High energy density deposition inside the bulk of dielectrics via resonance absorption

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Ultrafast laser processing of nanochannels and nanovoids in the bulk of dielectrics such as fused silica, glass or sapphire is highly desirable for a number of applications such as stealth dicing, nano-fluidics or nano-photonics. It was demonstrated more than 10 years ago that high angle femtosecond Bessel beams can generate high aspect ratio with only a single laser pulse. However the exact mechanism of energy deposition was still lacking. Indeed, most numerical models were predicting defocussing of the pulse on the plasma, and very weak energy density deposition which was incompatible with the experimental result using an imaging technique developed in [1].

Here, we experimentally image the propagation of 100 fs Bessel pulses in fused silica and sapphire. High absorption and absence of defocussing are demonstrated, as it is shown in Fig. 1(a).

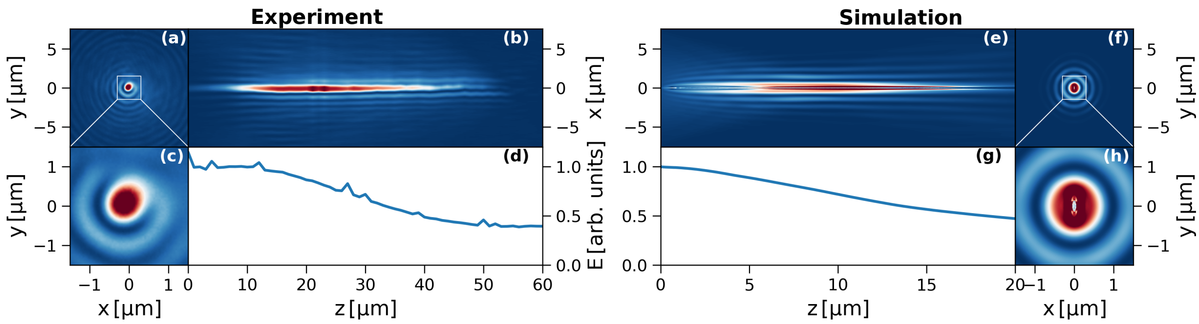

Figure 1: Comparison of near field fluence of a femtosecond Bessel pulse propagating in fused silica in experiments and simulations. Simulations are for a nanoplasma with critical diameter 125 nm. (a,c) show experimental cross-section of the beam in the middle of the nanoplasma column ($z = 30\ \mu$m) . (d) shows the energy of the pulse as a function of propagation distance. The corresponding data are shown for numerical simulations (e-h).

We analyze the laser-plasma interaction using Particle-In-Cell (PIC) numerical simulations in 3D of a Bessel pulse impinging on a preformed cylindrical nanoplasma, using EPOCH code [2]. We demonstrate an excellent agreement with all our experimental diagnostics for fluence distributions, absorption.

Our results reveal that the nanoplasmas formed by the single Bessel pulse are overcritical, and in their diameter is well below the central spot size. It is typically on the order of 300 nm. Our simulations also reveal the mechanism at play for energy deposition. The main mechanism is resonance absorption, which is collisionless. We investigate the role of surface waves generated in the vicinity of the critical surface in the heating and electron acceleration.

We have therefore demonstrated the generation, for the first time to our knowledge of overcritical plasmas inside the bulk of transparent dielectrics. Resonance absorption explains the extremely high energy density deposited by the laser pulse in single shot. We anticipate that our results will find applications for developing new strategies of laser materials processing and the study of Warm Dense Matter that is generated in the wake of the laser pulse.

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