Scaling studies with the dual crystal spectrometer at the OMEGA-EP laser facility[a)]

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The dual crystal spectrometer (DCS) is an approved diagnostic at the OMEGA and the OMEGA-EP laser facilities for the measurement of high energy x-rays in the 11–90 keV energy range, e.g., for verification of the x-ray spectrum of backlighter targets of point projection radiography experiments. DCS has two cylindrically bent transmission crystal channels with image plate detectors at distances behind the crystals close to the size of the respective Rowland circle diameters taking advantage of the focusing effect of the cylindrically bent geometry. DCS, with a source to crystal distance of 1.2 m, provides the required energy dispersion for simultaneous detection of x-rays in a low energy channel (11–45 keV) and a high-energy channel (19–90 keV). A scaling study is described for varied pulse length with unchanged laser conditions (energy, focusing). The study shows that the Kα line intensity is not strongly dependent on the length of the laser pulse. *© 2010 American Institute of Physics.* [doi:10.1063/1.3494222]

I. INTRODUCTION

A wide range of high energy density experiments at large laser facilities requires efficient high-energy x-ray sources for imaging purposes. Point projection radiography[1,2] is one of the experiments that are intended to gain spatial information of laser produced high density matter. The ideal x-ray source is very bright, has high energy (above ~20 keV), and monoenergetic to allow high resolution and high contrast imaging. This requirement makes the characterization and optimization of the backlighter x-ray sources indispensable. Short pulse nonthermal laser interactions with solid targets are routinely used as backlighters at the OMEGA-EP laser facility.[3] High energy x-ray spectrometers in the Cauchois geometry[4] are well equipped diagnostics to characterize the x-ray source used in these experiments. A high resolution x-ray spectrum is detected by the dual crystal spectrometer (DCS) at the OMEGA-EP laser, enabling the study of relative x-ray line intensities with changing laser or target parameters. The scaling study introduced in this paper also demonstrates the performance of the DCS diagnostic at the OMEGA-EP laser facility. DCS was previously used at the Titan laser facility at Lawrence Livermore National Laboratory for studies of K-shell emission of high Z targets.[5]

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II. THE DUAL CRYSTAL SPECTROMETER

The DCS x-ray diagnostic is available for users at the OMEGA and OMEGA-EP laser facilities. The DCS includes two crystal channels that enable two different x-ray spectral ranges to be recorded in the same shot. Figure 1 shows a schematic view of the two crystal channels inside the spectrometer section of the instrument. In front of this section a "nose cone" is installed, which may be fitted with a pointer to facilitate the pointing of the instrument in any of the ten inch manipulator diagnostic ports of the OMEGA or OMEGA-EP chambers. Furthermore, the nose cone of the DCS includes shielding to mitigate scattered high-energy bremsstrahlung. Table I summarizes the major design parameters of DCS.

RC stands for Rowland circle in the table, a circle that has the diameter of the crystal radius. Figure 2 shows the plate functions of the two crystal channels of DCS. The cylindrically bent transmission crystal in a Cauchois type spec-

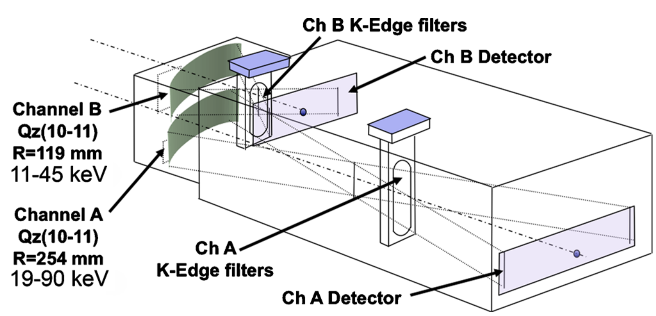

FIG. 1. (Color online) Sketch of the spectrometer section of the DCS. The high energy channel (a) is on the bottom and the low energy channel (b) is on the top of the instrument.

TABLE I. Most important design parameters of DCS.

DCS parameter	Channel "A" high energy channel	Channel "B" low energy channel
Crystal	Qz(10–11)	Qz(10–11)
Radius of curvature	254 mm	119 mm
Source to crystal	1.2 m	1.2 m
Crystal to detector	358 mm	119 mm
Energy range	~11–45 keV	19–90 keV

trometer produces a pair of spectral images (see example in Fig. 4 below) mirrored around the optical axis of the spectrometer. If the detector [in the case of DCS Fuji MS or SR Image Plates (IPs)] is placed on the focusing RC, the x-rays will be focused providing a detector resolution limited spectrum even for extended sources. In the case of laser produced x-ray sources, placing the detector beyond the RC further improves resolution and makes spectral features sensitive to the source size.[5] The source size and detector resolution are limiting factors in the effort of optimizing resolution. The high-energy channel of DCS (channel A) has the IP placed slightly beyond the focusing RC which results in a slight improvement in spectral resolutions compared to the RC geometry. In the case of DCS, the resolution of the IPs and the spectrometer geometry (large standoff) are limiting the system to be sensitive to source size broadening of spectral lines.[6]

