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Metallic surface functionalization by femtosecond laser beam shaping and LIPSS for industrial applications

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Abstract

Literature demonstrated the advantages of surface nanoscale texturation in many industrial applications, including batteries, medical implants and linear encoders. The next step is to find a cost-effective and non-invasive solution to replace actual material deposition and tooling techniques at industrial scale.

In the scope of the LASER4SURF project, we developed a new automated workstation enabling fast texturing of large surface samples (i.e. A4 format), using state of the art beam shaping techniques involving DOE and SLM combined with LIPSS generation to increase functionalization performances of the textured materials.

A key part of the workstation is its ability to automatically determine optimal laser processing parameters based on preliminary study done on any other laser processing device.

We also demonstrate that LIPSS texturation increases battery collectors charging capabilities, as well as their lifetime. We also demonstrate better bio-integration of medical implant for the human body, as well as increased accuracy linear encoders.

Keywords: Femtosecond laser ; surface texturing ; surface functionalisation ; beam-shaping

1. Introduction

As it has been proven in many industrial fields over the years, the possibility to modify and control the structuration of part surfaces at the nanoscale can enhance or give new properties to materials such as in Stratakis et al. 2011, Pan et al. 2014 or Dusser et al. 2010.

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However, those processes often use consumables that are toxic, difficult to handle and pollute the environment. Also, the industrial deposition methods often do not enable nanoscale texturation control but only changes the roughness of part surface or are too slow be used in a production chain in the industry.

To address those problematics, LASEA built a dedicated laser machine that is able to texture large surfaces of parts at the nanoscale using with LIPSS (Laser Induced Periodic Surface Structures) phenomenon induced by laser-matter interaction during the laser ablation process. This work has been achieved in the scope of the LASER4SURF European project (https://www.laser4surf.eu).

In the following sections, we will present the specifications of the laser workstation as well as the results obtained for applications in three different industrial sectors: medical implants, battery collectors and precision linear encoders.

2. Machine development

2.1. Laser workstation

To generate the laser beam, we use a Satsuma from Amplitude Systems. Then, the beam passes through the LS-Shape optical module, which adapts the beam diameter depending on the target application. After that, the laser is directed towards the beam-shaping module, which includes a DOE (Diffractive Optical Element) to modify the beam shape from gaussian to top-hat. Finally, the laser beam enters the LS-Scan scanner-head which contains fast moving precision mirrors and a focusing lens to control the beam movements on the processed parts.

The laser workstation also includes translation stages of 1.5m which enable treatment of large surface parts. On top of the stages, there is a sucking table system that maintain thin samples flat to avoid local defocusing during the laser texturing process.

Finally, the laser workstation includes an inline monitoring system which will measure LIPSS period at the end of the laser process to validate part texturation quality.

Fig. 1. (a) front view of the laser workstation without the monitoring system; (b) side view of the laser workstation with the monitoring system integrated

2.2. Parameters conversion module

In the scope of the LASER4SURF project, we needed a tool that is able to convert the laser processing parameters used on a test machine for the laser workstation. To achieve that goal, a software was developed to calculate optimal laser parameters which needed to be used on the workstation to reproduce the best texturing results obtained on the test machine, based on laser and optical parameters of both machines.

The conversion algorithm was established first theoretically, then adapted to fit the experimental tests done with the laser workstation to reproduce the optimal structuration done with the tests machine, such as de Rossi et al. 2015.

2.3. Fully automated sequence integration

To ensure that the Laser workstation could be used in a production chain at industrial scale, each component of the machine is tunable via a control software. More than individual, it is also possible to create an automated sequence of actions detailed below:

- Loading of laser and optical parameters established on the tests machine
- Use the conversion module to adapt laser parameters to the laser workstation
- Control hardware to apply the new parameters
- Laser processing of the part
- Movement of the sample to the inline monitoring system
- Start the analysis of the part
- Display the result of part analysis

3. Results

3.1. Test protocol

In each application presented in the following subsections, the test protocol used was identical. Firstly, the test machine was used to make an exhaustive study of the different surface texturation achievable on flat test samples. Then, best candidates were chosen and their performances were tested depending on their final application (more details in the following subsections for each application). Based on the performance results, best laser and optical parameters were established.

After this step was complete, these parameters were adapted to the laser workstation via the parameters conversion tool to reproduce the optimal surface texturing on real parts. In the frame of the LASER4SURF project, three different applications were targeted for texturation: medical implants, batteries current collectors, linear stages encoders.

3.2. Medical implants

In the case of the implants, we first validated that the optimal surface texturing could be reproduced on flat test samples.

After this was done successfully, we applied this texturation on cervical plates on which different performance tests were done. The first one was a wear test which consists of using a tool to simulate natural friction of the implant with local tissues when implanted in the human body. Those tests showed that laser texturing achieved better performances than non-textured parts and parts textured by sand-blasting.

