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High Energy Density Physics

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F. Girard[1*], M. Primout[1], B. Villette[1], D. Brebion[1], H. Nishimura[2], K. B. Fournier[3]

[1] *CEA, DAM, DIF, F-97297 Arpajon, France*
[2] *Institute of Laser Engineering, Osaka University, 2-6 Yamada-Oka, Suita, Osaka 565-0871, Japan*
[3] *Lawrence Livermore National Laboratory, P.O. Box 808, L-473, Livermore, California 94550, USA*
ILE, Osaka, Japan
LLNL, Livermore CA 94550, USA

*Corresponding author. Tel.: +33 1 69 26 74 03
E-mail address: frederic.girard@cea.fr

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Abstract

This work describes measurements of laser propagation through very low density aerogels and subsequent multi-keV photon production from titanium foils. For efficient foil heating, SiO_2 aerogel with densities of 2 and 5 mg/cm^3 have been cast into a plastic cylinders, which are then mounted to Ti foils that are 3 – 20 μm thick. Experiments have been performed on the GEKKO-XII laser facility to characterize laser propagation through the aerogel and X-ray production from the Ti foil. Multi-keV emission is diagnosed by a full set of diagnostics giving laser-to-X-ray conversion efficiencies, time dependent X-ray power and two-dimensional X-ray imaging.

1 Introduction

Development of bright emission sources in the multi-keV photon energy range [1-4] is necessary for radiography of dense materials on LMJ and NIF experiments. Accurate predictive simulations are important to set up relevant X-ray sources for radiography experiments and to improve our knowledge about X-ray production from K-shell metallic targets [5,6]. The goal of the present work is to explore the domain between solid metallic foils, with low conversion efficiencies in the multi-keV range, and low-density metal-doped aerogels, where efficiencies are limited by the doping percentage of metallic atoms due to target fabrication constraints. To fill this gap, x-ray output from *hybrid* foam-foil targets has been measured for the first time during a campaign on the GEKKO XII laser facility in late 2009. Hybrid targets are composed of a metallic foil located at the end of a low-density aerogel inside a plastic cylinder (cf. figure 1). Measurements of supersonic heat wave propagation in the aerogel cylinder are of great interest for comparison with simulations. This is indeed a test of our simulation code's ability to model thermal transport in a low-density medium and to predict the nonlocal thermodynamic equilibrium (NLTE) multi-keV x-ray emission. This work gives absolute measurements of multi-keV x-ray yields from hybrids targets and propagation velocity through various densities and sizes of the aerogels.

2 Experimental set-up

2.1 Laser conditions

Twelve laser beams of GEKKO XII laser facility have been grouped for one-sided irradiation towards the HIPER chamber: three 2ω (527 nm) laser beams (~ 200 J per beam) and nine 3ω (351 nm) laser beams (~ 150 J per beam), with pulse durations from 1 to 2.5 ns, see Figure 1. The 2.5 ns duration pulse shape has been chosen in order to get total-laser energies between 1 and 2 kJ. Individual beams are 320 mm in diameter and considering beam-pointing precision, the spot-size at best focus is 300 μm when the 12 beams are overlapped. Laser intensities thus obtained are of the order of 10^{15} W/cm^2 for 12 overlapped beams.

2.2 Targets

Hybrid targets are composed of a titanium foil located at the end of a plastic cylinder filled with low-density aerogel. SiO_2 aerogels with densities of 2 or 5 mg/cm^3 have been cast into the cylinder. The walls of the cylinder are 0.1 mm thick, which allows for the transmission of x-ray signals from the heated region. Dimensions of the different cylinder sizes are the following: length=0.5mm and diameter=1 mm for S-N (short-narrow) target type, length=1mm and diameter=1 mm for L-N (long-narrow) type and length=1mm and diameter=2 mm for L-W (long-wide) target type. The foil thickness is either 3 μm or 20 μm. As reference, some cylinders were not filled with aerogel in order to test the effect of the aerogel on x-ray emission.

3 Data analysis

Absolute conversion efficiencies (CEs) from hybrid target emission have been monitored by the CEA diode-based x-ray broadband spectrometer called microDMX. CEs are defined as the ratio of the time-integrated x-ray energy between 4 – 6 keV to the total laser energy. The CEs are given per solid angle unit in steradian as it represents x-ray measured in the direction of the diagnostic.

