AIP Review of Scientific Instruments

Monochromatic radiography of high energy density physics experiments on the MAGPIE generatora)

G. N. Hall, G. C. Burdiak, L. Suttle, N. H. Stuart, G. F. Swadling, S. V. Lebedev, R. A. Smith, S. Patankar, F. Suzuki-Vidal, P. de Grouchy, A. J. Harvey-Thompson, M. Bennett, S. N. Bland, L. Pickworth, and J. Skidmore

Citation: Review of Scientific Instruments **85**, 11D608 (2014); doi: 10.1063/1.4890262

View online: http://dx.doi.org/10.1063/1.4890262

View Table of Contents: http://scitation.aip.org/content/aip/journal/rsi/85/11?ver=pdfcov

Published by the AIP Publishing

REVIEW OF SCIENTIFIC INSTRUMENTS 85, 11D608 (2014)

Monochromatic radiography of high energy density physics experiments on the MAGPIE generator[a)]

G. N. Hall,[b)] G. C. Burdiak, L. Suttle, N. H. Stuart, G. F. Swadling, S. V. Lebedev, R. A. Smith, S. Patankar,[c)] F. Suzuki-Vidal, P. de Grouchy,[d)] A. J. Harvey-Thompson,[e)] M. Bennett, S. N. Bland, L. Pickworth,[f)] and J. Skidmore[c)]
The Blackett Laboratory, Imperial College, London SW7 2BW, United Kingdom

(Presented 4 June 2014; received 31 May 2014; accepted 2 July 2014; published online 23 July 2014)

A monochromatic X-ray backlighter based on Bragg reflection from a spherically bent quartz crystal has been developed for the MAGPIE pulsed power generator at Imperial College (1.4 MA, 240 ns) [I. H. Mitchell *et al.*, Rev. Sci. Instrum. **67**, 1533 (2005)]. This instrument has been used to diagnose high energy density physics experiments with 1.865 keV radiation (Silicon He-α) from a laser plasma source driven by a $\sim$7 J, 1 ns pulse from the Cerberus laser. The design of the diagnostic, its characterisation and performance, and initial results in which the instrument was used to radiograph a shock physics experiment on MAGPIE are discussed. © *2014 AIP Publishing LLC*.
[http://dx.doi.org/10.1063/1.4890262]

I. INTRODUCTION

Diagnostics with the ability to radiograph hot, dense plasmas with high spatial and temporal resolution are vital for the understanding of high energy density physics (HEDP) experiments. These instruments are particularly useful for the study of inertial confinement fusion and laboratory astrophysics. Monochromatic backlighters, based on Bragg reflection near normal incidence from a spherically bent crystal,[2,3] have previously been used to image wire-array Z-pinches and pulsed-power-driven HEDP experiments[4] and laser-plasma interactions relevant to Inertial Confinement Fusion.[5,6] A monochromatic backlighter has been developed for the study of HEDP experiments on MAGPIE,[1] a pulsed power generator capable of producing a 1.4 MA electrical pulse with a rise time of 240 ns. This instrument uses a spherically bent quartz 1011 crystal to perform radiography with 1.865 keV X-rays (Silicon He-α) driven by a $\approx$7 J, $\approx$1 ns, 527 nm pulse from a long-pulse arm of the Cerberus multi-beam laser system. Here, the design and characterisation of the instrument, and some initial results are discussed.

II. DESIGN OF THE INSTRUMENT

A detailed description of the principles of monochromatic backlighters can be found in the literature.[2,3,7,8] Typically, these instruments perform radiography with X-rays from a single atomic line, and since the Bragg angle must be close to 90° to minimize astigmatism, the source wavelength and the crystal 2d spacing must be closely matched.

The diagnostic discussed in this paper uses a quartz 1011 crystal (2d = 6.687 Å) which, under the Bragg condition $n\lambda = 2d\sin\theta$, reflects 1.865 keV X-rays from the Silicon He-α line at a Bragg angle of 83.9°. Figure 1 illustrates the imaging system, in which the backlighter source is placed on the Rowland circle such that the crystal focuses reflected radiation back onto the Rowland circle, where it passes through a 4 mm diameter aperture and is imaged at the detector plane. The object is placed 145 mm from the crystal, which has a curvature radius of 250 mm, resulting in a magnification of 6.0 at the detector plane at a distance of 870 mm from the crystal. The field of view at the object plane is 4 × 20 mm, resulting in a 24 × 120 mm image at the detector. The detector is a BAS-TR image plate, which is mounted in a film pack and kept light tight with 25 μm of beryllium.

