Hot electron production at shock-ignition-relevant conditions characterized by high-resolution x-ray spectroscopy and monochromatic imaging

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Diagnostic applications of x-ray spectroscopy provide comprehensive information on environmental conditions and processes accompanying creation and evolution of moderately or strongly coupled plasmas. Successful exploration of ultradense plasma formations, where x rays offer the most efficient and sometimes the only vehicle capable of providing the desired diagnostic information, requires interlinking of the measured radiative properties with underlying phenomena occurring in the extreme-state matter and application of the well-tested advanced instrumentation suitable for obtaining high quality spectroscopic data. We provide a brief survey of high-resolution spectroscopic methods based on x-ray Bragg diffraction from crystals and define limits of their performance. Benefiting from application of modern spectroscopic approaches, we report experiments aiming at characterization of suprathermal electron production in Cu foils laser-irradiated at shock-ignition-relevant conditions.

Generation of hot electrons accompanying interaction of high-intensity lasers with targets, their transport and energy deposition in the near-solid density matter with a varied degree of ionization represent one of the key issues for realization of alternate schemes of inertial confinement fusion. In a series of experiments being performed at Prague Asterix Laser System PALS, the laser-plasma coupling is studied at intensities up to 5×10^{16} W/cm^2, i.e., at parameters of the laser spike envisaged to launch the shock wave igniting the fusion reaction. The role of hot electrons is ambiguous: they contribute to enhancement of the ablation pressure but they may also preheat the pre-compressed targets. Here we report a novel approach to diagnosis of hot electrons based on a combination of monochromatic x-ray imaging and high-resolution K-shell spectroscopy.

The experimental part of this research was carried out using the PALS iodine laser with the wavelength of 1.315 μm, pulse duration 0.25 ns, and energy of about 400 J focused to a diameter of 100 μm, i.e., massive or thin-foil Cu targets were irradiated at coupling parameter $I\lambda^2 = 3.5\times10^{16}$ W μm^2/cm^2. The 2D-resolved quasi-monochromatic x-ray images of the Cu Kα emission produced by interaction of hot electrons with near-surface copper ions were recorded using the spherically bent crystal of quartz (422) in the normal incidence imaging configuration. The 1D spatially resolved Cu K-shell spectra covering the photon energy range of 7.5-8.5 keV (i.e., Cu He-like to Kα emission) were observed using the x-ray spectrometer equipped with the spherically bent crystal of quartz (223). Based on results of modelling, the recorded spectra were interpreted with respect to the hot electron presence in early stages of the target irradiation. The measured intensity distribution of spectral lines close to Kα emission, particularly $2p\rightarrow1s$ transitions in Ne-like to He-like Cu ions, is of paramount importance for rigorous evaluation of fluorescence cross-sections decisive for quantitative interpretation of 2D images. By combining results of X-ray imaging, high resolution spectroscopy, and Monte-Carlo Penelope code modelling of hot electron penetration and deposition of their energy into low temperature, quasi-solid density target we provide more precise estimates on conversion efficiency of the laser energy into hot electrons.

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