LASER4FUN
European ESRs Network on short pulsed laser micro/nanostructuring of surfaces.
GA Nº 675063

Funded by the European Union
Marie Sklodowska-Curie Actions

NEWSLETTER

Nº 2 | September 2017

This is the second newsletter, containing the latest news from the LASER4FUN project.

Table of contents

The Laser4Fun project

By Andrés Escartín Barduzal, coordinator of the project (BSH Electrodomésticos Spain)

LASER4FUN project (European ESRs network on short pulsed laser micro-nanostructuring of surfaces) started on 1st September 2015. The project aims at the creation of an International Training Network (ITN) for Early Stage Researchers (ESR's) in the field of laser-material processing. The general target is to structure surfaces embedding properties for industrial applications. Project consortium is composed by 10 international partners with wide experience in the field (4 academic partners, 3 research centers and 3 industrial partners) providing support for 14 ESRs.

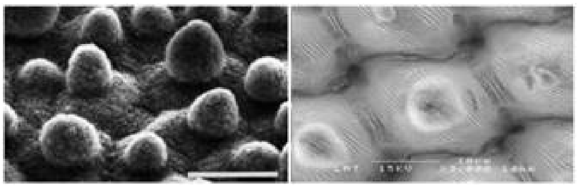


Figure 1 — The project deals with fabrication of micro- and nano- structures on the surface and in the bulk of different materials

The ESRs at the 2nd LASER4FUN summer school at University of Twente, Netherlands (August 21-25, 2017).

The project selected short pulsed and ultra-short pulsed laser technologies according to the progress reported in the state of the art and the background of the project partners. Techniques such as Laser-Induced Periodic Surface Structures (LIPSS), Direct Laser Interference Patterning (DLIP), Direct Laser Writing (DLW) or other hybrid ones are being used. This part is carried out by 11 researchers, hosted by Alphanov (France), Consiglio Nazionale delle Richerche (Italy), Fraunhofer Institute (Germany), Polytechnic University of Madrid (Spain), Robert Bosch (Germany), University of Birmingham (UK) and University of Twente (Netherlands). The researchers will focus on the interaction of the laser energy with selected materials and on new surface functionalities like tribology, aesthetics, biofilm control and wettability. Prior to it, the definition of industrial applications and technical requirements, including materials, properties and use cases was completed. Those have been defined by the industrial partners; Airbus, BSH and Robert Bosch.

Characterization research should be performed in order to understand the effects of the surface structures. Existing techniques are analyzed and improved as part of a research with the target understanding and modeling laser processing, and defining adequate characterization protocols.
This second part of the project is being carried out by 3 researchers, hosted by Airbus (Germany), BSH (Spain) and Leibniz-Institut für Polymerforschung (Germany). The project also involves a high effort into establishing an innovative training program aiming at coaching a new generation of creative, entrepreneurial and innovative ESR's. It will ensure that after 36 months of research and training, the ESRs will be ready for acquiring PhD awards, and will be prepared to face EU laser-engineering new challenges. Nowadays the project has reached the median point, and it is fully working on the research activities. Recruitment was completed on month 8 while target applications were completely defined and prioritized on month 12. The ESR's have been working together with their Supervisors in the technical work packages, achieving promising results with first structures and samples. Characterization tasks are also advancing, providing first feedback to the laser processing ones.

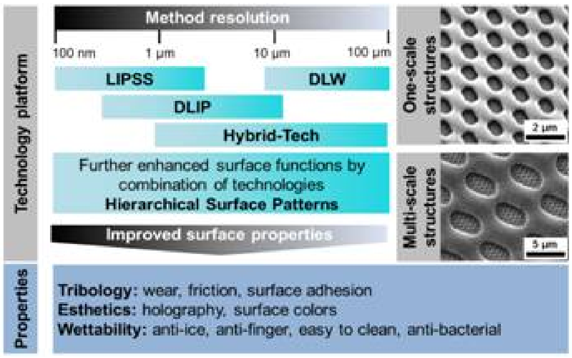


Figure 2 — The project includes different technologies in order to functionalize and give the materials pre-determined properties.

Furthermore, more than 100 individual trainings and 6 global ones have been completed, including two summer schools, as well as 8 secondments. The network between partners and researchers is fully functional including 3 project meetings and a fourth one planned for October 2017.

Regarding dissemination, several events have been reported including press releases, newsletters and project presentations. Almost 20 papers are published or under preparation.

From the management point of view, all pending deliverables and milestones planned have been completed. Project advances with minor delays, adjusted according to the recruitment dates.

2nd Summer school at University of Twente

By Gert-willem Römer and Luigi Capuano (University of Twente, Netherlands)

In total 22 persons attended and contributed to the 2nd Laser4Fun Summer School on Advanced Laser Processing. The Summer School was organized and hosted by the Chair of Laser Processing at the University of Twente in Enschede, the Netherlands.

Figure 3 – Each ESR gave a presentation regarding the work he/she is carrying out for the LASER4FUN project

From August 21st to 25th, the participants were "fully-immersed" into the world of advanced laser materials processing. Lectures and presentations by academic experts, specialists from industry, as well as of the participants (see Fig. 3) alternated, with ample time for discussions. The summer school also included practical exercises and workshops (see Fig. 4) in state-of-the-art laser-laboratories.

Topics included, but were not limited to:

- Fundamentals of laser-material interaction
- Pulsed laser surface ablation
- Pulsed laser processing of bulk materials
- Laser-induced Periodic Surface Structures (LIPSS)
- Micro/nano structuring
- New trends in laser processing
- Laser cladding
- Laser-induced Forward Transfer (LIFT), see Fig. 4
- Applications of laser processing
- Training on generic research relevant skills

The next summer school of the LASER4FUN project will be organized in 2018 by CNR in Bari, Italy. Make sure to check the project's website (http://www.laser4fun.eu) for updates.