The design of the diagnostic and its integration into the MAGPIE experimental chamber is shown in Fig. 2. The final optics assembly, mounted on the lid of the experimental chamber, focusses the drive laser through a vacuum window and onto the backlighter target using an f = 30 cm lens. The final optics assembly includes an alignment window, allowing a camera to view the backlighter target and verify that the laser is focussed at the correct position during alignment of the system (performed at atmosphere), and to correct any misalignment after the chamber has been placed under vacuum.

The position of the laser focal spot, and the focus of reflected rays from the crystal (i.e., the centre of the aperture), are set by the target-aperture assembly, shown in Fig. 3. Defining the position of these two points is critical to aligning the imaging system, since when the crystal is positioned such that rays reflected from it are well focused at the centre of the aperture, the Bragg angle is set correctly. The target-aperture assembly has the facility to remove the silicon backlighter target

[a)]Contributed paper, published as part of the Proceedings of the 20th Topical Conference on High-Temperature Plasma Diagnostics, Atlanta, Georgia, USA, June 2014.
[b)]Author to whom correspondence should be addressed. Electronic mail: gareth.hall@imperial.ac.uk. Present address: Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California 94550, USA.
[c)]Present address: AWE, Aldermaston, Reading, Berkshire RG7 4PR, United Kingdom.
[d)]Present address: Laboratory of Plasma Studies, Cornell University, 439 Rhodes Hall, Ithaca, New York 14853, USA.
[e)]Present address: Sandia National Laboratory, 1515 Eubank, Albuquerque, New Mexico 87123, USA.
[f)]Present address: Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California 94550, USA.

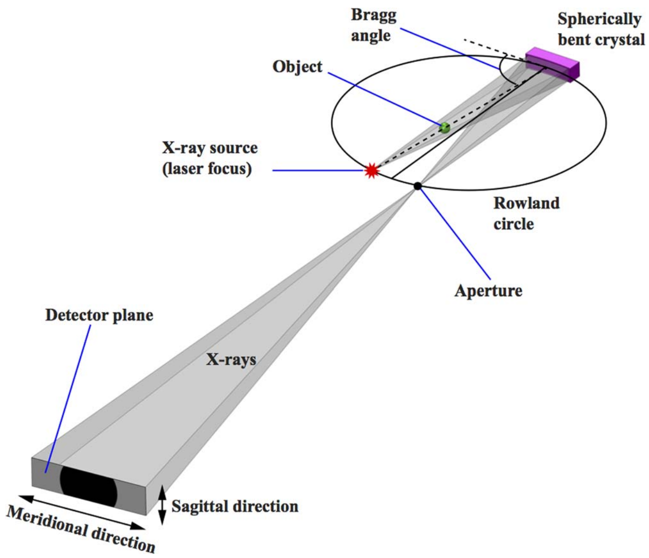

FIG. 1. The imaging system, showing the relative positions of the X-ray source, object, crystal, and detector.

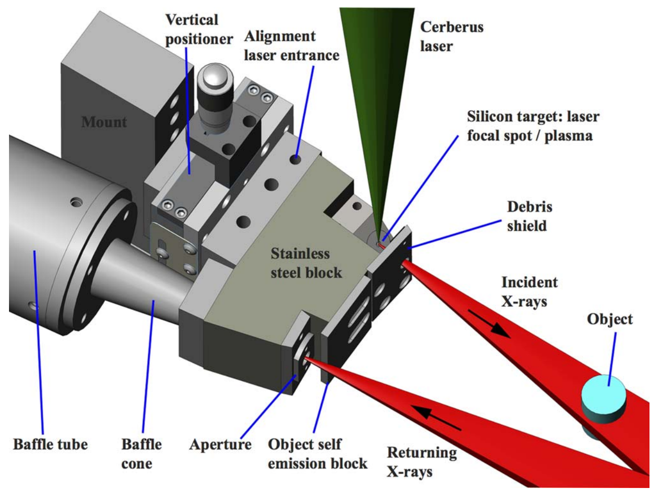

FIG. 3. The target-aperture assembly defines the position of both the laser focal spot, and the focal spot of reflected radiation, which together determines the Bragg angle of the imaging system.

and place a pinhole at the same position. An alignment laser can be directed into the assembly at the point shown in Fig. 3 and, using an internal mirror, illuminates the rear of the pinhole. The backlit pinhole acts as a reference point visible on the alignment camera that is used to determine the required focal spot position for the drive laser.

Additionally, the target-aperture assembly ensures that there is no direct line of sight between the object and the detector, which is one of the principle advantages of backlighters based on Bragg reflection. The main body of the assembly is stainless steel, designed to block hard X-rays emitted along the direct path from the experiment to the detector. A baffle couples the film-pack chamber directly into the rear of the target-aperture assembly, ensuring that the only open path to the detector is through the aperture, and a sliding plate mounted on the front of the assembly blocks the line of sight from the aperture to the object, preventing self emission and debris from entering the aperture. These measures ensure that self emission from the experiment can only reach the detector via the narrow bandpass of Bragg reflection from the crystal, and since the line emission from the backlighter is usually much brighter than the object self-emission at the same wavelength, good signal to noise can be achieved even when the experiment itself is an intense emitter.

