Microphysics of femtosecond Bessel beam interaction with dielectrics

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Ultrafast, infrared laser pulses have been used since more than two decades for laser materials processing down to the sub- micron scale. It has been a successful story for a large number of applications, particularly within transparent materials for the processing of photonic components, opto fluidics, eye surgery, or for the even larger market of consumer electronics.

The control of energy deposition over extended length is particularly benefiting of the regime created by Bessel beams which are propagation-invariant [1]. Despite a number of successes in the fields of drilling high aspect ratio nanochannels and cutting of glass, the complex interplay between light and matter has not yet been understood. Our group has developed a strategy combining experiments and advanced numerical techniques [2,3] to uncover the role played by the laser-plasma interaction. Interestingly, we have demonstrated that Bessel beams, in the regime of single laser shot nanochannel drilling, create an over-dense plasma that is very small in diameter (typically 200 nm)[3]. We have discovered that resonance absorption is the main mechanism driving the energy deposition inside the solid, which was not taken into account in most models describing laser-dielectric interaction.

The energy density deposited by the laser pulse reaches several MJ/kg [3,4], which drives the matter into the warm dense matter regime within 10-100 ps after the laser pulse. In addition, we experimentally observe second harmonic generation in single shot [5], and predict the generation of terahertz radiation. The talk will review the microphysics phenomena occurring during the laser-plasma interaction.

Overall, this works opens new perspectives for high energy density physics, the synthesis of new material phases and obviously paves the way for new approaches in terms of laser material processing.

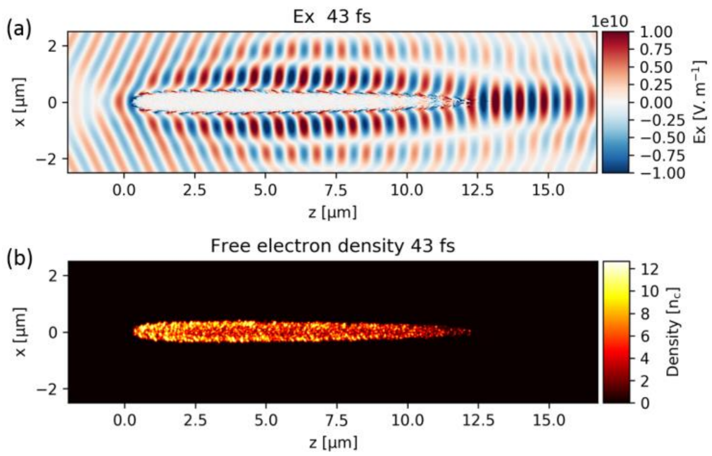

Figure 1. Results of Particle-In-Cell simulation including ionization. (a) Spatial distribution of the component of the electric field along the laser polarization, 43 fs after the pulse peak; (b) corresponding spatial distribution of the free electrons.

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[5] Femtosecond laser-induced sub-wavelength plasma inside dielectrics. II. Second-harmonic generation, Kazem Ardaneh, et al, Physics of Plasmas 29, pp. 072716 (2022).