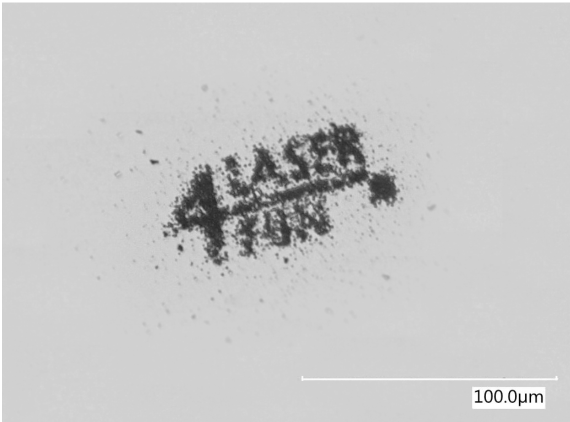


Figure 4 – A microscope image from a first trial of reproducing a pure gold Laser4Fun project logo designed and printed by the attendants of the summer school during one of the workshops (LIFT laboratory led by Matthias Feinaeugle) using the Laser-induced forward transfer (LIFT)[1,2] method.

Controlling wettability of surfaces by DLIP

By Alfredo Ismael Aguilar Morales, Andrés F. Lasagni (Fraunhofer IWS, Germany)

Numerous examples of the superhydrophobic effect can be found in the natural world[3] which has become relevant for the surface functionalization of metals. Therefore, the micro replication of the topography has attracted attention due to the remarkable water repellency. On the other hand, the wetting behavior of materials required not only to control the surface topography, but also its chemistry.

Direct Laser Interference Patterning (DLIP) allows producing periodical structures up to the sub-micrometer level on metallic surfaces. Particularly, by means of a two-beam configuration, we were capable to produce line- and pillar-like structures on stainless steel with spatial periods of 2.6 µm and 5.2 µm and aspect ratios up to ~2. Additionally, hierarchical features resulting from the combination of Laser Induced Periodic Surface Structures (with spatial periods of approximately to 180 nm) with the DLIP structures were also produced. These geometries mimic for instance the complex micro and nano-roughness observed in some plants as the Nelumbo Nucifera[4].

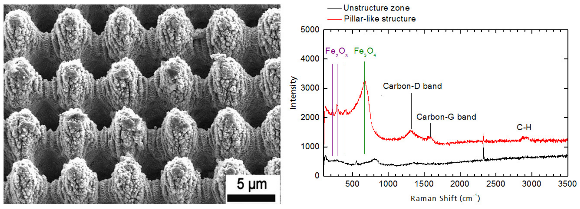


Figure 5 — Pillar-like structure on Stainless Steel fabricated by Direct Laser Interference Patterning with a spatial period of 5.2 µm in two-step process using a two-beam configuration and its Raman spectrum compared with an unstructured zone.

Measurements of the water contact angle permitted to determine the hydrophobic state, especially for the pillar-like patterns (Fig. 5), with values up to 145° (measured 30 days after fabrication). This behavior could be explained by the combination of the surface topography with changes in the surface chemical composition, being the last related with the decomposition of carbon dioxide into carbon which slowly takes place after the laser process[5]. After a certain period of time, the accumulation of the non-polar carbon layer promotes a hydrophobic state that acts together with the hierarchical microstructure produced by picosecond DLIP. The formation on the carbon layer was confirmed by Raman spectroscopy (see Fig. 5), which highlights an increment of carbon in the D and G bands compared with a unstructured area.

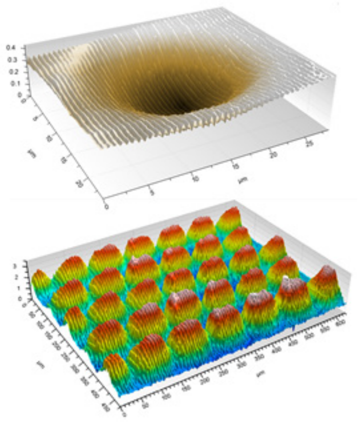
Laser micro-structuring of polymers by DLIP

By Sabri Alamri, Andrés F. Lasagni (Fraunhofer IWS, Germany)

Laser based surface processing methods in polymeric materials have permitted in the last years to fabricate arrays of periodic micro-structures to achieve different surface functions. Within these methods, Direct Laser Interference Patterning (DLIP) has demonstrated to be able to efficiently produce micro-structures on a wide range of materials, with flexibility in geometry and dimensions of the patterns. It relies on the principle of the interference between two or more laser beams to produce periodical structures on materials capable of absorbing the laser radiation.

However, identical processing conditions can lead to complete different results when applied to different types of polymers. In recent works[6,7], polycarbonate sheets (PC) with different colorants has been treated by means of a two-beam interference setup, using UV (263 nm) and IR (1053 nm) laser radiation.

The key-achievement is that, according to the composition of the material, the main structuring process can be induced by selective ablation, swelling or a combination of both. In fact, for transparent materials irradiated with the UV radiation, the main structuring process is ablation, which takes place either following the laser intensity distribution, or additionally producing a non-selectively ablated region (fig. 6a).



(a)

(b)

Figure 6 – (a) Single DLIP-pixel showing a modulated ablation on transparent polycarbonate and (b) swelled DLIP-pixels on black-doped polycarbonate.

