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# Formation of Oxide Layers with Femtosecond Laser on Steel Surfaces for Color Marking

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*Abstract. With the appearance of ultrashort pulse lasers, the researchers have begun working on various laser marking technology. Atmospheric heating and ablation of a surface induce laser coloration of metal surfaces. However, their application is still problematic today in the industry. With the appearance of femtosecond pulse lasers, a new concept became available for color marking. This concept is based on the formation of laser-induced periodic surface structures (LIPSS) on metal surfaces. The purpose of this article is to summarize the literature of laser color marking with ultrashort pulse lasers.*

## Introduction

In today's world there is no product that are not marked somehow. There are several marking methods and one of which is the laser marking [1]. These laser marking methods are developing as technology develops behind them. As ultrashort pulse lasers started to appear in the industry, they opened new ways for these marking methods. One of these methods is laser color marking. Before the investigation of laser color marking methods, we need to overview the technology behind it, the ultrashort pulse lasers.

## 1. Ultrashort pulse lasers

There are several types of pulse lasers for example pulse lasers, short pulse lasers and ultrashort pulse lasers. We talk about ultrashort pulse lasers when their pulse duration is shorter than the thermal vibration period of molecules, which is around tens of picoseconds [3]. This means the ultrashort pulse lasers have pulse duration under nanosecond. In the case of ultrashort pulse laser machining the laser-material interaction time is very short, resulting in a variety of unique phenomena. The heat energy does not have time to diffuse in the lattice because the pulse time is shorter than the relaxation time between the electron and phonon [8]. This is the reason that the ultrashort pulse laser machining considered as cold application (Figure 1).

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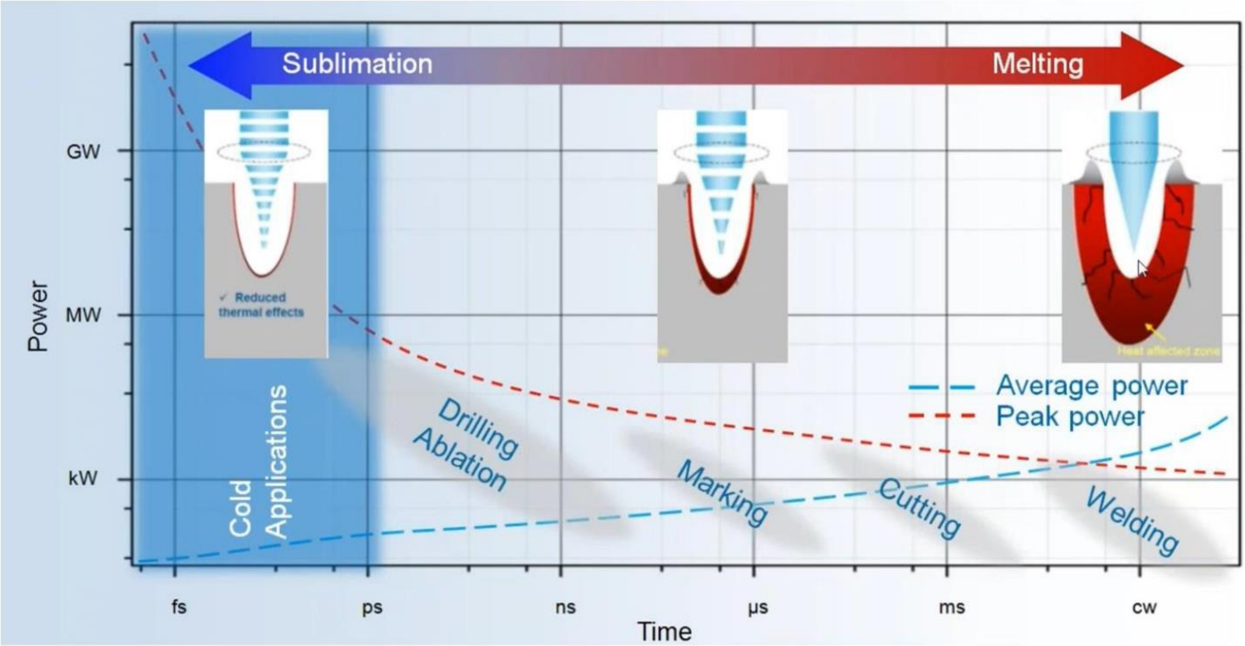


*Figure 1. Applications of different type lasers [8]*

As the Figure shows, the ultrashort pulse lasers have high peak power, this means that the material quickly reaches the evaporation temperature and the separated particles are removed from the surface. Because of the fast interactions there are no hydrodynamic and thermal conductivity phenomena resulting in high machining accuracy (Figure 2) [8].

