World of Photonics

19th International Conference

June 15 – 18, 2009, Munich

Lasers in Manufacturing

Organized by

Wissenschaftliche Gesellschaft Lasertechnik e.V.

Abstracts

Abstracts of the

WLT-Conference

"Lasers in Manufacturing" 2009

June 15 – 18, 2009, Munich, Germany

Colocated with LASER 2009 – World of Photonics

Edited by WLT – German Scientific Laser Societey

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A personal Welcome to Munich!

Thank you for coming to Munich and participating in LiM 2009! The International Conference on Lasers in Manufacturing LiM 2009 has been well established as one of the most important meetings in the field of laser based material processing. One of the main reasons for the continuous success of LiM might be the location. Germany and its laser industry as well as a very powerful scientific landscape with large laser and photonics institutes has been one of the pacemakers in this field over the past decades. Of course, Munich with its nice beergardens also offers many other opportunities in summertime. The German Scientific Laser Society (WLT) as the organizer of LiM, wants to stimulate the exchange of knowledge and ideas with international researchers in this exciting field. Therefore, we are very pleased that again many international participants contribute either by very interesting presentations or just by visiting this event. On behalf of the conference chairs we express our special welcome to those who travelled long distances, despite the difficult economic situation all over the world. This gives us confidence that research in new production technologies will still be a very important factor in the preparation of industry for the turnaround.

Lasers in Manufacturing is both: an old and a fresh topic. Old in this sense does not mean that it has passed its heights already. It is established more and more not only in huge global companies but gradually also in small and medium sized companies. The evidence that this field is still as fresh as in the beginning is brought to you by LiM 2009. New laser concepts with extraordinary beam qualities and output powers orders of magnitude higher than a few years ago, open the horizon for many applications people have thought about in the past as science fiction. Today it is reality.

Finally, we wish you a very successful week at LiM 2009, many new impressions also in combination with the exhibition LASER – World of Photonics, and – very important – a lot of new friends!

Andreas Ostendorf (Conference Chair LiM 2009)

LiM is organized by:

Wissenschaftliche Gesellschaft Lasertechnik e.V.

We are very grateful to the cooperating societies:

the association of AILU laser users

Laser Institute of America
Laser Applications and Safety

ELI European Laser Institute

JLPS

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Session and Room Timetable

Start	End	Monday, 15 June		Tuesday, 16 June			Wednesday, 17 June		Thursday, 18 June		
Subconference		High Power Laser Material Processing, Room 2	Microprocessing, Room 3	High Power Laser Material Processing, Room 2	Microprocessing, Room 3	Joint Session, Room B0.R1	High Power Laser Material Processing, Room 2	Microprocessing, Room 3	High Power Laser Material Processing, Room 2	Microprocessing, Room 3	Joint Session, Room B0.R1
08:30	10:15	9:30-11:00 Opening Ceremony Room 1		Direct Metal Deposition I Chair: Kelbassa	Applications in Electronics Chair: Otto		Rapid Technologies Chair: Kruth	Applications in Photovoltaics Chair: Michalowski	Process Sensing and Control I Chair: Fabbro	Microjoining I Chair: Miyamoto	
10:45	12:30	11:00 - 12:45 Keynote Session Room 13b Chair: Ostendorf		Direct Metal Deposition II Chair: Brandt	Micromachining of Metals and Ceramics I Chair: Gillner		Cutting Chair: Powell	Micromachining of Semiconductors, Glass and Other Dielectrics I Chair: Baumert	Process Sensing and Control II Chair: Kogel-Hollacher	Microjoining II Chair: Seefeld	
14:00	15:45	Welding and Brazing I Chair: Petring	Biomedical Applications Chair: Graf	Welding and Brazing III Chair: Katayama	Start 13.45 Micromachining of Metals and Ceramics II Chair: Dürr	Start 14.30 Fibre Lasers and Amplifiers: Concepts to Applications I Chair: Richardson	Advanced System Technologies and Applications I Chair: Emmelmann	Micromachining of Semiconductors, Glass and Other Dielectrics II Chair: Dumitru	Surface Modification I Chair: Huis in't Veld	Fundamentals and Modelling of Materials Processing with Lasers Chair: Herman	
16:15	18:30	Welding and Brazing II Chair: Reisgen	Laser Micro Forming Chair: Seefeld	Final Project Presentation - Fülas - Flexible laser-guided arc welding of high-strength steels and light metals Chair: Hermsdorf	Micromachining of Metals and Ceramics III Chair: Weber	Fibre Lasers and Amplifiers: Concepts to Applications II Chair: Vollertsen	Advanced System Technologies and Applications II Chair: Lai	Micromachining of Semiconductors, Glass and Other Dielectrics III Chair: Romano	Surface Modification II Chair: Huis in't Veld	Media Assisted and Hybrid Processes Chair: Kling	Fundamentals and Modelling of Material Processing with Lasers Chair: Graf

	Monday, 15.6.	
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**
9:30-10:45	Opening Ceremony World of Photonics Congress (Dittrich, Loosen, Ippen)	
10:45-11:00		
11:00-12:45	Room 13b Opening LiM 2009, WLT-Award, Keynote-Session: Advances in Laser Material Processing Kilian (Trumpf Werkzeugmaschinen GmbH & Co KG, Germany) Arnold (Princeton University, USA) Konov (General Physics Institute, Russia) Chair: Ostendorf (Ruhr University Bochum, Germany)	
12:45-14:00	Lunch	
	Welding and Brazing I **Chair: Petring (ILT)**	**Biomedical Applications** **Chair: Graf (IFSW)**
14:00-14:15	Berners (LBBZ-NRW GmbH, Germany): Laser welding in automotive manufacturing (Invited)	Fadeeva, Schlie, Koch, Chichkov (Laser Zentrum Hannover e.V., Germany): Femtosecond laser based functionalization techniques for biomedical applications
14:15-14:30		Emmelmann, Munsch (Hamburg University of Technology TUHH, Germany): Laser freeform fabrication of porous network structures for dental application
14:30-14:45	Hu, Huang, Wu (Shanhai Jiao Tong University, China): Study of Microstructure and Properties on Laser Welded Joints of High Strength Steel Used in Cars	Celen, Özden, Efeoglu, Celen (Ege University Izmir, Turkey): Micromorphological Characterisation of Laser Modified Titanium Dental Implant Surface
14:45-15:00	Ahmad, Kujanpää (Lappeenranta University of Technology, Finland): Laser absorption in CO2 laser welding of medium, high and ultra high strength steels	Boutinguiza, Lusquiños, Riveiro, Comesaña, Boutinguiza, Quintero, Pou (Universidade de Vigo, Spain): Laser-Assited Production of calcium phosphate nanoparticles
15:00-15:15	Kägeler, Grimm, Otto, Schmidt (blz Bayerisches Laserzentrum GmbH, Germany): Frequency-modulated zero-gap laser beam welding of zinc-coated steel sheets in an overlap joint configuration	Schauer, Krautkremer, McAfee, Milroy, Montague, Rundquist, McGowan (Boston Scientific, USA, Ireland): A computational thermal model of the laser bonding process in polymer balloon catheter medical devices
15:15-15:30	Neumann, Seefeld (Bremer Institut fuer Angewandte Strahltechnik BIAS, Germany): Humping in single mode laser beam welding of different materials	Lemke, Ashkenasi (LMTB GmbH Berlin, Germany), Trebst (CeramOptec GmbH, Germany), Eichler (Technical University Berlin, Germany): Ultra-short laser pulse processing of non-stripped medical quartz fiber wave guides
15:30-15:45	Eltze (Laserline GmbH, Germany): New Applications for Welding with Diode Lasers	Ranella, Barberoglou (Institute of Electronic Structure and Laser IESL Crete, Greece), Melissinaki (University of Crete, Greece), Mourka (Institute of Electronic Structure and Laser IESL Crete, Greece), Psycharakis (University of Crete, Greece), Gaidukeviciute, Vamvakaki, Farsari, Stratakis, Fotakis (Institute of Electronic Structure and Laser IESL Crete, Greece): Laser Based Fabrication Of Micro/Nano 3D Structures For Tissue Engineering Applications
15:45-16:15	Coffee Break	
	Welding and Brazing II **Chair: Reisgen (ISF)**	**Laser Micro Forming** **Chair: Seefeld (BIAS)**
16:15-16:30	Kleiner (Mangiarotti S.p.A., Italy), Verhaeghe (TWI Ltd., UK): High-power Yb-fibre laser welding of heavy-section tube-to-tubesheet assemblies	Stampfl, Inführ, Stadlmann, Pucher, Lichtenegger, Liska (Vienna University of Technology, Austria): Materials for the fabrication of optical waveguides with two photon photopolymerization (Invited)
16:30-16:45	Bingbing, Sun, Zhang Xiaoyun (Shanghai General Motors Corp. Ltd., China): Optimization for Laser Welding Fillet Joint Based On Response Surface Method	
16:45-17:00	Kawahito, Niwa, Nishimoto, Katayama (Osaka University, Japan): Application of Laser-Assisted-Metal and-Plastic Joining for Dissimilar Metal Welding	Farsari, Reinhardt, Terzaki, Gaidukeviciute, Giakoumaki (Institute of Electronic Structure and Laser IESL Crete, Greece), Ovsianikov (Laser Zentrum Hannover e.V., Germany), Vamvakaki, Fotakis, Chichkov (Institute of Electronic Structure and Laser IESL Crete, Greece) : Laser fabrication of nonlinear and metallic photonic nanostructures (Invited)
17:00-17:15	Schimek, Herzog, Haferkamp (Laser Zentrum Hannover e.V., Germany): Local Effects of Bead on Plate and Overlap Welding Seams to increase Strength and Rigidity of Sheet Metal Constructions	
17:15-17:30	Buschenhenke, Sakkiettibutra, Zeiler, Vollertsen (Bremer Institut fuer Angewandte Strahltechnik BIAS, Germany): Distortion during laser beam welding in consideration of the gap width	Obata, Koch, Chichkov (Laser Zentrum Hannover e.V., Germany): Advanced two-photon polymerization using holographic technology
17:30-17:45	Capella de Oliveira, Riva, Lima (Instituto de Estudos Avançados, Brazil): Autogenous laser beam welding of an aluminium alloy	Schütz, Dudziak, Herzog, Haferkamp (Laser Zentrum Hannover e.V., Germany): Analytically solvable model for process parameter estimation in laser sintering
17:45-18:00	Zäh, Daub (Technische Universitaet Munich, Germany), Mahrle, Beyer (Technissche Universitaet Dresden, Germany): Influence of CO2 in the Ar Process-Gas on the Heat-Conduction Mode Laser Beam Welding Process with Nd:YAG and Diode Lasers	Süß, Streek, Ullmann, Horn, Ebert, Exner (University of Applied Sciences Mittweida, Germany): Material analysis at selected, furnace treated, laser-generated solids
18:00-18:15	Suder, Williams, Colegrove (Cranfield University): Absolute spot size effect on penetration depth in laser welding	Bobitski (National University Lvivska Polytechnika, Ukraine), Jillek (University of Applied Science Nuremberg, Germany), Lesyuk (National University Lvivska Polytechnika, Ukraine): Ink-jet printing of conductive tracks of PCBs with laser sintering

	Tuesday, 16.6.	
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**
	Direct Metal Deposition I **Chair: Kelbassa (RWTH Aachen)**	**Applications in Electronics** **Chair: Otto (U. Erlangen)**
8:30-8:45	Haubold (Rolls-Royce Deutschland Ltd. & Co. KG, Germany): Industrial experience in using direct metal deposition for repair - is there a perspective for manufacturing? (Invited)	Steinbrecht (ROFIN / Baasel Lasertech, Germany): Laser Applications in the Electronic Industry
8:45-9:00		Mandamparambil, Flederrus, Dietzel (Holst Centre, TNO, The Netherlands): Ultrafast laser ablation studies on OLED stack
9:00-9:15	Thivillon, Novichenko, Bertrand, Smurov (Ecole Nationale d'Ingénieurs de Saint-Etienne, France): Laser assisted Direct Metal Deposition technology: manufacturing of macro-parts and composite coatings	Perrone, Maccioni, Chiolerio, Martinez de Marigorta, Naretto, Ferrero, Scaltrito ,Pandolfi, Martino (Politecnico di Torino, Italy): Study on the possibility of graphene growth on 4H-silicon carbide surfaces via laser processing
9:15-9:30	Emmelmann, Vogel (Hamburg University of Technology TUHH, Germany): Development of complex cooling systems for laser freeform fabricated molds by using FEM (finite element method) simulation	Varga, Mojzes (Budapest University of Technology and Economics, Hungary): Investigation of the physical and optical characteristics of the solder masks marked by laser beam
9:30-9:45		Wu, Shen, Tsai, Chien, Cheng (ITRI South, Taiwan): High Aspect Ratio Micro Drilling of Silicon Wafers Using Femtosecond Lasers with Hole Diameters Controllable
9:45-10:00	Amado, Suárez ,Tobar, Yáñez (Universidade da Coruña, Spain), Fraga, Peel (European Synchrotron Radiation Facility, France): Study of residual stresses generated in laser adding by diffraction of synchrotron radiation	Laakso, Ruotsalainen, Halonen, Kemppainen (VTT Technical Research Center, Finland): Sintering of printed nanoparticle structures using laser treatment
10:00-10:15	Brückner, Lepski, Beyer (Fraunhofer Institute for Material and Beam Technology IWS, Germany): Calculation of stresses in two- and three-dimensional structures generated by induction assisted laser cladding	Luesebrink (DynTest Technologies GmbH, Germany), Slagle (J. P. Sercel Associates Inc., UK), Schulz (Bookham AG, Switzerland): Singulation of Optoelectronic Devices
10:15-10:45	Coffee Break	
	Direct Metal Deposition II **Chair: Brandt (IRIS)**	**Micromachining of Metals and Ceramics I** **Chair: Gillner (ILT)**
10:45-11:00	Ocylok, Weisheit, Wissenbach (Fraunhofer Institute for Laser Technology ILT, Germany): Multi-graded layers by laser cladding for wear and corrosion protection of die-casting moulds	Waedegaard, Byskov-Nielsen, Balling (University of Aarhus, Danmark): Incubational effects in femtosecond laser ablation of metals: Changes in reflectivity
11:00-11:15	Van Rooyen, Burger, Theron (National Laser Centre-CSIR, South Africa): Crack Repair of Austenitic Stainless Steel by Laser Cladding	Daurelio, Andriani (University and Polytechnic of Bari, Italy), D'Alonzo (S.GI. S.r.l. , Italy), Catalano, Marano (University and Polytechnic of Bari, Italy): Laser Percussion Micro-Drilling of Al and Cu Alloys by 532 nm Green Light
11:15-11:30	Amado, Tobar, Yánez (Universidade da Coruña, Spain): Structure of tungsten carbide reinforced NiCr layers obtained by laser cladding	Schwagmeier, Müller, Ashkenasi (LMTB Laser- and Medical-Technology Berlin GmbH, Germany): Laser micro machining of metal foils, ceramics and silicon substrates
11:30-11:45	Kathuria, Uchida, Uchida (Aichi Institute of Technology, Japan): Synthesis of WC-12Co laser cladding	Schille, Ebert, Exner, Löschner, Schneider (University of Applied Sciences Mittweida, Germany): 3D micro machining with a high repetition rate ultra short fibre laser
11:45-12:00	Lusquinos, Comesana, del Val, Riveiro, Quintero, Pou (University of Vigo, Spain): Parametric study of fibre laser micro-cladding of Co-based alloy on stainless steel	Nicolet (California Institute of Technology, USA), Romano, Meier (University of Bern, Switzerland), Theodore (Freescale Semiconductor Inc., USA), Marble (Tarleton State University, USA), Bertsch, Dommann (Neutechnikum Buchs, Switzerland): Ablation of an amorphous Ta42Si13N45 film with a femtosecond laser pulse
12:00-12:15	Kovalev, Zaitsev (Khristianovich Institute of Theoretical and Applied Mechanics of SB of RAS, Russia), Bertrand, Smurov (Ecole Nationale d'Ingénieurs de Saint-Etienne, France): Modeling of 3D gas dynamics and particle transport in a multi-jet DMD nozzle	Narania, Voisey, Gindy (University of Nottingham, UK): A design of experiments study of Nd:YAG laser milling for the production of micro-dies
12:15-12:30		Ebert, Hartwig (University of Applied Sciences Mittweida, Germany), Hagemann (ThyssenKrupp Steel AG, Germany), Peuckert, Klötzer, Schille (University of Applied Sciences Mittweida, Germany), Wischmann (ThyssenKrupp Steel AG, Germany), Exner (University of Applied Sciences Mittweida, Germany): High rate ablation with 3 kW single mode fibre laser

	Tuesday, 16.6.		
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**	**Joint Session (Room B0.R1)**
	Welding and Brazing III **Chair: Katayama (JWRI)**	**Micromachining of Metals and Ceramics II** **Chair: Dürr (Lasag)**	**Tech Focus: Fiber Lasers and Amplifiers: Concepts to Applications I (together with ECLEO)** **Chair: Richardson (ORC Southampton)**
13:45-14:00			
14:00-14:15	Thomy, Vollertsen (BIAS Bremer Institut fuer Angewandte Strahltechnik, Germany): Effect of Process Parameters on Joint Properties in Laser MIG Hybrid Welding of Aluminium to Steel	Likhanskii, Campbell, Semak (Pennsylvania State University, USA): Numerical study of laser pulse duration effect on material removal depth and melt thickness for laser pulses in the range from femtosecond to nanosecond (Invited)	
14:15-14:30	Gook, Gumenyuk, Lammers, Rethmeier (BAM, Federal Institute for Materials Research and Testing Berlin, Germany): Orbital Laser-Hybrid Welding of Pipelines Using a 20 kW Fibre Laser	Döring, Ancona, Hädrich, Limpert, Nolte, Tünnermann (University of Jena, Germany): Microdrilling of metals using high repetition rate ultrashort laser pulses at 1030 nm and 515 nm	
14:30-14:45	Rosenfeld, Herzog, Haferkamp (Laser Zentrum Hannover e.V., Germany): Process combination of laser welding and induction hardening	Scholz, Baumeister, Dickmann (University of Applied Sciences Muenster, Germany): Modelling of cluster formation during laser ablation process	Minelly (Coherent Inc., USA): Technology trends for High Power Fiber Lasers (Invited)
14:45-15:00	Südmeyer, Rohde (Research Center Karlsruhe, Germany): Brazing of ceramic - steel joints by a laser process	Biffi, Previtali (Politecnico di Milano, Italy): Application of novel nozzle to reduce spatter production in microdrilling with nanosecond fiber laser	
15:00-15:15	Möller, Thomy, Vollertsen (BIAS Bremer Institut fuer Angewandte Strahltechnik, Germany): Development of a Plasma-Laser Brazing Process for Fluxless Joining of Aluminium to Steel	Doubenskaia, Bayle, Smurov (École Nationale d'Ingénieurs de Saint-Étienne, France): Monitoring of direct metal deposition by near infra-red pyrometry and IR-camera	Shiner (IPG Photonics, USA): Recent technical and marketing developments in high power fiber lasers (Invited)
15:15-15:30	Seefeld, Buschenhenke, Vollertsen (Bremer Institut fuer Angewandte Strahltechnik BIAS, Germany): Laser beam welding with hypereutectic AlSi filler material	Byskov-Nielsen (University of Aarhus, Danmark), Holm, Højsholt (Grundfos A/S, Danmark), Balling (University of Aarhus, Danmark): Laser structuring of metal surfaces: micro-mechanical interlocking	
15:30-15:45	Le Guen, Fabbro, Coste (CNRS LALP, France), Carin, Le Masson (Université de Bretagne Sud, France): Analysis and modelling of hybrid laser Nd:Yag – MIG/MAG welding process	Mildner, Haag, Englert, Wessel, Horn, Bückner-Foit, Baumert (University Kassel, Germany): Two-dimensional mapping of surface microcracks in TiAl by femtosecond laser-induced breakdown spectroscopy	Samson, Carter, Tankala (Nufern, USA): Recent Progress In High Efficiency Tm-doped Fiber Lasers (Invited)
15:45-16:15	Coffee Break		
	Final project presentation - Fülas - Flexible laser-guided arc welding of high-strength steels and light metals **Chair: Hermsdorf (LZH)**	**Micromachining of Metals and Ceramics III** **Chair: Weber (IFSW)**	Coffee Break
16:15-16:30	Hermsdorf, Kling, Otte (Laser Zentrum Hannover e.V., Germany): Development of the LGS-GMA welding process	Stute, Weiler (Trumpf Laser GmbH &Co. KG, Germany): High-class processes and productivity in micro machining enabled by disk lasers (Invited)	**Tech Focus: Fiber Lasers and Amplifiers: Concepts to Applications II (together with ECLEO)** **Chair: Vollertsen (BIAS)**
16:30-16:45			Norman, Appleyard, Duka (SPI Lasers, UK): 400W class fibre lasers for manufacturing applications (Invited)
16:45-17:00	Rippl, Tradt, Berger (KUKA Systems GmbH, Germany), Hermsdorf (Laser Zentrum Hannover e.V., Germany): Requirements for industrial applications for the innovative LGS-GMA welding process	Naeem, Keen (GSI Group, UK): Novel route to high quality ablation in a range of materials with a 400W single mode continuous wave fiber laser	
17:00-17:15		Gedvilas, Račiukaitis (Institute of Physics, Vilnius, Lithuania), Girdauskas (Vytautas Magnus University, Lithuania): Structuring of Metal Films by the Laser Beam Interference Ablation	Nilson, Jeong, Codemard, Farrell, Vasquez, Ji, Abidin, van der Westhuizen, Yoo, Sahu (University of Southampton, UK): High power fibre lasers: Exploitation of unique properties (Invited)
17:15-17:30	Höfemann (Salzgitter Mannesmann Forschung GmbH, Germany): Gas metal arc welding combined with a low powered laser beam for joining high strength steels	Maccioni, Martinez de Marigorta, Scaltrito, Chen, Chen, Fokine (Politecnico di Torino, Italy): Study of micro-structured master fabrication on Ni alloy by DPSS laser ablation technique	
17:30-17:45		Riva, Simões, Destro, Lima, Rodrigues (Institute for Advanced Studies, Brazil): Prediction of cavity shape in laser drilling with nanosecond pulses	Ishide (Mitsubishi Heavy Industries, Japan): Latest multi kW fiber laser application in Japan (Invited)
17:45-18:00	Bettermann (TUEV SUED Automotive GmbH, Germany): Wöhler-tests as a method to compare LGS-GMA welding process against conventional welding	Stephen, Walther, Vollertsen (Bremer Institut fuer Angewandte Strahltechnik BIAS, Germany): Removal rate model laser chemical micro etching	
18:00-18:15		Pedarnig, Heitz, Stehrer, Praher, Viskup (Johannes Kepler University, Austria), Wolfmeir, Arenholz (voestalpine Stahl GmbH, Austria): Laser-induced breakdown spectroscopy and plasma plume photography of iron oxide materials	

	Wednesday, 17.6.	
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**
	Rapid Technologies **Chair: Kruth (KU Leuven)**	**Applications in Photovoltaics** **Chair: Michalowski (IFSW)**
8:30-8:45	Van Vaerenbergh LayerWise N.V., Belgium): Metal Rapid Manufacturing: History, present state-of-the-art and future prospects (Invited)	Schmitt, Schulz-Ruthenberg, Olowinsky, Gillner (Fraunhofer Institute for Laser Technology ILT, Germany): Laser Joining Processes for Photovoltaic Module Production
8:45-9:00		Wu, Shen, Tsai, Chien, Cheng, Wu, Horng (ITRI South, Taiwan), Wang, Chang (National Chiao Tung University, Taiwan): Femtosecond laser grooving on silicon wafers for applications to solar cells
9:00-9:15	Emmelmann, Petersen, Goeke (Hamburg University of Technology TUHH, Germany): Laser Freeform Fabrication for Aircraft Applications	Baidullaeva, Bojko, Vlasenko, Mozol (V. Lashkaryov Institute of Semiconductor Physics, Ukraine): 2D structure formation on the surface of CdTe crystals under pulse laser radiation
9:15-9:30	Yadroitsev, Bertrmd, Smurov (Ecole Nationale d'Ingénieurs de Saint-Etienne, France): Selective laser melting technology: study of parameters influencing single track formation and properties of manufactured samples	Colina, Molpeceres (Univ. Politécnica de Madrid, Spain), Nos (Universitat de Barcelona, Spain), Sánchez, Lauzurica, García-Ballesteros (Univ. Politécnica de Madrid, Spain), Gandia (Energía Solar Fotovoltaica, CIEMAT, Spain), Ocaña (Univ. Politécnica de Madrid, Spain): Micro-Raman study of the thermal affected zone generated after a laser scribing process in a-Si:H photovoltaic thin films
9:30-9:45	Yasa, Kruth (Catholic University of Leuven, Belgium): Microstructure evolution of selective laser molten 316 L stainless steel parts with laser re-melting	Huber, Englmaier, Hellwig, Heiss, Kemnitzer, Kuznicki (Munich University of Applied Sciences, Germany), Brenning, Vogt, Palm (Avancis GmbH, Germany): Structuring of CIS thin-film solar cells by ultrafast laser pulses with industrial relevant process speed
9:45-10:00	Doll, Partes, Vollertsen (Bremer Institut fuer Angewandte Strahltechnik BIAS, Germany): Selective Laser Melting of Graded Metal Matrix Composites	Lauzurica, Molpeceres, García-Ballesteros, Colina, Sánchez-Aniorte, Ocaña (Univ. Politécnica de Madrid, Spain), Huber (Munich University of Applied Sciences, Germany), Gandia (CIEMAT, Spain): Comparative study of nanosecond and picosecond laser pattering of thin film for photovoltaic solar modules based on a-Si:H
10:00-10:15	Becker, Meiners, Wissenbach (Fraunhofer Institute for Laser Technology ILT, Germany): Additive manufacturing of components out of copper by selective laser melting	Trusheim, Schulz-Ruhtenberg (Fraunhofer Institute for Laser Technology ILT, Germany), Hernández, Urueña (IMEC Belgium), Krantz (Solland Solar Cells BV, The Netherlands), Morilla (BP Solar, Spain), Sarnet (CNRS-LP3, France), Olowinsky (Fraunhofer Institute for Laser Technology ILT, Germany): Damage-less laser ablation of thin films for Silicon solar cells
10:15-10:30 10:30-10:45	Coffee Break	
	Cutting **Chair: Powell (Lulea UT)**	**Micromachining of semi-conductors, glass and other dielectrics I** **Chair: Baumert (U. Kassel)**
10:45-11:00	Al Mashikhi, Powell (University of Nottingham, UK), Kaplan (Lulea University of Technology, Sweden), Voisey (University of Nottingham, UK): An explanation of striation free cutting of mild steel by fibre laser	Stoian (Université Jean Monnet, France): Controlling laser-induced refractive index changes in optical glasses (Invited)
11:00-11:15	Petring (Fraunhofer Institute for Laser Technology ILT, Germany): Calculable laser cutting	
11:15-11:30	Mahrle, Beyer (Technical University Dreden, Germany): Theoretical Estimation of Achievable Travel Rates in Inert-gas Fusion Cutting with Fibre and CO2 Lasers	Geoffray, Bourdenet, Faivre, Bednarczyk (CEA, France): Laser micro-machining for targets manufacturing
11:30-11:45	Lütke, Klotzbach, Himmer, Wetzig, Beyer (Fraunhofer Institute for Materials and Beam Technology IWS, Germany): Remote - Cutting – One Technology Fits for Various Materials	Loeschner, Mauersberger, Schille, Ebert, Exner (University of Applied Sciences Mittweida, Germany): Machining of Transparent Materials with Short Pulse and Ultrashort Pulse Laser Sources
11:45-12:00	Zäh, Musiol, Schober (Technical University Munich, Germany): Heat induced distortion during remote laser cutting	Zimmer, Böhme (Leibniz-Institute fuer Oberflaechenmodifizierung, Germany), Hopp (University of Szeged, Hungary): Backside etching of transparent materials - comparison of different techniques and applications
12:00-12:15	French (Liverpool John Moores University, UK), Naeem (GSI Group, UK), Clowes (Finanium Ltd., UK), Sharp (Liverpool John Moores University, UK): Fibre Laser Material Processing of Aerospace Composites	Giet, Michakis, Pary (Heriot Watt University, UK), Kidd (Renishaw plc, UK), Shephard, Hand (Heriot Watt University, UK): Novel laser-based machining process for high precision optical position encoders
12:15-12:30	Riveiro, Quintero, Lusquiños, Comesaña, Boutinguiza, Pou (Universidade de Vigo, Spain): CO2 laser cutting of carbon fibre reinforced plastic composite	Fiedorowicz, Bartnik, Jarocki, Kostecki, Szczurek, Szczurek (Military University of Technology, Poland): Processing Organic Polymers using a Laser Plasma EUV Source

