LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-CONF-213086

Absolute X-Ray Yields From Laser-Irradiated, Ge-Doped Aerogel Targets

K.B. Fournier, M. Tobin, J.F. Poco, K. Bradley, C.A. Coverdale, D. Beutler, T. Vidnovic, M. Severson, E.A. Smith, D.L. Reeder

June 21, 2005

32nd EPS Plasma Physics Conference
Tarragona, Spain
June 27, 2005 through July 1, 2005

Absolute x-ray yields from laser-irradiated, Ge-doped aerogel targets

K.B. Fournier[1], M. Tobin[1], J.F. Poco[1], K. Bradley[1], C.A. Coverdale[2], D. Beutler[2], T. Vidnovic, III[1], M. Severson[2], E.A. Smith[3], D.L. Reeder[3]

[1] *Lawrence Livermore National Laboratory, Livermore, CA, USA*

[2] *Sandia National Laboratory, Albuquerque, NM*

[3] *KTech Corporation, Sandia National Laboratory, Albuquerque, NM*

Bright, multi-keV x-ray sources are essential for radiography of inertial-confinement fusion (ICF) experiments. In this context, there are two parameters of importance: the energy of the emitted photons, which determines how penetrating the x-rays are for radiographic purposes, and the brightness of the source, which determines the ability of a radiograph to resolve small features. As ICF experiments continue to get larger, such as those that will be carried out at the National Ignition Facility at Lawrence Livermore National Laboratory, or at the French Commissariat à l'Energie Atomique's (CEA) Laser MegaJoule, and compression in fuel capsules gets higher, sources for x-ray backlighting will have to have harder-photon spectra [1]. For a given laser energy available to drive the multi-keV x-ray-backlight source, the only way for the source to get brighter is for it to convert the laser to x-rays more efficiently. We have been developing and characterizing laser-driven, underdense x-ray sources that are highly efficient in recent years [2-5]. CEA researchers have also recently had great success efficiently making multi-keV x-rays from pre-pulsed foils [6].

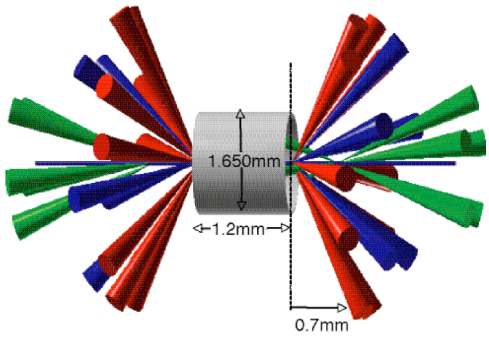

Figure 1: The 75 μm thick Be cylinder that hold the underdense aerogel targets used in the current experiments. Also shown are the three cones of beams at the OMEGA laser that irradiate the two faces of the target.

Very recently, we measured the production of $h\nu \geq 10$ keV x-rays from low-density Ge-doped aerogel targets at the OMEGA laser (Laboratory for Laser Energetics, University of Rochester). The targets were 1.2 mm long by 1.5 mm inner-diameter beryllium cylinders filled with Ge-doped (20 atom percent) SiO_2 foam. The doped-foam density was 4.8 or 6.5 mg/cc, which yielded plasmas with electron densities of 0.14 and $0.19 n_{cr}$, respectively, where n_{cr} is the laser's critical density ($\approx 10^{22}$ cm^{-3} for 3ω light). These targets are a major advance over previous doped aerogels [4]: instead of suspending the dopant in the SiO_2 matrix, the Ge atoms,

