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Titanium lined hohlraums as multi-keV x-ray converters.

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Target design for multi-keV x-ray laser-produced experiments is necessary in Inertial Confinement Fusion and hence for future LMJ experiments. On the way to ignition, a series of experiments is scheduled to reach hot and dense plasma regimes. The need in backlighters for target radiography goes toward brighter x-ray sources linked with higher photon energies [1]. Solid targets enable the creation of multi-keV sources at various photon energies but exhibit low efficiencies. X-rays mainly originate from hot underdense region of the ablated material of the solid target [2]. Underdense radiators such as gas, doped foam or doped aerogel [3-5] are more efficient but have a limited spectral domain limited to photon energies accessible with materials for which such targets can be made. Using a thin foil irradiated with 2 laser pulses (one delayed in time) leads to hot and underdense plasmas which are efficient to produce multi-keV K-shell emission [6,7] since ablation and hydrodynamics energy losses are low and the major part of the laser energy is efficiently absorbed by inverse Bremsstrahlung [8,9]. An extension to the exploded foil concept is the confinement of the plasma by the walls of a cylindrical hohlraum in order to have good plasma conditions over a large volume and longer in time. Experiments with titanium lined hohlraums have been tested at the OMEGA laser facility (University of Rochester) for two pulse shapes (a 1ns flat square pulse shape and a 2.6ns long with 'picket' cf. Figure 1) and 2 sizes of hohlraums.

OMEGA laser is a 60-beams facility delivering a maximum of 30 kJ at 3ω (λ=351 nm), designed for direct drive implosions. Our experiment uses a subset of the laser beams grouped in three cones: 10 beams for cone 21° (incident on the foil at 21° from target normal axis), 10 beams for cone 42° and 20 beams for cone 59°. The beams were equipped with polarization smoothing plates (DPR) but no other smoothing technique was used on these experiments. All the beams had the same pulse shape (flat square 1ns, ~465 J per beam@3ω or picket pulse shape, 400 J per beam). Laser energies obtained are from 16.6kJ to 17.1kJ for the square pulse shape used for the first 4 shots (from #41886 to #41889) and 14.5kJ for the 2 shots with the picket pulse shape (shot #41890 and #41891).

Targets were plastic hohlraums with a liner of titanium. There were 2 types of target: short ones 2.5mm long and long ones 3mm long. They also differed by an inner diameter of 1.6mm and a plastic thickness of 100µm for the short target to be compared to 1.2mm inner diameter and 400µm of plastic for the long ones. The thickness of the titanium liner varied from 3µm for short targets to 6µm for the long ones (only one target had a liner of 5µm, shot #41888).

Titanium x-ray emission has been consistently observed with an x-ray diodes based absolutely calibrated diagnostic DMX and time integrating or time resolved x-ray imaging diagnostics.

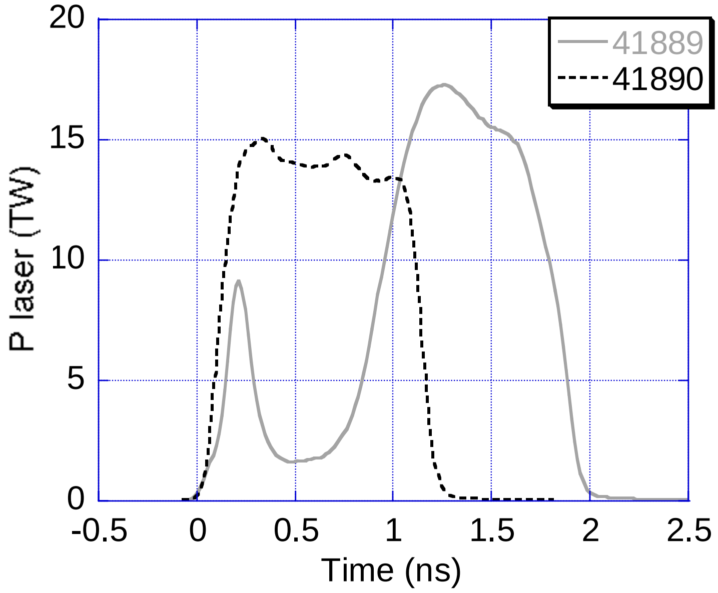

Figure 1 Laser pulse shapes: 1ns squared SG1018 (dot curve) and picket pulse shape ALPAHA501P (solid line).