During this campaign, we have been able to test this new kind of targets in multiple ways. First, aerogel density influence on x-ray output has been seen by varying density from 0 mg/cm^3 (i.e. empty tube), to 2 and 5 mg/cm^3. As unexpected X-ray yields are lowered when an aerogel is placed before the foil, except for the S-N target type where the highest value is found for and aerogel density of 5 mg/cm^3 (figure 2). Surprisingly, the lowest x-ray output is obtained for intermediate density. This fact is currently not understood. Second, by varying the size of cylinder (while keeping a constant aspect ratio of length to inner diameter) with a diameter of 1 or 2 mm and a length of 0.5 or 1 mm it appears that these targets produce similar multi-keV yields close to $5x10^{-3}$ J/J_{laser} per sr. Third, foil thicknesses were varied by using either 3 or 20 μm thick foils. For the thickest foil, there is a difference in the measured CE trend for 2 and 5 mg/cm^3 aerogels, where x-ray emission is lower at 5 mg/cm^3.

In addition, this campaign greatly benefited from multiple time- and space-resolved spectrometers and imagers provided by the ILE laboratory. Images of the time evolution of multi-keV x-ray emission shown in figure 3 come from a x-ray streaked camera diagnostic called XSC. For an empty tube, emission from the expanding plasma first occurs when the laser hits the foil, and a noticeable rear side emission is visible when laser beams have totally ablated the solid foil. In both instances, the expansion of the emitting plasma is very rapid. When aerogel is present, there is early times emission during laser propagation through the aerogel (indicated by the red line drawn on the middle and right images) that is a signature of the heat wave propagation. This emission is followed by strong emission from the expanding titanium plasma that is created when the laser reaches the foil. Finally, a rear side emission appears when the laser passes through the metallic foil. This rear side emission is stronger for 2 mg/cm^3 target than for the 5 mg/cm^3 target as less energy is lost to heating the lower density medium before reaching the foil.

These images allow propagation velocity measurements of heat front propagation as the laser light passes through a low density medium. Measured values are shown in figure 5 for 4 kinds of targets. For S-N and L-N cylinder types filled with aerogel density of 2 mg/cm^3, the ionization wave passes through aerogel at a speed of about 10^8 cm/s. This velocity is decreased by 20-30 percent in both narrow targets in the 5 mg/cm_3 cases. On the contrary, for a large-diameter cylinder (L-W type), the speed is more than two times higher than for other targets (L-N and S-N) in the case of the 2 mg/cm^3 aerogel density. Velocities for a 5 mg/cm^3 aerogel density are similar for both the wide and narrow target types at about $7x10^7$ cm/s. These high velocities should be taken with caution as the contrast on the images is very low for 2mg/cm^3 aerogel density.

4 Conclusion

This campaign took place at GEKKO XII laser facility in Osaka to test effects of cylinder dimension, foil thickness and aerogel density on titanium x-ray emission. The presence of aerogel mainly tends to reduce multi-keV x-ray production but this trend is not valid for all target types. Spatial and temporal x-ray emission has been carefully characterized giving heat-front propagation speeds through the aerogel of few 10^8 cm/s for wide targets tamped by 2 mg/cm^3 aerogels. Conversion efficiency and propagation speed have to be compared with simulation to get better understanding of hybrid target behaviour relative to the measured x-ray output and thermal-wave propagation speed. K. B. Fournier's work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

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FIGURE CAPTION LIST (color online only)