For doped polymers, the treatment with the IR radiation revealed features consisting of swelled structures at the positions corresponding to the interference maxima, which could be explained by the interaction of the laser radiation with the colorant (fig. 6b). On the other hand, colored polymers treated with the UV radiation showed the possibility to switch from ablation to swelling just by changing the laser fluence.
The experimental results have been used to develop an empirical model, capable to predict the contribution of four different observed structuring mechanisms. The model used to simulate the structures obtained experimentally, will allow in the future the design of more complex structures, combining for instance ablation and swelling.

The shape of laser modifications in sapphire

By Luigi Capuano (University of Twente, Netherlands)

Processing of single crystal sapphire (Al_2O_3, Fig. 7) and other glass-type materials using a combination of laser and chemical processes is a technology that has been increasingly used in the past years. After selecting a laser wavelength (used ones for the research are 515nm and 1030nm) which gets easily transmitted through these type of materials, by focusing very tightly a laser beam inside the bulk it is possible to cause a change in the chemical structure of the material itself. The modified part can be later chemically removed, thus, creating hollow volumes and structures. At University of Twente, in the framework of the Laser4fun project, we are developing a repeatable method to functionalize single crystal sapphire in order to be used directly and indirectly in the industrial process. One of the key factor of this developing is selecting the right set of parameters optimized to be used in certain conditions.

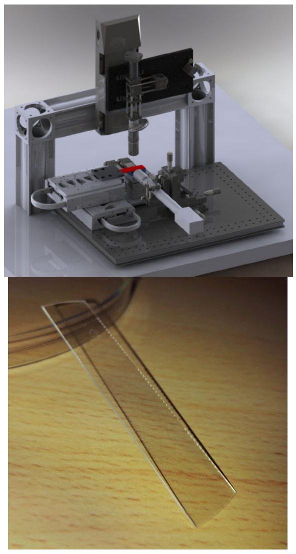


Figure 7 – Top: a 3D render of the set-up used for conducting the experiments, bottom: single crystal sapphire specimen with structures (on the edge of the specimen)

In particular studying the impact of the:

1. laser intensity (power per area)
2. the "depth of processing below the surface" on the obtained structures.

These 2 parameters have great influence on the final shape of the modifications mainly because:

1. The affected zone for higher intensity is more extended
2. The spherical aberrations[8] play an important role in determining the

size of the laser spot in the transparent material

Our goal is to determine (with experiments and simulations) how the two parameters can be balanced to produce always the needed modification in any condition.

Effect of storage conditions on wettability

By José Cardoso (Universidad Politécnica de Madrid, Spain)

Structures in the form of microcells were patterned via Direct Laser Writing (DLW) technique, using a nanosecond near-infrared laser source on Al2024 aluminium alloy plates with 2 mm thickness. To investigate the influence of laser parameters on the shape and size of the produced patterns, confocal measurements were effectuated to study the effects of varying the total irradiated fluence. Through static contact angle measurements the evolution over time of the wettability properties for the laser patterned samples was studied for different storage conditions. During such measurements, samples were found to be superhydrophobic with a single step laser patterning process, requiring no further treatment and exposure to ambient air was shown to be a key factor in the property changes of the samples over time.

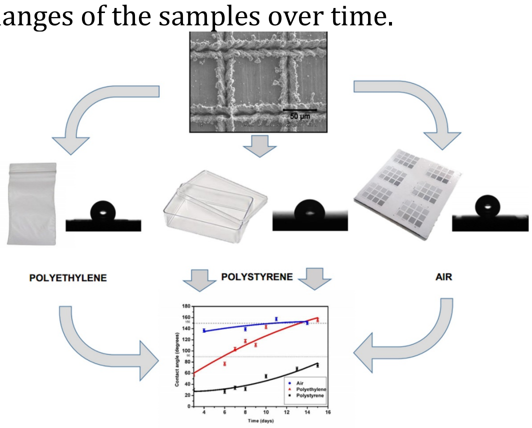


Figure 8 –Hydrophobicity induced by laser patterning

Measurements proved that privation of airflow delayed the aging process that is responsible for hydrophobicity. The produced surface patterns with different laser parameter settings were correlated with the contact angle measurements, also revealing a great influence of the amount of recast material, formed during the ablation process, on the material's hydrophobic properties. Through X-Ray photoelectron spectroscopy the impact of surface chemistry changes on hydrophobicity was also studied, analysis of elemental composition of the Al2024 plate surface, proved that chemisorbed organic molecules present in the ambient air, such as acetic and formic acid, were responsible for the hydrophilic to superhydrophobic transition. This work allowed a deeper understanding on the influence of ambient conditions on the evolution of wettability properties.

Controlling spike size on steel

By Fotis Fraggelakis (ALPhANOV, France)

Material surface texturing by ultra-short pulse (USP) lasers is an attractive technology since it enables the tailoring of some highly interesting material properties. By inducing periodical (ripples) and quasi periodical surface structures (spikes), also referred as LIPSS (laser induced periodic surface structures) the material surface wettability behavior[9,10,11], optical aspects[12,13], and tribological properties[14] could change radically without the need of coatings. In fact, with USP lasers it is possible to texture the surface of several materials such as metals, semiconductors and ceramics[15,16,17,18], subsequently modifying the surface interaction properties.

However, the exploitation of LIPSS into an industrial environment for commercial purposes requires implementing a reliable and effective production system. In order to obtain time values compatible with industry, the use of high average power, high repetition rate femtosecond lasers becomes necessary.

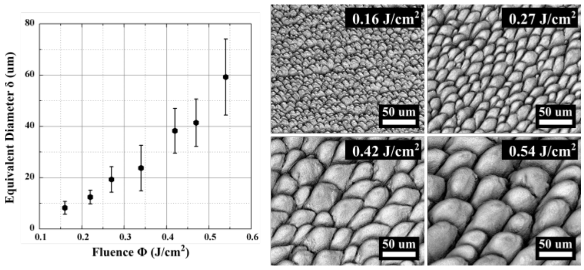


Figure 9 – SEM images (right) and graph (left) illustrating the continuing change of the equivalent diameter δ with increasing fluence. The SEM images correspond to the data shown on the graph and where obtained at a 45° tilt. The fluence values are inserted in the corresponding SEM images.