DMX is a channels broadband spectrometer (from 0-20 keV), time resolved x-ray diodes array [10], measuring the x-ray power emitted by the target. It was configured with 17 channels at the time of the experiments to look after the high-energy part of the spectrum, with eight channels covering the helium-like and hydrogen-like titanium lines spectral region within the range 4-6 keV. The spectral range of each channel was adjusted by choosing appropriate filter materials. DMX had a view at a 37.6° angle with respect to the foil normal. Figure 2 shows multi-keV yields from the vanadium channel measuring emission from 3.8 to 5.3keV. The overall relative uncertainty is 20% on x-ray power from DMX data considering the filter transmission and detector sensitivity calibrations and the data reduction treatment necessary to take into account the broadband response of the DMX channels. Signals show very different time evolutions depending on the target type. With short targets, the yields are higher and there is and a shoulder after the end of the laser pulse. This is due to plasma collision and confinement maintaining high electron temperature within the hohlraum when the laser has been cut off.

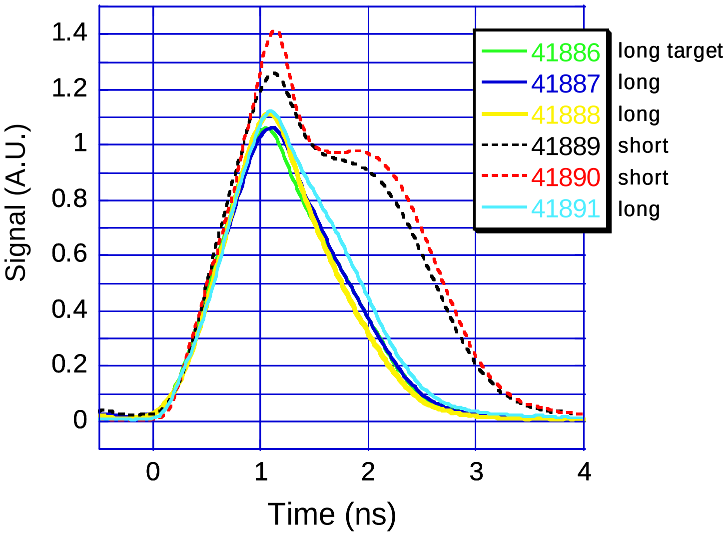

Figure 2 DMX signals versus time from the vanadium channel for the 6 shots. It shows the long duration of multi-keV emission (3.8-5.3keV) obtained with the short target.

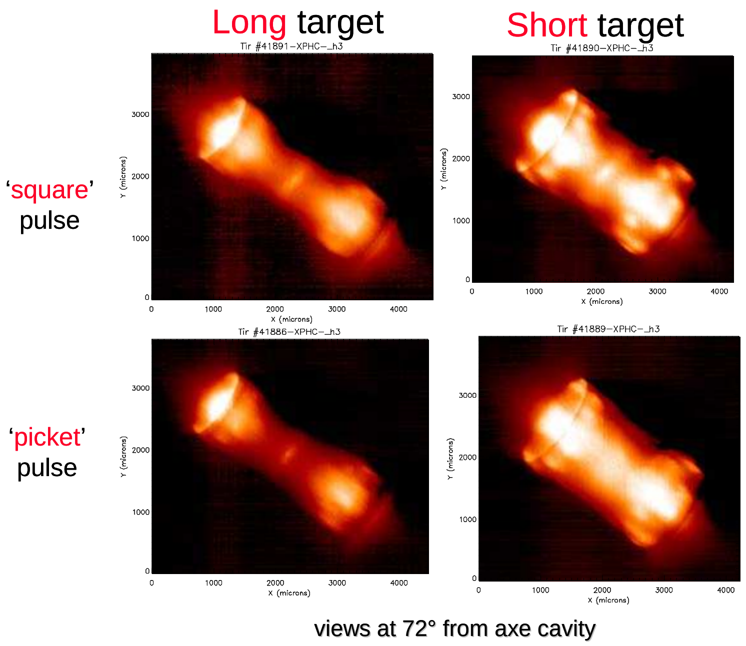

Figure 3 Pinhole images of the two hohlraums (long target on the left hand side) with the two laser pulse shapes ('square' pulse above).

