Unveiling the formation process of laser-induced periodic surface structures on stainless steel using ion implantation

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Ultra-short laser (fs-laser) pulses can be used to generate laser-induced periodic surface structures (LIPSS, ripples) on different types of materials. A variety of potential applications of these grating-like LIPSS have already been demonstrated in the field of surface functionalization [1]. Examples include structural colors (e.g. for optical effects or safety features), beneficial friction and wear reduction, modification of the wetting behavior of surfaces, and antibacterial or cell adhesion promoting properties for medical implants. Despite decades of research, however, some aspects regarding the formation mechanism are still unclear and the subject of controversial debate. This involves the two main models of coherent electromagnetic scattering and matter reorganization, which are used for explaining aspects of LIPSS formation and phenomenology [2]. One major issue is to quantify the actual amount of material removal during the fs-laser processing due to the lack of an independent depth reference and to visualize the so-called heat-affected zone accompanying intense fs-laser irradiation.

In the present study, near-surface implantation of Mn and N ions into different material depth of Mn-free austenitic stainless steel alloy FeCrNiMo18-12-2 was used to create reference layers of a defined thickness containing the respective elements. LIPSS (type low-spatial frequency LIPSS, LSFL) were fabricated on the polished substrate surfaces in an air environment by fs-laser irradiation (λ = 1025 nm, τ = 300 fs, f_{rep} = 100 kHz, F_0 = 1.5 J/cm^2). The implanted layers subsequently served as a kind of coordinate system to assess the material removal during the formation process via cross-sectional Transmission Electron Microscopy (TEM) and Energy Dispersive X-ray Spectroscopy (EDXS). Using both analysis methods enabled in particular to determine the position of peaks and valleys of the LIPSS topography in relation to the initial surface before fs-laser irradiation. This confirmed the selective ablation in the LIPSS valleys. Moreover, linking changes in the material's microstructure, e.g., the crystallinity and near surface elemental composition before and after fs-laser treatment, gave additional insights regarding the transient cooling rates, as recently shown for NiTi alloys [3].

References:

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