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Nuclear Instruments and Methods in Physics Research A 505 (2003) 683–687

**NUCLEAR
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Section Awww.elsevier.com/locate/nima

Soft X-ray transmission of optical blocking filters for the X-ray CCD cameras onboard Astro-E 2

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Received 31 October 2002; accepted 4 February 2003

Abstract

We measured soft X-ray transmission of Optical Blocking Filters for Charge Coupled Device cameras, which will be launched as focal plane detectors of X-ray telescopes onboard the Japanese fifth X-ray astronomical satellite, Astro-E 2. The filters were made from polyimide coated with Al. The X-ray absorption fine structures at the K edges of C, N, O and Al were measured. The depth of the absorption edge of O was deep, compared to the other elements of polyimide. This is the evidence of the oxidation of Al.

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PACS: 95.55.Aq; 95.55.Ka; 07.85.Qe; 61.10.Ht

Keywords: X-ray; CCD; XAFS

1. Introduction

A Charge Coupled Device (CCD) is widely used as an X-ray detector [1–4] and has many wonderful advantages. As well as its good imaging capability with a resolution of less than 10 μm , it has the almost ideal energy resolution of a Si detector if it is used as a photon detector. We are

planning to install CCD cameras on the Japanese 5th X-ray astronomical satellite, Astro-E 2, which is now scheduled for launch in early 2005.

Since a CCD has high detection efficiency for optical and ultra-violet light, we will use an Optical Blocking Filter (OBF) in front of a CCD chip. The experimental calibration of the soft X-ray transmission of them is very important. Especially, the X-ray transmission properties around the absorption edges are complex [5,6], which is known as X-ray Absorption Fine Structure (XAFS).

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Unexpected high transmission of optical light compared to the design value has been reported [7,8]. There is a possibility that the oxidation of the Al makes filters transparent for optical light. Thus, the precise and quantitative confirmation of the oxidation is required.

We measured the soft X-ray transmission of flight candidates of the OBFs, paying attention to XAFS and the oxidation of Al.

2. OBFs for Astro-E 2

The Astro-E 2 satellite is a recovery satellite of Astro-E, which was launched on 10 February 2000 but could not enter a satellite orbit. Thus, the Astro-E 2 satellite was proposed and is scheduled for launch in early 2005. Because of this short time scheduling, the design of Astro-E 2 is almost the same as that of Astro-E. The design of the CCD cameras is also similar. The properties of the CCD camera for Astro-E can be seen in various reports [9–11], and some reports on the OBFs have also been published [8,12]. However, the measurement of soft X-ray transmission of the OBFs for Astro-E was not sufficient and it was necessary to combine the results of the other experiments such as ACIS onboard Chandra [6]. For Astro-E 2, we had the opportunity to measure the details of the soft X-ray transmission using synchrotron radiation.

The OBFs, which were made by Luxel Co. LTD, are composed of a thin polyimide (C₂₂H₁₀O₄N₂) film sandwiched by Al. Four cameras will be installed on the Astro-E 2 satellite and we have six OBFs including spares. Three films were made. Two pieces were cut from each film and were attached to two custom frames. The thickness measured by Luxel Co. LTD is summarized in Table 1. The polyimide is composed of carbon (C), nitrogen (N) and oxygen (O), as well as hydrogen

Table 1
Thickness of the materials of three films

Film ID	Al (Å)	Polyimide (Å)	Al (Å)
8913-2	414±50	978±100	812±50
8929-1	400±50	1065±100	816±50
8929-2	400±50	1031±100	816±50

(H). Thus, we have to measure XAFS of Al, O, N and C.

3. Measurement

The measurement was performed at Beam line 11A of the Photon Factory in the Institute of Material Structure Science, High Energy Accelerator Research Organization (KEK-PF). In this beam line, a grazing incident monochrometer is installed with varied-line-spacing plane gratings [13–15]. By changing the grating, this beam line can provide soft X-rays from 90 to 1900 eV covering the C-K, N-K, O-K and Al-K edges. Three setups were used in our measurement and the conditions are summarized in Table 2. When we measured the transmission around the C-K, N-K and O-K edges, we used a Ni double-mirror system to eliminate the higher-order light.

The measurement configuration is schematically shown in Fig. 1. The beam intensity emerging from the monochrometer (after the Ni double-mirror system) was monitored by measuring the current of the photo-electrons from an Au-coated W mesh, which was installed in front of the samples. The beam was restricted by a slit, resulting in a beam size of 2 mm × 5 mm. The OBFs were installed on rotational axles and the OBFs could be put in or out of the beam. A window-less photodiode (AXW-100 TS) was used as a detector and its current was measured. A window-less Si(Li) detector cooled by LN₂ was also used to check the energy spectrum of the beam.

The transmission of an OBF was calculated as a ratio of currents measured with a photodiode with the OBF and one without it after normalizing by the current of the photo-electrons from the

Table 2
Measurement setups

Energy range (eV)	Grating (l/mm)	Incident angle (deg)	Double mirror system
150–450	300	86.9	Ni filter, 5.5 deg
450–700	800	86.9	Ni filter, 4.0 deg
800–1800	800	88.1	no

Fig. 1. Schematic view of the experimental configuration. The top view is drawn.

