential of beam melting of polymeric powders, the step into serial production of highly individualized products was yet not realized. Nevertheless the medial driven hype related to additive processes is still increasing, although a lack in scientifically assured knowledge about basic interactions on material, process and part property level appears.

The Collaborative Research Centre 814 – Additive Manufacturing (CRC 814), established 2011 in Erlangen by German Research Foundation (DFG), investigates further mentioned various interactions between materials, processes and part properties. Therefore metal as well as polymeric powders are focused concerning their processing in beam based manufacturing techniques (e.g. laser beam melting and electron beam melting). Furthermore the built up of multi-level simulation models and the setup of inline measurement systems is performed.

Within this invited lecture an overview about the interdisciplinary research activities of CRC 814 is given, presenting basic aims as well as latest results.

Application of CO_2 laser for 3D printing utilizing thermal assisted polymerization of PVC plastic

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Abstract

In this article fabrication and testing of a 3D printer based on polymerization of PVC plastic under CO_2 laser exposure is discussed. PVC is the third most widely used plastic in the world. It's monomer called Vinyl Chloride (Chloroethen) is in liquid form. Ones heated, the polymerization process starts and the liquid monomer solidifies to produce Poly Vinyl Chloride (PVC). In our setup for 3D printing application this heat is produces by selective exposure of Vinyl Chloride monomer by CO_2 laser. The structure of the 3D printer is the same as conventional SLA 3D printers except that instead of photo-polymerization of a resin by a UV laser, CO_2 laser performs the Polymerization of PVC plastic. A tank is filled with Vinyl Chloride liquid monomer, a build plate is placed below the surface of the liquid and the CO_2 laser scans the first layer of a model on the surface of the liquid tank utilizing a galvoscanner. The exposed area polymerized, solidifies and attach to the build plate. The build plate in then lowers in the tank by 100 micrometer and a blade spreads fresh monomers on the first polymerized layer. The CO_2 laser scans the second layer. This process is repeated until the model is complete. Next, the built model rinsed and baked in an oven to unify the layers and a hard solid PVC plastic model produced. The fabrication process is presented and the effect of different parameters such as laser power, scanning speed and post bake process on the quality of models is discussed.

Additive manufacturing based on laser cladding of cp-Ti for dental implants

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Abstract

Humans have attempted to replace missing teeth with root form implants for more than 4000 years using bamboo, ivory, shells or precious metals. Nowadays, a typical dental implant consists of a screw made of commercially pure titanium, cp-Ti, with a roughened surface to improve the osteointegration. Titanium and its alloys are successful metallic biomaterials for dental implants because of their biocompatibility, corrosion resistance, fatigue strength and a relatively low elastic modulus to minimize “stress shielding” and osteopenia.

Dental implants are manufactured by conventional subtractive methods, which show a set of inconveniences: titanium has low machinability; loss of high cost material during machining; and the geometrical limitation for the shapes of the dental implants achieved by subtractive methods. Nevertheless, Rapid Prototyping based on Laser Cladding (RPLC) can become a solution to manufacture advanced pure titanium dental implants tailored to the patient, with new geometries to improve the osteointegration and with enhanced microstructures/mechanical properties for a better performance.

This study is an initial analysis to produce pure titanium parts by RPLC as dental implants. RPLC is employed to generate simple 3D geometries using cp-Ti powder as precursor material. The parts generated are studied to determine the properties related to a good fixation of the implant and the osteointegration: elastic modulus is analyzed by nanoindentation; surface roughness is measured by optical interferometry; and wettability by means of contact angle technique.

Additive process chain using selective laser melting and laser metal deposition

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Abstract

Selective Laser Melting (SLM) and Laser Metal Deposition (LMD) are prominent methods in the field of additive manufacturing technology. While the powder-bed based SLM allows the manufacturing of complex structures, buildrate and part volumes are limited. In contrast, LMD is able to operate with high deposition rates on existing parts, however shape complexity is limited. Utilizing their respective strengths, a combination of these two additive technologies has the potential to produce complex parts with high deposition rates.

In this paper, a process chain consisting of additive technologies SLM and LMD is described. The experiments are conducted using the alloys Ti-6Al-4V and Inconel 718. A cylindrical test specimen is produced and the microstructure along the SLM-LMD zone is described. In addition, this process chain was tested in the manufacturing of a turbine blade. The feasibility of implementing this process chain for small batch production is discussed. The results are evaluated to show advantages and limitations of the SLM-LMD process chain. This paper is relevant for industrial or scientific users of additive manufacturing technologies, who are interested in the feasibility of a SLM-LMD process chain and its potential for increased deposition rates.

Experimental and theoretical study of residual deformations and stresses at additive manufacturing by fusion

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Abstract

Controlling the residual deformations and stresses at additive manufacturing is important to minimize the deviation of the part from the model and to avoid cracking. The tendencies and mechanisms of formation for residual stresses and deformations are studied at 3D printing with fused polymer. Horizontal beams are manufactured on thin vertical supports connecting them to a rigid substrate. The bending of the beam after detachment from the substrate is measured. The curvature radius appears to be proportional to the height of the beam and independent of the layer height. The thermoelastic theory applied to the multilayer beam confirm the experimental tendencies. The obtained results are common for other technologies adding melt layer-by-layer.

Influences of process parameters on deposition width in laser engineered net shaping

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Abstract

Process parameters have great influence on deposition width in laser engineered net shaping. However, due to the complexity in fabrication process, the relationships of process parameters and deposition width are difficult to figure out quantitatively. Based on energy and mass balance of deposition layers, this study proposed a process model about layer deposition width, which involves the main process parameters of laser engineered net shaping. This model clearly reveals the relationships between deposition width and laser power, scanning speed and powder flow rate. The model shows that the layer deposition width is proportional to $P^{1/2}$ and inversely proportional to $v^{1/2}$, but has almost no relationship with the powder flow rate. The conclusions from the proposed model were verified by the deposition of several 316L stainless steel single-bead wall structures.

Build-up strategies for generating components of cylindrical shape with laser metal deposition

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Abstract

Laser Metal Deposition (LMD) as additive manufacturing process offers the potential to produce near net shape components. This reduces the amount of material and post-processing. The components are composed of individual layers. Already small irregularities within a layer can add up over multiple layers and lead to error propagation. This paper deals with the issue of build-up strategies to minimize irregularities and prevent error propagation. Different travel paths and the influence of a changing starting point regarding to error propagation are discussed. Different deposition rates between core and peripheral area are detected and successfully compensated by adjusting the build-up sequence. Stainless steel and titanium alloy Ti-6Al-4V are used in the experiments. The results are intended to illustrate the potential of an adjusted build-up strategy and provide basic information on the way to an automated deposition process. This paper is of interest for engineers in industry or science using LMD as additive manufacturing process.

Influence of temperature gradients on the part properties for the simultaneous laser beam melting of polymers

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Abstract

By Laser Beam Melting of polymers (LBM), parts with almost any geometry can be built directly out of CAD files without the need for additional tools. Thus, prototypes or parts in small series production can be generated within short times. Up to now, no multi-material parts have been built by LBM, which is a major limitation of the technology. To realize multi-material parts, new mechanisms for depositing different polymer powders as well as new irradiation strategies are needed, by which polymers with different melting temperatures can be warmed to their specific preheating temperatures and be molten simultaneously. This is achieved by simultaneous laser beam melting (SLBM). In the process, two different materials are deposited next to each other and preheated a few degrees below their melting temperatures by infrared emitters and laser radiation (λ = 10.60 µm), before in the last step the two preheated powders are molten simultaneously by an additional laser (λ = 1.94 µm).
So far, multi-material tensile bars have been realized and analyzed regarding their boundary zone between both materials. The experiments showed that the temperature gradients in the boundary zone and along the building direction seem to be of great importance for the process stability and the resulting part properties. Therefore, a detailed analysis of the occurring temperature gradients during the process is needed to identify adequate process adjustments regarding the temperature controlling. To analyze the temperature gradients, thermocouples positioned inside the powder bed are used. By varying the temperature of the building platform, the influence of different temperature gradients on the resulting part properties is shown.

Laser sintering of silver ink for generation of embedded electronic circuits in stereolithography parts

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Abstract

The requirements for mechatronic devices in terms of functionality, integration density and costs have risen according to the different application areas whereby a high demand for complex mechatronic modules exists. Furthermore, fast implementation of mechatronic modules in series production requires functional prototypes in the early stages of the development process. However, the manufacturing technology offers several methods which are suitable for prototype and small series production. In this context, the stereolithography (SLA) is a suitable technology, which can be used for production of functional prototypes. The layer-wise building process by means of laser polymerization of resin offers the integration of e.g. sensor functions without thermal damaging and opens up new possibilities for the realization of multi-functional components with high integration density. In addition, embedding of electronic circuits provides protection against environmental influences. The following paper presents a hybrid manufacturing technology that combines stereolithography and dispensing system technologies to fabricate mechatronic devices with embedded electronic circuits. This so-called embedding stereolithography (eSLA) requires a flexible and modular system technology which allows continuing the layer-wise process after integration of the electronic circuit. In order to fulfill this requirement, the laser sintering of silver filled conductive adhesive is an appropriate method to create conductive circuits directly after dispensing on the current surface of parts. Additionally, the placement of the electronic components could be realized by preformed cavities of SLA parts and the contacting of them could be done in situ by laser radiation. Thereby, the conductive adhesive is used like solder for fixing and contacting the components. In this paper, the laser sintering of conductive adhesive on SLA parts using UV-laser radiation (λ = 355 nm) is investigated regarding the transition resistance of contacted components by four point measurement and the characterization of laser contacted components by cross sections. The investigations are intended to evaluate the beam-matter-interaction of the silver filled conductive adhesive and the UV-laser radiation by an optical analysis of the material, the curing behavior and the long-term stability of the contacting under environmental stresses.

Reliable beam positioning for metal-based additive manufacturing by means of focal shift reduction

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Abstract

Metal-based additive manufacturing enables the production of even complex shaped parts that cannot be produced with conventional processes (e.g. milling). Taking advantage of the geometrical freedom in part production, an increasing number of industrial applications nowadays resort to these techniques. Hence, the additive manufacturing technology has currently passed the threshold from prototyping to mass production. This requires short processing times which are potentially reached by the adoption of multiple lasers with increasing output power. Typically, single mode lasers are used to reach customer demands, e.g. surface smoothness.
An optical setup of fibre beam delivery, collimation, focusing, and beam deflection is utilized to allow laser scan velocities of up to 1000 mm/s. For future applications of laser powers in the range of several kilowatts a critical level of absorbed power in these optical elements is likely to occur. The resulting thermally induced focal shift can lead to an undesirable beam defocussing and the corresponding increase of beam diameter will then lead to a loss of intensity in the powder bed interaction zone. To encounter this challenge for a future utilization of even higher laser powers, measures can be taken to reduce thermally induced focal shift. One possible approach comprises the insertion of additional optical glasses which compensate the focal shift by means of a converse thermal behaviour, i.e. negative refraction index gradient. Related to this topic, the measurement of absorption in optical components and the power dependent focal position are presented within this work. Laboratory measurements are complemented by the application of the corresponding results on an appropriate manufacturing system configuration. The investigations demonstrate that the desired reduction of thermally induced focal shift can be reached.

Nanoparticles during additive manufacturing

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Abstract

Additive manufacturing is particular interesting to fabricate structures that are not accessible by conventional machining processes [1-3] and therefore an emerging field. Beside the unique geometries that can be fabricated attaching gold nanoparticles to the powder materials results in enhanced sintering parameters and sintering thresholds decrease in case of off-resonant [4] and resonant laser sintering [5]. More remarkable, the fabrication of dispersed micro/nano ultra-structures is observed after sintering of the compounded gold-nanoparticle/zinc oxide-microparticle hybrid material. By cutting a thin micro lamella from the sintered and un-sintered ZnO@Au particles we could show that the gold nanoparticles are embedded in the ultra-structure after laser sintering. Therefore laser processing of nanoparticle/microparticle composition gives access to interesting hybrid materials. Observations for the process window to cause sintering in dependence of gold nanoparticle amount on zinc oxide led to the conclusion that off-resonant near field enhancement is responsible for amplified photon conversion. This demonstrates that during additive manufacturing nanoparticle materials can be embedded into the sintered matrix of microparticles.

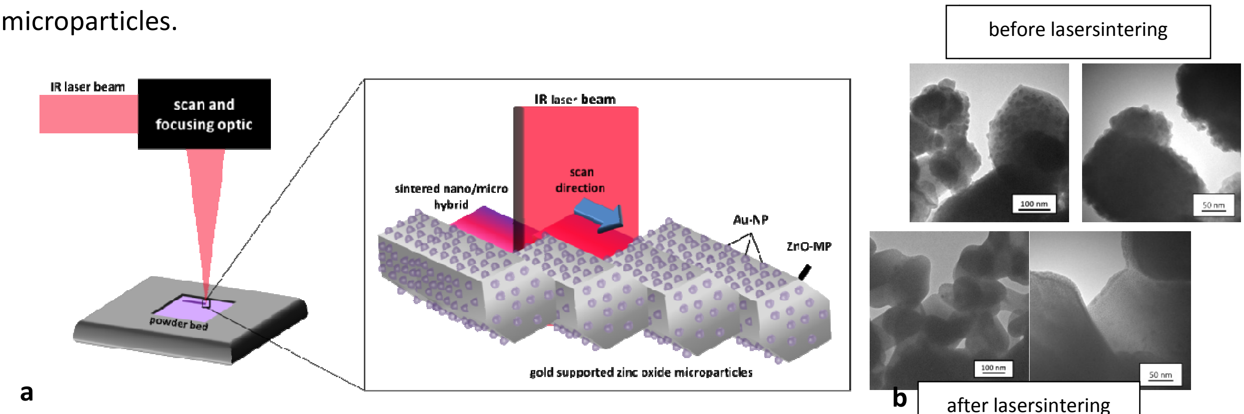

Figure (a) Schematic illustration of the laser process to fabricate sintered structures. (b) Transmission electron pictures taken from the un-sintered (top) and sintered (bottom) microparticles with 5 wt% of surface adsorbed gold nanoparticles. After laser sintering a smooth surface with sintered microparticles can be observed [4].

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Simulation of the effect of different laser beam intensity profiles on heat distribution in selective laser melting

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Abstract

The application of Additive Manufacturing technologies is rapidly increasing. Despite the numerous advantages, one of the major shortcomings is the comparable low productivity of the process. An optimized laser beam intensity profile promises a more uniform energy input, increased energy efficiency, reduced vaporization and therefore an increase in melting rate and productivity.
This paper presents a 2D-FEM model, which qualitatively simulates the heat distribution for the melting of TiAl6V4 powder on top of a solid TiAl6V4 block in an efficient way. With the help of the model, the heat distribution during the melting of a single track was simulated for three different laser beam intensity profiles as well as scanning speeds and laser powers. The results show a significant increase in energy efficiency as well as lower amount of vaporized material for donut shaped laser beam intensity profiles in comparison to Gaussian ones, promising higher build-up rates.

Some optimization strategies for tool path generation in 3D laser metal deposition

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Abstract

Laser direct metal deposition has proven to be successful in the manufacturing of 3D parts. In this process, the required geometry is built up layer by layer on overlapping laser clad beads. However, some problems are often encountered regarding surface finish and dimensional accuracy. These are mainly caused by heat accumulation effects during the process (resulting in changes in material temperature and powder catchment efficiency) and/or inadequate tool path trajectories and scanning parameters. All these factors lead to defects in the manufactured 3D part, particularly when bulk solid structures (as opposed to hollow) are involved in the process.
In this work we test and discuss the effect of different tool path strategies in dealing with the above issues. Results will be presented on the laser 3D manufacturing of stainless steel parts. A monitoring device (online CMOS camera) will be used to supervise and get and better understanding of the deposition process under the different approaches.

Laser printing and curing/sintering of silver paste lines for solar cell metallization

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Abstract

The main objective of this work is to adapt the Laser Induced Forward Transfer (LIFT), a well-known laser direct writing technique for material transfer, to define metallic contacts (fingers and busbars) onto c-Si cells and to use continuous wave laser sources to curing and sintering the deposited line.
Commercial silver pastes (with viscosity around 30-50 kcPs) are applied over a donor glass substrate using a coater with a controlled thickness in the range of tens of microns. A solid state pulsed laser (532 nm) is focused at the glass/silver interface producing a droplet of silver that it is transferred to an acceptor substrate. Lines are drawn by means of scanning the laser spot. The influence of the process parameters (silver paste thickness, gap between donor and acceptor, and laser parameters - spot size, pulse energy and overlapping of pulses) is studied as a function of the morphology of the deposited lines using confocal and scanning electron microscopy. With an appropriate process parameterization it is possible to transfer a high paste volume per pulse (~400 pL) and then large aspect ratio lines (~ 0.5) can be drawn at high speeds (2 m/s).
After the printing process a continuous wave green laser is used to heat the silver paste line to remove the organic layer (curing) or even to produce some melting between the silver grains (sintering) in order to reduce the line resistance. Process parameters such as laser power, spot size, processing velocity, and number of scans are studied. Results show that all-laser based metallization processes are possible.

TRIZ-based biomimetic part-design for laser additive manufacturing

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Abstract

Laser additive Manufacturing (LAM) possesses a great potential regarding part complexity and adaption for an innovative part design due to a layer-wise buildup offering multiple geometry variants form a broad design solution space. Thus, design optimization is a complex challenge for the designer that requires systematic design approaches.
A methodology for an application-oriented systematic part design development is introduced in this paper using TRIZ: TRIZ's wide collection of methods is analyzed with respect to easy applicability in order to identify a suitable set of methods to be used. This is augmented with databased biological solutions as an inexhaustible source of evolutionary principles and structures. Additionally, design restrictions for LAM are taken into consideration. Altogether an application-oriented methodology is introduced that systematically creates a solution space for a design problem specifically for LAM. The presented methodology is evaluated in a case study of an external reamer. The results obtained by the optimization process are compared to a conventional trial-and-error approach conducted by a practitioner. The use of the presented approach results in a reduction of mass by 10 %and increased functionality compared to a non-methodological practitioner solution.