Nonetheless, surface processing at repetition rates within the MHz range, could induce inter-pulse heat accumulation, compromising the surface morphology. For instance, during the irradiation with repetition rate values close to 1 MHz a metallic surface is expected to reach a surface temperature T_s of several hundreds of degrees[19]. The pulse to pulse overlap, the fluence and the repetition rate are also expected to have a bearing on the T_s value.
Nevertheless it is possible to overcome the detrimental thermal effects by careful selection of process parameters enabling the creation of homogeneous spikes on the surface. Moreover, for 1 MHz our results show that it is possible to finely tune the size of the micro-spikes. In Figure 9, we demonstrate that by a systematic variation of the fluence we could vary the average diameter of the induced structures for f = 1 MHz. In our experiment, we deliver the same number of pulses (pps_{tot} = 3500), by scanning the surface 50 times using an overlap of 70 pps and we varied the fluence between $\Phi = 0.11$ J/cm^2 and $\Phi = 0.54$ J/cm^2.

Laser functionalization of hardened surfaces

By Antonio García Girón (University of Birmingham, England)

One of the major concerns about functionalised surfaces is their durability. If coatings are applied, they will disappear with time due to their wear or interactions with surrounding environments. Thus, they can limit the products' life spans or require a new treatment to recover the properties. Similar concerns arise when the properties are achieved by modifying the surface topographies, where again wear and scratches impact their durability. Thus, the use of hard and wear resistant materials is very important to increase the life span of such functionalised surfaces.
Low temperature plasma surface alloying is a process used to increase surface hardness of different metals. Especially, atoms are diffused into their surfaces to create interstitial supersaturated solid solutions with a higher hardness. On the other hand, nanosecond direct laser patterning is a cost-effective technique widely used to create patterns at micro scale and thus to obtain the desired surface properties, e.g. hydrophobicity, oil diffusion or ice repellence.

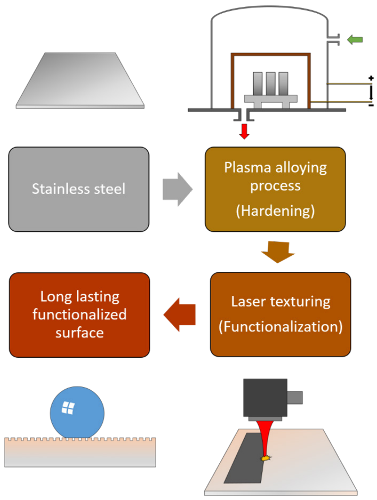


Figure 10 – Schematic of the process chain used.

Ferritic stainless steel plates were hardened employing the DC Plasma carburising process, assisted with a gas mixture containing CH_4. In particular, the hardness increased from 172 to 305 HV by forming 1 µm thick layer. Then, the samples were processed with an IR nanosecond laser to create both grids and channel like patterns on the surfaces, with sizes of approximately 100 µm. The properties of the patterned samples were studied and it was determined that the hardness was maintained while the surface exhibited hydrophobicity, with contact angles higher than 150°. Thus, hard and wear resistant stainless steel plates with water repellence properties were successfully produced.

Hierarchical microstructures on Ti6Al4V

By Daniel Huerta (Universidad Politécnica de Madrid, Spain)

Lasers have been used on several technological fields over the last decades for many applications, in laser engineering particularly, laser micro-machining systems for fast and precise material processing have been created. These systems allow different materials to be patterned in the nano- and micro-scale using pulsed laser irradiation, creating distinct geometrical shapes and enhancing some of the material's properties, consequently, the possibility of processing a material gives the opportunity to create complex structured material with some interesting features. Laser micro-machining allows then to reproduce structure topographies present in plants like the lotus leaves or the rose petals, which present a surface roughness with micro- and nano-features, also known as hierarchical structures, and exhibit a high hydrophobic behavior (non-wetting property). These bio-inspired hierarchical surface structured materials have shown several improvements with respect to wettability or corrosion resistance.

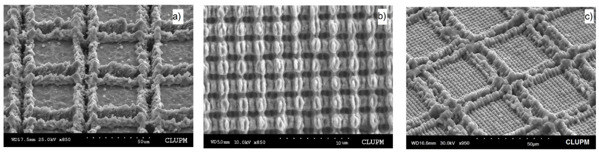


Figure 11 – Scanning electron micrographs of: a) DLW Structures b) DLIP Structures c) Hierarchical structures by combining DLW+DLIP.

In the Laser4Fun project, hierarchical surface patterns fabricated on Ti-6Al-4V alloy have been made combining two laser micro-machining techniques: UV nanosecond Direct Laser Writing (DLW) and IR picosecond Direct Laser Interference Patterning (DLIP). Squared shape micro-pillars were produced by Direct Laser Writing (Fig. 11.a) with depths values in the micro-scale, forming a well-defined closed packet. Subsequently, cross-like periodic patterns were fabricated by means of Direct Laser Interference Patterning (Fig. 11.b) using a two-beam configuration, generating a dual-scale periodic surface structure in both micro- and nano-scale due to the formation of Laser-Induced Periodic Surface Structure after the picosecond process. As a result a triple hierarchical periodic surface structure (Fig 11.c) was successfully generated by combining DLW and DLIP, allowing the creation of bio-inspired surfaces for several potential applications.

