Laser-Induced Self-Organized Microrod Arrays

I. Gnilitskyi[1,2], G. D. Tsibidis[3] and A. V. Zayats[1]

1- Department of Physics and London Centre for Nanotechnology, King's College London, Strand, London WC2R 2LS, UK

2- Department of Applied Physics, Lviv Polytechnic National University, 79013 Lviv, Ukraine

3- Institute of Electronic Structure and Laser (IESL), Foundation for Research and Technology (FORTH), N. Plastira 100, Vassilika Vouton, 70013, Heraklion, Crete, Greece

*Corresponding author email: iaroslav.gnilitskyi@kcl.ac.uk

Femtosecond laser machining has emerged as a powerful tool in material processing and modification as well as nanostructure fabrication. The advantages of this approach compared to longer pulse duration lasers can be attributed to the non-thermal ablation mechanisms taking place at the femtosecond timescales, which make it appealing for material treatment applications where mitigation of heat-induced damage is important for dielectric, semiconductor or metallic substrates. This technique facilitates the direct formation of microstructures in ambient conditions, avoiding the requirement for vacuum processing.

Here, we will discuss fabrication of microrod arrays on metallic (Ti alloy) surfaces due to self-organization processes during ultrashort laser illumination. The technique enables rapid direct inscription of self-organized microstructures over large surface areas. These microstructures typically feature a nanorod dimeter in the range from 5 to 25 micrometers and height spanning from 5 to 30 micrometers. The microrods have quasiperiodic arrangement (5--20 micrometers range). The geometrical dimensions can be controlled by choosing laser irradiation parameters. The formation of laser-induced microstructures occurs within the laser ablation regime and arises from the cumulative effect of multiple pulses.

The principal mechanisms underlying the microstructure formation involve three sequential steps: (i) interference phenomena between incident electromagnetic waves and surface plasmon waves, enabled by electron plasma formation, engender spatially periodic modulation of laser field energy density; (ii) heat transfer within the metal lattice, encompassing electron relaxation and carrier-lattice heating through ultrafast dynamics and carrier-photon coupling; and (iii) hydrodynamic processes governing molten material and resolidification dynamics, incorporating contributions from recoil pressure and surface tension effects. These mechanisms collectively result in the formation of laser-induced microrod arrays through the intricate interplay of electromagnetic, thermal, and fluid dynamics phenomena. We present a systematic investigation of the above multiscale physical processes by evaluating the role of the laser parameters in the features of the induced morphologies. The modelling based on these mechanisms is validated in the experimental observations.

The developed self-organised microrod arrays are important for the development of structured surfaces for microbiology, catalysis and biomedical applications.