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Characterization Study of a Cylindrical Pyrolitic Graphite Neutron and X-ray Condenser Lens

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A toroidal bent pyrolitic graphite (PG) is developed for neutron optical device which is effective for thermal neutrons. Three bent PG along a toroidal surface were adjusted and glued in order to obtain a cylindrical shape neutron condenser lens. This toroidal PG has a large size typically 60 mm in diameter and 80 mm in length with 120 mm focal length for $\lambda = 1.54$ Å. Using x-rays a very good focusing with large flux gain more than 200 (maximum 325) times as strong as primary intensity was reported. We obtained very sharp image (resolution typically 0.5 mm) with high flux gain of about 150 for thermal neutron ($\lambda = 1.54$ Å). Present results indicate that this toroidal PG is a powerful tool for neutron optical devices.

KEYWORDS: toroidal Graphite, neutron optics, neutron condenser lens, thermal neutrons

§1. Introduction

There is strong demand to obtain high neutron flux which is an inevitable probe for the fundamental research as well as industrial use. Especially neutron imaging attracts strong interest in addition to the traditional method like scattering technique or activation analysis. For these purposes sophisticated neutron optical device has to be developed and used with high-density neutron storage media like a neutron image plate. Several methods are known to control the neutron beam pass. Total reflection mirror is the most traditional and successful neutron optical device.[1)] Recent ultra-high vacuum and sample preparation technique like MBE or sputtering enable us to synthesize even $4q$ super mirror which requires monoatomic flatness within the area in which neutron coherence is maintained. Besides the reflective device, refractive one such as neutron material lens is also being developed.[2)] The most modern technique is to drive neutrons by magnetic field interacting with neutron spin. The magnetic neutron optical devices have a great advantage, in which the optical component is absorption free and neutron is inevitably spin-polarized.[3,4)]

Although these neutron optical devices have often brought great success, it is widely accepted that these devices are not so effective for thermal neutrons. There is no useful material for reflective/refractive devices for thermal neutrons, in which the refractive index significantly deviates from unity. Only limited curvature of the neutron beam pass is possible by using magnetic devices composed of conventional superconducting magnet. Since present neutron sources have a maximum flux at thermal region, it is particularly important to develop neutron optical devices for thermal neutrons.

Very recently double bent pyrolitic graphite (PG) along the toroidal surface was developed in Matsushita electric Industrial Co.[5)] By constructing a cylindrical shape condenser lens with use of the toroidal bent PG, a very good focusing with large flux gain more than 200 (maximum at 325) times as strong as primary intensity has been reported for Cu-K_α radiation of $\lambda = 1.5407$ Å.[5)] The purpose of this study is to characterize the imaging and magnification of the neutron flux of this toroidal PG crystal as a neutron condenser lens.

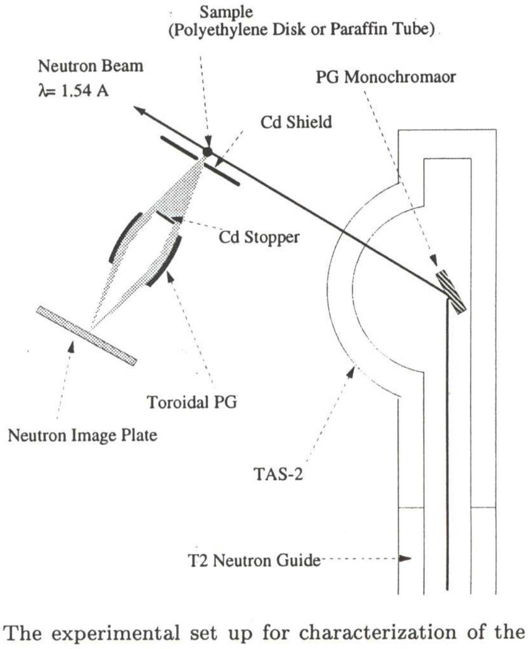

Fig. 1. The experimental set up for characterization of the neutron condenser lens composed of bent toroidal PG.

§2. Experimental

The toroidal double bent pyrolitic graphite is made of polyimide sheets. The glassy carbon sheets were obtained by annealing a stuck of several hundred polyimide sheets at 1000°C. The glassy carbon sheets can be easily bent along any two-dimensionally curved surface. After forming an toroidal surface within the accuracy of 1 %, the carbon sheet is annealed about 2800°C under pressure in order to crystallize graphite. Then, the curved graphite was annealed again at 3100°C in argon atmosphere to improve the quality of the graphite crystal. Three piece of PG crystal were adjusted and glued in order to obtain a cylindrical shape optical device. This cylindrical PG has a large size typically 60 mm in diameter and 80 mm in length with 128 mm focal length.