	Wednesday, 17.6.	
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**
	Advanced System Technologies and Applications I **Chair: Emmelmann (TUHH)**	**Micromachining of semi-conductors, glass and other dielectrics II** **Chair: Dumitru (Inspire)**
14:00-14:15	Magnano (Comau, Italy): Status and future for robotized remote welding system designs and applications (Invited)	Miyazaki, Miyaji (Kyoto University, Japan): Nanostructuring of solid surfaces ablated with femtosecond laser pulses (Invited)
14:15-14:30		
14:30-14:45	Klotzbach, Schwarz, Bartels, Wetzig, Beyer (Fraunhofer Institute for Materials and Beam Technology IWS, Germany): High dynamic axes systems for laser processing "on the fly"	Hörstmann-Jungemann, Gottmann, Keggenhoff (RWTH Aachen University, Germany): In Volume Selective Laser Etching of sapphire
14:45-15:00	Schneider, Petring, Nazery, Nüsser (Fraunhofer Institute for Laser Technology ILT, Germany): 2D - and 3D - Laser Cutting and Welding with the Combi-Head: Efficient Production by Flexible Process Changes	Kaszemeikat, Müller, Ashkenasi (Laser- und Medizin-Technologie GmbH Berlin, Germany): Strategies in laser machining and surface structuring of glasses and glass ceramics with a new developed trepanning device
15:00-15:15	Diettrich, Stollenwerk (RWTH Aachen University, Germany), Kogel-Hollacher (Precitec KG, Germany): Coaxial laser brazing head	Kibben, Koerdt (BIAS – Bremer Institut für angewandte Strahltechnik, Germany), Garcia, Kolpakov (Universitat de Valencia, Spain), Daren, Solomon-Tsvetkov (Daren Laboratories and Scientific Consultants, Israel), Seefeld, Vollertsen (BIAS – Bremer Institut für angewandte Strahltechnik, Germany): Single step holographic grating inscription in a PMMA-based copolymer
15:15-15:30	Vihinen, Latokartano, Pajukoski (Tampere University of Technology, Finland), Lehtinen, Harkko, Lassila (Cavitar Ltd., Finland): Direct diode laser with coaxial material feeding	Biesheuvel, Krijgsman (NCLR B.V., The Netherlands): High speed parallel laser processing with a high power excimer laser
15:30-15:45	Price, Martinsen (nLight Photonics, USA), Pfeffer, Reinl (nLight- Optotools, Germany), Huang (nLight Photonics, China), Deininger (TGSW, Germany): Industrial Direct Diode Laser Systems Supporting 99.99% Up-time with Lowest Cost of Ownership	Chiolerio, Maccioni, Martinez de Marigorta (Politecnico di Torino, Italy): Thermal flash treatment in a controlled atmosphere under a magnetic field for magnetic tunnel junctions (MTJ)
15:45-16:15	Coffee Break	
	Advanced System Technologies and Applications II **Chair: Lai (CRF)**	**Micromachining of semi-conductors, glass and other dielectrics III** **Chair: Romano (U. Bern)**
16:15-16:30	Dutta Majumdar (Indian Institute of Technology, India): Laser Assisted Fabrication of Materials	Kazansky, Yang, Corbari, Beresna (University of Southampton, UK), Shimotsuma, Sakakura, Miura, Hirao (Kyoto University, Japan), Qiu, Svirko (University of Joensuu, Finland): Recent advances in ultrafast laser micromachining of transparent materials (Invited)
16:30-16:45	Shin, Lee, Lim (Korea Institute of Machinery & Materials, Korea), Kim(Korea Maritime University, Korea): Laser Assisted Machining of Silicon Nitride using HPDL	
16:45-17:00	Biermann (Fraunhofer Institute for Laser Technology ILT, Germany), Goettmann (RWTH-Aachen University, Germany), Zettler (EADS Germany), Bambach (RWTH-Aachen University, Germany), Weisheit (Fraunhofer Institute for Laser Technology ILT, Germany): Hybrid Laser-Assisted Incremental Sheet Forming – Improving Formability of Ti- and Mg-based Alloys	Pfleging, Kohler, Danneil, Stüber, Ulrich (Research Center Karlsruhe, Germany): Surface Modification and Functionalization of polymers and thin films on µm-scale
17:00-17:15	Prithwani, Otto (University of Erlangen, Germany), Griffiths, Edwardson, Dearden, Watkins (University of Liverpool, UK): Laser Beam Forming of Aluminium Plates under Application of Moving Mesh and Adapted Heat Source	Piili, Salminen (Lappeenranta University of Technology, Finland), Martinkauppi, Hauta-Kasari (University of Joensuu, Finland): Monitoring of laser cutting of paper materials
17:15-17:30	Wolf, Maerten, Schwede, Kramer, Brandl (PRIMES GmbH, Germany): Temporal Behaviour of Focus Shift with Laser Power	Matiolli, de Rossi, Samad, Freitas, Vieira Jr (Center for Lasers e Applications, Brazil): Femtosecond laser ablation properties of BK7 and Ti:Sapphire
17:30-17:45	Reitemeyer, Seefeld, Vollertsen, Bergmann (Bremer Institut fuer Angewandte Strahltechnik BIAS, Germany): Influences on the laser induced focus shift in high power fiber laser welding	Richmann, Willenborg, Wissenbach (Fraunhofer Institute for Laser Technology ILT, Germany): Laser polishing of fused silica
17:45-18:00	Campbell, Blomster, Pålsson (Optoskand AB, Sweden): Small fiber connector for high-power transmission	Bulkin (RFAC-VNIIEF, Russia), Sysoev, Chadin (FGUP Lavochkin Association, Russia): Laser technology of glass species "Triplex" processing
18:00-18:15	Braunreuther, Zäh (Technical University Munich): Systematic development of safe high performance laser applications	Shoursheini (Alzahra University, Iran), Parvin (Amirkabir University, Iran), Sajjad (Alzahra University, Iran): Dual laser beam induced breakdown spectroscopy of alloy samples using simultaneous CW-CO2 and Q-SW Nd:YAG lasers

	Thursday, 18.6.	
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**
	Process Sensing and Control I **Chair: Fabbro (LALP)**	**Microjoining I** **Chair: Miyamoto (U Osaka)**
8:30-8:45	Doubenskaia, Smurov (Ecole Nationale d'Ingénieurs de Saint-Etienne, France): Monitoring of phase transitions under millisecond pulsed laser irradiation by comprehensive optical diagnostics	Schmidt (blz Bayerisches Laserzentrum GmbH, Germany): Laser Droplet Joining – Systems, Process and Applications (Invited)
8:45-9:00	Aubry (CEA/GERAILP, France), Guiraud (GERAILP, France), Fabbro (LALP/GERAILP, France): Control of Laser Metal Deposition Process for Direct Manufacturing by Coaxial Vision	
9:00-9:15	Chivel (Institute of Physics, Belarus), Smurov (Ecole Nationale d'Ingenieurs, France), Zatiagin (Institute of Physics, Belarus): Advanced optical system for SLS/SLM-process monitoring	Devrient, Frick, Schmidt (blz Bayerisches Laserzentrum GmbH, Germany): Laser transmission welding and laser soldering of flexible flat cables on three dimensional devices by usage of one laser system
9:15-9:30	Jorge (Instituto Tecnológico de Aeronáutica, Brasil), Riva, Rodrigues, Destro (Instituto de Estudos Avançados, Brasil): M^2 beam quality measurement of a single pulse of the Nd:YAG laser	Roesner, Aden, Olowinsky (Fraunhofer Institute for Laser Technology ILT, Germany): Laser transmission welding under special consideration of scattering
9:30-9:45	Fallahi Sichani, Kruth, Duflou (Katholieke Universitieit Leuven, Belgium): Real time monitoring and optimization of laser piercing of thick mild steel plates by means of photodiode sensors	Boglea, Olowinsky, Gillner (Fraunhofer Institute for Laser Technology ILT, Germany): Local and temporal laser beam modulation strategies for the robust and highly efficient welding of polymers
9:45-10:00	Meißner, Wollnack, Emmelmann (Technical University Hamburg-Harburg, Germany): Sensor guidance of robot based Laser Remote Systems for implementing the innovative Welding-on-the-fly Technology	Lorenz, Millar, Hand (Heriot-Watt University, UK): Localised Laser Joining of Micro-Devices for Hermetic Packaging Using a Glass Frit Intermediate Layer
10:00-10:15	Reisgen, Olschok, Longerich (RWTH Aachen University, Germany): Design of a Sensor-Assisted Control of the Weld Filling Degree for the Manufacturing of Segments for Steam Turbine Cooling	Gärtner (FGSW Stuttgart, Germany), Weber (IFSW, University Stuttgart, Germany): Spatter formation and keyhole observation with high speed cameras
10:15-10:45	Coffee Break	
	Process Sensing and Control II **Chair: Kogel-Hollacher (Precitec)**	**Microjoining II** **Chair: Seefeld (BIAS)**
10:45-11:00	Abt (FGSW GmbH, Germany), Nicolosi (Technical University Dresden, Germany), Blug (Fraunhofer Institute for Physical Measurement Techniques IPM, Germany), Dausinger (Dausinger & Giesen GmbH, Germany), Tetzlaff (Technical University Dresden, Germany), Höfler (Fraunhofer Institute for Physical Measurement Techniques IPM, Germany): CNN-Cameras for Closed Loop Control of Laser Welding – Experimental Results and Prospects	Miyamoto (Osaka University, Japan), Cvecek, Bechtold, Schmidt (blz Bayerisches Laserzentrum GmbH, Germany, Okamoto (Okayama University, Japan), Herrmann (LUMERA Laser GmbH, Germany), Kangastupa (Corelase, Finland): Fusion welding technology of glass based on new concept using ultrashort pulse lasers (Invited)
11:00-11:15	Thiel (FGSW GmbH, Germany), Weber (University Stuttgart, Germany): Process Control System for High Speed Welding with Lasers of High Brightness	
11:15-11:30	Norman, Karlsson, Kaplan (Luleå University of Technology, Sweden): Basic analysis of monitoring undercut, blowouts and root sagging during laser beam welding	Markert, Pfleging, Rohde (Forschungszentrum Karlsruhe, Germany): Experimental and Numerical Studies on Laser Micro Welding of Aluminium Alloys
11:30-11:45	Capello, Colombo, Previtali (Politecnico di Milano, Italy): Process monitoring through the optical combiner in fiber laser welding applications	Russek (Rheinische University of Appiled Sciences Cologne, Germany): Laser Welding of Polymers – Superior Process Curve
11:45-12:00	Olsson, Eriksson (Luleå University of Technology, Sweden), Powell (Laser Expertise Ltd, UK), Kaplan (Luleå University of Technology, Sweden): Pulsed laser weld quality monitoring by the statistical analysis of reflected light	Gedicke, Olowinsky, Gillner (Fraunhofer Institute for Laser Technology ILT, Germany): Performance of micro ring welding as an alternative method for laser spot welding
12:00-12:15	Naeem, Richmond (GSI Group): Laser percussion drilling with a low cost, high beam quality and high peak power pulsed Nd: YAG laser	Wilden, Jahn, Kotalik, Neumann (Berlin University of Technology, Germany), Holtz (LASAG AG, Switzerland): Pulsed Nd:YAG laser beam welding: Effect of pulse shape modulation on the weld pool flow and solidification
12:15-12:30	Sibillano, Ancona, Lugarà (CNR-INFM Regional Laboratory Bari, Italy), Miric (Institute of Physics - Belgrade, Serbia): Spectroscopic analysis of plasma optical emission for laser welding process control	Jandaghi , Parvin (Amir Kabir University of Technology, Iran), Torkamany, Sabbaghzadeh (Laser Sciences and Technologies National Laboratory, Iran): Alloying Elements losses of Al and SS during pulsed Nd-Yag laser welding and corresponding modeling

	Thursday, 18.6.		
	High Power Laser Material Processing (Room 2)	**Microprocessing (Room 3)**	**Joint Session (Room 14b)**
	Surface Modification I Chair: Huis in't Veld (U Twente)	**Fundamentals and Modelling of Materials Processing with Lasers Chair: Herman (U Toronto)**	
14:00-14:15	Ocaña, Morales, Porro, Molpeceres, Blasco, Guarneros (Universidad Politécnica de Madrid, Spain): Design Issues of Engineered Residual Stress Fields and Associate Surface Properties Modification by LSP in Al and Ti Alloys	Koch, Leitz, Otto (University of Erlangen-Nuremberg, Germany): Process Analysis of Laser Beam Welding Steel Sheets in Overlap Configuration by Using a 3D Transient Simulation Model	
14:15-14:30	Lima, Riva (Instituto de Estudos Avançados, Brazil), Ladario (Instituto Tecnológico de Aeronáutica, Brazil), Arroyo, Diniz (Universidade de Campinas, Brazil), Viana, Machado (Universidade Federal de Uberlândia, Brazil), Marques, Guerreiro (Thyssen-Krupp Metalúrgica Campo Limpo Ltda, Brazil): Development of laser texturing for enhanced lifetime of cutting and forging tools	Schuster, Dinkelmann (University Stuttgart, Germany): Observation of evaporating surfaces and vapour flows at capillary front geometries	
14:30-14:45	Ostholt, Willenborg, Wissenbach (Fraunhofer Institute for Laser Technology ILT, Germany): Laser polishing of metallic freeform surfaces with non-perpendicular angle of incidence	Leitz, Koch, Otto (University of Erlangen-Nuremberg, Germany): A 3D Transient Numerical Model of Solid, Liquid and Gas Phase during Laser Beam Drilling with Short Pulses	
14:45-15:00	Temmler, Willenborg, Pirch, Wissenbach (Fraunhofer Institute for Laser Technology ILT, Germany): Structuring by remelting	Michalowski, Weber, Graf (University Stuttgart, Germany): Basic study of melt transport and hole-formation during ultrashort pulse laser drilling	
15:00-15:15	Cretteur, Vierstraete, Yin (ArcelorMittal, France), Ehling, Pinard (Noble International Europe, France/Belgium): Development of a laser decoating process for fully functional Al-Si coated press hardened steel laserwelded blank solutions	Ashkenasi (LMTB Laser- and Medical-Technology GmbH Berlin, Germany): Laser induced color centers in glasses: similarities to X-ray excitation and possible implications for optic design	
15:15-15:30	Traub, Hoffmann, Johnigk, Stollenwerk (Fraunhofer Institute for Laser Technology ILT, Germany): Novel Beam Shaping Optics for Laser-Based High Speed Coating Removal	Horn, Haag, Mildner, Englert, Sarpe-Tudoran, Baumert (University Kassel, Germany): High Resolution LIBS of sapphire using femtosecond double pulses	
15:30-15:45	Kirchhoff, Emmelmann (Hamburg University of Technology TUHH, Germany): Virtual Process Planing for Laser Joining Processes	Gusarov, Smurov (Ecole Nationale d'Ingénieurs de Saint-Etienne, France): Thermal model of single track formation at selective laser melting	
15:45-16:15	Coffee Break		
	Surface Modification II Chair: Huis in't Veld (U Twente)	**Media Assisted and Hybrid Processes Chair: Kling (LZH)**	**Fundamentals and Modelling of Materials Processing with Lasers (together with ECLEO) Chair: Graf (IFSW)**
16:15-16:30	Fortunato (University of Bologna, Italy), Orazi (University of Modena-Reggio Emilia, Italy), Campana, Ascari (University of Bologna, Italy), Cuccolini (University of Modena-Reggio Emilia, Italy), Tani (University of Bologna, Italy): Laser hardening of large cylindrical martensitic stainless steel surfaces	Dietrich, Brajdic, Mirau, Klinkmüller, Kelbassa (RWTH Aachen University, Germany): The Influence of process gases on laser drilling	
16:30-16:45	Soriano, Leunda, Lambarri, Sanz (Tekniker, Spain): Comparison of laser surface hardening of austempered ductile iron and low-alloy steels	O'Connor, Sedao, Conneely (National University of Ireland, Ireland): Understanding enhanced laser micro-machining of silicon in halogenated gas ambients	Katayama, Oiwa, Matsumoto, Mizutani, Kawahito (Osaka University, Japan): Fundamentals of Fiber Laser Remote Welding and Deep Penetration Welding (Invited)
16:45-17:00	Crossa Archiopoli, Mingolo, Martínez (Universidad de Buenos Aires, Argentina): Use of photothermal deflection signal as a fast correlation to nano-hardness and phase characterization	Neuenschwander, Bucher, Schwaller, Nussbaum, Joss, Muralt, Schütz (Bern University of Applied Sciences, Switzerland): Direct Generation of Conducting Microstructures by Laser Induced Plasma Assisted Ablation with ps - Laserpulses	
17:00-17:15	Pityana (CSIR National Laser Centre, South Africa): Hardfacing of aluminium alloys by means of Metal Matrix Composites produced by laser surface alloying	Dehghanpour (Amir Kabir University of Technology, Iran): The investigation of micro-structuring on glass by ArF eximer laser in SF6 atmosphere	Wollenhaupt, Englert, Sarpe-Tudoran, Baumert (University Kassel, Germany): Principles of femtosecond pulse tailoring for advanced material processing (Invited)
17:15-17:30	Dutta Majumdar, Mordike, Manna (Indian Institute of Technology, India): Laser Surface Engineering of Mg Alloys		
17:30-17:45			Rode (Australian National University, Australia): Ultrafast laser induced microexplosion: A new strategy to synthesise super-dense nanomaterials (Invited)
17:45-18:00			

Keynote-Session

“Advances in Laser Material Processing”

Monday, 11:15h - 11:45h

Laser Cutting Today and Tomorrow

F. Kilian

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Abstract

CO_2-Lasers are the most widely used sheet metal cutting lasers due to their robustness and the range of sheet metal thicknesses. However, solid state lasers and especially disc lasers have undergone a steep development in the last few years drawing attention to their utilization not only in laser welding but also laser cutting machines. This article is intended to give answers on how solid state lasers will influence the sheet metal cutting business in the near future. Moreover, the advantages and disadvantages as well as the commercially viable fields of laser cutting applications will be shown for different laser types.

Monday, 11:45h - 12:15h

Laser-Based Direct-Write Methods for Nanomanufacturing

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Abstract

The ability to directly print patterns on size scales below 100 nm is important for many applications where the production or repair of high resolution and density features are important. Laser-based direct-write methods have the benefit of quickly and easily being able to modify and create structures on existing devices, but throughput is low and feature sizes are conventionally limited by diffraction. In this presentation, we review methods to overcome these limits and introduce a new method of probe-based near-field nanopatterning with the ability to parallelize the direct-write process. A CW laser is used to optically position arrays of dispersed microspheres near a substrate using a 2-d Bessel beam optical trap while a second, pulsed laser is directed through the bead and used to modify the surface below the microsphere, taking advantage of the near-field enhancement. Issues of feature size control, positional accuracy and scaling for high-throughput and large area nanomanufacturing will be discussed.

Monday, 12:15h - 12:45h

Precise surface and bulk laser structuring of initially transparent materials

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Abstract

It will be shown that, under proper short pulsed laser irradiation conditions, it is possible to fabricate fine surface and bulk structures in initially transparent samples as a result of material phase transformations which can be accompanied by chemical treatment and ablation. This approach will be demonstrated for laser processing of diamond materials: monocrystalline diamond stones, nano and polycrystalline diamond plates and films, diamond-like coatings. In such cases a key-point is laser induced graphitization of diamond. Ti:Al_2O_3, Nd:YAG and KrF lasers with femto, pico, nano and microsecond pulse duration were used in the experiments. Laser irration fluence was in the range 1-1000 J/cm^2.

1. Surface structuring

The dependence of laser ablation rate and thickness of graphitized layer on pulse duration was studied. New regimes of diamond ablation by its laser induced surface oxidation and activation in atmospheric air with rates as low as 10^{-2}-10^{-4} nm/pulse were found. Reasonable quality and highest ablation rates up to 10 µm/pulse were observed for microsecond

pulses. Different types of laser produced surface micro and nanostructures (grooves, diffractive optical elements, etc.) will be presented.

2. Bulk structuring

Novel technique for bulk structuring of diamond by high intensity tightly focused ultra-short laser pulses was proposed and experimentally realized. It requires formation of initial small graphitized volume either on the surface or inside a diamond sample. It serves as an ignition site for development in the lenz direction of graphitization waves by subsequent laser pulses. The velocity of such waves was in the range 2-600 nm/pulse depending on the laser pulse duration (0,1-5 ps). Direct correlation between wave velocity and laser fluence (1-50 J/cm^2) was established. Influence of laser wavelength was also studied.

Formation of graphitic channels with diameter from submicron up to tens of microns (spot size 3.5µm) and aspect ratio as high as 1000 was achieved by moving the focusing lenz in respect to the sample surface. It was also demonstrated that graphitic material can be selectively etched away and by this technique hollow channels could be produced inside the body of a diamond sample.

High Power Laser Material Processing

Monday, 14:00h - 14:30h

Laser Welding in Automotive Manufacturing

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Abstract

The broad spectrum of laser welding applications will be presented by using examples from LBBZ. Special applications as well as regular applications in the range from single unit production to large series production are presented.
Automotive applications such as camshaft welding and gear welding are presented with a focus on quality control, the advantages provided by laser welding and how to avoid common mistakes when planning a laser based production line.
A short review about the single unit application is provided using examples in the field of laser cladding and conventional laser welding.
An example will be presented for the development of a laser welding head with integrated filler wire supply and the application of this head in the production of flex-gear elements.

Monday, 14:30h - 14:45h

Study of Microstructure and Properties on Laser Welded Joints of High Strength Steel Used in Cars

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Abstract

Reducing car's weight has become an important goal for automobile industry in China. Laser welding of automotive high-strength steel play a significant role in reducing car's weight. Experiments of CO_2 high power laser welding of 800MPa grade complex phase steels with a thickness of 2.8mm for automobile plate are performed under different welding speeds and shield gas flows by using a 15 kW CO_2 laser. The reduction of the welding line energy resulting from the increase of the welding speed changes the solidification conditions of the weld pool, which results in different microstructure and mechanical properties. Both optical and TEM microphotoes demonstrate that the welded joint consists mainly of small-sized and uniformly distributed martensite. The effect of welding line energy on joints microstructures and mechnaical properties are analyzed. The test results show that all the mechanical properties of welds can meet the technical requirements for automobile Industry.

Monday, 14:45h - 15:00h

Laser absorption in CO2 laser welding of medium, high and ultra high strength steels

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Abstract

Laser welding of carbon steels are quite common. The absorption of steel for a wavelength of CO2 laser is 12 % at normal room temperature. The previous studies have shown absorption increases rapidly once keyholes are formed. In this paper three different grades of carbon steels of medium, high and ultra high strengths have been CO2 laser welded. Two different approaches have been adopted to measure their absorption. One method is by using calorimeter in which the estimation of absorption of laser energy is made by water temperature rise and in the another method the absorption is calculated from weld cross section using thermal transformation during heating and cooling of the weld. The paper evaluates the measured absorption in terms of process parameters in both these methods.

Monday, 15:00h - 15:15h

Frequency-modulated zero-gap laser beam welding of zinc-coated steel sheets in an overlap joint configuration

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Abstract

Stable processes at welding of zinc-coated steel sheets with high-brightness lasers are an important demand of today's industry, especially regarding the automotive sector. As a precondition, the welding process and its behaviour has to be understood. This paper summarizes the most important experimental and analytical results of the BMBF research project *FM-LaB*, dealing with the process analysis and control of Yb:YAG laser welding of zinc-coated steel sheets. The project reveals new insights into the process behaviour including keyhole oscillations and defect mechanisms as well as results concerning the possibility to have an influence on the welding process. Combined photodiode and high-speed camera observations of the workpiece surface enable detailed analysis of the real weld pool and keyhole geometry and its optical emissions in the time- and frequency-domain. This leads to a new process model for zero-gap laser beam welding of coated steel sheets in an overlap joint configuration.

Monday, 15:15h - 15:30h

Humping in single mode laser beam welding of different materials

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Abstract

In laser beam welding processes, a serious challenge is to overcome limitations in processing speed set by the humping effect. This effect is characterized by melt pool instabilities leading to periodic droplet formation on the seam surface. Experimental results showed that in welding with single-mode fiber lasers at higher laser power the welding speed from which humping will occur decreases with increasing power.
Using a single-mode fiber laser with a beam power of 1 kW and a beam quality of $M^2 < 1.05$, an experimental study of the humping effect was conducted for bead-on-plate welding of various steels, aluminum and titanium alloys. To improve the understanding of this phenomenon, welds showing uniform periodical humping have been evaluated in view of their geometrical characteristics such as humping distance, width of the humps and humping frequency, including an evaluation of their statistical spread.
The detailed evaluation of the welds showed that the geometrical characteristics of the humping beads are closely associated with process parameters like laser power, welding speed, beam quality focal length, focal position and inclination angle of the beam and the resulting weld geometry. These observations are evaluated in view of the potential effect of the individual parameters for shifting the humping limit to higher welding speeds.

Monday, 15:30h - 15:45h

New Applications for Welding with Diode Lasers

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Abstract

Battery casings, bellows or stainless steel sinks with highquality requirements for the visible surfaces have long been welded with diode lasers with a heat conduction welding process. Recent developments in diode lasers now allow their successful use in keyhole welding tasks, historically the domain of conventional solid state lasers. The diode laser achieves a typical welding spot of 0.6 mm for output power levels well into the multikW range. It can therefore replace lamppumped solid state lasers in most applications, as the welding results are directly transferable when the laser power and the focus are identical. Therefore, diode lasers are bound to further increase their market share for demanding welding tasks, i.e. in aluminum and galvanized sheet metal.

Monday, 16:15h - 16:30h

High-power Yb-fibre laser welding of heavy-section tube-to-tubesheet assemblies

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Abstract

Mangiarotti S.p.A., a leading pressure vessel, reactor and heat exchanger manufacturer, have developed, with the help of TWI Ltd, a unique fully-integrated laser processing cell for the welding of heavy-section tube-to-tubesheet components. Laser welding was identified as a high-productivity alternative to the conventionally applied TIG welding process, offering speeds at least an order of magnitude higher. The welding cell is fully autonomous, can be moved around the workshop, and is capable of welding heat exchangers typically comprising up to 5000 tubes and tubesheet diameters in excess of 4.5m. An 8kW Yb-fibre laser is manipulated using a 6-axis shelf-mounted articulated robot arm, and a machine vision operated slide to ensure accurate tube location and joint alignment. Filler wire addition and scanning optics have been implemented to compensate for joint gap variations, with real-time (laser) process monitoring to assist in assuring a weld quality in accordance with relevant product standards (e.g. ASME).

Monday, 16:30h - 16:45h

Optimization for Laser Welding Fillet Joint Based On Response Surface Method

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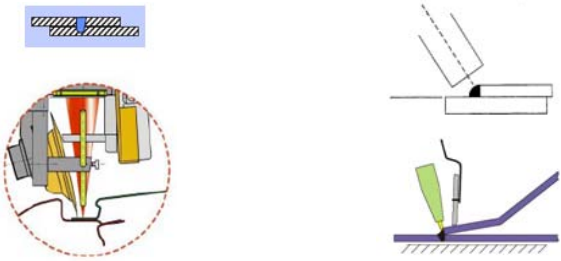
Abstract

Roof to body side welding is one of the most important assembly processes in the manufacturing of body in white (BIW). Traditional process uses spot welding which has some disadvantages such as the appearance is not so smooth and the seal condition is not so good. As laser applications are being used more and more in industry, it provides an effective way for the welding of roof to body side.

The laser welding of roof-to-body side is general divided into two kinds. The first is called the lap joint, as is shown in figure 1-a. It uses a pressure wheel to push the two work pieces together. Then the contact surface is melted by laser to form a joint. The other kind is called the fillet joint, as is shown in figure 1-b. The pressure wheel make the two pieces contact with a certain degree (about 5°). Then the laser melted the contact point to form a joint. Compared to the lap joint, fillet joint does not need the special complex fixture so it can save production cost greatly.



a: lap joint b: fillet joint

Figure 1: Two kinds of laser welding roof-to-body side

Although fillet joint have many advantages for the roof-to-body side welding, the weld quality is sensitive to the process parameters such as laser power, laser speed, laser angle and offset distance. This paper takes the joint of 0.7mm low carbon steel as an example, uniform experimental design method and response surface method (RSM) are used to study the influence of welding process parameters on the joint quality. Quadratic regress models of weld size and production efficiency on welding parameters are founded. The acceptable weld size is defined by GM15425 standard (figure 2). Considering the welding quality and production efficiency, the optimum welding parameters are conclude to ensure weld quality, save energy and improve production efficiency.