Laser fumes of fs laser processes – Product, process and environment considerations

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Abstract

Laser treatment is increasingly used in material patterning. Avoiding thermal impact is for some of them crucial to achieve high quality products. This requirement let to recent increased utilization of ultra-fast laser processes. The following article investigates laser safety requirements of ultra-fast processes with respect to particle generation, shape and filtration. Especially, particles of ultra-fast processes are significant smaller and have a non-hemispherical shape, which asks for specialized solutions to achieve a long filter life time.

System technology for high speed laser welding

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Abstract

Improved laser sources in terms of beam parameter product initiated the idea of remote welding with a laser scanner. Various concepts for combining a standard robot with a scanner have been realized during the last years. Key problems have been the missing accuracy of the robot´s guiding behavior, the interlinking of the control units of the base machine and the scanner and last but not least the generation of programs for welding-on-the-fly. Therefore, applications were limited to less complicated joint geometries such as overlap joints on more or less flat assemblies. ERLAS was the first company to decide using laser remote welding for three dimensional processing and butt seam welding in mass production. A new type of machine was born in 2012. Special features of this machine are hybrid kinematics for movement of both, the 3D-scanner by Cartesian Axes and the work piece by rotating and tilting axes. Based on these ideas ERLAS decided to go forward again and place a novel laser welding cell on market.

Latest trends in high power disk laser technology

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Abstract

Diode pumped solid state lasers have become an important tool for many industrial materials processing applications. They combine ease of operation with efficiency, robustness and low cost. This paper will give insight in latest progress in disk laser technology ranging from kW-class CW-Lasers over fundamental mode beam quality to frequency converted lasers, as well as advances in new applications realized with disk lasers.
As of today, the disk principle has not reached any fundamental limits regarding output power per disk or beam quality, and offers numerous advantages over other high power resonator concepts, especially over monolithic architectures. Recently a TruDisk 6001 with 6 kW from a single disk completed the TRUMPF portfolio. The disk laser enables high beam quality at high average power and at high peak power at the same time. The power from a single disk was scaled from 1 kW around the year 2000 up to more than 10 kW today. Coupling of two disks in a common resonator results in even higher power of 20 kW. Consisting of two 16 kW units laser beam can be applied scalable up to 32 kW through one single twin-fiber.
Recently was demonstrated more than 4 kW of average power from a single disk close to fundamental mode beam quality ($M^2 = 1.38$). The extremely low saturated gain makes the disk laser ideal for internal frequency conversion. We show >1 kW average power and >6 kW peak power in multi ms pulsed regime from an internally frequency doubled disk laser emitting at 515 nm (green). Also external frequency conversion can be done efficiently with ns pulses. More than 500 W of average UV power was demonstrated.

Creation of the laser system for testing the damage threshold of optical materials and coatings

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Abstract

This article describes the system for testing the damage threshold of laser phosphate glass active elements that should be resistant to impulse radiation with duration of 3÷5 ns at wavelength 1054 nm and stand single exposure not less than 30 J/cm2. Measurements are conducted by direct focused laser radiation effect on bulk or surface of sample with recording the laser radiation parameters (energy, area of the exposure spot, distribution of radiation density in the exposure spot).

Laser joining of glass and metal

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Abstract

Joining of glass and metal is in the most cases realized by ultrasonic welding, soldering or gluing. Another possibility is the direct bonding of glass and metal by glazing. This technology exists since more than 100 years. Most prominent examples are the light bulb or the television tube. At the moment, this technique is developed for additional applications in combination with the new tool laser. Actual examples are solar collector tubes or X-ray tubes. Here the most important requirement is the vacuum tightness for several 10 years. In the industry this process is realized with burners in semiautomatic processes.

This paper shows a new processing method for the combination of glass and metal with CO_2-laser radiation. Fundamental material properties of the bonding partners, physical and chemical correlations and the following process steps will be discussed. The presentation of the system techniques and the process cycle gives an overview of the level of automation and the aspects for production, like process time and laser power. The research in joining glass and metal regarding to stability, mechanism of bonding and the internal stress will allow for the evaluation of this joining method. An outlook for further steps in the development of this procedure will complete this article.

Identification of process phenomena in DMLS by optical in-process monitoring

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Abstract

Additive manufacturing processes of metals were investigated by an optical in-process monitoring setup.

Direct Metal Laser Sintering (DMLS) is an AM-process in which parts are built from metal powders, which is fused layer by layer, through exposure with an infrared laser.

The basic layout of the monitoring setup is photodiode-based sensing of process light in combination with software-based data evaluation of the photodiode signals.

Enhancing a monitoring or measuring system for the purpose of automatic quality inspection requires sufficient knowledge about the correlation between involved sets of variables. In this context, variables were partitioned into three categories: input variables (meaning the process control e.g. laser power, scan speed etc.), material properties and photodiode signals including their signal characteristics.

Correlations between monitoring signals and process conditions were found, based on a comparison of nominal process (baseline population) and faulty process (defect population).

Faulty process was induced by intentional variation of the input parameters (provoked errors, e.g. variation of laser power), as well as investigation of known and undesired process effects (e.g. overheat effects, interaction of laser beam and process smoke). Characteristics in the corresponding photodiode signals were identified.

Algorithms to auto-recognize these signal characteristics were created and tested successfully. Examples are given that show the successful auto-detection of selected process effects.

New approaches for seam tracked laser beam brazing and welding

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Abstract

Laser brazing of steel and laser welding of aluminum and steel parts with filler wire are state of the art in mass production processes, e.g. in the automotive industry. As the standard supplier for wire guided brazing/welding optics Scansonic frequently receives inquires about customized beam shaping. Within this contribution beam shaping approaches aiming on process optimization by optimized energy distributions are presented. Therefore, technical approaches, resulting intensity distributions at the work piece and processing results are discussed. One example shown here is beam shaping by the use of a diffractive optical element (DOE) inside of the brazing and welding optics Scansonic ALO3. The DOE shapes the collimated laser beam for a resulting characteristic intensity distribution in the focal plane. The application addressed in this contribution is the Bifocal Hybrid Laser Welding (BHLW), an innovative technique for welding aluminum alloys with high surface quality and reduced hot cracking susceptibility of the weld seam. The DOE allows for bringing the BHLW process with laser powers up to P = 8 kW from research to industrial application.

Statistical distribution of protection times of passive laser safety barriers – normal distribution or is there a better description?

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Abstract

Recent developments in laser material processing technology, like the rapid increase of maximum output power, the remarkable improvement of the beam quality, and the availability of deflection optics, have put a focus on laser safety technology. Moreover, the development of new application fields, such as processing of CFRP, has led to a higher demand for laser technology, and an increased need for suitable safety technology. The protective exposure limit (PEL) according to IEC 60825-4 is currently calculated based on the assumption that protection times are normally distributed. This approach is criticised for generating too low protection times and for not reflecting the reality. Thus, the question arises whether there is a better way to describe the distribution of protection times for a more accurate calculation of the PEL. The aim of this work was to take the first step to answer this question by executing protection time tests, using steel plates and a fibre laser, and to determine the statistical distribution. In the following, random based protection time calculations were executed by the aid of the resulting distributions. This normative procedure was opposed to an alternative method, and the results were compared. It could be demonstrated, that both approaches lead to similar results for the examined case.

Development of an adaptive focus position control system for a new high-performance laser remote welding head

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Abstract

The Institute of Laser and System Technologies (iLAS) of the Hamburg University of Technology (TUHH) investigated an intelligent vision guided laser remote scanner (LRS) system not only for thin sheet or structure applications, but also for thick sheet welding tasks with brilliant high power lasers up to $30\ kw$ optical laser power. Two different wavelength acting; $532\ nm$ for measuring and analyzing processes, $1070\ nm$ for welding and other laser processes. Mechanical, thermal and optical effects mainly influence the manufacturing results after position, shape and machining path measuring processes. Especially the high laser power induced interaction between the laser beam and optical components will change the optical guidance properties in the course of time. Changing the refraction index n is one of the important effects for the thermo-optical reaction; focal shift takes place. The conclusion is now, that the machining position of an infrared high power laser spot does not fit anymore to the measured and analyzed position of the green pointing laser spot. The paper describes a first basic simulation model of the optics from this new LRS system with influencing components and important parameters. Furthermore the thermal influences have been simulated and the first results are presented. These results demonstrate the importance to develop within the next steps a combined practical and fast correction algorithm design supported by real sensor signals and implemented in the laser remote scanner controller unit.

Sub-100μs latency feedback control of laser machining using FPGA-powered inline coherent imaging

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Abstract

Accurate real-time measurement of laser penetration depth for feedback control is desirable for a variety of laser material processing applications in both micro- and macro-processing fields. Inline coherent imaging (ICI), a recently-developed interferometric technique, provides this capability with micron-scale precision whereby images can be captured at rates up to 312 kHz[1]. However, ICI image analysis is computationally intensive, and its usefulness in high-speed feedback control is limited by the >1ms latency that is introduced by PC architecture. To address this issue, we have implemented ICI analysis for real-time applications on a dedicated Field-Programmable Gate Array (FPGA). FPGAs consist of configurable digital logic that offers superior parallel processing capabilities with exceptionally deterministic performance. Using this FPGA technology, we have managed to reduce the latency of a complete depth measurement cycle (including both acquisition and analysis) to 54±5 μs, more than an order of magnitude improvement over traditional processing methods.

We will present the FPGA ICI system's performance as a sensor for an autofocus feedback loop, wherein the ICI depth signal is used to control the height of a mechanical motion stage to maintain machining beam focus at the surface of samples with variable morphology. The response time of this system (41 ms) is dominated by the motion of the stage and not by the latency of the feedback signal. Since industrial kW-class laser powers can be modulated at much faster rates, active control of laser welding depth fully exploits the low-latency of our FPGA imaging system. We will also present the results of this preliminary FPGA-based welding control.

Reinventing thermal laser power measurements

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Abstract

A novel design of a thermal laser power detector is presented, which allows minimizing the sensor dimensions, namely thickness and passive device area. The detector is intended to monitor medium laser power between 5 and 50 W. As its key feature, the sensor exhibits a rise time of just 200 ms, which is 5 times faster than conventional disc sensors. Such a low rise time is achieved by an axial thermopile arrangement combined with a minimized thermal mass.

In order to fully exploit the speed advantage of the new design, a specific optical absorber coating has been developed. The coating has a broadband absorption characteristic and damage threshold of 1.5 kW/cm2.

Use of inline coherent imaging for laser welding processes: Process control and beyond

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Abstract

The introduction of inline coherent imaging technologies as a sensor for the laser materials processing is accompanied by the integration into several applications. One of these is the measurement of the depth of the vapor capillary for laser welding applications, now allowing to keep record of the welding depth with an accuracy of micrometers and a sub millisecond temporal resolution. The broader achievement is the closed-loop control of the welding depth that was not available in industrial environments till now due to the lack of an adequate sensor. Further use includes the acquisition of 3D images around the laser process itself, allowing for coaxial integration of pre- and post-process sensors. These applications are demonstrated by using the In-Process Depth Meter (IDM).

Seam tracking for fillet welds with scanner optics

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Abstract

Fillet welding requires a high positioning accuracy of the laser beam in respect to the joint. Workpiece manufacturing tolerances and variations of the clamping require the individual positioning for every workpiece, i.e. an online seam tracking is needed. The proven concept of simultaneous observation of the joint and the laser spot by a coaxial camera sensor and real-time image processing are adapted to the PFO 3D scanner optics. Light-section measurement of the joint ensures robust detection and insensitivity to workpiece surface attributes and to variations of the workpiece cut shape. The system has shown excellent performance at different workpieces and different weld configurations (e.g. incident angle) and is presently under industrial qualification

Using the optical measuring techniques to investigate the hot cracking susceptibility laser welded joints

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Abstract

The safety of components or constructions is of great importance in the manufacturing and processing of metallic materials. Solidification cracking as well as the weldability of materials remain still for many years a highly contentious issues, particularly with regard to the causes of the hot crack formation. Many of studies have been conducted to determine the critical condition of occurrence of the solidification cracking. In this study different digital image correlation measuring techniques in conjunction with laser diodes as the illuminating source have been employed to measure the arising strain field during the laser welding process at the surface of the workpiece directed to the laser beam in the close vicinity of the weld pool. The Controlled Tensile Weldability test (CTW) was used to apply an external tensile load during the laser beam welding in order to generate the solidification cracks. The results showed that by means of those techniques it is possible to measure the strain field without any disturbances from the intense welding light or the smoke. Additionally, the strain and the strain rate as a critical factor determining solidification crack formation can be measured and analyzed.

How fast is fast enough in the monitoring and control of laser welding?

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Abstract

In the present study we show how fast the fluid dynamics change when changing the laser power for different feed rates during laser metal welding. By the use of two high-speed cameras and a data acquisition system we conclude how fast we have to image the process to measure the fluid dynamics with a very high certainty. Our experiments show that not all process features which can be measured during laser welding do represent the process behavior similarly well. Despite the good visibility of the vapor plume the monitoring of its movement is less suitable as an input signal for a closed-loop control, due to its high noise. Additionally, the plume does adjust with a delay on a change of process parameters. This physical limit restricts the maximal possible monitoring rate. Therefore, a reliable real-time control of laser welding over a wide range of process parameters might not be possible by the monitoring of the vapor plume. The features measured inside the keyhole show a good correlation with changes of process parameters. Due to its low noise, the area of the keyhole opening is well suited as an input signal for a closed-loop control of the process.

Autocorrelation analysis of plasma plume oscillations in deep penetration laser welding

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Abstract

The light emissions of plasma plume in deep penetration laser welding are typically characterized by irregular short-time pulses. Their timing is closely related to the dynamics of the keyhole formed within the workpiece and the surrounding weld pool. The nature of pulses limits the use of Fourier analysis because in most cases the frequency spectrum corresponds only to a colored noise. In this paper we present a study of the plasma plume oscillations using an autocorrelation function. We show that the autocorrelation function is an efficient tool to detect period of oscillations which are typically in the order of milliseconds. Finally, we compare the characteristics of autocorrelation function and the geometry of resulting welds carried out on a 2 kW Yb:YAG laser welding machine for the steel workpiece and various welding parameters settings.

On the detection of defects and of incorrect actuator settings in laser machining

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Abstract

The detection of “unknown objects” is commonplace in several technical fields including sonar, radar and ultrasonic inspection. The techniques used in these fields have one common approach, that can figuratively be abbreviated as the “send & listen” approach: the emission of known wave fields and the observation of how these fields are refracted, attenuated or retarded by the unknown object. The usability of the send & listen approach for detecting defects and their causes and for silencing inherent random signal fluctuations has been researched during remote laser welding with a 4kW disk laser. We used the processing laser as a wave emitter (“send”) and observed wave reception (“listen”) within a multi-sensor arrangement. Sensors included band-filtered photodiodes and sound pressure detectors, both of which varied in position or direction. Our results show that the application of send & listen to laser machining may be beneficial for detecting changes in process results and for discriminating which machine setting is responsible for the individual change. In our spectral analyses we found unique spectral footprints for common defect occurrences such as lack of fusion and full/partial penetration and for common causes such as changes in axial focus, in lateral focus, in workpiece thickness, in the gap between joined parts, in laser power and in lateral beam velocity. This paper details our send & listen approach, shows some of the found spectral footprints and outlines their usability for process monitoring and control.

Laser cutting and joining in a novel process chain for fibre reinforced plastics

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Abstract

Laser transmission joining and cutting are presented as the final steps of a novel process chain comprising fibre spraying, variothermal consolidation, joining and trimming of glass fibre reinforced parts to promote efficient manufacturing of light-weight components in high volume production.
The transmission joining is demonstrated up to a material thickness of 2 mm of the transparent joining partner (glass fibre / polyamide with 60 wt.-% fibre content). With this joining technique closed cross sections can be generated to increase the stiffness of the component thereby supporting lightweight design.
For the trimming, a CO_2-laser was used operating either in continuous wave mode (cw) or in pulsed mode with a pulse width of a few hundred nanoseconds and an average power >1 kW. For both operating modes appropriate process regimes were identified for GFRP cutting with a focus on cw-mode for the component production due to higher productivity. Single-pass cutting with coaxial assist gas as well as multi-pass cutting has been investigated. Also some comparisons to cutting of CFRP and to cutting with fibre laser are provided. The selected demonstration part is a seat component for trucks, which was welded with a circumferential seam and trimmed at the edge of the seam in the welded zone.

Analytical model for laser cutting of carbon fiber fabrics: Maximum cutting speed and the heat affected zone

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Abstract

Laser cutting of carbon fiber reinforced plastics (CFRP) and carbon fiber textiles offers various advantages over conventional machining methods such as milling, water jet cutting, and ultrasonic knife cutting. The process is force and wear free, highly automatable and offers a high quality cut. Yet, it is not used on a large scale in industry. This is partially due to the anisotropic behavior of the material, which makes it hard to predict the cutting speed and the heat affected zone in relation to the angle between the fibers and the direction of the cut.
In the presented study, an analytical model is developed, which predicts the heat affected zone and the maximum cutting speed for cutting non-crimp fabrics made from carbon fiber. The temperature distribution is modeled using a modified line heat source model which accounts for the anisotropic behavior of the fibers. The cutting speed is calculated by using an energy balance. The results of the analytical modeling are compared to those of an empirical analysis. The model will also be suitable for consolidated CFRP consisting of fiber and resin.

Ultrafast pulse lasers jump to industrial macro applications

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Abstract

Ultrafast Lasers have been proven for several micro applications, e.g. stent cutting, for many years. Within its development of applications Jenoptik has started to use ultrafast lasers in macro applications in the automotive industry. The JenLas D2.fs-lasers with power output control via AOM is an ideal tool for closed loop controlled material processing. Jenoptik enhanced his well established sensor controlled laser weakening process for airbag covers to a new level. The patented process enables new materials using this kind of technology. One of the most sensitive cover materials is genuine leather. As a natural product it is extremely inhomogeneous and sensitive for any type of thermal load. The combination of femtosecond pulse ablation and closed loop control by multiple sensor array opens the door to a new quality level of defined weakening. Due to the fact, that the beam is directed by scanning equipment the process can be split in multiple cycles additionally reducing the local energy input. The development used the 5W model as well as the latest 10W release of JenLas D2.fs and achieved amazing processing speeds which directly fulfilled the requirements of the automotive industry. Having in mind that the average cycle time of automotive processes is about 60s, trials had been done of processing weakening lines in genuine leather of 1.2mm thickness. Parameters had been about 15 cycles with 300mm/s respectively resulting in an average speed of 20mm/s and a cycle time even below 60s. First samples had already given into functional and aging tests and passed successfully.

