range of the photon energy was from 4.5 keV to 70 keV. A preliminary analysis showed that the detection efficiency decreased in the photon energy range from 4.5 keV to 30 keV and increased over 30 keV. The latter increase seems to be due to Compton scattering. We are planning to measure the efficiency in the range below 4.5 keV to clarify the peak structure at the energy of several keV.

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EVALUATION OF X-RAY REFRACTIVE LENS MADE OF LIQUID MATERIAL

In spite of the extremely small X-ray refractive index decrement, an X-ray refractive lens was first achieved in an array of pinholes on an aluminum alloy plate (compound refractive lens, [1]). A two-dimensional lens was also developed by crossing two linear arrays in perpendicular directions [2]. This was also discussed in a case of parabolic lenses [3]. When liquids and gases are used as the lens material, the surface tension seems to form spherical and parabolic shapes much more naturally. Lenses were manufactured in the following way. First, the so-called "bubble lens" was manufactured by forming bubbles in a liquid adhesive (Figure 1). A mixture containing glycerol was used as the liquid and an acrylic container was designed so that 168 bubbles with diameter of about 2.8 mm each could be aligned in a straight line in the liquid. Pure helium gas from a gas cylinder was injected into the liquid through a needle valve and a syringe needle with an outer diameter of 0.5 mm

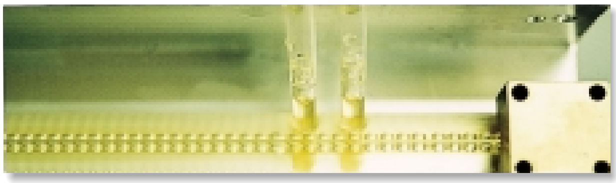

Fig. 1: Liquid container for X-ray "bubble lens" made from acrylic resin and Kapton films. Two pipes worked as inlet and outlet of the bubbles and a triangular ceiling kept the bubbles in a straight line. Courtesy of SPIE [4].

We further evaluated the so-called "micro-capillary lens". This lens was made by the Belarusian State University [5,6,7]. Bubbles were formed in a glue in thin glass capillaries and then solidified to obtain a solid X-ray refractive lens. The surface tension of the glue gives the surface of the bubbles an approximately spherical shape. So far, lenses with small apertures of around 0.2 mm in diameter have been developed (Figure 2). A similar lens with a diameter of 0.8 mm was also made with glycerol [7].

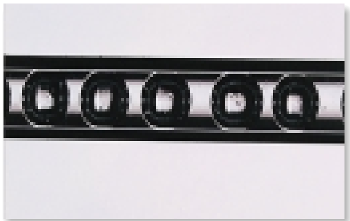

Fig. 2: Image of a micro-capillary lens taken with an optical microscope. The inner diameter of the glass capillary is 0.8 mm.

These two types of lenses were probably the first two-dimensional X-ray refractive lens systems using spherical lenses [4, 5].
An evaluation of the lenses was made at the beamline **BL47XU**. The demagnified image of the undulator source was taken, and the image size and gain at the focal plane were measured. The experimental conditions (ID gap and X-ray energy) were **(a)** 27 mm, 19 keV for the "bubble lens" and **(b)** 26 mm, 18.3 keV for the "micro-capillary lens". The observed focal lengths were **(a)** 5.4 m and **(b)** 0.8 m.

The distance between the source and the lenses was about 45 m. The coupling constant of SPring-8 was as small as 0.2%, and the vertical undulator source size was extremely small, i.e., less than 30 micrometer (FWHM) [8].

The vertical sizes and gains of the demagnified source image were measured at the focus of these lenses. Here, gain means the increase of flux from the condition of a tiny pinhole. The transmissivities of these lenses were measured with an air-filled ionization chamber as the ratio of the currents with and without the lenses as summarized in **Table I**.

The measured vertical sizes at the focus of these two lenses were larger than the geometrically expected size. For both "bubble" and "micro-capillary" lenses, however, a relatively high gain of 12 was obtained.

The "bubble lens" together with the "micro-capillary lens" have the advantage of high transmissivity and high gain. The solidified "bubbles lens" was also extremely stable to high flux of $4X10^{12}$ photons/sec/0.03 mm^2 at 18 keV (gap = 10 mm, 1 hour exposure). To improve gain, much more precise formation of the bubbles would be required.

The surface tension of the bubbles should be larger to keep them in perfect spherical shape. This may be done by using liquids with larger surface tensions or by pressurizing the bubbles. Moreover, it would be interesting to vary the focal length of the "bubble lens" by changing the pressure inside the liquid container.

The "micro-capillary lens" is most promising in terms of the focus size, but development of lenses with a larger aperture and parabolic surfaces is needed.

Table I. Results of two-dimensional focusing test using "bubble lens" and "micro-capillary lens".

	X-ray Energy (keV)	Vertical Image Size (µm, FWHM)	Transmissivity (%)	Gain
Bubble Lens	19	~60	16	12
Micro-capillary Lens	183	8	18	12

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