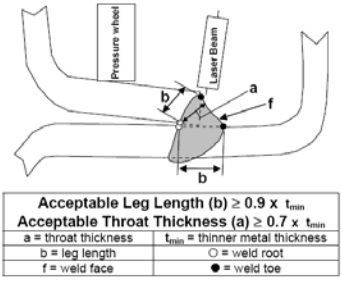
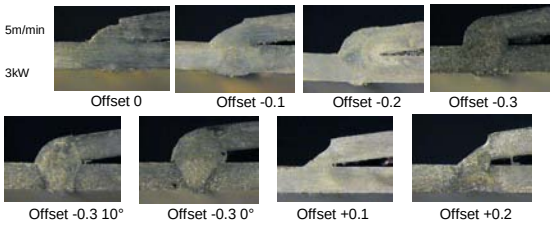
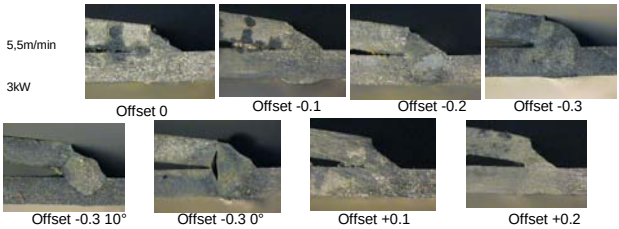


Figure 2: Accept. weld size for fillet joint according GM15425

Some of the experimental results are shown as follows:





Monday, 16:45h - 17:00h

Application of Laser-Assisted-Metal and-Plastic Joining for Dissimilar Metal Welding

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Abstract

In recent years, transportation machines such as automobiles and aircrafts need to be lightened from the environmental viewpoint. In order to achieve this, dissimilar metals joining utilizing light weight metals is promising. However, in direct joining of dissimilar metals such as aluminium alloy and steel, brittle intermetallic compounds are formed between them and dissimilar metal corrosion or bimetal (electrical) corrosion should occur. In this research, therefore, in order to solve the above problems, LAMP (Laser Assisted Metal and Plastic) joining method, which needs neither parts nor tools such as adhesive and rivets, was applied to join dissimilar metal plates sandwiching a plastic plate as insulator. It was confirmed that the method could produce very strong joints between plastics and aluminium alloy or stainless steel. The process of LAMP joining for dissimilar metals of steel and aluminium and the effect of a plastic sheet between metals will be presented.

Monday, 17:00h - 17:15h

Local Effects of Bead on Plate and Overlap Welding Seams to increase Strength and Rigidity of Sheet Metal Constructions

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Abstract

Local physical and geometrical effects which have only been observed so far as side effects in laser welding processes may also be used purposefully, in order to achieve locally adapted mechanical properties and to improve load-transferring components significantly. The influences of laser-based welding seams on structure rigidity for simplified sample geometries are currently investigated. As shown in previous papers a defined local increase in strength and rigidity by linear and geometrically adapted bead-on-plate weldings can be achieved.
This paper points out the influence of geometry on rigidity and strength behaviour of bead-on-plate and overlap welding seams in comparison to specimen without welding seams by using 3-point bending and tensile test. The results of the mechanical investigations will be verified by numerical simulations. In the first step finite element analysis are done, which describe the mechanical characteristic values versus the material and process parameters. In the second step the simulations of the flexible deformation behaviour under mechanical load are carried out. The simultaneous practical analysis includes extensive metallographic hardness measurements and static load tests.

Monday, 17:15h - 17:30h

Distortion during laser beam welding in consideration of the gap width

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Abstract

To ensure the high quality of laser beam welded seams, the welding process is nowadays analyzed in numerically calculations and validated in experimental investigations. Especially finite element based models are used to predict the released residual stresses and to understand the distortion mechanisms during the process. The focus of previous investigations was limited on external thermal and mechanical boundary conditions, but in general the complex influence of the welding gap was neglected. This paper deals with the effects of different welding gaps on the weld pool at butt joints to characterize the influence of the thermal bridge within the welding gap. Furthermore, the modelling of the mechanical behaviour of the gap was focused by using the FEM based Software SYSWELD. The investigations on a basic geometry are a precondition to model gaps in more complex geometries joint (e.g. T-joints and shaft-hub connections) in order to investigate the effect of the gap on the welding distortion of the whole part.

Monday, 17:30h - 17:45h

Autogenous laser beam welding of an aluminium alloy

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Abstract

In this study the weldability of AA6013 aluminium alloy sheet was examined in orderto obtain the optimal welding conditions using a high-power fiber laser (2 kW). Two types of autogenous joints were investigated: bead-on-plate and T-joints. In a firstcase, welds were made to get the limits concerning welding speed and power laser considering the material thickness. Within the process optimization, in all T-joint weldings the emphasis was placed on the sensitivity of the penetration depth with the change in the angle of beam laser relative to the workpiece surface. The results had shown the possibility of controlling the process parameters to obtain relative weld stability with no severe porosity. Also, although the hot cracking phenomenon is frequently observed in laser welding of these high strength aluminium alloys, no crack was verified in the cross sections of the welds.

Monday, 17:45h - 18:00h

Influence of CO_2 in the Ar Process-Gas on the Heat-Conduction Mode Laser Beam Welding Process with Nd:YAG and Diode Lasers

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Abstract

Ar+CO2 mixtures are used as process-gases to optimize welding results. However, the mode of action of the gas mixture is not yet well-understood and practical applications of active gas components strongly depend on empirical experiences. This work identifies the effects of Ar+CO2 mixtures on the welding process. The influence of the variation of CO2 in the Ar process-gas on the melt-pool temperature, the alloy, the seam geometry and the absorption-coefficient is experimentally analysed. A Nd:YAG and a diode laser system have been used for the experiments to determine the dependence of the process-gas / melt-pool interaction on the laser wavelength and the beam profile.
Two significant effects have been observed. First of all a higher rate of CO2 can bring more energy into the welding seam. Secondly the cross section profile can be altered. A simulation model is presented which explains details of the mode of action and can support the choice of adapted Ar+CO2 mixtures for laser applications.

Monday, 18:00h - 18:15h

Absolute Spot Size Effect on Penetration Depth in Laser Welding

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Abstract

In laser welding there are three primary material interaction parameters, intensity, interaction time and spot size. Studies of the effect of spot size are often not carried out in a meaningful way. In particular if the spot size is changed with a constant laser power and travel speed then the intensity and interaction time are also changed. The changes due to the real effect of spot size are masked by the more significant changes due to the rapid changes in other material interaction parameters. This has led to a strong belief that penetration depth increases with decreasing the spot size. In this work the effect of the spot size on penetration depth has been studied whilst keeping the intensity and interaction time constant. The results show that the penetration depth increases with increasing spot size. The rate of increase varies with different intensities and interaction times. The reason for this dependence is discussed in this paper. The results have important implications because other properties, such as weld quality, also often increase with increasing spot size.

Tuesday, 8:30h -9:00h

Industrial experience in using direct metal deposition for repair: is there a perspective for manufacturing?

Th. Haubold

Rolls-Royce Deutschland Ltd. & Co. KG, Germany

Abstract

Tuesday, 9.00h - 9:15h

Laser assisted Direct Metal Deposition technology: manufacturing of macro-parts and composite coatings

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Abstract

Direct Metal Deposition (DMD) is 3D material deposition process arising from laser cladding technology with co-axial powder injection. The objective of the present study is to demonstrate the possibility to manufacture large-sized near-net-shape components and to deposit functionally graded coatings in one-step process. DMD-deposited coatings from Ti (Ti6Al4V), Fe (17-4PH, Inox AISI 431), Co (Stellite 6) -based alloys and TiC compound are tested. Laser cladding parameters for high-efficiency rapid manufacturing of parts are determined. Relationships between the employed DMD manufacturing strategies and geometrical and mechanical properties of the built objects are discussed. Composite coatings from Ti6Al4V alloy reinforced by TiC particles are deposited which demonstrate improved microhardness and wear resistance.

Tuesday, 9:15h - 9:30h

Development of complex cooling systems for laser freeform fabricated molds by using FEM (finite element method) simulation

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Abstract

The laser freeform fabrication processes offer new options for product design and allow the production of complex shapes without a direct cost increase. The possibility to create interior structures is used to generate molds with efficient freeform cooling systems which are adapted to the three-dimensional mold surface. While the conventional design rules of mold cooling are based on mechanical drilling, the new freedom of design and the different material and surface properties of laser generated molds enhance the necessity for new design rules. With FEM (finite element method) software the influence of different process and design parameters can be analysed. The fatique strength analysis sets mechanical limitations for the cooling channel system. Furthermore the moldflow analysis can identify the thermal requirements of the molding process for an efficient and uniform heat removal. The simulation results lead to the development of rules for the optimum mold cooling design with respect to the properties and limitations of laser freeform fabrication.

Tuesday, 9:45h - 10:00h

Study of residual stresses generated in laser cladding by diffraction of synchrotron radiation

J.M. Amado[1], A. Suárez[1], M.J. Tobar[1], A. Yáñez[1], E. Fraga[2], M. J. Peel [2]
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[2] European Synchrotron Radiation Facility, 6 rue J Horowitz, 38042 Grenoble, France.

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Abstract

The high energy inputs and cooling rates associated to coating procedures based on laser cladding may result in non-negligible mechanical deformations and residual stresses of the processed parts. Residual strains measurements in test coupons made of Co-based alloy (Stellite) deposited on stainless and tool steels were carried out by the method of diffraction of synchrotron radiation at the European Synchrotron Research Facility (ESRF). Internal stresses profiles throughout the width and depth of the test samples were obtained and will be analyzed in conjunction with model predictions for different sets of processing conditions. Such model is based on a 3D FEM analysis which will allow to obtain a comprehensive view of the thermo-mechanical phenomena and better understand the effect of the different choices of processing parameters on the resulting deformation and stress fields.

Tuesday, 10:00h - 10:15h

Calculation of stresses in two- and three-dimensional structures generated by induction assisted laser cladding

F. Brückner[1], D. Lepski[1], E. Beyer[1, 2]

[1] Fraunhofer Institute for Material and Beam Technology, IWS Dresden, Winterbergstraße 28, Dresden, D-01277, Germany
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Abstract

Laser cladding is successfully applied not only to the generation of wear and corrosion resistive coatings but also to the built-up of three-dimensional structures, e.g. in the repair of tools or turbine blades or in rapid prototyping. Such structures consist of a lot of single beads. The different thermal histories of the substrate and the various beads may lead to the development of high thermal stresses and sometimes even to the formation of cracks. These stresses depend on the properties of the materials involved and on the details of heat impact but also on the pattern of beads forming the structure. Inductive pre-heating appears as an appropriate tool to reduce the danger of cracking. Hence the development of thermal stresses and the thermal and mechanical interaction of overlapping beads within two- and three-dimensional structures during the induction-assisted laser cladding are studied with the aim to minimize dangerous tensile stresses.

Tuesday, 10:45h - 11:00h

Multi-graded layers by laser cladding for wear and corrosion protection of die-casting moulds

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Abstract

Die casting moulds are exposed to severe wear and corrosion. A major demand of the die casting industry is to increase lifetime of the moulds to save costs. The choice of the material is one key factor to meet this demand. However, commonly used tool steels are limited regarding the required properties, which often need to combine opposed properties like ductility and wear resistance. Laser cladding represents an established process to increase wear and corrosion protection locally and it ofters the possibility to combine properties by multi-graded layers. The paper will show the process layout to achieve smooth graded layers. A method to build up 3D graded layers for generating complete tool inserts will also be discussed. Furthermore, results on graded layers based on Fe-, Ni- and Co-alloys will be presented regarding microstructure and hardness. Finally an outlook will be given on further steps to test the graded layers.

Tuesday, 11:00h - 11:15h

Crack Repair of Austenitic Stainless Steel by Laser Cladding

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Abstract

Laser cladding crack repair of austenitic stainless steel vessels subjected to internal water pressure was evaluated. The purpose of this investigation was to develop process parameters for in-situ repair of components or vessels under pressures up to 2 bar with through wall cracks. Successful crack sealing of 4.5 mm and 6.0 mm platethickness @ 1.5 bar water pressure was achieved with hammer peening prior to lasercladding. Positional cladding trials were also performed for 4 mm bead width at various cladding positions. Calculated powder efficiencies ranged between 87% and 93%.

Tuesday, 11:15h - 11:30h

Structure of tungsten carbide reinforced NiCr layers obtained by laser cladding

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Abstract

The development of hardfacing coatings has become technologically significant in many industries where wear can cause severe damage on different components and often resulting in considerable economic costs. A common approach is the production of metal matrix composites (MMC) layers, consisting of a mixture of hard ceramic phases immersed in a ductile metal matrix. In this work, a study on the development of NiCr-WC hardfacing layers by means of laser cladding is presented. As for the reinforcement hard phase, different WC powders are available which differ in phase composition and mechanical properties in virtue of their fabrication process. Spheroidal fused tungsten carbides (Spherotene®) have been used in this study in virtue of its exceptional hardness which may range from 2500 HV up to 3300 HV. The microstructure of the layers will be analyzed and discussed in relation with the laser cladding parameters used in the process.

Tuesday, 11:30h - 11:45h

Synthesis of WC-12Co laser cladding

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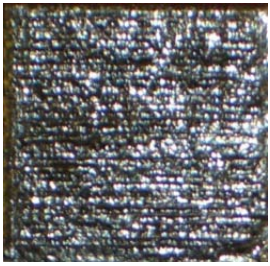
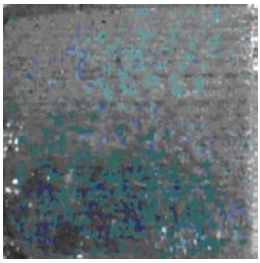
Abstract

In the recent past years the development in surface modification against erosion /corrosion have undertaken a new dynamic turn in laser cladding of hard materials. The unrelenting demand of low erosion, high wear resistance and increased hardness value with low thermal effects have forced the manufacturers to adopt /develop innovative techniques which could meet this demand. This led to the selective use of laser cladding of carbides specially WC-12Co onto various base materials. This paper demonstrates the feasibility of generating such a clad coating by using the pulsed Nd-YAG laser beam irradiation of pre-placed WC-12Co powder bed on the SS304 base material. The microstructure study of the clad was carried out using x-rays diffraction (XRD), optical and scanning electron microscope (SEM). The result show that the hard metal carbide (WC) gets dissolved in the molten liquid metal (12Co), acting as binder thus producing the desired matrix (Figure). In the post processing, a precision grinder was employed to smoothen the top surface. Microhardness mapping was performed at various points across the surface. The results show the average microhardness value of 1910 HV.

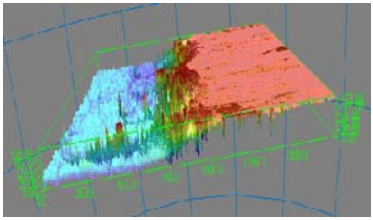
Part of this work was done at TechnoCoat Co., Ltd.



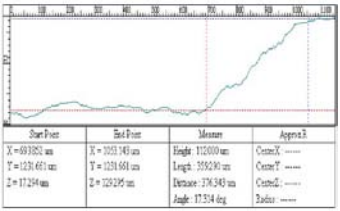
Laser clad surface



After surface grinding



3D surface profiling



t = 12µm, µHardness = 1910 HV

Top flat is the clad surface after grinding

Clad thickness profiling and **µ**Hardness

Tuesday, 11:45h - 12:00h

Parametric study of fibre laser micro-cladding of Co-based alloy on stainless steel

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Abstract

Lateral powder injection laser micro-cladding has been applied to produce Co-based alloy clad strips with geometrical characteristics in the micrometer range (i.e. clad width: 45 µm and clad height 15 µm). Main features of laser micro-cladding processing are the ability to reduce the thermal load applied to the substrate but keeping the good mechanical properties of the coating material.
A new experimental set-up based on the use of a single mode fibre laser and a powder micro-feeder was used to produce the micro-coatings. The study of the influence of several processing parameters on the geometric features of the clad strips was carried out. Moreover, mechanical properties measurements of the micro-clad strips allow affirming that these micro-cladding coatings maintain the mechanical characteristics typical from this hardfacing alloy.

Reparation of defective microparts, surface functionalisation of small areas, or rapid fabrication of prototypes are areas of application of this rapid one step microcoating technique.

Tuesday, 12:00h - 12:15h

Modeling of 3D gas dynamics and particle transport in a multi-jet DMD nozzle

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Abstract

3D numerical simulation of the carrier gas and particle flow in a coaxial nozzle of TRUMPF-DMD-505 is carried out. Argon serving as carrier and shielding gas is supplied into an axial and two annular channels of the nozzle. Particle size distribution varies in the range 60-100 µm. In the present simulation, constant parameters are particle flow rate (60 g/min), carrier gas flow rate in the axial (18 l/min) and in the annular channels (20 l/min). Shielding gas flow rate is varied from 5 to 20 l/min. Two-phase jet flowing into the substrate and particle focusing mechanism are analyzed. Radial distribution of the particle mass flow over the substrate versus shielding gas flow rate is calculated. The developed software is used to analyze peculiarities of the particle heating and melting by the laser beam. This way, trajectories and thermal history are calculated for particles of different size.

Tuesday, 14:00h - 14:15h

Effect of Process Parameters on Joint Properties in Laser MIG Hybrid Welding of Aluminium to Steel

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Abstract

Laser MIG hybrid welding was recently suggested as a feasible process for joining of aluminium to steel for both structural as well as tailored blank applications. To promote an understanding of the effect of process parameters on joint properties, laser MIG hybrid welding experiments were performed to join aluminium alloy AA 6016 to DC05 zinc-coated mild steel sheets in the thickness range of 1 mm in butt joint configuration. Among the process parameters varied were laser power, MIG arc power, wire feed rate, welding speed and arc position relative to the abutting edges.
By metallographic cross sections and tensile tests, the effect of these process parameters on joint properties such as wetting length, intermetallic phase layer thickness and tensile strength could be elucidated. Based on these results, a process parameter envelope resulting in adequate and reproducible joint properties (sound weld bead, sufficient and regular wetting, thin intermetallic phase layer, tensile strength exceeding 180 MPa) was established.

Tuesday, 14:15h - 14:30h

Orbital Laser-Hybrid Welding of Pipelines Using a 20 kW Fibre Laser

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Abstract

The new brilliant high-power lasers such as disc laser and fibre laser open new fields of applications for laser-hybrid welding, e.g. power generation, ship building and pipeline constructions. For the use of laser-hybrid welding in pipe laying insensitivity towards tolerances and the possibility of orbital welding are very important factors in additions to the weld seam quality.

The paper will focus on the welding experiments which have been carried out with orbital welding machine on 16 mm thick pipe rings (914 mm pipe diameter) of X65. Influence of particular welding parameters such as welding speed, welding wire feed speed, welding current and arc length on the appearance of the weld in the different welding positions is discussed.

The paper will give an overview of special features of material behavior, e.g. outer appearance, hot cracking.

Future aspects will be discussed which have to be faced in order to make it a safe and reliable welding process.

Tuesday, 14:30h - 14:45h

Process combination of laser welding and induction hardening

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Abstract

Usually parts made of heat treatable steel have to be preheated before welding to avoid hardening and cold cracks. In order to save production time and simplify production these two process steps were combined to one. While a sample of heat treatable steel is welded with a Nd:YAG Laser it is heated inductively. The energy of induction hardening is used for preheating the specimen before welding. The combined process head consists of an integrated inductor, a laser processing head and a quenching shower. The Laser welding process is carried out while the work piece is heated to austenite temperature (approximately 900°C). After quenching the work piece the heat affected zone and welded seam do not show cold cracks. This part of the work piece shows the same material properties and can be used as a functioning surface.

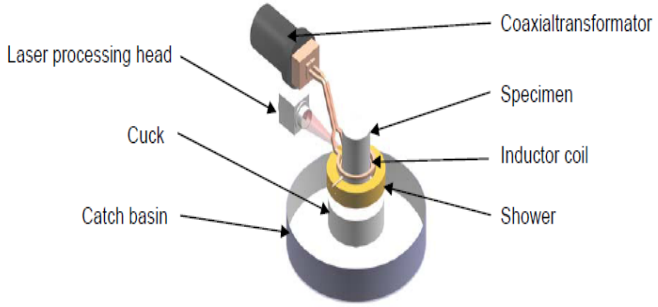

Figure 1: Schematic experimental setup with combined process head

Tuesday, 14:45h - 15:00h

Brazing of ceramic - steel joints by a laser process

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Abstract

A laser brazing process has been developed for joining alumina and a silicon carbide to metal carriers. With the help of a CO_2 - laser cylindrical ceramic steel compounds were joined. The brazing of oxide ceramics is performed using a commercially available active braze filler. However, AgCuTi - braze fillers exhibited only a poor wetting on silicon carbide. Therefore a SngTi brazing alloy has been developed which showed a good wettability on SiC.

Accompaning the microscopic investigations of polished microsections the shear strength of brazed compounds was determined in order to evaluate and compare the quality of the different ceramic - steel joints. Within the framework of the mechanical evaluation different surface structures are applied on the SiC pellets using a Nd:Yag laser and their effect on the shear strength was studied. Finally the brazing process was successfully transferred to the application geometry of a clutch system.

Tuesday, 15:00h - 15:15h

Development of a Plasma-Laser Brazing Process for Fluxless Joining of Aluminium to Steel

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Abstract

Due to the demand for light-weight constructions to reduce fuel consumption especially in the aerospace and automotive industries, the joining of dissimilar materials has been paid much attention in recent years. In this paper, the development of a coaxial laser-plasma-hybrid welding process for fluxless joining of aluminium-steel tailored hybrid blanks in overlap configuration is reported. The overlap joints (EN-AW 6016, 2mm + DC 05+Z, 0.8 mm) were carried out using AlSi12 filler wire (to improve wetting length and prevent hot-cracking) and subjected to metallographic analysis and mechanical testing (tensile strength and hardness). It was established that the heat input has a significant influence on wetting length and wetting angle, intermetallic phase seam thickness and tensile strength. This result, together with observations on the optimum position of the filler wire, was the basis for establishing a process parameter envelope, allowing up to 3 m/min joining speed.

Tuesday, 15:15h - 15:30h

Laser beam welding with hypereutectic AlSi filler material

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BIAS - Bremer Institut für angewandte Strahltechnik GmbH, Bremen, 28359, Germany

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Abstract

For laser welding of AlMgSi (6xxx) alloys filler alloys are commonly required to reduce the hot cracking susceptibility by rising the silicon content in the weld pool to a non critical value. For narrow weld pools obtained e.g. in welding with high brightness lasers, this is often difficult to achieve. The use of hypereutectic Al-Si filler materials might be helpful; however these fillers are not readily available in the form of thin wire.

In the present work, hypereutectic Al-Si filler alloys with up to 30% Si and additional grain refiners were produced by spray forming. These were processed into strip material, and the effect on hot cracking susceptibility of the weld metal was demonstrated using the delta-test.

Furthermore, filler wire was produced from spray formed AlSi18 material with additional Ti-B grain refiner. The 1.2 mm wire was continuously fed during laser welding with a thin disc laser. A strong gradient of the silicon concentration was observed between the top and the root regions of the weld, indicating a lack of vertical transport of alloying elements from the filler within the melt pool. Thus an alternating magnetic field was thus applied to stir the melt, and it was demonstrated that a supercritical silicon concentration and a homogeneous distribution were achieved in all regions of the melt pool.

Tuesday, 15:30h - 15:45h

Analysis and modelling of hybrid laser Nd:Yag – MIG/MAG welding process

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Abstract

Hybrid laser-MIG/MAG arc welding show decisive advantages compared to laser welding or arc welding used separately when improved productivity is required. For an efficient use of this process, it is necessary to precisely understand the complex physical phenomena that govern this welding technique. This understanding is also necessary if one wants to elaborate adequate simulations of this process. This paper presents the analysis of the main physical processes controlling this hybrid welding and the numerical approach we used for modelling it: the coupling of usual conservative equations is solved by using the COMSOL Multiphysics software in order to model the thermal and hydrodynamic field of the resulting melt pool whose 3-D free surface is obtained. The influence of various operating parameters, such as laser power and welding speed, on the melt pool 3-D shape and its temperature and velocity field, is discussed through several experimental results and corresponding simulations.

Session: Final BMBF project presentation – Fülas – Flexible laser-guided arc welding of high-strength steel and light metals

Tuesday, 16:15h - 16:45h

Development of the LGS-GMA welding process

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Abstract

The trend in production industry to lightweight construction using high strength steels calls for faster, yet stable production processes. To realise these requirements, we have developed a gas metal arc welding process using laser radiation for guidance and stabilisation (LGS- GMA welding). First, the relevant physical effects for the guidance and stabilisation of the electric arc were obtained. To verify the effects TIG-welds by using different laser sources on bead on plate were carried out. Based on the TIG experiences two laser sources were chosen for the first LGS-GMA welding processes. With a laser source optimized for the optogalvanic effect higher welding speed and a more stable process compared to the electric arc process alone for square butt and overlap seams were possible. The paper presents the experimental results of the LGS-GMA welding process. The guidance of the electrical arc with low power laser radiation is demonstrated.

Tuesday, 16:45h - 17:15h

Requirements for industrial applications for the innovative LGS-GMA welding process

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Abstract

The new production process "laser guided and stabilized GMA welding" (LGS-GMA welding) is based on a gas metal arc welding process in which the electrical arc is stabilized by a laser beam of low power output also on high welding speed with the result of a high class quality of the joint.

The laser beam used for guidance enables a higher feed rate during the welding process. The lower energy input per unit length enables the processing of high strength steels and also a development with less distortion of steel and aluminum.

The lecture presents the results of the experiments on the process. One important result is the device-related development of the new process which combines the GMA welding torch and a laser optic. The lecture illustrates the benefits and the applications possible by the new welding process.

FÜLAS Presentation

Tuesday, 17:15h - 17:45h

Gas metal arc welding combined with a low powered laser beam for joining high strength steels

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Abstract

Aim of the lecture is to create a research base for increasing efficiency and including environmental aspects by the design of lightweight structures in steel constructions, especially the automotive industry.

The project focused the improvement of the welding process for high strength steels by integrating an additional low powered laser beam treatment step into the welding process. In this case, metal sheets within a thickness range of < 1,0mm have been welded successfully using the gas metal arc welding technology.

The main criteria for evaluating the improvement of the welding process were the mechanical properties. Results of this lecture are metallographic characterisations, hardness profiles across the seam, and tensile strength. Another criteria is an increased process speed.

These results enable the integration of the laser guided welding process into new fields of manufacturing high strength steels and thus to take the next steps towards efficient light weight constructions.

Tuesday, 17:45h - 18:15h

Wöhler-tests as a method to compare LGS-GMA welding process against conventional welding

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Abstract
The trend in production industry to lightweight construction using high strength steels calls in all matters for effective and stable production processes. To realise these requirements, the consortium of the BMBF funded FüLas-Project has developed a gas metal arc welding process using laser radiation for guidance and stabilization (LGS- GMA welding). First some Wöhler-curves of conventional welding processes on typical testspecimen were taken as a basis for comparison. To verify the effects of the new developed LGS-GMA-welding process similar test-specimen were taken for the Wöhler-tests. Furthermore box-type specimen were tested under torsion loads and crash-tests.
The paper presents the experimental results of taking Wöhler-Curves and crashresults in a reduced scale of operation to compare the LGS-GMA welding process against conventional welding processes.

Wednesday, 8:30h - 9:00h

Metal Rapid Manufacturing: history, state-of-the-art and future opportunities

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Abstract
Based on many years of experience and technology development, LayerWise offers its Metal Rapid Manufacturing services for the production of metal components for industrial and medical applications. Recent technology developments and the enlargement of the number of materials now allow the direct digital production of entirely functional components. By taking advantage of the possibilities of Rapid Manufacturing technology, very complex metal components can be manufactured that were even impossible to produce conventionally! Further advantages are the short lead times, the absence of tooling, function integration and an unprecedented production flexibility that makes metal Rapid Manufacturing a valuable tool for the production of unique components, customized products and small series. The presentation will demonstrate the state-of-the-art in the Metal Rapid Manufacturing technology and its materials illustrated with industrial case studies. Remaining problems and demands will be point out as well as some future opportunities.

Wednesday, 9:00h - 9:15h

Laser Freeform Fabrication for Aircraft Applications

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Abstract
Laser Freeform Fabrication processes exhibit advantages over conventional machining especially in terms of short production time and lower production cost for geometries of complex shape with individual design of each part. Thus design engineers who develop parts for aircraft applications are given new degrees of freedom for product innovations and product design customized to mechanical loads.

Introduction:
Today´s aircraft are characterized by customerspecific design and a high number of variants. Thus, aircraft manufacturers and their suppliers have to manufacture components and replacement parts in very small lot sizes. Due to weight requirements lightweight materials such as aluminum or titanium have to be used in combination with composite materials. Processing of these lightweight materials especially of titanium and its alloys is complex and expensive. Additionally, high efficiency concerning material and energy consumption is necessary because of high prizes of raw materials and energy. Therefore the development of process strategies that cover innovative product design on the one hand and adequate efficient process technologies on the other hand has to be conducted. One eligible near net shape manufacturing process is selective laser melting (SLM) of three dimensional metal parts enabling light weight product design.

State-of-the-art and current research for processing of metal parts
Nowadays, abrasive shape cutting technologies such as milling and drilling processes are used for the manufacturing of almost every metal part. Within these processes the net

shape of the part is cut from a semi-finished part. Depending on part geometry about 30 to 80 percent of the volume of this semi-finished part is machined, which has to be disposed as chippings. Because of high cost of raw materials and cutting tools this volume of material waste needs to be reduced significantly. Therefore generative near net shape manufacturing technologies have a great potential for aircraft applications.

Like most other laser-based processes involving powder material the SLM process is based on a principle in such manner that metal powder is applied in very thin layers on a building platform and melted due to the thermal influence of a laser beam. The powder particles typically have a statistical distribution of size from 5 to 20 up to 50 µm. Therefore the thickness of each layer is at least 20 to 50 µm.