Effect of several gas ambiences on HAZ suppression in CFRP cutting with nanosecond laser

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Abstract

The laser cutting for a carbon fiber reinforced plastic (CFRP) is one of suitable way because of contact-free and high speed processing. However, a matrix material composed of CFRP was quickly decomposed before the carbon fiber deformation, which caused to form a heat affected zone (HAZ) which composed matrix evaporation zone (MEZ) and resin alteration zone (RAZ). The improvement of HAZ is the most important task in the laser cutting for CFRP. In this study, we have demonstrated that the CFRP plates were cut with a pulse fiber laser at pulse width of 0.4 ns, wavelength of 1064 nm and average power of 100 W under air and nitrogen (N_2) gas flow.

Analysis of potentially hazardous substances emitted during laser processing of carbon fiber reinforced plastics

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Abstract

Lasers are promising tools to cut, ablate or even weld carbon fiber reinforced plastics (CFRP). Nowadays, it is possible to achieve very good product qualities (especially relevant for lightweight constructions) using specific laser processing strategies such as multipass cutting or short-pulsed ablation. The intention of these processing strategies is to minimize laser energy deposition within the material, because excessive heat causes defects such as pores, blowholes or delamination.

Nevertheless, CFRP laser processing is connected with the emission of potentially hazardous substances, i.e. particles and fiber segments as well as inorganic and organic gases.

This work describes a generalized approach to investigate hazardous emissions released during laser processing of CFRP. Measurement methods to quantify the emitted particles and gases in the exhaust air as well as in the air at the workplace are presented. These methods are applied to determine emission rates of specific material process combinations. The obtained values are implemented into a specific database to enable a fast access to the comparison with existing limit threshold values, maximum permissible exposures and adequate protective measures. The thorough analysis of various processes will help to assess the risks related to laser processing of CFRP in general and thus to create the framework, including standardization, for a safe handling of the emitted hazardous substances.

High power UV laser processing of CFRP with short ns pulses and pulse splitting

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Abstract

As the use of CFRP material in industrial applications increases, achieving high cutting speed and minimizing thermal damage remain the most challenging issues for laser-based processing. Among the various parameters in laser processing, we have focused on short-nanosecond pulses to investigate cutting speed and HAZ occurrence using a high power 355nm UV Quasar® laser from Spectra-Physics. The pulse width was varied from 2 ns to 10 ns and TimeShift™ pulse splitting with burst mode technology was also tested. In single pulse mode, the laser power was changed from 6 to 60 W by adjusting the repetition rate from 100 kHz to 1 MHz. To evaluate the effect of pulse splitting we compared ablation results achieved using a single 10-ns pulse with those achieved using two 5-ns pulses and five 2-ns pulses in a single burst. The samples used were PAN-based CFRP with thickness of 250m. We measured the time to cut through the samples and evaluated HAZ for various parameter sets. It was found that shorter (single) pulse widths and pulse splitting were both effective at increasing cutting speed and reducing HAZ for the PAN-based CFRP.

Theoretical and experimental determination of the polarization dependent absorptance of laser radiation in carbon fibers and CFRP

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Abstract

A detailed consideration of the fundamental mechanisms of interaction between laser radiation and carbon fibers is required to explore the potential of the laser as a tool for processing of carbon fiber reinforced plastics (CFRP). A key factor for laser materials processing is the absorptivity of laser radiation in the material at the laser wavelength that determines the fraction of laser energy coupled into the material. In the case of CFRP, the complex composite structure of the material requires sophisticated theoretical and experimental investigation of the absorptance.

The absorptance was calculated modelled for a wide range of wavelengths and for an orientation of the electric field perpendicular and parallel to the symmetry axis of the carbon fibers. The model includes the nearly circular cross-section and the birefringent properties of carbon fibers as well as multiple reflections. For carbon fibers it was found, that the total absorptance is larger than 70% for wavelengths in the UV, VIS and NIR and drops to less than 40% for a wavelength of 10.6 µm (CO_2-Lasers). The absorptance for light polarized perpendicular to the carbon fibers was shown to be larger than for light polarized parallel to the fibers. For CFRP the absorptance is increased to values around 80% for wavelengths in the VIS and NIR.

Experimental measurements of the absorptance of carbon fibers and CFRP for laser radiation with a wavelength of 532 nm and 1047 nm were performed to validate the model predictions. Polarization states of the laser radiation perpendicular and parallel to the carbon fiber symmetry axis were investigated. The absorptance was measured to be about 90% for both wavelengths. The calculated higher absorptance for an orientation of the electric field perpendicular to the carbon fiber axis was verified.

Metal meets composite - Hybrid joining for automotive applications

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Abstract

Especially in automotive construction the bonding of dissimilar working materials is an important requirement. The combination of different working materials, such as thermoplastic composite materials and body steels, adapted to local loads should create new opportunities for further weight reduction. The presented approach consists of a microstructuring process to generate undercut grooves on the metal surface. In a second laser based process the thermoplastic composite material is melted and by external clamping the plasticized material is pressed into the generated structures and forms after curing a mechanical interlocking between both materials.
In case of the presented PSA demonstrator a composite reinforcement bar has to be joined to a commercial vehicle door. At first suitable parameters for the surface treatment of automotive body steels P260 and XSG are presented. For the surface treatment a scanner based single mode fiber laser system is used, varying parameters like scan speed, laser power and number of iterations to generate microstructures in form of lines with undercut grooves.
Afterwards the results of a diode laser based simultaneous joining process are shown, whereby the parameters laser power and pulse duration are changed. To find out suitable joining parameters, which guarantee a homogeneous structure filling and high connection strength, flat shear tension specimen are joined and tested. The strength results are used to specify the bonding area between door and reinforcement bar to fulfill the requirements. At last all gained results are transferred to the demonstrator to join hybrid parts for crash tests at PSA.

Temperature monitoring independent of laser-beam-position during laser transmission welding of fibre reinforced thermoplastics

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Abstract

The heterogeneous heat conductivity in carbon fibre reinforced plastics (CFRP) critically influences process temperature during welding and increases the necessity for temperature control to secure weld quality. While infrared cameras are a powerful tool for monitoring process temperature they have a low temporal resolution and they are comparatively expensive. A potential alternative is sought by utilisation of a dynamically movable pyrometer measuring spot.
In this work, heat development during bead-on-plate laser welding on carbon fibre reinforced polyphenylenesulfide (PPS) is investigated. The pyrometer spot is capable of measuring temperatures locally independent of the processing laser spot. Thus, temperatures are monitored at a high temporal resolution during welding in front of, behind, and aside the current weld area.
Results of this investigation give rise to expectations that a dynamic pyrometer spot allows for precise temperature measurements at critical points of complex weld geometries such as curved weld seams. This will set up the basis for an automatic laser welding control, which will be capable of adjusting the laser welding power according to required temperatures for a supreme weld quality.

Cutting of CFRP with short-pulsed lasers at 1 µm and 10 µm wavelength and average powers of more than 1 kW

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Abstract

Simulations of laser processing of carbon fibre reinforced plastics (CFRP) show that laser intensities of more than 10^8 W/cm^2 are needed to achieve thermal damage at the cutting edge of less than 10 µm.
Today these high intensities are mainly achieved by pulsed laser systems with pulse durations below 1 µs. Furthermore an average power above 1 kW is needed to achieve industrial relevant cutting velocities in the range of 1 m/min.
In this experimental study cutting of CFRP with two pulsed laser sources at the wavelength of 1 µm and 10 µm with an average power of more than 1 kW was investigated. The cuts were performed with fast laser scanners applying multiple passes to achieve complete separation of the processed parts. The cutting strategy was optimized in order to avoid heat accumulation from pulse to pulse and from scan to scan.
The 10 µm wavelength laser source was a pulsed CO_2-laser prototype from TRUMPF with pulse duration of 170 ns and a repetition rate of 20 kHz. The peak intensity was $6{\cdot}10^8$ W/cm^2. The achieved thermal damage was less than 50 µm with an effective cutting speed of 0.4 m/min.
The 1 µm wavelength laser source was the IFSW-Kilowatt-Picosecond laser with pulse duration of 8 ps, a repetition rate of 300 kHz, and an average power of more than 1.4 kW. The peak intensity was $7{\cdot}10^{12}$ W/cm2. The minimal thermal damage was less than 10 µm with an effective cutting speed of 0.9 m/min.
With these systems it could be shown that both short-pulsed laser systems with average powers of more than 1 kW are able to cut CFRP with industrial relevant cutting velocities. Furthermore with the correct process strategies the extent of the thermal damage is less than 50 µm.

Experimental and analytical description of the multi wavelength remote laser ablation process at fiber reinforced polymers

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Abstract

To increase the acceptance of fibre reinforced polymers (FRP) in the industry, near net shape preforms with a minimum of material consumption are required. This should be accompanied by appropriate, fast and flexible processes. The remote laser processing expands the area of possible kinds of processing strategies, wherefore the laser can be a tool for the future. But the development of remote laser processing is accompanied with the understanding of the interaction between tool and material. Laser cutting processing of FRP is an ambitious process because of the inhomogeneity of both the reinforcement material and the polymer matrix material. The present paper shows an experimental set up for combining beam radiation with wavelengths of 1.07 µm and 10.6 µm. First results on carbon fiber reinforced polymers prove the increasing efficiency.

Influence of remote laser cutting on the fatigue strength of CFRP

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Abstract

For the production of components made from carbon fibre reinforced plastics (CFRP), the cured parts need to be trimmed to the final outline. State-of-the-art technologies for this processing step are either milling or abrasive waterjet cutting. Although remote laser cutting is a wear free process, it is not yet used in industrial application. Recently, the heat affected zone (HAZ), resulting from the ablation of the material by the laser radiation, has been discussed as a quality criterion related to visible components.

To evaluate the influence of the cut edge on the fatigue strength, dynamic tensile tests were performed with an open hole specimen geometry. Noticeable higher values of the fatigue strength were observed using remote laser cutting compared to waterjet cutting.

The specimens manufactured by remote laser cutting endured a higher average number of load cycles and showed a lower deviation of the fatigue strength than the control samples cut by a waterjet. Before fracture, only the laser cut samples showed a noticeable decrease of stiffness which could be relevant for purposes of structural health monitoring. Furthermore, the fracture patterns of the laser cut samples showed characteristics of a matrix based failure, whereas the waterjet cutting led to fibre fractures.

This study confirms that remote laser cutting is suitable for structural CFRP parts which are exposed to dynamic loads.

Correlation between temperature field and heat affected zone during laser cutting of carbon fiber reinforced polymers

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Abstract

Due to its ability for wear free 3D-processing and a high degree of automation, the laser remote cutting is a suitable technology for the mass production of carbon fiber reinforced polymers (CFRP) parts in the automotive industry. The heat affected zone (HAZ), which is typical for the laser process, is measured after the cutting process by a time-consuming and expensive preparation of cross sections. A missing in-situ measurement procedure for the cutting quality handicaps the laser processing of CFRP in an industrial application.

The investigation deals with the question, if a relationship between the temperature field around the cutting kerf and the heat affected zone exists. The temperature field is measured by infrared camera while the corresponding HAZ is quantified conventionally by cross section preparation.

The investigation shows that a positive correlation between the temperature field and the HAZ exists. Regarding the typical spreading of the HAZ during laser processing of CFRP, its prediction by measuring the temperature field is possible, independent of the laminates thickness, process parameters and cutting directions. Thus an in-situ measurement of the cutting quality is applicable. An algorithm to predict the HAZ reliable at areas with heat accumulation has to be developed.

Laser-remote-cutting of large-scale semi-finished carbon-fiber products using a solid state laser

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Abstract

Since carbon fiber reinforced polymers (CFRP) have excellent mechanical and weight-specific properties, and lightweight concepts become increasingly important, especially in the automotive and aircraft sector, the demand for automated, cost-efficient manufacturing processes such as laser cutting of CFRP and semi-finished products is quickly rising. This paper presents an approach of establishing a process of laser remote cutting large-scale 3D semi-finished carbon-fiber products using a high power continuous-wave (cw) laser. The result is a stable and fast process with a cutting speed up to 15 m/min. Flat and sealed cutting edges ensure a good handling as well as the possibility to drape and inject within an Resin Transfer Moulding (RTM) process.

Productive laser processing of CFRP

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Abstract

Laser processing of carbon fiber reinforced plastic (CFRP) is a very promising method to solve a lot of the challenges for large-volume production of lightweight constructions especially in automotive and airplane industries. Laser processes are very promising for tasks like cutting of dry fibers, trim cutting of parts after the curing process, or drilling of holes for riveting. The challenge for these processes is to reach both, the productivity and quality which is needed for large-volume production. In this paper processing with different laser sources including cw-lasers with high average power up to 6 kW and ps-lasers with average power from 30 W up to 1 kW will be compared in terms of productivity and quality for different applications. The main issue reducing the quality of laser-processed CFRP parts is the heat affected zone which results from heat conduction into the material. In the present paper, the influence of the heat affected zone on the mechanical strength of CFRP components will be discussed. It will be shown that damage-free laser processing of CFRP is possible when using high intensities above 108 W/cm² and avoiding any kind of heat accumulation in the processing zone. To reach this intensity it is favorable to use short and ultra-short pulsed lasers with pulse duration of several ns down to ps. However, the productivity of the process is dominated by the average laser power available which is actually below 150 W for commercial systems. Therefore it is necessary to increase the efficiency by using advanced process strategies.

Sputter-free and reproducible laser welding of electric or electronic copper contacts with a green laser

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Abstract

Today's commonly used IR-lasers suffer from two limitations: Firstly the process reproducibility can be quite low as copper is highly reflective at 1 µm wavelength, and secondly the process parameters used today typically result in splatters emerging from the welded region during the deep penetration welding process, leading to short circuits.

A newly developed purely green laser source meets all requirements of optimized process quality. For a pulsed welding process at 0.5 µm wavelength, local power density distribution and pulse shape have been examined and optimized. The results have been compared to 1 µm wavelength.

The most precise method to detect splatters is the recording of the welding process by means of a high-speed camera. This allows to detect exactly which types of splatters exist and which process phase is responsible for their formation.

The time and the type of coupling of laser light into highly reflective materials can be determined as well.

By using green laser pulses no splatters occur from 0.1 mm to 0.8 mm penetration depth. Welding spots do not differ in size. Surface condition of copper has no influence on the welding. In addition to tests on overlap welding and butt welding of electric contacts, special attention has been turned to welding of DCB´s (Direct copper bondings in power electronic substrates).

Energy efficiency in laser rod end melting

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Abstract

The energetic efficiency of a laser based process, called "laser rod end melting" is investigated. Laser rod end melting allows the generation of spherical geometries at the end of cylindrical rods. After the spherical geometry at the rod end is generated in the master forming stage, this part can be used as a preform for a micro cold forming operation in a subsequent process stage. Within the laser rod end melting process, rods with diameters less than 1 mm are used as wrought material. The presented process is based on the size effect that when scaling down the size of a body, the ratio between surface area and volume is increasing
In this paper, results of the laser rod end melting process concerning the process efficiency with regard to usage of energy are presented. Therefore, the laser rod end melting process is carried out with two different laser beam propagations relative to the rod. For both experimental setups a fiber laser and rods of chromium nickel steel are used. The laser power is measured with a power meter on the work piece surface. A method is presented to determine the energetic efficiency of the laser rod end melting process. It is found that the lateral orientation of the laser beam avoids the defocusing effect so that the energetic efficiency remains constant during accumulation process allowing the total process efficiency to take values of up to 0.45 compared to 0.19 under influence of defocusing effect. Power measurements of the laser beam show a significant deviation between measured laser power and requested power.

Laserwelding of transparent polymer films

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Abstract

In the field of packaging technology in many cases transparent polymer films are used for food but also for goods packaging. The polymer based packaging protects the goods in transit from the environment but also against transportation typical stresses such as shocks, etc. Conventionally the polymer films are sealed by a heat sealing jaws method or ultrasound. So far, the use of laser sources could be realized only for very thin or specially modified absorbing films. Polymers have a wavelength dependent absorption coefficient. Most polymers, which a relevant to the packaging technology, have in the spectral range from 1500 nm to 2000 nm an absorption peak or areas of increased absorption. Newly especially for polymer welding developed diode laser modules emit laser radiation precisely in these areas of higher absorption. Therefore it is possible with the aid of an adapted beam shaping to laserseal directly commercially available packaging films without any modification. On the basis of thin sections and tensile tests the suitability of laser-based sealing process is demonstrated on representive samples directly from the packaging industry.

High precise welding of transparent polymers

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Abstract

Since the well established classic laser plastic welding has become a favourite standard clean serial production proceeding, providing reliable strength and tight joints, its major field of application is still located in automotive and adjacent industry sectors. However, LPKF Laser & Electronics now targets the sophisticated requirements of researchers and manufactures in a modern and pioneering medical technology field. These so called BioMEMS (Bio-Microelectromechanical Systems) or Lab-on-a-chip devices are mainly based on complex systems of micrometer scale canals, enabling a rapid detection method for food safety and clinical diagnostics, chemical synthesis or biological research (Bhattacharya, Jang, Yang, Aakin, & Bashir, 2007)(Sackmann, Fulton, & Beebe, 2014).

