Lasers in Manufacturing Conference 2023

Laser deposition and sintering for the fabrication of a multicomponent microelectronic device with Barium Titanate as dielectric component

Maria Canillas[a], David Canteli[a], C. Muñoz[a], Miguel Angel Rodriguez[b], Miguel Morales[a,*], Carlos Molpeceres[a]

[a]*Centro Laser from Universidad Politécnica de Madrid, Alan Turing 1, Madrid 28031, Spain*
[b] *Instituto de Cerámica y Vidrio del Consejo Superior de Investigaciones Científicas, Kelsen 5 , Madrid 28049, Spain*

Abstract

This work aims the fabrication of a multicomponent device by using laser technology. The process requires, first, shaping step by additive manufacturing and, second, consolidation step by sintering. In this study, the multicomponent device is a microcapacitor which comprises a dielectric component based on Barium Titanate (BTO) sandwiched between the metallic electrodes. The manufacturing is carried out in two main steps, layer-by-layer deposition of the different components by Laser Induced Forward Transfer (LIFT), and the layer-by-layer sintering by Selective Laser Sintering (SLS). Suitable conditions were achieved for the LIFT deposition of the dielectric and metallic phases. In the case of dielectric component, the conditions and parameters were optimized to print in 3D. For the first time, 2 layers of the in column of a ceramic component were deposited by LIFT. For the sintering step, the conditions for the SLS of the metallic component were achieved while the SLS treatments on the dielectric component were compared with conventional methods.

Keywords: Laser-Induced Forward Transfer; Selective Laser Sintering; Microfabrication; Dielectrics; Multicomponent devices.

1. Introduction

Additive Manufacturing (AM) technologies are in the spot as the future manufacturing technologies mainly to their non-destructive and digitizable natures. Polymers, metals, and ceramics can be shaped by different AM technologies. However, the fabrication of multicomponent devices by 3D printing technologies presents a challenge when attention is focus on the densification process. The different thermal properties of the components or phases involved make impossible to densify them at the same temperature and time. In this point, Selective Laser Sintering (SLS) could be the key to fabricate multicomponent devices. By SLS is possible to apply in a specific area a specific laser energy. It allows a localized sintering treatment which not affect to the surrounding phases and components.

SLS is a type of powder bed selective laser processing. The technique basically consists in a powder bed of the material that is heated by a laser beam to bond particles because of solid-state sintering. It has been targeted as a promising AM technology. It means a challenging solution due to the possibility of fabricating complex parts on demand in a one-step process that comprises shaping and consolidating steps. The success of the process requires the optimization of feedstock properties like the flowability. It ensures a homogeneous powder bed and for hence in the densification process. Of course, also laser parameters play a key role. The optimization of energy density apply in the material is mandatory. It is controlled by power and scan speed parameters. [1]

In the specific case of SLS in ceramics, a CO_2 laser (λ = 10.6 µm) or a Nd:YAG fiber laser (λ = 1.065 µm) are commonly used. In the latter case, the absorbance of some ceramic powders must be adapted to better absorb the energy emitted by the laser device. Most oxides have low absorbance in the wavelength issued by Nd:YAG lasers but higher absorbances in the wavelength range of CO_2 lasers. However, the absorbance range of the ceramic powder can be adequate to the Nd:YAG lasers by adding absorbent components such us graphite, carbon black, titanium carbide and silicon carbide [2]. To avoid the use of additives, which can contaminate the dispositive and consequently change the dielectric and electrical behavior, the use of laser devices working in the absorption range of ceramics (355 nm for example) can be a promising alternative.

In other hand must be mentioned the disadvantages of SLS process. Pieces shaped and sintered by SLS are characterized by low densities, high porosities, and rugosities (low resolution). In addition, the powder bed method complicates again the 3D printing process in the case of multimaterial devices. In this point, must be mentioned another laser technology: LIFT.