Parameter optimization for LIPSS generation

By Marek Mezera (University of Twente, Netherlands)

Nowadays, products do not only compete on functionality, but they need to have additional features than the competing products. Therefore, the industry demands new and cutting edge technologies to achieve advanced applications. One of these technologies could be LIPSS (Laser induced periodic surface structures), which are highly regular nanoscale structures which

appear on nearly all kind of materials such as metals, semiconductors, polymers and ceramics.
For a technology to interest industry, the process needs to be predictable. Now, the manufacturing process of LIPSS is experimental: scientists fabricate LIPSS by trial-and-error attempts.

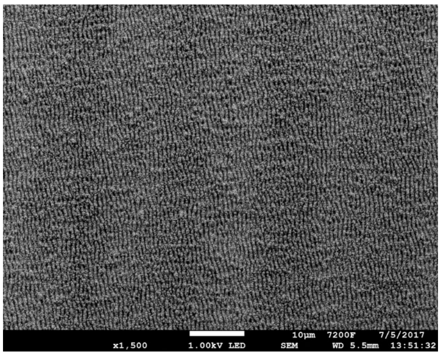


Figure 12 – Homogeneous area of LSFL (Low Spatial Frequency LIPSS) on Silicon processed with an ultrashort pulsed IR laser

To overcome this problem means to predict the appearance of LIPSS by both material- and laser dependent parameters. At the University of Twente, a new method to calculate the appearance of LIPSS is in exploration with which the process parameters could be optimized to generate homogeneous areas of LIPSS.
The model is being tested with an infrared, ultrashort pulsed laser system on thin silicon wafers. The laser beam is scanned over the wafer surface with varying amounts of energy and velocity. By changing the scanning velocity, the overlap of the pulses differ. The local energy input rises with a higher overlap and sinks with lower overlap. Taken material dependent parameters into account at which LIPSS develop, one can calculate and predict, when LIPSS occur on the surface.

Uniform submicron laser texturing

By Jean-Michel Romano
(University of Birmingham, England)

For a number of applications there is an increasing need to fabricate submicron structures over large surfaces and thus to "imprint" properties, e.g. optical, bacterial repellence, etc.. At the same time the high repetition rate of ultrashort pulsed lasers and high dynamics of beam deflectors enable a viable selective, chemical-free surface processing technology. However, the resolution achievable by laser ablation is inherently limited by the diffraction limit of light, which is related to lasers' wavelength. At the University of Birmingham, we are investigating two laser-based processing routes to go beyond the micron barrier. One of the routes is to use near-field optical enhancements. A dense monolayer of hexagonally-packed spherical nanoparticles is deposited onto the surface that will undo texturing.

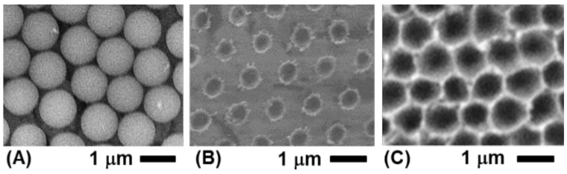


Figure 13 – Monolayer of microspheres deposited on stainless steel (A) and example of resulting textured surfaces (B-C).

A broad laser beam is concentrated below the spheres that act as lenses in their vicinity, creating so called Photonic Nanojets (PN). The resulting surface textures are regular arrays of submicron holes with varying hexagonal spacings, hole diameters and depth.
Laser Induced Periodic Surface Structures (LIPSS) is another promising way to fabricate sub-micron topographies. An interesting fact about LIPSS is that they are self-organised on processed surfaces after irradiating them with not sufficient energy to melt or vaporise the material. By varying the wavelength and polarisation of laser beams, it is possible to tailor the periodicity

and orientation of the resulting nano-grooves. Such topographies usually present very wavy, irregular ripples. One of the main challenges is to produce uniform, regular topographies over large area.

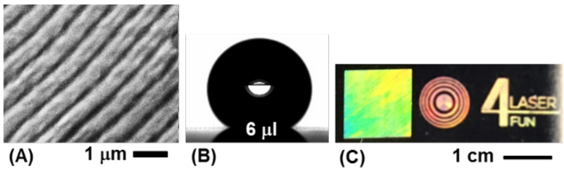


Figure 14 – LIPSS on stainless steel (A) exhibiting superhydrophobicity (B) and structural colourisation (C).

Such submicron surface topographies can exhibit light scattering and self-cleaning properties. Ongoing research on how to fabricate more complex submicron topographies has revealed that other interesting sub-micro structures such as squares and triangles can be produced.

Lab-based bacterial assays can be misleading

By Melissa Sikosana (Leibniz IPF, Germany)

New age, bio-responsive antimicrobial surfaces are being developed and put to the ultimate test by scientists at Leibniz-Institut für Polymerforschung, Dresden. Although applications in the biomedical and water industries are promising, IPF researchers experienced difficulties in evaluating the efficacy of their novel surfaces when using current 'scientific' techniques. This led them to question: 'how relevant and reliable are conventional bacterial assays performed in laboratories and how are their outcomes exploited within the scientific community and beyond?' Therefore, by developing new techniques and pushing the boundaries of application driven research, they envision the emergence of more trustworthy innovation that will narrow the translation gap (often experienced) between lab and industry.

'How often does a microorganism experience an environment like optimized growth conditions of LB medium or minimal media in laboratories?'

- S.E Finkel Nature reviews 2006

"The efficacy of silver, in terms of drinking-water disinfection, is currently a long way from convincing,...the lack of consistency of what has been and how it is examined.. means that it is difficult to compare data.'

-Silver water disinfection and toxicity assessment (WHO review 2014)

The IPF have attempted to progressively develop a bacterial assay that quantifies and differentiates from other antimicrobial techniques, specifically the antimicrobial activity of their new age bio-responsive coatings under close to 'realistic' conditions - based on their intended application (maintaining drinking water quality).