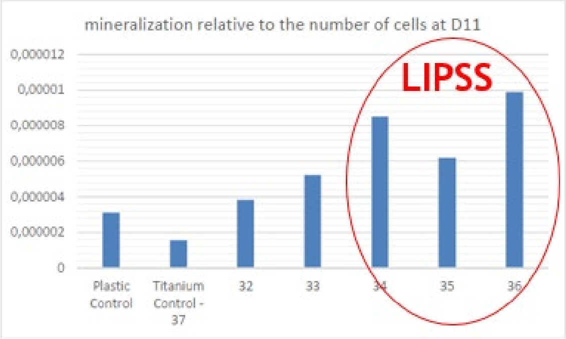

Fig. 2. Quantification of the mineralization relative to the number of cells

The second test done consisted in developing human tissues at the surface of the sample to check adhesion and propagation. Again, laser textured parts exhibited better adhesion and propagation than non-textured parts and similar performances than sand-blasting textured parts. However, tissues propagation direction is strongly influenced by the texturation geometry, which can be precisely controlled by the laser process and opens up new opportunities to improve osteointegration of the implants as stated in Martínez-Calderon et al. 2016.

Finally dental screws were also textured by laser with an LS5-3D laser machine to demonstrate the possibility to apply such texturations on parts with complex 3D geometries. The productivity of such fully automated system was calculated to reach more than 15 000 screws per year depending on the geometry of the parts.

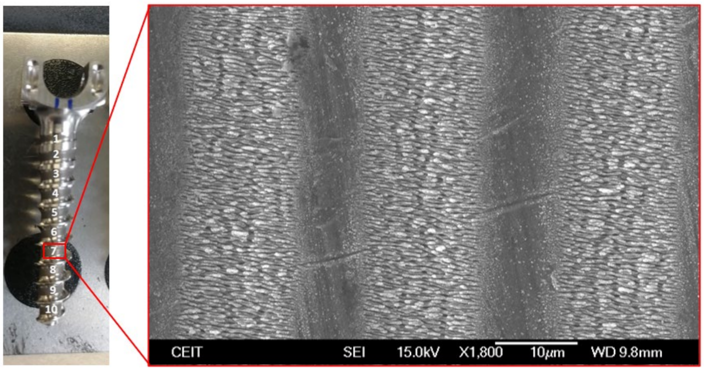

Fig. 3. (a) macroscopic view of a dental screw; (b) SEM images of the LIPSS nanostructures

3.3. Current collectors for batteries

After validating texturing reproducibility on test samples, large surface current collector (A4 format) were textured both on Cu and Al foils, then treated by adding an LTO slurry to fabricate anode and cathode.

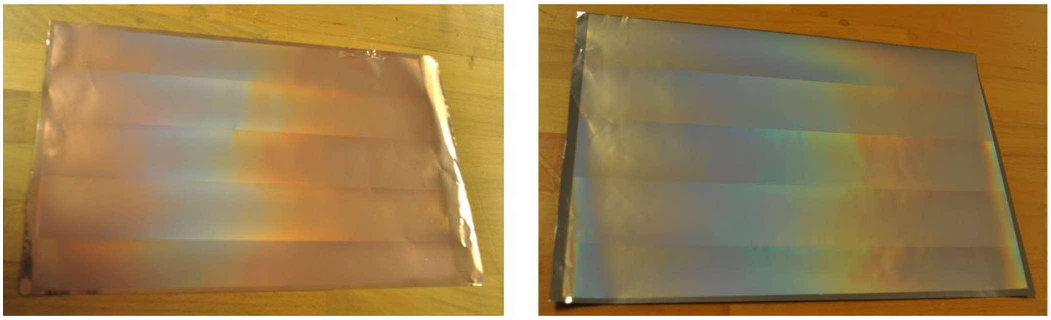

Fig. 4. (a) A4 format texturing of Cu foil; (b) A4 format texturing of Al foil

The adhesion of the LTO slurry on the structured samples was proven to be better on textured through peeling tests. Indeed, this test shown that less material was removed on laser textured samples as well as requiring a higher strength to remove the material.

After the assembly of pouch cells with the textured current collectors, electrochemical tests were performed demonstrating that life time of the pouch cells could be increased by 10% as well as having a higher charge and discharge rates at higher current densities.