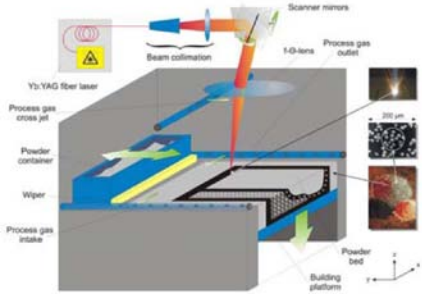

Fig. 1: Operating principle of SLM processes

Layerwise the laser beam generates the body of the part by melting the powder particles selective due to CAD geometry data. In between this layer melting process the building platform is lowered and coated with a new layer of powder (Fig. 1). In order to achieve this coating a wiper or roller device pushes the new layer of powder onto the previous layer. The laser beam is being redirected to the powderbed by scanner optics in such a way that the powder particles can be melted selectively with dedicated intensities and melting speeds. The surface tension of each powder particle changes and neck formation between adjacent particles occurs resulting in coalescence of the powder particles and creation of a solid shape. Output of this process is a three dimensional freeform fabricated solid state body with nearly 100 percent density. A variety of metals are available such as stainless steel, tool steel or titanium alloys. Numerous research projects concerning the application of SLM technology in several industrial fields such as medical markets or automotive and aviation industry have been conducted. However, the

technology has not yet been introduced industrially on a large scale.
In June 2008 aircraft manufacturer Boeing and the companies EOS (Munich), MTT Technologies (Luebeck) and the company Evonik Industries (Essen) have joined the Direct Manufacturing Research Center (DMRC) at the University of Paderborn. An agreement was signed to push the development of SLM processes and systems. The research budget is up to EUR 11 million for the next five years.

Recent developments concerning selective laser melting of aircraft parts

SLM processes offer a great degree of freedom concerning complex geometry, such as freeform designs, hollow structures or periodic cells.

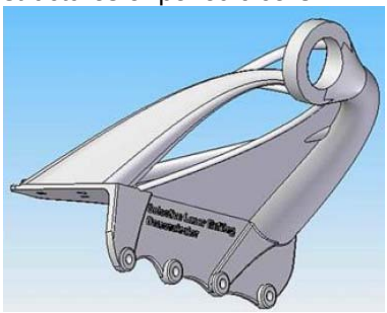

Fig. 2: Optimized Bracket (Source: Airbus)

Present analyses have been conducted concerning topology optimization and part fabrication of a so called "bracket", which is part of the aircraft body structure and has to be manufactured in lot size one
due to customer requirements. Today this part is produced from a semi-finished aluminum part by means of a milling process. Due to this process more than 60 percent of the semi-finished part is abrasively chipped and disposed as waste. Inprospective aircraft series these brackets have to be made from titanium due to the extended application of Carbon Reinforced Plastics (CFRP) and the high corrosion gradient between aluminum and CFRP. This titanium part could not be manufactured economically by means of milling processes. Preliminary investigations demonstrated the applicability of SLM for manufacturing this complex part geometry. By means of a preceding topology optimization and the use of titanium as basic material a weight reduction of more than 50 percent in comparison to the milled aluminum part was realized, while still meeting mechanical stress requirement.

Wednesday, 9:15h - 9:30h

Selective laser melting technology: study of parameters influencing single track formation and properties of manufactured samples

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Abstract

Selective laser melting (SLM) is a manufacturing process where parts are made layer-by-layer directly from a 3D CAD data. Properties of manufactured parts depend strongly on each single melted track ("vector") and each single layer. Experiments were carried out at laser power densities $0.3 \div 1.3 \times 10^6$ W/cm^2 by cw Yb-fiber laser. This study examines effects of scanning speed, laser power and powder layer thickness on single vectors formation for stainless steel (SS) grade 316L (-25 µm) powder. Optimal ratio between laser power and scanning speed (technological processing map) for 50 µm layer thickness was determined for SS grade 316L (-25 µm) and 904L (-16 µm), tool steel H13 (-25 µm), CuNi10 (-25 µm), and Inconel (-16 µm) powders. A considerable negative correlation was found between the thermal conductivity of bulk material and the range of optimal scanning speed for continuous single vector sintering. Relations between scanning strategy (two-zone technique, cross-hatching) and internal structure, porosity, mechanical properties SLM parts are discussed.

Wednesday, 9:30h - 9:45h

Microstructure evolution of selective laser molten 316 L stainless steel parts with laser re-melting

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Abstract

Selective Laser Melting (SLM) is a solid freeform fabrication process whereby a three-dimensional part is built in a layer by layer manner. During the process, a laser source selectively scans a powder bed according to CAD data of the part to be produced and the powder particles are completely molten by a high intensity laser beam. SLM is capable of producing near full density and functional metallic parts with a high geometric freedom. However, insufficient surface quality of produced parts is one of the important limitations of the process. In this study, laser re-melting is applied using a continuous wave Nd:YAG laser during SLM of 316 L stainless steel parts to overcome this limitation. After each layer is fully molten, the same slice data is then exposed to laser re-melting. In this manner, laser re-melting does not only improve the surface quality but also has the potential to change the microstructure and improve density. The influence of laser re-melting on density enhancement and microstructure is studied in the present research varying the operating parameters such as scan speed, laser power and scan spacing.

Wednesday, 9:45h - 10:00h

Selective Laser Melting of Graded Metal Matrix Composites

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Abstract

Selective laser melting is a technique for the layer by layer manufacturing of parts. This process allows to handle a lot of materials like polymers, metals and ceramics. This paper describes processing of cobalt based alloy and tungsten carbide (WC-Co) with selective laser melting. The basic idea consists of the generation of tools for micro cold forming with a tailored friction coefficient. In addition the advantages of a directed heterogeneous composite based on these two basic materials are shown. The outcome of changing the chemical composition of the composite is compared. The quality of the produced specimens is analyzed by parameters as density and hardness. Densities of produced MMC parts are above 98%.

Wednesday, 10:00h - 10:15h

Additive manufacturing of components out of copper by Selective Laser Melting

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Abstract

Selective Laser Melting (SLM) is a powder based additive rapid manufacturing technique. As well as other areas, SLM is used for the manufacture of tooling moulds from tool steel with conformed cooling channels. These enable shorter cycle times during the injection moulding process and improved quality of plastic parts. Due to the high thermal conductivity of copper, inserts made from copper alloys are often used to conduct the heat out of the tool. The most efficient way of cooling would be an insert made from copper combined with conformed cooling channels. Until now, copper alloys could not be processes by SLM with properties required for tooling applications. Copper alloys require a high laser power for the laser melting process. This is due to their low absorption of laser radiation and high thermal conductivity. Therefore a SLM-machine with a laser of 1 kW maximum output power was set up. In this presentation the results of the process development of SLM for copper alloys and its first applications will be presented.

Wednesday, 10:45h - 11:00h

An explanation of striation free cutting of mild steel by fibre laser

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Abstract

Striation free cutting has been previously reported when fibre laser cutting mild steel with oxygen. In this paper 1mm mild steel was cut with a multimode fibre laser and oxygen. Under certain conditions, a smooth, striation free, cut surface was obtained (at higher or lower speeds the cut edge is covered in striations). This phenomenon has been investigated by analysing the size and chemistry of the sparks ejected from the cut zone over a range of speeds. It was found that the average particle size is smallest for the striation free cuts. Also, the oxygen content in the collected particles decreases as cutting speed increases. An explanation for striation free cutting is given based on the variation of melt viscosity as a function of temperature and composition.

Wednesday, 11:00h - 11:15h

Calculable laser cutting

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Abstract

A comprehensive physical model of the laser beam cutting process has been developed, implemented in a simulation program known as CALCut, and qualified since first half of the 1990s. It allows for calculating the geometrical, thermo-physical, and hydrodynamic process variables of the three-dimensional steady-state cutting front, depending on the applied parameters of the laser source, focussing optics, cutting gas, and material. The simulation program CALCut serves to analyse characteristic process regimes, to reveal physical process limits, and to find most efficient parameter settings. Presently, the influence of wavelength, beam quality and power on laser cutting processes is vitally discussed in academia and industry. With CALCut substantial explanation and quantitative answers can be given to questions about common and differing cutting features of CO_2, disk and fiber lasers. Type and extent of beam coupling (e.g. contribution of multiple reflections), maximum possible cutting speed, effect of thickness as well as threshold and rate of evaporation are calculable. Various calculations are presented and compared with practical laser cutting results.

Wednesday, 11:15h - 11:30h

Theoretical Estimation of Achievable Travel Rates in Inert-gas Fusion Cutting with Fibre and CO2 Lasers

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Abstract

Inert-gas fusion cutting is commonly realised with CO2 lasers. However, it has been demonstrated in recent investigations that the use of fibre lasers offers the potential to improve the process efficiency dramatically. Comparative experimental studies have shown that the maximum cutting rates in fibre laser cutting can be much higher than the travel speeds in CO2 laser cutting. Unfortunately, this advantage seems to be currently limited to thin sheet metal cutting whereas the travel rates in medium
and especially in thick section cutting are of comparable magnitude. This experimental fact is in a good agreement to theoretical estimations of the achievable cutting rates provided that the different absorptivity behaviour of ferrous alloys at the corresponding wavelengths of 1.07 and 10.6 microns of fibre and CO2 laser radiation is taken into account.

Wednesday, 11:30h - 11:45h

Remote - Cutting – One Technology Fits for Various Materials

M. Lütke[1], A. Klotzbach[2], T. Himmer[2], A. Wetzig[2], E. Beyer[1,2]

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Abstract
During the last years material requirements became more and more specific. Today, the market offers various types of materials and combinations. Even composite materials take on greater significance. Existing processing technologies are faced with the demand of improved productivity accompanied by a higher part quality. In addition to marking, scribing and joining also cutting plays an important role in processing the various materials. One technology, which can handle well different types of materials, is the laser remote-cutting technology. Disclaiming any cutting gas a nozzle is no longer necessary. In combination with a handling system and a 2D-Scanner the laser beam is flexible in the working area of the cutting system. The materials can be cut with high processing speeds economically. This paper describes the processing of various materials, e.g. composite materials, with laser beam sources in order to reach high quality cutting edges without neglecting the cutting speed. Moreover, the process itself and the advantages will be explained.

Wednesday, 11:45h - 12:00h

Heat induced distortion during remote laser cutting

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Abstract

Heat induced distortion is a well known phenomenon during welding applications. Due to high local heating structural deformation and in consequence residual stresses appear locally or globally at the part. These effects can also be observed during the remote laser cutting (RLC). At the RLC process, the material is partly molten or vaporized and removed from the cutting kerf by vapour pressure. Since there is a high amount of energy applied to vaporize the material and no cooling processing gas is used, the distortion appears significant and must be decreased in order to qualify the process for industrial applications.
This paper describes the main RLC influencing parameters, e.g. cutting velocity, Rayleigh length and focal diameter on the cutting performance and the heat induced distortion. These experimental results are the basis for a modelling approach to simulate the heat influenced work piece. The simulation provides results of structural distortion and residual stress within the part. Additionally measures, like different scan strategies and customized clamping devices, can be derived.

Wednesday, 12:00h - 12:15h

Fibre Laser Material Processing of Aerospace Composites

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Abstract

The aerospace industry is showing an increased interest in composite materials. The A380, A350XWB and the Boeing 787 are using or plan to use a large percentage of composite material in their construction. Aerospace companies at present are favouring water jet machining for material processing of composites, i.e. cutting, milling.

We have investigated the use of fibre lasers in processing aerospace composite. We have used two different types of laser, the first a 200W CW fibre laser system from GSI Laser Group to investigate laser cutting. The second laser was a picosecond pulsed fibre laser system from Fianium investigating micromachining applications.

Our results show that by carful control of processing parameters laser cutting of thin composite material is possible and our micromachining experiments showed that it's possible to structure the surface of carbon composite and affect the surface energy so increasing the bond strength in a composite component.

Wednesday, 12:15h - 12:30h

CO_2 Laser Cutting of Carbon Fibre Reinforced Plastic Composite

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Abstract

Carbon fibre reinforced plastic (CFRPs) composites have significant properties such as high specific strength, specific stiffness and easy of tailoring to a particular application, which made them very attractive for structural applications, especially for aeronautics.

In this work, a study on the possibilities of a high quality CO_2 laser to cut such composites is presented. Plates of CFRP 3 mm thick were cut by means of a 3.5 kW CO_2 slab laser. The influence on the cut quality of different processing parameters such as pulse frequency, pulse energy, duty cycle, and type and pressure of the assist gas were studied. The quality of the cuts was evaluated in terms of kerf width, perpendicularity of cut kerf, delaminating degree, and extension of the heat affected zone. An adequate selection of the values of the processing parameters allows obtaining good quality cuts.

Wednesday, 14:00h - 14:30h

Remote laser welding with integrated scanner head in the production of doors at Fiat's Cassino Plant

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Abstract

Comau, a company that is part of the Fiat Group and the world leader when it comes to production systems for the automotive industry, after to have introduced in 2003 the AgiLaser system, last year introduced in the production at Fiat Group Automobiles the new remote welding system.
SmartLaser, patented 3D REMOTE LASER SYSTEM fully integrated with a "NH" COMAU robot, used to Cassino Plant for doors production of the New Lancia Delta.

Wednesday, 14:30h - 14:45h

High dynamic axes systems for laser processing "on the fly"

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Abstract
Remote processing is known as a new trend to increase the productivity of production processes. Typical remote applications are not only laser welding of metals. Also the field of metal and non metal cutting and welding are well suited for remote processing. Within this presentation new industrial proven solutions will be described, using high speed beam deflection systems and classical Cartesian axes systems. The new system technology enables to realize cutting speeds up to 5 m/s for non-metals or contour cuts of thin metal sheets up to 60 m/min. In combination with specially adapted motion planning tools the production lines work in a flexible, efficient and stable manner.

Wednesday, 14:45h - 15:00h

2D - and 3D - Laser Cutting and Welding with the Combi-Head: Efficient Production by Flexible Process Changes

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Abstract

The Combi-Head for laser cutting and welding makes the arbitrary and instantaneous change of processes possible. Thus integrated manufacturing with both processes in one machine with one tool leads to technical and economical advantages resulting from shorter process chains and eliminated setup-times. Higher accuracy by using a single tool center point for both processes even supersedes seam tracking. Besides 2D-applications demonstrating the high-speed capability of the combi-processing, the focus of the current work is on 3D-cutting and welding. Automotive application examples show results with a fiber laser and the latest generation of the combi-head. This head is optimized for robots with internal beam guidance enabling enhanced 3D-performance. The influence of process parameters such as focal position and beam quality on combi-processing is discussed.

Wednesday, 15:00h - 15:15h

Coaxial Laser Brazing Head

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Abstract

Laser brazing has been established as a widely used joining technology in the auto motive and electronics industry due to its specific advantages. So far mostly laser brazing heads with lateral brazing wire feeding have been deployed for industrial manufacturing. To overcome the disadvantages of laser brazing heads with lateral wire feeding, such as the need of constant reorientation of the brazing head or restrictions in maneuverability, a coaxial laser brazing head with a ring shaped laser beam distribution that enables coaxial wire feeding without crossing of laser beam and filler wire has been developed. This coaxial laser brazing head enables the brazing of more complex shapes, such as car bodies, without the above mentioned disadvantages of lateral wire feeding. Together with a coaxial process control this brazing head truly functions independent of direction.

This paper presents the prototype of the new coaxial laser brazing head and first application results.

Wednesday, 15:15h - 15:30h

Direct Diode Laser with Coaxial Material Feeding

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Abstract
Coaxial material feeding can significantly improve quality and yield in laser materials processing applications such as brazing, soldering, coating, rapid manufacturing or welding with wire. It is, however, often technically difficult or even impossible to realize coaxial material feeding in practice. A novel high power direct diode laser concept for materials processing with built-in coaxial material feeding capabilities has been realized. Diode lasers are arranged in sectors around the optical axis which results in an axial tool opening through the entire device. This tool opening can also be utilized for other purposes such as heating, suction or monitoring.
In addition to coaxial material feeding, the concept enables exceptionally high wall-plug efficiency, high beam quality and compact size. Unlike in many other direct diode lasers, the output beam is circularly symmetric, which simplifies robotics and automation.
The performance and properties of a new laser prototype weighing a few kilograms and having a volume of a few liters will be presented.

Wednesday, 15:30h - 15:45h

Industrial Direct Diode Laser Systems Supporting 99.99% Up-time with Lowest Cost of Ownership

R. K. Price[1], R. Martinsen[1], F. Pfeffer[2], S. Reinl[2], Z. Huang[3] and C. Deininger[4]

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Abstract

Direct semiconductor diode based systems have emerged as the preferred tool to address a wide range of material processing applications including hardening, brazing, cladding, welding of metals, and plastic welding. Broad deployment of these tools in industrial settings however force fundamental platform shifts consistent with the demands of 24/7 manufacturing. We present the architectural framework for kW-class laser tools capable of continuous operation in pulsed mode for several years with >99.99% up-time. We show how efficiency and reliability can be engineered to minimize operating and service costs for an extremely compelling cost-of-ownership over legacy systems. Related topics of failure mode effects analysis, device- and system-level burn-in, reliability modelling and FIT rate estimates based on accelerated life test results will also be included. In addition, we demonstrate the application of these systems in a variety of industrial systems.

Wednesday, 16:15h - 16:30h

Laser Assisted Fabrication of Materials

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Abstract

Light amplification by stimulated emission of radiation (laser) is a coherent and monochromatic beam of electromagnetic radiation that occurs in a wide range of wavelength, energy/power and beam-mode/ configuration and capable of delivering a very high power density. As a result, laser finds wide-ranging applications in materials processing. A high power laser beam may also be applied in shaping and fabrication of materials. However, the shape of the component, it's microstructure and properties are dependent on the applied laser parameters. In the present lecture, studies on laser assisted bending of AISI 304 stainless steel has been discussed in details. The effect of laser parameters on the bend angle and microstructures of the bend zone have been investigated to optimize the process parameters for laser bending. A high power laser beam may also be used as a source of heat for melting materials and subsequently, depositing it in a layer by layer fashion to form the pre-determined shape of the component. Studies on fabrication of AISI 316L stainless steel, SiC dispersed AISI 316L stainless steel and the effect of process parameters on microstructures and properties have been discussed. Finally, the application of high power laser in shaping of novel materials has been discussed with examples.

Wednesday, 16:30h - 16:45h

Laser Assisted Machining of Silicon Nitride using HPDL

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Abstract

In this paper, laser-assisted machining (LAM) has been employed to machine Si_3N_4 workpieces. Si_3N_4 workpieces are more difficult to machine compared to normally metal based workpieces. In LAM, the intense energy of laser was used to enhance machinability by locally heating the workpiece and thus reducing yield strength. In experiments, the laser power ranges from 200W to 800W and the diameter of workpieces is 16mm. While machining, the surface temperature was kept nearly constant by laser heating except for a short period of rise time of max. 58 seconds. Results showed as feed rate increases the surface temperature of Si_3N_4 workpieces decreases slightly, whereas the effect of depth of cut is disregardable. With a laser power of 800W, achievable maximal depth of cut was 0.7mm and feed rate was 0.03mm/rev.

Wednesday, 16:45h - 17:00h

Hybrid Laser-Assisted Incremental Sheet Forming – Improving Formability of Ti- and Mg-based Alloys

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Abstract

Incremental sheet forming (ISF) is a manufacturing process, suitable especially for prototype and small batch series production. It is possible to form Al- and Fe-based alloys at room temperature with good shape accuracy. Ti- and Mg-based alloys -in contrast- feature only limited formability until fracture occurs. Using a hybrid process consisting of ISF and local heating by laser radiation, the formability of TiAl6V4, Ti Grade 2 and magnesium AZ31B sheet metal at different temperatures can be improved. The laser radiation is guided onto the same sheet side as the forming tool moving ahead of the forming tool. The influence of different parameters (e.g. laser power, beam shape, beam size, lubrication) on formability and the necessary process forces will be presented and discussed. Furthermore, results of metallographic analysis and hardness of the formed material will be presented. Finally, an outlook on further steps (e.g. developing of a process adapted optic) will be given.

Wednesday, 17:00h - 17:15h

Laser Beam Forming of Aluminium Plates under Application of Moving Mesh and Adapted Heat Source

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Abstract

In order for the laser thermal forming process to be industrially applicable, the outcome must be predictable. The predictability can be enhanced through finite element simulations. However, at the macro-scale, finite element simulations can be time consuming, especially when a high degree of accuracy and meshing of the whole part is required. The application of special meshing techniques can reduce the computation time significantly. A mesh consisting of a highly meshed block moving synchronously with the laser beam is applied to an otherwise coarsely meshed Aluminium 99.5 substrate, allowing multiple irradiations to be modelled within computation time limits. In addition, the geometric effect of the component deformation and its influence on the irradiation area is considered, resulting in a faster and more detailed simulation. Further validation of the FE model is performed by laser forming experiments and surface shape measurements using comparative material samples and process conditions.

Wednesday, 17:15h - 17:30h

Temporal Behaviour of Focus Shift with Laser Power

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Abstract

A constant high quality in material processing with lasers requires a good knowledge of the "tool" Laser. It's "sharpness" is defined by the quality of the optical system. Changed input parameters of the laser beam as well as absorption in the optical substrate, the coatings, and at contaminated surfaces of the optics can affect a thermal focus shift. Depending on the processing parameters, this effect leads to a continual change of the focus position, despite of a constant laser power. Analysis of this effect shows, that because of the different principles of cooling, several time constants for the heating-up and the cooling curve exist. In the following all main effects for a theoretical description of a thermal focus shift are shown. Furthermore it will be explained how to measure the different time constants of an optical system with the help of measuring devices. Finally it will be shown how to calculate a matched compensation curve for a precise example of material processing.

Wednesday, 17:30h - 17:45h

Influences on the laser induced focus shift in high power fiber laser welding

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Abstract

Welding with laser beam sources combining high power and beam quality leads to high intensities on the optical elements of the processing head. Already the absorption of a small amount of the laser light heats up the lenses, mirrors and glasses in the welding optic. This heat impact causes a shift of the focal plane which leads to a change in the intensity on the work piece. The amount of absorption and hence the amount of the focus shift does not only depend on the material properties but also on the condition of the welding head. Especially the cover glass which protects the focussing lens from process contaminations is subject to significant condition changes. In this paper a multimode 8 kW fiber laser was used to investigate the influence of the condition of the cover glass on the focus shift of a laser welding head.

Wednesday, 17:45h - 18:00h

Small fiber connector for high-power transmission

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Abstract

Fiber Optic connectors for high-power transmission are normally relatively large in size. In industrial applications, that is normally accepted, but in some cases smaller and more cost efficient connectors are necessary. Small fiber connectors capable of handling medium powered lasers are available on the market. Typical connector types are the SMA905 and LD80. The capability to handle power losses, for example radiation falling outside the fiber core is, due to the small size and restrictive design, limited. A new type of fiber connector, designed for high-power loss capability will be presented. The basic principle is to strip off the losses in terms of radiation rather than being absorbed in the fiber connector. The radiation is instead absorbed in the female connector housing or within the laser housing, where it can easily be cooled away. In this paper both the principles and measurement of power capability will be presented.

Wednesday, 18:00h - 18:15h

Systematic development of safe high performance laser applications

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Abstract

The advent of modern laser beam sources, like fiber- and disk laser beam sources, led to laser applications for economic mass production. Their laser beam is highly brilliant, highly energy and invisible. In some laser applications, the beam can be oriented without spatial limitations. The risk potential is increased, compared to conventional systems and the conventional safety technology is extremely challenged. Conceivable claims are personal injuries like blindness, burns, long-tail claims and death, as well as material damage. According to the standards, those claims should be avoided by laser safety barriers. Those barriers are merely a delay element to gain time until the beam breaks through the wall. In other sectors, machines are self-monitoring for a controlled shut-down in an emergency case. This antagonism between laser safety and general machine safety shows the backwardness of the current standards.

A modern holistic safety concept for a laser application bears the requirements of the process and the definitions of the accepted error margins. Furthermore, risks need to be identified and rated with risk assessments. Too high risks can be reduced via modern safety components. With this approach, laser safety is economically achievable.

Thursday, 8:30h - 8:45h

Monitoring of phase transitions under millisecond pulsed laser irradiation by comprehensive optical diagnostics

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Abstract

Synchronised application of complimentary optical diagnostic tools provides comprehensive analysis of heat-and-mass transfer induced by Nd:YAG laser irradiation of INOX 304L substrates. The following optical devices are employed: (a) original multi-wavelength pyrometer in the near infrared range (1,370- 1,531 µm); (b) IR-camera FLIR Phoenix RDAS with InSb sensor with 3 to 5 µm band pass arranged on 320x256 pixels array; (c) commercial ultra-rapid camera Phantom V7.1 with SR-CMOS monochrome sensor, up-to 10^5 frames per second for 64x88 pixels array. Laser irradiation parameters: variation of energy per pulse in the range 15-30 J at a constant pulse duration of 10 ms with and without protective gas (Ar). True temperature evolution is restored based on the method of multi-colour pyrometry; this way, melting/solidification is analysed. Variation of intensity of the surface evaporation visualised by camera Phantom V7.1 is linked with the surface temperature evolution. The results are compared with numerical simulation.

Thursday, 8:45h - 9:00h

Control of Laser Metal Deposition Process for Direct Manufacturing by Coaxial Vision

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Abstract

In order to generate 3D complex structures by laser cladding, it is necessary to control the width and the height of the deposited material. First, we present a general overview of the problem. The phenomenological model linking the main the process parameters with the output parameters (width and height of the deposited material) is presented. As this model evidences, the process control can be achieved by decoupling the control of the two output parameters: the z-height is mainly controlled by the apparent feeding rate and the width of the melt pool by the laser power. The apparent feeding rate is controlled by a gas flow actuator. The measures of the output parameters are made by a dedicated coaxial sensor that we present in the next section. Then, we describe the design and implementation of the control system itself on a real time Linux kernel. Finally, we present some results and performances of the process control system on simple geometries.

Thursday, 9:00h - 9:15h

Advanced optical System for SLS/SLM-PROCESS MONITORING

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Abstract
Methods and apparatus for surface temperature monitoring during laser machining were developed some years ago. The next step is to develop appropriate monitoring systems and integrate them with laser technological equipment.
In the present paper, development of a monitoring system adapted for SLS/SLM-process are discussed. The system provides the possibility to visualise regularity of the powder bed deposition, progress of the sintering/melting process and its results (layer by layer).
To control correct choice of the process parameters and to visually inspect the process quality, a four channel Monitoring System for Sintering and Melting Process was designed and fabricated. Monitoring of the process is based on visualization and measurements of temperature distribution at the sintering zone by the spectral ratio method using both high speed videocamera and intensified camera. Visualisation is carried out at different scales. Surface illumination is carried out using a Light-Emitted Diode (LED) ringlight system.
Maximum surface temperature is calculated based on measurements of two wavelengths pyrometer with time resolution 100µs and spatial resolution 50 µm and its values are used for express control of manufacturing quality. Deviation of maximum surface temperature from its optimal value was chosen as a criterion for the express method of quality control. All equipments are integrated with the optical system of laser machine.

Thursday, 9:15h - 9:30h

M² beam quality measurement of a single pulse of the Nd:YAG laser

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Abstract

During the machining laser is very difficult and or laborious to measure the laser beam quality factor M², which is proportional to the product of the beam divergence and waist diameter. The method to evaluate the M² factor, described in the current standard ISO11146 requires taking diameter measurements in different positions about a beam waist. Usually, the diameters are measured at each position with a camera, a rotating knife edge or a scanning slit. Consequently, these methods are time consuming and fast fluctuations on M² are not detected. To overcome this problem, we proposed a method based on a single measurement of light scattering. The M² factor of a single pulse of a Nd:YAG laser is obtained with one transverse scattered light image, which is the lateral view of a laser beam propagating in a scattering medium. This way the fluctuations of the M² factor are observed pulse to pulse.

Thursday, 9:30h - 9:45h

Real time monitoring and optimization of laser piercing of thick mild steel plates by means of photodiode sensors

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Abstract

In this paper real-time monitoring and optimization of the laser piercing process is discussed. Firstly, an overview of the used optical setup is presented. Secondly, two major quality factors of the laser piercing process are introduced and the correlations between these quality factors and a photodiode signal are mentioned. Finally the algorithm for real-time control and optimization of the piercing process is discussed.

Thursday, 9:45h - 10:00h

Sensor guidance of robot based Laser Remote Systems for implementing the innovative Welding-on-the-fly Technology

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Abstract
The competition in the manufacturing industry is increasingly supported by the corporate capability to customize their products. The development of robot based laser remote systems for welding applications already allows the considerable augmentation of the flexibility and productivity within the manufacturing process. In the context of a new research project the scanner system is supplemented with the assembling of optical sensors. In combination with a proper strategy of calibration this extension shall facilitate the realization of cooperative motions between robot and scanner to implement the innovative welding-on-the-fly technology and thereby generate further advantages in competition.

