FEMTOSECOND SELF-RECONFIGURATION OF LASER-INDUCED PLASMA PATTERNS IN DIELECTRICS

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Laser micro-machining of transparent material by femtosecond pulses promises fast integration of 2D and 3D nanophotonic and nanofluidic devices with tailored properties. Exposition of solid materials to intense laser radiation typically gives rise to complex light-matter interaction processes like high harmonic generation, ionization avalanche breakdown, and ultrafast plasma dynamics. Such nonlinear light-matter interaction processes are often associated with instabilities that lead to the formation of periodic surface and bulk patterns. Thus far, static surface mode analysis (Sipe theory [1]) has successfully explained the origin and characteristics of periodic patterns formed on laser-processed metals and semi-conductors. However, better understanding of femtosecond laser-plasma interaction dynamics is necessary to explain nanograting formation in dielectrics.

For transparent dielectrics, the Sipe theory is only valid in the early ionization stage, where the plasma density is fairly low. During the ionization avalanche, transient optical properties, referred to as *intrapulse feedback*, have to be taken into account to allow for self-interaction and therefore, self-organization of the plasma patterns while the plasma is being formed. An extended Sipe theory with a plasma density that is homogeneous in both space and time has been explored [2], but this approach does not account for the self-interaction of plasma structures. The local and dynamic nature of the interactions between plasma and light is the missing ingredient to describe the intrapulse structural self-organisation.

We show that a self-consistent dynamic treatment of the plasma formation and its interaction with light triggers an ultrafast reconfiguration (see Fig. 1) of the periodic plasma patterns on a field-cycle time scale [3]. Within this framework, a simple stability analysis of the local light-plasma interactions explains how the laser-induced plasma patterns change their orientation with respect to the incident light polarization, when a certain energy density threshold is reached. Moreover, the reconfigured sub-wavelength plasma structures grow into the bulk of the sample and agree with the experimental findings of self-organized volume nanogratings [4]. Mode coupling of the incident and transversally scattered light with the periodic plasma structures is sufficient to initiate the growth and the self-organization of the characteristic pattern with a periodicity of a half-wavelength in the medium.

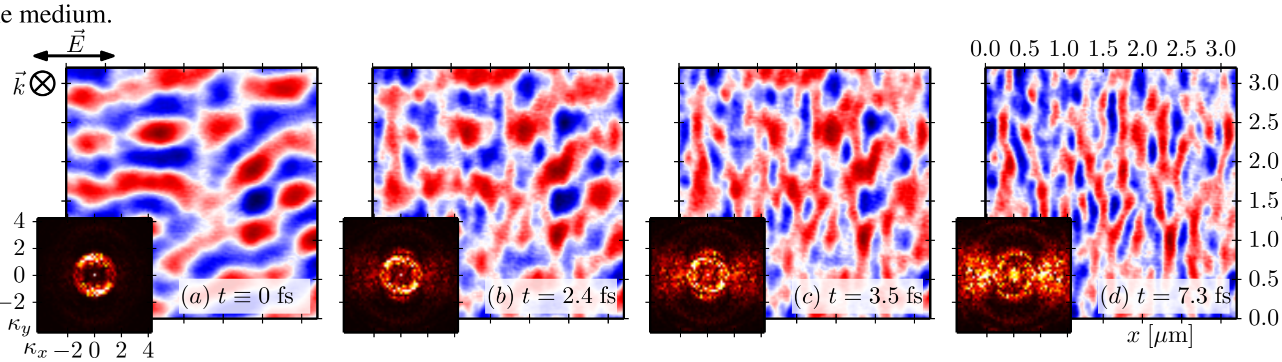

FIG. 1. Time evolution of the variations in plasma density (from blue minima to red maxima) generated by a $\lambda = 800$ nm laser source with pulse duration $\tau = 10$ fs and fluence $F = 3$ J/cm^2 in a fused silica sample (refractive index $n = 1.45$). From (a) to (d), there is a structural transition from $\Lambda_\parallel \sim \lambda/n$ (periodicity parallel to light polarization) to $\Lambda_\perp \sim \lambda/2n$ (periodicity orthogonal to light polarization). Overlayed subfigures are the corresponding 2D Fourier transforms. Wavenumbers $\vec{\kappa}$ are all in units of λ^{-1}.

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