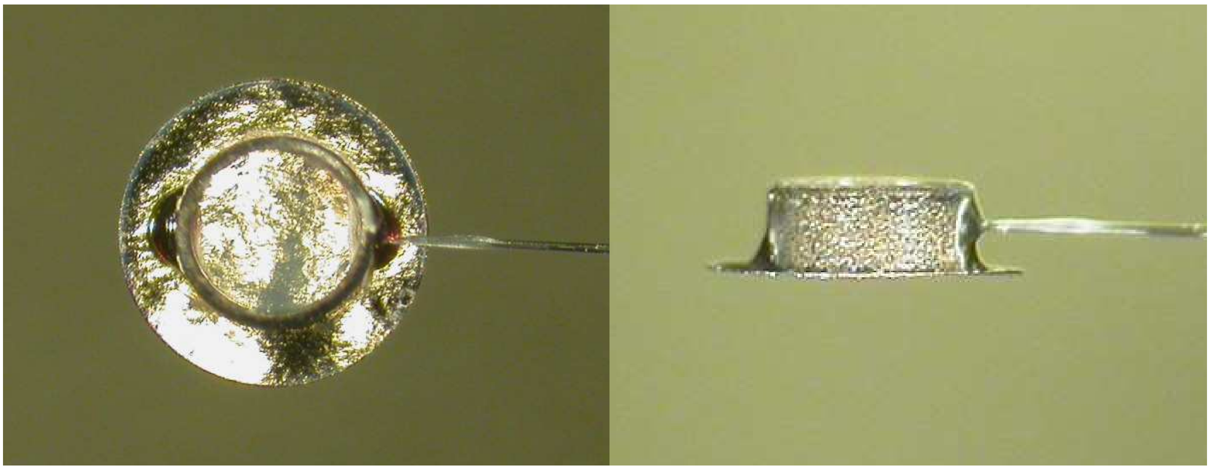
Figure 1 Pictures (side view on right and front view on the left) of an hybrid target of the S-N type (L=0.5mm Φ=1mm).

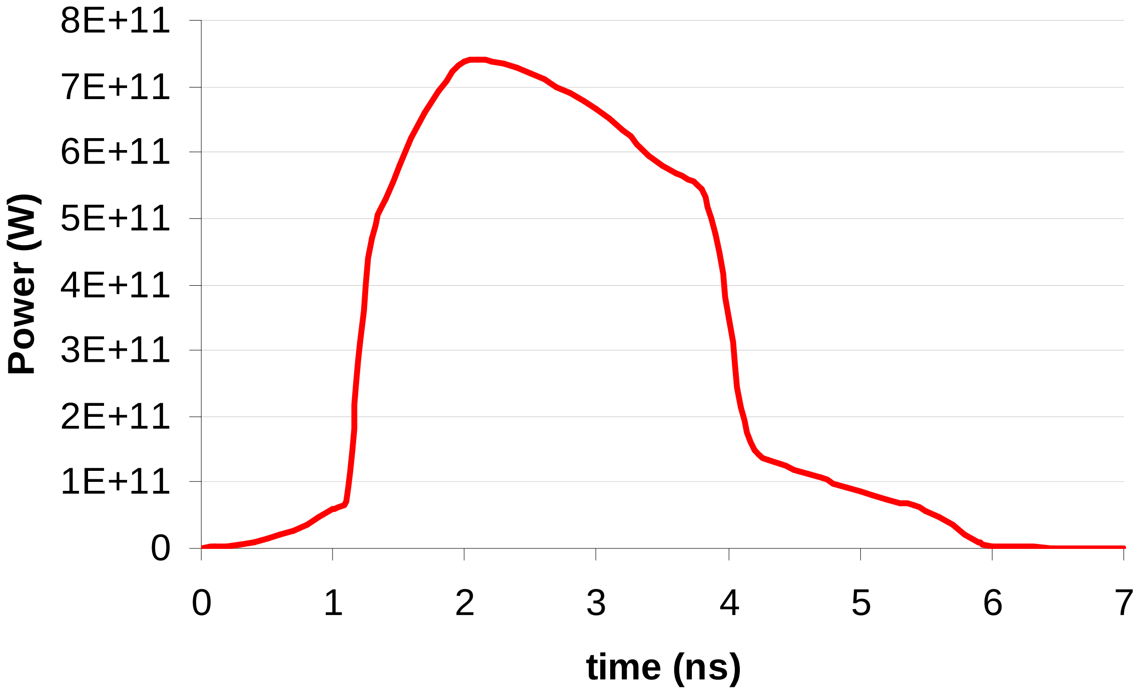
Figure 2 Laser power versus time showing the FWHM duration of 2.5 ns for the use of 12 beams.

