Grazing-incidence XFEL scattering to study ultrafast surface ablation and nano-structuring dynamics

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Nanoscale surface manipulation utilizing ultrashort intensity laser irradiation has gained significant attention in recent decades due to its capacity to tailor surfaces, thereby enhancing their mechanical, structural, or electronic properties to open substantial potential for various technical applications. Specifically, laser-induced periodic surface structures (LIPSS), which are created by the interaction of ultra-short laser pulses with solids, facilitate the direct inscription of sub-micrometer gratings, offering opportunities across the fields of tribology, mechanical engineering, biology, plasmonics, photovoltaics, and medicine [1]. Despite the extensive effort on experimental investigations, a comprehensive understanding of the dynamics governing the generation of periodic structures from irregular rough surface under laser irradiation remained elusive, lacking experimental visualization with requisite temporal (ranging from picosecond to milliseconds) and spatial (of the order of nanometers) resolution [2].

We recently conducted a study to assess the visibility of utilizing an XFEL (X-ray Free-Electron Laser) for high-resolution visualization of surface and sub-surface structures at the nanometer and sub-picosecond scales. This investigation employed grazing-incidence small angle x-ray scattering (GISAXS). Our experiment unveiled the nanoscale density dynamics within multilayer materials under high-intensity femtosecond high-intensity laser irradiation [3]. Subsequently, we extended this technique to monitor the evolution of nanoscale surface morphology. Additionally, to elucidate the fundamental physics driving surface restructuring via ablation, we employed the grazing-incidence diffraction (GID) to track sub-surface atomic-scale dynamics, including phenomena such as melting and compression. The concurrent use of GISAXS and GID will facilitate comparison with the state-of-the-art simulation theory [4].

In this talk, we will discuss our recent experimental findings utilizing grazing-incidence x-ray scattering performed at SACLA XFEL and European XFEL at HED (High Energy Density) instrument. We will present our experimental findings, outline our near-future perspectives.

[1] J. Bonse et al., IEEE J. Sel. Top. Quantum Electron. **23**, 9000615 (2017).
[2] J. Bonse and K. Sokolowski-Tinten arXiv: 2309.02971 (2023).
[3] L. Randolph et al., Phys. Rev. Res. **4**, 033038 (2022).
[4] A. Rudenko et al., Acta Materialia **194**, 93 (2020).