# Evaluation of the X-ray Bubble Lens & X-ray Hollow Plastic Ball 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 $\beta$ are refractive index and absorption index, respectively), an X-ray refractive lens has been unrealistic until recently. An X-ray refractive lens has been realized for the first time by Snigirev et al. by producing a linear array of many cylindrical lenses.

We here present focusing test using new refractive lenses by placing gas bubbles on a adhesive liquid & hollow plastic balls on pure water. The gas bubbles & hollow plastic balls work as spherical lenses and two dimensional focusing can be achieved. These lenses are low cost and the lens parameters, such as the focal length are easily controlled by changing the number & size of the bubbles & hollow plastic balls. Using both an X-ray bubble lens & an X-ray hollow plastic ball lens, the source images of the undulator radiation were successfully taken at the BL47 of SPring-8.

## Lens Specifications

For the bubble lens, the liquid needed to be adhesive. A mixture of three chemicals, glycerol, oreic acid, and the nitrilo-ethanolamine, was chosen. 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 mm$\phi$. We formed a bubble lens with a uniform bubble radius of ~1.4mm and the number of the bubbles was 168. The bubbles , however, were not spherical but were more like ellipsoidal due to the ceiling and the neiboring bubbles.

For the hollow plastic ball lens, pure water was used and we used hollow polystyrene balls supplied by the Institute of Laser Engineering, Osaka Univ., originally manufactured as the target for cryogenic laser fusion. The ball outer diameter was carefully selected to be 1.9~2.0 mm using the optical microscope. The shell thickness was not so uniform (100~150 μm) and the typical inner radius of the ball was 0.85mm. We placed 199 balls into the liquid container.

For both lenses, a liquid container made from acrylic resin was used 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 & hollow plastic balls and a triangular ceiling to keep them in a straight line.

## Experimental Conditions and Results

Characterizations of the bubble lens & hollow plastic ball lens were done at BL47 of SPring-8 with the beam current of around 18 mA. Undulator gap was set to 26mm & 27 mm and the images of the source were taken using a cooled-CCD (Hamamatsu Photonics, C4880-17) with a 10 μm phosphor. The lens were set at 45 m downstream of the undulator. 19 keV & 24.5 keV X-rays, above the peak of the 1 st order harmonics were illuminated at the lens. The beam profile was relatively flat around the optical axis, with a bright rim at off-axis positions.

Using the bubble lens, a high gain was obtained but the imaging capability was not so good. The focal length of this lens was around 5.4 m and the observed image size at focus was 220 μm×60 μm (horizontal×vertical, FWHM), 2 and 7.5 times larger than expected. Though the image size was much worse than expected, we still observed the gain of 12 using this lens. The gain here was defined as the ratio of the observed peak intensity and the intensity through a pin-hole. We can expect much higher gain by improving the precision of the lens.

Using the hollow plastic ball lens, on the other hand, a much better imaging capability was obtained but the transmission or the gain was much lower. The observed image size at focus, in this case, was 124 μm×44 μm (horizontal× vertical, FWHM). The horizontal size coincided with the expected size while the vertical size was still 6 times larger than expected. The attenuation through the polystyrene shells was found to be significantly large. To improve this lens, manufacturing balls with much thinner and more spherical shells is needed.