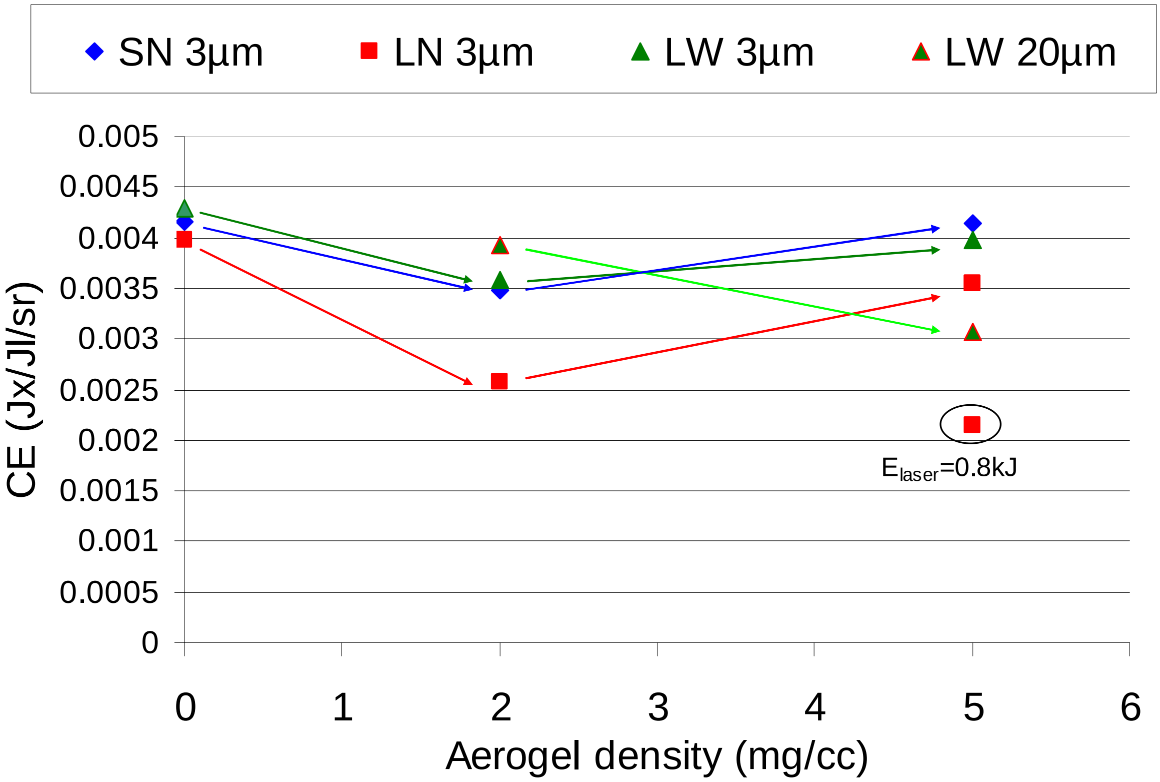
Figure 3 Conversion efficiencies from titanium emission versus aerogel density for different target sizes.

Figure 4 Space and time resolved images obtained from XSC diagnostic for an empty tube, 2 and 5 mg/cc aerogel densities. Cylinders are L-W type (L=1mm Φ=2mm) and titanium foil thickness is 3µm.

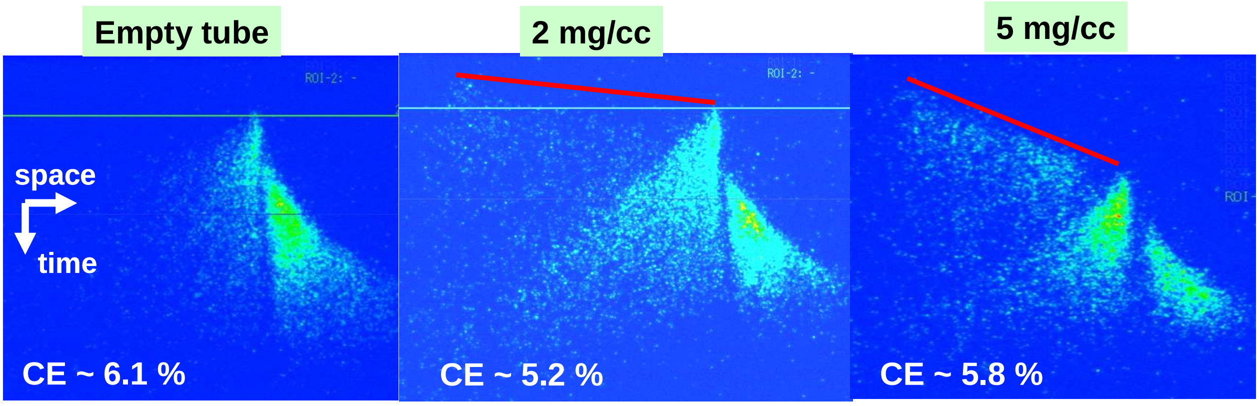
Figure 5 Ionisation wave propagation velocity versus aerogel density.

