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Short pulse laser driven hard x-ray sources for radiography of shocked matter

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Introduction High energy density physics (HEDP) research requires bright x-ray sources to probe dense matter, e.g. for radiography or diffraction experiments. Typical sample sizes ($\approx$ 500 μm) and opacities of mid-Z materials require high photon energies (> 40 keV).

The development of short pulse lasers offers the possibility to create bright high energy x-ray bursts with temporal durations of few ps [1]. During the interaction of such lasers with a solid target a large number of energetic electrons (up to 15 % conversion efficiency) are generated, these propagate into the bulk material, creating K-shell vacancies by collisions that produces x-ray photons. The electric potential, created by the initial escaping electrons, traps the electrons responsible for the K_α radiation, causing them to oscillate through the target (refluxing) increasing the x-rays yield [2].

The x-ray emission stops a few ps after the end of the laser pulse, as the electrons lose their energy due to classical charged-particle stopping processes. Using laser pulse durations of $\approx$ 10 ps, a temporal resolution of less than 20 ps is achieved. In the case of density measurements for equation-of-state (EOS) studies, where the shock velocity is in the range of 10 km/s, a temporal resolution of few 10s of ps is sufficient.

In this article we present an experiment to characterize a short pulse laser driven hard x-ray source for the radiography of shocked materials. We studied different target materials and geometries , the influence of laser parameters as well as detector filtering and shielding.

Experimental setup The experiments were performed at the 100 TW laser system at LULI, France, which produced 20 J in 0.3 to 10 ps-pulses at a wavelength of 1057 nm and frequency doubled pulses with 6 Joule in 0.3 ps. The latter were used to study the influence of preformed plasma and the effect of a higher critical density. The prepulse of the laser system is mainly an ASE pedestal of 500 ps with a contrast of 10^{-6}.

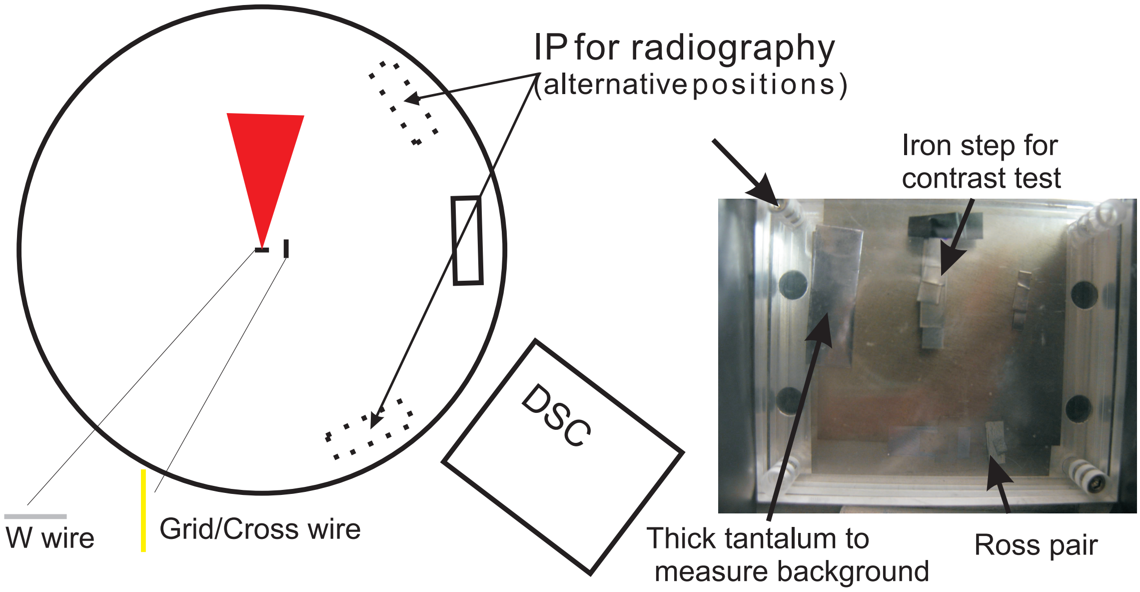

Figure 1: Experimental setup for the radiography test. The filters shown in the photo are for W targets.

The targets were made of either Mo, Dy or W, producing K_α energies of 18, 46 or 60 keV respectively. To produce a small source required for high spatial resolution in two dimensions, we used either thin (18 μm diameter) W and Mo wires or small ($\approx 20\mu m$) Dy grains, glued onto a plastic foil. We also used small flags of Dy and W, which offer a 1D resolution to compare yields and performance [2].

The spatial resolution of the x-ray source was measured either with a 300 lp/inch, 10 μm thick gold grid or with a crossed pair of 100 μm diameter gold wires. The latter one was used for the high energy x-rays, as the absorption of gold grid is too low ($\approx$ 5%). The magnification of the point-projection in this experiment was 30x, with a source–detector distance of 30 cm. Imaging plates were used as detector (see fig. 1) which were filtered with Sm, Zr or Tm for Dy, Mo and W K_α radiation respectively. For Dy and W an additional 2.5 cm plastic layer was used to stop energetic charged particles emerging from the target. This detector could be placed at 3 different angles to test possible configurations of the final experiment.

To characterize the spectral distribution of the x-rays, a transmission crystal spectrometer (DCS [3]), which used image plates as detector, was implemented. In addition, a Ross-pair filter and a thick Ta filter were placed in front of the radiography imaging plate to have supplementary information about the K_α-yield and the contribution of high energy x-ray background to the radiograph image.

