

PERSPECTIVE

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Industrial-grade processing of metal surfaces via femtosecond laser

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and Linas Jonušauskas^{1,2} ¹ Femtika Ltd Saulėtekio Ave. 15 Vilnius LT-10224 Lithuania² Laser Research Center Vilnius University Saulėtekio Ave. 10 Vilnius LT-10223 LithuaniaE-mail: linas@femtika.lt**keywords:** femtosecond pulses, functional surfaces, industrial machining, aerospace, maritime, medicine**Abstract**

Surfaces with micro- and nanofeatures were proven to be a superb solution to selectively induce various surface functionalities like anti-bacterial, self-cleaning, friction reduced, hydrophilic or hydrophobic. While there are multiple ways to achieve it, femtosecond (fs) laser-based solutions were shown to offer the best balance between price, throughput and result. Thus, here we will discuss how Horizon 2020 project FemtoSurf will address this challenge and what industries it covers.

1. Introduction

In the last decades, photonics-based solutions revolutionized countless fields, including communications, medicine, data storage and many more. Industrial machining is no exception. It relies on lasers and other specialized light-based solutions on all levels of the process. Most of these light sources operate in CW or relatively long pulse duration regimes. While it allows reducing the price and complexity of such laser systems and is completely acceptable in macro-manufacturing, like in the car industry, the excessive heat accumulation during process reduces the applicability of such light sources for true micro- and nano-processing [1]. Additionally, optical solutions now employed in radiation control have minimal capabilities to control spatial characteristics of light, further decreasing the potential of the overall process as it was shown to have the potential of increasing fabrication throughput [2], improving its quality [3], or both [4].

To advance industry-oriented photonic solutions, pulse duration of laser sources should be reduced from nanosecond (ns) to ultrashort picosecond (ps) and femtosecond (fs) pulses. Ultrashort laser pulses enable precise control of temporal and thermal aspects of light-matter interaction, allowing the targeted application of radiation generated heat or complete elimination of light-induced thermal effects (so-called “cold processing”) or any possible regime in-between [5]. Additionally, high-intensity (TW/cm^2) fs pulses can induce a controlled modification in any given material, including plastics, metals, glasses and ceramics [6]. Combined, it virtually nullifies any limitations previously restricting usage of lasers in the advanced industrial applications bringing about material-independent high-precision cutting, drilling, 3D printing, volume and surface modifications ever closer to wide-spread use [1]. All of these fields are now rapidly developing with novel concepts being actively proposed and tested.

The especially attractive area of research is ultrafast surface patterning, as functional surfaces are incredibly important in the fields ranging from medicine to naval or aerospace. When fs pulses are interacting with surface an array of processes take place [7, 8]. The leading theories of the cause of surface modification are the initial interference between ultrashort pulse laser and induced surface plasmon waves that generate initial ripple formations called laser-induced periodic surface structures or LIPSS. Followed by a thermodynamic effect known as Marangoni convection. As a result, surfaces can be made both hydrophobic and hydrophilic, playing into the needs of a variety of applications, including shipbuilding, healthcare, aerospace and healthcare. Nevertheless, despite the high potential of fs laser surface patterning, at

