Characterizing the energy distribution and the propagation of laser-accelerated relativistic electrons in mass-limited Ti-wire target

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Characteristics and transport of relativistic electron beams (REB) generated in high-intensity short-pulse laser plasma interactions are of great interest for relativistic high energy density physics (HED) and applications such as fast electron heating for fast ignition (FI) laser fusion. To investigate warm dense matter (WDM) generated by relativistic laser-accelerated electrons, we studied the interaction of the PHELIX laser with a Ti-wire (experiment number P077). Our experimental setup is illustrated in Fig. 1. Free-standing mass-limited Ti-wires, with a diameter of 50 µm and a length of up to 3 mm, were used as targets. The PHELIX laser beam (E_L=120 J on target, t_P=500 fs, λ=1064 nm) was focused by an off-axis parabola to about 5 µm focal spot on a polished tip of the wire, leading to maximum intensities of $I_L=10^{21}$ W/cm^2 with a ns-contrast up to 10^{-10}. Due to several acceleration mechanisms in the laser field, a flow of relativistic electrons is produced. When electrons propagate in matter, K-shell and Bremsstrahlung emission occurs, making the electrons propagation experimentally traceable. By using a focusing spectrometer with spatial resolution (FSSR) [1], we defined the wire depth where heating by x-rays and thermal electron conductivity can be excluded, and thus, in contrast to existing studies [2], only WDM-generation by hot electrons could be considered. Thereby we were able to measure the hot electrons penetration depth, as well as the warm dense matter (WDM) isochoric-heating deep into the target. In addition, a “Bremsstrahlung canon” acted as a hard x-ray dosimeter [3] and was used to infer the internal hot electron energy distribution. At high-intensity and high-contrast conditions, we measured a hot electron tail of 2 MeV energies, in good agreement with our “Particle-in-cell” (PIC) simulations (PICLS [4]). By analyzing both broadening and shifting of characteristic K-shell lines in the FSSR, the WDM temperature T_e values along the wire were inferred, see Fig. 2. The maximum T_e achieved by isochoric heating was ~50 eV. On the other hand, the Kα intensity profile along the wire gives rather direct information on the relativistic electron propagation. It was surprisingly found to decrease exponentially up to ~1 mm deep, though a stopping range of 3 mm was expected in cold Ti. To further understand the physics at play, we performed hybrid PIC simulations [5] for the REB transport using a T=2 MeV exponential electron distribution as input. We used a simplified model for the possible reflexing of electrons inside the wire. Indeed, electrons spread in and out of the target dissipating their energy and creating an electric potential at the target surface. This potential is a barrier ϕ that electrons must overcome to escape from the wire. As illustrated in Fig. 2, the best results for reproduction of the T_e values (as well as the Kα profile, not shown here) along the wire were found by estimating <ϕ>~2 MeV. The electron flow description near the surface is a very challenging topic and our model should still be improved. Concerning electron stopping mechanisms in the WDM, the calculated resistive contributions are found to be three times higher than collisional effects. That is why the stopping power was found to be higher than in cold Ti where only collisional effects play a significant role. To conclude, our hybrid PIC simulations clearly demonstrate that both, electron confinement in the wire and competition between resistive and collisional stopping powers in the WDM are the key points to describe the REB transport in a mass-limited target.

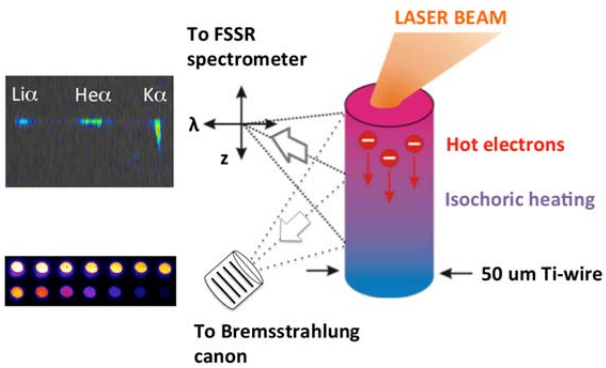

Figure 1: Schematics of our experimental set-up

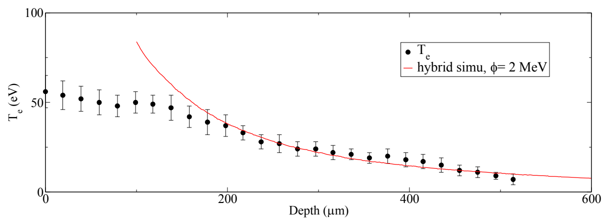

Figure 2: Temperature T_e profile vs. depth in the wire as measured for I=7.10^{20} W.cm^{-2} and 10^{-10} contrast shot. Hybrid PIC simulation with ϕ=2 MeV is also given.

References

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