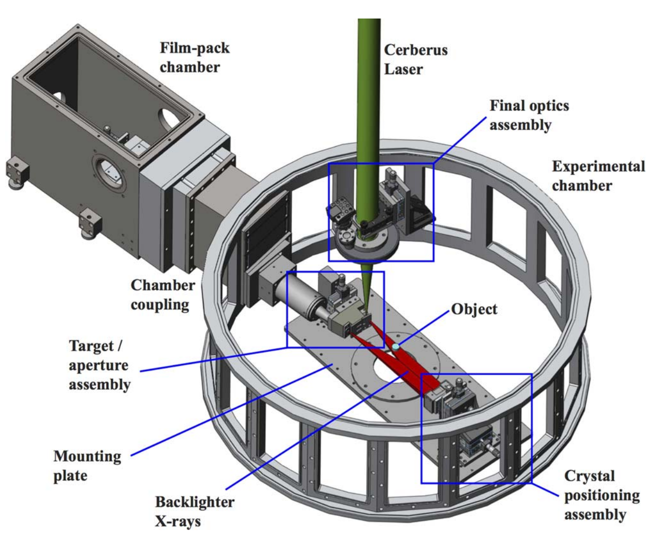

FIG. 2. The imaging components of the backlighter are loaded into the MAGPIE chamber on a mounting plate, whilst a separate chamber containing the film-pack is attached to a chamber port.

The Si backlighter source was driven with a 7 J, 1 ns flattop laser pulse at 527 nm generated by frequency doubling a 20 J 1053 nm beam from a long-pulse arm of the Cerberus laser. Cerberus is a hybrid Nd:Glass and optical parametric system able to deliver a combination of ns and sub-ps probe beams to the MAGPIE target area.

III. INSTRUMENT CHARACTERISATION

The resolution was measured using a 50 μm thick photochemical-machined stainless steel grid with 2 mm square holes and 0.5 mm mesh. Tungsten wires (round cross section) with diameters varying from 4 μm to 250 μm were placed across the grid as additional test objects. Figure 4(a) shows a radiograph of these objects. The mean resolution (defined as the spatial extent of a 10%-90% signal change across an edge) over the full field of view is $\sim$30 μm. Monochromatic backlighters with very similar imaging specifications[9] have achieved resolutions of $\sim$10 μm, and so it is expected that the system described here is capable of significantly better than $\sim$30 μm resolution when fully optimized. The resolution of monochromatic backlighter systems is given by the equation:[8]

$$\sigma = \frac{Sp(M+1)(1-\sin^2\theta)}{yM}, \qquad (1)$$

where σ is the expected resolution, S is the backlighter source size, p is the object–crystal distance, y is the source–object distance, M is the magnification, and θ is the Bragg angle. Time integrated, spatially resolved spectroscopy of the backlighter source was used to measure the spatial profile of the silicon He-α line. This was found to have a FWHM of 1.2 mm, which would give $\sigma \approx 11$ μm similar to the previously mentioned system, but also a low intensity halo

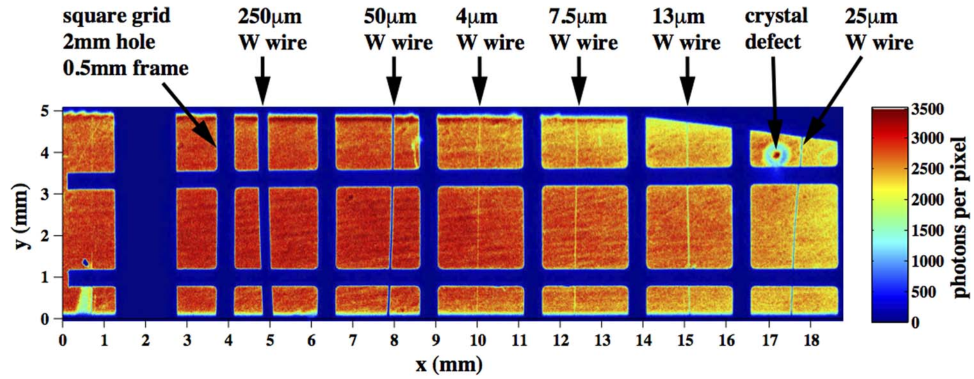

FIG. 4. Radiograph of 50 μm stainless steel grid and W wires.

that extends over a ≈3.3 mm width at 10% of the peak intensity, giving $\sigma \approx 30\ \mu$m. This is most likely the reason for the underperformance in resolution, and the eradication of this halo is the subject for future improvements to the backlighter system.

