Evaluation of the X-ray Bubble Lens

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Introduction

Due to the extremely small refractive index decrement of X-rays ($\delta \sim 10^{-6}$, $n=1-\delta+i\beta$, where n and β are refractive index and absorption index, respectively), an X-ray refractive lens has been unrealistic until recently. An X-ray refractive lens using a high-atomic number (high-Z) material has been proposed by Suehiro, Miyaji and Hayashi for focusing undulator radiation [1], but a long beamline of around 1km was needed. Yang[2] has come to the idea of a lens made of low-Z material for the focusing of hard X-rays, but the lens radii, a few micrometer, was too small. An X-ray refractive lens has been realized for the first time by Snigirev et al. [3] by producing a linear array of many lenses. Their lens, compound refractive lens (CRL), successfully focused the highly collimated undulator radiation with a focal length of around 1.8 m with a aperture of around 0.4 mm [3]. Their CRL was manufactured by drilling holes on a metal plate, such as aluminum and beryllium [3]. It is important to make the spacings between the holes as small as 10 μm.

Here we show a new refractive lens by placing gas bubbles on a adhesive liquid surface. The gas bubbles work as spherical lenses and two dimensional focusing can be achieved. The spacings between the bubbles can be easily reduced to less than 100 μm. This lens is low cost and the lens parameters, such as the focal length & aperture, are easily controlled by changing the number & size of the bubbles you produce. By precisely controlling the pressure of the gas, focusing in a wide energy band with a fixed focal length would be possible. The control of the bubble shape, however is not so easy. Using an X-ray bubble lens, the source image of the undulator radiation was taken at the BL47 of SPring-8.

Lens Specification

For the bubble lens, the liquid needed to be adhesive. A mixture of three chemicals, glycerol, oreic acid, and the nitrilo-ethanolamine, was chosen which had the density of 1.18 g/cm^3[3]. The liquid container was made from acrylic resin which was sealed with Kapton films of 26 μm in thickness at both ends. It has two pipes as the inlet&outlet of the bubbles and a triangular ceiling to keep them in a straight line (Fig.1.). To produce bubbles with a constant volume, gas pressure from a helium gas cylinder was reduced to 1 kg/cm^2 and the gas flow was controlled by a needle valve and a syringe needle with the outer-diameter of 0.5 mmϕ. The bubbles were not spherical but were more like ellipsoidal due to the ceiling and the neiboring bubbles (Fig.1). The length of the container, 480 mm, and the number of the bubbles, 168, indicated the radius of the bubbles to be around 1.4 mm.

Experimental Conditions and Results

Characterization of the bubble lens was done at BL47 of SPring-8 with the beam current of around 18 mA. Undulator gap was set to 27 mm and the image of the source was taken using a cooled-CCD (Hamamatsu Photonics, C4880-17) with a 10 μm phosphor (Fig.2). The lens were set at 44.7 m downstream of the undulator. 19 keV X-rays, above the peak of the 1 st order harmonics (17.2 keV) was illuminated at the lens. The beam profile was relatively flat around the optical axis, with a bright rim at off-axis positions.

An elliptic source image was obtained using the bubble lens (Fig.3.). The observed focal length was 5.35 m and 5.51 m in the horizontal and vertical directions, respectively. The focus size in FWHM was about 180 μm $\times$ 48 μm (horizontal $\times$ vertical), larger than the expected size of 132 μm $\times$ 13 μm (horizontal $\times$ vertical). The discrepancy of the expected and the observed focus size could have resulted from the irregularity of the size and the center positions of the bubbles. If we define the gain as the ratio of the observed peak intensity and the intensity through a pin-hole, a gain of around 12 was obtained at the focal plane. The radius of the bubbles was estimated from the focal length to be 1.40 and 1.36 mm, using the measured focal lengths in the horizontal and vertical directions, respectively, assuming the refractive index decrement of 7.54×10^{-7} at the energy of 19 keV. This was consistent with the size assumed from the number of the bubbles (1.4 mm).

We obtained a source image with the resolution of about 50 μm using the bubble lens. We however found that adhesive liquid was not so stable at a high X-ray flux. Small bubbles, with the diameter of less than 1mm, were formed at the Kapton-liquid interface at the energy of 17.2 keV, the peak energy of the 1 st order harmonics. We observed a visible light radiation at the surfaces of Kapton film with an intensified CCD camera and this visible light possibly forms the small bubbles at the surfaces of the films.

