X-ray radiography on millimetre-scale high-Z targets for the plasma physics program at FAIR*

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Heavy ion pulses with unprecedented intensities at the upcoming Facility for Antiproton and Ion Research (FAIR) will offer novel and unique approaches to the generation of dense plasmas, allowing accurate laboratory studies of matter at such extreme conditions. A variety of schemes has been proposed to exploit the opportunities to generate matter at High Energy Density (HED) conditions. In many of these schemes targets undergo a large hydrodynamic evolution, mostly in the so-called warm-dense matter (WDM) regime. For this reason, accurate monitoring of the target density distribution is crucial to verify the target performance. Radiography to measure the target density distribution is considered an indispensable diagnostic technique for future HED experiments at the FAIR facility.

Powerful hard x-ray sources can be realized with high-energy short pulse lasers. When irradiating solid targets with laser intensities >10^{18} W/cm^2 electrons are accelerated to MeV energies, causing emission of energetic bremsstrahlung. Such x-ray sources are being employed at many large HED facilities to enable point-projection radiography with spatial resolution down to 10 µm and temporal resolution of order 10 ps (e.g. [1,2]).

In order to assess the potential of intense-laser-driven hard x-ray radiography as diagnostic for the often large, high-Z targets proposed for FAIR, we have simulated radiographic images for calculations of the target evolution presented by Tahir et al. [3]. X-ray emission spectra are calculated by a Monte-Carlo electron-photon transport code, using a 1-temperature hot electron spectrum with a mean electron energy of 200 keV, corresponding to a focused intensity of about 10^{18} W/cm^2 [4]. We assume a laser pulse energy of 400 J, and conversion of 10 % of the laser energy into this hot electron population, which is typically found in experiments at these conditions [5].

Figure 1 shows simulated radiographic images of the lead target after expansion to conditions near the critical point (T ≈ 5600 K, ρ ≈ 4 g/cm^3). As can be seen, an average transmission of approx. 50% at the maximum areal density in the target centre provides a good image contrast. The image noise includes the photon shot noise, absorption statistics, and the energy dependent detection quantum efficiency. A signal-to-noise ratio (SNR) of around 60 suggests that absolute measurement of the areal density with few percent accuracy can be achieved. Also shown in Figure 2 is the signal behind a calibration wedge, consisting of steps with thicknesses from 20 to 600 µm, manufactured from the same material as the target. This provides an absolute calibration allowing to directly relate the image exposure to the areal mass density.

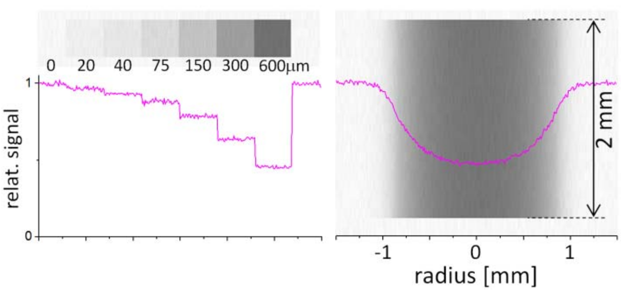

Fig. 1: Simulated radiographs (from [6]) of a Pb calibration step filter (left) and a heavy-ion heated cylindrical Pb-target after expansion for 400 ns.

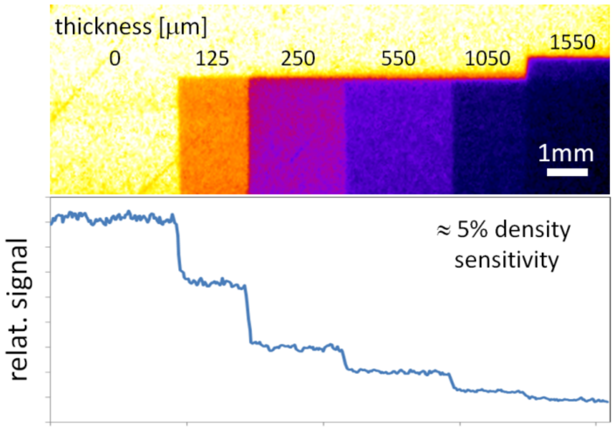

Fig. 2: Radiographic image (top) of a Ta step filter, obtained from a hard x-ray source driven by the PHELIX laser.

A demonstration experiment (P056) was carried out using GSI's high-energy high-intensity laser PHELIX. Laser pulses of 120 J and duration 0.7 ps were focused onto a 5 µm thin Au-foil. Fig. 2 shows a radiographic image of a step filter target made from tantalum sheets of various thicknesses up to 1.5 mm. The SNR in the resulting radiographic image allows for discrimination of areal mass differences of approx. 5 %, in reasonable agreement with our simulations. This demonstrates the viability of intense-laser driven hard x-ray radiography as diagnostic in future dense plasma physics experiments at FAIR [6].

References

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