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Abstract. Single-shot in-line phase-contrast imaging with the Inverse Compton Scattering X-ray source available at ATF (Accelerator Test Facility) at Brookhaven National Laboratory is experimentally demonstrated. Phase-contrast images of polymer wires are obtained with a single X-ray pulse whose time length is about 1 picosecond. The edge-enhancement effect is clearly visible in the images and simulations show a quantitative agreement with experimental data. A phase-retrieval step in the image processing leads to a accurate estimation of the projected thickness of our samples. Finally, a single-shot image of a wasp is presented as an example of a biological sample.

Keywords: Inverse Compton Scattering, X-ray imaging, phase-contrast imaging
PACS: 87.59.-e

INTRODUCTION

Inverse Compton Scattering (ICS) sources are capable of producing very short X-ray pulses characterized by high flux and brightness, tunable energy, quasi-monochromatic spectrum and small spot size. These properties can be exploited to realize high-quality X-ray imaging of particular interest for the biomedical field [1, 2, 3]. An application to in-line phase contrast imaging is here presented.

EXPERIMENTAL SET-UP

Figure 1 depicts our experiment layout: the X-ray are generated inside the Compton chamber by a head-on collision of a bunch of relativistic electrons with an intense laser pulse. After the interaction the electron beam is deflected by a dipole magnet into the beam stopper while the X-ray beam exits through the Be window and reaches the sample. A helium-filled pipe minimizes the intensity losses due to absorption while the beam propagates towards the X-ray detector. For a more accurate description of the beamline we refer the reader to a previous work [5].

The X-ray detector is a CMOS sensor coated with 165 μm of directly deposited microcolumnar CsI (Hamamatsu $C9728DK-10$). The pixel size is $50 \times 50\,\mu$m for a total active area of about 5×5 cm. The detector has

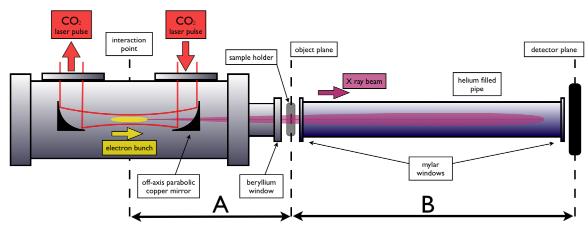

FIGURE 1. Sketch of the experiment (not to scale), $A = 105$ cm and $B = 223.5$ cm.

been characterized with respect to its Line Spread Function and energy response in order to perform quantitative measurements.

TABLE 1. X-ray beam parameters.

X-ray beam [4, 5, 6]	
photons/pulse	$2 \cdot 10^8$
Energy_{max}	10.4 keV
spread_{min}	0.6%
divergence	5 mrad
pulse length	~ 1 ps

Table 1 summarizes the parameters of the X-ray beam. The estimated number of photons scattered into 1 mrad^2 to $\approx 2 \cdot 10^6$ per pulse. Keeping in mind that this is a single-shot experiment, the flux density is approximately $7 \cdot 10^{16}$ ph. s^{-1}mrad^{-2}(0.1%bw)$^{-1}$.

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RESULTS

A single-shot exposure of a PET (polyethylene terephthalate) wire 520 μm thick is shown in figure 2; the image is only corrected for the dark current. The intensity distribution without the object is estimated with a two-dimensional Gaussian fit using all the pixels that do not contain any sample detail. With this approximation to the flat-field the raw image can be equalized. In figure 3 the PET sample and a PMMA (polymethyl methacrylate) wire with diameter 1124 μm are shown. The fitting procedure for the flat-field is required due the shot-to-shot fluctuations of the beam (intensity, position and shape).

