Impact of Topography and Thermophysical Properties on Multi-Shot LIPSS Generation

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Laser-Induced Periodic Surface Structures (LIPSS) on metals, produced by ultrashort pulsed laser ablation, have been focus of extensive research due to their possibility to modify the surface below the diffraction limit, controlling mechanical, optical, and chemical functionality. Despite complex mechanisms involving hydrodynamics, the generation of LIPSS fundamentally relies on periodic field modulations, created by the interference of scattered surface waves with the incoming laser pulse and the resulting ion-temperature modulation [1].

To further understand the influence of surface scattering and thermophysical material properties on generation of LIPSS, this comparative study investigates multi-shot USP laser ablation (500 fs, 1040 nm) on Aluminium (Al) and AISI 304 stainless steel. These materials were chosen for their significant differences in electron-phonon coupling and heat conductivity. Morphology changes were investigated with Scanning electron microscope and atomic force microscope (AFM) measurements (20 nm lateral, 1 nm vertical resolution). For numerical analysis, simulations with Finite-Different-Time-Domain (FDTD) of AFM surface data and following Two-Temperature-Model were employed.

AISI 304's morphology significantly changes with increasing number of pulses, from rather smooth surface to High-spatial and Low-spatial frequency LIPSS (LSFL) after 3 and 10 pulses, respectively. From FDTD simulations, periodic field intensity modulations created by surface plasmon polariton excitation (SPP) and corresponding temperature modulations due to high electron-phonon coupling are evident for all applied pulses, explaining LSFL with the established model [2]. Contrary for Al, the surface after the first pulse generates µm-high structures due to the higher heat conductivity [3], leading to random field intensity variations diminishing coherent periodic modulations and thus preventing LIPSS generation.

Our findings highlight the critical role of the morphology outcome after the first pulse - depending on thermophysical and mechanical material properties - in dictating optical scattering effects for subsequent evolution of the surface and the potential for LIPSS formation. This comparative study builds the foundation for a more general understanding of the possibility to generate LIPSS on metals.

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