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Performance Measurement of Beam Splitters and Mirrors for an X-ray Interferometer

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We are developing an X-ray interferometer with beam-splitters for future observation of celestial objects. We fabricated test beam-splitters and mirrors and measured their performances with a synchrotron source at KEK-PF. Obtained results of the mirrors are roughly consistent with the design values, but the reflectivity of the beam splitter is roughly half of the design value.

1 Introduction

A high resolution imaging observation of celestial objects with micro-arc-sec will open a new science of black holes. A direct imaging of the shadow of a black hole is a direct evidence of the existence of a black hole. The light bending effect is an evidence of the general relativity in the strong gravitational field. The shape of the shadow will relate to the spin parameter of black holes [1]. However, such high-resolution imaging cannot be achieved with an usual X-ray telescope. One possible way is an usage of an X-ray interferometer.

The idea of the X-ray interferometer for an observation of celestial objects has been examined from 1990s. Martin et al. (1990) [2] and Cash et al. (1997) [3] proposed it and Cash and his collaborators extensively studied and developed the X-ray interferometer for the observation of celestial objects[4]. Their idea was an imaging of the celestial objects, using two-dimensional interferences of X-rays. In their study, a very long length of the optics was required and formation flight of satellites was a desired important technique. Kitamoto et al. (2011) [5] proposed a new type of a simple X-ray interferometer with much smaller size and Kitamoto et al. (2012) [6] demonstrated a calculation of visibility patterns of shadows of black holes assuming an intensity profile of accretion disk with a simple and much smaller system. Therefore we are trying to develop such a simple X-ray interferometer. Also the aimed wave-length is set to be a soft X-ray region, for example O-K band, and this makes the required precision relax.

For this purpose. we fabricated a test mirrors and beam splitters. In this study we report the results of the measurement of their reflectivity and the transmission.

2 Experiment

Test X-ray mirrors and X-ray beam splitters are fabricated. Since these are designed for the laboratory experiment [6], the incident grazing angle is set to be both 10 deg, for the K lines from neutral O atoms. Their pictures are shown in figure 1. The mirrors are Mo/Si multilayers with their bi-layer thickness of 6.9 nm on a substrate of Si wafer. The size of the mirrors is 20 mm x 20 mm. The beam splitters are also Mo/Si multilayers with the same bi-layer thickness. The number of the bi-layer is 4. The multilayer is once fabricated on the Si wafer and then the wafer with 10mm x 10mm region was removed.

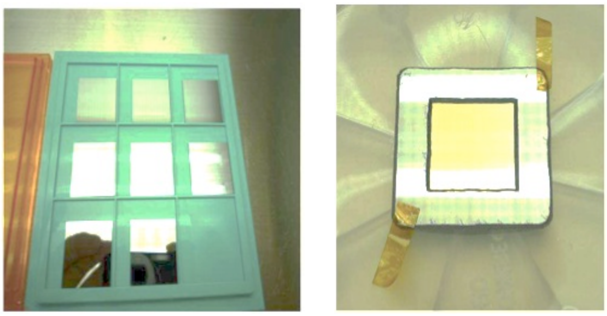

Fig. 1: The picture of test samples of mirrors (left) and a beam splitter (right).

The reflectivity of the mirrors and the reflectivity and the transmission of the beam splitter are measured by a synchrotron source at KEK BL 11A. Figure 2 shows a picture of the inside of our measurement chamber. A sample is installed on a translation table attached on two rotational tables, constructing a $\theta-2\theta$ table. On the arm of the 2θ table, a back illumination CCD is installed. After determination of the origins of the rotational angle of both the θ and 2θ table, the reflectivity and the transmission are measured.

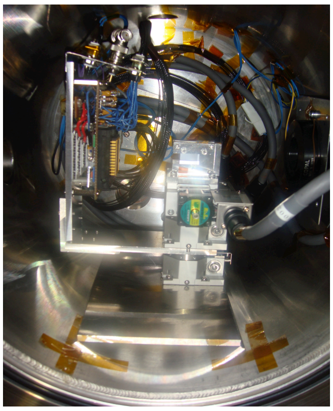

Fig. 2: A picture of inside of the chamber, used for the reflectivity and transmission measurement. A translate table is installed on a θ -2 θ table. A back illuminated CCD is used as a detector.

