

OPTIMIZATION OF X-RAY BACKLIGHTING FOR EXPERIMENTS ON Z *

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Abstract

Sandia National Laboratories' *Z-Backlighter* laser facility is using a laser driven monochromatic X-ray crystal imaging concept at the manganese He-alpha energy of 6.151 keV to backlight experiments for High Energy Density Physics (HEDP) on the '*Z*'-Facility, the world's most powerful pulsed power engine and X-ray source.

To further improve the reliability and efficiency of this tool, a series of experiments has been performed to determine the system's sensitivity to parameter variations such as changes in target properties, pre-pulse levels, pre-pulse separation or pulse energy.

In addition, an improved hardware set has been developed to enhance the precision and robustness of the target setup for transport between pre-alignment and final shot implementation.

and indirect, scattered contributions are minimized by implementing a small circular aperture in front of the image detector, specifically on the so called Rowland circle, where one finds a mirror image of the laser driven X-ray source.

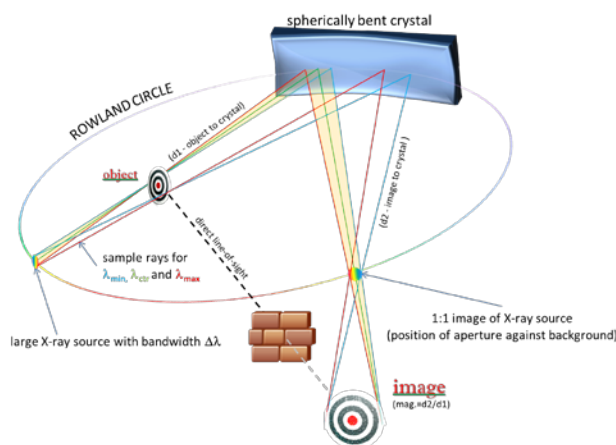


Figure 1. Schematic drawing of the crystal backlighting concept.

Z-Beamlet can be operated in a single pulse mode (with or without pre-pulse) or in a two pulse mode, in which both pulses have identical (or absent) pre-pulses. The double pulse mode is required for a two-frame imaging setup [1], which has become standard for backlighting with *Z*. The laser provides pulse energies of up to two kilojoules of laser light at 527 nm wavelength, which are focused onto a 1/8" wide manganese foil. The laser heated manganese emits characteristic radiation in the He-like state. The backlighting concept uses spherically bent quartz 2243 crystals, which image the primary experiment in the center section of *Z* via Bragg-diffraction, using the intercombination line at 6.151 keV [2]. A finite spot size allows for a finite range within the X-ray spectrum provided by the linewidth of the intercombination line to contribute to the image as sketched in Fig. 1. This concept can deliver details down to 15 micrometer characteristic size [3] and allows for a substantial reduction of the massive X-ray background emitted from the actual experimental load in *Z*: The direct line of sight between imaging detector and experiment can be blocked,

The crystal backlighting concept has successfully and reliably been used for many years now. However, improvements can still be made to increase the reliability, signal strength, and required setup-time for the system. The latter is particularly important as *Z* experiments involve multiple diagnostic teams and a tight schedule. Figure 2 depicts the summary results of a study of signal strength for 49 experiments on *Z* during which the exposure could vary by as much as a factor of ten.

Part of this is caused by varying read-out delays due to radiological hold times (detector decay) and by variations in reflectivity for the individual crystals, which are destroyed in the experiment. These influences cannot be mitigated by improvements of the experimental design. However, changes in hardware precision and target interaction design can reduce exposure fluctuations.

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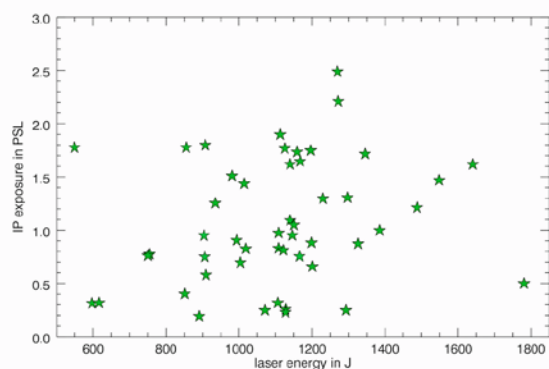


Figure 2. Exposure fluctuations over 49 backlit shots on Z. Data collected by D.B. Sinars of Sandia National Laboratories between 2009 and 2010.