III. SCALING EXPERIMENT FOR LASER PULSE LENGTH

A. Experimental setup

The experiment used the OMEGA-EP backlighter beam focused onto a silver microflag target at the target chamber center, with an 80 μm nominal focal spot. The laser energy was nearly 1 kJ and the pulse length was varying between 10 and 74 ps in the four full energy shots. The DCS had an "edge on" view of the target. The Ag microflag target was 5 μm thick and 100 μm^2. Figure 3 shows a sketch of the experimental setup. X-ray data were recorded from a 10 ps, 32 J shot before the four full energy shots with changing pulse length. This low energy shot serves as a "cold reference" as the laser irradiance and with that the heating of the target is not sufficient to provide significant ionization of the silver target material. The spectrum for this low energy shot is used as the neutral reference in the analysis.

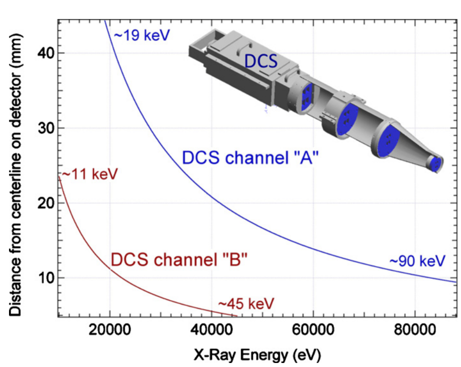

FIG. 2. (Color online) Plate functions of the two spectrometer channels of DCS. The inset shows the 3D model of the spectrometer.

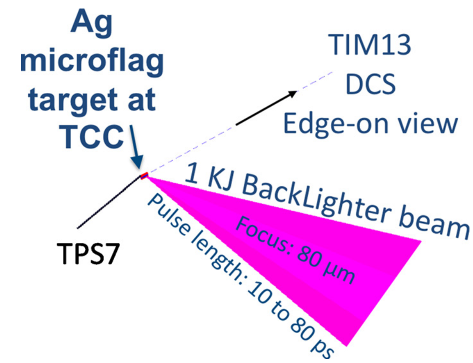

FIG. 3. (Color online) Experimental setup of the scaling study experiment with typical radiography backlighter target held by the TPS7 target positioner in "edge on view" to the DCS spectrometer.

B. The acquired x-ray spectra

For the scaling study, the high-energy channel data were analyzed. Figure 4 shows typical spectral images and raw spectra from both channels of the DCS instrument. On the lower half of the spectral image of channel B, absorption edges are identified that are due to absorption filters (Y, Zr, and Cd foils) placed near the cross-over slit of the channel.

IV. EXPERIMENTAL RESULTS

The goals of the experiment were to observe scaling of the x-ray intensity with changing pulse length. Figure 5 shows the sample spectra plotted on the energy scale. The low energy shot (SN4885) is normalized to the energy of the high energy shot (SN4886) in the figure. Due to higher ionization of the target atoms, the K x-ray peaks broaden and/or shift in the case of higher laser irradiance. Table II summarizes the shot parameters for the five target shots during the experiment.

Peak intensities were determined by fitting Gaussians to the peaks in the spectra. The area of the peaks above back-

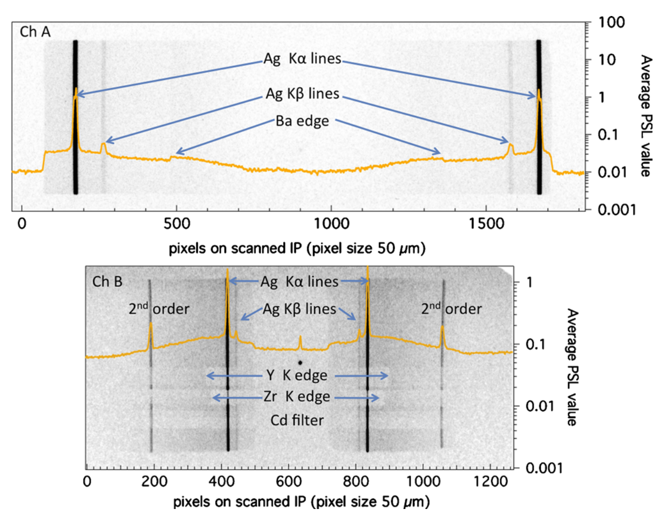

FIG. 4. (Color online) Typical raw x-ray spectral images and column averages of the DCS spectrometer channels. Channel A (Ch A) high energy channel and channel B (Ch B) low energy channel.