By combining the weldability of two transparent polymers using a 2 µm fiber laser (Mingareev et al., 2012) with a high precise mechanical and optical positioning system the LPKF PrecisionWeld now provides an effective way for prototype or serial production of microfluidic devices. The heat generation for the welding process of the transparent polymers, typically polycarbonate, PMMA or COC, is based on intrinsic absorption of ~ 30 %/mm at the laser wavelength of 2 µm. The TEM_{00} shaped beam profile from the fiber laser can be focused down to ~ 60 µm spot diameter enabling the generation of extreme fine weld seams sealing the micro canals. By using a galvanometer scanner and a high precision mechanically moveable holding fixture the weld seams can be positioned with accuracy of 10 µm, besides this the treatment area can be increased by stitching scan fields based on automatic fiducial detection. With this new technique no critical absorbing additives or glue are needed for the joining procedure avoiding any toxic risk to high sensitive biological samples and it also pushes forward the existing canal diameter limits of previously known manufacturing methods.

Direct bonding of transparent PMMA using an ultrafast fiber CPA laser system

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Abstract

Laser welding of transparent materials with micrometer precision is attracting growing interest in several application fields, especially for the assembly of biomedical devices.
In this work, we exploited the flexibility of focused laser light to weld two transparent 1-mm-thick layers of polymethyl-methacrylate (PMMA) in a lap-joint configuration. A high repetition rate ultrafast fiber CPA laser system delivering pulses ranging from 15 ps to 650 fs at the wavelength of 1030 nm was used for our experiments. Non-linear absorption and heat cumulative processes originated in the focal volume by the high repetition rate (> 200kHz) produced localized melting of the polymer at the interface between the two layers.
The influence of the pulse width on the morphology of the laser-induced modifications in the bulk PMMA was evaluated exploring a wide range of repetition rates and pulse energies.
An appropriate set of process parameters was found able to generate continuous and localized melting of the material. Based on these results, ultrashort pulsed laser lap welding of two 1-mm-thick PMMA layers was demonstrated. A simple microfluidic polymeric device has been then assembled taking advantage of this novel joining technique and the effectiveness of the sealing has been proved by a static leakage test with injected fluid pressures up to 1 bar.
The intrinsic flexibility of the proposed ultrashort-laser micro-welding technique to seal microfluidic devices with complex geometries without the need for any absorbing layer or chemical additive which could in principle contaminate the biological samples, make this technology very promising for the direct laser fabrication of transparent polymeric microfluidic devices.

Influence of welding parameters and stack configuration on pore formation of laser welded aluminum foil stacks

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Abstract

Ultra-thin copper and aluminum foils with a thickness of 10 µm and 20 µm respectively are used as base material for the active layers in lithium ion batteries. In a pouch cell design, several layers of coated copper (anode) and aluminum (cathode) electrode foils are stacked alternately. All layers are separated by an ion conductive synthetic material. The uncoated aluminum foil contact tabs of all cathode layers must be welded in a stack configuration to an aluminum terminal sheet. On the anode side, the copper foil stack has to be welded to a copper terminal sheet.

Continuous wave laser welding of such aluminum foil stacks with up to 30 layers with a 1 µm wavelength fiber laser was investigated as presented in the following. Advantages in comparison to state of the art ultrasonic welds can be found in less mechanical stress from the joining process. However, especially this cathode laser weld shows imperfections such as porosity and sporadic separations of foils from the weld seam.

Seam porosity was characterized by computer tomography and image analysis of cross sections to investigate the influence of the welding parameters and the number of welded foils in the stack. It was noticed that the variation of these parameters affects the pore volume and distribution.

Camera based closed-loop control of laser micro-welding processes by observation of the full penetration hole

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Abstract

In macro welding-processes, monitoring and closed-loop control by using the so-called "full penetration hole" is well known. This paper reports first results for the transfer of this technology to laser micro-welding processes for lap joints as they are used for housings or fuel cells. The laser source was a 400 W cw fiber laser with a Gaussian beam profile and a spot size of 28 µm. A cellular neural network (CNN) camera was used to measure the image feature of the full penetration hole within the thermal image of the welding process. For full penetration weldings on stainless steel samples, the laser power was controlled by the rate of full penetration hole detection. The effect of the feedback system is that the laser power is automatically adapted to changes in sheet thickness or feeding rate. The sheet thickness was varied between 220 and 350 µm and the feeding rate between 10 and 40 m/min without significant change in the weld seam quality. The closed-loop system increases the robustness of the process against perturbations and the process is always guided at the minimum laser power necessary for full penetration thus reducing spatter and smoke residues.

Laser welding simulation of microfluidic devices

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Abstract

In this study, a numerical approach is presented for the simulation of the transparent laser welding process of thermoplastic polymers. In particular, the numerical tool is used to develop the welding process of a microfluidic device. The studied microfluidic device consists of two thermoplastic sheets, one of them has been previously micro-machined by a specific UV femtosecond laser setup. The assembly of the microfluidic device is then obtained by scanning a laser beam over its entire surface.
The weld quality of laser welded thermoplastics is strongly influenced by the amount of laser energy that is converted into heat, which also depends on the optical and thermal properties of the materials. In practice, finding suitable processes parameters for new products is often a difficult task given that temperatures at the interface need to reach the melting point without exceeding the degradation temperature of the polymer. Furthermore, the presence of micro channels in microfluidic devices modifies the heat absorption and heat transfer resulting in inhomogeneous temperature distributions at the weld interface.
The numerical approach followed here gives access to values that are difficult to measure experimentally, in particular the temperatures in the melted zone. The development of the process was carried out in steps of increasing complexity, from the study of the assembly of two plates without any micromachining to the analysis of the microfluidic device. Experimental welding tests are also presented and were carried out to validate the simulation observations and are also presented.

Thermal analysis of laser transmission welding of thermoplastics: Indicators of weld seam quality

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Abstract

This work presents a thermal analysis of the process of laser transmission welding of thermoplastics using the finite element method. In addition to the heat transfer equations, an original approach was used to calculate phase transformation phenomena such as melting, evaporation or decomposition, and solidification of the polymer. This yields a prediction of the size and shape of the weld seam as well as eventual porosity that may arise due to heating of the plastic beyond its decomposition temperature.
By defining the weld bead quality as a function of its shape, size, and porosity, the results of the simulations with the variation of process parameters can be used to create a mapping between these parameters and the resulting weld quality.

Effect of processing parameters in welding of biocompatible polymer film to metal sheet using an infrared laser source

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Abstract

Miniaturisation and light weight design has become one of the key trends in today's manufacture industry. This transformation is also happening in the medical instrumentation industry. In addition to size and weight reduction, biocompatibility and hermetic sealing are other common quality requirements for medical applications. Laser welding is a unique non-contact joining process which yields a high precision weld with small heat-affected zone. This work employs an infrared laser source for generating micro-scale welds. Process development of micro laser welding of dissimilar biocompatible materials is reported herein. The optimisation of parameters and different weld designs are investigated. The micro laser welding process developed targets the joining of heat-sensitive miniature devices that require air-tight joining quality.

Adjustment and impact of the thermoplastic microstructure of the melting layer in laser-based joining of polymers to metals

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Abstract

In this paper, the influence of specific time-temperature parameters on the melting layer and mechanical properties is shown for laser-based joining of thermoplastics with metals. Based on a differential scanning calorimetry, the base material is characterized by parameters of melting temperature range and solidification range. These results were transferred to time-temperature profiles and correlated to the melting layer within the thermoplastic joining. Considering these results, the change in morphology and the influence on mechanical properties can be shown and correlated to fracture behavior within the plastic base material as well as the energy absorption of the joint during mechanical testing.

Laser hybrid joining of plastic and metal components for lightweight assemblies

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Abstract

Plastic-metal hybrids are replacing all-metal structures in the automotive, aerospace and other industries at an accelerated rate. The trend towards lightweight construction increasingly demands the usage of polymer components in drive trains, car bodies, gaskets and other applications. However, laser joining of polymers to metals presents significantly greater challenges compared with standard welding processes.

We present recent advances in laser hybrid joining processes. Firstly, several metal pre-structuring methods, including selective laser melting (SLM) are characterized and their ability to provide undercut structures in the metal assessed. Secondly, process parameter ranges for hybrid joining of metals (steel, stainless steel) and polymers (MABS, PA6.6-GF35, PC, PP) are given. Both transmission and direct laser joining processes are employed. Lap-shear test results are shown that demonstrate that joint strengths exceeding the base material strength (cohesive failure) can be reached routinely with metal-polymer joining. Weathering test series prove that such joints are able to withstand environmental influences typical in targeted fields of application. The obtained results pave the way toward implementing metal-polymer joints in manufacturing processes.

Multi parallel ultrashort pulse laser processing

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Abstract

Ultra-short pulse lasers present a new class within high-performance laser beam sources for industrial applications [Du et al 2012]. Due to the outstanding features of the radiation emitted from these sources, which are addressing important physical principles of light-matter interaction, traditional processes of deposition of light energy into the material can be circumvented. With pulse durations in the picosecond and femtosecond range, the absorbed energy is concentrated in the material to a few nanometers, so that thermal damage to the materials can be avoided.
These properties have generated numerous processes in in precision machining at solar cells, batteries, injection molding tools and electronic components [Hartmann et al 2008]. Due to the current developments for power scaling of ultrafast lasers in the kilowatt range, also potential applications for macro processing are obtained, which opens large markets in other than the micro processing field [Russbüldt et al 2010]. Thus, with high-power ultrafast lasers, fiber reinforced composites can be processed without thermal influence and large surfaces can be provided with friction-minimizing microstructures. However, using high power ultrashort pulsed lasers with high repetition rates in the MHz region can cause thermal issues like overheating, melt production and low ablation quality as long certain parameter sets and fluence ranges have been considered. High ablation quality only can be achieved, when the processing fluence is closed to the ablation threshold, which requires new processing strategies and innovative system components. Beside ultra high speed scanning using polygon scanners the use of multiple laser beams provide the best and most versatile high power ablation solution. With switchable single beams out of a special light modulator or a diffractive optical beam splitter high ablation rates can be achieved while maintaining the high processing quality of ultra short pulse laser ablation. With this approach a next step up to an all optical manufacturing system can be provided.

Investigation of femtosecond laser texturing in cemented carbide cutting tools

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Abstract

The aim of this work is to characterize uncoated cemented carbide tools textured by femtosecond laser and to investigate the influence of texturing on the cutting tool in machining. Thus, parallel micro-grooves were machined on the rake face of uncoated cemented carbide inserts at 100, 200, 300 and 400 µm from the cutting edge using a Ti:Sapphire laser set for 15 µJ, 30 fs pulses emission centered at 775 nm and at 4 kHz of repetition rate. The cutting forces were monitored along the semi-orthogonal turning of austenitic stainless steel (V304UF) for textured tools and compared with non-textured ones (reference). The cutting conditions were kept constant. The results showed reproducible grooves with mean width and depth of 35±3 and 32±6 µm, respectively; a reduction of 27.6% in the machining force for textured tool at 200 µm from the cutting edge and lower surface roughness for textured tools at 200 and 300 µm when compared with reference ones.

Shorter than short: How does the pulse duration influence the process efficiency of conductive materials?

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Abstract

Material micro processing with ultrashort laser pulses has been established during the last few years. There are a lot of processes that ultrashort pulsed (USP) lasers can be used for. Drilling of injection nozzles and cutting of Nitinol stents are already established in production lines. Other examples for the use of those kinds of lasers are scribing of silicon as well as processing of hard and brittle transparent materials. The range of possible applications is huge and nevertheless the micromachining market is still in its infancy. For many years since the invention of USP based material micro processing, pulse durations in the range of ten picoseconds were considered as the optimum choice for micro machining applications regarding process quality (Dausinger, Hügel, & Konov, 2003).

In scientific laboratories a well known technique to decrease the pulse duration of high power lasers from the picosecond into the femtosecond regime was based on chirped pulse amplification (CPA) since many years (Strickland & Mourou, 1985). However, this technique for a long time was too expensive to transfer it to industrial reliable high power lasers.

Today there are cost efficient and reliable high power CPA based femtosecond laser sources available for the industry. This ability seems to offer new micromachining opportunities for better quality and often also for even higher efficiency.

We have examined the influence on the efficiency and the quality for an ablation process on conductive materials. Therefore the pulse duration was reduced from 6 ps to 900 fs and even down to 400 fs.

By comparing those three pulse durations it will be much easier to decide which laser should be used for a certain process and material. And on the other hand it offers a good chance to discover new applications for lasers with ultrashort pulses.

Laser micro structuring using adaptive mirror for extra-cavity beam shaping of high-power ultra-short laser pulses

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Abstract

In laser micro processing there is a demand of shaped beams to improve the ablation results. Beam shaping is used e.g. for generating isolation grooves in solar cells. In addition the variation of the beam profile allows modifications of the surface properties of the processed material. These modifications can result in surface functionalization e.g. hydrophobic behavior. Phase changing optical elements are used to influence the wave-front and vary the beam shape. For high-power laser applications these elements have to be compliant with large pulse energies or high average power. A deformable mirror is one of the most suitable tools for the application with high power lasers, because of the absence of intensity losses due to diffraction. In this study a unimorph deformable mirror was used for beam-shaping during a picosecond laser ablation on metals and dielectrics. A piezoelectric disc behind the deformable mirror is separated into 35 segments, which can be individually driven by a voltage from -100 V up to 250 V. This feature allows complex deformation of this mirror which results in an individual variation of the spot geometry. The generation of different focus geometries, e.g. elliptical or line geometries, were analyzed. For this purpose on one hand the intensity profile and the beam propagation and on the other hand the influence to the surface modifications were studied. Another field of application for deformable mirrors is the variation of the focus position. By using additional optical components a controllable focus shift of 5 mm with a step size down to 25 µm was realized. This feature was required to keep a continuous spot size on the ablation surface. The influence of this defined defocusing during the ablation process was analyzed and compared to a focus shift realized by a motorized translation axis. It could be shown that beam-shaping based on a deformable mirror is a precise method for intensity variations of the laser spot and focus shifting without loss of intensity.

Cutting diamond tools using the LaserMicroJet® technology on a 5-axis machine

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Abstract

The Laser MicroJet® technology uses a water coupled ns-laser to cut various materials e.g. diamond, semiconductors, ceramics and metals. The laser light is guided to the workpiece by the water jet and the material is cut by the laser radiation. This technology can thus cut the same materials as a dry laser. However, the Laser MicroJet® technology exhibits several advantages over dry laser cutting such as a parallel sided kerf, less heat damage due to the additional cooling of the water, no adjustment of the laser focus and higher kerf depth to kerf width aspect ratios. The cutting of ultra-hard diamond tool materials with this technology is now showing very promising results in terms of low surface roughness and high cutting speed. PCD, PcBN, and single crystal diamond tool materials, including those backed with cemented tungsten carbide, can all be cut and shaped with the Laser MicroJet®. Latest results show a surface roughness Ra for the PCD/PcBN region of the cut surfaces of < 0.3 µm and < 0.5 µm on the cemented carbide. The effective cutting speed on 2 mm thick, carbide backed PCD/PcBN is 5 mm/min. The cutting edge radius (i.e. sharpness) achieved is r < 10 µm for PcBN samples and r < 5 µm for PCD or CVD samples. For some applications, this level of edge sharpness will be more than adequate and finish grinding will not be necessary. This paper presents the first results cutting ultra-hard tooling materials on the 5-axis platform using the already well established Laser MicroJet® technology.

Influence of coaxial cw laser heating on the ablation of silicon with ultra-fast lasers

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Abstract

These days most common way to produce electrical components like LEDs, solar cells or transistors is a batch process. Therefore a lot of identical components are processed parallel on one big wafer and eventually each chip has to be singulated. Currently two dicing technologies have established themselves, which can be devided in mechanical blade sawing and laser based processes with nanosecond lasers. In contrast to these technologies, laser dicing with picosecond lasers offers fundamental advantages like smaller kerf width and marginal heat effected zones. However the process efficiency and the attainable aspect ratio are limited and thus some deep cutting or drilling processes are not feasible. In this paper the influence of coaxial laser heating on the cutting process of Si wafers with ps lasers is investigated. It turns out that already with cw average powers in the range of 20 W a significant decrease of the ablation threshold can be obtained. Furthermore the aspect ratio can be increased by approx. 20 %.

Effects of ultrashort laser ablation in copper and stainless steel

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Abstract

Precision machining with ultrashort laser pulses strongly depends on the relationship between process parameters and physical and metallurgical properties of the metal machined. This relationship, however, varies in the course of the process depending on the number of pulses that hit the same spot on the material being processed, and this need to be known and compensated for precision machining. This variation arises due to defects in the crystal lattice produced by the laser pulses. These defects are cumulative and their influence is described by the incubation effects. Thus, the relationship between the threshold fluency F_{th} and the number N of overlapping pulses is a fundamental condition to obtain controlled and precise ablation with ultrashort laser pulses.

By means of a method developed by the authors, the D-Scan (Diagonal Scan), this study acquired a great amount of experimental data that allowed obtaining many $F_{th} \times N$ curves. These curves were measured for pulsewidths of 25, 80 and 120 fs for both copper and stainless steel. The results show differences with respect to the temporal widths and even more significant variations between the two metals. Copper, presented a 25 fs single pulse ablation threshold of 0.80 J/cm^2, much greater than for stainless steel, which is 0.30 J/cm^2. The incubation factor for copper, 0.78 is smaller than that for stainless steel, which is 0.85. After N=1,000 pulses the two metals presented Fth of around 0,07 J/cm^2.

The D-Scan technique also allowed observing many different morphologies of the ablated region. The process parameters (fluency, N and temporal width) related to these morphologies could be easily determined in a clear and fast way. Therefore, the process conditions to obtain a specific surface structure as LIPSS, nanocones, fusion and fusion with phase explosion was determined to these two materials and the method can be used to any other kind of material.

Direct laser beam interference patterning for fabrication of plasmonic hole arrays

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Abstract

Periodic arrays of apertures in thin metallic films act as metamaterials with interesting properties such as extraordinary transmission due to surface plasmon resonances and can be applied as biosensors or filters of electromagnetic radiation. We have tested the Direct Laser Beam Interference Patterning (DLIP) technique as a tool for the fabrication of the periodical hole' arrays in thin metal films using picosecond laser pulses. A novel scanning technique allowed the production of uniform patterns in the tens of square millimetres sized areas. Such device areas are sufficient for most applications. Properties of the hole' array depend on the shape of the hole and the lattice structure. The shape of the hole was controlled by adjusting irradiation fluence and by introducing sample translation between laser exposures. The lattice structure was adjusted using a certain number of interfering beams. Reflectance measurements of the DLIP patterned samples show reflectance dips corresponding to the extraordinary transmission. The reflectance modulation depth strongly depended on fabrication parameters. Longer pulse duration may be favourable to avoid sub-period irregularities in the ablated structures.