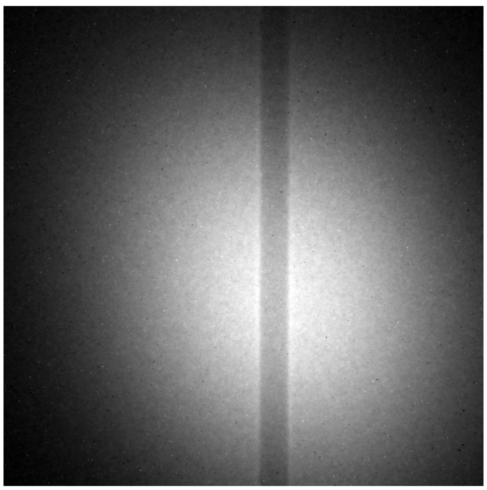

FIGURE 2. Raw single-shot image

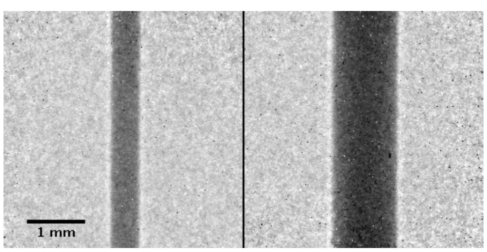

FIGURE 3. Ffit-based image equalization.

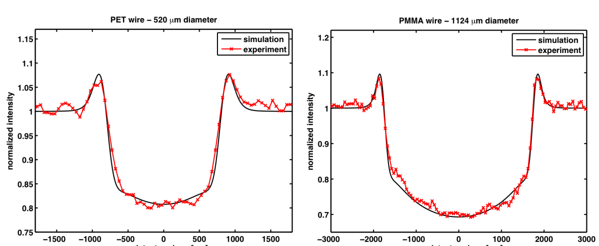

FIGURE 4. Comparison with simulation for the PET 520 μm diameter sample (left) and for the PMMA 1124 μm (right).

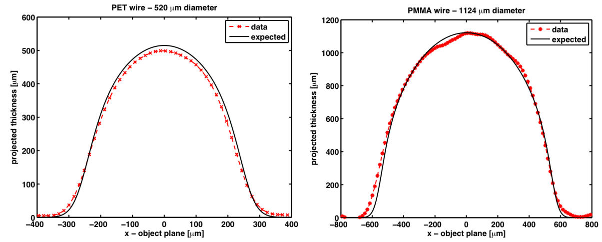

FIGURE 5. Projected thickness at the object plane, PET (left) and PMMA (right) samples.

A simulation [7] is compared to the normalized intensity profile (fig. 4). The source is modeled as a superposition of independent point sources, Gaussian distributed with a Full Width Half Maximum of 80 μm. The spectrum is chosen as quasi-monochromatic with mean energy 10.4 keV and standard deviation 0.04 keV. The detector Line Spread Function is modeled with two Gaussian functions (σ 93 and 238 μm relative amplitude 0.4). The normalized intensity profile is then processed [9] with a phase-retrieval algorithm [8] based on the monochromatic TIE for a homogeneous object. From the phase-retrieved image the projected thickness of the wires can be accurately estimated as shown in figure 5.

A single-shot image of a wasp is shown in figure 6. It contains both absorption and phase contrast, absorption dominates in the central part of the sample while phase effects are visible at the edges of the legs, mesosoma and wing. The noise pattern present at the corners is a consequence of the intensity fall-out.

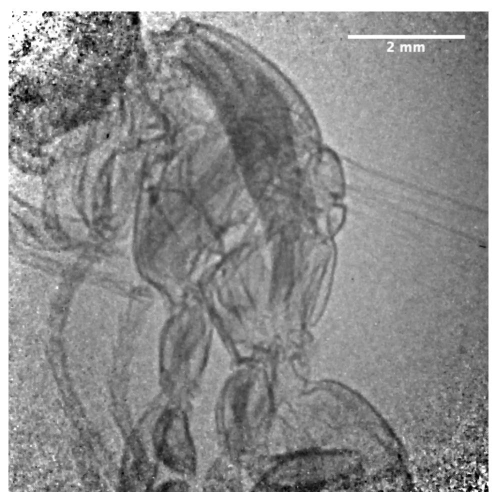

FIGURE 6. Single-shot image of a wasp.

CONCLUSION

Single-shot phase-constrast imaging has been experimentally demonstrated with an Inverse Compton Scattering X-ray source using in-line geometry on a very short time scale. The edge-enhancement effects are clearly visible in the images and a preliminary analysis of homogeneous samples shows quantitative agreement with the simulations. These results are encouraging for future application of this kind of sources to X-ray biomedical imaging.

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