II. MECHANICAL IMPROVEMENTS

The backlighting setup is largely pre-assembled with precisely machined target holders and return aperture, which are both located at opposite sides of the Rowland circle as depicted in Fig. 1. The crucial adjustable element is therefore the spherical quartz 2243 crystal. The first generation of crystal holders used custom crystal back-plates and commercial off-the-shelf mounts. These mounts operated tip and tilt with fine pitch screws pressing against the force of a retaining spring. During transport and when being subject to vibrations or minor impacts the alignment of the crystal could be compromised. To mitigate this problem, a new crystal holder with built in flex-and-friction tip/tilt adjustments has been developed. The new mount employs a monolithic design in which the front part of a partially cut aluminum block can be steered elastically over a few degrees. The remaining aluminum bridge between front and back part of the aluminum block can be bent by applying pressure against the front part with a set screw that is seated in the rear part. This concept results in a dramatically higher spring force compared to commercial mounts. In addition, the involved force applies a high amount of friction to the set screw, which prevents accidental rotation of the screw. Figure 3 shows a photograph of the new double-crystal mount (for 2-frame imaging as described by Bennett et al. [3]) with arrows that indicate push directions of the hidden tip/tilt adjustment set screws for the upper crystal. The new design has shown uncompromised accuracy over a period of six months in a test setup.

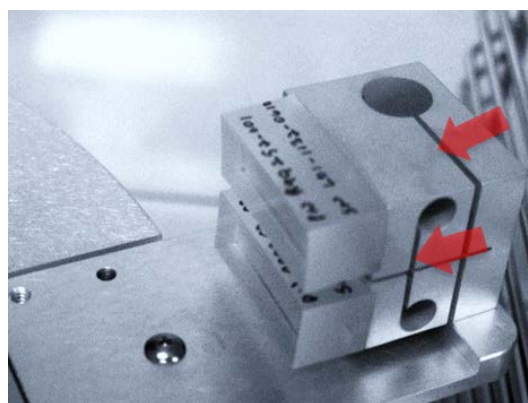


Figure 3. Sandia's new flex-and-friction mount for spherically bent crystals (double crystal version shown).

III. TARGET PROPERTIES

Manganese is a brittle material and therefore difficult to produce in thin, homogeneous samples. Thin foils are typically supported by polyester substrates and show prominent cracks. They are not light tight and even standard lamps leak through the samples. It is conceivable that a fraction of the laser light could penetrate the cracks and be absorbed by the polyester backing instead of the manganese target material. Thicker, sintered samples are light tight, but a deep darkened discoloration suggests oxidation of large parts of the material, which could also compromise X-ray conversion efficiency. An alloy involving the addition of 12% Ni seems promising for improving the X-ray conversion efficiency for manganese K-shell radiation. Figure 4 shows microscope images at 64x magnification for 25 μm polyester-backed Mn, 50 μm polyester-backed Mn, 1 mm sintered Mn, and 25 μm free standing $\text{Mn}_{88}\text{Ni}_{12}$ alloy.

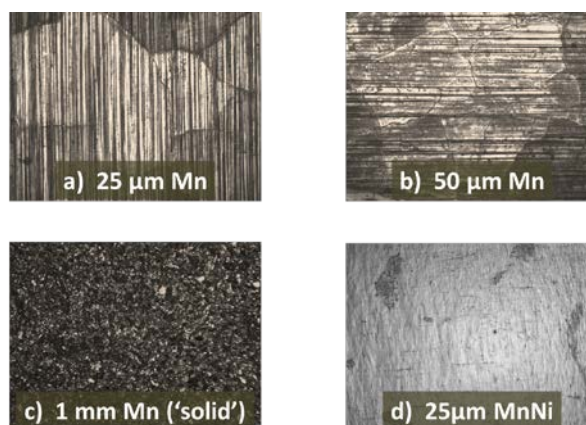


Figure 4. Microscope pictures of the surface quality for four manganese target types 'a, b, c, and d' (see text).