Results The experiment reliably delivered high qualityradiographs of static targets. Best results were obtained at intensities of $10^{18}\frac{W}{cm^2}$ for W (60 keV) and $10^{17}\frac{W}{cm^2}$ for Mo (18 keV). Shots with a frequency doubled laser beam show similar results, although a detailed analysis of conversion efficiencies is not yet completed.

Fig. 2 shows a radiography at 60 keV of a test target (100 μm thick gold wire in 30x magnification) obtained from a 18 μm diameter W-wire. Analyzing the absorption profile of the wire on the detectors shows a spatial resolution better than 20 μm.

The iron steps on the target demonstrated the ability to resolve density gradients and confirm that the x-ray energy is 60 keV. Typical parameters of future targets to be radiographed are cylinders with 500 μm diameters and being shock compressed (compression by a factor of 2). The lineout of the steps (fig. 2) shows, that the density of such a target can be determined within 10 % precision.

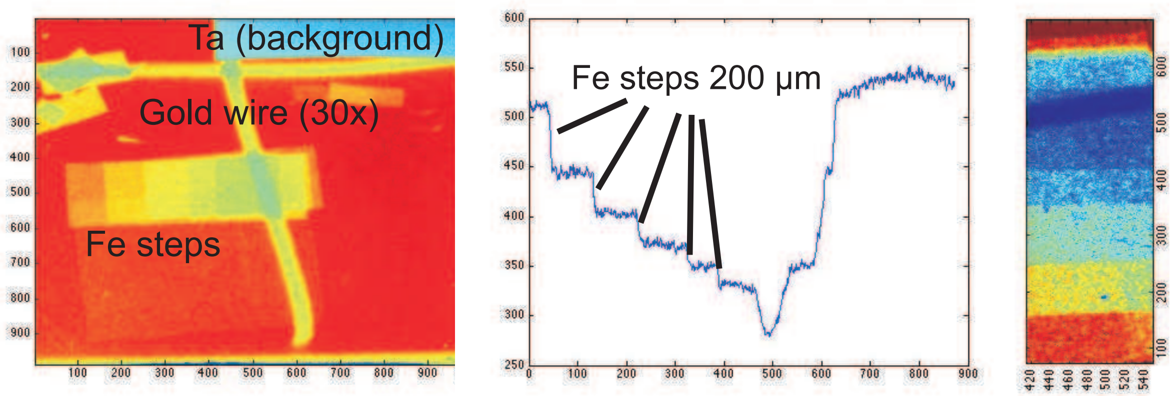

Figure 2: Radiography made with 60 keV x-rays from a short pulse irradiated W-wire. The contrast allows to deduce the density of the shocked material with error bars lower than 10 %

An interesting point is the dependence of the quality of the radiograph on the experimental geometry. Fig 3 shows three radiographs obtained with the same target (18 μm Mo) each at different angles of laser incidence. If the angle between laser and radiography axis is 22.5 °, the data show a noisy structure and quite poor contrast. Turning the target (incidence is now 90 °), but leaving the detector in the same position, the noise remains similar, but the contrast is strongly increased due to an enhancement of K_α yield (factor 20). The loss of spatial resolution in one direction is expected, as the wire is not pointing to the detector. Finally, also turning the detector to 90 ° results in a high quality radiograph with good 2D resolution and little noise structure.

The experimental geometry thus is important for both noise level (probably due to particles and directed x-rays, which are emitted in laser direction) and the K_α production. The reduction of K_α seems not to originate from a decreased laser absorption, since for 60 keV radiation we did not observe a very strong dependence on the incident angle. A preliminary explanation is a transport inhibition of low energy electrons (<50 keV), as for large angles of incident the density in the absorption region is lower and the propagation distance to the bulk material is therefore longer.

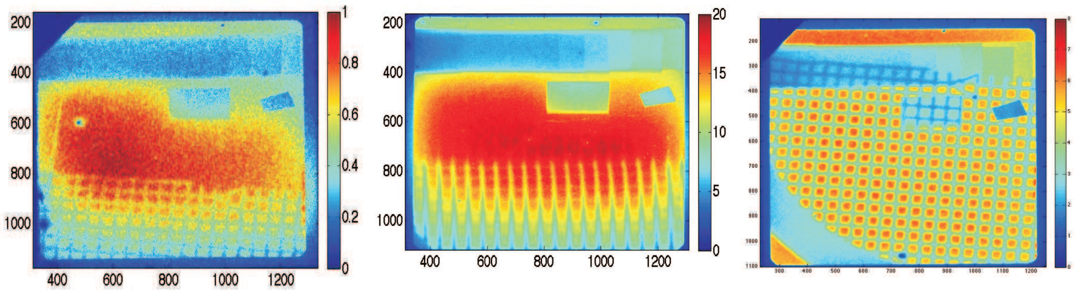

Figure 3: Dependence of the experimental geometry: Left the detector is 22.5 ° from the laser axis, the wire pointing to the detector; the middle has the detector at 22.5 °, but the is wire at 90 °; right wire and detector are both at 90 °

Summary In summary, we have studied high energy x-ray sources suitable for radiography of strongly compressed materials. Spatial resolutions of better than 20 μm was demonstrated as well as sufficient dynamic for quantitative density measurements. The importance of the experimental geometry was demonstrated for the 18 keV x-rays, where the radiograph quality decreased significantly, when the laser axis is close to the radiography axis.

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