Optimization of a Short-Pulse–Driven Si He$_\alpha$ Soft X-Ray Backlighter

C. Stoeckl,[1] M. J. Bonino,[1] C. Mileham,[1] S. P. Regan,[1] W. Theobald,[1] T. Ebert,[2] and S. Sander[2]

[1]Laboratory for Laser Energetics, University of Rochester
[2]Technical University of Darmstadt

Backlighting is a powerful method to interrogate the plasma density distribution in high-energy-density plasma experiments. A high backlighter brightness is not only important to maximize the photon-counting statistics, but it also helps to minimize the background from the self-emission of the plasma object. Backlighting high-performance layered cryogenic DT implosions[1] is especially challenging because of the strong self-emission from the hot core of the stagnated assembly and the low opacity of DT. This requires a soft x-ray backlighter with a photon energy of less than 2 keV, which is close to the maximum of the self-emission spectrum for cryogenic implosions on OMEGA.[1]

A number of approaches are described in literature to increase the brightness of laser-driven x-ray backlighters. Some experiments have used low-density foams;[2,3] others employed prepulses to increase the plasma density scale length.[3,4] Some groups used V-shaped or cylindrical targets to create a cavity to absorb reflected laser light.[3,5] These ideas were tested on the OMEGA EP laser[6] at energies of the order of ~1 kJ and ~20-ps pulse length. Figure 1 shows the illumination geometry of the backlighter targets used for these experiments.

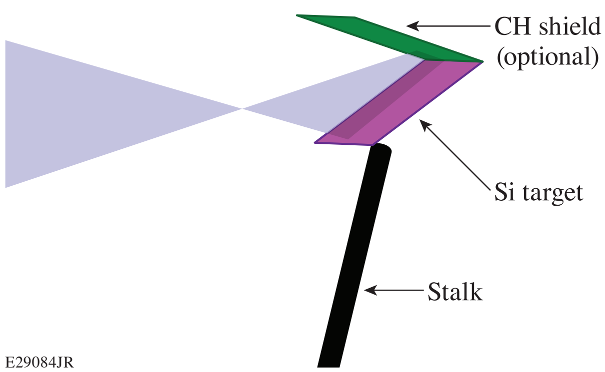

Figure 1
Illumination geometry for the backlighter targets.

An extensive suite of diagnostics was used to evaluate the improvements from each of these three approaches. The time-integrated x-ray emission spectrum from the backlighter target was measured using a flat crystal x-ray spectrometer.[7] The temporal history of the x-ray emission from the backlighter targets was recorded using an ultrafast x-ray streak camera.[8] To observe the effect of the different backlighter configurations on the number of photons that can be used for imaging, the shaped crystal imager (SCI) on OMEGA EP was run in the Si He$_\alpha$ configuration[9] for some of the backlighter tests. The best backlighter configuration was fielded on OMEGA to radiograph cryogenic DT implosions. In these experiments the data are recorded on a fast (~40-ps) time-gated x-ray framing camera.[10]

The data from the low-density (20-mg/cm^3 and 100-mg/cm^3) SiO_2 foam targets showed some changes in the shape of the hot K-shell spectrum but no significant increase in x-ray emission. In its optimum configuration (50 J of UV laser energy, 100-ps pulse duration, 1 ns before the short pulse, 400-μm distributed phase plate defocus) the prepulse experiment showed an ~5× improvement in time-integrated emission. However, time-resolved measurement showed a large tail in the x-ray emission lasting more than 300 ps, making this setup not suitable for the 40-ps, time-gated cryo backlighting application. The targets with the CH shield showed the best performance, with a 5 to 10× improvement in time-integrated emission of the Si He$_\alpha$ line compared to a simple solid target (see Fig. 2). The duration of ~25 ps for the main x-ray emission pulse was only marginally longer than the emission from the flat target (20 ps). In addition a low-level "afterglow" that lasted for a few 100 ps was observed. Tests with the time-integrated narrowband (~10 eV) SCI system showed an improvement consistent with the time-integrated spectral measurement. To evaluate the effect of the afterglow, one experiment was performed with the 40-ps time-gated SCI system, which as expected showed a small reduction of the benefit of the "shield" target to ~6× over a flat target.

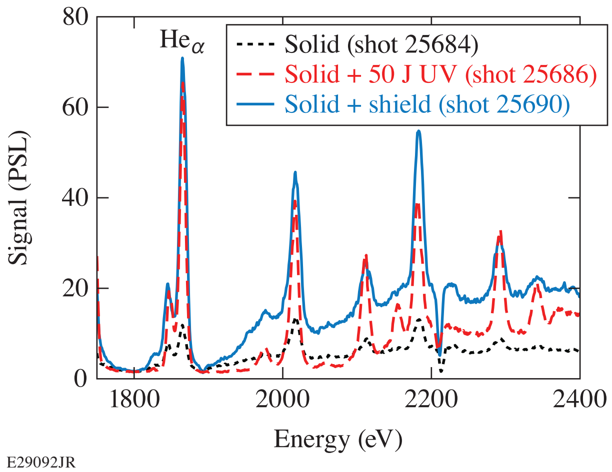

Figure 2
K-shell spectra from targets with and without shield compared to data from experiments with a 50-J UV prepulse.

To help guide future experiments, the conversion efficiency from laser light into Si He$_\alpha$ photons was inferred from the time-integrated spectra and the time-integrated SCI measurements. Both instruments gave similar values of the order of 1×10^{-5}.

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1. C. Stoeckl *et al*., Phys. Plasmas **24**, 056304 (2017).
2. C. M. Huntington *et al*., Rev. Sci. Instrum. **83**, 10E114 (2012).
3. F. Girard, Phys. Plasmas **23**, 040501 (2016).
4. M. Afshari *et al*., Struct. Dynam. **7**, 014301 (2020).
5. H.-S. Park *et al*., Phys. Plasmas **13**, 056309 (2006).
6. C. Stoeckl *et al*., Fusion Sci. Technol. **49**, 367 (2006).
7. D. B. Thorn *et al*., Rev. Sci. Instrum. **89**, 10F119 (2019).
8. C. Stoeckl *et al*., Bull. Am. Phys. Soc. **52**, BAPS.2007.DPP.CO6.2 (2007).
9. C. Stoeckl *et al*., Rev. Sci. Instrum. **83**, 033107 (2012); C. Stoeckl *et al*., Rev. Sci. Instrum. **83**, 10E501 (2012).
10. C. Stoeckl *et al*., Rev. Sci. Instrum. **85**, 11E501 (2014).