Temporal evolution of hole geometry and influences of energy deposition in ultra-short pulse helical drilling

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Abstract

This paper presents a static investigation on temporal evolution of hole geometry and influence of laser energy deposition on hole quality in helical drilling process. By using a rotating dove prism a circular oscillation of the laser spots is performed and holes are drilled at intervals in 1 mm thick stainless steel (1.4301) by ultra-short laser pulses of 7 ps at 515 nm. The formation of hole and the behavior of energy deposition differ from other drilling strategies due to the helical revolution. The temporal evolution of the hole shape is analyzed by means of SEM techniques from which three drilling phases can be distinguished. The first phase is characterized by a highest drilling rate and the formation of a sharp-edged circular groove with a pin inside the workpiece. In the following phase, the molten and vaporized material is ejected out from the hole and a funnel-like borehole with a slim tip deepens to the backside of workpiece, growth of hole depth slows down in this period. The exit is broadened to the final shape in the final phase. Laser scanning microscope (LSM) measurements of structure details on the hole wall demonstrate that the quality of the helical-drilled hole is determined by a correlation between the pulse energy applied and the overlapping rate of laser pulses, which is described mainly by helical path and the rotation speed of laser beam.

Laser micro-drilling of multi-layered artificial skin

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Abstract

A multi-layered artificial skin is mainly consisted of three layers of silicone elastomer, print paper, and resin plate. Sealing of facial defects with the multi-layered artificial skin causes perspired water from the surface of missing parts, which results in insanitary conditions to the skin surface. Therefore, the laser micro-drilling using nanosecond and picosecond pulsed laser was investigated to provide the breathability for multi-layered artificial skin without human eye's recognition of drilled holes, which can satisfy both the breathability and aesthetic problems. The visibility of drilled hole was affected by the pitch distance of drilled holes, and its visibility decreased with increasing the pitch distance. A small color difference measured using a colorimeter led to the low visibility, and laser micro-drilling with small color difference is effective to obtain the breathable multi-layered artificial skin with low visibility of drilled holes, which can improve the breathability for the multi-layered artificial skin.

Energy transfer mechanisms during laser pulsed processing of metals

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Abstract

The basic behaviour of material removal rates in volume laser ablation processes when using ultra-short laser pulses can be described by simple models based on the Beer-Lambert law with an exponential decay of the energy density into the material of an externally applied laser field according to preliminary findings of J.H. Lambert, 1760 and A. Beer, 1852. Neuenschwander et al., 2014 showed that the use of different pulse lengths results in different "effective" penetration depths of energy into the material. At certain parameters, these are in the range of the optical penetration depth. However, for a wide range of pulse durations the effective penetration depth is much larger than the optical penetration depth. The reasons for this behaviour are several energy transfer mechanisms like photon-electron, electron-electron and electron-phonon interactions.

For short- and ultrashort-pulsed laser processing, wide-range two temperature model calculations for several pulse durations were carried out for aluminium. The simulations enable to distinguish between different energy transfer mechanisms. The influence of optical absorption and energy transport mechanisms for different pulse durations and applied fluences are discussed in the present paper.

Highly reproducible laser micro drilling of titanium-based HLFC sections

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Abstract

The reduction of fuel-consumption is an environmentally relevant priority of the aviation industry. One of the key technologies in this field is the hybrid laminar flow control (HLFC), which is based on perforated sections on the leading edge of aircrafts. Up to now the economic efficiency as well as the quality of several micro drilling processes, such as laser drilling, cannot meet the requirements of a high-speed and large-area generation of micro holes with highly reproducible diameter. In this paper, an approach for a highly reproducible laser micro drilling of 0.8 mm thick titanium is presented. The influences of drilling parameters on process stability and bore diameter are discussed. With a commercially viable system technology based on a short pulsed fiber laser and a galvano-scanner, a stable production of micro holes of 35 µm to 90 µm in diameter with a through-going bore density of about 95 % was realized at drilling rates up to 175 holes/s. In terms to improve the inner form and to enlarge the hole diameter, a chemical pickling was carried out. Depending on the required dimension, this results in bores of 50 µm to 130 µm in diameter with deviations less than 10 %.

Calculating the optimal combination of pulse-to-pulse distance and fluence for scribing and surface ablation with ultrashort pulsed lasers

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Abstract

The application of ultrashort pulsed lasers for surface structuring or line scribing enables precise control of the ablation depth. A general challenge for high quality laser ablation is to find the optimal combination of pulse-to-pulse distance and fluence in order to minimize the surface roughness.

In this study, a model was developed to calculate the surface roughness as a function of the pulse-to-pulse distance and fluence. In the model, the surface is irradiated by a laser pulse with a Gaussian fluence profile; ablation starts if the fluence is above a certain threshold fluence, while the depth is proportional to the logarithm of the fluence. This model is used to calculate the surface profile generated by multiple adjacent craters. The surface roughness was determined as a function of the pulse-to-pulse distance and the peak fluence.

The calculations indicate that the surface roughness reaches a first minimum when the pulses begin to overlap. If the distance between the pulses is reduced further, several minima and maxima can be found. The pulse-to-pulse distances, where the minima of the surface roughness are located, increase with the square root of the logarithm of the fluence.

Laser ablation of SiC_p/Al composite

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Abstract

Particulate reinforced metal matrix composites (PRMMCs) have been known for several decades. The combination of their outstanding properties such as strength and ductility makes them superior to many metal alloys. SiC_p/Al is one of the most promising PRMMCs for aerospace and automotive applications. However, SiC_p/Al is very difficult to machine with conventional methods due to the hard SiC particles. Specifically, machining of SiC_p/Al with conventional diamond tools always suffers surface damages and rapid tool wear, which compromises machining precision and increases costs. This paper involves a fundamental investigation on the precision machining of SiC_p/Al composite using nanosecond laser. The microstructure evolution and product during ablation was demonstrated by scanning electron microscopy (SEM) and X-ray diffraction (XRD), respectively. Based on the distinct morphology features, the ablated surface can be generally divided into three types, i.e. Al is ablated while SiC particles remain, Al reacts with SiC to form a homogeneous surface layer, and both Al and SiC particles are ablated. The homogeneous surface layer consisted of mullite ($3Al_2O_3 \cdot 2SiO_2$) and sillimanite ($Al_2O_3 \cdot SiO_2$), which resulted from the decomposition of SiC and the melting of Al. The effects of mullite and sillimanite on the final properties of the material and the ablation mechanism are discussed.

Computational study on the effect of the pulse length on laser ablation processes

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Abstract

Laser assisted ablation technology is widely used for micro-fabrication of metal and semiconductor components in the electronic industry. The outcome of those processes strongly depends on several variables such as the used material and different laser parameters. For a better understanding of these processes a study on the effect of the pulse length based on multi-physical simulations was performed. The use of a complex model which extends original CFD-capabilities of OpenFOAM simulation software with multiple physics allows us to obtain detailed description of the phenomena taking place during the process. Special attention is paid to transient process characteristics including melt ejections and metal vapor dynamics as well as ablation depth and their dependency on the pulse length scales applied. The limitation of the model, especially at ultra short pulses, is analyzed and possible improvements are discussed. Apart from the computational investigation comparison of simulated results against available experimental data is finally provided.

Scaling of ablation rates. Ablation efficiency and quality aspects of burst-mode micromachining of metals

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Abstract

Considering the energy efficiency and the ablation quality, ultra-short double-pulse laser micromachining of stainless steel is examined for ps and fs pulses. Pulse delays from 0.3 ns up to 220 ns are realized with the help of an external delay line or a linear MOPA laser system. Burst-mode ablation is found to be less efficient for all investigated double-pulse delays. Keeping the single-pulse fluence and the overall incident energy constant, a drastic decrease of the ablation rate is observed when the double-pulse delay is reduced. Despite the lower ablation efficiency, ultra-short double-pulse laser ablation offers the possibility to machine strongly reflective and smooth surfaces and thus can improve the ablation quality.

Analysis of shape geometry of Ti6Al4V parts fabricated by nanosecond laser ablation

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Abstract

The process of laser milling, or laser ablation as it is also known, was developed over the last decade. In conventional milling techniques material is physically removed by a milling tool. In laser milling the material is removed by a laser beam through the layer by layer ablation mechanism. Generally, in laser ablation the quality of the processing result is reduced by melt accretions and thermal damage of the workpiece and therefore increases with shorter pulse duration. However, ablation efficiency decreases as well. Thus, laser ablation in the nanosecond range is still offering a good compromise between process quality and efficiency. The aim of this paper was to study the shape geometry and dimensions of Ti6Al4V parts fabricated by laser milling using a nanosecond Nd:YAG laser source. The impact of the laser processing parameters onto the machining outcomes was studied in order to find out optimized processing conditions. Particularly the influence of average power, repetition rate and scan speed was investigated.

The geometry of micro-parts was revealed using a 3D digitizing system Optimet Mini Conoscan 4000, which combines a non-contact, single-point measuring sensor based on conoscopic holography technology. The use of this measurement technology allowed obtaining complete information of the shape geometry and dimensions of built parts.

Crater shape dependence on pulse duration in crystalline silicon generated using an IR Gaussian laser beam: From femtosecond to microsecond regime

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Abstract

Semiconductor micromachining is one of the most common industrial applications where laser has been used in the last few years. Laser ablation is widely applied in the microelectronic field and in the photovoltaic industry. These two applications typically require a non-contact method for welding, cutting and scribing and the laser is one of the most suitable solutions for them. The prediction of the cratershape is a relevant issue due to the surface requirements of these processes. Semiconductors are also very interesting to study in the infrared due to their electromagnetic penetration that is strongly dependent on the wavelength, because of the material band gap. At the same time the physical proprieties of semiconductors, in particular the thermal ones, are likely to affect the final crater shape. The dependence of final crater shape on the laser pulse duration is relevant in laser material processing because different phenomena occur at different time regimes; this is why a systematic study of the crater shape, depending on the pulse duration, has been carried out. Four different temporal regimes have been studied. In femtosecond regime, a 330 fs laser has been used, with central wavelength at 1032 nm with energies below 10 µJ per pulse. In the picosecond regime, a 10 ps laser has been used, with central wavelength at 1064 nm with energies below 200 µJ per pulse. In nanosecond regime, the range between 9 ns and 220 ns has been used, with central wavelength at 1064 nm with energies below 1.1 mJ per pulse. In microsecond regime, the range between 2µs ns and 20 µs has been used, with central wavelength at 1064 nm with energies below 1.6mJ regime. Different fitting functions have been suggested for the different crater shapes depending on the phenomena involved in the ablation process, considering the different pulse durations.

Rapid nanointegration with laser-generated nanoparticles

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Abstract

After several decades of intense research in the field of nanostructures, nanoparticles are widely implemented for functionalization on surfaces, into volumes and as nanohybrids, with application in active nanoparticle-polymer-composites and as nanoparticle-bioconjugates. But nowadays only a limited variety of materials can be integrated into advanced functional products due to limitations of gas phase and chemical synthesis methods such as particle sintering or impurity. As alternative synthesis route, laser ablation and nanoparticle generation in liquids has proven its scalability and capability to generate totally ligand-free colloidal nanoparticle building blocks.
This contribution highlights how the unique properties of laser-generated nanoparticles can be harvested in prospective real-world applications rapidly via "nanointegration" into the fields of biomedicine and catalysis. Furthermore, it addresses how laser parameters, chemical environment and reactor design may be tuned in order to obtain monodisperse nanoparticles and to enhance the productivity of the laser process.

Production of silver nanoparticles in liquid by cw and pulsed lasers

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Abstract

The new properties of nanoparticles have accelerated the growth of production of nanostructured materials and their use in many different applications. In particular, silver nanoparticles have attracted much attention as a subject of investigation due to their well-known properties, such as high electrical and thermal conductivity, antibacterial and antifungal effects, etc. They are used in many different areas, medicine, industrial applications, and scientific investigation, etc. The size as well as the shape is very important for certain applications.
Almost all publications reporting synthesis of nanoparticles by laser ablation of solids in liquids use pulsed lasers, especially nanosecond and femtosecond lasers. Nevertheless nanoparticles can be also obtained in liquid media using long pulse lasers and continuous wave (CW) lasers. In the present work we present the results of ablating Ag target in water using a pulsed, as well as, a continuous wave laser.
The obtained particles consist of pure Ag nanoparticles showing rounded shape and uniform size distribution. Crystalline phases, morphology and optical properties of the obtained colloidal nanoparticles were characterized by means of X-ray diffraction (XRD), transmission electron microscopy (TEM), high resolution transmission electron microscopy (HRTEM) and UV/VIS absorption spectroscopy.

Bioactive glass nanofibers produced by laser spinning for biomedical applications

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Abstract

The Laser Spinning technique was employed to produce long, dense and flexible glass nanofibers with different bioactive compositions. Laser Spinning is a novel technique that allows the rapid and scalable production of high quantity of glass nanofibers under ambient conditions. The bioactive glass nanofibers have potential utility as reinforcement in composites, fillers in bone defects or scaffolds for tissue engineering. The morphology and structure of these nanofibers was analyzed using SEM, XRF, NMR, TEM and ATR-FTIR. The bioactivity of the glass nanofibers is demonstrated with in-vitro tests. They also present antimicrobial properties against different bacteria. The flexibility of this material, easy of manipulation and sterilization as well as antibacterial properties, made the laser-spinning glass nanofibers an excellent alternative to present granulated material for bone defect restoration and for tissue engineering.

Femtosecond laser ablation in liquids of iron-based nanoparticles

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Abstract

Nanoparticles are intensively investigated in several fields of research due to their wide range of properties and potential applications. Especially magnetic nanoparticles are of great interest in the field of magnetic fluids, catalysis, biotechnology/biomedicine, magnetic resonance imaging, data storage, and environmental remediation.

Pulsed laser ablation in liquids (PLAL) is a simple method for the rapid production of colloidal nanoparticles. The technique requires a suitable laser source, the desired target material and a solvent. One further advantage of the PLAL produced particles is the ligand-free surface which makes them chemically more active than chemical synthesized ones.

Here, we present a study on the generation of magnetic iron-based nanoparticles generated by high power femtosecond PLAL with peak powers up to 1010 watts. We discuss the influence of the used solvent and applied laser parameters on the generated nanoparticle properties. These properties, size distribution, shape and composition are investigated by several methods, e.g. TEM, EDX, dynamic light scattering, and Raman spectroscopy.

Formation of a periodically distributed inverted pyramid structure on silicon using direct laser interference ablation and surface etching processes

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Abstract

In this paper, we present a new method of structuring a crystalline silicon surface using laser ablation and wet anisotropic etching processes that produce periodic inverted pyramid surface structure. The direct laser interference patterning technique was used as a first process instead of the single focused laser beam. That resulted in the idea- periodicity structure produced on a large area with just a single laser pulse. The morphology investigation of the formed structure depending on the laser processing and etching parameters was performed using SEM and AFM microscopy.

Direct laser patterning as alternative method for production of THz Components and plasmonic structures

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Abstract

In this work we discuss the alternative laser patterning method for fabrication of the frequency selective components, plasmonic structures and compact optics on various metals. Research was focused on demonstration of the suitability of laser DLP process for THz components fabrication. Experiments with different DLP process parameters was performed to find optimal ones for fast fabrication procedure of various THz components. The fabricated structures morphology analysis in terms of shape accuracy and processing quality was estimated. Finally the performance of fabricated components was tested.

Evaluation of picosecond laser-induced shunt resistance in CIGS thin-film solar cells

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Abstract

CIGS thinfilms became even more attractive to PV industry after rapid efficiency increase over the last years for small scale devices. However, the transition from the small scale to full-sized modules introduces efficiency losses due to increased photocurrent and related ohmic losses. On the other hand, the high efficiency can be maintained if the large module area is divided into many smaller segments interconnected in series by a three-step patterning process. We utilized a picosecond laser working at the 532 nm wavelength to perform P3 type scribing process to separate the adjacent cells. Initially, we applied the technique of nested circular scribes proposed by K. Zimmer to evaluate the laser-induced shunt resistance after the P3 process. Further, we investigated the model including the top-contact resistance effects to the I-V measurement. Finally, we applied a simpler laser-induced shunt evaluation model by performing the P3 scribes between screen-printed silver grids of the CIGS mini cells. In both cases, parallel resistance values of the cells were extracted by analyzing I-V characteristics. Both evaluation techniques allowed to improve the laser parameter optimization process and the measurement accuracy of shunt formation during the laser scribing.

Picosecond laser modification of thin-film CIGS solar cell absorber layer for P2 micro-welding process

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Abstract

The high efficiency of a large thin-film solar cell can be maintained if cells are divided into smaller segments interconnected in series in order to reduce photocurrent and resistance losses. Laser patterning is a promising tool for monolithic interconnect formation, although cell deposition processes have to be interrupted for the laser scribing to be applied. These issues are especially important when going to the mass role-to-role production. P2 micro-welding process can be made after the front-contact layer deposition replacing the standard P2 scribing process which interrupts absorber and window layers deposition. After being affected by laser radiation CIGS compound melts and recrystallizes becoming a metallic compound which makes the interconnection between two adjacent cells. The metallic compound can be made due to the formation of Cu-rich areas and diffusion of TCO to the CIGS layer in the laser affected zone. In this work, we used picosecond laser to form molten lines in CIGS layer. Energy dispersion spectroscopy analysis together with Raman spectroscopy was applied to investigate the composition of chemical elements and crystal structural changes along various laser scribes made in CIGS absorber layer. Electrical characterization of the CIGS mini-cells after laser modification revealed changes in the cell parallel resistance indicating changes of the CIGS conductivity in the laser modified areas. Our investigations showed the potential of the picosecond laser in local modification process of the CIGS material which could be appliedto the P2 welding process.