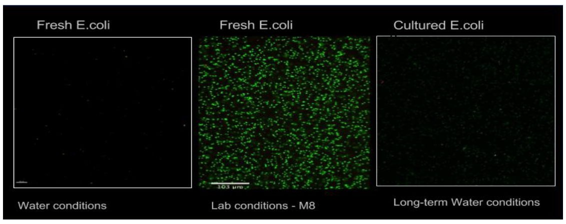


Figure 15 – The efficacy results of Fresh E.coli and Cultured E.coli exposed to the antimicrobial surface for 8 hours, in water conditions and laboratory conventional minimal media

In this case, the activity of an antimicrobial surface, comprising of a (bacterial protease) cleavable peptide + hexetidine construct bound irreversibly to a polystyrene (PS) surface by means of an anchor copolymer, was tested against common water bacteria isolates (Fresh / 4 pass LB and water conditioned Escherichia coli; and Staphylococcus aureus) under varying nutrient conditions. Using conventional techniques, the antimicrobial activity of the surface could not be reproducibly compared. However, this particular coating performed better in close to application conditions, reducing the bacterial viability to as low as 30%. Moving forward, the IPF is looking to develop, together with industry partners, even more realistic and application-based methods. This may lead to new developments in the microbiological understanding of the behaviours of real world bacteria.

Tribological application of laser textures

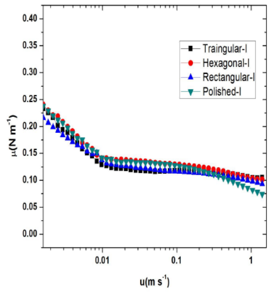
By Tobias Stark (Robert Bosch GmbH, Germany)

The lifetime of many Bosch products is limited due to wear and friction. One objective in product development therefore is to reduce wear and friction. A key factor to influence these parameters is lubrication. Furthermore, it has been shown that laser-surface-texturing has an impact on the frictional behavior. Within the scope of this study, the focus is laid on laser-texturing of the bodies surfaces. Indeed, in our study, we show that laser-surface-texturing can help to reduce friction.
One effect that plays an important role is the displacement of the lubricant. This effect can be explained with the help of a rain tyre. There, the grooves are big such that the water is displaced and the tyre is in contact with the asphalt of the street. Nonetheless, in a tribocontact, where body and counterbody are in contact and friction occurs, the opposite should hold: we want to avoid that the fluid is displaced in order to have a lubricating film between the two bodies. This can be achieved by texturing the surface with small structures. It was chosen, that the methods to structure the surfaces with a cross-like pattern is Direct Laser Writing for comparable big structures and Direct Laser Interference Patterning for comparable small structures. The evaluation shows that, compared to a polished reference sample, the big structure has a higher friction coefficient whereas the small structure has a lower friction coefficient. The main result of the study is that the effect depend on the size of the structures. For comparable big structures the lubricant is displaced easily whereas for comparable small structures the lubricant is hold in the tribocontact.

Surface texturing for friction reduction

By Gagandeep Singh Joshi (CNR, Italy)

Surface texturing in terms of topographical modification and design have been shown to be a means of controlling friction at oil lubricated interface. Understanding the relationship between the surface texture topography and the tribological properties in lubrication contacts, is of utmost importance to control the friction. This could be very helpful to reduce the friction and increase the life time of mechanical components[20],[21]. In lubricated contacts, the effect of surface topography and texture are also influenced a lot by the viscosity and type of the lubricant used. Consequently, the impact of surface texture (due to different geometries) was studied by measuring friction under different lubrication regimes[22]. Different kind of geometries can be used for surface texturing, which could reduce friction and wear in mechanical components[23]. Specifically, surface texturing (LST) in the form of quasi-rectangular geometry lead to friction reduction in the case of non-conformal point contacts. The impact of surface texturing on the basic tribological mechanisms was evaluated using appropriate testing, surface and subsurface analysis and characterization.



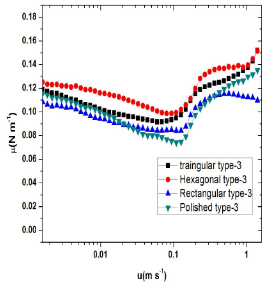


Figure 16 – Stribeck diagram of LST samples with different texture geometries (Triangular geometry: dimples with diameters d=183µm, depth h~6.7µm, areal density A [%] =0.29; Hexagonal geometry: dimples d=183µm, h~6.6µm, A [%]=0.27; Rectangular geometry: dimples: major axis L=200µm, minor axis W=100µm depth h~7.3µm, areal density A[%]=0.53) compared to the stainless steel polished surface .

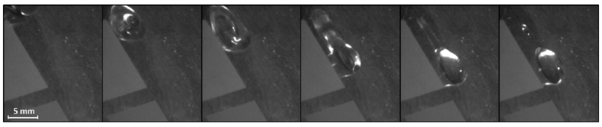
The tests performed on these textured geometries show friction reduction under different lubrication regimes as shown in fig.16. It shows, how friction is influenced by different factors, which include stress (or pressure), void ratio and viscosity. We use two different viscosity values of PAO (Poly-Alpha-Olefin). Pressure measurement tests were performed aimed at measuring the contact area between the ball (100 Cr6-G28) and sample surface (Stainless steel). The measurements were carried out by using a MCR rheometer 301(Ball on three plate), under an applied load of 20N by using Fujifilm pressure measurement foils placed upon the samples. The outcome of the experiments shows that in the case of textured surfaces the contact area between the two considered surfaces is of the same order of the magnitude as the width of the micro-holes. Figure 16 shows that samples textured with higher void ratio presents higher friction reduction at low speed. It was also found that the parallel alignment of the quasi-rectangles along the major axis (L) with respect to the sliding direction of the ball, allows a reduction of friction coefficient (see Fig. 16). In addition, the friction behavior was observed due to the varying temperature on un-textured samples in lubricated non-conformal point contacts.