3 Results

The obtained reflectivity of the mirrors are plotted in figure 3, as well as the calculated reflectivity. The figure 3(left) shows the reflectivity of 2.34nm X-rays at the grazing angle from 6 deg to 14 deg, and the right figure shows the reflectivity of the X-rays from 1.0nm to 3.0nm at the grazing angle of 10.4 deg. The bi-layer thickness is adjusted to fit the data and the difference from the design value is 0.4nm. Reasonable agreement between the measured reflectivity and simulation was confirmed. The peak reflectivity is ~0.14 and the band path ($\lambda/\Delta\lambda$) (FWHM) is roughly 10.

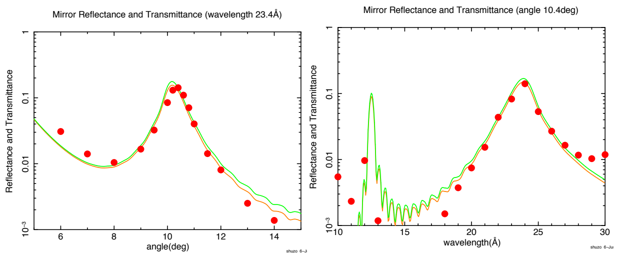

Fig. 3: Reflectivity of a sample mirror. The red circles are measured values and green and red lines are simulation of the P and S polarized beams. The left figure shows the reflectivity of a 2.34nm X-rays as a function of the grazing incident angle. The right figure shows that at 10.4 deg as a function of the wave-length. The bi-layer thickness was adjusted to fit the data.

The figure 4 shows the reflectivity and the transmission of the beam splitter, together with the simulation. The measurement was performed in the angle from 6 deg to 14 deg of 2.34nm X-rays and also performed in the wave-length range from 1.5nm to 3.0nm by fixing the grazing incident angle of 9.9 deg. The peak reflectivity is roughly 0.03 and this is roughly half of the design value. The transmission at the 2.34nm is roughly 0.06 and again a little smaller than the design value.

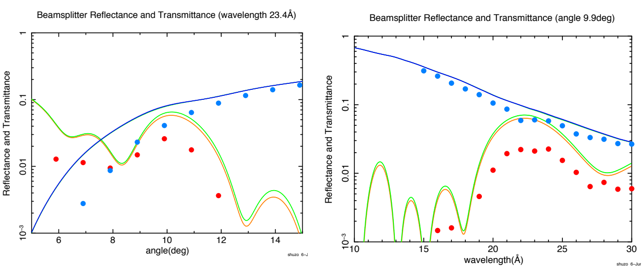

Fig. 4: Reflectivity and transmission of a sample beam splitter, as a function of the incident angle for 2.34 nm X-ray (left), and as a function of the wave-length at 9.9 deg (right). The red circles are measured values and green and red lines are simulation of the P and S polarized beams.

4 Discussion

We measured the reflectivity of the test mirrors and the reflectivity and the transmission of the test beam splitter and found that the reflectivity of the mirrors are almost consistent with the design values but the reflectivity of the beam splitter is roughly a half of the design value. This might be due to the roughness of the multilayers. However, we obtained actual values of the performance of the beam splitter.

Using these measured values we can evaluate an observation strategy. Kitamoto et al. (2014)[7] reported the estimation of the observation possibility of some celestial objects. Since theses interferometer requires small band pass, the collection of the photons is the most serious problem. Only some very bright X-ray stars can be candidates of observable objects with a reasonable effective area and exposure time. If we can use a high-energy resolution imager with ~4eV(FWHM) such as the SXS on board ASTRO-H, much more photons can be collected with a reasonble coherent length. Then a reasonable size of mirrors can be used and we can expect a possible observation to detect a fringe pattern for many of celestial objects.

Acknowledgement

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