The characterization study with neutron has been carried out using triple axis spectrometer TAS-2. The incident beam was monochromatized at the wavelength of 1.54 Å with a flat PG monochromator. The small sample rod was exposed and used as a point neutron source. The incoherent scattering from the sample was collimated and stored on a neutron image plate. A Cd disk was mounted on the optical axis to prevent the incoherent scattering from hitting directly onto the image plate. The focus was roughly adjusted by minimizing the image size of a polyethylene disk with 3 mm diameter with changing the distances between sample tube, double toroidal PG, and image plate. Finally, the focusing was finely tuned by the image of 1 mm diameter paraffin tube. This sample was also used to check the imaging and the magnification of the neutron bean flux. The experimental set up is schematically shown in Fig. 1.

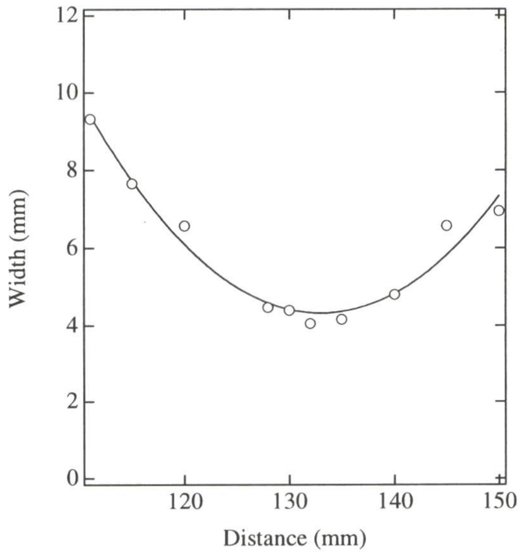

Fig.3. The full width at half maximum (FWHM) of the profile of the polyethylene disk (3 mm). The line width is plotted as a function of the distance between the toroidal PG and image plate. The line is guide for eye.

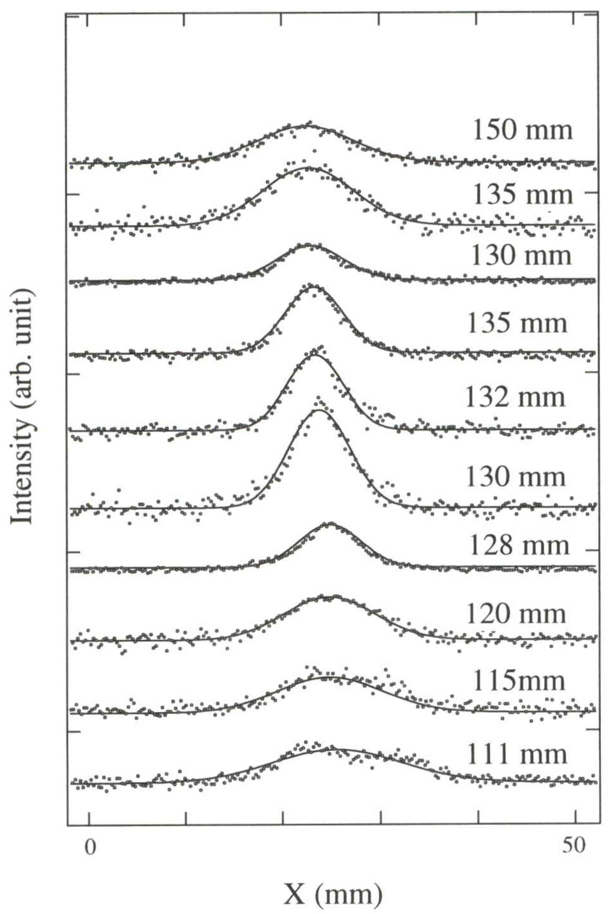

Fig.2. The profile of the image of polyethylene disk (3 mm) scanned along the horizontal axis X on the image plate. The profiles were observed as a function of the distance between the toroidal PG and image plate. This distance is shown for each profile in the figure. The data were fitted by Gaussian profile.

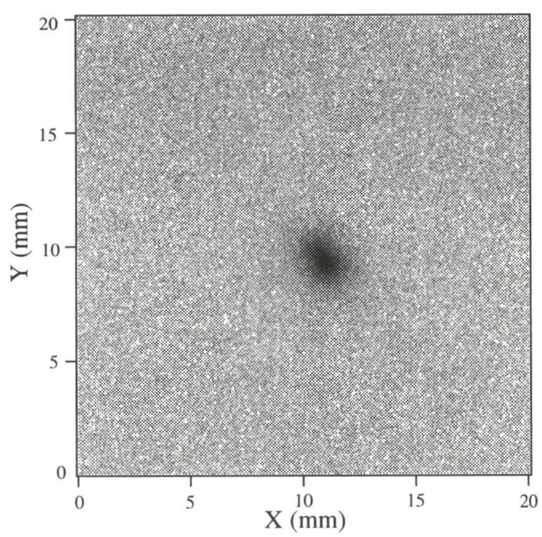

Fig.4. An image of a paraffin tube of 1 mm diameter.

