Growth of laser-induced periodic surface structures Under competing ablation and photo-expansion mechanisms

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We study the formation of laser-induced periodic surface structures (LIPSSs) using a femtosecond pulsed laser source on the basis of the Sipe-Drude theory solved with a finite-difference time-domain (FDTD) scheme. LIPSSs consist of wavy nanometric structures and can be categorized depending on their orientation with respect to the incident laser polarization and their periodicity Λ with respect to the incident laser wavelength λ. The Sipe-Drude theory predicts with success a few types of experimentally observed structures by considering electromagnetic propagation through the rough surface of a bulk with given ionization density. For instance, structures orientated perpendicular to the light polarization and with periodicity of $\Lambda \sim \lambda$ are predicted for strongly absorbing materials, such as metals or ionized dielectrics. For less absorbing materials, structures parallel to the polarization with periodicity of $\Lambda \sim \lambda/\mathrm{Re}(\varepsilon)$ (ε is the permittivity obtained with the Drude model) are predicted. With our FDTD solver, we find, in as yet unexplored regions of parameter space, that a linearly polarized laser pulse can interact with a rough surface such that bidimensional structures could grow with both parallel and perpendicular periodicity of $\Lambda \sim \lambda$. However, this theory cannot predict the strong organization and regularity in the space domain, as observed in the experiments. Implementing self-organization mechanisms in the model as inter-pulse feedback is a possible solution to simulate the growth of strongly organized LIPSSs from one laser pulse to the next. This method [1] uses a non physical ablation process to qualitatively account for material removal between two laser pulses. This model can reproduce a larger variety of structures with much better spatial regularity than the Sipe-Drude Theory, but still fails to predict amplitude growth of some of the structures. We suggest that those remaining structures can grow by considering an inverse mechanism, a non physical photo-expansion process. By combining ablation and photo-expansion mechanisms, we have successfully simulated the growth of a large class of LIPSSs in the space domain.

[1] J. Z. P. Skolski, G. R. B. E. Römer, J. Vincenc Obona, and A. J. Huis in't Veld, J. Appl. Phys. **115**, 103102 (2014).