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Performance of the YB_{66} soft X-ray monochromator crystal at the wiggler beamline of the UVSOR facility

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Soft X-ray spectra have been measured using a pair of YB_{66}(400) monochromator crystals at the double-crystal monochromator beamline BL7A of the UVSOR facility, where the wiggler radiation has a magnetic field of 4 T. Deformation of the YB_{66} crystal due to heat load from the synchrotron radiation is almost negligible. The photon flux is about 10^8 photons s^{-1} $(100\ mA)^{-1}$ in the energy region 1.2–2 keV and the energy resolution is 0.7 ± 0.1 eV around $h\nu = 1.5$ keV. These results show that the YB_{66} crystal is suitable for use as a monochromator crystal. Its application to soft X-ray spectroscopy is discussed.

Keywords: soft X-ray beamlines; YB_{66} crystals; double-crystal monochromators; wigglers.

1. Introduction

YB_{66} [$2d$ = 11.76 Å for (400) reflection] is known to be one of the best monochromator crystals covering the soft X-ray region from 1.1 to 2 keV, with high performance (Wong *et al.*, 1990) such as high-energy resolution, no absorption structures originating from the elements of the crystal in the photon energy range, resistance to radiation damage *etc.* So far, only the SSRL (Stanford Synchrotron Radiation Laboratory) group has used a YB_{66} crystal (Rowen *et al.*, 1993), since there are several difficulties associated with the use of YB_{66} crystals in synchrotron radiation facilities. One of the difficulties is that a single crystal of sufficient size has not, until very recently, been available. The other difficulty is that such a crystal has a very low thermal conductivity and is easily deformed by the high heat load from synchrotron radiation from a high-energy machine. Even in the SSRL facility, there seems to be some difficulty in using the crystal for spectroscopy experiments because of the heat load.

The storage ring of the UVSOR facility is operated at a rather low energy (750 MeV) and is expected to produce a lower heat load than a high-energy machine. For example, at the double-crystal monochromator beamline BL11B of the Photon Factory (2.5 GeV), the power density was estimated as 3.3 W mm^{-2} on the first crystal (Funabashi *et al.*, 1989). However, the density in the present case is less than 0.03 W mm^{-2}. A wavelength-shifter-type wiggler with a 4 T magnetic field (Nakamura *et al.*, 1996) is installed at the UVSOR beamline BL7A (Murata *et al.*, 1992) to provide a high photon flux in the soft X-ray region. This prompted us to examine the performance of a YB_{66} monochromator crystal at the UVSOR facility. The crystal ($10 \times 20 \times 1$ mm size) is a commercial product, synthesized by Crystal Systems Inc., Yamanashi, Japan.

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2. Overview of the wiggler beamline at UVSOR

Fig. 1 shows a schematic view of the double-crystal monochromator (DXM) beamline BL7A. The superconducting magnet wiggler is installed in the straight section upstream of the bending-magnet section B7. When the higher-energy light from the wiggler is used with crystals such as InSb(111) and Ge(111), the beamline is fixed just downstream of the straight section (0° line). In the case of synchrotron radiation from the bending section, the DXM accepts synchrotron radiation emitted at a point on the electron orbit that is 2° downstream of the edge of the bending section. In order to avoid radiation damage to the insulator crystals of, *e.g.* beryl and quartz (energy being covered 0.8–2 keV), we use bending-magnet radiation. Between the use of wiggler radiation and bending-magnet radiation, the beamline set-up is changed from the 0° line to the 2° line. YB_{66} is a semiconductor and may be better at withstanding radiation damage than insulator crystals. If we succeed in using a YB_{66} crystal in the lower photon energy region, it will not be necessary to change the beamline between the wiggler and bending lines. This will enable us to provide high-performance beamtime to users.