Introduction
Due to the large distance between optic and welding point the use of robot based laser remote systems within material processing is characterized by a high part accessibility and versatility. The assembling on a jointed-arm robot with six axes allows the scanner to reach every position in each orientation inside the processing area. Furthermore non-productive time can be reduced through dynamic positioning of the laser focus. Though up to now the obtainable augmentation of productivity is limited. The generation of trajectories can be realized by synchronized motions of robot and scanner using a clocked signal of the control system. In such set-ups the scanner works without information about the actual positioning of the robot. Hence the need of a high

process stability with defined accuracies still demands the successive motion of scanner and robot including the upper expenditure of time for tracing the trajectories. To implement the innovative weldingon- the-fly technology with cooperative motions between robot and scanner this article describes the use of laser measuring procedures based on the methods of 3D/6D-videometry.

Absolute and repeat accuracy within robot based laser remote systems

The accuracy of industrial facilities is defined by the interaction of systematic and random error, i.e. absolute and repeat accuracy of the overall system. Predominantly the systematic error of robot based plants is one scale inferior to the repeat accuracy.

To improve the absolute accuracy trajectories are calibrated on a sample. Afterwards sensors can be used to detect deviations within the part geometry and compensate existing inaccuracies through appropriate adjustments of the continuous path control. But the realized algorithms for joint tracking do not contain information about the actual motion of the robot, that depends on the repeat accuracy. In fact according to the law of error propagation the random error of the sensors results in a deterioration of the repeat accuracy from the overall system. In consequence for a correct joint tracking it has to be ensured that the total random error is smaller than the aspired position.

Purpose and implementation of the project

The realization of defined production accuracies within robot based laser remote systems can be ensured through individual video metric measurement of geometric aspects. In the research project two cameras are assembled at the scanner, so that the methods of triangulation can be used to adjust failures in positioning and guide the laser focus on unique parts while robot and scanner are moved simultaneously. As a fundament for this manufacturing strategy a calibration of the overall system is needed. Fig. 1 shows the components which have to be considered in this context.

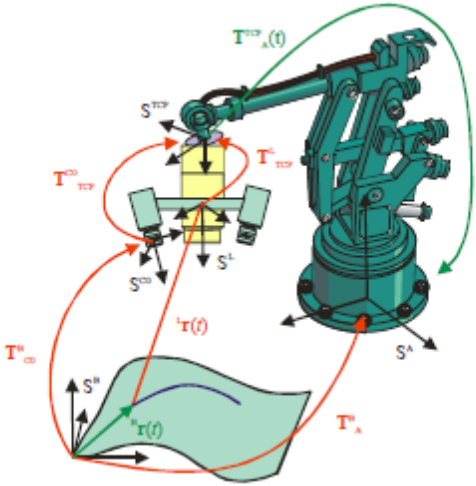

Fig. 1: Robot based laser remote system

Initially physical models, that describe the geometric aspects of the system environment, have to be developed for the calibration of the scanner, the robot and the cameras. Within each model the relations between the cartesian coordinates of the system components are defined by homogeneous coordinate transformation with six degrees of freedom of the pose. Subsequent to the development of the model is the determination of the non-linear model parameter through formulation of the identification problem as a minimization problem. To reduce the negative impact from numerical rank defects on the accuracy, a structured hierarchical calibration of the models is favorable. The linearly independent parameters with the biggest influence are minimized in the first step to be able to include successively more parameters. A complete modeling is not to be aspired, because not all physical effects can be represented and therefore as a matter of principle structural model errors exist. Within the scope of this project the examination of the parameters position, pace, acceleration and jolt as well as their impact on the fine positioning of the laser focus is sought.

Thursday, 10:00h - 10:15h

Design of a Sensor-Assisted Control of the Weld Filling Degree for the Manufacturing of Segments for Steam Turbine Cooling

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Abstract
In order to increase the efficiency of combined cycle power plants up to 65%, special structures consisting of nickel base materials are joined with and without filler materials using the laser beam welding method. The particular joining geometry of these structures requires bridging of the air gap during welding. For this purpose, a closed-loop control has been designed which, dependent on weld
speed, wire feed speed and joint geometry, allows to control the added filler material in a way that complete fusion and uniformly reinforced welded seams are achieved. The software LabView has been used for the realisation of the control. The joint geometry is optically measured via a light-section sensor, subsequently converted into analogue signals and, as a last step, evaluated. These data are used for the control of the oscillating mirror of the laser optic and also of the NC control of the applied CO2 laser. The design of this control is not limited to this particular task, it is, moreover, universally applicable. In this paper, the general set-up and design of the control are demonstrated, also the possibilities and the measuring range of the respective components are specified. The programming and alternative programming possibilities are introduced.

Thursday, 10:45h - 11:00h

CNN-Cameras for Closed Loop Control of Laser Welding – Experimental Results and Prospects

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Abstract

Camera based in-process control for laser welding enables flexible image processing which allows the adaption of the system to different processes and quality features. With "Cellular Neural Networks" (CNN) it is now possible to integrate processor elements in the electronic circuitry of CMOS cameras resulting in a Single-Instruction-Multiple-Data (SIMD)-architecture on the camera chip itself which provides extremely fast real-time image processing.
A closed loop control system controlling the laser power was implemented into a laser welding machine. This system uses a CNN based camera surveying the contour of the full penetration hole with a frame rate of over 10 kHz for both, acquisition and evaluation of area images. As a result the system reaches and holds the full penetration state automatically. This paper shows the latest experimental results and gives a prospect on further improvements of the control system.

Thursday, 11:00h - 11:15h

Process Control System for High Speed Welding with Lasers of High Brightness

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Abstract

The latest generation of single mode cw-lasers allows deep penetration welding at a very high speed in thin sheet metal. In order to minimize the reject rate of the welding process it must be an approach to scale down the control cycle. The formation of weld seam defects has to be detected within few seconds so that parameter improvements can be accomplished. A multimodal process monitoring system which can detect typical major welding errors, e.g. humping and formation of blowholes was developed for sample processes. The small dimensions of the weld defects of only a few microns and the short time of their formation have been taken into account. Not only the composition of the monitoring system will be presented but also typical errors and error detection rates as well as mechanisms leading to a pseudo error rate.

Thursday, 11:15h - 11:30h

Basic analysis of monitoring undercut, blowouts and root sagging during laser beam welding

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Abstract

12mm thick cold-formed steel S420MC is welded together by a 14 kW CO_2-laser with a machined shaft pivot made of 25CrMo4 steel as part of a truck rear axis. A photodiode-based on-line process monitoring systems is applied for detecting defects. However, the occurrence of certain defects, namely undercut, blowouts and root sagging is often not detectable from the sensor signal. The time dependent signal results from emissions from the melt pool surface as well as from the plasma plume. Based on analysis by the aid of high speed imaging and its evaluation, explanations for the fundamental potential and limitations of detecting these defects can be given. Although first conclusions can be drawn, uncertainties like the not fully known emissivity and the keyhole and plasma radiation characteristics require further studies.

Thursday, 11:30h - 11:45h

Process monitoring through the optical combiner in fiber laser welding applications

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Abstract
Different solutions are already available for monitoring of fiber laser (FL) welding but none of them is optimized for fiber laser systems. This paper deals with a new monitoring concept in which optical emissions from the welding pool are directly observed through the optical combiner of the FL source. This solution, referred as T.O.C. (Trough the Optical Combiner) monitoring, can be easily installed on all the FL sources in which an optical combiner is present. In this configuration the advantages of coaxial monitoring devices, such as the independence from the laser moving direction or the robustness of the sensing optics towards environmental damages are achieved. Furthermore, the insertion of the monitoring device directly inside the laser source avoids the increase in weight and volume of the focusing head and doesn't require any modification of the laser focusing path. Thanks to a common SMA interface, different optical devices such as photodiodes or spectroscopes can be easily plugged in and used for process monitoring both in time and wavelength domains.
TOC monitoring was performed during the welding process of Ti6Al4V plates with a 1 kW FL. Comparison between TOC and off-axis monitoring showed a signal attenuation of 8 dB in the former configuration and the presence of a background radiation centred at the laser wavelength. Optical emissions were acquired both in reference and in fault process conditions and their evaluation will be discussed in the work.

Thursday, 11:45h - 12:00h

Pulsed laser weld quality monitoring by the statistical analysis of reflected light.

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Abstract

This paper describes a technique for monitoring the quality of laser welds by statistical analysis of the reflected light signal from the weld surface. An algorithm is used which analyses the variance of the reflected signal as a measure of surface weld dynamics during pulsed Nd:YAG laser welding in the conduction limited mode. Kalman filtering is used to separate a useful signal from the background noise. A good correlation between weld disruption and signal fluctuation has been identified.

Thursday, 12:00h - 12:15h

Laser percussion drilling with a low cost, high beam quality and high peak power pulsed Nd: YAG laser

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Abstract

Laser percussion drilling is now a well-established material processing technique in the aerospace industry. These holes are important as they allow boundary layer cooling of the component. Of the two different drilling techniques, percussion and trepanning, percussion drilling is preferred as it allows the reduction in the cycle time of the component. This is a very important factor as some components can have up to 40,000 holes. One of the major aspects that concern the aerospace industry is the quality of the holes. Hole geometry such as taper, roundness and variation between holes must be within certain tolerances if the component is going to be used in an aero engine. Other important factors with respect to hole quality are metallurgical issues concerning recast layer and micro-cracking with in the hole.

This paper inestigates laser percussion drilling of high quaility holes for the aerosoace market with a new low cost high peak power up to 16kW and high beam quality (M^2=11) pulsed Nd: YAG lsaer especially developed for this aplication. Holes were drilled with various laser and processing parameters on coated and uncoated nickel based superalloy material to quantify laser drilling times, recast layer, taper, oxidised layer and cracking.

Thursday, 12:15h - 12:30h

Spectroscopic analysis of plasma optical emission for laser welding process control

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Abstract

Spectroscopic analysis of the plasma plume optical emission is attracting growing interest for real-time monitoring of laser welding processes, since it is non-intrusive, low cost and easy to embed in an automated system. In this work we present some experimental investigations of the plasma optical emission during welding processes in different process conditions by employing several spectroscopic techniques. Variations of the main process parameters influencing the weld quality have been correlated to the spectroscopic signals. We also report the application of the discrete wavelet analysis on the study of optical signals coming from the plasma. The discrete wavelet transform (DWT) is used to decompose the optical emission signals into various discrete series of sequences over different frequency bands. The results show that different types of defects may yield different optical emission features in a specific range of frequencies.

Thursday, 14:00h - 14:15h

Design Issues of Engineered Residual Stress Fields and Associate Surface Properties Modification by LSP in Al and Ti Alloys

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Abstract

Laser shock processing (LSP) is consolidating as an effective technology for the improvement of surface mechanical resistance properties of metallic alloys and is being developed as a practical process amenable to production engineering. Following a short description of the theoretical/computational and experimental methods developed by the authors for the predictive assessment and experimental implementation of LSP treatments, experimental results on the residual stress profiles and associated surface properties modification successfully reached in typical materials (specifically Al and Ti alloys) under different LSP irradiation conditions are presented. In particular, the analysis of the residual stress profiles obtained under different irradiation strategies and the evaluation of the corresponding induced surface properties as roughness, microhardness and wear resistance are presented. Based on this analysis, some component design guidelines are extracted referred to the presumable degree of protection provided by the LSP treatment against mechanical failure and the corresponding life extension expectations.

Thursday, 14:15h - 14:30h

Development of laser texturing for enhanced lifetime of cutting and forging tools

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Abstract

A laser surface texturing process was developed to modify steel and cemented carbide surfaces prior to physical or chemical vapour deposition of hard coatings. The surfaces were ablated using 30-ns pulses from a Cu-vapour laser at 13.8 kHz repetition rate and using scanning speeds between 0.08 and 30 cm/s. The lasered surfaces presented periodic patterns due to laser shots and very controllable roughness, which are function of the intensity and the number of scans. PVD and CVD layers of the different materials were then applied to the modified surfaces. The laser treatment changed the materials surface properties improving adhesion of the coating on the substrate, in respect to unmodified surface condition, due to supposedly controlled roughness and microstructural changes (such as remelting and cobalt vaporization).

Machining tests using HSS twist drills showed a huge increase on tool life (up to ten times), when the lasered tools were compared to the conventional ones. Cemented carbide tools also presented some increase on tool life when ablation occurs under very low laser intensities. Further, the in-service tests of laser-modified steel dies showed a notable increase in performance and lifetime. All these studies have been aimed to decrease the need for regrinding and premature discard of tools contributing toward waste minimization and manufacturing processes sustainability. The preliminary results are encouraging and may serve as starting point for further investigations.

Thursday, 14:30h - 14:45h

Laser polishing of metallic freeform surfaces with non-perpendicular angle of incidence

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Abstract

Laser polishing represents a new procedure to automate surface finishing of moulds with freeform surfaces. This technique is based on remelting a thin surface layer using laser radiation.
When freeform surfaces are laser-polished, the angle of incidence is generally not perpendicular to the treated surface. The influence of this angle on the melt pool and the obtained surface roughness is investigated. Adequate measures to compensate these influences for angles up to 65° to the surface-normal are demonstrated. To achieve sufficient surface roughness, laser power and line-spacing have to be adjusted depending on the angle of incidence.

Additionally, the CAM process chain for laser polishing of freeform surfaces is discussed. On the basis of a 3D model of the workpiece, tool-path data are generated by conventional CAM software. These data are processed using procedure-specific software that comprises a database with technological information and are subsequently transferred to a 3D laser-polishing machine.

Thursday, 14:45h - 15:00h

Structuring by Remelting

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Abstract

A totally new approach to structuring metallic surfaces with laser radiation is structuring by remelting. In this process no material is removed but reallocated while molten. The innovation of structuring by remelting is the new active principle (remelting) in comparison to the conventional structuring by photochemical etching or the structuring by laser ablation (removal).
The process is based upon the physical interrelationship between variation of melt pool volume and movement of three phase point (point where the three states of aggregation solid, liquid and gaseous meet). This movement determines the resulting surface topography as a consequence of the variation of the melt pool volume which can be precisely modulated. Therefore, surface structure and micro roughness result from a laser-controlled self-organisation of the melt pool due to surface tension. Furthermore, this new process generates surfaces with smooth technical structures like cones or pyramids which are precisely the current trends for new surface appearances.

Thursday, 15:00h - 15:15h

Development of a laser decoating process for fully functional Al-Si coated press hardened steel laserwelded blank solutions

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Abstract

ArcelorMittal was the first steelmaker to offer the automotive industry a coated press hardened steel: Usibor®1500P which demand is strongly increasing for body-in-white applications due to their exceptional structural caracterics. For the widely used aluminium coating it is mandatory to produce weld seams which are not weakened by the presence of Al-Fe phases compared to the base material. On the other hand, this Al-Si-coating is also needed as corrosion protection. Noble International and ArcelorMittal were the first to develop and industrialize a laser decoating and an online control process for these steels by which it is possible to remove the Al-Si coating and leave a corrosion resistant intermetallic layer which does not cause Al-Fe phases in the weld seam. This patented process with pulsed Q-switch lasers makes it possible to produce high-quality weld seams with press hardened steels. The excellent mechanical caracteristics and a satisfying corrosion protection are maintained.

Thursday, 15:15h - 15:30h

Novel Beam Shaping Optics for Laser-Based High Speed Coating Removal

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Abstract
Laser based coating removal offers numerous advantages compared to traditional methods. As no additional processing agents like solvents are needed and the residuals can be removed easily by a vacuum system, laser based processes are environmentally friendly. In addition, if the damage threshold of the base material is significantly higher compared to the ablation threshold of the coating material the laser process is highly selective and the coating can be removed without damaging the base material. A linear scanner offers a fast movement of the focus on the workpiece. Thus, the movement of the cleaning optics perpendicular to the scanning direction can be comparably slow. With increasing laser power, the scanning frequency usually limits the cleaning speed. To expand this limit for cleaning with high power solid state lasers, we have developed a beam shaping device that transforms the circular far field distribution of a collimated beam to a rectangular distribution before entering the scanning device. As the momentum of inertia mainly limits the speed of state-of-the-art scanners, the speed of the scanner can be increased by a factor of four by reducing the size of the ollimated beam perpendicular to the scanner's axis of rotation by a factor of two. We will present the optical setup for optimizing the beam shape at the scanner mirror without influencing the intensity distribution at the workpiece. Results of the coating removal experiments gained with a scanner frequency of 220 Hz corresponding to a scanning speed of 24 m/s will be shown, and the setup of the 1.7 kW pulsed Nd:YAG laser will be presented.

Thursday, 15:30h - 15:45h

Virtual Process Planing for Laser Joining Processes

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Abstract

In recent years many different laser joining technologies have been developed. Thus, a variety of possibilities exist to design a joining process regarding its achieved quality, process time and overall cost.

Implementing laser joining in industry faces the question of choosing the right process technology and, moreover, appropriate process parameters. In order to design a cost and time effective process, experience and know-how is indispensable and, as with any new technology, not always readily available. Consequently, to gain this knowledge process parameters have to be determined in experimental studies, which, however, occupy manufacturing capacity.

One way to overcome this issue is to apply theoretical analysis based on theoretical process models that are solely based on results gained from other previous laser joining processes. Hence, no further experimental studies have to be carried out.

This approach allows also for optimization of certain characteristics. One example of such an important characteristic is welding distortion. The quantity of distortion depends on the process itself as well as design parameters, among others. Therefore, it is complex to predict the amount of welding distortion, especially when using new technology or welding new parts. Numerical based modelling and simulation of the process, only based on results from previous processes, allows cost-effectively to choose an adequate technology to achieve, in this case, a minimal distortion and to virtually optimize the process.

In the presentation the aim and requirements of such a design tool for the above described modelling and simulation approach is shown using a concrete example, reflecting its potential and use of applications.

Thursday, 16:15h - 16:30h

Laser hardening of large cylindrical martensitic stainless steel surfaces

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Abstract

This paper refers to the laser surfaces hardening of a martensitic stainless steel. The components to be treated have a cylindrical shape with a thin variable thickness. The areas to be heat treated are larger than the laser spot so that multi-tracks or the virtual spot technique are needed. The typical problems of such a hardening method, concerning tempering phenomena, are faced and scanning strategies optimization are considered. The process optimization has been carried out by using a Laser Hardening Simulator (LHS) developed by the Authors. LHS allows to simulate the laser-material interaction and the resulting micro-structures after the treatments according to laser trajectory. The accuracy of the software is proved by means of experimental comparison on components delivered by the Italian firm MARPOSS.

Thursday, 16:30h - 16:45h

Comparison of laser surface hardening of austempered ductile iron and low-alloy steels

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Abstract

Austempered ductile irons (ADI) present a very good combination of properties such as good ductility, high strength and toughness, and excellent fatigue resistance comparable to cast and forged steels. Due to these mechanical properties and its low cost, reduced density and design flexibility, ADI is widely used in different industrial sectors, as automotive, railway, wind power industry, replacing in many applications (crankshafts, gears and cases, camshafts,), cast irons and cast and forged steels. However, ADI grades offer a reduced wear resistance compared to low-alloy steels that can be improved within the application of surface treatments. A comparative study of the Nd:YAG laser surface hardening of ADI and medium carbon steels AISI 1045 and 4140 is presented in this work. The influence of the process parameters involved and the effect of the surface hardening on the micro-structure and the properties of the materials treated are showed.

Thursday, 16:45h - 17:00h

Use of photothermal deflection signal as a fast correlation to nano-hardness and phase characterization

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Abstract

We present the results of the correlation between the thermal diffusivity measured at the micrometer scale by means of the photothermal deflection method and the nano-hardness measurements performed by a nanoindentation technique. The results on steel surfaces treated by pulsed beams and hardened only a few microns in depth show that the photothermal method is a rapid non contact technique for characterization of the regions where the ferrite phase has been transformed to martensite in very thin surface layers. The method used [1] is based on the lock-in detection of the deformation induced on surface due to the heating produced by a modulated tightly focused low power laser. The explored region is of the order of the beam size, in our case about 3 μm but can be reduced to the diffraction limit of the objective used.

1] O.E. Martínez, F. Balzarotti y N. Mingolo. Applied Physics B. 90, 69-77, 2008.

Thursday, 17:00h - 17:15h

Hardfacing of aluminium alloys by means of Metal Matrix Composites produced by laser surface alloying

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Abstract

Metal matrix composite layers were formed on an aluminium substrate by means of laser surface alloying method. Aluminium 1200 was used as a host material and TiC particles were used as the reinforcement. The microstructure of the modified layer consisted of the hard particles uniformly distributed in the host metal matrix. A strong bond between the particles and matrix was formed in the modified layer. A Rofin Nd: YAG laser was used for melting the ceramic powder and substrate. In these experiments the laser power was fixed at 4.0 kW, the laser scan speed was varied from 0.8 to 2.0 m/min. The powder feed rate was varied from 2 to 5 rpm. The structural characterisation of the metal matrix composite included X-ray diffraction (XRD), optical and scanning electron microscope (SEM) as well as microhardness measurements. The micro-hardness of the layers increased from 20 HV to 350 HV. This represented a significant improvement of the surface properties compared to the base metal.

Thursday, 17:15h - 17:30h

Laser Surface Engineering of Mg Alloys

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Abstract

Magnesium and its alloys are of great interest in the field of automotive and aerospace industries because of their low densities (from 1.75 to 1.85 g/cm^3) and high specific strength. Despite the attractive range of bulk mechanical properties, a relatively poor resistance to corrosion and corrosion is a serious impediment against wider application of Mg alloys. A high power laser beam may be used as a source of heat to modify the surface of metallic materials by melting, alloying and cladding. In the present study, the effect of laser surface engineering on wear and corrosion resistance properties have been studied in details. Laser surface melting, laser surface alloying (with Al and Mn) and laser composite surfacing (by dispersion of SiC, Cr_2C_3 and Al_2O_3) have been attempted using a 10 kW continuous wave CO_2 laser. Followed by surface engineering, a detailed characterization of the surface was carried out by optical/scanning electron micrograph, x-ray diffraction study and the properties like wear and corrosion resistance have been evaluated in details. Laser surface melting was found to refine the microstructure with improvement in hardness and corrosion resistance properties. Laser surface alloying with Al + Mn led to formation of intermetallics of Mg/Al (Al_3Mg_2) and Al/Mn (Al_8Mn_5 and $AlMn_6$) in grain refined magnesium with improved microhardness and corrosion resistance. A defect-free microstructure consisting of uniformly dispersed Al2O3, SiC and Cr3C3 was achieved by laser composite surfacing, which enhanced the microhardness and wear resistance significantly A comparative studies of different processing have been made with the future scope of its application in automotive sectors.

Microprocessing

Monday, 14:00h – 14:15h

Femtosecond laser based functionalization techniques for biomedical applications

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Abstract

Functionalization – controlling of surface properties – is of increasing interest for many biomedical and technical applications. Here, one very attractive technique is applying microstructured surface topographies, since it enables functionalization without adding or changing workpiece materials. This can be realized using femtosecond laser material processing.
We present topography modifications in the micrometer and sub-micrometer range obtained with different femtosecond laser based techniques. For characterization of surface properties we performed wettability tests. The fabricated samples have shown promising results for biomedical applications.

Monday, 14:15h – 14:30h

Laser freeform fabrication of porous network structures for dental application

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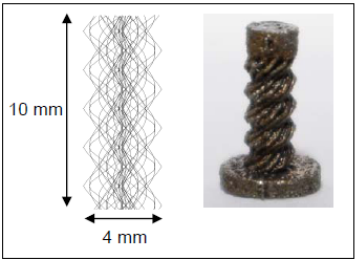
Abstract

The use of laser freeform fabrication (LFF) such as Selective Laser Melting shows great potential as production tool for parts in medical technology. LFF allows, in contrast to conventional cutting manufacturing, the realization of new design rules that render the possibility of innovative and complex part geometries. In addition to the fabrication of ordinary solid bodies, LFF enables the creation of periodic lattice structures or bionic structures that lead to novel part features. Research in process development yielded the qualification of several biocompatible powders as basic materials for LFF such as titanium or cobalt chrome alloy. Hence, by the utilization of these new design rules, it is possible to fabricate medical implants with innovative properties. Conventional tooth implants are made of titanium and have a solid body. Due to the difference in elasticity of titanium and bone stress shielding occurs. Gradient porous network structures, dimensioned for use as artificial tooth root replacement, allow an adaption of bone behavior regarding their mechanical properties. Figure 1 shows the CAD data of such a porous structure and its respective laser freeform fabricated test specimen for compressive testing.



Preliminary analyses of compressive testing yield less rigid behavior than solid specimens. Thus, in comparison to conventional solid tooth implants, use of gradient porous network structures in dental applications opens up a potential for reduction of the effect of stress shielding and, furthermore, for increased osseointegration.

Monday, 14:30h – 14.45h

Micromorphological Characterisation of Laser Modified Titanium Dental Implant Surface

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Abstract

Today, titanium and its alloys are widely utilised for manufacturing bone implants that will be subjected to biomechanical loading, because of their mechanical strength, corrosion resistance and biocompability. Surface morphologies of titanium implants are of crucial importance for long-term stability following implantation. Several surface treatment methods have been used to modify the surface morphology of titanium dental implants in order to increase the effective interfacial area of bone-implant contact. Surface treatment techniques have been devised to improve the mechanical and the morphological aspects of bone and soft tissue integration of dental implants. The laser modification technique is a unique and promising, non-contact, no media, contamination free, and flexible treatment method for modifying surface properties of materials in biomedical industry. The purpose of the present study is to investigate and compare the micro morphological characteristics of machined, blasted and laser treated Ti-6Al-4VELI titanium dental implant material specimen surfaces.

Monday, 14:45h – 15:00h

LASER-ASSISTED PRODUCTION OF CALCIUM PHOSPHATE NANOPARTICLES

M. Boutinguiza, F. Lusquiños, A. Riveiro, R. Comesaña, M. Boutinguiza, F. Quintero, J. Pou

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Abstract

Calcium phosphate-based bioceramics are widely used in medicine because of their excellent biocompatibility, bioactivity and osteoconductive characteristics. It has been also reported that the use of low crystallinity β-tricalcium phosphate (β-TCP) particles with nanosize dimensions, improve the performance of apatitic cements and increase the bioactivity when it is used in scaffolds. On the other hand natural hydroxyapatite has good metabolic activity and more dynamic response to environment, compared to synthetic biocrystals. In this work calcined fish bones which were previously milled to achieve microsized particles, was used as precursor material in de-ionized water dissolution to be fragmented by laser. A pulsed Nd:YAG laser, as well as, continuous wave Yb:YAG fiber laser were employed to reduce the size of the suspended particles.

The morphology and the composition of the obtained particles were characterized by scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX) and conventional and high resolution transmission electron microscopy (TEM, HRTEM). The results show that nanometric particles of hydroxylapatite and β-TCP can be obtained. The presence of β-TCP is due to the high temperature which causes the transformation of hydroxyapatite into β-TCP. The use of both lasers lead to the mentioned particles, but pulsed Nd:YAG laser promoted particles formation by evaporation and rapid condensation, while C.W. Yb:YAG fiber laser favoured particles reduction by melting process. The reduced particles preserve the same composition as started materials.

Monday, 15:00h – 15:15h

A computational thermal model of the laser bonding process in polymer balloon catheter medical devices

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Abstract
The polymer bonding process used to assemble cardiovascular catheters for stent delivery systems is a critical process for safety and performance. In an effort to further enhance bonding understanding, a computational model has been developed for laser welding of a polymer catheter. Utilizing the catheter symmetry, an axi-symmetric model was developed that incorporates the laser beam profile, laser absorption, optical effects, temperature dependent thermal material properties, and product component dimensions, which have wall thicknesses on the order of 50 microns. Experimental results for melt pool, bond length, surface temperature and laser drive will be presented. The data demonstrates the validity of a constant laser power model as well as a closed loop PID temperature controlled model. In addition to gaining insight into bond formation, the verified model can be used to rank key process and material inputs for quality and process control in the catheter manufacturing systems.

Monday, 15:15h – 15:30h

Ultra-short laser pulse processing of non-stripped medical quartz fiber wave guides

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Abstract

The enhanced flexibility of ultra-short laser technology has stimulated a growing interest in exploiting this technology for micro-machining. The high peak powers available at relatively low single pulse energies allow for a precise temporal and spatial localization of photon energy. Utilising the ultra-short material processing technique at a wavelength of 800nm and a pulse width of 250fs we were able to internally modify 400µm quartz medical wave guides without need of removing the nylon buffer. This method yields an alignment of locally acting stray centres near the core-cladding interface at a potentially pre-defined distribution without jeopardizing the necessary mechanical stability for medical wave guides. The optical leakage enforced by a given pattern of a few cm can be set easily above 70%, the out-coupling intensity distribution can be engineered, e.g. homogenous over a given length. The material reaction mechanism and the possible optical character of the modifications will be discussed.

Monday, 15.30h – 15:45h

Laser Based Fabrication Of Micro/Nano 3D Structures For Tissue Engineering Applications

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Abstract

A lot of studies moot the question about how the topographical features of a tissue scaffold affect cell behaviors related with viability, proliferation, motility, adhesion, morphology, cytoskeletal arrangement and gene expression. Deploying the laser based techniques, two-photon polymerization (2PP), fs micro/nano structuring (FMNS) and Laser Induced Forward Transfer (LIFT) the following structures have been fabricated: a) 3D columns of zirconium or titanium based materials have been obtained using 2PP, b) 3D micro/nano cones have been attained by FMNS and c) Scaffolds of biodegradable material have been fabricated by parallel deposition, via LIFT, of alginate gel and cells. In each case, control over the topography and the chemistry of the structures is demonstrated.