LIFT is a direct writing technique able to print a wide range of materials such as metallics and ceramics. The main advantage of the technique, if compared with other mature printing technologies like inkjet or extrusion, is the capacity to transfer material in an enormous range of viscosities and rheological behavior, from solid-state to low-density inks. It allows to work with inks characterized by a high solid content and for hence higher densities after densification. Most LIFT approaches use a pulsed laser beam to transfer material from a donor substrate to an acceptor surface. The donor substrate consists of a transparent substrate with a thin layer of ink previously deposited onto the surface. The laser energy irradiates the interface between the transparent substrate and the material to be transferred. Conversion of laser energy into kinetic energy of part of the material allows the transfer of small volumes with high spatial accuracy, providing a printing method with spatial resolution in the order of 1 µm. The dynamics of the process are strongly dependent on the physical properties and thickness of the material, the gap between acceptor and donor substrate, the configuration of the donor substrate, and the parameters used in the laser irradiation process such us energy pulse and scan sped. [3]

In the present study we suggest the combination of different laser technologies: LIFT for the 3D printing process (shaping) and SLS for densification. Both lasers can be coupled in just one device, and both are digital processes. It means that shaping and sintering can be carried out in two steps but in the same device avoiding the manipulation of the sample during the manufacturing process. In addition, laser technologies make possible to achieve energy saving processes and very short fabrication times.

2. Materials and Methods

A water-based ink was formulated with commercial powders of BTO (Aldrich) for the LIFT deposition of the dielectric phase. In case of silver paste (DuPont PV 19B) with viscosity adjusted to 11,8 Pa·s by adding thinner (DuPont 9450). [4]

To study the deposition conditions of Barium Titanate (BTO) platinum waffles were used. Platinum was considered for two reasons: the inert behavior at high temperatures achieved during the sintering and the metallic nature which provides one of the two electrodes required in the sandwich structure for a first microcapacitor prototype.

Three different laser systems were used in this work. Table 1. shows the. Explorer system was used for LIFT deposition of the dielectric and metallic components. Such system is coupled to Milenia system as just one device. SLS parameter were optimized in Milenia system for the sintering of the metallic component. While the first attempts of SLS for the dielectric component were carried out with Milenia, the most promising results were obtained in Hippo system. Conventional sintering of BTO has been carried out by thermal treatment in a furnace able to achieve 1600 °C.

Table 1. Laser systems used in the study.

Laser system/Step process	Type	Wavelength	Power	Frequency	Spot
Explorer/ Deposition*	ns-pulsed Nd:YVO_4	532 nm	>2 W - 50 kHz	20 -150 kHz	18 µm
Milenia/Sintering*	CW	532 nm	5-15 W	CW	21.1 µm
Hippo/Sintering	ns-pulsed Nd:YVO4	355 nm	5 - 50 kHz	15-300 kHz	15 µm

* Coupled Systems in just one device

3. Discussion of Results

3.1. LIFT deposition of BTO

A water based BTO ink has been prepared for the BTO deposition. The formulation designed has a high solid content with the aim to achieve a suitable densification.

The deposition of BTO lines and layers by LIFT has been successfully carried out over platinum waffles (Fig. 1). The thickness of the ink coating, the gap between acceptor and donor substrate, and the laser irradiation parameters (energy pulse and scan speed) have been optimized in each case.

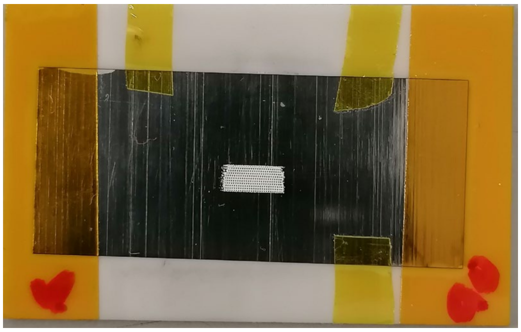

Fig. 1 Layer of BTO deposited by LIFT over Pt waffle.