Acknowledgment

The synchrotron radiation experiments were performed at the SPring-8 with the approval of the Japan Synchrotron Radiation Research Institute (JASRI) (Proposal No. 1998A0162-NM-np).

References

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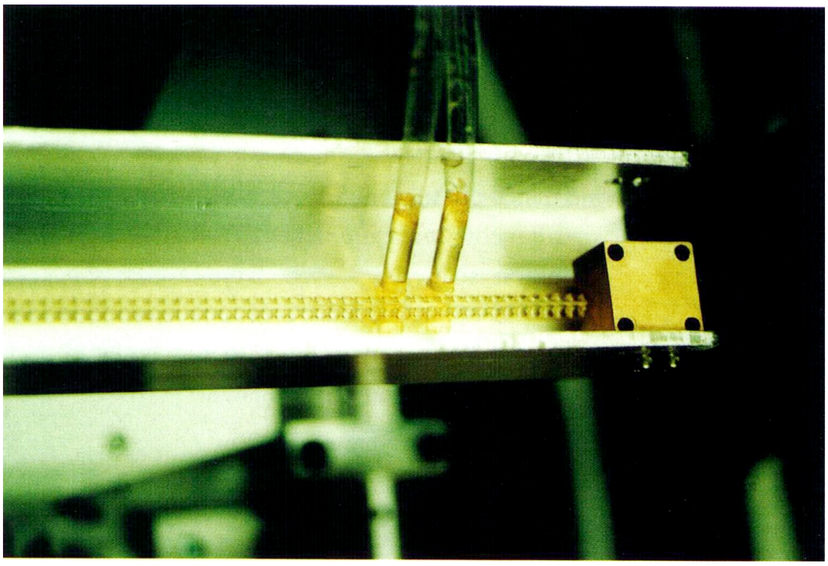

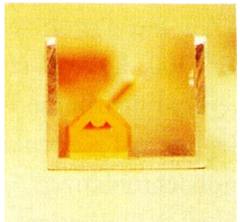

Fig.1. The liquid container for the X-ray bubble lens made from acrylic resin. Liquids was sealed with kapton films of 26 μmt at both ends. It has two pipes as the inlet&outlet of the bubbles and a triangular ceiling to keep them in a straight line.

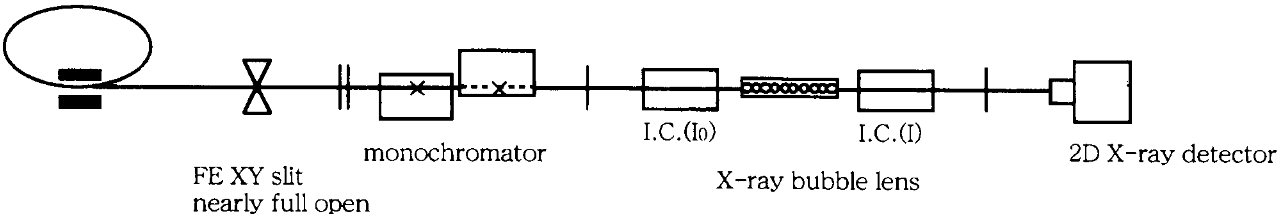

Fig.2. The experimental setup for evaluating the X-ray bubble lens.

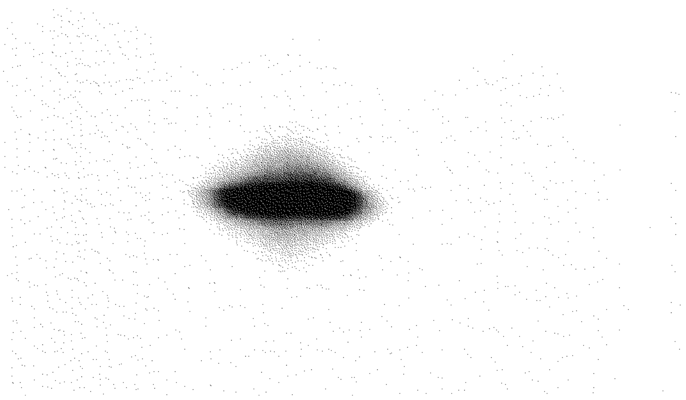

Fig.3. An elliptic source image of the undulator by focusing 19 keV X-rays using the X-ray bubble lens. The energy was set above the peak of the 1 st order harmonics (17.2 keV) because high flux made the bubble lens unstable as mentioned in the text. The observed focal length was 5.35 m and 5.51 m in the horizontal and vertical directions, respectively, and the focus size in FWHM was about 180 μm × 48 μm (horizontal × vertical).