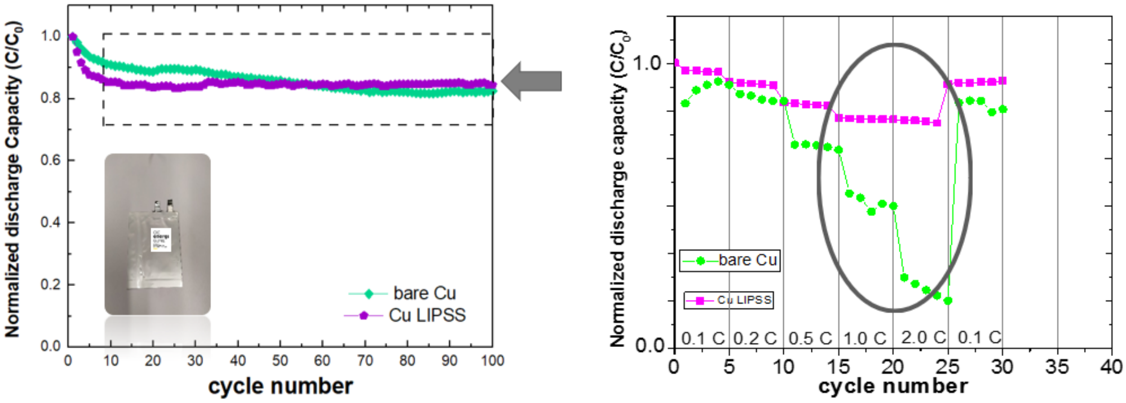

Fig. 5. (a) Normalized discharge capacity at 1C; (b) Normalized discharge capacity at different C-rates

3.4. Linear encoders

In that case, we also first validated that we could reproduce the optimal texture on test samples. Afterwards, real encoders were textured by laser on an area of 10x150mm. The signal/noise ratio of the encoder was then qualified through optical tests which validated the precision and quality of the laser texturing.

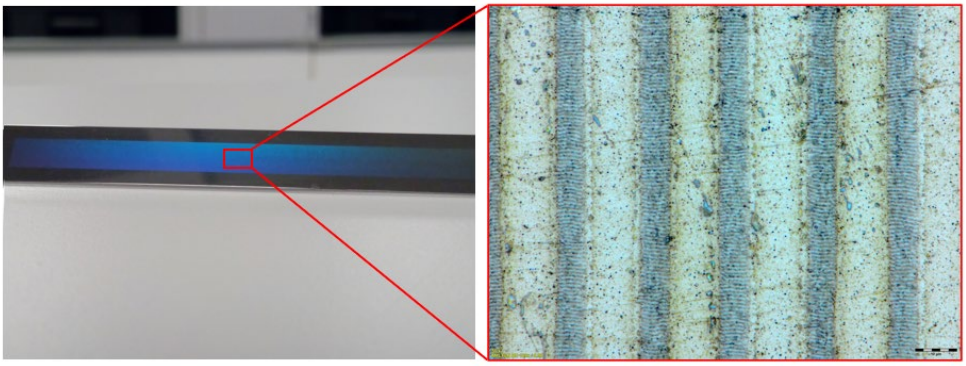

Fig. 6. (a) macroscopic view of a dental screw; (b) SEM images of the LIPSS nanostructures

Moreover, it was possible to improve contrast and regularity of the LIPSS texturing by using the DOE module. This element optically modifies the intensity profile of the laser beam to a square top-hat profile.

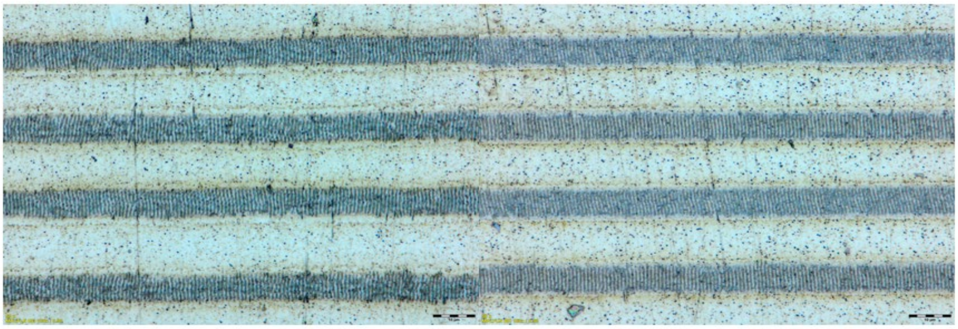

Fig. 7. (a) LIPSS structures processed with gaussian intensity profile; (b) LIPSS structures processed with square top-hat intensity profile

4. Conclusion

We demonstrated the possibility to build a fully automated laser workstation capable of nanoscale texturing of LIPSS structures on industrial parts in the medical, batteries and linear encoders industry.

After various performance tests done for each application, it could be proven that laser textured parts showed better results than untextured parts or parts with more conventional treatment, enabling to reduce the full manufacturing process by removing several steps, and this in a greener manufacturing way.

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