Superhydrophobicity by fs-laser texturing

By Vittorio Vercillo (Airbus Group Innovations, Germany)

Icing is a topic of major interest in the aviation industry, since its effects impact the safety and performances of aircrafts and rotorcrafts. Among the several approaches, superhydrophobic surfaces represent an interesting solution to tackle icing phenomena, due to their water repellency properties.
Short/Ultra Short (S/US) Pulsed laser technologies are a promising candidate to mimic the *lotus effect* on different materials and produce superhydrophobic surfaces. As a matter of fact, dual-scale structured surfaces can be manufactured via laser-texturing with limited thermal interaction between material and laser beam.
Hereby the extremely low wettability of a laser-treated Aluminum surface is described. Frames taken with a high speed camera are shown in Fig. 17; the frames display different moments of the impact of a 15 µl water droplet at room temperature falling from 30 cm height, on a bare and a laser-treated Al2024 surface, both inclined by a 60° angle. In the upper row the droplet is impacting on the bare surface. After the impact, the droplet spreads on the surface, slowly flows down and stops approximately 1 cm below the impact point. The bottom row shows instead the droplet impacting on an area treated with Direct Laser Writing (DLW) using a femtosecond laser (310 fs, 1030 nm). In this case, the droplet impacts, spreads and

slides off the surfaces, leaving the material completely dry.


Bare Al2024

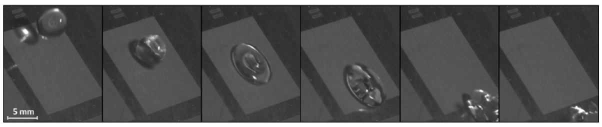

Laser-Treated Al2024

Figure 17 – Upper row: water droplet impacting on the bare Al2024. Bottom row: water droplet impacting on the treated area and sliding away.

In conclusion, short and ultrashort pulsed laser technologies are viable processes to manufacture superhydrophobic surfaces.
In the next months ice accretion and ice adhesion will be tested to investigate their icing behavior.

Publications

In the framework of the Laser4Fun project, the following papers have been published (so far).

Fotis Fraggelakis, Girolamo Mincuzzi, John Lopez, Inka Manek-Hönninger, and Rainer Kling. Texturing metal surface with MHz ultra-short laser pulses *Optics Express* 25(15), pp. 18131-18139, 2017. doi.org/10.1364/OE.25.018131

F. Fraggelakis, G. Mincuzzi, J. Lopez, Inka Manek-Hönninger, R. Kling. Ultrashort pulse laser-induced texturing of stainless steel at 1 MHz and high average power: impact of process parameters. *Proc. SPIE 10092, Laser-based Micro- and Nanoprocessing XI*, 1009213. San Francisco, February 2017, 1009213-1. http://spie.org/Publications/Proceedings/Paper/10.1117/12.2251867

Sabri Alamri and Andrés F. Lasagni. Direct laser interference patterning of transparent and colored polymer substrates: ablation, swelling, and the development of a simulation model. *Proc. SPIE 10092, Laser-based Micro- and Nanoprocessing XI*. 10092-1009219, 2017. dx.doi.org/10.1117/12.2251740

Sabri Alamri and Andrés F. Lasagni. Development of a general model for direct laser interference patterning of polymers. *Optics Express*, 25, pp. 9603-9616, 2017 dx.doi.org/10.1117/12.2251740

G.S. Joshi, C. Gaudiuso , C. Putignano, A. Ancona, G. Carbone. Tribological effects due to different geometries of surface texturing on lubricated non-conformal contacts. Proceedings of the 6th European COnference on TRIBology, Slovenian Society for Tribology, Ljubljana 2017.

J. Romano, A. Garcia-Giron, S.S. Dimov. Laser-textured masters for high throughput replication of hydrophobic surfaces 5th Industrial Laser Applications Symposium, 2017.

A. Garcia-Giron, J. Romano, S.S. Dimov. Fabrication of Super-Hydrophobic Metallic Surfaces by Direct Laser Patterning, 5th Industrial Laser Applications Symposium, 2017

D. Huerta-Murillo, A.I. Aguilar-Morales, S. Alamri, J.T. Cardoso, R. Jagdheesh, A.F. Lasagni and J.L. Ocaña. Fabrication of multi-scale periodic surface structures on Ti-6Al-4V by direct laser writing and direct laser interference patterning for modified wettability applications. Optics and Lasers in Engineering, 98, 2017. doi.org/10.1016/j.optlaseng.2017.06.017

J. T. Cardoso, A. Garcia-Girón, J. M. Romano, D. Huerta-Murillo, R. Jagdheesh, M. Walker, S. S. Dimov and J. L. Ocaña. Influence of ambient conditions on the evolution of wettability properties of an IR-, ns-laser textured aluminium alloy. RSC Advances, 63, 2017. doi.org/10.1039/C7RA07421B

J. Romano, P. Penchev, S.S. Dimov. Bulk metallic glasses: enabling technology for micro manufacturing Conference on Industrial Laser Processing JNPLI, 2016.

Many more publications are under preparation. Be sure you to regularly point your web browser to http://www.laser4fun.eu for updates.

Contact

Andrés Escartín Barduzal
BSH Electrodomésticos España, S.A.
P : +34 976 102 716
E : andres.escartin[at]bshg.com (replace [at] with the @ character)
Website : http://www.laser4fun.eu

This Newsletter was compiled by University of Twente, Netherlands, from contributions of the partners of the Laser4Fun project.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement Nº. 675063.