Material modification of reinforced glass fibers using pulsed laser radiation

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Abstract

In this paper, laser processing of glass fiber reinforced thermoplastics is investigated with different laser sources. The aim of the study is to determine process windows in which uniform selective ablation of polymer matrix and homogenous ablation of matrix and fiber occurs. Laser sources with different wavelengths (10600 nm, 1064 nm and 355 nm) and pulse durations in µs and ns regime are compared on their ablation behavior of natural and black colored glass fiber reinforced polypropylene. Further the effect of laser processing on the fiber strength is investigated for different parameter settings where selective ablation of polymer matrix was achieved.

Laser processing of lithium iron phosphate battery electrodes

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Abstract

Lithium iron phosphate (LFP) battery electrodes are exposed to laser radiation at 100 mm/s and 1000 mm/s while systematically varying pulse duration (4-200 ns), repetition rate (20-1000 kHz) and average power (1-150 W). An optical profiler operating in confocal mode is utilised to establish material removal efficiency in all cases, while scanning electron and Raman microscopes are employed to determine macroscopic, microstructural and chemical changes near the cut edges. The laser pulse fluence ranges leading to lowest minimum cutting power at 100 mm/s are found to be 35–40 J/cm^2 (100 kHz) and 100–110 J/cm^2 (20 kHz) for the cathode and anode, respectively. The same laser parameters are found to result in the smallest clearance width of the upper coating layer and the smallest defects. By increasing the exposure velocity to 1 m/s and scaling the average laser power and repetition rate proportionally, clearance width and defect size are found to reduce moderately, while chemical and microstructural degradation of the active layers is all but eliminated. This study confirms the process as a viable alternative to mechanical blanking.

Fabrication of microchannels by picosecond laser pulses spatially shaped with cylindrical lens

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Abstract

Microchannels have applications in heat sinks, solar cell panels, fuel-cell systems and structuring of surfaces for tribological applications. Laser ablation with picosecond pulses promises small melt formation and precise machining of the metals. However, the pulse heat accumulation can reduce the advantages of picosecond machining. Beam shaping strategies are able to improve the machining quality through manipulation of the heat accumulation. In the current work, microchannels were produced on the surface of milled stainless steel samples. A combination of a cylindrical lens with a plano-convex lens was used creating a line focus on the sample surface up to the length of 500 µm. The experiments were performed with a 1 µm-wavelength picosecond laser with repetition rates of 50 kHz and 100 kHz. The maximum pulse energy of 188 µJ yields fluenceabout twenty times above ablation threshold. The geometrical properties of the microchannels obtained were compared with the result of conventional processing with a circular spot with respect to the width and depth, sharpness of profile. Beamshaping with acylindrical lens allows improving the quality of microchannels, narrower microchannels and reduction of debris.

Experimental study on laser marking of alumina

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Abstract

Alumina is one of the most employed ceramics in industry because of its good properties. Components made of alumina are essentially identified by a code or a symbol printed directly on them. However, there is still a lack of a reliable and efficient method to mark alumina. Particularly, laser typically produces marks with poor contrast.

In this work, an extensive experimental study on laser marking of alumina was carried out with the aim of finding out the optimal parameters to produce high contrast marks. Four different lasers working at three different wavelengths (infrared, visible and ultraviolet) were employed for the treatments. Colorimetric analyses were carried out in order to have an objective and quantitative comparison among marks and resulting contrast. The optimum operating conditions of the laser marking process were determined.

On line evaluation of femtosecond laser ablation efficiency on copper structures

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Abstract

Femtosecond laser ablation is a flexible method to generate accurate structures in the micrometer range. Yet, the efficiency for the removal of bulk material is lower than ablation with micro- or nanosecond pulses. To evaluate the efficiency of ultra short pulse material ablation copper test stripes were prepared and partly ablated with a titanium sapphire laser. The electrical resistance of material is inversely proportional to its wire cross-section. Therefore, the change of resistance is an indirect measure for the ablated material. This instantaneous feedback enables on line optimization of laser processing parameters. The results for various repetition rates, spot overlaps, ablation strategies and pulse energies with pulse durations of 35 femtoseconds are compared with surface profiles measured by white-light interferometry.

Reducing the roughness of the kerf for brass sheet cutting with the laser MicroJet® by a systematic parameter Study

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Abstract

The Laser MicroJet® technology uses a 532 nm ns-laser coupled into a water jet for precision cutting. The water jet is used to guide the laser and also cools the work piece so that a heat affected zone in the material is reduced or even eliminated and the kerf is parallel. The Laser MicroJet® is widely used for processing of various materials such as metals, hard materials and semiconductors.

This paper shows how the roughness on the kerf of 0.2 mm brass sheet can be reduced to < 0.2 µm by choosing laser parameters and processing strategy. A systematic study for cutting of brass sheet with a thickness of 0.2 mm is carried out in which laser parameters including frequency, pulse width and laser power are varied. Using three different laser systems in this study the pulse width ranges from 7-350 ns. Additionally different processing parameters are tested such as feeding speed, nozzle size and number of passes.

This work provides the users of Laser MicroJet® a deeper understanding of the relation between kerf roughness, laser parameter and process strategy. We observed that multiple passes lead to higher roughness so that cutting with one pass is preferred. Above a threshold peak intensity, which enables to cut through with one pass, the roughness decreases for higher peak intensities with the same fluence. However, for too high peak intensities and energies per unit length, the cooling effect of the water jet is not sufficient so that a heat affected zone evolves and the roughness increases. Same as known from dry laser cutting, with low pulse widths, low roughness down to 0.2 µm on the kerf can be achieved.

3D laser micro-machining for targets manufacturing

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Abstract

High power experiments require complex targets that include various geometries and materials. Laser micro-machining processes offer reliable and accurate solutions, able to fulfill demanding specifications. This paper gives examples of recent developments in 3D laser micro-machining of targets components, involving either UV nanosecond pulses (excimer laser) or ultrashort pulses (Ti:Sa femtosecond laser).

Mechanical properties of ultrafast-laser cut poly(lactic acid) films

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Abstract

The use of ultrashort laser pulses to cut polymers for medical applications has important advantages. Heat transmission to the region surrounding the cuts is limited, so that the cuts are precise and the effects on the regions around the cuts are small; in this way, the need for post-processing is reduced and ultrashort-pulse laser cutting becomes interesting for industrial applications. In general, both cutting speed and heat effects increase with the energy of the pulses and the repetition rate of the laser; it is important to identify process parameters with which polymer samples can be cut quickly and without compromising the chemical and mechanical properties of the polymer. In this work we present measurements of mechanical properties (elastic modulus, ultimate tensile strength and elongation at break) of cut samples of films of poly(lactic acid) – a biodegradable polymer with many different medical applications– as a function of laser repetition rate and examine how mechanical properties are correlated with the width of the heat-affected zones that can be observed with an optical microscope.

Effect of the pulse duration on the surface roughness and the heat affected zone in laser micro polishing processes

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Abstract

Micro polishing of metal surfaces by means of pulsed laser has attracted increased interest in the last decade, especially due to the precision it offers and the absence of waste byproducts in relation to traditional mechanical abrasive methods. The process for micro laser polishing requires melting a thin surface layer in order to reduce the roughness by means of the surface tension of the melt pool. This in turn produces a heat affected zone beneath the melted layer. In applications where the structural properties of the material must remain unchanged, the depth of the melted layer plus the heat affected zone have to be tightly controlled. One of the most important parameters that conditions both the maximum affected spatial period of the surface roughness (which increases the efficiency of the process) and the maximum thermally affected depth is the pulse duration. In this work the authors have studied the effects in these magnitudes as a function of the pulse duration between 20 and 200 ns. This has been done with a variable pulse laser of a wavelength of 1064 nm over an iron and nickel alloy, scanning the surface with a fixed frequency of 5 kHz. In the case of the evaluation of the surface roughness, a frequency-domain spectral analysis of the images has been performed to study the effect of the pulse duration on the frequency spectrum of the surface roughness. Considering the half width at half maximum (HWHM) of the frequency-domain spectral content of the images, the results show a gradual decrease of the minimum affected frequency of the surface roughness down to 0.21 μm^{-1} (which corresponds to a spatial period of 4.76 micrometers). This means that the process can erase surface features with a maximum width of 4.76 micrometers. In the case of the depth of the heat affected zone (plus the melted layer), a range of 1.5 to 4.5 µm was measured for pulse widths between 20 and 200 nanoseconds.

Scanned mask imaging: The economical approach to high resolution micro-machining using UV solid state lasers

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Abstract

Two methods currently exist for micro-structuring materials by laser: mask projection and direct write. This paper outlines anovel and alternative method called Scanned Mask Imaging (SMI), the resulting quality of SMI is comparable to that of excimer laser mask projection systems, but delivered at a fraction of the cost and burden of ownership. SMI has the potential to unlock the development of novel micro-machining techniques via programmable illumination patterns and dual plane imaging optics. Advantages of this new Scanned Mask Imaging method compared with conventional excimer laser based mask projection systems are discovered and summarized in this paper.

Laser based surface structuring for lightweight design

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Abstract

One of the most important issues in automotive industry is lightweight design, especially since the CO2 emission of new cars has to be reduced by 2020. Plastic and fiber reinforced plastics (e.g. CFRP and GFRP) receive besides new manufacturing methods and the employment of high-strength steels or non-ferrous metals increasing interest. Especially the combination of different materials such as metals and plastics to single components exhausts the entire potential on weight reduction. This article presents an approach based on short laser pulses to join such dissimilar materials in industrial applications.

Investigation and application of laser induced surface functionalization with pulse delays between 40ns and 50µs on silicon and steel foils

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Abstract

Laser induced quasi-periodic cone-like surface structures contribute to the functionalization of material surfaces. The resulting topography depends on manifold laser and ambient process parameters. In this study, the fundamental influence of a pulse delay between 40ns and 50µs has been investigated for the laser processing of silicon. During the processing, parameters of laser fluence and pulse overlap were set at constant condition used in the three laser systems. As the results, laser induced surface topographies are visualized by microscopy and analyzed with self-developed image processing tools to determine cone distance and cone density. The obtained knowledge from laser-induced quasi-periodic cone-like structuring helps to develop laser processes for various applications and materials, e.g. for photovoltaics or in medicine. In an exemplary case the surface functionalization is demonstrated for cathodes on steel foil.

One-step generation of ultrahydrophobic aluminum surface patterns by nanosecond lasers

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Abstract

In recent years, metal surfaces that could mimic the water repellence properties of some natural surfaces have been the area of an intense research due to their potential applications such as self-cleaning, anti-contaminating and anti-sticking applications. Ultra short laser machining/structuring is a promising technique to obtain the dual scale roughness on the metal surface, which promotes the complex interfaces between solid-liquid-air, thus improves the wetting property of the surface. An attempt was made to study the improvement of wetting properties of aluminum by nanosecond laser source in one step process. Flat aluminum sheets of thickness 100 µm were laser machined with ultraviolet laser pulses of 30 ns with different laser parameters to optimize the process parameters. The samples produced at the optimum conditions with respect to contact angle measurement were subjected to microstructure and chemical analysis. The wetting properties were evaluated by static contact angle measurements on the laser patterned surface. The laser patterned microstructures exhibited ultrahydrophobic surface with a maximum contact angle of 180° for the droplet volumes of 8µL.

Structuring of injection molding tools with ultrashort laser pulses for surface functionalization after casting

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Abstract

We structured injection molding tools and subsequently imprint the micro-structured surface onto the work piece during the molding. We studied the influence of the laser parameters for the fabrication of micro- and nanostructures. They are characterized using laser scanning microscopy and scanning electron microscopy. Finally, the tools are applied for two different purposes. We achieved vanishing adherence to blood in small capillaries of microfluidic devices. In a second example, we show that the forces to remove the tool from the workpiece after casting are reduced.

Laser beam propagation and energy deposition in particulate PEEK layers

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Abstract

The usage of high-temperature resisting thermoplastic polymers like PEEK (polyether ether ketone) as coating material represents an alternative to conventional corrosion protection layers. One promising approach to manufacture these coatings is to deposit particulate PEEK and, subsequently, melt the PEEK particles by laser radiation in order to create a dense, pore-free layer. Understanding the laser beam propagation and the energy deposition in the particulate PEEK layer is essential to simulate (time-dependent) temperature distributions within the layer system. These simulations allow an efficient identification of suitable process parameters for laser melting of the PEEK layer. Therefore, the absorbance of the layer system composed of substrate and PEEK powder with admixed laser-absorbing particles is determined experimentally. Subsequently, a model-based simulation of the optical properties is conducted and fitted to the measured data. Hence, the complex refractive indices of the bulk materials, particle-size distribution, powder density, multiple reflection, various scattering effects as well as layer thickness are taken into account. Based on the simulation results the spatial energy deposition in the layer system is extracted.

Use of high-energy laser radiation for surface preparation of magnesium for adhesive applications

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Abstract

This paper is intended to demonstrate how the parameters for the surface preparation of magnesium alloys for adhesive bonding can be optimized. The effects of different laser parameters are analyzed using a combination of advanced sample preparation and ultra-high resolution scanning electron microscopy on the nanoscale level and a specific combination of mechanical tests on the macroscopic level. This data allows a discussion of the physical principles and the key parameters influencing the interaction of laser radiation with the magnesium surface.

Nanostructures fabricated by laser interference lithography and their potential applications

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Abstract

We introduce a rapid and flexible method for polymeric nanostructure fabrication by using four-beam interference lithography. The influence of the laser processing parameters (peak pulse intensity, the number of laser beams, etc.) and photopolymer thickness to the shape of these nanostructures are analyzed, and the shape formation of nanostructures is explained.Also, the potential applications of the structures fabricated by interference lithography are discussed.

Investigation of the influence of laser surface modifications on the adhesive wear behavior in dry cold extrusion of aluminum

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Abstract

One of the main wear mechanisms in cold extrusion of aluminum is adhesion. While this can be prevented by excessive usage of lubrication, due to environmental and economic reasons a surface modification which allows dry metal forming, i.e. processing without lubrication is highly desired. In this paper first results concerning the effect of the spectral surface roughness characteristics of laser polished specimens made from AISI D2 cold work steel on their tendency to adhesive wear with aluminum are presented. By using macro polishing as well as micro polishing different spatial wavelength ranges of the surface roughness are modified, resulting in surfaces with a unique spectral roughness distribution. The laser polished specimens are tested in a compression-torsion tribometer under conditions adapted from cold extrusion. Before and after testing the topography of each specimen is measured via white light interferometry. By comparing both topographies the volume of adherent aluminum is determined. The influence of the laser surface modification is investigated on basis of the spectral roughness distribution and the characterization of the adhesive wear behavior.

Fabrication of graphene-chitosan electrodes films for sensing applications by laser-induced modification of the composite film

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Abstract

Graphene based electrodes have already shown an advantage in electro-catalytic activity and macroscopic scale conductivity. Formation of uniform graphene structure remainsa significant challenge. Lasers have been already shown as useful tool for formation and modification of graphene structures.

In this research, we present our results on formation graphene-chitosan electrodes by a picosecond laser irradiation of the active film. Graphene was casted by a spin-coating from the weak acidic dispersion of the chitosan solution on the ITO electrode surface, and the laser treatment was applied for regular nanostructure formation.

Modified electrodes were investigated applying the cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). The same characterization was performed after the laser treatment of the samples. Experimental setup of laser treatment included picosecond laser (Atlantic, 10 ps, 100 kHz, Ekspla) working at the 1064 nm and 532 nm wavelength and the galvanometric scanner with a focusing objective (F=80 mm).Picosecond laser parameters and GO concentration were optimized according to the capacitance and the resistance changes, calculated from the EIS data of the laser-modified electrodes. The Raman spectroscopy showed that laser irradiation can cut out graphene sheets in the graphene-chitosan composites into smaller pieces inducing more edge defects. Moreover, laser irradiation with the average power higher than 150 mW, caused an increase in capacitance at the electrode surface due to the formation of nanocrystals of graphene.

Influence of laser marking on stainless steel surface and corrosion resistance

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Abstract

Laser marking is the modern industrial application for non-contact surface modification. An incidence of a laser beam on the marked surface causes material and structural changes, which lead to optical changes of the surface. The processes during the laser-surface interaction can also affect other surface properties, especially corrosion properties in the case of stainless steel. Laser marking of stainless steel using the pulsed fiber laser SPI G3 is described in the contribution. Possibilities and limitations of steel laser marking are discussed. Some of the latest results of the material analysis and corrosion tests of the laser treated material are presented. Examples of laser marking influence on steel surface, structure and corrosion properties are shown.

High velocity laser printing of conductive tracks

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Abstract

Printing micrometer size conductive structures is a key challenge for the development of printed electronics. Inkjet technology is the main digital process currently used for this application, but it suffers from some drawbacks like head clogging and limitation to low viscosity inks. We use the laser-induced forward transfer (LIFT) technique to print at high-velocity long lines of metallic nanoparticle ink. A picosecond laser emitting at 343 nm with a repetition rate of 1MHz is used to realize 2D conductive tracks at velocity as high as 10m/s. The control of process parameters allows the fabrication of 20µm widthlines with various thicknesses and a resolution of few micrometers.
The physics of laser printing was studied by means of time-resolved imaging technique and these results areused to discuss the potential and limitations of this technology. Sensor electrodes were realized on flexible substrates as well as passive components like resistors and capacitors, by printing high viscosity inks. These applications will be presented to illustrate the feasibility of using high repetition rate laser for the fast and reliable printing of conductive structures.