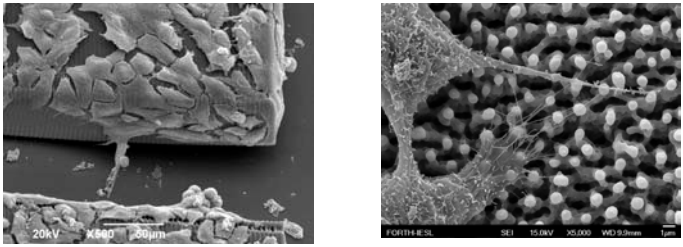

Fig. 1 SEM observations of fibroblast cells after 3 days of cultivation on 3D structures fabricated by a) 2PP and b) FMNS.

The bioactivity of the fabricated scaffolds was checked by the cultivation of murine fibroblast cell line (NIH/3T3 fibroblasts) on them. The morphologies of 3T3 NIH fibroblasts seeded on patterned surfaces were observed by confocal and SEM microscopy while for the convenient discrimination between live and dead cells the Live-Dead Cell Staining Kit (BioVision) was used. In addition, the expression and orientation of F-actin as well as the appearance of Vinculin in fibroblasts have been studied, in purpose to investigate their healthy and functional development on the modified surfaces.

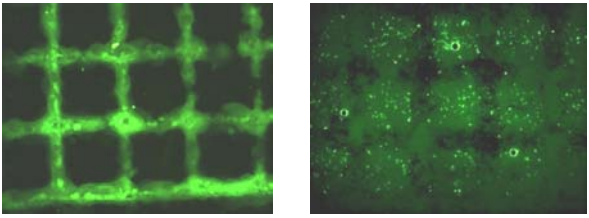

Fig. 2 Fluorescent images of 3D scaffold made via LIFT and b) cells transferred also by LIFT inside each square of the 3D scaffold

Monday, 16:15h – 16:45h

Materials for the fabrication of optical waveguides with two photon photopolymerization

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Abstract
Two photon polymerization (2PP) is an innovative method for 3D-structuring structural and functional materials. 2PP allows the fabrication of sub-micron structures from a photopolymerizable resin. By the use of near-infrared lasers it is possible to produce 3D structures with a spatial feature resolu-tion as good as 200 nm. This technique can be used in polymer-based photonic and MEMS, for 3D optical data stor-age or for the inscription of optical waveguides into materials based on a local refractive index change upon laser exposure. Since 2PP only takes place inside the focus of the laser beam, complex 3D-structures can be inscribed into a suitable matrix material.
In the presented work, 2PP is used to write optical waveguides into a prefabricated mechanically flexible polydimethylsiloxane matrix. The waveguides were structured by selectively irradiating a polymer network, which was swollen by a monomer mixture. The monomer was polymerized by two photon photopolymerization and the uncured monomer was removed by evaporation at elevated temperatures. This treatment led to a local change in refractive index in the order of $\Delta n = 0.02$, which was significantly above the industrial requirement of $\Delta n = 0.003$. The measured optical losses were around 2.3dB/cm. Since all unreacted monomers were removed by evaporation, the final waveguide was stable up to temperatures of 200°C. Since commercially available one-photon-photoinitiators are only of limited use for 2PP, a new class of photoinitiators (PIs) has been developed. These PIs exhibit a large 2PP-crossection and therefore contribute to a process with higher throughput. The PIs were evaluated using UV-Vis and fluorescence measurements. The TPA-cross-section was determined by the use an open aperture Z-scan technique. In 2PP structuring tests the ideal building parameters for each PI were determined, indicating that the presented PIs can be used at very low concentrations (0.05 wt%).

Monday, 16:45h – 17:15h

Laser fabrication of nonlinear and metallic photonic nanostructures

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Abstract
We present our investigations into the fabrication by direct laser writing of photonic structures using organic-inorganic hybrid materials that have (i) nonlinear optical properties, (ii) can be selectively covered with metal.
Direct laser writing by two photon polymerization (2PP) is a nonlinear optical technique which allows the fabrication of three-dimensional (3D) structures with a resolution beyond the diffraction limit. The polymerization process is initiated when the beam of an ultra-fast infrared laser is tightly focused into the volume of a transparent, photosensitive material. Two-photon absorption takes place within the focal volume; by moving the focused laser beam in a three-dimensional manner within the resin, fully 3D structures can be fabricated. The technique has been employed successfully in the fabrication of nano-photonic structures and devices.
Here, we present our most recent work into the structuring by two photon polymerization of a series of hybrid organic-inorganic materials. These materials fall into the following two categories:

(i) Silicon oxide-based sol-gels where a nonlinear optical molecule has been chemically bound onto the photopolymer, potentially enabling the dynamic tuning of the optical properties of the fabricated structures. The

sol-gels investigated include materials with second and third-order optical nonlinearity. One example is shown in Figure 1, where the plasmonic waveguide pictured has been fabricated using a photopolymer incorporating the nonlinear optical molecule N-(4-nitrophenyl)-(L)-prolinol (NPP).

(ii) Composite sol-gels with metal binding affinity. These materials can be structured accurately and, due to metal binding groups, can be readily metalized with silver and other metals by simple immersion in a metal bath, without the need to modify the surface of the structures or to use other, complementary techniques. An example is shown in Figure 2, where the structure has been covered with silver. As seen, the silver coating is uniform and without blemishes (Figure 3).

The combination of direct laser writing with specially designed, functional materials can lead to advanced applications in photonics and metamaterials.

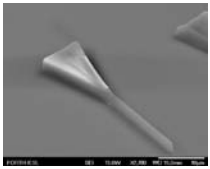

Figure 1: A plasmonic waveguide fabricated using a nonlinear optical silane

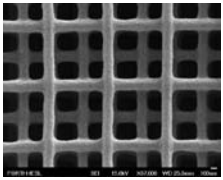

Figure 2: A 3D photonic crystal structure fabricated using a metal binding copolymer.

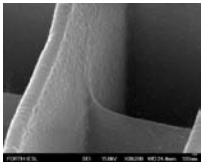

Figure 3: Detail from a silver-coated structure.

Monday, 17:15h - 17:30h

Advanced two-photon polymerization using holographic technology

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Abstract

Two-photon polymerization (2PP) of photosensitive polymer materials using femtosecond lasers is an attractive technique for true three-dimensional micro- and nano-scale structuring. Recently, the increasing 2PP process resolution leading to much solwer processing speeds became a problem for practical use. To overcome this problem, several beam separation techniques such as parallel process with a beam split optics, fly's eye type lens, or diffractive optical elements (DOE) have been demonstrated. However, these parallel processes can realize an efficient mass production technique, but they are not suitable for the fabrication of single complex structures and unsymmetrical array structures. To overcome this problem, we demonstrate a novel two-photon polymerization multi-focus setup with holographic technique generated by spatial light modulator (SLM). These multi-focus beams can induce 2PP at each focus position. In addition, each focus spot can be independently controlled in position and laser intensity with SLM.

Monday, 17:30h – 17:45h

Analytically solvable model for process parameter estimation in laser sintering

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Abstract

Various models have been developed for laser welding and melting processes. There are also approaches for the modelling of laser sintering processes. Therein, finite element methods turn out to be very time and cost consuming. To achieve a targeted adaptation of process parameters in laser sintering processes, the knowledge of changing physical parameters of single powder layers depending on the total number of layers and their geometry is indispensable. To achieve a sufficient description of the process at adequate calculation times, an analytically model based on law of conservation of energy has been evolved. The description of the powder bed layers is realized by coupling of their geometric factors with thermodynamic properties. The model is verified in a micro laser sintering process of a nickel-titanium shape-memory alloy powder. Doing so, it is possible to generate structures with gradient porosity and fully dense material as well consisting of an arbitrary number of layers.

Monday, 17:45h - 18:00h

Material analysis at selected, furnace treated, laser-generated solids

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Abstract

Structures obtained from ceramic powders by lasermicrosintering are characterized by a high porosity and an inhomogeneous material composition, in particular if powder blends are processed. During laser micro sintering of metal powder blends, only incomplete fusion of the materials to the alloy corresponding to the material ratio of the powder is obtained. By an additional furnace treatment homogenization of compound and equilibration of its modification is achieved, yielding a material more suitable for technical applications.

Examples of ceramics and metals, subjected to an additional furnace process after laser micro sintering, are presented. For example, in the case of ceramic sintering, it can be shown, that the as laser sintered solid from a mixture of alumina and silica needs additional furnace sintering to achieve its final modification of the corresponding aluminum silicate.

Monday, 18:00h - 18:15h

Ink-jet printing of conductive tracks of PCBs with laser sintering

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Abstract

Laser sintering is intended for significant reducing of conductive tracks manufacturing time with ink-jet technology. We investigate silver "nano ink" sintering conditions using YAG:Nd laser (1064 nm) with pulsed irradiation for the purpose of obtaining of maximal conductivity and optimal mechanical properties. We used silver colloid (mean particle diameter 5 – 10 nm) with organic matrix of triethylene glycol monoethyl ether. Nanoink was deposited with special ink-jet equipment onto polyimide and ceramic substrates and was sintered by 60 µm width laser beam. It is ascertained the optimal sintering conditions to be the follow: pulse energy 35 µJ, pulse width 5 µs, pulse rate 90 kHz. Specific conductivity of obtained conductive tracks reaches 10 % of bulk silver conductivity.

Tuesday, 8:30h - 8:45h

Laser Applications in the Electronic Industry

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Abstract

Electronic is a common part of our life. Everyone nowadays uses mobile phones, computers, television and whatever consumer electronic can offer to make our life more comfortable. The amount of electronics in cars increases on constant level. 20 years ago not even the car radio was included while nowadays navigation systems are sometimes standard.
All this devices need to be manufactured in high quantities, in best quality, efficient and with low cost. At the same time complexity increases through higher product diversification and shorter life times.
Laser and laser based systems are production tools which combine the requested criteria: flexibility, availability, throughput and quality in a perfect way. In the following some laser applications for the manufacturing of electronic devices and their advantages will be shown.

Laser Marking

Marking of keyboards is common technology where the country specific marking can be done on individual orders while the keyboards are pre-produced as standard. Keypads for mobile phones in various colours are done in "day-night" design via removal of thin colour layers.
Product traceability, the relatively small area needed to generate a data matrix code and the fast laser marking drives the market for machine readable codes. Good examples are wafers and dies on wafers marked without any material removal and damage of the die as well as data matrix codes on PC boards generated with CO2 lasers.

Laser Welding

There is a strong trend for consumer electronic products towards metal. More and more parts specially for the high price mobile phone segment are produced in stainless steel or aluminium. Connections between metal parts can be welded via pulsed YAG and for thin materials also with fiber lasers. Applications are mobile phone parts, PDA housings, mobile phone batteries, read/writing heads of hard disc drives, pressure sensors, lamp contacts, electro motors and many more.

On the other side is laser based plastic welding a new and growing market where sensitive electronic devices can be produced in higher quality compared to conventional methods such as ultrasonic welding.

Laser Cutting

Laser cutting is compared to marking and welding a relative small market. Various stainless steel housings, metal keypads and copper based thin material can be processed with pulsed YAG and q-switched lasers if other methods (chemical etching, punching) do not allow to achieve good enough quality. Typical applications are SD-card and solar cell cutting with q-switched lasers, lead frame cutting with pulsed YAG lasers and PC board cutting instead of sawing with CO2 lasers. .

Laser Ablation

Ablation in the electronic industry is heavily related to the photovoltaic industry which is not part of this paper.

Tuesday, 8:45h - 9:00h

Ultrafast laser ablation studies on OLED stack

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Abstract

Ultrafast laser ablation of a stack of organic light emitting diode (OLED) on a flexible polymer substrate has been carried out. Using nanosecond (ns) lasers, on flexible plastic substrates, it is difficult to selectively ablate a certain layer of the OLED stack and to stop on a specific layer underneath. The pulse duration τ , of ns lasers is longer than the electron-photon relaxation time of the material in question leading to a less efficient ablation mechanism. In femtosecond (fs) ablation, the laser pulse duration is less than the electron-photon relaxation time. This may lead to multiphoton absorption leading to a decrease in the ablation threshold. The Initial experiments carried out with femto second laser operating at 800nm shows a positive trend in selectively ablating a certain organic layer and stopping on transparent conductive layer such as ITO. The results are discussed at length comparing with the ns ablation of the same stack.

Tuesday, 9:00h - 9:15h

Study on the possibility of graphene growth on 4H-silicon carbide surfaces via laser processing

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Abstract

Graphene is a two-dimensional solid constituted by carbon atoms packed in a flat monolayer, interesting mainly for its singular band structure (gapless semiconductor) and electronic transport properties. The possibility to obtain graphene by micromechanical exfoliation of graphite has been discovered in the past, however direct growth of graphene on 4H- and 6H-silicon carbide polar surfaces has been recently performed by means of thermal annealing at temperatures exceeding 1000°C in high vacuum conditions. Graphene-based Field Effect Transistors (FETs) can be developed starting from the presence of few monolayer of graphene on 4H-SiC. In this work we use laser annealing in vacuum in order to investigate the possibility to obtain graphene on the two types of 4H-SiC polar surfaces (known in literature as "Silicon-face" and "Carbon-face"). The laser used is a self produced DPSS laser system (20W CW at 1064nm, 8ns minimum pulse width). The presence of graphene (and the number of monolayers obtained) can be studied by STM, XPS and Raman spectroscopy.

Tuesday, 9:15h - 9:30h

Investigation of the physical and optical characteristics of the solder masks marked by laser beam

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Abstract

With the mass production of electronic appliances, it gains increased ground that the product identification codes i.e. 1D and 2D codes, respectively, are marked by means of laser beams into the solder mask of printed circuit boards whereby a motif of tint different from that of layer material appears. The thickness of solder mask varies between 20 µm and 300 µm. In the industrial praxis two marking methods are used: Discoloration of the SM, the laser beam penetrates into the layer only down to a depth of several µm's; The SM is completely removed up to the copper layer, according to the pattern of Data Matrix Code. In both cases, the accurate parameters of laser processing can only be selected by means of previous testing. During the manufacture, however, problems are raised if the raw material is changed, including the changes in the thickness and/or material of the solder-stop layer. The individual materials absorb the laser radiation of the same wavelength to a different extent. The result of marking process is greatly influenced by the optic properties of the solder-stop enamels that depend on their composition and have been a little examined so far.

Tuesday, 9:30h - 9:45h

High Aspect-Ratio Micro Drilling of Silicon Wafers Using Femtosecond Lasers with Hole Diameters Controllable

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Abstract

High aspect-ratio micro drilling by lasers is increasingly demanded for industrial applications such as through vias for interconnections between layers in 3D multistack wafers. This work investigates the effects of femtosecond laser processing parameters on the hole diameters for high-aspect micro drilling, rather than conventionally on the hole depths. The hole diameters appear to be chiefly dependent on laser pulse energy but irrelevant to exposure time variation, according to the measurement results of diameters and depths of the blind holes drilled with several combinations of pulse energy and exposure time on P-type [100] silicon wafers. Further experimental study reveals that the hole diameters vary linearly with the pulse energy that increases from 3 μJ to 100 μJ. The holes can achieve 5 μm in diameter with the aspect-ratio more than 5. Samples of arrays of high aspect-ratio micro drilling on silicon wafers are illustrated and discussed with a view to TSV (through silicon vias) applications.

Tuesday, 9:45h - 10:00h

Sintering of printed nanoparticle structures using laser treatment

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Abstract

Printed intalligence is a promising new technology to produce low-cost electronics. Non-conductive circuits can be printed using nano-scale metal particle inks. Due to the nanoscale size of the particles, the typical sintering temperatures of 100–300 °C are only a fraction of the macroscopic melting point of the corresponding materials, thus allowing the use of paper or plastic substrates.

Sintering of printed nanoparticle structures using laser treatment has been investigated at VTT. Laser sintering can be utilized in manufacturing of printed conductor structures such as antennas, circuits and sensors. A drop-on demand printer was used to print patterns with metallo-organic silver nanoparticles on a flexible polyimide substrate. Laser sintering was made with a 940 nm CW fiber coupled diode laser. Process was optimized using different scanning speeds, laser power levels, line separation and repetition rounds. Conductivity of laser sintered samples was compared to conductivity of samples sintered in convection oven.

Tuesday, 10:00h - 10:15h

Singulation of Optoelectronic Devices

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Abstract
Introduction:

This paper compares the possibilities and benefits of laser scribe technology in combination with controlled mechanical fracture to achieve a high quality and throughput manufacturing process for the ever shrinking compound semiconductor optoelectronic devices.

Discussion:
The test material, a 230µm thick GaAs wafer was laser scribed with a 355nm DPSS laser at 300mm/s resulting in a 3µm kerf with 7µm envelope. The V-shaped scribe reduces the overall material thickness and thus provides a defined starting point to achieve controlled fracture for device singulation (Fig. 1). The fracture was induced by a mechanical, parallel impact knife and programmable anvils in the breaker system.

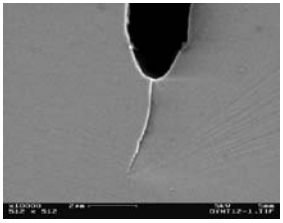

Fig. 1 V-Shape Laser Scribe

Conclusion:
The device edge definition and facet quality is superior to that of a conventional dicing saw performance, yet adding the benefit of debris and waste material management control, reducing the dicing street width and delivering higher overall throughput performance.

Tuesday, 10:45h - 11:00h

Incubational effects in femtosecond laser ablation of metals: Changes in reflectivity

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Abstract

When a metal surface is exposed to multiple femtosecond laser pulses, the threshold fluence for ablation is known to decrease with increasing number of pulses, a phenomenon known as incubation. In the present investigation, it is suggested that the observed incubation is a signature of a strong decrease in the material reflectivity, which leads to an increase in the absorbed energy. In our experiment, a feedback system, which allows for the simultaneous measurement of the reflectivity of the sample and the depth of the ablated hole as they evolve during the laser exposure, is demonstrated. This information is used to test theoretical models describing the ablation process including incubational effects.

Tuesday, 11:00h - 11:15h

Laser Percussion Micro-Drilling of Al and Cu Alloys by 532 nm Green Light

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Abstract

A laser percussion micro-drilling process have been tested on 11 different aluminium alloys (Series 1000 – 2000 - 5000 and 6000; in particular AA1090 - AA2024 - AA5083 – AA 5059 – AA 5383 - AA5754 - AA6082 and AA 8090) and on 7 different Cu alloys. The thicknesses tested for Al alloys ranging from 70 - 240 - 480 - 800 and 1000 µm as well as 50 – 100 – 180 – 280 and 500 µm for Cu alloys. A Nd:YAG Laser Source, (QUANTEL), YG 580 type, was used for the experiments. This laser, in Q- Switch Mode, has the following characteristics:

Repetition Rates (Single Shot, 2Hz and 10Hz), Focusing Lens BK7 - 60 mm F.L., λ_2 532 nm - Pulse Width 11ns – E 150 mJ / pulse.

The aim of this work was the possibility to obtain micro-drills on the range from 500 to 25 µm diameters with some Aspect Ratio high values. At the same time the realization of some "blind drills", "passing holes" as well "straight and tilted holes" were proved

Tuesday, 11:15h - 11:30h

Laser micro machining of metal foils, ceramics and silicon substrates

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Abstract

Laser induced micro ablation using diode-pumped solid-state lasers offers the possibility to machine and structure a whole range of different materials at adequate speed and quality. For example, the machining of metals, ceramics and semi conductors is of high industrial importance, however, they differ strongly in their thermal, optical and mechanical properties. To avoid negative thermal and mechanical effects at given laser parameters such as pulse width (nanosecond regime) and wavelength (e.g. 1064nm) that obstruct the precision the LMTB GmbH has developed and implemented new trepanning devices. The trepanning system allows for a fast distribution of the laser pulses at variable displacement and beam angle and is especially designed for the generation of micro holes, pockets and grooves. The optical devise can be easily customized for different lasers and applications. The presentation focuses on the processing strategies and quality assessment, e.g. processed hole tolerance and taper accuracy.

Tuesday, 11:30h - 11:45h

3D micro machining with a high repetition rate ultra short fibre laser

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Abstract

First investigations in laser micro machining with high repetition rate ultra short fibre lasers have shown new mechanisms in laser material interaction, such as heat accumulation and particle shielding. Heat accumulation effects cause locally rises in temperature accompanied by better absorption conditions and lower ablation thresholds of the irradiated material. Otherwise laser processing with repetition rates in ranges faster 500 kHz shows phenomena of particle shielding and plasma shielding. Furthermore processing with high laser power causes the occurrence of laser induced periodical surface structures (LIPSS), for example ripple formations or conical micro structures, which influence the material surface behaviour.

However, respectively the new processing technology and laser material interacting mechanism innovative machining strategies have been developed. Results of 3D structuring of e.g. steel or silicon with a high repetition rate ultra short fibre laser are presented to demonstrate the possibilities and limits of the new technology in laser micro machining.

Tuesday, 11:45h - 12:00h

Ablation of an amorphous $Ta_{42}Si_{13}N_{45}$ film with a femtosecond laser pulse

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Abstract
Films of atomic composition $Ta_{42}Si_{13}N_{45}$ and 260 nm thickness have been irradiated in air with single laser pulses of 200 femtoseconds duration and 800 nm wave length. As-deposited the films are structurally amorphous under high-resolution cross-sectional transmission electron microscopy. A laterally truncated Gaussian beam of a fluence of around 0.6J/cm^2 incident normally on the film ablates 23 nm of material. Cross-sectional transmission electron micrographs show that the surface of the remaining film contains many densely distributed sharp protrusions that sometimes surpass the height of the original surface. Sphere-like features of enhanced electron transparency are also present near the surface, especially as the fluence rises. These features are apparently associated with the nitrogen because an amorphous nitrogen-free film irradiated similarly does not show them. Nanograins aren't observed after ablation in dark field micrographs and none are detected by glancing angle x-ray diffraction scans either. By all evidence the remaining film remains amorphous after the pulsed femtosecond ablation.

Tuesday, 12:00h - 12:15h

A design of experiments study of Nd:YAG laser milling for the production of micro-dies

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Abstract

Laser ablative milling is a very useful process for machining parts that are difficult to machine conventionally. It is a micromachining process and has great potential for manufacturing micro-dies. To fully exploit the advantages of laser milling, processing parameters must be optimised for each application according to the material used and the required surface finish.

A design of experiments approach was used to study the effects of power, frequency, pulse length and scanning velocity of a pulsed Nd:YAG laser miller. A feature representative of a micro-die was machined into tool steel, a material frequently used for micro-dies. The output parameters measured were material removal rate and surface roughness.

Material removal rate can be increased by varying other parameters instead of simply increasing the power. This leads to a reduction in the energy usage and hence overall cost. Results also showed that velocity and frequency have a strong interaction.

Tuesday, 12:15h - 12:30h

High rate ablation with 3 kW single mode fibre laser

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Abstract

A novel processing technology (High Rate Laser Ablation) realized by employing a 3kW continuous wave single mode fibre laser and a high deflecting scanning system with deflection velocities up to 25m/s, was investigated subject to applied focal lengths and scanning velocities as soon as laser power. In strong dependence of the processing parameters areas with deep welding effects, debris deposition, and material ablation were observed, whereby the ablation process initiates by exceeding a material depending processing velocity.
First machining results on stainless steel 1.4301, different high speed steels and high-purity Al_2O_3 ceramics will be discussed by means of the major influencing processing parameters. The maximum achieved ablation rate was 50mm^3/s.
Further the fabrication of cavities in stainless steel will be shown based on cross sections and digital microscopy images to demonstrate the possibilities and limits of this new kind of high power laser machining.

Tuesday, 14:00h – 14.15h

Numerical study of laser pulse duration effect on material removal depth and melt thickness for laser pulses in the range from femtosecond to nanosecond

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Abstract

The results of a theoretical study are reported demonstrating the effect of laser pulse duration of an ultrahigh intensity laser on interactions with metals. A modified Two-Temperature Model (TTM) was used to simulate ultrashort laser pulse drilling. The cardinal modification to the well-known formulation of TTM includes an electron acceleration mechanism in the near surface area due to the effect of ponderomotive force. The electron acceleration increases with laser intensity increase, such that at laser intensities corresponding to femto- and picosecond pulse durations the energy deposition depth becomes significantly larger than the optical absorption length. This causes deeper drilling accompanied by thick melt production. The developed model demonstrated accurate predictions of drilling depth in a wide range of interaction conditions for a variety of materials. The computation results show that the optimal pulse duration in the range from 500ps to 1ns that minimizes melt thickness. The computations also predict that the minimum in the drilling dependence on pulse duration is in the vicinity of 50 ps. In contrast to conventional ultrashort pulse theories, melt production can be reduced by using longer pulses without sacrificing drilling rate by choosing the optimal pulse duration for a material.

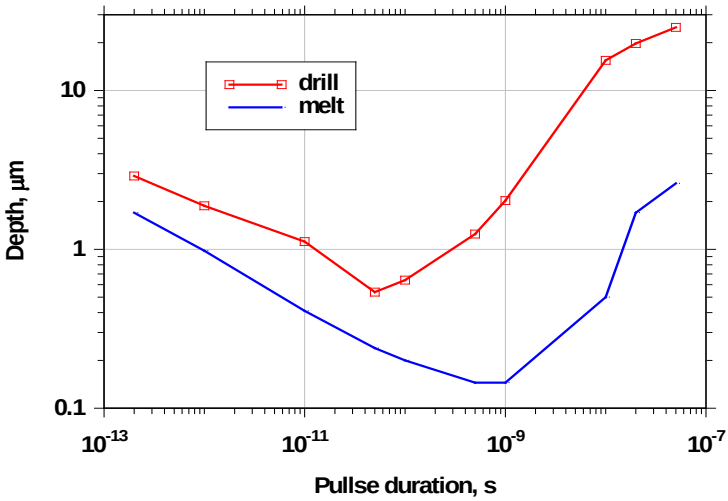

Figure 1: Depth of drilling per pulse and depth of melt produced during titanium drilling as a function of laser pulse duration for constant laser pulse energy E=200 µJ, laser beam radius on $1/e^2$ level w_0 = 6.5 µm, and laser wavelength λ = 532nm.

Tuesday, 14:15h -14:30h

Microdrilling of metals using high repetition rate ultrashort laser pulses at 1030 nm and 515 nm

S. Döring[1], A. Ancona[1,2], S. Hädrich[1], J. Limpert[1], S. Nolte[1,3], A. Tünnermann[1,3]

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[2] CNR-INFM Regional Laboratory LIT3, Physics Department, Bari, 70126, Italy
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Abstract

We investigate the influence of pulse duration (800 fs to 19 ps) and wavelength (1030 nm and 515 nm) on the microdrilling of different metals. In the experiments we used an Ytterbium-doped fiber CPA system providing pulse energies and repetition rates up to 70 µJ and 1 MHz, respectively. The number of pulses to drill through the 0.5 mm thick samples is influenced by particle shielding and heat accumulation depending on laser parameters and material properties. For metals with low thermal conductivity particle shielding leads to a decrease in ablation efficiency at several hundred kHz, while this is overbalanced by heat accumulation at higher repetition rates at the expense of reduced quality. In contrast, metals with high thermal conductivity can be processed without such influences even at the highest repetition rates investigated. The experiments at 515 nm demonstrate that the main parameter governing the ablation efficiency is the pulse energy for these experimental conditions.

Tuesday, 14:30h - 14:45h

Modelling of cluster formation during laser ablation process

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Abstract

Recent developments of fiber and disc laser sources are leading to a continuously increasing brilliance of laser radiation. As one result, the brilliance enables higher intensities at the workpiece during cw operation. This combination can modify the interaction of radiation with matter for the case of ablation processes. Various authors have shown that cluster condensation takes place within the expanding vapour plume. The cluster formation occurs due to short pulse laser ablation. With regard to short pulse laser ablation, the cluster formation is slow in growth in relation to pulse duration. Thus, losses due to scattering and absorption of radiation within the cluster dominated plume are negligible. As a consequence of the combination of high available intensity and cw operation, the situation has changed. Based on the comparison between experimental results and numerical analysis, the influence of cluster formation and losses due to scattering on laser ablation process is discussed.

Tuesday, 14:45h - 15:00h

Application of novel nozzle to reduce spatter production inmicrodrilling with nanosecond fiber laser

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Abstract

In laser micromachining the introduction of PW fiber lasers, which are the evolution of CW fiber laser sources, presents a great interest due to their positive features (high beam quality and strong focusability), which are fundamental to obtain small features. In this work percussion microdrilling on commercially pure titanium with an IPG 50 W nanosecond fiber laser is investigated. Due to the long pulse width as well as the high energy of the investigated laser source, the material removal mode is prevalently melting-contributed. As a consequence typical defects of the melting regime, such as taper, recasted material and spatter on the hole entrance, are produced. A new nozzle design is investigated aimed at reducing spatter production on the hole entrance without affecting the material removal rate. The new nozzle consists of an additional chamber, where the inert gas is supplied at high pressure, preventing deposition of the vaporised and molten material around the hole. The effect of shielding gas and process parameters is pointed out, when both the standard nozzle and the new nozzle are used.

