aberration of asymmetric crystals (leading to an energy-angle correlation in the output beam) does not appear.

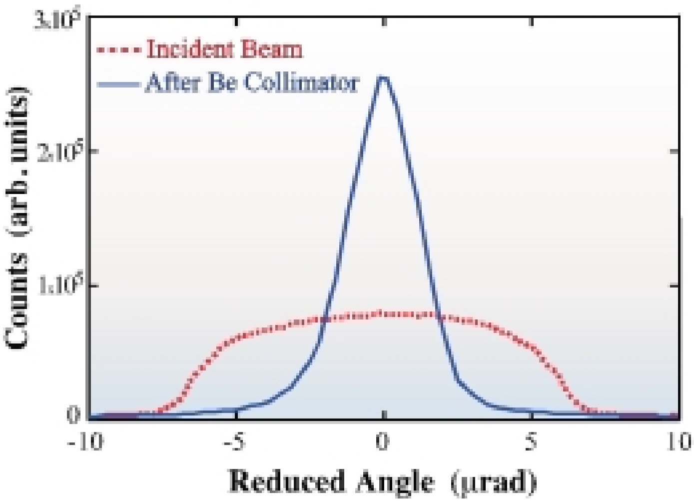

Fig.2: Effect of beryllium collimator at 18.5 keV. Dashed line shows beam divergence without the collimator. Solid line shows divergence measured after the collimator. X-ray divergence is reduced from 11.5 to < 3.0 μrad (FWHM) while 89% of incident intensity is transmitted. Note that "reduced" angle for x-axis corresponds to measured divergence of X-ray beam (see text).

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ATOMIC IMAGING AROUND Zn IN GaAs:Zn USING MULTIPLE -ENERGY X-RAY HOLOGRAPHY

The X-ray fluorescence holography makes it possible to obtain direct three-dimensional atomic images around atoms emitting fluorescent X-rays [1]. However, only the holograms of single crystals, whose atomic configurations are already known by the X-ray diffraction method, have been measured because of the weakness of the primary X-rays. Therefore, we applied this method to imaging the atomic structure around zinc (Zn) atoms doped in gallium arsenide (GaAs) with synchrotron radiation [2]. X-ray fluorescence holography has two types of experimental techniques. One is called "X-ray fluorescence holography" (XFH) and the other is called "multiple-energy X-ray holography" [3] (MEXH). MEXH is the result of the optical reciprocity theorem applied to XFH and has the advantage of suppressing the twin image effect. We adopted here the MEXH mode for obtaining the hologram. The incident X-ray energy 9.8 keV was selected, which is between the Zn and Ga K absorption edges, so as to avoid excitation of the Ga and As X-ray fluorescence. The sample was mounted on a two-axis rotatable stage. Figure 1 shows the experimental setup. The Zn Kα X-ray fluorescence intensity was measured as a function of azimuthal (ϕ) and incident (θ) angles by an Si PIN detector, and the resulting holographic pattern was obtained, as shown in Figure 2.

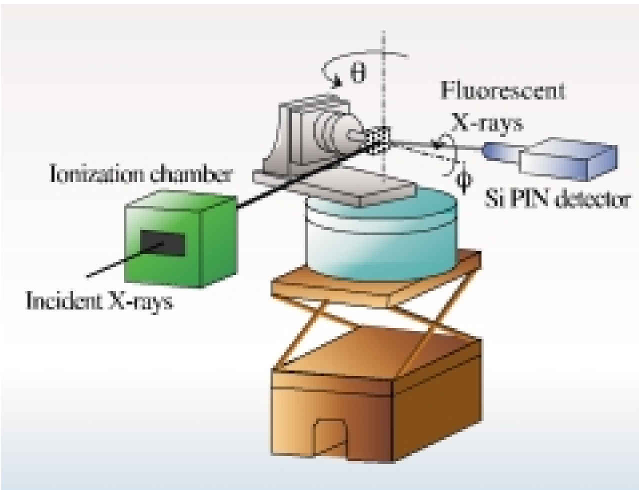

Fig. 1: Experimental setup.