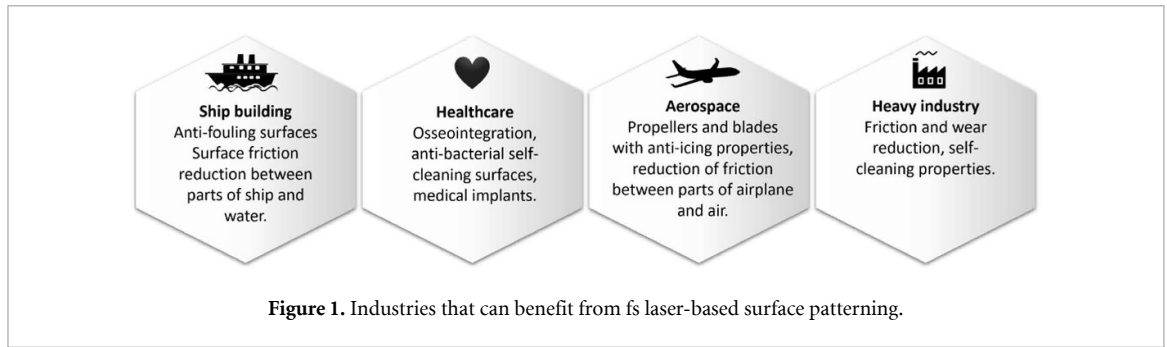


Figure 1. Industries that can benefit from fs laser-based surface patterning.

the moment it is limited to academic research. One of the main problems preventing this technology from becoming a wide-spread solution is insufficient fs laser power preventing scaling of processing. Currently, the pulse energies needed to achieve the required result can reach up to mJ, which results in average fs laser power in the range of W or even tens of W, pushing standard amplified fs lasers to their limit. Application of fs laser of kW-level average power would allow using multiple laser spots for parallel processing, dramatically increasing the throughput of the process pushing it from lab to fab. However, currently, high average power fs lasers are scarce. Also, new beam control and shaping techniques have to be developed in order to control and use such a powerful laser beam in the most efficient and applicable manner. All of these areas will be addressed in the FemtoSurf project, which aims at pushing fs laser surface patterning from laboratory-level research to the industrial-grade solution that could benefit multiple areas of industry (figure 1). It will be achieved by combining sufficiently a powerful fs laser (up to few kW average power) and a highly automated processing setup with such advanced features as auto-focus needed for arbitrary shaped elements and on-the-fly quality control.