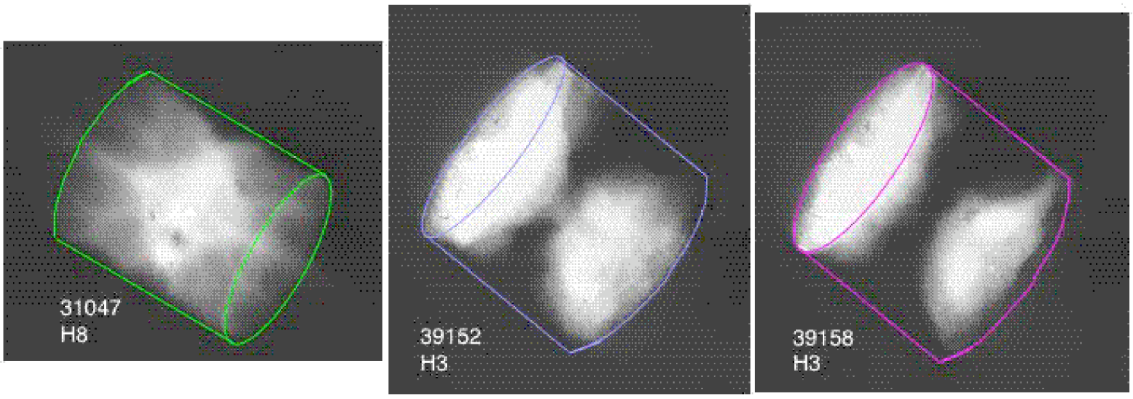

Figure 2: X-ray pinhole-camera images from three low-density aerogel targets shot at OMEGA. From left to right, 3 atom % Ti-doped SiO_2 at ρ=3.1 mg/cc ($0.09n_{cr}$), 20 atom % Ge-doped SiO_2 at ρ=4.8 mg/cc ($0.14n_{cr}$) and ρ=6.5 mg/cc ($0.19n_{cr}$).

with chemistry similar to Si, are incorporated directly in the polymer matrix. Thus, the level of dopant is increased by more than a factor of six over our previous Ti- and Zn-doped aerogels. Forty beams of the OMEGA laser (λ=351 nm) illuminated the two cylindrical faces of the target with a total power that approached 20 TW. Figure 1 shows a drawing of one of our targets and the irradiation geometry. The beams at OMEGA, for this orientation, come in three cones, with angles of 21, 42 and 58 degrees with respect to the axis of the target.

The laser interaction strongly ionizes the target, and allows a laser-bleaching wave [7] to ionize, supersonically, the high-Z emitter ions in the sample. Three time-integrated x-ray images from aerogel targets with densities that ranged from 3.1-6.5 mg/cc are shown in Fig. 2. The left image is from a target that is 2.2 mm long and 2.0 mm in diameter, which is $\approx$3.3$\times$ larger in volume than the two Ge-doped targets. A strong density dependence of the volumetric heating of our targets is clearly visible; however, the higher concentration of Ge in the two higher-density targets means that they have a slightly higher average ionization state ($< Z >$=13 versus $< Z >$=10), which may also play a role [5]. The heating of our targets was imaged with a gated (60 ps resolution) x-ray framing camera (XRFC), filtered to observe the target in emission $>$ 3 keV. Previously, a continuous record of the heat-front propagation in low-density aerogels was obtained [9]; there, early-time velocities of v $\approx 10c_s$, where c_s is the plasma sound speed, were observed. Figure 3 shows a series of XRFC images from one of our 4.8 mg/cc targets as the laser-drive beams heat the sample. The heat fronts from the two faces of the target have collided by $\approx$750 ps. This shot, 39154, was the highest performing x-ray emitter of our recent campaign.

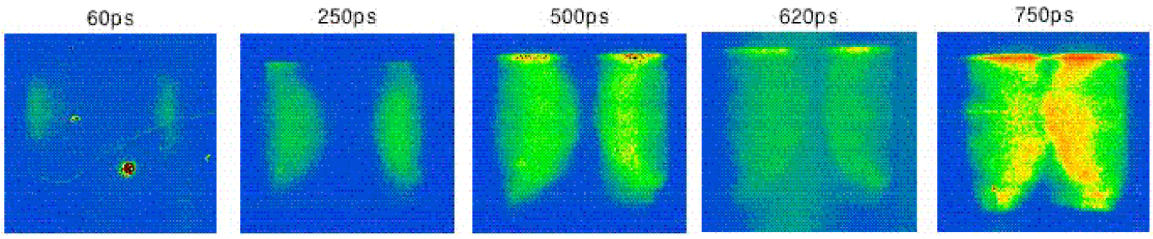

Figure 3: XRFC images from shot 39154 (ρ=4.8 mg/cc) at 60, 250, 500, 620 and 750 ps after the start of the laser pulse; the image is in x-rays with $h\nu > 3$ keV. The camera's view has same orientation as figure 1. For this shot, 18.4 kJ of 3ω laser light were delivered to the target.

