Dense plasma generation inside transparent solids with femtosecond Bessel beam

F. Courvoisier, B. Morel, M. Hassan, K. Ardaneh, P.J. Charpin,
V.V. Belloni, L. Furfaro, L. Froehly, R. Giust

FEMTO-ST Institute, Univ. Bourgogne Franche-Comté, CNRS,
15B avenue des Montboucons, 25030, Besançon Cedex, France
**francois.courvoisier@femto-st.fr*

Ultrafast, infrared laser pulses are ideal tools to excite or process transparent materials with submicron scale. The nonlinearity of the ionization process allows depositing energy within the bulk of materials and opens the way to 3D treatment of the materials. In this context, controlling the energy deposition process is critical. In contrast with *surface* processing, the energy deposition via electron-hole plasma formation in the *bulk* is highly coupled to the nonlinear pulse propagation.

In this framework, so-called “non-diffracting” Bessel beams, i.e., a cylindrically-symmetric interference field, bring an interesting new degree of freedom to control ultrafast laser interaction with transparent dielectrics [1]. Not only the Kerr effect can be circumvented, but we demonstrate that this beam shape allows for reaching extreme plasma densities while this is generally impossible using conventional Gaussian beam focusing. One of the first successes of Bessel beams has been the generation, in a single shot, of extremely high aspect ratio nanochannels in glass. They are now widely used to cut glass at very high speed. The laser pulse creates a plasma rod that is subwavelength in diameter but can reach up to centimeters in length [1]. Here, we have unraveled the physics at play by comparing the results of hydro and Particle-In-Cell codes to experimental data [2,3].

This presentation will review several recent results unveiling the physics at play during plasma formation within the bulk of dielectrics. We demonstrate the crucial role of field amplification and of the phenomenon of resonance absorption, which efficiently transfers energy from the laser wave to the plasma.

Notably, the ability to deposit high energy density within materials opens a wealth of new perspectives for high energy density physics: we report second harmonic generation, THz wave generation, and the dense, excited plasma transforms into warm dense matter [3-5]. This thermodynamical state is still very challenging to study and model since it lies between condensed matter physics and hot plasmas. Its physics is relevant to the interior of several astrophysical objects such as brown dwarfs and planets.

This work has been supported by the European Research Council (ERC) 682032-PULSAR. It was granted access to the PRACE HPC resources under the Project "PULSARPIC" (PRA19_4980), (RA5614), A0070511001 and A0090511001.

References

[1] R. Meyer, L. Froehly, R. Giust, J. D. Hoyo, L. Furfaro, C. Billet and F. Courvoisier " Extremely high-aspect-ratio ultrafast Bessel beam generation and stealth dicing of multi-millimeter thick glass ", Appl.Phys. Lett. **114**, 201105 (2019).

[2] B.Morel, R. Giust, K. Ardaneh, and F. Courvoisier, “Two-fluid plasma model for ultrashort laser-induced electron-hole nanoplasmas” Phys. Rev. B, **106**, 035207 (2022).

[3] K. Ardaneh, et al" High energy density plasma mediated by collisionless resonance absorption inside dielectrics ", https://doi.org/10.48550/arxiv.2109.00803 (2021)

[4], Kazem Ardaneh et al, Femtosecond laser-induced sub-wavelength plasma inside dielectrics. : I. Field enhancement, Physics of Plasmas **29**, 072715 (2022)

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