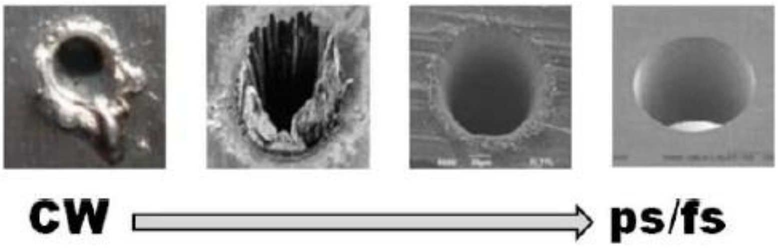


*Figure 2. Holes made with different types of lasers [3]*

Another feature of the ultrashort pulse lasers is the universal material machining. The high peak intensity only induces multiphoton absorption. The multiphoton absorption and ionization threshold depend primarily on atoms and not on the density of electrons in the material which means any material is suitable for the process even transparent materials. There is one more phenomenon, the laser-induced periodic surface structures.

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## 2. Laser-Induced Periodic Surface Structures (LIPSS)

LIPSS is a phenomenon on almost all the solids, including metals, semiconductors, dielectrics, polymers and ceramics. There are different types of LIPSS. The low-spatial-frequency LIPSS (LSFL) and high-spatial-frequency LIPSS (HSFL). These types of LIPSS have different properties as shown in Figure 3 [5].