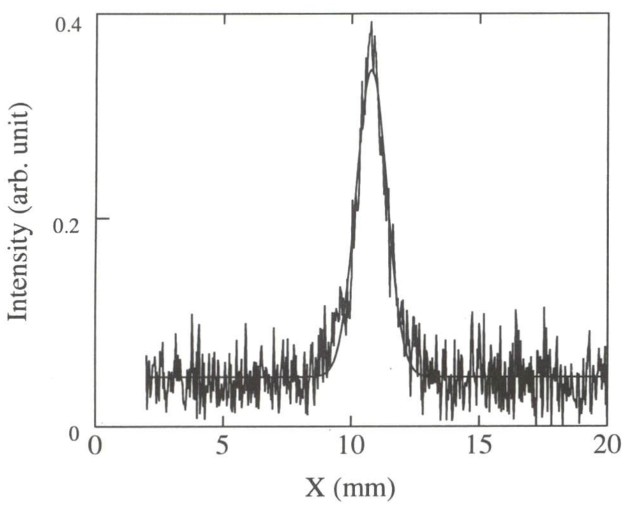

Fig. 5. The profile of the image of a paraffin tube of 1 mm diameter.

§3. Results and Discussions

Figure 2 shows the profile of the image of polyethylene disk (3 mmϕ) as a function of the distance between the toroidal PG and image plate. The line width of the profile changes with distance and exhibits a clear minimum at the focusing point as shown in Fig. 3. This result confirms that the neutron stored on the image plate was diffracted and collimated on to a spot by toroidal PG. From the diameter (60 mm) and the focal length (128 mm) of the toroidal PG, the size of the defocused image at 20 mm from the focusing point is roughly estimated to be

$$60{\times}20/128 = 9.4[mm]. \tag{3.1}$$

This size is consistent to the experimental result as shown in Fig. 3.

After determined the focusing point, the image from a paraffin tube of 1 mm diameter has been stored (Figure 4). It took about 8 hours to take this picture. Surprisingly we obtained a very sharp spot on the image plate which is about 260 mm apart from the sample. Figure 5 shows the profile of the image along the horizontal axis. We found that the width was about 1.5 mm which is very sharp and comparable to the size of the diameter of the paraffin tube (1 mm). The magnification of the neutron beam flux was estimated as follows: First the image was stored with Cd stopper in Fig. 1 which removes the signal of the incoherent scattering hitting directly on the image plate. Secondly the image was stored on another image plate without the Cd stopper. It means we obtained the unfocuced signal intensity as a constant back ground on the second image. The magnification of the neutron beam flux was obtained by comparing the focuced signal intensity to the unfocuced one measured as a constant back ground in the second image without Cd stopper. We found that the magnification of the neutron beam flux was about 150. From our knowledge, this value would be the world record for the magnification of a neutron beam flux by reflective neutron optical device. Therefore we conclude that this double bent PG has very good toroidal surface and it can be used as a condenser lens for high flux neutron beam. By improving the mosaic spread and the error of the curvature, we can expect an increase of the flux of the toroidal PG, which is a powerful tool as a neutron device for imaging as well as focusing of thermal neutrons.

§4. Conclutions

We have characterized the cylindrical shape toroidal bent PG with thermal neutrons. We obtained very sharp image (resolution typically 0.5 mm) and very good magnification of about 150 for thermal neutron ($\lambda = 1.54$ Å). This study demonstrates that the double bent PG is a powerful tool for neutron optical device.

1) For example, V.F. Sears: Neutron Optics, Oxford University Press, Oxford (1989).
2) M.R. Eskildsen, P.L. Gammel, E.D. Isaacs, C. Detlefs, K. Mortensen and D.J. Bishop: Nature **391** (1998) 563.
3) H.M. Shimizu, Y. Suda, T. Oku, H. Nakagawa, H. Kato, T. Kamiyama, C. Otani, H. Sato, T. Wakabayashi and Y. Kiyanagi: Nucl. Instr. and Meth. A **430** (1999) 423.
4) T. Oku and H.M. Shimizu: Physica B, to be published.
5) Nishiki *et al.*, unpublished.