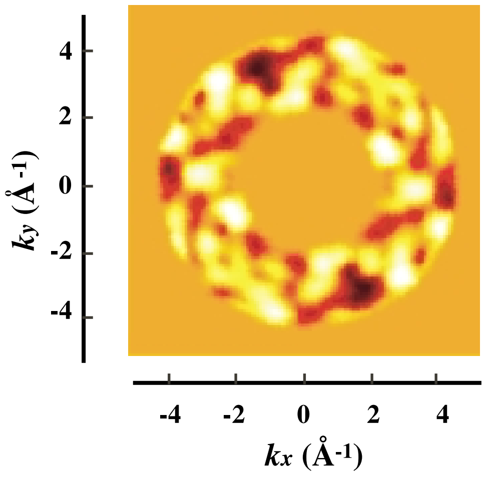

Fig. 2: Measured hologram from Zn doped in GaAs. Courtesy of Jpn. Anal. Chem. [2].

A real space atomic image was calculated by Fourier transformation from the hologram. The reconstruction in Figure 3 **(a)** is the environment around Zn atoms on the (001) plane. Four atoms were found in the image at a distance of 4.0 Å from the center. The Ga and As layers stack alternately along the c-axis; these two layers are separated by 1.41 Å. The atomic configuration of the Ga layer is the same as that of the As layer, and the nearest Ga-Ga and As-As distances are 4.00 Å. It was found from the reconstructed image in Fig. 3 **(a)** that the Zn atoms substitute for Ga or As host atoms. We also observed four blurry atoms at a distance of 2.0 Å from the center Zn atom in Fig. 3 **(a)**. This image is a superposition of two different Ga or As layers above and below the emitter, because the spatial resolution along the z-axis was not good. In order to determine the structure of the layer above the Zn atom, we reconstructed the atomic image of the (004) plane situated at z = 1.41 Å above the emitter, as shown in Figure 3 **(b)**. The atomic image exhibits two enhanced atoms at a distance of 2.0 Å from the center, revealing that the Zn atoms substitute selectivity for one site of Ga or As. The possibility of As-site substitution may be negligible because of the charge neutrality.

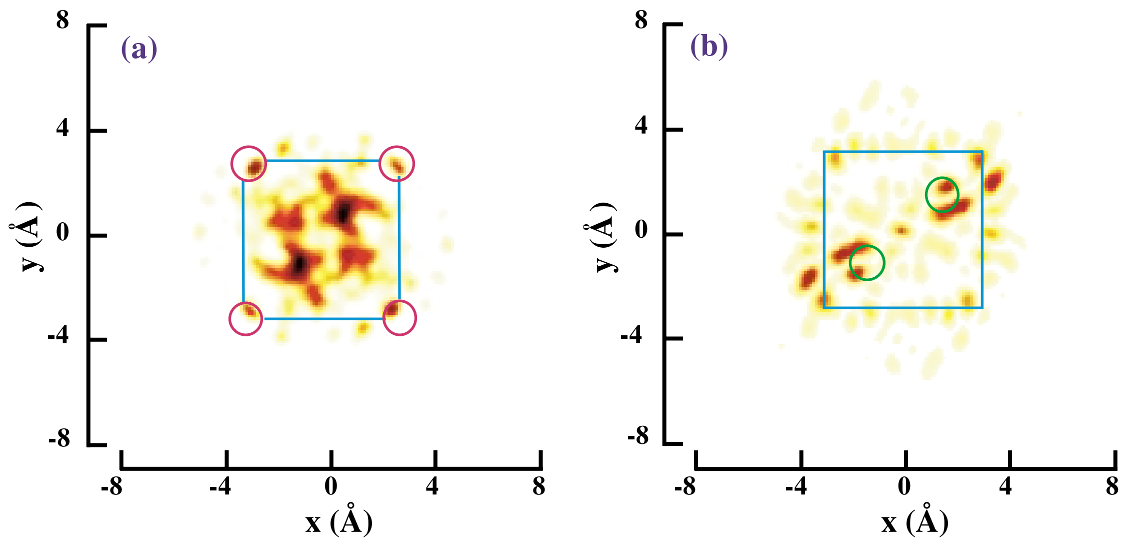

*Fig. 3: Reconstructed holographic images around Zn. **(a)** (001) plane, center is the Zn atom. **(b)** (004) plane, 1.71 Å above the Zn atom. Solid lines show outline of crystal cell. Courtesy of Jpn. Anal. Chem. [2].*

In conclusion, we measured the X-ray fluorescence hologram of 0.02 wt% (200 ppm) Zn in a GaAs wafer and successfully obtained local atomic images around Zn. These images revealed that Zn atoms occupy the substitutional site. The results demonstrate that the X-ray holography technique is applicable to practical structural analysis of trace impurities for a reasonable measurement time using the third-generation synchrotron radiation facility.

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