The yield enhancement observed on DMX channels are confirmed with time-integrating pinhole camera which PHC 3 which has a side view at 72° angle with respect to the target axis. The magnification is 4 and the filtering is 25µm beryllium plus 25µm aluminium filter restricting detection above 4keV. PHC images in Figure 3 show the increase of the hard x-rays intensity with short targets in comparison to long ones. This is true with the two laser pulse shape. Multi-keV emission mostly originates from hohlraum axis and also from the middle along the axis on all cases.

This enhancement can be quantified from x-ray spectra assessed from DMX by time and spectral integrations from 4 to 6keV. Figure 4 shows titanium yields obtained over the past few years with different types of targets. Energies $\sim 10^{-2}$ Jx/Jlaser/sr are obtained with short hohlraums for the picket and the squared pulse shape. Yields produced with long hohlraums are comparable to those obtained with an exploded foil by 2 laser pulse at high flux ($\sim 2 \times 10^{15}$ W.cm^{-2}).

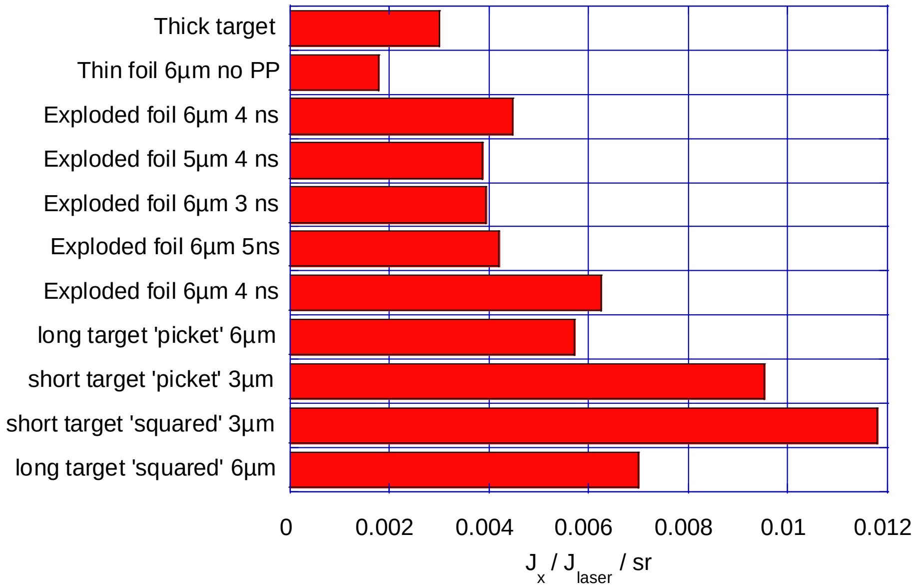

Figure 4 Time integrated multi-keV yields normalized by incident laser energy. This is measured by DMX within the spectral bandwidth 4 to 6keV which has an observation angle of 37.6° relatively to the hohlraum axis.

In summary, titanium lined hohlraums as multi-keV x-ray source have been tested for the first time with 2 different pulse shapes. These experiments showed highest titanium K-shell yields ever published. These strong emitted energies can be explained by very favourable plasma conditions lying in the hohlraum more than 1ns after the end of the laser pulse. A plasma collision along the axis in addition to the plasma confinement by the hohlraum itself lead to a high electron temperature which enables high ionization states and hence strong titanium K-shell emissions around 5keV. Titanium lined hohlraum are in all the cases we tested more efficient by a factor of 3 than thick targets.

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