An experimental campaign was dedicated to investigate the dependence of X-ray conversion efficiency from type a, b, and c target properties (see Fig. 4). Figure 5 shows the results of this study based on the strength of a 6.151 keV signal on the Image Plate detector in photostimulated luminescence units (PSL). It could also be shown in this experimental series that there are very strong, linear correlations between the image plate exposures and X-ray PIN diode signals. This fact allows us to compare the diode signal of older shots, for which not all relevant information may exist to properly evaluate the exposure level. So far the data suggest that there is no influence of the target properties on the X-ray generation. All target materials deliver the same, reliable results. However, a comparison with the promising MnNi alloy is still pending, which will either prove or disprove that the previously used targets were all compromised by roughly the same factor.

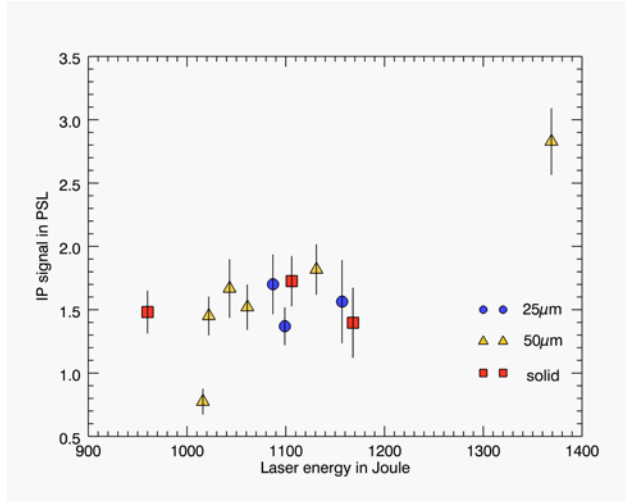


Figure 5. Recorded signal strengths from the 6.151 keV imager for targets of type a, b, and c of Figure 4 versus the energy of the laser driver.

IV. PRE-PULSE INFLUENCE

Pre-pulses are frequently used to create a pre-plasma, in which absorption is more efficient for the duration of the main laser pulse. The effect of such a pre-plasma is dependent on the target, the pre-pulse energy and separation delay, but also on the energy level, focus size, wavelength, and pulse shape of the main pulse. As most laser systems differ in these parameters from each other, the optimum pre-plasma is essentially unique to each laser system and target material. The addition of a pre-pulse dramatically improved the X-ray conversion efficiency for Sandia's backlighting concept [4]. Figure 6 illustrates the X-ray yield based on X-ray sensitive PIN diodes ('XRD'). The blue circles represent shots with pre-pulse, and the green squares represent shots without.

statistical averages of the diode signals are 167.7 pC with pre-pulse versus 36.6 pC without pre-pulse.

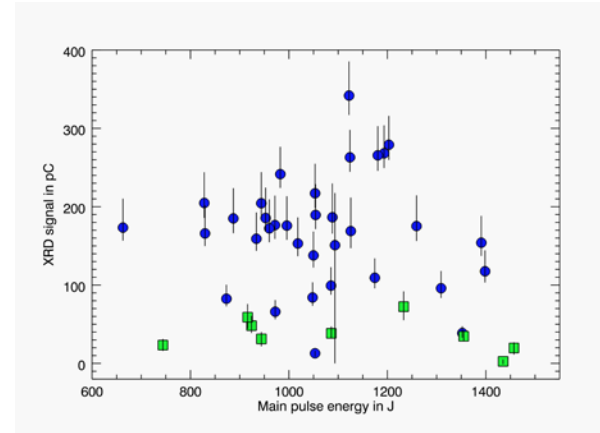


Figure 6. X-ray PIN diode signals with (blue circles) and without (green squares) pre-pulse vs. laser energy.

A. Pre-Pulse Level

The pre-pulse studies were all done with a constant pulse width of the pre- and main pulses of the laser. The series of experiments investigating target properties (see Section III.) was used to compare pre-pulse levels to the resulting X-ray conversion efficiency. Figure 7 shows the X-ray conversion efficiency, which is derived from the 6.151 keV imager's exposure level. The values are measured in units of PSL/Joule of the incident main pulse energy. The data are shown in dependence of the energy contained in the pre-pulse.