References

1 Visser, C. W., Pohl, R., Sun, C., Römer, G.-W., Huis in 't Veld, B., & Lohse, D. (2015). Toward 3D Printing of Pure Metals by Laser-Induced Forward Transfer. Advanced Materials, 27(27), 4087–4092. http://doi.org/10.1002/adma.201501058

2 Feinaeugle, M. (2013) Laser-induced forward transfer of intact, solid-phase inorganic materials University of Southampton, Physical Sciences and Engineering, Doctoral Thesis , 225pp.

3 K.W. Hayden, J. C. Russell, P.I. Elena, "Wettability of natural superhydrophobic surfaces", Adv. Coll. Int. Sci. 210, 58-64, 2014.

4 H.J. Ensikat, P. Ditsche-Kuru, C. Neinhuis, W. Barthlott, "Superhydrophobicity in perfection: the outstanding properties of the lotus leaf" Beilstein J. Nanotechnol. 2, 152-161, 2011.

5 A.M. Kietzig, S.G. Hatzikiriakos, P. Englezos, "Patterned Superhydrophobic Metallic Surfaces", Langmuir. 25(8), 4821-4827, 2009.

6 Sabri Alamri and Andrés F. Lasagni, "Development of a general model for direct laser interference patterning of polymers," Opt. Express 25, 9603-9616 (2017)

7 Sabri Alamri and Andrés F. Lasagni, "Direct laser interference patterning of transparent and colored polymer substrates: ablation, swelling, and the development of a simulation model", Proc. SPIE 10092, Laser-based Micro- and Nanoprocessing XI, 1009219 (February 17, 2017)

8 https://en.wikipedia.org/wiki/Spherical_aberration

9 D. H. Kam, S. Bhattacharya, and J. Mazumder, "Control of the wetting properties of an AISI 316L stainless steel surface by femtosecond laser-induced surface modification," J. Micromechanics Microengineering, vol. 22, no. 10, p. 105019, 2012.

10 M. Barberoglou, V. Zorba, E. Stratakis, E. Spanakis, P. Tzanetakis, S. H. Anastasiadis, and C. Fotakis, "Bio-inspired water repellent surfaces produced by ultrafast laser structuring of silicon," Appl. Surf. Sci., vol. 255, pp. 5425–5429, 2009.

11 L. Gemini, M. Faucon, L. Romoli, R. Kling, R. F. Mitterrand, and I. Industriale, "High throughput laser texturing of super-hydrophobic surfaces on steel," Proc. SPIE, vol. 10092, pp. 1–6, 2017.

12 A. Y. Vorobyev and C. Guo, "Colorizing metals with femtosecond laser pulses," Appl. Phys. Lett., vol. 92, no. 4, pp. 1–4, 2008.

13 J.-M. Guay, A. C. Lesina, J. Baxter, M. Charron, G. Côté, L. Ramunno, P. Berini, and A. Weck, "Enhanced plasmonic coloring of silver and formation of large laser-induced periodic surface structures using multi-burst picosecond pulses," arXiv Prepr., vol. 1609.04847, pp. 1–8, 2016.

14 J. Bonse, R. Koter, M. Hartelt, D. Spaltmann, S. Pentzien, S. Hohm, A. Rosenfeld, and J. Kruger, "Femtosecond laser-induced periodic surface structures on steel and titanium alloy for tribological applications," Appl. Phys. A Mater. Sci. Process., 2014.

15 E. Skoulas, A. Manousaki, C. Fotakis, and E. Stratakis, "Biomimetic surface structuring using cylindrical vector femtosecond laser beams," Nat. Publ. Gr., no. November 2016, pp. 1–11, 2017.

16 S. Höhm, a. Rosenfeld, J. Krüger, and J. Bonse, "Femtosecond laser-induced periodic surface structures on silica," J. Appl. Phys., vol. 112, no. 1, p. 014901, 2012.

17 M. Faucon, A. Laffitte, J. Lopez, and R. Kling, "Surface blackening by laser texturing with high repetition rate femtosecond laser up to 1MHz," Proc. SPIE, vol. 8972, no. February, p. 89721M, 2014.

18 S. K. Das, D. Dufft, A. Rosenfeld, J. Bonse, M. Bock, and R. Grunwald, "Femtosecond-laser-induced quasiperiodic nanostructures on TiO 2 surfaces," J. Appl. Phys., vol. 084912, no. 2009, 2013.

19 F. Bauer, A. Michalowski, T. Kiedrowski, and S. Nolte, "Heat accumulation in ultra-short pulsed scanning laser ablation of metals," Opt. Express, vol. 23, no. 2, pp. 1035–1043, 2015.

20 Friction Properties of Lubricated Laser-MicroTextured-Surfaces: An Experimental Study from Boundary- to Hydrodynamic- Lubrication ; Michele Scaraggi • Francesco P. Mezzapesa • Giuseppe Carbone • Antonio Ancona • Luigi Tricarico.

21 Femtosecond laser full and partial texturing of steel surfaces to reduce friction in lubricated contact ; Antonio Ancona*, Giuseppe Carbone, Michele De Filippis, Annalisa Volpe and Pietro Mario Lugarà

22 Effect of surface topography on mixed lubrication film formation during start up under rolling/sliding conditions; I. Krupka , P. Svoboda, M. Hartl

23 Minimize friction of lubricated laser-microtextured-surfaces by tuning microholes depth; Michele Scaraggi a, Francesco P. Mezzapesa b, Giuseppe Carbone c,n, Antonio Ancona b, Donato Sorgente c, Pietro Mario Lugarà b,d