Laser-induced breakdown investigation in ultra-relativistic laser-solid interactions

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Research on Petawatt-class lasers-matter interaction gives rise to novel laser-plasma-based particle accelerators bearing potential for applications in medicine as well as inertial confinement fusion. Especially for laser-solid interactions, controlled interaction conditions are key. The acceleration of ions critically depends on the so-called target pre-expansion, driven by the leading edge of the pulse. Even before the ultra-relativistic peak interacts, the leading edge transforms the solid through a variety of different regimes of laser-plasma physics, e.g., laser-induced breakdown (LIB) [1] and collisional non-thermal equilibrium in the vicinity of relativistic laser intensities [2].
In this contribution, we utilize time-resolved off-harmonic optical shadowgraphy [3] to image the transition from the solid to the plasma state as well as subsequent plasma dynamics during the leading edge of a Petawatt laser with peak intensities of up to 6 x 10^{21} W/cm^2 in interaction with a cryogenic hydrogen-jet target [4]. The results show that LIB, i.e., the onset point of target pre-expansion, occurs much earlier than what is expected following the concept of barrier-suppression ionization. We highlight the dependence of LIB on laser-pulse duration in the context of the leading edge. Our results connect the field of LIB at lower laser intensity to research with Petawatt-class lasers at highest-available peak intensity.

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[2] L. Yang, et al., "Time-resolved optical shadowgraphy of solid hydrogen jets as a testbed to benchmark particle-in-cell simulations", Commun. Phys. 6, 368 (2023)
[3] C. Bernert, et al., "Off-harmonic optical probing of high intensity laser plasma expansion dynamics in solid density hydrogen jets", Sci. Rep. 12, 7287 (2022)
[4] M. Rehwald, et al., "Ultra-short pulse laser acceleration of protons to 80 MeV from cryogenic hydrogen jets tailored to near-critical density", Nat. Commun. 14, 4009 (2023)