3. Performance of the YB_{66} monochromator crystal

Fig. 2 shows the throughput of the monochromator with the use of YB_{66}(400). The absolute value of the photon flux was obtained by measuring the photocurrent from a Si photodiode (Interna-

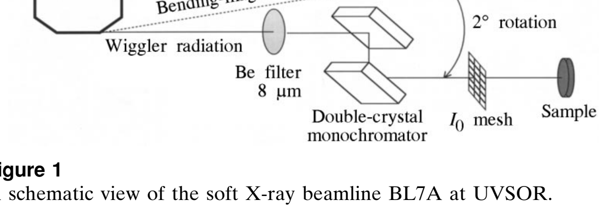

Figure 1
A schematic view of the soft X-ray beamline BL7A at UVSOR.

tional Radiation Detectors Inc., USA) whose quantum efficiency has been calibrated absolutely. When radiation from the wiggler is used, the photon flux is approximately 10^8 photons s^{-1} (100 mA)$^{-1}$. The decrease in the flux at lower photon energy is due to the cut-off of the Be foil. A flux of 10^4–10^7 photons s^{-1} (100 mA)$^{-1}$ is obtained with bending-magnet radiation.

The X-ray absorption fine-structure (XAFS) spectra for Mg and Al oxides in Fig. 3 were measured by the total photoelectron yield method as described previously (Murata *et al.*, 1992). The step width of the monochromator scanning was 0.01°, which corresponds to about 0.15 eV at $h\nu$ = 1310 eV. The reproducibility of energies was within the step width. The spectra obtained using the YB_{66} crystal show almost the same features as those obtained using beryl and quartz crystals. During the spectroscopy measurements, we also checked the effects of the heat load. We monitored the beam intensity at the sample position and tuned the angle of the second monochromator crystal to maximize the intensity. The angle deviation originating from the change of the lattice spacing in the first crystal was estimated by measuring the deviation of the tuning angle of the second crystal. The angle correction due to the heat-load effects was estimated to be less than 0.01°, which corresponds to energy shifts of less than 0.15 eV around $h\nu$ = 1.3 keV. The value of the energy shift is much less than that in the SSRL, where an approximately 3 eV shift is reported (Wong, private communication). It is concluded from the above result that the effect of heat load at BL7A is almost negligible for spectroscopy measurements.

We have tried to measure the rocking curves of the YB_{66} crystal by rotating the second crystal in order to estimate energy resolution (not shown here). The rocking curves showed some multi-structures and were wider than those reported before (Rowen *et al.*, 1993). This may result from the multi-domain structures of the crystal, as will be discussed below. If we assume the multi-structures are a convolution of single peaks, the width of each single peak is estimated to be about 0.7 ± 0.1 eV around $h\nu$ = 1.5 keV. This value is equal to the deconvoluted value of the photoemission resolution discussed in §4 and almost comparable with that in the SSRL beamline under standard conditions. We have also observed the image of output light with the fluorescence screen. The image was not homogeneous. These results mean that the crystal is not an ideal single crystal, but instead consists of multi-domains. The effect of the multi-domains is not a serious problem. For example, we have obtained reasonable spectra [except for the problem of the (600) reflection as described below] with higher-energy resolution than that of a beryl crystal, as shown in Fig. 3. If we could obtain a crystal with a single domain, the intensity and resolution may be improved.

These results show that the YB_{66} crystal is suitable for use as a monochromator crystal. However, there remains another problem which needs to be solved in order to use the YB_{66} crystal for spectroscopy. The problem is that two positive glitches at 1385.6 and 1438 eV are observed in Figs. 2 and 3(*a*). These glitches are known to be due to the sharp reflectivity increase associated with anomalous scattering of the (600) reflection at the Y $L_{2,3}$-edges (Tanaka *et al.*, 1997). The original [(400) reflection light] peaks are also observed in Fig. 2 at 2080 and 2156 eV, respectively. In order to record more precise extended XAFS spectra, the high-energy component of the light must be reduced for the next step of the beamline improvement. We plan to install a pair of pre-focusing mirrors coated by Si between the Be window and the front end. The Si-coated mirror system is expected to be useful not only as a focusing system but also as a high-cut filter.

4. Application to spectroscopy

We have applied the light monochromated with the YB_{66} crystal not only to measurements of absorption spectroscopy but also to photoemission measurements. We present here, as an example, the resonant photoemission study of heavy rare-earth compounds (Kinoshita *et al.*, 1998). Although the photon intensity is not great enough, the photoemission study becomes possible by using a high-performance electron analyser (Fisons, ESCALAB220i-XL).