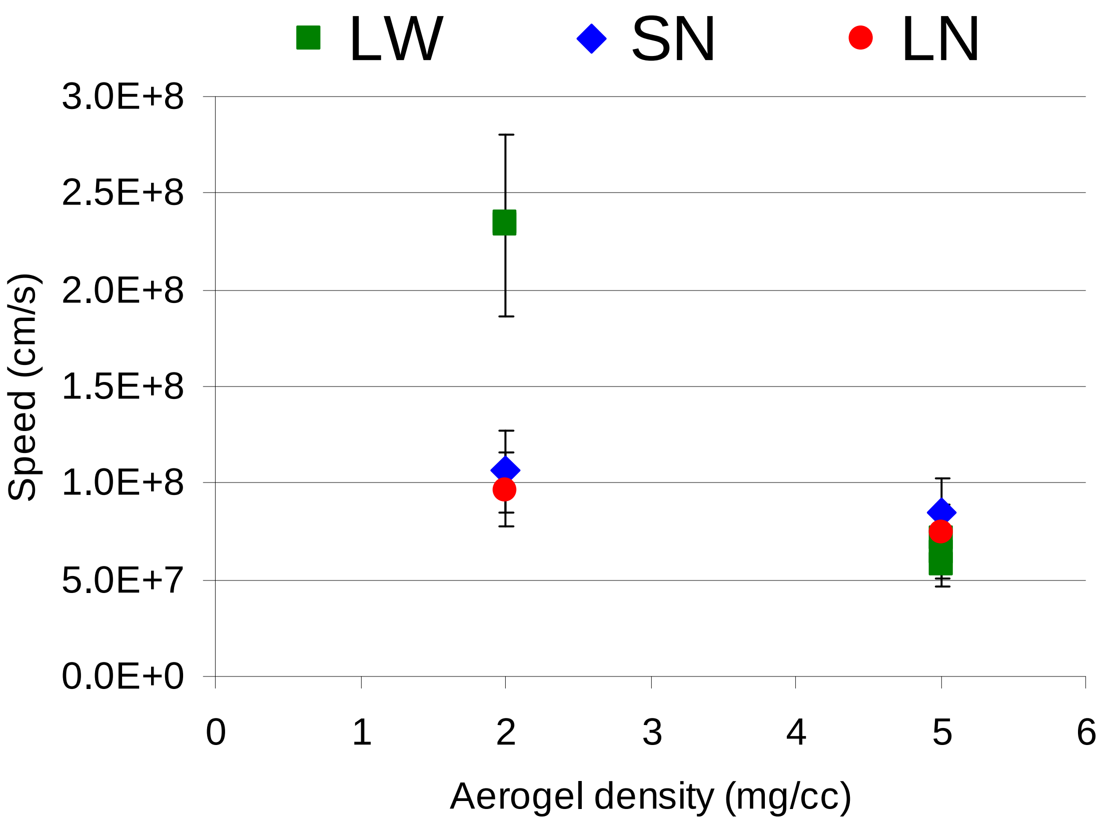



8E+11
7E+11
6E+11
5E+11
4E+11
3E+11
2E+11
1E+11
0
Power (W)
0
1
2
3
4
5
6
7
time (ns)



SN 3µm
LN 3µm
LW 3µm
LW 20µm
CE (Jx/Jl/sr)
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
1
2
3
4
5
6
Aerogel density (mg/cc)
E_laser=0.8kJ


Empty tube
2 mg/cc
5 mg/cc
space
time
CE ~ 6.1 %
CE ~ 5.2 %
CE ~ 5.8 %



LW
SN
LN
3.0E+8
2.5E+8
2.0E+8
1.5E+8
1.0E+8
5.0E+7
0.0E+0
Speed (cm/s)
0
1
2
3
4
5
6
Aerogel density (mg/cc)