Extreme absorption in femtosecond Bessel pulse interaction with nanoplasma rod

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Bessel pulses can be created by beam shaping from the cylindrically-symmetric interference of plane waves. They are becoming a very useful tool in many areas of optics and photonics because the central high-intensity lobe can extend orders of magnitude larger than the equivalent Rayleigh range. Our group has experimentally demonstrated that high aspect ratio channels can be opened in dielectrics using a single pulse. This has led to a large number of new applications for glass cutting but also opens new perspectives in the study of Warm Dense Matter. The experimental evidence shows a very high absorption in the range of 40 % and above, and plasmas rods with sub-500 nm diameter. Energy densities are therefore on the order of ~ 8 MJ/kg, enough to drive solids to the Warm Dense Matter regime. However, the plasma profiles are experimentally inaccessible. The fundamental questions were the profiles and mechanisms that could lead to such high absorption together with a subwavelength plasma diameter.

We have performed Particle-In-Cell simulations for the interaction of femtosecond Bessel femtosecond pulses with nanoscale plasmas rod, extending over $\sim 30\mu$m and compared the results to available experimental diagnostics (absorption, near field, far-field). We have comprehensively investigated the processes of field enhancement, plasma density modification, dynamics of the electrons, and the resulting radiation pattern. We have found that extreme absorption is a result of the resonantly driven electron plasma waves near the critical surfaces. The wave-particle interactions is the primary mechanism of energy absorption. We have also found that the plasma cross-section is the key factor in the far-field radiation pattern. We could obtain semi-quantitative agreement for the cases of void formation in sapphire and fused silica, as shown in Figure 1. In sapphire, an elliptical nanoplasma is predicted and was experimentally confirmed by the electron microscopy image of the nano-void cross-section. In the fused silica, extremely small diameters (typ ~ 200 nm) with overcritical density explain the high absorption together with uniform far-field pattern.

This work will impact the development of new technology for ultrafast laser materials processing, and the field of laser-plasma interaction with shaped beams that are increasingly attractive.

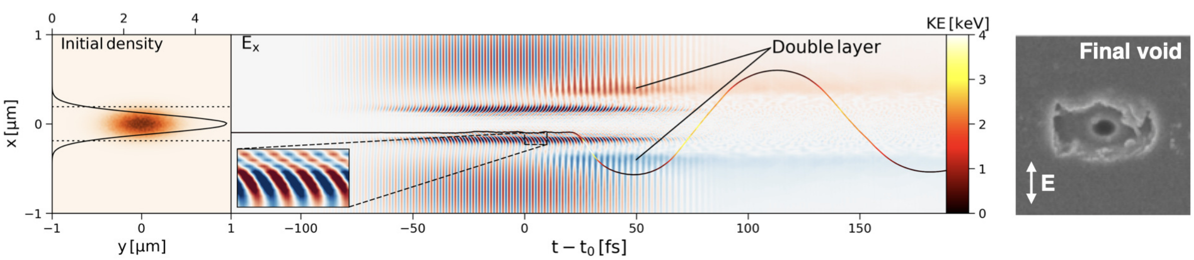

Figure 1: The interaction of a Bessel beam with a preformed nanoplasma channel (250 nm diameter). We can see the development of double layer from ≈0 fs. The trajectory of a representative electron is over-plotted in the middle panel. The final void from the experiment is shown in the right panel.

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