Fig. 2. Soft X-ray transmission of six OBFs. The transmissions are the same within $\pm 1\%$.

Au-coated W mesh. The calibration of the absolute photon energy was conducted using a K-edge of the 4- μm -thick pure Al for the 800–1800 eV setup. For the other two setups, C-K edge energy of 7 μm kapton film was used. These were adjusted to 1559 and 284 eV, respectively, with an accuracy of ~ 1 eV. Derived X-ray transmission is shown in Fig. 2, where the transmissions of six filters are compiled. The X-ray Absorption Fine Structures (XAFSs) around the K-edges of Al, O, N and C were clearly measured. The X-ray transmissions of the six filters are almost same within $\pm 1\%$.

4. Results and discussion

4.1. Overall structure

To analyze the overall structure, we first fitted the transmission, masking the regions of the

Table 3
Best-fit model parameters

OBF ID	Polyimide ($\text{\AA}$)	Al ($\text{\AA}$)	Al ₂ O ₃ ($\text{\AA}$)
8913-2	1371	1251	
8913-2-2	1367	1257	
8929-1	1421	1231	
8929-1-2	1367	1222	
8929-2	1355	1255	
8929-2-2	1350	1249	
Average	1361 ± 4	1247 ± 2	
Average	1284 ± 5	1162 ± 4	109 ± 4

complex XAFSs, by a two materials model composed of polyimide and Al using the available absorption coefficients [16]. The thickness of the polyimide and the Al are determined and listed in Table 3, where we assume the densities of Al and polyimide are 2.699 and 1.43 g cm⁻³, respectively. The thickness of the Al is consistent with the Luxel values but the thickness of the polyimide is significantly thicker. Since the transmissions of the six OBFs are very similar, we calculated the average and the standard deviation. The maximum of standard deviations is 0.56% and most of them are distributed between 0.2% and 0.5%. Thus, we assumed the error of 0.5% uniformly, and fitted the average transmission by the two materials model. The top panel of Fig. 3 shows the average transmission and the best-fit model. The residuals (data-model) are plotted in the middle panel of Fig. 3. The best-fit thickness is listed in Table 3.

The residuals, shown in the middle panel of Fig. 3, indicate the edge depth of O of the data is deeper than that of the model, whereas the depths of the C and N are shallower. This means the

existence of extra oxygen in addition to the contents of the polyimide. One possibility for this is the oxidation of Al, which has been pointed out in previous works [7,8]. Therefore, we fitted the

Fig. 3. Average soft X-ray transmission. The top panel shows the data and the best-fit curve of the two materials model composed of polyimide and Al. The middle panel shows the residuals of the data from the two materials model. The bottom panel shows the residuals from the three materials model composed of polyimide, Al and Al_2O_3 .

data by the three materials model composed of polyimide, Al and Al_2O_3 , where the density of Al_2O_3 is assumed to be 3.97 g cm^{-3} . The residuals are shown in the bottom panel in Fig. 3. Due to the extended X-ray absorption fine structures, the residuals are still wavy but the overall edge depths become more refined. The best-fit thickness is listed in Table 3. Although the thickness of Al is consistent with the Luxel value, the obtained thickness of the polyimide is still thicker than the Luxel values.

4.2. XAFS

XAFS of C, N, O and Al are measured and shown in Figs. 4(a)–(d). The structures of six filters are very similar. The wavy transmission below 250 eV, as seen in Fig. 2, is due to the extended X-ray absorption fine structure (EXAFS) of the Al L-edge. The detail of XAFS analysis is beyond of this work. Since the structures are the same within $\pm 1\%$, and considering the energy resolution of the CCD of $\sim 50 \text{ eV}$ at the O-K edge [6,11], the average of the six OBFs provides a sufficient transmission model of the OBFs, including the complex XAFSs.

Fig. 4. XAFS of (a) Al, (b) O, (c) N and (d) C.

5. Conclusion

We measured the soft X-ray transmission of the optical blocking filter for the CCD cameras onboard Astro-E 2. Six filters were almost of the same transmission within $\pm 1\%$. Thus, the average data provided a good model transmission including XAFS. Small gaps of the measurement could be interpolated and the energy region above 1800 eV could be extrapolated using the best-fit model. We found the existence of the extra O by the comparison of the depth of the absorption edges, comparing the two materials model composed of polyimide and Al. This discrepancy can be reconciled by introducing the Al_2O_3 .

Acknowledgements

Three of the authors (S.K., K.H. and T.K.) gratefully acknowledge the financial support of the Grant-in-Aid for Scientific Research (Grant Nos. 14654039 and 14654047) and that of the Japan Society for the Promotion of Science for Young Scientists. The present work has been performed under the approval of the Photon Factory Program Advisory Committee (PF-PAC No. 2002G038).

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