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An advanced high resolution x-ray imager for laser-plasma interaction observation

D. Dennetiere[1,a], Ph. Troussel[1], C. Courtois[1], R. Wrobel[1] and P. Audebert[2]

[1] *CEA, DAM, DIF, 91297 Arpajon, France*
[2] *Laboratoire pour l'Utilisation des Lasers Intenses, Ecole Polytechnique, 91127 Palaiseau Cedex, France*

Abstract. We present here the latest results obtained with our high resolution broadband X-ray microscope. These results, both spatial and spectral, were obtained in several facilities such as Berlin's synchrotron Bessy II and LULI's laser ELFIE 100TW. The results show clearly the opportunity in high resolution microscopy that offer mirror based diagnostics.

1. INTRODUCTION

The path to ignition requires to overcome many challenges. One of these is to control the shape evolution of the ignition target. This requires to build precision equipment such as high resolution X-ray imagers.

We will discuss in this paper the advances made in this field. Both spatial and spectral advances will be presented. We will then show recent images recorded by our state-of-the-art microscope at the ELFIE 100 TW [1] facility. We will finally discuss how to extrapolate such an optical system for MegaJoule class lasers experimentations.

2. EHRXI: A HIGH RESOLUTION, BROAD-BAND X-RAY PLASMA IMAGER

2.1 HRXI: using two toroidal mirrors to achieve high resolution

Previous work at the CEA investigating Rayleigh-Taylor instabilities has lead to a high resolution microscope. This microscope, HRXI [2] (High Resolution X-ray Imaging system), was used on several campaigns like ICF target implosions at the OMEGA laser facility [3]. It consisted of two toroidal (see Table 1) mirrors based on a Wolter design. The microscope achieved a 5 μm spatial resolution over a 2 mm field of view (FOV). Its mirrors were Ni-coated allowing a high reflectivity up to 6 keV at a grazing angle about 0.6°.

2.2 EHRXI: using multilayer coating to expand the reflectivity energy range

In order to get ready for LMJ conditions, R&D needs to be performed on higher energy X-ray radiography. A first objective was to obtain significant reflectivity (>30%) up to 12 keV. Continuing with a simple metallic layer was not an option since it would require to dramatically decrease the mirrors grazing angle.

[a] e-mail: david.dennetiere@polytechnique.edu

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Table 1. Optical characteristics of HRXI's mirrors.

Mirror #	Grazing angle	Tangential radius	Sagittal radius	Surface roughness	Slope error
1	0.584°	85 m	9.13 mm	3 Å	3 μrad
2	0.6°	88 m	9.13 mm	3 Å	3 μrad

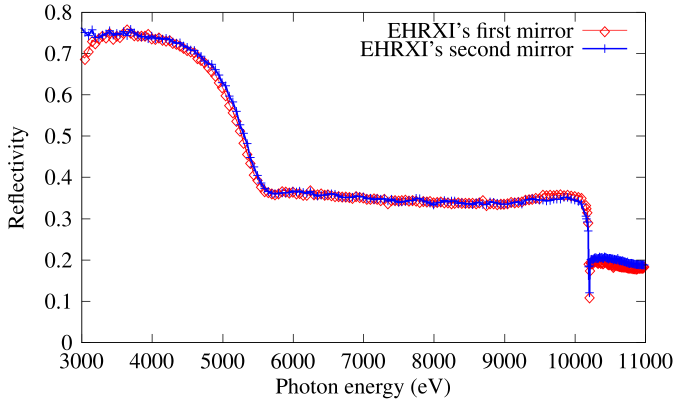


Figure 1. EHRXI's mirrors reflectivity vs X-ray energy at 0.6°. Two mirrors were tested: the first mirror of EHRXI (blue crosses) and the second one (red diamonds).

An alternative way based on Mezei's work [5] on neutron mirrors, was to use non-periodic multilayer coatings [4] on the surface of our mirrors. Such a coating is based on interferences between partial reflections of the grazing X-rays on the layers interfaces. By designing and controlling the width of these layers, one can actually shape the spectral responses of the mirrors. We were thus able to achieve the desired reflectivity thanks to the work of our collaborators at CEA and at the "Laboratoire Charles Fabry de l'Institut d'Optique" (LCFIO) [6].

This coating was originally intended for another diagnostic working at a grazing angle of 0.7°. It has been used at an angle of 0.6° in order to extend HRXI's bandwidth. The new diagnostic was then named EHRXI (Extended HRXI). The mirrors reflectivity was measured at 0.6° at Bessy synchrotron in Berlin. The results are shown figure 1.

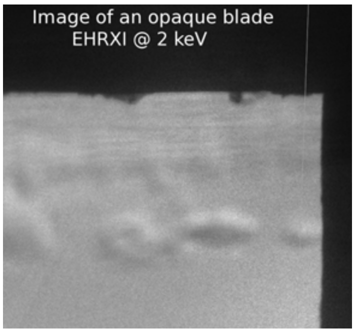
Since we changed the HRXI's mirrors in order to extend its bandwidth, its spatial resolution had to be measured. It was done on a continuous X-ray generator and the experimental resolution is now 4 mm[1]. We recorded the image of an Heavyside-step-like blade shown figure 2a on a CCD with a magnification ratio of 11.5. We then used this image to calculate the associated MTF shown figure 2b.