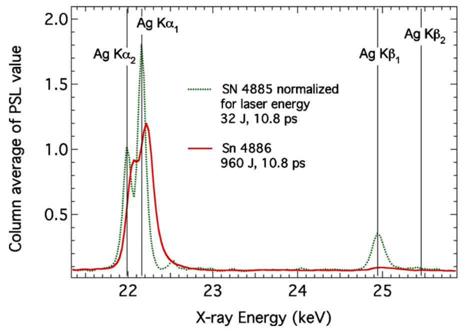

FIG. 5. (Color online) Comparison of the "neutral" low energy shot (SN4885) with the highest ionization and laser irradiance shot (SN4886).

TABLE II. Summary of shot parameters in the pulse length scaling experiment.

Shot No.	Laser energy (J)	Laser pulse length (ps)	Focus (μm)	Laser irradiance (W/cm^2)
SN4885	32	10.8	80	4.72×10^{16}
SN4886	960	10.8	80	1.39×10^{18}
SN4888	946	21	80	7.04×10^{17}
SN4889	956	39	80	3.83×10^{17}
SN4890	914	74	80	1.93×10^{17}

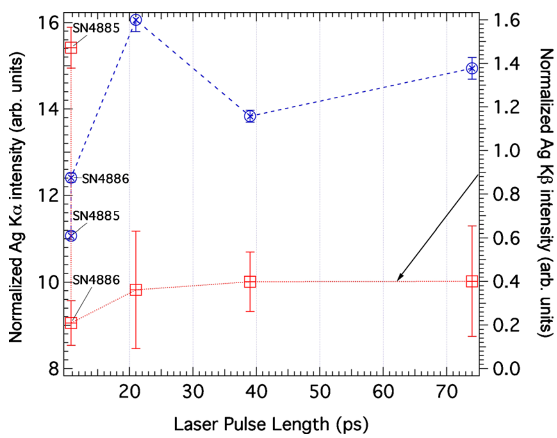

FIG. 6. (Color online) Kα (circles) and Kβ (squares) peak intensities deduced from the spectra in the five target shots. The intensities are normalized for laser energy.

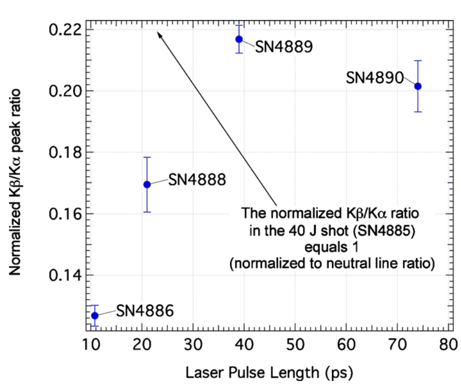

FIG. 7. (Color online) Kβ/Kα ratios in the experiment normalized to the neutral Kβ/Kα ratio in the low energy shot. The Kβ/Kα ratio of the low energy shot (SN4885) is normalized to equal one and is not shown in the figure.

ground is compared from shot-to-shot with variable pulse length in Fig. 6. No large dependence of overall x-ray intensity on the pulse length could be observed, the Kα yield is almost unchanged at constant laser energy and variable pulse length. However, minor change of the intensity and shape of the Kα and Kβ peaks in the x-ray spectrum was observed. This is most likely due to the slightly different high-energy electron creation circumstances inside the microflag target with different laser irradiance. A decrease of Kα and Kβ intensity can be observed at the shortest (10.2 ps) laser pulse length. A possible explanation for this result could be that higher-laser irradiance is creating more high-energy electrons with higher average energy. These high-energy electrons with higher average energy have smaller cross-section for K x-ray creation. Also based on the ratio of the Kβ and Kα peak intensities, the overall ionization of the target is higher at higher laser irradiance.

The Kα_1 peak broadens on the high-energy side as the shorter the pulse gets (as observed in Fig. 5 in the two extreme cases). This indicates higher ionization of the target in the case of higher laser irradiance. The shorter the laser pulse, the larger broadening of the Kα_1 peak can be observed. This ionization effect of the target material can be followed in the development of the overall intensity of the Kβ peak as well. As observable in Fig. 6, the overall intensity of the Kβ peak increases slightly with increasing pulse length, which means lower average ionization in the target. Figure 7 shows the Kβ/Kα ratios for all high energy shots with increasing laser pulse length. The data points in the figure are normalized to the Kβ/Kα ratio in the case of neutral material as observed in the initial low energy shot. It is clear that higher laser irradiance (shorter laser pulse at constant energy) produces smaller Kβ/Kα ratios, which means higher ionization states inside the microflag target.

V. CONCLUSION

A scaling experiment for the laser pulse length was carried out at the OMEGA-EP laser facility to help optimize backlighter beam parameters for radiography experiments. The study showed no strong dependence of the x-ray intensity on the laser pulse length. On the other hand, the changing laser irradiance has a very well observable effect on the average ionization of the used microflag targets that is observable in the form of peak shifts and broadening in the x-ray spectra.

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