Adjustment of surface energy on steel surfaces due to CLP generation by picosecond laser processing

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Abstract

With regard to mechanical and chemical resistivity metal surfaces can benefit from hydrophobic behavior. Against this background, results of laser-induced generation of hydrophobic surfaces on three different steel alloys without any additional coating are presented. Therefore, a dual-scale structure - consisting of micro cones and nano-ripples and droplets - is generated by picosecond laser structuring in ambient air.
Firstly, the dependencies of the formation of these micro cones, called cone-like protrusions (CLP), on different parameters of the laser ablation process - the peak fluence, the spot diameter, the effective pulse number per unit area and the material - are investigated. Secondly, the hydrophobicity and surface energy of the resulting surface topography of the irradiated substrate are evaluated by means of contact angle measurements. For that purpose identical topographies are generated on stainless steel, hot- and cold-working steel. The time-dependency of the contact angle is investigated depending on the material and the morphology.
For CLP formation a high number of scans is preferred to provide a high effective pulse number per unit area, which is advantageous for homogeneous generation of larger micro cones. By measuring the contact angle a change from an initially hydrophilic to a hydrophobic behavior of the surfaces can be observed due to a change of surface chemistry over time. Thus, contact angles higher than 90° can be measured on laser treated surfaces of different steel alloys.

Tribological surface functionalization via femtosecond laser-induced periodic surface structures on metals

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Abstract

Laser-induced periodic surface structures (LIPSS, ripples) were generated on titanium and steel surfaces upon irradiation with multiple linear polarized femtosecond laser pulses in air environment (pulse duration 30 fs, central wavelength 790 nm, pulse repetition rate 1 kHz, Gaussian beam shape). The conditions (laser fluence, spatial spot overlap) were optimized in a sample-scanning geometry for the processing of large surface areas covered homogeneously by two different types of nanostructures, i.e., low-spatial frequency LIPSS (LSFL) with periods around 600 nm and high-spatial frequency LIPSS (HSFL) having periods around 100 nm only.
The tribological performance of both types of nanostructured surfaces was characterized under reciprocating sliding condition against a ball of hardened steel at 1 Hz using different lubricants. After 1,000 cycles, the corresponding wear tracks were characterized by optical and scanning electron microscopy. For specific conditions, the wear was strongly reduced and the laser-generated nanostructures (LSFL) endured the tribological treatment. Simultaneously, a significant reduction of the friction coefficient was observed in the laser-irradiated LIPSS-covered areas when compared to the non-irradiated surface, indicating the potential benefit of laser surface structuring for tribological applications.
For optimization, the spatially Gaussian shaped beam used for the laser processing was transformed into a “Top-Hat” distribution at the surface of the samples. This was experimentally realized by using a spatial light modulator (SLM). The tribological performance of samples processed with a Top-Hat beam is compared to the one generated with a Gaussian shaped laser beam.

Studies on laser surface texturing of titanium alloy (Ti-6Al-4V)

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Abstract

In the present study, a detailed characterization of laser-assisted surface textured titanium alloy **(**Ti–6Al–4V) has been undertaken. Laser surface texturing with line and dimple geometry has been carried out using ArFexcimer laser operating at a wavelength of 193 nm with a pulse length of 5 ns. Following surface texturing, an extensive characterization of the textured surface has been carried out by scanning electron microscopy, electron back scattered diffraction (EBSD) and X-ray diffraction technique. There is refinement of microstructure along with a higher mass fraction of □-titanium phase and oxides of titanium (rutile, anatase and few Ti_2O_3 phase) in the textured surface as compared to as-received one. Furthermore, in order to investigate the impact of laser surface texturing on surface energy; wettability studies have been carried out before and after laser modification. The area fractions of linear texture and dimple texture measured by image analysis software were 45 % and 20 %, respectively. The surface energy (and hence, wettability) was increased due to linear (45.6 mN/m) and dimple (39.4 mN/m) texturing as compared to as-received Ti-6Al-4V (37 mN/m).

Non-uniform micro-texturing of tribological steel surfaces by femtosecond laser ablation

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Abstract

Femtosecond laser ablation (fsLA) allows fabricating surface micro-textures of complex shape and geometry with a micrometer precision. In this work, we exploit the intrinsic flexibility of fsLAtechnology to realize non-uniform micro-textures on steel thrust bearing (un-tapered) pad surfaces, which have been shown (within the recent Bruggeman Texture Hydrodynamics theory, BTH) to optimize the tribological characteristics of the bearing. Moreover, a complete tribological characterization of all the sample surfaces was performed. We found, in agreement with the BTH predictions, that the micro-fluid dynamics, occurring locally at the scale of the structural defect and induced by the same, is integrated out in term of a macro hydrodynamic regime in the friction curve, which would otherwise not exist for the macro-geometry of the contact.

Generation of low-spatial frequency laser induced periodic surface structures driven by surface finish

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Abstract

We investigate the influence of different angles between the polishing direction of linearly polished surfaces and the electrical field of the impinging laser on the generation of low spatial frequency LIPSS on stainless steel. The electrical field is rotated with respect to the polishing direction and its effect on the orientation and homogeneity of the LIPSS is determined. In addition, the influences of the initial surface roughness and laser parameters such as the laser fluence on the generation of LIPSS are investigated. It can be shown, that the formation of LIPSS is driven by the initial surface roughness. The experimental results lead to the assumption that LIPSS are attracted by the linear grooves caused by polishing. Depending on the used parameter set, the orientation of the generated LSFL formation deviate up to a value of 45° against the common predictions. Furthermore, a dependence of the required fluence for LSFL on surface roughness and polishing direction is demonstrated. In particular, LSFL generated with a low fluence are more attracted by the surface polishing. Continuatively, the results may contribute to a further understanding of the underlying mechanisms involved in the generation of LIPSS. In addition, the results can be useful for producing LIPSS on large-scale for possible applications.

Time resolved ablation mechanisms during fs-laser structuring of dielectric thin films with differing band gaps

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Abstract

In the production process of silicon microelectronic devices and high efficiency silicon solar cells, local openings in thin dielectric layers are required. In the latter case, silicon nitride (SiN_x) thin films are used as anti-reflection layers and silicon oxide (SiO_2) films as passivation layers. The openings can be selectively structured with ultra-short laser pulses by confined laser ablation processes in a fast and efficient single-pulse production step.

The aim of this work is to obtain a deeper understanding of the physical laser-material interaction during the laser ablation processes. For this purpose, two dielectric thin films with different band gap energies, SiO_2 (E_{gap} = 8 eV) and SiN_x (E_{gap} = 2.5 eV), on planar silicon (Si) wafers are structured with infrared fs-laser pulses (E = 1.2 eV). Pure Si is laser processed in comparison to study the role of bare substrate. The results show, that SiO_2 layers are selectively structured by confined laser ablation. SiN_x layers, however, are ablated by a combination of direct laser ablation and confined laser ablation at fluences well above the ablation threshold (factor 2.5). Then, SiN_x islands remain in the spot center. The applied Gaussian shaped laser pulses cause a nonlinear multi-photon absorption in the spot center leading to a local direct laser ablation process of the SiN_x film. Due to the larger band gap of SiO_2 films direct ablation is not observed here.

Pump-probe investigations are performed to investigate and to compare the temporal course of the different ablation types. The direct ablation process is observed on the Si sample, the pure confined ablation on the SiO_2 sample. The combination of both ablation types is observed during the SiN_x structuring.

By comparing the temporal ablation process of a substrate and two thin film systems with different band gaps the corresponding physical ablation mechanisms can clearly be identified. Absorption leads to direct laser ablation in the bare Si as well as in the center of the irradiated SiN_xwhereas low absorption in the rim of the irradiated SiN_x and in the SiO_2 film leads to absorption in the underlying Si substrate leads to confined ablation.

Improving a finite element thermal simulation of the nanosecond laser ablation on silicon targets

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Abstract

In semiconductor manufacturing, as in several other industrial sectors, lasers are massively used in many machining processes. In particular, nanosecond laser ablation is a valid alternative for the dicing of ultra-thin silicon wafers, providing better cut quality and lower production costs with respect to the more traditional mechanical sawing. Despite the broad application of lasers in industrial machining, much remains to be understood about the mechanisms underlying laser ablation. Numerical modeling is a useful tool in the understanding of the complicated mixture of tightly interconnected physics involved and in the optimization of the dicing process, which is nowadays still performed by a trial and error approach. Nevertheless, the complex multi-physical nature of laser ablation poses serious challenges in the simulation of the process and in the development of a common modeling framework. A gap exists in particular between pure and applied researchers. The former usually analyze in detail the fundamental mechanisms involved in the interaction of laser with matter, using analytical or one-dimensional models which are generally not suited for the simulation of real applications. The latter, while attempting to describe the overall industrial process typically by means of simulation packages, often approximate the problem by neglecting or over simplifying important aspects, as the effect of the laser-induced plasma or the target response at critical temperature. This work is aimed to bridge this gap. A thermal transient finite element model is developed using a commercial package. Additionally, theoretical and numerical techniques are described and implemented in order to account in a simplified, yet physically consistent manner, for the most relevant mechanisms underlying nanosecond laser ablation. The improved finite element model, among several other aspects, considers the initial non-equilibrium plasma formation governed by collisional and radiative processes. This description is essential, as the laser-induced plasma shields the target from the incoming laser beam and reduces both the efficiency and the controllability of the process. Further, the main mass removal mechanisms are qualitatively accounted for by an element deactivation technique. In particular the transition from evaporative to volumetric removal occurring at the target critical temperature is implemented. The numerical results are finally compared with experimental data.

Improvement of the adhesion between CoCr and dental ceramics by laser surface structuring

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Abstract

The preparation of the interface between dental ceramics and non-precious metal alloy cobalt-chromium (CoCr) at veneered dental restorations is crucial to the durability of the bonding strength and thus to the lifetime of the prosthesis. Conventionally the surface finishing is carried out by manual sandblasting, which is a highly subjective process. Due to this fact, the reproducibility of the required surface roughness for the bonding is limited. In addition, embedded residues of the blasting material can result in failure of the bonding.

Laser based surface finishing represents a promising approach to condition dental prostheses. Through its reproducible working principle while avoiding the use of foreign particles, laser processing offers advantages over the conventional process. With laser ablation the creation of a determined surface roughness as well as the functionalization of surfaces by defined structures becomes feasible. Therefore surface structures that enhance the adhesion between CoCr and dental ceramics have been developed in the present study. The subject was to improve the metal-ceramic bonding strength by conditioning the CoCr surface. First, the structures were derived from natural models, abstracted to technical application and then implemented with laser ablation. The structures were ablated on CoCr test specimen with a nanosecond (ns) pulsed Ybfiber laser with maximal pulse energy of 1 mJ. After ceramic veneering, a Schwickerath test was performed. Overall, the laser structured surfaces show bonding strengths up to 57 MPa. These adhesive forces are significantly higher than those of conventionally treated surfaces. Thus, laser ablation appears to be an attractive technology for surface finishing of dental implants for reasons of reproducibility and enhanced surface properties.

Pulsed laser surface pre-treatment of aluminium to join aluminium-thermoplastic hybrid parts

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Abstract

Thermal joining of aluminium and thermoplastics by laser radiation is promising. To obtain a high joint strength, the metal surface is pre-treated prior to bonding. Laser surface pre-treatment was used to pre-treat aluminium specimens in this study. The laser process allows a flexible processing of surface structures in the range from nanoscopic to macroscopic scale. An infrared pulsed single-mode fibre laser with a pulse width of 100 ns was used to form a microscopic structure on the specimens. The surface was overlain by a porous oxide layer. This oxide layer differs significantly from the natural passivation layer. It is assumed that the oxide layer contributes to a great extent to the cohesion between the aluminium and the thermoplastic material. This study focuses on the generation of the microscopic structure with anoxide layer and its influence on the resulting joint strength between aluminium and thermoplastics. To create a variety of surface topologies, different cumulative energies were applied to the specimens. The resulting surface topologies were investigated by scanning electron microscopy, the surface enlargement was characterized using gas adsorption, the surface roughness was quantified by laser scanning microscopy, and the surface chemistry was analysed by X-ray photoelectron microscopy. The oxide layer was removed from the structured specimens by an etching process to compare both samples, with and without a porous oxide layer. Subsequently, joints of the laser structured aluminium and the thermoplastics were prepared by thermal joining. The joint strength was measured by tensile shear tests and correlated to the surface areas, roughness values, and laser energies for etched and non-etched aluminium specimens to identify the influence of the microscopic structure and the oxide layer.

Surface conditioning of copper to improve the continuous wave laser micro welding

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Abstract

Copper is used in almost all electronic components. The contacts are laser welded if a low electrical resistance, a high mechanical and thermal long-term stability is required. For example these requests occur in modern motor vehicles, where the power electronics are installed in the engine room to save weight and cost of electric lines. One of the main problems in laser welding of copper is the low and locally varying absorption of the infrared radiation of established laser systems, which currently limits the stability of laser welding. This limits the efficiency of conventional laser welding, as well as its reliability.

Studies have shown that the irradiation of the copper surface with a green laser (532 nm) adduced a significantly higher absorptivity of infrared laser radiation. Figure 1 shows welding results with and without preconditioning. It can be seen that for preconditioning only a fraction of the energy is required. With the combination of green and IR radiation a 100% weld probability and an energy saving of 20 – 40 % was detected.

This work analyses the surface conditioning of copper, by irradiation of the copper surface with a 532 nm nanosecond laser, to improve the welding quality of the copper with an infrared continuous wave fiber laser source. The irradiation under well-defined conditions produces a durable preconditioning, which improves welding quality when irradiated on the preconditioned area.

This paper is focused on the analysis of the copper surface, after the laser preconditioning. In this presentation, the process conditions and laser parameters for surface conditioning of copper are analysed, to demonstrate the relationship between: the laser parameters and the surface conditions after the irradiation. Furthermore the influence of surface conditioning to the subsequent welding process with continuous wave infrared radiation will be shown.

Femtosecond laser manufacturing of highly hydrophobic hierarchical structures fabricated by combining surface microstructures and LIPSS

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Abstract

The manufacturing of metal surfaces with highly controllable wetting properties is becoming a very active and promising area in research and engineering. Based on nature examples like rose petals or lotus effect, an effective approach for this purpose is the combination of micro- and nano-structures into hierarchical structures. Traditionally these structures are manufactured by using different types of coatings or by processes which involve too many steps and techniques to become commercial solutions. However, this can be achieved by only using femtosecond laser ablation in air atmosphere. In this work we have developed hierarchical structures that consist of micro-patterned surfaces covered by nanostructures with this technique.
The first part of this work is a complete study to determine the microscale modifications produced on a stainless steel alloy (AISI304) surface at high pulse energy, different velocities, and focal distance in order to obtain microstructures with a selected depth of around 10µm and line widths of 20µm. The second part of the work is focused on finding the optimal irradiation parameters to obtain the nanostructure pattern. Nanostructures have been defined by means of Laser Induced Periodical Surface Structures (LIPSS) of around 250 nm high and a period of 600 nm, which constitutes the nanostructure pattern. Finally, dual scale gratings of 50 mm^2 were fabricated for a range of irradiation parameters (line period, fluence, velocity, ablated depth or focal distance) and their effect on the measured contact angle. Combining the micro-pattern with the LIPSS nano-pattern, highly hydrophobic surfaces have been developed with measured static contact angles higher than 150º starting from an initial contact angle of 75º.

Comparison of UV-to M-IR laser for surface pre-treatment based on the ILSS-test

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Abstract

Carbon fiber-reinforced plastics (CFRP) offer a great potential for any lightweight construction. Besides there are also some challenges – especially the joining technology and the repair process. Adhesive bonding is a key factor to solve both challenges, namely and based on the common CFRP fabrication processes it requires a surface pre-treatment because of residues of release agents. For the removal of those contaminations and also for the ablation of whole fiber plies for the repair process, laser radiation is a suitable tool. However due to the thermal interaction of laser radiation and CFRP there is a tendency to cause delamination during laser treatment. This paper describes the approach of predicting the delamination tendency in bonded CFRP joints with a very simple mechanical test. It is shown that the results gained out of the ILSS-test are correlating with the amount of delamination in adhesively bonded and previously laser ablated CFRP-joints.

Pulsed laser induced photo ablation of diamond

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Abstract

Laser processing of diamond is governed by metastability of its crystal structure. When heated up to T_g~2000K diamond lattice tends to rearrange globally showing so called graphitization. Several regimes of short-pulsed laser graphitization of diamond are observed. If laser fluence exceeds a certain threshold E_g then multi-photon absorption in diamond can lead to material heating up to T_g and formation of permanent graphitic layer. After that pulse energy can be easily absorbed (absorption in graphite is many orders of magnitude higher than that of diamond). This results in graphitic layer heating and vaporization (ablation) at the sample surface. For $E<E_g$ so called accumulation effect takes place: diamond graphitization (blackening) requires a number N pulses, N increasing for smaller E. This effect is explained as a two – step process. Initially graphitic nano (micro) regions are formed. Diamond lattice rearrangement starts at tiny graphitic inclusions. Then thermal growth of graphitic regions size from pulse to pulse results in phase transformation of adjacent diamond layers.

Further removal of thus formed graphitic layer can be realized either by its vaporization or chemical etching if irradiation takes place in reactive atmosphere, e.g. air. In the latter case, photoinduced phenomena can play an important role. This regime was called laser nanoablation and takes place at $E<<E_g$. Its first step is diamond ionization. Each act of ionization contributes to lattice rearrangement and activation of a number of top-layer carbon atoms which can react more easily with oxygen. This process is threshold free, that is pure photolytic. The number of exited and correspondingly oxidized carbon atoms grows with concentration of charge carriers.

Diamond ablation rates, photoionization and surface graphitization in air were investigated for femtosecond (λ=800, 400 and 266 nm) and nanosecond (λ=193 nm) laser pulses. Depending on multiple-pulsed irradiation conditions ablation rates ranging from 10^{-7}nm (reactive etching of exited surface carbon atoms) to 100 nm/pulse (laser graphitized surface vaporization) were observed at fluence $0,1<E<10$ J/cm^2. The examples of fine diamond micro and nanostructuring will be presented.

Nanosecond laser processing of diamond materials

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Abstract

Laser processing of synthetic diamonds for tooling application has been industrially established since the early 2000's. Though there are many publications dealing with the interaction between laser radiation and diamond materials using scientific laser sources, there are no comprehensive studies available for achievable ablation rates using industrially wide spread nanosecond laser sources. This paper will focus on the investigation of laser ablation results for various polycrystalline diamond materials using a NIR laser source with maximum pulse energy of 1 mJ and tunable pulse width between 10 and 240 ns. Single pulse ablation results for different laser parameters show that the ablation depth for polycrystalline diamonds is limited by absorption of laser radiation in the plasma plume. The plasma plume is visualized by high speed photography and correlated to the ablation results.