3.2. SLS vs. conventional sintering of BTO

The parameters for SLS of BTO has been optimized in a ns-pulsed Nd:YVO4 device working at 355 nm. The system has been proposed for the SLS of the ceramic phase because its works at wavelength 355 nm. It is in the range of absorption of the material. The analysis shows that only superficial sintering has been achieved.

In parallel, conventional thermal treatment has been carried in BTO samples deposited over Pt surface with the aim to fabricate a first prototype. The most important observations show a great attachment between layers after sintering.

3.3. Deposition and SLS of silver pastes over BTO

Finally, the deposition of silver paste layers has been studied over BTO surface. The same printing parameters used in previous works to print lines, were used in this case to print layers. Just the distance between lines was optimized in this case with the aim to print layers with homogeneous morphologies in the surface.

In addition, also the same parameters used in previous work to sinter the previously deposited lines were used to sinter Ag layers deposited over BTO. The design to carried out the process is based on parallel lines. First experiments study the sintering by applying different the distances between lines and looking for suitable resistivity conditions (Fig. 2)

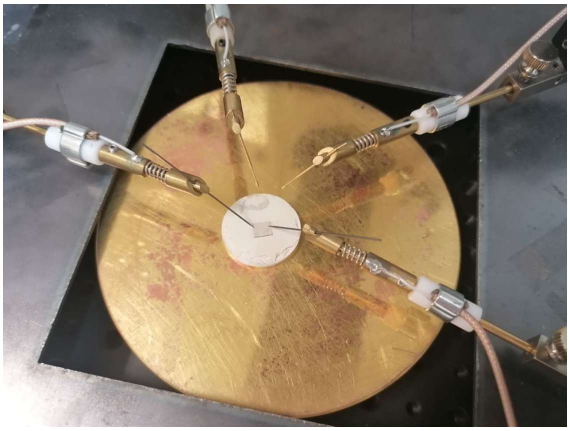

Fig. 2 Layer of silver paste deposited by LIFT over TBO waffle and sintered by SLS. The picture shows the sample when electric measurements are being carried out.

4. Conclusion

The study present promising results in the way to fabricate a multicomponent device by additive manufacturing but also exclusively using laser technologies. The LIFT deposition of TBO and Ag pastes layers over Pt and TBO substrates respectively, has been successfully achieved. SLS of silver pastes has shown good densifications as well as promising resistivities by optimizing the design of the scan map. Densification of TBO by SLS still requires wide study to optimize parameters. However, conventional sintering provide a good attachment between layers previously deposited by LIFT.

Acknowledgements

The authors thanks the financial support provided by SCALED (PID2019-109215RB-C44) Spanish National Program.

References

Chen, Y., Muñoz Martín, D., Morales Furió, M., Molpeceres Álvarez, C., Sánchez Cortezón, E. and Murillo Gutierrez, J, 2016, LIFT of high viscosity silver paste for new metallization methods in photovoltaic and flexible electronics industry, Physics Procedia 83, p. 204.

Grossin, D., Montón, A., Navarrete-Segado, P., Özmen, E., Urruth, G., Maury, F., Maury, D., Frances, C., Tourbin, M., Lenormand, P., Bertrand, C., 2021. A review of additive manufacturing of ceramics by powder bed selective laser processing (sintering / melting): Calcium phosphate, silicon carbide, zirconia, alumina, and their composites, Open Ceramic 5, p. 100073.

Marquez, A., Gómez-Fontela, M., Lauzurica, S., Candorcio-Simón, R., Munoz-Martin, D., Morales, M., Ubago, M., Toledo, C., Lauzurica, P. and Molpeceres, C., 2020. Fluorescence enhanced BA-LIFT for single cell detection and isolation, Biofabrication 12, p. 025019.

Urruth, G., Maury, D., Voisin, C., Baylac, C., Grossin, D., 2022. Powder bed selective laser processing (sintering/melting) of Yttrium Stavilized Zirconia using carbon-based material (TiC) as absorbance enhancer. Journal of the European Ceramic Society 42(5), p. 2381.