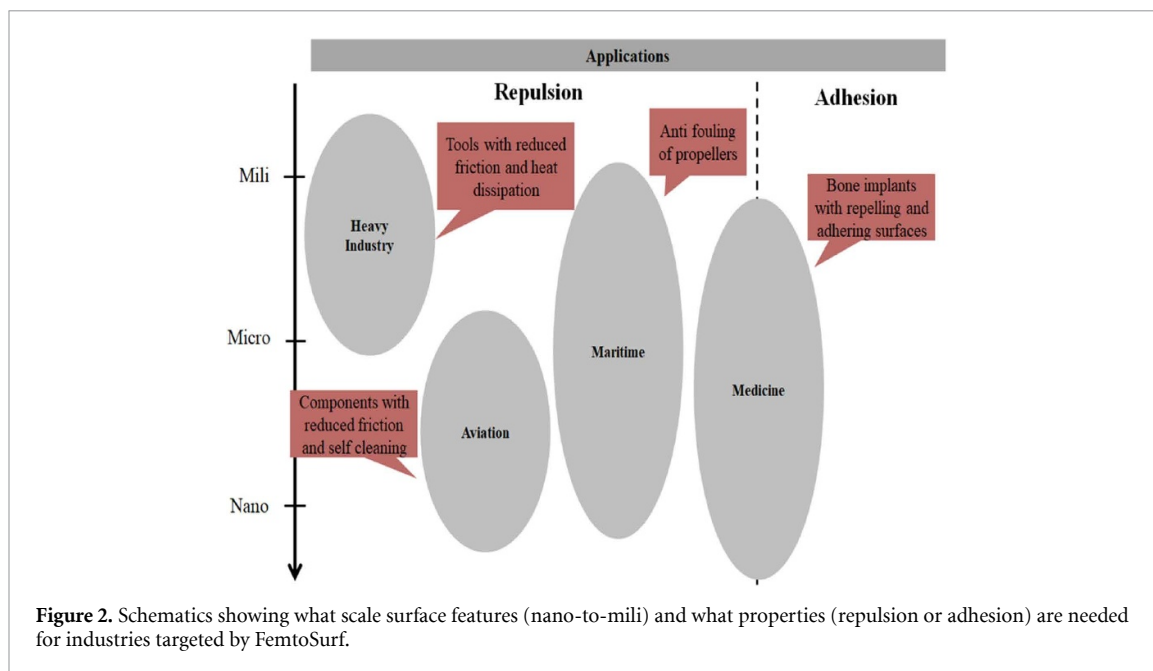
2. FemtoSurf application areas

While the capabilities of laser surface patterning are highly promising, each application requires special attention to scales of surface features involved (figure 2). For instance, lubricants play an enormous role in modern tool manufacturing, reducing the wear of industrial tools and making the whole process smooth. However, sometimes getting lubricant to required places can be problematic or impossible. Ultrafast laser treatment of surfaces will address this issue in two ways. First, patterns can be created in order to guide lubricant to specific places of the machining setup. Second, friction can be reduced by special surface features in the operations where lubricant cannot be used due to adverse conditions of the process (for instance ultra-high temperature). As FemtoSurf is dedicated to metal surfaces it has synergy with the manufacturing sector where metal is a prevalent material of choice for its durability, property kept by the fabrication techniques applied in FemtoSurf.

FemtoSurf will also bring new solutions to the aerospace industry. Wear and contamination of aviation components operating under constant stress is a major issue. It requires constant cleaning/restoration operations that are complex and costly. Furthermore, spacecrafts operating beyond Earth's atmosphere cannot be reached for regular maintenance. Thus their operational wear or contamination should be minimized directly enhancing their lifespan. The surface treatment developed in FemtoSurf will remedy these problems by covering airplane or spacecraft components in surface patterns enhancing their self-cleaning properties and reducing the overall friction between components under heavy load enhancing their lifespan. It is important to note that due to the nature of light-matter interaction at fs time-scale any metal can be processed this way, including exotic alloys used in the aerospace industry.

Fouling is a massive issue in all seafaring vessels. It results in increased drag and fuel consumption, raising both operational costs and the carbon footprint of ships. While hulls of ships can be to some extent covered with special anti-fouling coatings, propellers, operating in constant motion, cannot. For this reason, propeller cleaning becomes the only solution, further increasing operational costs, as sometimes it must be done in the intervals as small as two weeks. The anti-fouling surface structures on ship propellers will be implemented using fs laser surface patterning. It will lead to a massive decrease in fuel consumption and maintenance of ships, directly impacting the maritime industry and indirectly worldwide shipping industry. Indeed, the decrease in fouling should result in operational costs decrease as much as 161 thousand euros for a single 42 meters long crew vessel.

The surface properties of any medical devices play a pivotal role in their functionality. It determines bio-compatibility, reaction to drugs and, most importantly for implants, repulsion or adhesion to living tissue. Titanium implants used today play a major role in orthopedics, as it allows to replace sick or damaged



bones. Thus, well-controlled and spatially targeted repulsion and adhesion properties are a must. At the moment it is achieved with various technologies covering implant in complimentary coatings, that are hard to apply, expensive, prone to wearing and could have long term toxicity, resulting in the necessity to have repeated surgical invasions to the patient's body to reach the implant and treat the long-term wear. FemtoSurf solution would allow to directly tune the properties of titanium implants, including targeted induction of repulsion or adhering in designated areas of the implant. It can be achieved simply by tuning laser and other processing parameters in the setup. Therefore, the FemtoSurf solution will lead to the giant leap forward in the functionality and longevity of orthopedic implants.

3. Outlook

With diverse applications and immense potential comes appropriate challenges. In order to increase the spot size and/or multiplex it via multiple focal points requires increasing average laser power to kW level. At the same time, an optical chain has to be tuned appropriately to sustain, direct and spatially shape such amount of laser light. It has to be integrated into a highly automated workstation which has to accommodate highly specific components relevant to discussed industries. All of these challenges will be addressed in FemtoSurf with the final product being an industrial-grade fs surface structuring system with surface structuring capability beyond $\text{m}^2 \text{min}^{-1}$.

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