3. EXPERIMENTAL SETUP AT LULI'S ELFIE 100 TW

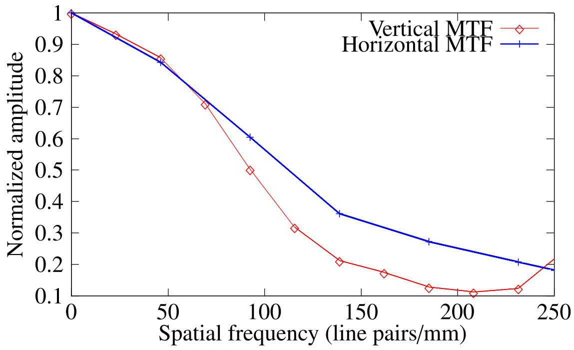
We tested our diagnostic on LULI's ELFIE 100 TW laser in late April 2011. The campaign's objective was to study multi-MeV X-rays. Among the other diagnostics, pinholes, spectrometers and dosimeters were used.

Several targets were shot. Those allowing us to image a spot consisted of a tantalum trapezoid with plastic foil at a variable distance from it. The schematic is presented figure 3. For the targets presented here, the laser configuration was the following: the ns beam exploded the plastic foil and the ps extracted and accelerated electrons from the plastic plasma. These electrons were then slowed down in the tantalum converter.

[1] Assuming that the resolution is the spatial frequency at which the MTF is 50%. Changing the criterion to 80% of the MTF would lead to a resolution of 8 μm.



(a) Image of an opaque blade obtained with EHRXI on a CCD with a magnification ratio of 11.5.



(b) MTFs given by a few columns or rows near the corner's blade.

Figure 2. Measurement of EHRXI's resolution using a Heavyside method.

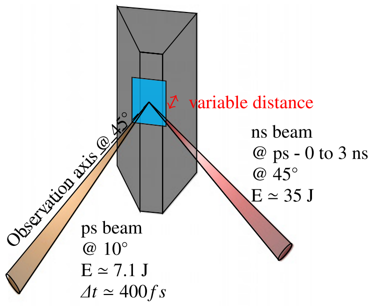


Figure 3. Schematic of the target respectively to the laser beams and to the observation axis.

The produced X-ray source had a bremsstrahlung spectrum coming from multi-MeV maxwellian electrons. The observed low energy[2] X-rays were emitted in 4π sr.

As shown figure 3, the diagnostic imaged the X-ray spot created by the electrons on the front surface. The observation axis was at 45° from the normal to the target. This leads to:

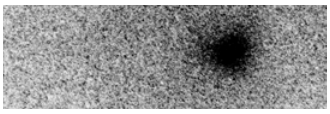
- a distorted image horizontally reduced by a factor of $\frac{\sqrt{3}}{2}$,
- and an emitting volume limited to the first few μm of tantalum.

4. EXPERIMENTAL RESULTS

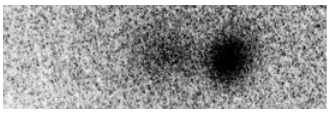
Figure 4 shows the image recorded with EHRXI with different targets with a pixel size of 50 μm. The recording was made using an Fuji MS image plate [7], leading to a resolution of $R \simeq 10\,\mu$m. The magnification ratio is 11.5. The images 4a, 4b and 4c were recorded with the ps beam sychronized with the falling edge of the ns pulse. They show the dependance between the CH plasma size and the varying distance (d) between the CH foil and the tantalum converter. This distance was respectively of 100, 400 and 700 μm.

Thanks to EHRXI, we were able to observe the influence of the geometrical target configuration on the CH plasma shape. The distance between the spots centers for the shots #54 (figure 4e) and #52

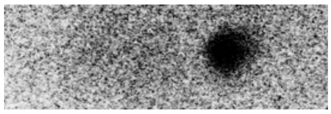
[2] Our bandwidth is limited to energies below 11 keV.



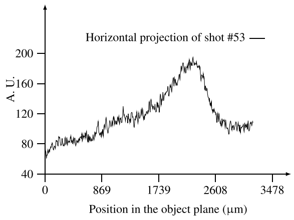
(a) Image of the X-ray source: d=100 µm, Δt_{ns-ps}=35 ps



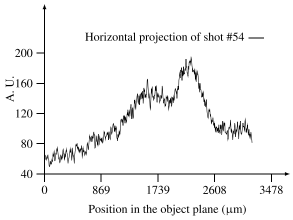
(b) Image of the X-ray source: d=400 µm, Δt_{ns-ps}=35 ps



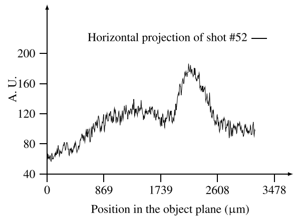
(c) Image of the X-ray source: d=700 µm, Δt_{ns-ps}=35 ps



(d) Horizontal projection of the X-ray source: d=100 µm, Δt_{ns-ps}=35 ps



(e) Horizontal projection of the X-ray source: d=400 µm, Δt_{ns-ps}=35 ps



(f) Horizontal projection of the X-ray source: d=700 µm, Δt_{ns-ps}=35 ps

Figure 4. Evolution of the X-ray source shape with the distance between the CH foil and the tantalum converter.

(figure 4f), respectively 530 μm and 760 μm are those approximately anticipated. The spreading of the CH plasma is wider on the side where no tantalum is met.

The spreading of the tantalum spot does not significantly change with the distance between the CH foil and the tantalum converter. That points to no measurable spreading of the electron beam between the two parts of the target. We observe though that the main spot is significantly wider than the ps focal spot (200 to 300 μm versus 20 μm respectively). We are currently investigating the Molière scattering contribution in this spread.

5. PERSPECTIVES

Since both the optical and the spectral concepts have been experimentally validated, we are currently building a new prototype. It will be monochromatic to find the best ratio between the X-ray radiography source and the parasite X-ray sources, and has an in-line design to reduce alignment difficulties. It will consist of 3 state-of-the-art mirrors – two toroidal mirrors for focusing and one planar mirror for spectral control.

This prototype will be available for use by the first semester of 2012.

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