Laser induced micro-dot generation inside transparent materials: A) Formation dynamics, refractive character and internal stress

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Abstract

The formation dynamics of ultra-short laser-induced micro-dots inside the bulk of transparent materials was studied using time-resolved phase contrast microscopy. A random laser is used as a stroboscopic illumination source, enabling the acquisition of speckle-free, time-resolved phase-contrast images with a temporal resolution in the nanosecond range.

The results demonstrate the onset and propagation of a heat front following the laser energy deposition. The heat-affected zone develops in a region that exceeds largely the footprint of the microdot. Based on the analysis of the thermal transients, it is possible to provide an estimate of the heat diffusion coefficient of the host substrate.

Complementary results obtained with polarization microscopy reveal the appearance of a permanent stress field around the microdot. Interestingly, the amount of laser-induced permanent stress depends strongly on the number of pulses and on the laser polarization. We demonstrate that by using appropriate laser parameters, ultra-short laser-induced microdots are a suitable method for embedded direct part marking in stress-sensitive materials.

Laser induced micro-dot generation inside transparent materials: B) Process implementation, optimization and utilization

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Abstract

Laser-induced micro-dots find their application in direct part marking, to address full life cycle traceability. In our studies on ultra-short laser interaction with transparent materials we address the possibility of generating internal markings with minimal stress. At present, we concentrate our effort in utilizing picosecond laser pulses at a wavelength of 532 nm.
One important strategy followed in (single-shot) laser pulse micro-dot generation is using scanner systems with standard optics, e.g. F-Theta lens with 80 mm focal length, to ensure industrial-near implementation. Recent results show that the transient energy relaxation processes up to several 100 ns after laser excitation can strongly affect the host material over a region that exceeds the micro-dot size by several micrometers.
We will present and discuss the processing strategies recently developed to optimize the size and appearance of internal micro dots, based on demonstrators and referring to the scientific results in material response obtained using time-resolved phase microscopy after femtosecond and picosecond laser pulse excitation.

Tuning the energy deposition of ultrashort pulses inside transparent materials for laser cutting applications

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Abstract

Laser cutting of sheet like brittle materials, in particular glass and sapphire, is attracting attention for an increasing number of applications for the display industry, micro optics, micro electronics and others. Nonlinear absorption in the bulk of transparent materials enables tailored energy deposition for cleaving even along complex contours. The separation can be induced by transient effects, the separation plane defined by permanent modifications.
We demonstrate examples of tuning the energy deposition by controlling the geometry, the density and accumulation of the energy absorbed in the bulk. The influence of pulse duration, pulse groups, repetition rate, feed rate and beam shaping on the absorption, the inscribed modification and the cutting results are presented. This enables developing different processing strategies for cutting applications covering a broad range of materials and requirements.

Laser-induced subsurface modification of silicon wafers

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Abstract

In addition to the processing of transparent dielectric materials, pulsed lasers can be used to produce subsurface modifications inside silicon by employing near- to mid-infrared light. An application of these modifications is laser-induced subsurface separation, which is a method to separate wafers into individual dies. We investigated the subsurface modification process using a combination of numerical simulations and experiments. Different wavelengths, pulse durations and pulse energies were tested. We found that subsurface melting of silicon followed by rapid resolidification is the primary material modification mechanism. Lattice defects and transformations to both amorphous silicon and pressure-induced high density silicon phases occurred as a result of the laser irradiation.

Investigation on bragg grating formation in a perfluorinated polymer optical fiber

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Abstract

We present first results of ultraviolet laser induced fiber Bragg gratings (FBG) in a commercially available perfluorinated polymer optical fiber (POF) and their characterization results. FBG have gained interest in the past few years as the fiber is very thin and therefore easily can be integrated into composite structures and monitor the temperature and strain state. The type of polymer used in this study shows a much higher transparency compared to Polymethylmethacrylate (PMMA) based optical fibers. Up to now, only gratings in thin slabs of CYTOP ® (cyclic transparent optical polymer) were successfully detected. The gratings presented were inscribed using a krypton fluoride excimer laser and the well-known phase mask method. The polymer optical fiber (POF) type used in the investigations was GigaPOF-62SR from Chromis Fiberoptics, Inc. The fabricated gratings have a reflection maximum at 1450 nm and show many reflection peaks over a bandwidth of 10 nm. Prior to the inscription, an overcladding was removed using dichloromethane. The gratings were inscribed with 40 mJ/cm² pulse fluence and a total fluence of 2.5 to 5 kJ/cm². A pre-treatment of the POF in an evacuated steel tube followed by an oxygen atmosphere at 80°C, each for one day, and a temper step after the grating inscription show promising results for a much lower total fluence of 1 kJ/cm² and lower. This also means shorter grating inscription duration. The inscription time is crucial for a commercial use of this new type of POF-FBG in the field of structural health monitoring of composite structures.

New approach of laser processing of transparent materials

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Abstract

The classical way of processing materials using laser ablation with galvanometer scanners or other optical elements limits the possible structures and geometries of features and parts. Holes without taper or other structures such as trenches with rectangular profile are hardly possible to machine.
In this paper 3D-Micromac AG presents a novel laser micromachining method for transparent materials using ultra short pulsed lasers. With this new method the described limits can be overcome. Structures like taper-free or negative taper walls walls can be achieved with very high aspect ratios. Typical dimensions of those structures are in range of a few 10 microns up to a few 100 microns. This type of structures are interesting as inkjet or other fluidic nozzles, for friction reducing surfaces or as casting moulds for polymer parts for life science and medical applications. Furthermore, laser machined micro parts like micro gears are presented. Such parts are of interest for micro drives, pumps for micro fluidics and other upcoming applications.

Straightforward laser machining of thin glass

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Abstract

The LMTB has been working very actively on the industrially related implementation of laser machining via micro-ablation of transparent substrates, such as float glass, borosilicate, soda-lime, quartz and sapphire. By selecting the right laser wavelength, machining can be initiated from the rear side of glass substrates. This very attractive method becomes difficult to control for glass thickness below 0.2 mm. For these thin glasses, the LMTB developed a short focal trepanning system type1.f18 for straightforward cutting and drilling. The machining can be characterized as micro milling, only using short or ultra-short laser pulses instead of a mechanical blade. This paper presents and discusses the system developments and laser processing strategies implemented at the LMTB laser application lab to optimize the cutting results for thin glass.

Influence of pulse duration on the glass cutting process

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Abstract

Glass has recently found increasing importance in industrial markets, especially in the rapidly growing sector of display or cover glass applications for consumer electronics. However, cutting of brittle materials is a demanding process if high quality standards are required. High quality industrial glass sheets with high bending stability require minimal micro-cracks, particularly on the cut edges. Cutting techniques involving mechanical or chemical processes lead to cracks, high levels of waste and therefore high processing costs. Nevertheless, these traditional processes currently dominate this area of industrial manufacturing. In addition, the market trend is towards thinner and hardened glass, where challenging demands are placed on the processing tools and mechanical methods fail or produce high reject rates. Therefore a new processing technology is needed. Cutting with ultrafast lasers has high potential for processing brittle materials efficiently without time consuming post-processing operations.

In this work the influence of pulse duration on the ablation process is discussed. Following our previous findings that the process parameters, such as scanning speed and average power, have a significant influence on the surface properties, which in turn affect the bending stability of the glass sample, we now investigate the influence of the pulse duration on the process by comparing the applications of pulses with 400 fs, 900 fs and 6 ps duration. The influence of the pulse duration on the ablation threshold of aluminosilicate glass is presented, the occurence of nanostructures and the impact on the quality of the cutting edge is discussed.

Laser controlled ion exchange process and its applications

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Abstract

We report on progress made in laser controlled ion exchange processes. In this study, a scanning CO_2 laser beam was used to heat a glass substrate and locally control an ion exchange process. The heat from the glass melted the required KNO3 ion source, and the exchange occurred only where the laser was locally incident on the substrate. This process does not require global heating of the glass substrate, and the ion exchange process can be varied across the object. A depth of layer of about 18 um was obtained after several minutes of laser processing. The ion exchange depth and relative ion concentrations were evaluated by SIMS analysis. This laser controlled ion exchange process could potentially be applied in processes for writing ion exchanged optical waveguides as well as locally strengthening glass substrates. Specific examples will be described for increased the strength of glass substrates near mechanically drilled holes by using laser controlled ion exchange processes. Potential applications of the technique to other areas of interest are discussed.

Fabrication of micro-pump device with mixing functionality in fused silica with ultrashort laser pulses

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Abstract

The microfluidic micro-pump device fabricated by femtosecond direct laser writing technique in combination with chemical etching is presented. The contour and lines scanning method was used to adjust the best etching rate of micro-pump structure inside bulk fused silica. The working principle of micro-pump is based on the Venturi tube model. The design modelling was performed using COMSOL Multiphysics. The flow dynamics inside micro-channelswas investigatedin order to achieve the suction effect in micro-pump. Depending on the used input flow speed, the liquid injection or pumping can be achieved. When the both inlets of the designed micro-pump were connected to liquids with different concentration of dyes, the micro-pump acted as a micro-mixer. Pumping and mixing capability of the device were characterized, depending on the input flow rate, and the results are presented.

Laser line etching technique using nozzle-induced bubble jet impact for glass

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Abstract

The study proposes a new technique of laser line etching for glass. An Nd:YAG laser was applied to the backside of the glass which was partially submerged in water. A metal plate was placed below the glass substrate. Most of the laser energy is absorbed by the metal plate. The metal vaporized the water and generated a bubble jet. A rectangular nozzle whose inlet and outlet are narrow and rectangular shape was proposed to enhance the impact of the bubble jet. Material ablation occurred by softening and rupture from impact of the bubble jet. The parameters of nozzle geometry, laser power, and laser scanning speed were obtained. The proposed laser etching method was successfully demonstrated for etching a line-strip of 50-500 μm in width on a glass surface. It was found that the bubble jet of the small width nozzle inlet was well confined and created a strong jet impact on the glass surface. The proposed technique can prevent thermal damage and has great potential as an improved solution for the micro-machining of glass.

Rear side processing of soda-lime glass using DPSS nanosecond laser

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Abstract

Common drawbacks of the front-side direct laser ablation are laser-induced thermal effects and interaction between the laser beam and ablation products. These aspects consequently lead to the lower processing efficiency, lower quality and the need for post-processing. When the processing is initiated from the rear side of transparent samples, the ablated material is ejected through the formed channel in the opposite direction. Therefore, the incident radiation is not scattered and the laser fluency inside can be kept constant. Tightly focused nanosecond laser pulses are absorbed in the bulk of glass via avalanche ionization, build up thermal stresses and induce formation of micro-cracks in the substrate. By setting a proper laser pulses arrangement in the volume of glass, it is possible to control the material cracking and form a preferred structure. Using this processing approach, less energy is wasted for the material melting and evaporation as the material is removed in particle form.

In our research, we investigated the free-shape cutting of thick soda-lime glass sheets initiating the process from the back-side of samples. Cuts were formed by using diode-pumped solid-state Nd:YVO_4 nanosecond laser (Baltic HP, 10-30 ns, 100 kHz, from Ekspla). The laser beam was positioned in the XY plane by galvanometric scanners (from ScanLab) and focused by the f-theta lens. In our work, we proposed the wobble mode laser beam scanning technique combined with vertical sample movement. This approach enabled us to achieve taper-less geometry of laser cuts. The wall surface was controlled by adjusting laser fluency and laser pulses overlap. The nanosecond laser rear-side processing was proved to be a fast and highly efficient method for forming complex cuts in the soda-lime glass.

Glass processing with high power Q-Switch CO_2 laser radiation

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Abstract

Recent results of glass processing with a prototype high power Q-switch CO_2 laser source with a maximum output power of $P_{Lmax,cw} \approx$ 190 W are presented. For this, several glass materials (fused silica, BK7, S-TIH6, S-FPL53) are investigated and results regarding the achieved ablation rate and the resulting roughness are compared amongst each other. Moreover, an analysis of the chemical composition of the ablated surface is conducted and the relevance of these results for several industrial applications is discussed.

Precise structuring by 2-photon absorption in positive photoresist materials

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Abstract

Two-photon polymerization, based on two-photon absorption, is a convenient direct laser writing process to fabricate maskless structures in micro- and nanometer range with submicrometer resolution. Negative photoresists are used in combination with this technique, however, utilization of positive resists with two-photon absorption is very innovative. Due to less shrinkage and economic manufacturing, positive photoresists have many advantages. Possible applications of this technique are the production of micro-electro-mechanical systems (MEMS) or micro-opto-electro-mechanical systems (MOEMS). In this paper, two-photon absorption of positive photoresist is discussed to be a potential basis for LIGA-process (lithography, electroplating, and molding) by two-photon absorption of positive photoresist is discussed. The maskless ultra short pulse illumination by femtosecond laser pulses with 780nm wavelength for generation of microstructures in positive photoresist is demonstrated. To assure high quality structure surfaces, the influence of processing parameters on the pattern width are studied. Therefore, the influence of average power of femtosecond laser pulses, as well as the influence of the scan velocity on the resolution for 3D-grid structure is experimental tested. These studies enable fabrication of arbitrary 3D-structures with high resolution and high aspect ratio. By utilizing a commercial positive photoresist, a minimum linewidth in submicron order with essential rise of the aspect ratio has been accomplished. Furthermore, the test of a precise structuring of complex geometry fabrication is presented with an elastomeric molding. Based on these results, the application possibility for LIGA-process is demonstrated.

Thermal simulation of confined SiO2/Si laser ablation

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Abstract

The selective structuring of a transparent silicon dioxide (SiO_2) film on absorbing silicon (Si) substrate is an important application for the photovoltaic. The SiO_2 is ablated by confined laser ablation, also referred to as laser "lift-off". It is initiated at the interface of transparent thin films and absorbing substrates by ultra-short laser pulses. The thermal mechanisms of this kind of laser ablation are not yet completely understood. The two-temperature-model is used to simulate an ultra-short laser pulse, which is transmitted through the SiO_2 and absorbed in the silicon. The laser pulse energy is absorbed by the electronic-system and transferred by electron-phonon coupling to the Si-lattice. In the following the energy is dissipated by heat diffusion. The temperature difference between the Si substrate and the overlying SiO_2layer generates thermal conduction. The simulation results show the transient heating process in the Si and the heat transfer between Si, SiO_2 and air for different SiO_2 layer thicknesses. The temperature increase leads to volume expansion of Si and SiO_2. In conclusion the simulation shows that the lift-off is not only initiated by the absorbing Si substrate but also by the heating and expansion of the transparent SiO_2.

Joint Session with ECLEO

JSL: Diagnostics and Control (Invited) (Tu_13a_1)

Chair L. Overmeyer

Laser process monitoring and control of real process features

S. Kaierle

Laser Zentrum Hannover e.V., Hannve

Abstract

Laser materials processing has already been established for many years in industrial application, however process monitoring is still on its way. This contribution describes the current state-of-art and new developments in research of process monitoring.

Control of femtosecond pulsed laser deposition by temporal pulse shaping

F. Garrelie

Université de Lyon, Lyon

Abstract

The temporal laser pulse shaping is shown to strongly modify the laser-induced plasma composition and kinetics, giving the possibility to an adaptive control of Pulsed Laser deposition of thin films.

Ship-in-a-bottle fabrication of functional biochips by hybrid femtosecond laser processing

K. Sugioka

RIKEN Center for Advanced Photonics, Wako

Abstract

We propose a new method termed hybrid femtosecond laser processing which combines subtractive 3D glass micromachining with additive two-photon polymerization for realizing 3D functional biochips. Biological applications of fabricated biochips are demonstrated.

Joint Session with ECLEO

TFI: Ultrafast Solid-State and Fibre Laser (Invited) (Tu_13a_3)

Chair L. Overmeyer

Micromachining and Materials Processing with High Energy Ultrafast Fiber Lasers

Tim Gerke

Fianium, Southampton

Abstract

The short pulsewidth and high peak power provided with ultrafast lasers allow for new processing regimes and materials. For example, processing transparent materials and inside the bulk of materials is newly enabled.

Mid IR fiber frequency combs and applications

Martin Fermann

IMRA America Inc, Ann Arbor

Abstract

We review recent developments in fiber based mid IR combs based on supercontinuum generation, DFG, OPOs and OPAs and discuss their applications in spectroscopy.

Industrial ultrafast lasers for advanced manufacturing applications

Eric Mottay

Amplitude Systèmes, Pessac

Abstract

Ultrafast lasers play a key role in many industrial processes. We review the current status of high power ultrafast laser technology, and present selected manufacturing applications in the pharmaceutical, mobile display and medical device industries

Joint Session with ECLEO
TFII: Materials Structuring Using Short Laser Pulses (Invited) (Tu_13a_4)
Chair L. Overmeyer

Functional surfaces generated with femtosecond lasers

R. Kling, M. Faucon, G. Mincuzzi

ALPhANOV, Talence, France

Abstract

In this presentation the creation mechanisms of LIPSS are introduced with the feedback on laser specifications and handling systems. Applications of the laser induced surface functions covering decoration, tribology and antireflection are discussed.

Ultrafast burst-mode fiber lasers: source development and material processing

F. Oemer Ilday

Department of Electrical and Electronics Engineering, Bilkent University, Ankara

Abstract

Ultrafast burst-mode micromachining allows enhanced control against thermal effects and increases processing speed. Developments in burst-mode fiber lasers and their applications to processing of metals, dielectrics, soft and hard tissue will be presented.

Additive and subtractive 3D-microfabrication of micro/nanostructures

Yongfeng Lu

University of Nebraska - Lincoln, Lincoln

Abstract

In this study, we developed a complementary 3D micro/nanofabrication process by integrating both additive two-photon polymerization (TPP) and subtractive multi-photon ablation (MPA) into a single platform of femtosecond-laser direct writing process.