Tuesday, 15:00h - 15:15h

Monitoring of phase transitions under millisecond pulsed laser irradiation by comprehensive optical diagnostics

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Abstract

Synchronised application of complimentary optical diagnostic tools provides comprehensive analysis of heat-and-mass transfer induced by Nd:YAG laser irradiation of INOX 304L substrates. The following optical devices are employed: (a) original multi-wavelength pyrometer in the near infrared range (1,370- 1,531 µm); (b) IR-camera FLIR Phoenix RDAS with InSb sensor with 3 to 5 µm band pass arranged on 320x256 pixels array; (c) commercial ultra-rapid camera Phantom V7.1 with SR-CMOS monochrome sensor, up-to 10^5 frames per second for 64x88 pixels array. Laser irradiation parameters: variation of energy per pulse in the range 15-30 J at a constant pulse duration of 10 ms with and without protective gas (Ar). True temperature evolution is restored based on the method of multi-colour pyrometry; this way, melting/solidification is analysed. Variation of intensity of the surface evaporation visualised by camera Phantom V7.1 is linked with the surface temperature evolution. The results are compared with numerical simulation.

Tuesday, 15:15h - 15:30h

Laser structuring of metal surfaces: micro-mechanical interlocking

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Abstract

An interesting application of surface structuring is the ability to develop new composite materials by employing micro-mechanical interlocking (MMI). The present state-of-the-art in composite materials is typically based on advanced chemical bonding, and to a much less extent the use of designed surface topography. These techniques may, however, not provide bonding that exhibits sufficiently high mechanical strength as well as a high tolerance to temperature changes that are essential for many industrially relevant situations. In our experiments we have investigated the relationship between the laser generated surface morphology and the mechanical strength of the joint. It is shown that the bonding can be increased by several orders of magnitude yielding interlocking of very high quality. Furthermore the optimum laser parameters for joining stainless steel and plastic are determined.

Tuesday, 15:30h - 15:45h

Two-dimensional mapping of surface microcracks in TiAl by femtosecond laser-induced breakdown spectroscopy

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Abstract
TiAl exhibits high temperature properties and little weight compared to pure titanium and expects to become a promising material for aeronautic applications. The alloy features a lamellar microstructure which strongly affects formation as well as propagation of cracks making it hard to get a full comprehension of its microcrack growth behavior. The small proportions of both microcracks and lamellae, being in the range of µm and below, impose an experimental challenge.
A laser-assisted two-dimensional mapping technique will be presented for microcrack investigations based on laser-induced breakdown spectroscopy (LIBS) combined with femtosecond laser radiation. Fs-LIBS offers spectrochemical analysis with a high spatial resolution in the range of µm [1]. Analysis of the characteristic lines emitted by the plasma enables the detection of specific elements in the lamellar microstructure of TiAl to distinguish between the different lamellae. Current results and progress of this 2D-mapping technique will be given.
[1] A. Assion *et al.*, Appl. Phys. B **77**, 391-397 (2003).

Tuesday, 16.15h – 16.45h

High-class processes and productivity in micro machining enabled by disk lasers

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Abstract

In micro machining, established laser processes use short pulse laser on a moderate power level. Drastically improvements in quality are achieved by using ultra-short pulse laser machining, enabling burr free production with negligible heat affected zone (HAZ). In order to achieve economically viable technologies, throughput and hence mean power must go along with these improvements in quality.
We report on disk technology enabling high mean power for pulse durations in the pico-second and in the nano- second range with high beam quality. The pulse durations (t_p) and average powers range from 50 W at t_p <10 ps to 750 W at t_p <50 ns. Using a disk for the active medium enables scaling towards high pulse energies with defined intensities on the medium, efficient cooling and hence prevents from thermal lensing. The benefit of these new laser sources is illustrated by examples of improvements in existing applications as well as examples on their enabling character in production.

Tuesday, 16:45h - 17:00h

Novel route to high quality ablation in a range of materials with a 400W single mode continuous wave fiber laser

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Abstract

Low power (up to 500W) single mode Ytterbium fiber lasers operating at 1080nm with a very good beam quality (M2 ~ 1.10) are routinely being used for a range of micromachining applications The high brightness of the fiber laser enable high power densities even at modest power levels, which is sufficient for cutting a range of thin metals, capable of welding of various materials including high reflective material and also drilling small holes in metals including aerospace alloys.
To date very little work has been carried out with these lasers for ablation applications. The laser ablation of metals is normally carried out with Q-switched pulsed lasers ranging from microsecond to femtosecond pulse durations, pulse frequencies up to 50 kHz and extremely high peak powers (MW). In this work, laser ablation of a variety of materials including TBC superalloys used for aerospace has been demonstrated with a single mode fiber laser up to 400W. The paper will investigate the material removal rates and ablation quality.

Tuesday, 17:00h - 17:15h

Structuring of Metal Films by the Laser Beam Interference Ablation

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Abstract

Interfering of laser beams with the high pulse energy gives an opportunity to direct structuring of materials by ablation. We present results of the laser beam interference ablation (LBIA) of thin metal film on the glass substrate irradiated by picosecond laser with a pulse energy upto1 mJ. Laser beam was divided in two beams by using the diffractive optical elements. The 4-F imaging system was used to produce interference pattern on the surface of the metal film. The grating consisting of metal wires with a width of about 200 nm and the period was 2 µm were produced in chromium film of 100 nm thick. The area of grating was extended by scanning the beam along the interference lines. Use of multiple laser beams is a way in formation of diverse patterns. The LBIA technique can be applied for production of periodical structures on surfaces and in thin films.

Tuesday, 17:15h - 17:30h

Study of micro-structured master fabrication on Ni alloy by DPSS laser ablation technique

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Abstract

A Ni alloy master microstructure for imprinting lithography was produced by means of a laser micromachining process. A self fabricated Ni alloy was chosen as master material due to its excellent properties such as low cost, good hardness and strength, high resistance to corrosion and no sticking problem with glass. Laser micromachining process was carried out by using a self produced DPSS laser system (20W CW at 1064nm, 8ns minimum pulse width).
The effect on the sample after different processes was analyzed in order to find the right conditions to produce a microstructured master avoiding the formation of debris. In particular, the influence of laser fluence, working frequency, number of passes, presence of inert gas in the laser processing chamber and presence of an applied electric field on Ni alloy was investigated. Both morphological and chemical surface modifications of Ni alloy were observed with a FESEM and 3D microprofilometer.

Tuesday, 17:30h - 17:45h

Prediction of cavity shape in laser drilling with nanosecond pulses

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Abstract

A time dependent thermal modeling of laser drilling process with nanoseconds pulsed laser is presented in this work. The model takes into account the photon-absorption processes, specifically inverse bremsstrahlung and photo-ionization of excited species, melt ejection and vaporization material removal mechanisms and it includes also the heat conduction losses. In the model, the cavity shape is estimated by solving two coupled integral energy balance equations for different radial positions of the laser beam profile. The depth in the centre of the cavity is estimated solving the complete energy balance equation with the maximum laser intensity. The second equation does not take into account the photo-absorption processes and it is used to estimate the laser intensity which is necessary to melt the surface. The diameter of the cavity is simply estimated by calculating the radial position of the laser beam profile in which the intensity attains that value. A 60 W multimode DPSS Nd-YAG laser was used for the experimental verification of the model. The depth and diameter of the holes drilled in low carbon steel were measured for a large set of laser beam parameters showing a remarkable agreement with the cavity shape theoretical prediction.

Tuesday, 17:45h - 18:00h

REMOVAL RATE MODEL FOR LASER CHEMICAL MICRO ETCHING

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Abstract

Laser chemical micro etching leads to high precision structures and debris-free smooth surfaces. It is a non-contacting and flexible manufacturing method. However, a particular requirement for the economic machining of precise shapes is to scale the material removal depending on the required geometrical precision and to control the removal rate of the processed material. The establishment of a local quality control loop for the process requires the development of a qualitative process model. In this paper, a model of the removal rate required for the local quality control loop is presented. The model is validated for different materials used for the manufacturing of micro forming tools. Those tools have demands for close tolerances and a good surface quality at small dimensions, but their mechanical properties strongly limit the variety of structuring technologies which can be applied.

Tuesday, 18:00h - 18:15h

Laser-induced breakdown spectroscopy and plasma plume photography of iron oxide materials

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Abstract

Iron oxide powder is a relevant by-product in industrial steel production. Iron oxide (Fe2O3) powder, pressed Fe2O3 powder pellets and sintered Fe3O4 ceramics are investigated by laser-induced breakdown spectroscopy (LIBS) and plasma plume photography. The plasma plume expansion into ambient air is studied by time-resolved photography and it depends significantly on the morphology of the laser irradiated material. Non-luminous particles are ejected from Fe2O3 powder and pressed powder pellets up to several hundreds of microseconds after the nanosecond laser pulse (λ = 1064 nm). Element analysis is performed by LIBS without any pre-treatment of the Fe2O3 powder. The achieved limits of detection (LOD) for minor and trace elements aluminium, manganese, nickel, and silicon are 8, 860, 66, and 15 ppm, respectively. Preliminary experiments indicate increased signal intensity, reduced standard deviation and improved LOD by using double laser pulses (λ = 532 nm) for plasma excitation.

Wednesday, 8:30h – 8:45h

Laser Joining Processes for Photovoltaic Module Production

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Abstract

Laser processes offer a large potential to meet the market driven demands for new solar cell concepts, a significant increase in efficiency and highly productive processes for solar cell and module manufacturing.
Due to the decreasing thickness of silicon solar cells below 200 µm contactless joining processes for module production required. A suitable technique for the electrical contacting of solar cells is laser-beam soldering, due to the low and locally restricted energy input involved. By selecting suitable solders, the joining temperature can be reduced to a minimum, and thanks to the non-contact process, the solar cells are not subjected to mechanical stress, unlike with conventionally used bowtype electrodes. By use of a diode laser system in combination with a highly dynamic galvanometer scanner the soldering process is examined. An alternative to soldering is the welding process using solid-state lasers. In comparison to soldering the process duration can be reduced by a factor of ten and the use of fluxing agent can be avoided.

Wednesday, 08:45h – 09:00h

Femtosecond laser grooving on silicon wafers for applications to solar cells

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Abstract
The quality of about 40 µm wide grooves ablated on silicon wafers using different scanning methods is investigated. Firstly, grooves were formed with a 10X microscope objective (Numerical Aperture 0.26). In order to ablate a trench with width of 40 µm, the laser beam was defocused to enlarge the spot size from 5 µm to 40 µm. Although the width of 40 µm can be achieved, the excess energy adds roughness to the surrounding area and bottom of the trench. Next, the effect of processing with focused beam in conjunction with different scanning algorithms was examined.
Through appropriate algorithm design, symmetric trench with quality finishing surface without debris accumulation can be realized (refer to Figure 1). Figure 2 shows a seed layer Ni film (approx. 300 nm thick) deposited using electroless plating and Cu is then electroplated on top of Ni (approx. 20 µm thick). The metal contact formed with silicon wafer can be applied to the groove formation in Buried Contact Solar Cells.

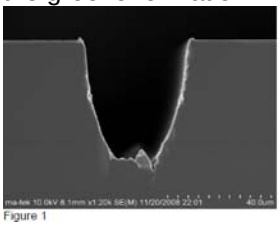
Figure 1

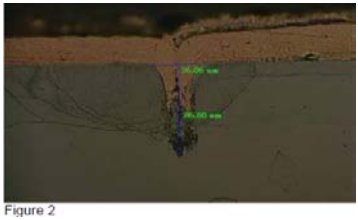
Figure 2

Wednesday, 9:00h - 9:15h

2D structure formation on the surface of CdTe crystals under pulse laser radiation

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Abstract

In this report the formation of ordered nano- and microstructures on the CdTe surface were investigated depending on power density (I) and pulse number (N) of the multimode Q-switched ruby laser radiation.
It is shown, that the nanocluster ensemble are formed on the surface of CdTe crystals under the action of a nanosecond single pulse of laser emission depending on I. A 2D structure of the surface nanore-lief is generated at the intensity I > I1 = 4 MW/cm2. The lateral size of the nanoclusters (period of the relief structure), first, increases and, then, decreases with an increasing of laser intensity.
It is shown, that process of surface nanostructuring depending on N occurs in three stages and its ordering depend on N oscillation character.Nanoclusters of dome-shaped form and 2D structure is formed at the second stage (10 <N <16). Possible mechanisms of formation and ordering of nano-dimensional clusters are discussed.

Wednesday, 9:15h - 9:30h

Micro-Raman study of the thermal affected zone generated after a laser-scribing process in a-Si:H photovoltaic thin-films

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Abstract

Laser scribing processes are being extensively used in thin-film photovoltaic (PV) technology. In particular, the fabrication of thin-film PV modules requires laser scribing steps for the monolithic series interconnection of the cells. In this sense, in order to perform thin-film PV modules based on a-Si:H, selective ablation (by means of laser direct or back-scribing) of this intrinsic material is required. Depending on the laser parameters employed in the scribing process (wavelength, pulse duration, frequency and pulse energy), the generation of a thermal affected zone in the vicinity of the patterned area is expected, especially when laser sources with *ns* pulse duration are employed. In fact, such thermal effects induced in the a-Si:H intrinsic layer could lead to an impoverishment of the electrical properties of the final module. In this work, a microstructure study of the zone closest to the laser patterned area was carried out. Micro-Raman spectroscopy was employed for the analysis of laser patterned a-Si:H layers deposited by PECVD onto glass substrates. The influence of the laser pulse duration on the patterned material was evaluated comparing the effects obtained with pulses in the range of *ns* and pulses in the range *ps*. Besides, the influence

of the laser wavelength was also evaluated using three different radiations for the a-Si:H patterning (355, 532 and 1064 *nm*). A clear transition from the amorphous to highly crystalline silicon is obtained as zones closer to the laser patterned area were evaluated. Such transition resulted specially remarked for the highest wavelengths. Finally, thermal effects appear to be reduced when using shorter pulse durations.

Wednesday, 9:30h - 9:45h

Structuring of CIS thin-film solar cells by ultrafast laser pulses with industrial relevant process speed

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Abstract
The production of CIS ($CuInSe_2$) thin film solar cells is still employing some mechanical steps of structuring, where thin layers with a thickness of approximately 1 µm are selectively separated in so called pattern 1, 2 and 3 (P1, P2 and P3) for the monolithic serial interconnection.
Here we report for the first time the selective structuring by direct and indirect induced picosecond laser ablation. We demonstrate that a ca. 500 nm thick Mo-layer (P1) can be structured with a process speed of more than 4000 mm/s without detectable residues and damages by direct induced laser ablation exhibiting a non- thermodynamic nature. A 1.5 µm thick ZnO film (P3) can be line separated with speeds up to several 1000 mm/s by indirect induced laser ablation, also a non thermodynamic ablation method occurring at low energy densities.
A 2.5 µm thick CIS layer is structured by direct laser ablation at higher energy densities up to 200 mm/s indicating thermodynamic behaviour. The validation of the processes P1 and P2 for the functionality within a CIS solar cell; as well as the first validation results for the P3 process will be presented.

Wednesday, 9:45h - 10:00h

Comparative study of nanosecond and picosecond laser pattering of thin film or photovoltaic solar modules based on a-Si:H.

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Abstract
Monolithical series connection of silicon thin-film solar cells modules performed by laser scribing plays a very important role in the entire production of these devices. Therefore a good characterization of the laser process, along with the assessment of different laser sources is compulsory. The current process is developed for a configuration of modules where the glass is essential as transparent substrate. In addition, the change of wavelength in the employed laser sources is sometimes enforced due to the nature of the different materials of the multilayer structure which make up the device. The aim of this work is to characterize the laser monolithic interconnection process accomplished with nanosecond and picosecond laser sources from the film side with the purpose of evaluating these laser sources to improve the process. The use of ultrafast sources, such as picoseconds lasers, gives the possibility to consider materials and substrates different than currently used, making the process more efficient and easy to implement in production lines. This approach with nanosecond and picosecond laser sources working from the film side offers no restriction in the choice of materials which make up the devices and the possibility to opt for an opaque substrate.

Wednesday, 10:00h - 10:15h

Damage-less laser ablation of thin films for Silicon solar cells

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Abstract

The ever-growing demand for renewable energies is an efficient motor for scientific developments in this field. Especially for Photovoltaics the processing with laser sources has recently gained more and more attention. As a contact-less, highly precise and fast machining tool the laser is ideally suited for processing solar cells, but only rarely used in industrial production up to now. To establish lasers as a standard tool for Photovoltaics is the major goal of the European funded SOLASYS project.

With the process of damage-less laser ablation of thin coatings an important tool for modern cell concepts was already developed in several institutes. The project aims at the implementation of these processes into demonstration lines with industrial scalability. In this paper the ablation of thin Silicon Nitride passivation layers from the front side of the cell is examined and the capabilities for industrial scale-up are illustrated. Especially the demands for zero damage to the underlying Silicon and a processing time of one second per wafer have to be met to make this process competitive.

Wednesday, 10:45-11:15

Controlling laser-induced refractive index changes in optical glasses

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Abstract

Ultrafast lasers emerged as promising tools to process embedded refractive index changes in bandgap materials. Photonic functions were demonstrated in various glasses of optical relevance. However, the irradiation outcome depends on the material relaxation paths as well as on the spatio-temporal characteristics of the writing beam. It can result in both positive and negative index variations, the latter being detrimental for waveguiding applications. These facts impose specific limitations to the photoinscription process. Recently, new beam manipulation concepts were developed which allow a modulation of the energy feedthrough according to the material transient reactions, enabling thus a synergetic interaction between light and matter and, therefore, optimal results. We consequently discuss the possibility of controlling laser-induced physical phenomena employing automated temporal pulse shaping. Examples of adaptive design of refractive index changes in "thermal" glasses will be shown as well as insights into 3D parallel writing techniques for complex structures using wavefront engineering.

Wednesday, 11:15h - 11:30h

Laser micro-machining for targets manufacturing

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Abstract
In the frame of the French "SIMULATION" program, CEA designs and manufactures targets dedicated to experiments on high power lasers. Laser micromachining techniques are widely employed to pattern 2D or 3D objects in a wide range of materials: metals, polymers, foams, dielectrics. Very strict specifications have to be fulfilled, in term of dimensions (in millimetre range), roughness, cutting edge quality (reduced heat affected zone, with few deposited materials). Different home-made laser work stations are used and described here. They are optimized for high-precision cutting, drilling and engraving. They are mainly based on excimer lasers (photo-ablation of polymers) or femtosecond laser (microablation of metals), and require a strict control of beams transverse profiles combined to a micrometric motion of the sample. Some results are given: micro-drilling of plastic micro-shells, engraving sinusoidal functions on polymer substrates, and foamballs machining.

Wednesday, 11:30h - 11:45h

Machining of Transparent Materials with Short Pulse and Ultrashort Pulse Laser Sources

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Abstract

This paper discusses the machining of transparent materials using two short pulse (nanoseconds) and one ultrashort pulse (femtoseconds) laser sources. The investigations were carried out with short pulse Nd:YAG lasers (1064 nm, 532 nm, and 355 nm) as well as a high repetition rate fs-laser (1030 nm). In our experiments the laser beam was focused onto the sample with both a stationary objective and a laser scanner with an f-theta-objective.
In our study we investigated in detail the dependencies of controlled defect generation inside bulk glass material on important process parameters like wavelength, pulse width, pulse repetition rate, and irradiation regime. Due to a smart arrangement of these defects in lines, planes, and shells cut surfaces can be generated. Finally, cutting of 3d parts, consisting of bulk transparent material, becomes possible.

Wednesday, 11:45h - 12:00h

Backside etching of transparent materials – Comparison of different techniques and applications

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Abstract
Direct micro- and nanomachining of transparent materials by laser radiation is of high industrial interest. Laser-induced backside etching techniques enable a precise patterning of these materials using industrial accepted ns-lasers. In dependence on the used absorber different implementations of laser-induced backside etching are known such as LIBWE (Laser-induced wet etching), LESAL (Laser-etching at a surface absorbed layer), and LIBDE (Laser-induced backside dry etching). The laser energy is absorbed at the substrate absorber interface resulting in heating-up the absorber and subsequently a near-surface region of the transparent material resulting in etching of the surface. Although a number of investigations are known the mechanism of these etch techniques are not clear yet.
In this presentation the characteristics of the etching using the different techniques are compared with respect to the threshold, the rate, the efficiency and the quality of the etch process. From the comparison of these processes characteristics the mechanisms of backside etching as well as the differences between the techniques are discussed. Finally, applications of these etching techniques are discussed regarding the mechanism and the characteristics of the different techniques.

Wednesday, 12:00h - 12:15h

Novel laser-based machining process for high precision optical position encoders

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Abstract

High precision optical position encoder systems are high value items that contribute to automated industrial precision manufacturing processes. They provide reliable high-accuracy position feedback essential in machine tools, assembly systems, high quality printing, robotics and medicine. In order to significantly reduce the cost of manufacturing and reduce waste, as well as to produce an improvement of their overall performance, there is a requirement to enhance the resolution of these encoders, which requires the feature sizes of the encoder scale to be reduced. In this university-company collaboration we are investigating novel techniques for encoder scale manufacture with the required precision and at commercially viable process rates. We present in this paper our development of a novel laser-based process to achieve the fine scale feature sizes (~200 nm vertically; 4 μm horizontally) at realistic process rates. This process uses a combination of nanosecond pulsed laser machining and post-processing.

Wednesday, 12:15h - 12:30h

Processing Organic Polymers using a Laser Plasma EUV Source

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Abstract

Organic polymers (PMMA, PTFE, PET, PI, etc.) are considered as important materials in micro-engineering, especially for biomedical applications. However, it is difficult to produce micro-parts with a high aspect ratio and sub-micron structural accuracy from some of these materials (i.e. PTFE). The possibility of high aspect ratio micromachining of PTFE by direct photo-etching using synchrotron radiation was demonstrated. In this paper we present the results of the experiments on micro- and nano-processing of various organic polymers using a compact laser plasma EUV source based on a gas puff target irradiated with 0.8 J/4 ns laser pulses at 10 Hz. EUV radiation in the wavelength range from 2 to 15 nm were focused onto polymer samples using a focusing optical system based on a grazing incidence ellipsoidal mirror. The use of the optics made possible to improve significantly the throughput of the processing. The results of investigations are presented and discussed.

Wednesday, 14:15h - 14:30h

Nanostructuring of solid surfaces ablated with femtosecond laser pulses

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Abstract

We present our recent experimental studies of nanostructure formation process in femtosecond laser ablation of solid surfaces. In a series of experiments for diamond-like carbon (DLC) film, we have found that the nanostructure starts to be formed in surface areas with small roughness, where the nanoscale ablation is preferentially induced with the help of a *local field* enhanced on the surface with a high curvature. This process accounts for the initiation of nanoscale ablation at a low fluence below the ablation threshold and its polarization dependence. We have attributed the origin of periodicity in the low-fluence ablation to the excitation of *surface plasmon polaritons* that produce periodically enhanced local fields in the surface layer. The observed period in nanostructures agrees well with the estimated plasmon wavelength. This picture reconciles with the characteristic properties of nanostructuring observed so far for the DLC, as well as for TiN film and solid silicon.

Wednesday, 14:30h - 14:45h

In Volume Selective Laser Etching of sapphire

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Abstract
Micro structuring of sapphire and fused silica is an important market. The reduction of time and material loss is still a challenge for the production of micromechanical parts in sapphire. New techniques for the processing of sapphire to enable for example the production of microfluidic devices and sensors that combine optical and microfluidic functions are requested.

In Volume Selective Laser Etching (ISLE) is a laser assisted wet etching process. First the sapphire is irradiated and by that modified with fs-laser radiation. Afterwards the sample is etched for about 48 hours in a 48% hydrofluoric acid. KOH also can be used as a solvent for the wet etching step.

Due to the non-linear absorption process in transparent materials a complete variability in three dimensions is given. This allows the modification also in the volume of sapphire samples for the fabrication of, e.g micro channels and hollow volumes. Moreover, Selective Laser Etching (SLE) can be used as a kind of cutting process to fabricate 3D micro parts, (Fig.1). New results achieved with the ISLE/SLE technique will be shown and discussed.

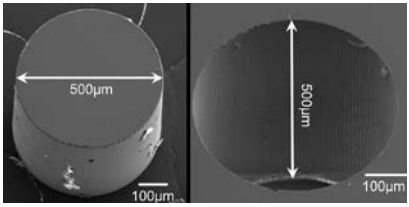

Fig. 1: Cylinder fabricated with ISLE in sapphire. Mechanical removed cylinder (left) from the cylinder hole (right).

Wednesday, 14:45h - 15:00h

Strategies in laser machining and surface structuring of glasses and glass ceramics with a new developed trepanning device

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Abstract

New strategies in laser micro processing of glass and other optically transparent materials are being developed with increasing effort. Utilizing diode-pumped solid-state laser generating ns pulsed green (532nm) laser light in conjunction with adequate processing optics can provide for high-quality glass machining with excellent efficiency. Correct choice of laser pulse distribution is of great importance to avoid strong chipping or cracking at ablation rate of other 100µm per pulse. For example, a 1mm through hole in 1.5mm thick B270 can be accomplished in 5 to 10s at an average laser power of only 3W. The paper presents several laser machining examples: long aspect micro drilling, slanted through holes, internal contour cuts, micro pockets and more complex geometries. Materials involved are soda-lime glass, B33, B270, D236T, AF45 and BK7 glass, quartz, S-TIH53 and Zerodur. The LMTB development of a new trepanning system as a key processing tool will also be presented.

Wednesday, 15:00h - 15:15h

Single step holographic grating inscription in a PMMA-based copolymer

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Abstract

Volume holographic gratings have recently attracted interest as wavelength-selective devices, for applications such as wavelength stabilizers for laser diode sources. These thick gratings are usually produced using various photosensitive materials like photo-thermo-refractive glass and specially prepared polymers, where two or more process steps are required. In this study a copolymer with MethylMethAcrylate as base material is used. The polymer has a glass transition temperature up to 155°C, which enables the use on higher laser powers unlike commercially available PMMA. The refractive index of the polymer is modified using 325-nm radiation. The polymer was not sensitized prior to irradiation, and after irradiation, no development was needed. The gratings were recorded with a Lloyd mirror setup and the phase mask method. The reflection characteristics were measured with a modified Michelson interferometer and a tunable laser source. Volume holographic gratings with extremely narrow bandwidth and angular selectivity can be produced on the polymer.

Wednesday, 15:15h - 15:30h

High speed parallel laser processing with a high power excimer laser

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Abstract

Nederlands Centrum for Laser Research (NCLR) has developed the Sirius 1000, a 1 kW UV excimer laser with an excellent beam quality.
The Sirius 1000 laser beam is nearly diffraction limited and therefore does not require mask projection systems. NCLR will present the latest developed applications for this laser such as high quality parallel hole drilling in complex materials. For example holes in Carbon Fibre Composite (CFC) for acoustic damping in aircraft nacelles as well as film cooling holes in ceramic coated metal parts of jet engines. Furthermore, the rapidly growing photovoltaic market has promising applications such as annealing, crystallization and texturing of solar cells.
By combining parallel beam processing and smart beam handling the Sirius 1000 laser system unites the industrially required high speed processing of YAG and fibre lasers with the quality levels associated with the high brightness femto-second lasers at costs unmatched by other UV lasers.

Wednesday, 15:30h - 15:45h

Thermal flash treatment in a controlled atmosphere under a magnetic field for magnetic tunnel junctions (MTJ)

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Abstract

A magnetic tunnel junction (MTJ) consists of an ultra-thin insulator placed as tunnel barrier between two metallic ferromagnetic layers. Si(100) / Co(20nm) / MgO(2nm) / CoCr(20nm) was the MTJ stack composition. Magnetic field cooling treatment was used in order to freeze the spin structure to a particularly ordered phase. This was obtained by increasing the temperature to 450°C, close to magnetic disorder, keeping the magnetic field during the cooling of the sample. A 50W at 808nm self made diode laser system was employed while the magnetic field was applied through the polar expansion during the increase of the temperature.
The annealing was performed also employing a boron nitride radiating oven, pre-heating the sample in an inert atmosphere (1mTorr of Ar). The laser treatment was applied in a load-lock, where sample was transferred by a translational manipulator.