The absolute x-ray yields from our doped-aerogel targets are determined by three independent diagnostics. A two-channel crystal spectrometer (HENWAY) measured the x-ray output between 1.5-3.5 keV (Potassium Acid Phthalate (KAP) crystal) and 4.5-15 keV (Pentaerythritol (PET) crystal). High-energy spectra (PET channel) from three of our targets are shown in Fig. 4. The x-ray spectra were recorded onto Kodak DEF film; the uncertainty in filter thicknesses, crystal reflectivity and film response combine for a total uncertainty of $\pm$ 30% in the HENWAY-measured target outputs. An array of 10 filtered photoconductive devices (PCDs) were fielded by Sandia National Laboratory; the PCDs gave information on both the target's x-ray output and the time-history of the x-ray waveform. Three of the PCDs were filtered with 10 mils of kapton and 15.6 μm of Al, which gave them response in a spectral range that is comparable to that of the HENWAY PET channel (Fig. 4). The responses of the PCDs are known from previous calibrations at pulsed-power facilities; the yields from these PCD channels are accurate to $\pm$ 25%. Thermoelastic calorimeters (TECs) were also fielded on four shots; on two shots the TECs were filtered with 10 mils of kapton (shots 39156, 39157), and with only 2 mils of kapton on the others. The yields as determined by these diagnostics are summarized in Table 1. The conversion efficiency (CE) of the laser-drive energy into multi-keV x-ray output is given in the last column of the table. Averaging the response for the

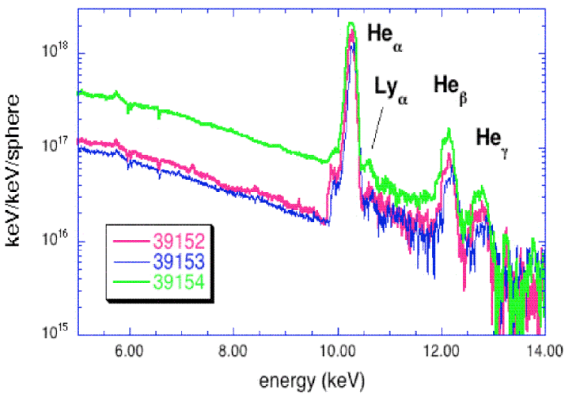

Figure 4: HENWAY PET-crystal channel spectra for three of our Ge-doped aerogel targets. Lines from K-shell Ge^{30+} and Ge^{31+} are labeled.

shot no.	ρ (mg/cc)	HENWAY total (J)	PET (J)	PCD (J)	TEC (J)	Y (J)	CE (%)
39152	4.8	2207	105.6			105.6	0.61
39154	4.8	6460	269.9	202.2	<u>5627.4</u>	236.1	1.28
39156	4.8	2374	140.2	107.5	123.6	123.8	0.68
39157	4.8	3097	145.2	112.8	149.1	135.7	0.72
39153	6.5	1652	85.6	55.0		70.3	0.40
39158	6.5	1956	98.1	79.7	<u>1814.3</u>	88.9	0.48

Table 1: Yields from Ge-doped aerogels: columns are shot number, target density, total yield from KAP and PET HENWAY channels (summed), yield between 4.5-15 keV from HENWAY PET channel, yield with $h\nu > 4$ keV from the PCDs, yield with $h\nu \gtrsim 4$ keV for shots 39156, 39157 from the TECs, or (underlined) total x-rays from the source estimated by the TEC response (39154, 398158), the average yield 'Y' in the $h\nu \gtrsim 4.5$ keV band and resulting CE.

four 4.8 mg/cc targets results in a CE of 0.82%, while the CE is only 0.44 % for the 6.5 mg/cc targets. A true optimal density has yet to be found since no lower-density shots with the 20 atom percent Ge-doped aerogels were done.

Large x-ray outputs from Ge-doped aerogels have been measured in the 4.5-15 keV band. The targets are heated volumetrically, supersonically, due to the underdense nature of the aerogel. This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

References

[1] O.L. Landen *et al*, Rev. Sci. Instrum. **72**, 627 (2001)

[2] C.A. Back *et al*, Phys. Rev. Lett. **87**, 275003, (2001)

[3] C.A. Back *et al*, Phys. Plasmas **10**, 2047 (2003)

[4] K.B. Fournier *et al*, Phys. Rev. Lett. **92**, 165005 (2004)

[5] K.B. Fournier *et al*, J. Quant. Spect. and Rad. Trans. Accepted (2005)

[6] F. Girard *et al*, Proc. of SPIE **5196**, 220 (2004); F. Girard, P1.155, this meeting

[7] J. Denavit, D.W. Phillion, Phys. Plasmas **1**, 1971 (1994)

[8] C. Constantin *et al*, Phys. Plasmas **12**, 063104 (2005)