Ultrafast Laser-Induced Surface and Bulk Nanostructuring: Similarities Revealed by Electromagnetic Modeling

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Progress in manufacturing, energy conversion or transportation is closely tied up to the ability to manipulate bulk and surface material properties at the nanoscale. The interaction of intense ultrashort laser pulses with rough surfaces and inhomogeneous volumes offers the possibility to localize light beyond diffraction limit, presenting a real potential of direct nanostructuring with spatial order and tunable physical characteristics by optical means. Laser Induced Periodic Surface Structures (LIPSS) with periodicity varying from near laser wavelength down to sub-100 nm scale, has been reported on a large variety of solid materials. As well, the formation of bulk nanogratings in dielectrics upon irradiation with multiple femtosecond-laser pulses share some strong similarities with LIPSS although their formation mechanisms have been the subject of speculation and intensive debate throughout the decade. To explain this "universal mechanism of self-organization", the role of surface and bulk roughness distributions will be discussed based on 3D electrodynamic simulations, first principles approaches and hydrodynamic processes [1]. A complex but similar electromagnetic origin, mainly induced by scattering and defined by the spatial coherence of the laser field [2], predicts a spatially-ordered energy deposition for periodic surface and bulk structuring. More precisely, simulations reveal the associated roles of coherent superposition of far-field scattered waves with refracted waves and local near-field enhancement [3]. This indicates that the control of the underlying mechanisms is achievable through reaching a detailed elucidation of the electromagnetic response of irradiated materials.

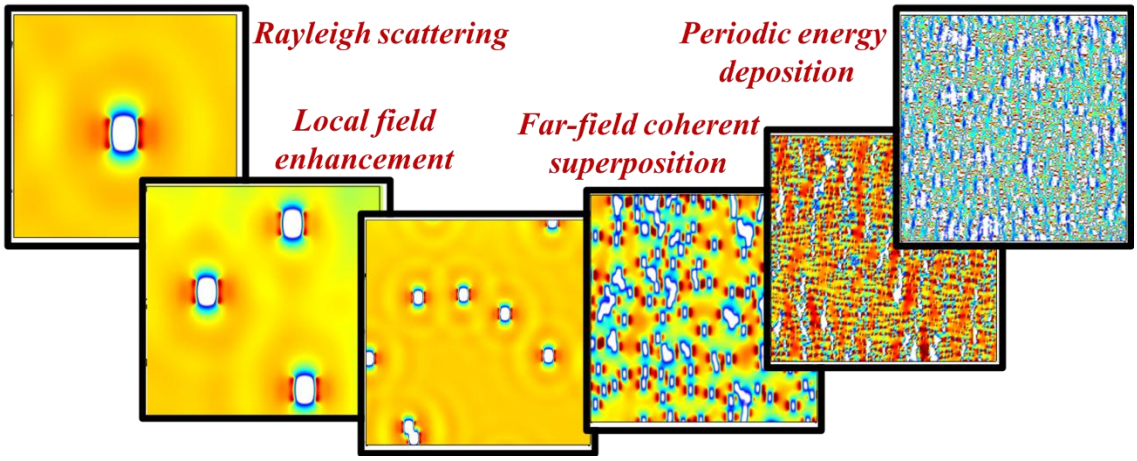

Fig. 1 Simulations of electromagnetic processes involved in laser-induced self-organization of material as a function of roughness concentration evolution.

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