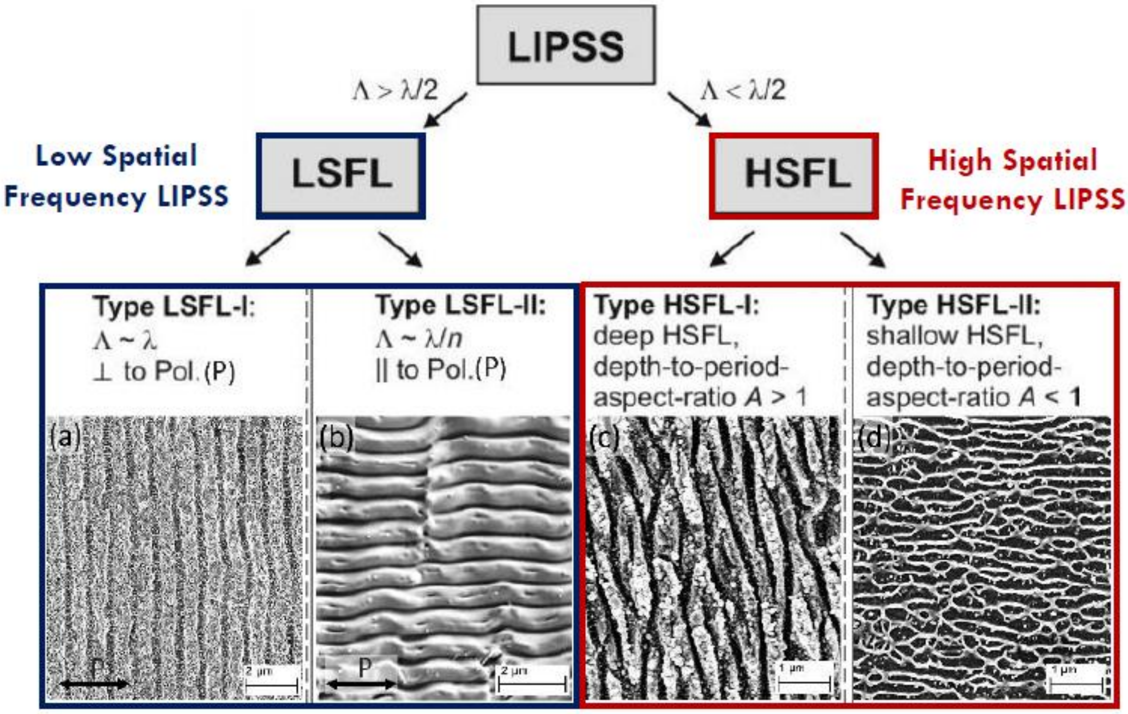


*Figure 3. Different types of LIPSS [4]*

As the Figure shows the polarity of the laser beam controls the orientation of these ripples. But there are different properties that can control these structures. For example, the laser wavelength, the angle of incidence, the pulse to pulse overlap, the laser fluence and the ambient pressure. The continuous wave lasers or long pulse lasers can only create LSFL LIPSS while the pico- or femtosecond lasers can create HSFL LIPSS. These structures can be used for different applications for example the LIPSS can control the hydrophobicity and hydrophilicity of the surface, improve absorption and emission properties on surfaces, change light scattering in thin solar panels, medical usage (Titanium-cell interaction improvement), reduce friction and wear and can be used for color marking on metal surfaces [5].

## 3. Colorization of metals with femtosecond lasers

Several researchers [5, 6, 7, 9, 10] demonstrated that femtosecond pulse lasers can create color on metals. These lasers provide controllable modification of optical properties of metals from UV to terahertz wavelength. The area that we modify can be as small as the focused laser spot or as big as we want with a scanning laser beam. The laser-induced periodic surface structures are the reason of the optical changing of the surface as Figure 4 shows [5].

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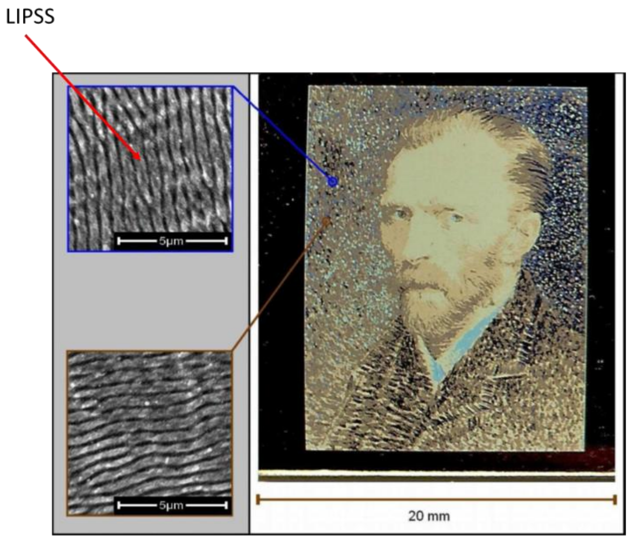


*Figure 4. Colorization on a 316L stainless steel sample [6]*

The reflection of light changes from such surfaces as shown in Figure 5. The color of the surface depends on the period, height and orientation angle of the structures on the surface of the metal [7].

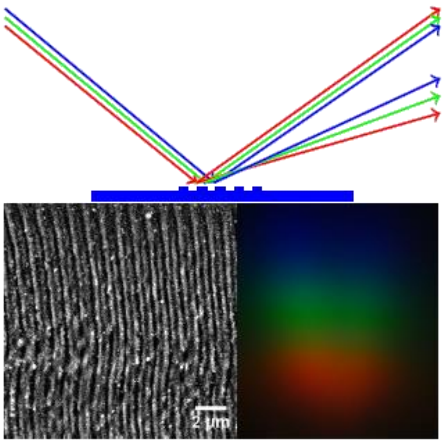


*Figure 5. Optical changing on a nanostructured surface [5]*

# Summary

Femtosecond lasers can be used for colorization of metals. This can be achieved with Laser-Induced Periodic Surface Structures (LIPSS) which can be controlled with the right selection of laser parameters. Thus, this phenomenon can be used for color marking on metals which can be used for authentication and traceability of a product.

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