Wednesday, 16:15h - 16:45h

Recent advances in ultrafast laser micromachining of transparent materials

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Abstract
Modification of transparent materials with ultrafast lasers has attracted considerable interest due to a wide range of applications including laser surgery, integrated optics, optical data storage, 3D micro- and nano-structuring [1]. Three different types of material modifications can be induced with ultrafast laser irradiation in the bulk of a transparent material, silica glass in particular: an isotropic refractive index change (type 1); a form birefringence associated with self-assembled nanogratings and negative refractive index change (type 2) [2,3]; and a void (type 3). In fused silica the transition from type 1 to type 2 and finally to type 3 modification is observed with an increase of fluence. Recently, a remarkable phenomenon in ultrafast laser processing of transparent materials has been reported manifesting itself as a change in material modification by reversing the writing direction [4]. The phenomenon has been interpreted in terms of anisotropic plasma heating by a tilted front of the ultrashort laser pulse. Moreover a change in structural modification has been demonstrated in glass by controlling the direction of pulse front tilt, achieving a calligraphic style of laser writing which is

similar in appearance to that inked with the bygone quill pen [5]. It has also been a common belief that in a homogeneous medium, the photosensitivity and corresponding light-induced material modifications do not change on the reversal of light propagation direction. More recently it have observed that in a non-centrosymmetric medium, modification of the material can be different when light propagates in opposite directions (KaYaSo effect) [6]. Non-reciprocity is produced by magnetic field (Faraday effect) and movement of the medium with respect to the direction of light propagation: parallel (Sagnac effect) or perpendicular (KaYaSo effect). Moreover a new phenomenon of ultrafast light blade, representing itself the first evidence of anisotropic sensitivity of isotropic medium to femtosecond laser radiation has been recently discovered [7]. We anticipate that the observed phenomena will open new opportunities in laser material processing, laser surgery, optical manipulation and data storage.

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Wednesday, 16:45h - 17:00h

Surface Modification and Functionalization of polymers and thin films on µm-scale

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Abstract

Laser material processing has been demonstrated to be a perfect tool for precise adjustment or tuning of surface properties of polymers and various thin film materials intended for applications in bio-interfaces, microfluidic chips or thin film electrodes. Different process strategies were developed and applied in order to realize localized chemical patterns, defined morphological structures or topographical modifications at the micro-scale. Polymers (polystyrene, polymethylmethacrylate) and amorphous carbon thin films were laser surface treated with respect to modifying their wettability and biocompatibility for applications in micro-fluidic chips and for bio-medical devices. In the case of thin film lithium ion battery development a significant improvement of battery performances was realized by laser structuring and modification of electrode materials ($LiCoO_2$) deposited by r.f. magnetron sputtering. Selective material removal, thermal effects as well as material redeposition play an important role during formation of micro-topographies, micro-sized periodical cone structures and chemical and morphological changes, which will be discussed with respect to application fields.

Wednesday, 17:00h - 17:15h

Monitoring of laser cutting of paper materials

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Abstract

Aim of study was to examine monitoring of laser cutting of pigment filled paper materials. This study was carried out in Lappeenranta University of Technology with University of Joensuu. Laser equipment used in this study was 2700 W CO_2-laser.
The material tested was copy paper with grammage 80 g/m^2, which was cut with laser beam with different cutting parameters. Spectral data emissions of cutting was examined by a sensor.
This study shows that on-line-monitoring of laser cutting of paper materials is in principle possible. Changes in equipment, process and material parameters have clear effect to spectral data received.
A change in the spectral data was noticed both in case of change in laser power and cutting speed.nThe spectral measurement was able to show different changes in material. Changes like holes, adhesive tape, multiple papers, office correction fluid and paper glue was possible to detect with the system tested.

Wednesday, 17:15h - 17:30h

Femtosecond laser ablation properties of BK7 and Ti:Sapphire

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Abstract

Short-pulse laser of femtosecond duration has been used in ultrahigh precision processing of optical, electronics, and micromechanical devices. This occurs due to the unique characteristic of the interaction between such short laser pulses with matter that in special conditions do not transfer heat to the parent material. To find such conditions for processing BK7 and sapphire in the range of femtosecond pulse length, a series of measurements were performed to determine superficial ablation threshold and ablation rate as function of the number of pulses and pulse length. The experimental procedures used two different methods for the threshold ablation measurement, comparing the traditional one with that developed at our lab. Optical and electronic microscopies as well AFM were used for the characterization of the ablated area. The results obtained have been used for precision processing of optical glasses and to help in finding conditions for increasing the fluence damage threshold for Ti: Sapphire crystals used in amplification chains.

Wednesday, 17:30h - 17:45h

Laser polishing of fused silica

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Abstract

A novel process for polishing fused silica involving CO_2 laser irradiation is presented. By this technique the roughness can be reduced to Ra < 10 nm. Processing rates for polishing of fused silica samples are up to 1 cm²/s.
The CO_2 laser irradiation is absorbed in a few tenths of microns in the silica sample. Therefore the laser irradiation is used to heat up a thin surface layer tight to the evaporating temperature without causing material removal. By the heating the viscosity in the thin layer is lowered. The roughness flows out due to the surface tension and the sample is polished. The samples are preheated to reduce thermal stress and to avoid cracks. The residual birefringence can be reduced to 5 nm/cm by tempering, what is usual for standard optics.

Wednesday, 17:45h - 18:00h

Dual laser beam induced breakdown spectroscopy of alloy samples using simultaneous CW-CO_2 and Q-SW Nd:YAG lasers

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Abstract

In this work, the enhancement of metal emission lines of Nd:YAG laser induced micro plasma is investigated due to the thermal effect of simultaneous irradiation of a CW-CO2 laser. The enhancement of emission lines was achieved at higher temperature with minimal distortion of the target where the focal point of Nd:YAG was located ~0.5mm from the sample surface. The alloy sample fineness is determined using dual beam to achieve precise measurements and minimal destructive simultaneously.

Thursday, 8:30h - 9.00h

Laser Droplet Joining – Systems, Process and Applications

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Abstract
New joining applications always demand new and innovative joining technologies in order to meet the different requirements of today's and future production. Laser Droplet Joining is a joining technology that opens up application possibilities beyond state of the art laser joining methods. At Laser Droplet Joining the process is realized by a laser generated liquid metal droplet which is deposited onto the parts to be joined. Regarding the restrictions of conventional laser micro welding or brazing, the advantages of Laser Droplet Joining become obvious: The droplets offer sufficient material to bridge gaps between the joining partners. The thermal influence on the joining partners is only given by the energy stored in the droplet. This technology is suited to join high reflective parts and heat sensitive components e.g. thin metallic foils or wires on thin metallizations of ceramic substrates. Different system technologies for the realization of the Laser Droplet Joining process with their advantages and disadvantages will be shown and discussed. Further investigations shown in this paper are focused on the process sequence, especially on the droplet creation, droplet flight and joining process on different materials for applications in the fields of electronics production, precision engineering as well as medical technology.

Thursday, 9:00h - 9:15h

Laser transmission welding and laser soldering of flexible flat cables on three dimensional devices by usage of one laser system

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Abstract

For the 3D-MID-Technology flexible interconnected devices can supply manyadvantages and lead for example to a higher amount of integrated features in onesingle device. Production orientated laser welding and laser soldering of flexible interconnected devices like flat flexible cables or flexible printed circuits on selective metalized substrates made of thermoplastics represent a promising approach to manufacture more flexible assemblies in the field of 3D-MID.Based on results concerning the weldability of similar and non-similar flexible andalso rigid thermoplastics experimental work on the improvement of the compatibilityof non-similar thermoplastics in accordance to the aimed process chain, comparativeconsideration of different metallization processes, thermal analyses of engaged laser processes, development of system technology and also accomplishment of joining considerations and characterisation of partial automated generated joints is presented in this paper. Outstanding findings are experimental results on laser welding and laser soldering.

Thursday, 9:15h - 9:30h

Laser Transmission Welding under special Consideration of Scattering

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Abstract

To efficiently and reliably weld thermoplastics using laser transmission, the joining partners must have matching optical properties. Not only do the influence of the transmittance, reflectance and absorbance on the beam characteristics have to be taken under consideration, but so do the scattering caused by the crystalline structure and the added aggregates. Until now the scattering of polymers has been measured by CCD or CMOS cameras, but reliable measurement is difficult to achieve without great effort, and the possibility of extrapolating the results to other sample thicknesses is given.
For this reason there is a demand to determine geometry-independent values like the scattering and absorption coefficients. In this paper a way to determine theses values by spectroscopic analyses is explained and results are shown. In addition a material characterization with regard to the optical properties is possible with this method, too.

Thursday, 9:30h - 09:45h

Local and temporal laser beam modulation strategies for the robust and highly efficient welding of polymers

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Abstract

The latest development of laser sources with excellent beam quality has brought new opportunities and also challenges for the laser welding of polymers. This paper presents the latest results for the polymer welding using high brilliance laser sources together with advanced irradiation strategies based on the local und temporal modulation of the laser beam such as the recently developed method called TWIST® – Transmission Welding by an Incremental Scanning Technique. This approach leads to the achievement of an optimized thermal management within the welding zone, an exact control of the temperature field generated by the absorbed laser energy, and a significant increase of process robustness, welding quality and process flexibility and efficiency. Experimental results for welding of different polymers with a weld seam width from 80 µm up to 800 µm and a processing speed up to 30 m/min are presented and discussed.

Thursday, 09:45h - 10:00h

Localised Laser Joining of Micro-Devices for Hermetic Packaging Using a Glass Frit Intermediate Layer

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Abstract

Packaging is one of the remaining issues in the production of micro-devices and MEMS. Standard techniques involve high temperatures, strong electric fields and whole device heating, which might be harmful for sensitive devices to be packaged. Intermediate layer bonding using localised laser heating offers a promising alternative whereby a considerably smaller amount of heat energy is applied in a highly localised manner. In this paper we present hermetic bonding of standard electronic packages according to MIL-STD-883E using a glass frit intermediate layer and localised laser heating. The device temperature in the centre of the package is kept below 400K throughout the entire process despite a required temperature from 600K to 650K in the joining region. A further development of this process to provide bonding of packages containing a moderate vacuum is also presented, relevant for the packaging of accelerometers and high Q-Factor devices.

Thursday, 10:00h – 10:15h

Spatter formation and keyhole observation with high speed cameras

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Abstract

Pores and spatters are a severe issue in high-brightness laser keyhole welding. An improved understanding of the process is necessary to develop means to prevent these effects.

A key to understand the spatter behaviour is to observe the welding process with high speed cameras around the workpiece. Different views of the process, from above (in different angle), from below and also from the side through a glass in to the keyhole, were combined. Results of such experiments are presented in the present talk.

Wednesday, 10:45h - 11:15h

Fusion welding technology of glass based on new concept using ultrashort pulse lasers

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Abstract

Glass has been widely used in a variety of fields due to its excellent mechanical, physical, optical and chemical properties. Nevertheless no reliable joining techniques of glass are available at the moment. The authors have developed a novel fusion welding technique of glass using ultrashort pulse lasers of fs to ps regimes based on a new concept where the interface of glass plates is selectively melted by nonlinear process without any absorbent and no cracks are developed without any pre- and post-heating. A mathematical model of thermal conduction developed is in good agreement with the contour of the experimental molten zone in different glass including fused silica and borosilicate glass. Physical process of laser-matter interaction in fusion welding of glass has been studied in details. Mechanical strength attained was as high as base material at high throughput competitive to metal welding, showing this process can be used in industrial manufacturing.

Thursday, 11:15h - 11:30h

Experimental and Numerical Studies on Laser Micro Welding of Aluminium Alloys

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Abstract

Laser beam micro welding can be implemented into the production process of small components. One of the main challenges in the laser process development is the realization of small weld seams with high mechanical stability, gas tightness and high aspect ratio. For aluminium alloys the weld seam geometry, microstructure, hot cracking susceptibility and porosity are affected significantly by the laser power and the temporal laser pulse shape.

Within this paper we have studied the effects of the laser beam pulse shaping in the time domain on the quality of the welding seam in laser micro welded AlMg3 with a thickness of 0.2 mm and 1 mm thick AlMg4.5Mg foils, respectively. The pulse shaping was realized by a time sequence of three different rectangular pulses with different duration and power level. The first pulse was used to pre-heat the sample, welding occurred with the second pulse and the third pulse controlled the melt pool behaviour. The power level and the duration of the single pulses were varied systematically and the resulting microstructure was analyzed by SEM. The experiments were accompanied by numerical simulations based on a finite volume model which considers the transient heat flow, melt convection and the evolution of a gas capillary during the deep penetration welding process.

Thursday, 11:30h - 11:45h

Laser Welding of Polymers – Superior Process Curve

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Abstract

Goals of industrial manufacturing are clearly defined: increasing product quality and process stability while simultaneously decreasing cycle times and costs. Application of laser technology may achieve these goals. Pre-Conditions are being familiar with determining-factors of production, striving for a holistically approach and holding a brilliant process understanding.
Until now, for setting up production processes with polymer welding a characteristic process curve and a partly extensive qualification procedure is considered. Both tools are limited to react quickly if changes of process conditions occur, such as material fluctuations. Therewith, industrial goals are not fully reachable.
On the basis of numerous experimental investigations and process modelling the idea of a superior process curve will be introduced. Up to now, it considers the global tensile strength maximum for contour welding if power and feed rate are varied. Additionally, approaches will be presented to expand the idea on the combined consideration of tensile strength, processing time and costs to fulfil industrial demands and goals.

Thursday, 11:45h - 12:00h

Performances of Micro Ring Welding as an Alternative Method for Laser Spot Welding

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Abstract

Novell high brilliance laset sources offer new processing for micro welding applications. An alternative method for spot welding is to move a comparatively small laser focus around a circular path, performing multiple revolutions e.g. with a galvoscanner. Experiments revealed that the shape of such welds can be controlled very precisely to spot welds carried out with a non-moved beam. The additional process parameters like circle diameter and track speed enable precise adjustment of the weld width and depth.

The thermodynamic mechanisms of this micro ring welding procedure have been investigated in previous experiments. Within the scope of this paper the energy balance of the process shall be explored in order to gain deeper understanding of the process capabilities and limits. Therefore welds carried out with varying focus diameter in different materials are examined regarding especially the influence of circle and focus diameter on the weld shape.

Thursday, 12:00h - 12:15h

Pulsed Nd:YAG laser beam welding: Effect of pulse shape modulation on the weld pool flow and solidification

J. Wilden[1], S. Jahn[1], P. Kotalik[1], T. P. Neumann[1], R. Holtz[2]

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Abstract
Nd:YAG laser beam welding with pulse shape modulation is studied both experimentally and theoretically. Observational results on the interaction between time-dependent heat fluxes and flows in the weld pool as well as on solidification of the molten material are presented. In the welds produced with the modulated laser pulse, finer and more homogeneously distributed grains are found. Using an axisymmetric 2D model for heat transfer coupled with surface tension driven flow of molten metals undergoing solid-liquid and evaporation phase transitions in the weld pool, it is shown that the time modulation of the pulse power influences the melting front and flow velocity which together with the predicted undercooling may explain the fine-grain structure of the resolidified welds that have no cracks inside.

Thursday, 12:15h – 12:30

Alloying Elements losses of Al5754 and SS316 during pulsed Nd-Yag laser welding and corresponding modeling

M. Jandaghi[1], P. Parvin[1*], M.J. Torkamany[2], J. Sabbaghzadeh[2]

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Abstract

Weld metal composition change of SS316 and aluminum alloy5754 during pulsed laser welding in the keyhole mode is investigated. A model was suggested based on the kinetic theory of gases and the thermodynamic laws to predict the concentration of volatile elements. The model results were supported by the measurements obtained from the LIBS (laser induced breakdown spectroscopy), Energy Dispersive X-ray/Wavelength and Dispersive X-ray (EDX/WDX) analysis. It is indicated that the laser parameters such as power density and pulse duration significantly influence on the vaporization rate of various elements. The element traces have been investigated to show that while Mn and Mg concentrations decrease in the weld metal, dose of base alloys like Al and Fe will increase simultaneously.

Thursday, 14:00h - 14:15h

Process Analysis of Laser Beam Welding Steel Sheets in Overlap Configuration by Using a 3D Transient Simulation Model

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Abstract

To gain a profound understanding of the laser beam welding physics a three dimensional simulation of laser keyhole welding was developed. The results obtained by this simulation help to understand different aspects of the physics of the keyhole and the melt pool like the melt pool perturbation e.g. caused by vaporized zinc and the formation of instabilities in the keyhole front at different wavelengths. The presented model includes the calculation of the heat flux in the solid and molten phase and a temperature dependent melting and solidification model. Different boundary conditions are modelled for the heat equation to describe alternating ambient influences on the work piece. The free surface of the melt pool is modelled using a Volume of Fluid method. This approach takes the coupled physics into account, i.e. the velocity field of the fluid given by the Navier-Stokes equation, the pressure balance and the surface tension of the liquid-vapour interface.

Thursday, 14:15h - 14:30h

Observation of evaporating surfaces and vapour flows at capillary front geometries

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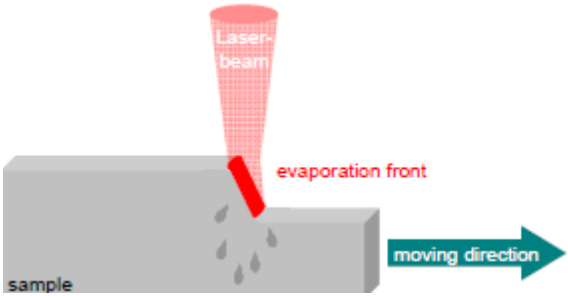
Abstract
In laser beam deep penetration welding it is known from X-ray observations that melt flow can be directed downwards at the capillary front, whereas in numerical simulations flow around the capillary often takes place in horizontal planes. To find driving forces for this downward flow, the laser-material interacting surface and the occurring vapour flow were directly observed. As detailed observation of the front is impossible during deep penetration welding, narrow metal bars were melted, see sketch.



As a result it was observed that humps exist on the evaporation front. Their size depends on the feeding rate. These humps are not only moving downwards as a wavelike surface structure, but also transport a good portion of the melt. The laser beam energy is only incoupling on the humps' top, while the shaded areas remain colder. Vapour plumes emerge only from these illuminated areas. In consequence vapour plumes are not perpendicular to the mean evaporation front.

Thursday, 14:30h - 14:45h

A 3D Transient Numerical Model of Solid, Liquid and Gas Phase during Laser Beam Drilling with Short Pulses

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Abstract

In laser beam drilling there is an opposing trend between quality and removal efficiency. Ultrashort laser pulses in the pico- and femtosecond range offer high structuring accuracy, however, suffer from low material removal rates. Therefore, in many industrial applications short laser pulses in the micro- and nanosecond range are still widely common. In order to investigate the influence of pulse length, pulse energy and pulse repetition rate on the laser beam drilling process with short laser pulses at the University of Erlangen-Nuremberg a 3D transient Volume of Fluid Model including solid, liquid and gas phase was developed. Within this paper simulation results showing the influence of the mentioned process parameters on spilling and burr formation and on the drilling hole geometry shall be presented.

Thursday, 14:45h - 15:00h

Basic study of melt transport and hole-formation during ultrashort pulse laser drilling

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Abstract

The production of small holes with high quality and high aspect ratios in metals with ultrashort laser pulses gains importance because of the flexibility and quality which is achievable. Although the fraction of evaporated material is higher than for longer pulse durations, unwanted melt recast can occur especially if high pulse energy is used to achieve the productivity objectives. Further advances in high quality laser drilling require a deeper understanding of melt dynamics which can be obtained by diagnostics of the drilling process. The material expulsion in the form of droplets from a bore hole was found to be an important mechanism of ablation even for ultrashort laser drilling at high fluences. Furthermore differences of hole-formation and melt transport comparing percussion and helical drilling can possibly explain the quality advantages of helical drilling.

Thursday, 15:00h - 15:15h

Laser induced color centers in glasses: similarities to X-ray excitation and possible implications for optic design

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Abstract

Ionizing radiation (X-ray, gamma rays, electrons) can induce numerous changes in the physical properties of glass. Most obvious effect is visible coloration, which is caused by the accumulation of color centers (defects). The application of induced color centers has prompted a renewed interest since these can be generated and bleached reversibly. Recently, it has been demonstrated that glass coloring can be induced by ultra short femtosecond laser pulses. This paper presents results on laser induced color centers using longer picosecond laser pulses. At a wavelength of 355nm and a pulse width of 6ps a surprising modest peak power threshold of only 10 kW/cm^2 for the laser induced coloring in soda-lime glass is obtained. In addition, picosecond laser pulses at 532 and even 1064nm induce color centers in many different glasses. The paper discusses the transmission changes, non-linear optical effects and possible implications for future optics guiding ultra-short laser pulses.

Thursday, 15:15h - 15:30h

High Resolution LIBS of sapphire using femtosecond double pulses

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Abstract

In our presented setup tailored femtosecond laser radiation is focussed by a microscope objective onto the surface of a sapphire sample. Irradiating with fluencies closely above the critical damage threshold, plasma is formed on the specimen surface emitting characteristic optical radiation. First results show a strong increase of the optical plasma emission (LIBS signal) using double-pulsed femtosecond laser radiation, compared to single pulse experiments with identical total pulse energies.

Three specifiable regions can be detected preliminary attributed to following photo physical processes: bound electron physics (t< 10ps), recombination of plasma electrons (10 ps<t<100ps), and phase transition followed by an enhanced concentration of atomic constituents in the ablation plume (100ps<t<2ns). LIBS using tailored femtosecond laser radiation with a microscope enables micro-chemical analysis of inorganic as well as organic materials with real µm-resolution and increased spectrochemical sensitivity.

Thursday, 15:30h - 15:45h

Thermal model of single track formation at selective laser melting

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Abstract

A model geometry is proposed where a normally incident laser beam draws a line on the top of a sandwich-like target consisting of a thin powder layer based on a semi-infinite solid substrate of the same material. The substrate simulates the previously remelted powder layers. The volumetric deposition of laser energy in the powder layer is numerically calculated by the radiation transfer equation for an equivalent absorbing scattering medium. The input parameters of the model are the radiative and thermal properties, the diameter and the power of the laser beam, the scanning velocity, and the thickness of the top powder layer. The model gives the temperature distribution in the laser-target interaction zone and the shape of the melt pool. Process parameters are estimated where a wide metallurgical contact between the melt pool and the substrate is formed, which is necessary for obtaining low-porosity parts. The calculated melt pools are analysed for capillary instability. It is shown that the Plateau-Rayleigh-type instability tends to separate too elongated or weakly bound with the substrate melt pools into droplets. This gives the estimate of the scanning velocity where the process becomes instable, which correlates with experiments.

Thursday, 16:15h - 16:30h

The influence of process gases on laser drilling

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Abstract

When drilling with laser radiation, the choice oft he process gas and the pressure must be determined as process gas parameters. Choosing the right process gas parameters in order to achieve a specified drilling result can reduce production costs by minimizing the amount of process gas or switching to a cheaper process gas.
Process gas parameters are important for the productivity of the drilling process and the quality of the drilled hole. Productivity is measured by the drilling time necessary to drill through a workpiece with certain thickness. Quality can be described by geometrical and metallurgical characteristics such as a hole diameter or the thickness of the recast layer.
Depending on the requirements, a specific gas is used, e.g. oxygen to achieve a high productivity when drilling deep holes and argon to avoid oxidation marks. Drilling productivity and quality can be influenced by combining effects of different process gases when drilling one hole with µs or ms pulsed laser radiation. Changing the process gases during drilling is presented resulting in increased productivity and quality.

Thursday, 16:30h - 16:45h

Understanding enhanced laser micro-machining of silicon in halogenated gas ambients

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Abstract

Enhanced nanosecond laser micro-machining of silicon in halogenated gas ambients of tetrafluorethane (R-134a) and sulphur hexafluoride (SF_6) is reported. Results show that depending on the aspect ratio of the machined feature, 35% – 100% increase in throughput can be obtained for these gases, compared to flowing air. The enhancement effect is identified from analysis of the accumulated ablated matter, re-deposited on side-walls of the laser–machined trenches. Capacitive–based relative humidity sensors, real time imaging of the laser interaction zone, and pH analyses of gas exhausts confirm the chemical decomposition of the fluoride gases. Chemical decomposition of R-134a suggests that hydrofluoric acid (HF) is formed and plays an important role in self cleaning the sidewalls of the laser machined trenches. The chemical decomposition of SF_6 proceeds differently and indicates that debris fluorination and volatile SiF_4 generation are important in enhancing the laser machining process for this gas.

Thursday, 16:45h - 17:00h

Direct Generation of Conducting Microstructures by Laser Induced Plasma Assisted Ablation with ps - Laserpulses

B. Neuenschwander, G. Bucher, P. Schwaller, C. Nussbaum, B. Joss, M. Muralt, P. Schütz

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Abstract

Laser Induced Plasma Assisted Ablation (LIPAA) can be used to generate arbitrary shaped contacting paths on transparent substrates. Using ps-laserpulses ($\Delta\tau$ = 10 *ps*) allows the direct generation without post processing, required with ns-pulses. The generated paths typically consist of particles with grain sizes in the nm range. The average grain size and the covered surface area drop exponentially with the distance from the laser track and both can be influenced by the laser parameters and the experimental conditions. This allows to tune the thermo-electrical parameters of the paths. Especially dense parallel paths or finger structures show interesting effects in the transverse electrical conductivity (between the paths), e.g. switching between ohmic and semiconducting behavior is realized by changing the temperature while the impedance strongly depends on the humidity. Applications are seen in the field of sensors and as catalysts in micro reactors.

Thursday, 17:00h - 17:15h

The investigation of micro-structuring on glass by ArF eximer laser in SF6 atmosphere

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Abstract

The excimer laser irradiation on the glass surface in SF_6 ambient gas, in spite of the glass ablation the self-organized micro-structuring takes place. In fact it is due to surface ablation leading to oxygen and electron which ejects from the surface and because of large dissociation cross section, makes SF_6 decompose afterwards exited fluorine which reaches the glass surface interacts with silicon to fabricate microstructure on the ablated sub-layer. Optical parameters of laser treated glass are different with bare one.

Joint Sessions together with CLEO Europe

Tuesday, 14:30h – 15:00h

Technology trends for High Power Fiber Lasers

J. Minelly

Coherent Inc., 5100 Patrick Henry Drive, Santa Clara, CA 95054, USA

Abstract

Fiber laser technology trends are discussed. While CW fiber laser applications are well served by conventional fiber designs, pulsed applications require advanced LMA fiber designs. Single emitter and bar based pumping schemes are compared.

Tuesday, 15:00h – 15:30h

Recent technical and marketing developments in high power fiber lasers

B. Shiner

IPG Photonics Corporation, 50 Old Webster Road, Oxford, MA 01540, USA

Abstract

The presentation will discuss recent advances in high power fiber lasers, including new and future fiber laser offerings. Also a review of the impact that fiber lasers are making in the material processing market and new applications that fiber lasers have developed

Tuesday, 15:30h – 16:00h

Recent Progress In High Efficiency Tm-doped Fiber Lasers

B. Samson, A. Carter, K. Tankala

Nufern, 7 Airport Park Road, East Granby, CT 06026, USA

Abstract

Work is advancing in the area of high efficiency, Tm-doped fibers. In this talk we will review the recent work in power scaling both CW and pulsed systems at 2um. Applications for the technology will also be covered.

Tuesday, 16:30h – 17:00h

400W class fibre lasers for manufacturing applications

M. Duka, S. Norman, A. Appleyard

SPI Lasers, 3 Wellington Park, Tollbar Way, Hedge End, Southampton SO30 2QU, UK

Abstract

Performance and application benefits of 400W-class fibre lasers with near diffraction-limited beam quality and with exceptional control capabilities in specific fine-feature manufacturing applications (cutting / welding / sintering) are presented.

Tuesday, 17:00h – 17:30h

High power fibre lasers: Exploitation of unique properties

J. Nilsson, Y. Jeong, C.A. Codemard, C. Farrell, L. Vasquez, J. Ji, M.S.Z. Abidin, G. van der Weisthuizen, S. Yoo, J.K. Sahu

University of Southampton, Southampton, UK

Abstract

High power fibre sources have reached several kilowatts of output power. Besides power, control, efficiency, manufacturability, and reliability are important attractions. We will discuss these unique properties and their exploitation.

Tuesday, 17:30h – 18:00h

Latest multi kW fiber laser application in Japan

T. Ishide

Mitsubishi Heavy Industries, Tokyo, Japan

Abstract

Industrial applications of fiber lasers in Japan will be reported, including an advanced heat treatment using a 40 kW fiber laser system.

Thursday, 16:30h – 17:00h

Fundamentals of Fiber Laser Remote Welding and Deep Penetration Welding

S. Katayama

JWRI, Osaka University, Ibaraki, Japan

Abstract

In remote welding and deep welding with fiber laser, the effects of plume behavior and laser absorption on weld penetration were elucidated by observing the behavior of a molten pool and a keyhole.

Thursday, 17:00h – 17:30h

Principles of Femtosecond Pulse Tailoring for Adanced Material Processing

M. Wollenhaupt

Institute of Physics, University of Kassel, Germany

Abstract

We study laser control of two basic ionization processes in dielectrics on intrinsic time and intensity scales with temporally asymmetric pulse trains.

Thursday, 17:30h – 18:00h

Ultrafast laser induced microexplosion: A new strategy to synthesise super-dense nanomaterials

A. Rode[1], S. Juodkazis[2], H. Misawa[2], E. Gamaly[2]

[1.] Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra, Australia
[2.] Research Institute for Electronic Science, Hokkaido University, Sapporo, Japan

Abstract

We observe a new high-pressure phase of sapphire formed by focusing ultrashort laser pulse. The results pave a new way to synthesise new super-dense nanomaterials in highly nonequilibrium conditions created by femtosecond laser pulses.