Insights into the microphysics of ultrafast Bessel beam interaction with dielectrics

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The creation of dense plasmas inside solids by ultrafast lasers is crucial for applications such as EUV radiation, warm dense matter study or laser materials processing. It is conventionally difficult to create large volumes of dense plasmas *inside the bulk* of dielectrics to benefit from pressure confinement. Here, we demonstrate that femtosecond Bessel beams generate overdense plasmas in single pulse over a very long, sub-wavelength rod. We report here on experimental and numerical investigations on the rich physics at play, that leads to extreme energy density deposition inside the solid, formation of plasma double layer, second harmonic and terahertz generation.

Conventionally, the filamentation of Gaussian beams leads to largely sub-critical densities. In contrast, using Bessel beams, the ionization dynamics triggers several specific mechanisms occurring during the interaction that leads to the extreme regime of ionization inside the bulk. The comparison between several experimental diagnostics and particle-in-cell numerical simulations allowed us demonstrating that overdense plasma can be created during a 100 fs pulse illumination of sapphire, in single shot regime. The generated plasma rod has a typical diameter of 200 nm, while its length can be scaled from tens of micrometers to centimeters. In particular, resonance absorption, which we characterized for the first time in the bulk, accounts for most of the energy deposition. Importantly, this mechanism is extremely efficient [1].

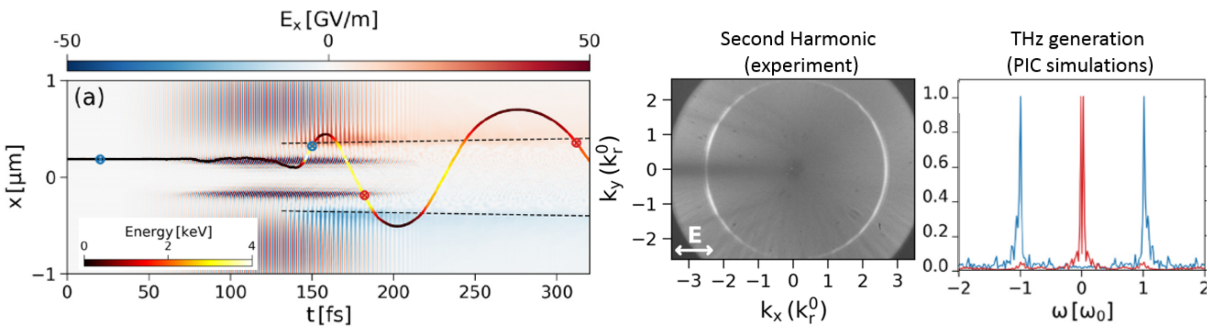

Fig. 1 (a) Electric field parallel to the polarization axis across the plasma rod. We show a trajectory of an accelerated particle that is trapped between the two double layers; (b) Experimental far-field measurement of second harmonic generation (thin ring); (c) Simulation of the radiated spectrum of the particle shown in (a), in the THz range. The blue spectrum corresponds to the particle trajectory between blue dots: it only scatters the pump. In contrast, when the particle is trapped between the double layers, THz emission appears (red curve).

Figure 1(a) shows a numerical simulation of the temporal evolution of the electric field of the Bessel beam impinging on the overcritical plasma. A high resonance is observable at the critical surface, which is the place where particles can be highly accelerated. We also observe the formation of a static electric field after the pulse, that reveals the formation of a plasma double layer on either side of the plasma rod. We have analyzed the radiation pattern emitted by the electrons. It reveals that second harmonic generation is produced during the laser-plasma interaction, which was confirmed experimentally (Fig 1b) [2]. In addition, our numerical simulations predict that the trapping of electrons within the double layer is prone to generate THz radiation [3].
These results open up new opportunities for high energy density physics inside transparent solids, enabling unconventional states of matter in confined geometries and high plasma densities for tailored interactions.

This research has been supported by H2020 European Research Council (682032-PULSAR), RENATECH CNRS, PRACE HPC resources (PRA19_4980, RA5614), HPC resource at TGCC, CEA (A0090511001, A0130511001), and Mésocentre de Calcul de Franche-Comté.

References

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