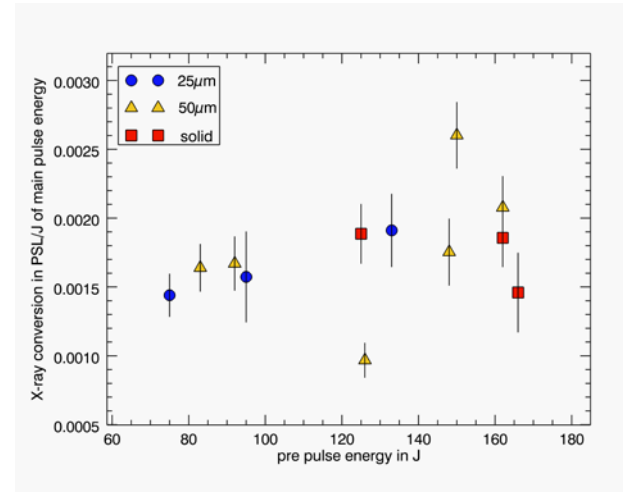


Figure 7. X-ray conversion efficiency versus pre-pulse energy for the shots discussed in Section III.

B. Pre-Pulse Delay

A series of 36 shots was performed between October 2011 and January 2012 in the calibration chamber of the Z-Backlighter facility. It was evaluated for X-ray conversion efficiency based on the XRD yield. 22 shots

were performed with a 3 ns delay between the peak of the pre-pulse and the peak of the main pulse, while the remaining 12 shots had a delay of only 2 ns. Figure 8 shows the results of the comparison.

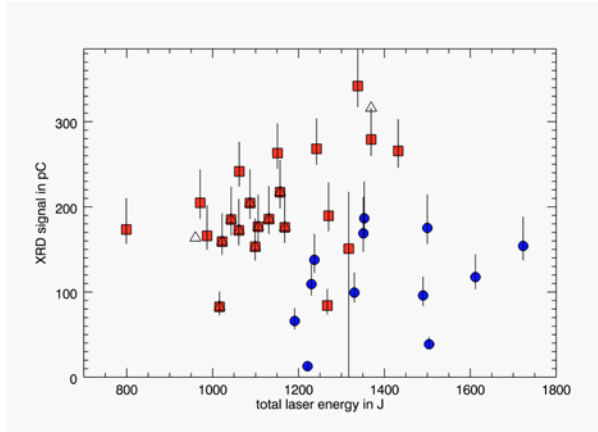


Figure 8. X-ray yield for 2 ns delay (blue circles) and 3 ns delay (red squares) versus laser energy. Triangles represent data from 3 ns shots of Section III.

The diode signals for 3 ns delay showed an average of 173 pC with a relative error of 30% while the signals dropped to an average of 108 pC \pm 49% for a 2 ns delay. It is noteworthy that the 2 ns delay shots even had almost 30% more laser energy in average than the 3 ns shots.

V. SUMMARY AND OUTLOOK

We have developed a new generation of rugged and precise crystal mounts based on a monolithic flex-and-friction concept to improve system reliability. We investigated the influence of three different manganese target types with respect to X-ray conversion efficiency, but there is no evidence of any influence of the target type so far. A more promising MnNi alloy is going to be tested in the near future.

We could confirm, that adding a pre-pulse to the temporal laser beam profile is of great advantage, and while the energy level of the pre-pulse seems of little importance within the frame of the study, we found a significant advantage with 3 ns delay between pre- and main pulse versus only 2 ns. More delay configurations are scheduled to be tested for the summer of 2013.

More potentially important details of the laser/target interaction are planned to be investigated to further improve the efficiency and reliability of Sandia's manganese backlighting imager. Among these are variations in the polarization of the incident laser light onto the target, variations of the laser spot size (intensity), an improvement of laser focus quality, and an investigation of the alternative use of the 6.181 keV He-

alpha resonance line instead of the 6.151 keV intercombination line. To further improve repeatability, a new Final Optics Assembly, which will be implemented in late summer 2013, will allow better control of the focus. Furthermore, the currently used quartz crystal characterization setup will be upgraded to include reflectivity, which will help to better understand shot-to-shot exposure variations.

VI. REFERENCES

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