IV. INITIAL RESULTS

Recent experiments at MAGPIE include the investigation of reverse shocks relevant to astrophysical systems such as stellar jets and accretion shocks, as well as those produced by ablated material in laser driven hohlraums and Z-pinches.[10] In these experiments, a reverse shock is created by placing a planar foil obstacle in the 1×10^5 m/s flow of ablated plasma produced by an inverse wire array Z-pinch. Ablated plasma stagnates on the foil, producing a reverse shock, but the electron density gradients are too large to allow measurements with laser probing diagnostics. If the ablated material is tungsten, the density of the stagnated plasma is expected to be $\sim 1.5 \times 10^{-4}$ g/cm^3 at 250 ns (assuming uniform density). Since the path length is ∼1 cm, a transmission of ∼60% might be expected for 1.865 keV X-rays (assuming cold tungsten) making the backlighter an ideal diagnostic to study conditions within the stagnated plasma. Figure 5 shows a radiograph of a stagnated tungsten plasma and reverse shock, taken at 250 ns, and is a promising first result.

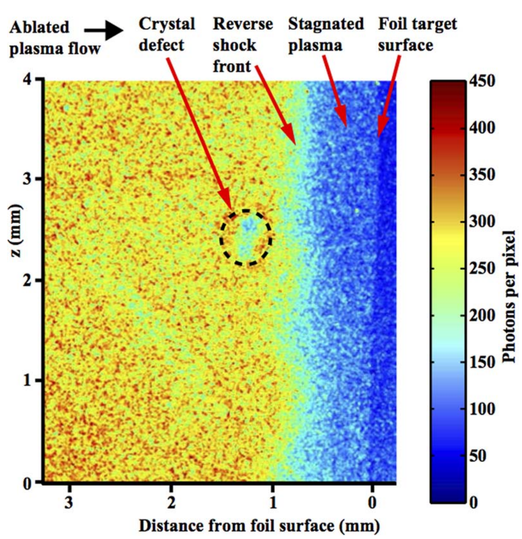

FIG. 5. Radiograph of the reverse shock produced from the stagnation of a 1×10^5 m/s laminar flow of ablated tungsten plasma onto a planar foil target on the MAGPIE generator. A low-pass signal filter and $25 \times 25\ \mu$m moving-mean filter have been applied to enhance features of interest.

The backlighter signal on this experiment was unusually low. This is partially due to the addition of an 8 μm polypropylene filter placed directly in front of the crystal to protect the surface from becoming coated with tungsten during the experiment, resulting in the loss of ∼40% of the backlighter signal. Additionally, the laser energy delivered to the target might have been reduced due to coating of the laser input window with debris from a previous experiment, and addition of protective filters to prevent this will be a future improvement to the system.

V. CONCLUSIONS

A monochromatic backlighter has been developed for the MAGPIE generator, and has successfully radiographed a pulsed-power driven shock physics experiment. The diagnostic utilizes Bragg reflection from a spherically bent quartz crystal to perform radiography with 1.865 keV X-rays (Silicon He-α) driven by the Cerberus laser. This diagnostic currently achieves $\sim 30\ \mu$m resolution over a 4×20 mm field of view, although it is expected that this can be improved to $\sim 10\ \mu$m in the future. Additional improvements will include the upgrade of the Cerberus laser to ∼30 J, which will result in increased backlighter yield and improved signal-to-noise.

ACKNOWLEDGMENTS

The author would like to acknowledge the support of the Imperial College Junior Research Fellowship scheme and the EPSRC. The Author would also like to thank Daniel B. Sinars of Sandia National Laboratories, Albuquerque, for his advice and support.

[1] I. H. Mitchell *et al.*, Rev. Sci. Instrum. **67**, 1533 (2005).
[2] S. A. Pikuz *et al.*, JETP Lett. **61**, 638 (1995).
[3] S. A. Pikuz *et al.*, Rev. Sci. Instrum. **68**, 740 (1997).
[4] D. B. Sinars *et al.*, Rev. Sci. Instrum. **75**, 3672 (2004).
[5] C. Brown *et al.*, Phys. Plasmas **4**, 1397 (1997).
[6] Y. Aglitskiy *et al.*, Phys. Scr. T **132**, 014021 (2008).
[7] Y. Aglitskiy *et al.*, Appl. Opt. **37**, 5253 (1998).
[8] D. B. Sinars *et al.*, Appl. Opt. **42**, 4059 (2003).
[9] D. B. Sinars *et al.*, Rev. Sci. Instrum. **74**, 2202 (2003).
[10] S. V. Lebedev *et al.*, Phys. Plasmas **21**, 056305 (2014).