Fig. 4 shows the 3*d*–4*f* resonant photoemission result for TmSe, which is typically known to be a material of mixed valency. Despite the advantages of studying 3*d*–4*f* resonant photoemission for heavy rare-earth compounds, in addition to 4*d*–4*f* resonance, only a few investigations have so far been performed. The reason why such experiments are difficult is that grating monochromators cannot cover such high-energy light with high-energy resolution and high intensity. As shown in Fig. 4, the spectra have

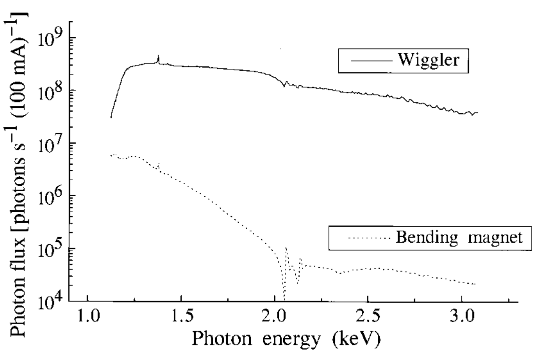

Figure 2
The throughput of the double-crystal monochromator with YB_{66}(400). Radiation from the wiggler and the bending-magnet section is used.

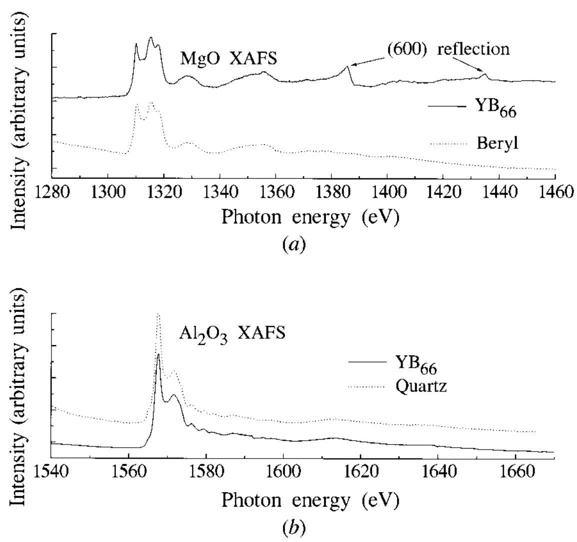

Figure 3
(*a*) Comparative X-ray absorption spectra of MgO around the Mg *K*-edge taken by YB_{66} and beryl crystals. (*b*) Comparative X-ray absorption spectra of Al_2O_3 around the Al *K*-edge taken by YB_{66} and quartz crystals.

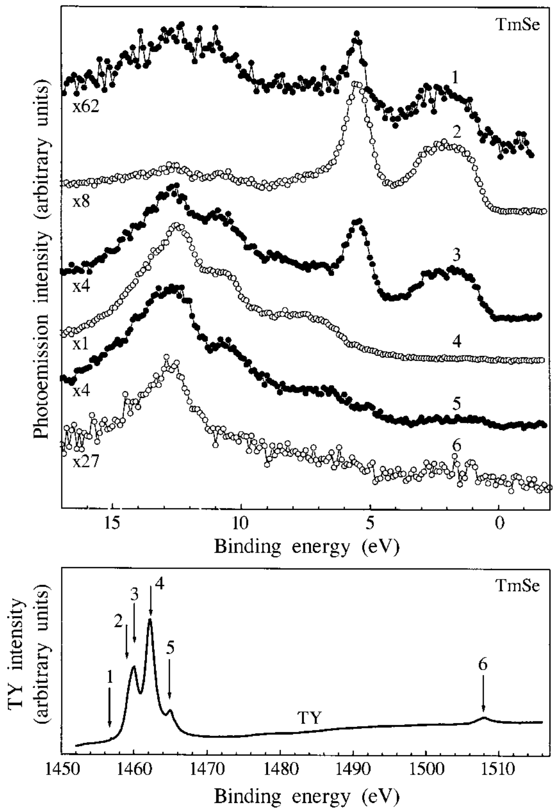

Figure 4
The photoemission spectra of TmSe at an excitation photon energy of the 3*d*–4*f* resonance region. The photoemission spectra were measured at the photon energies of the points indicated by arrows in the absorption (total photoelectron yield; TY) spectrum (bottom).

been obtained with a resolution of 0.9 $\pm$ 0.1 eV and a reasonable S/N ratio in the photon energy region 1.45–1.52 keV. The resolution of the data seems to be better than that obtained for a $TmAl_2$ sample with a beryl monochromator crystal (Laubschat *et al.*, 1990), especially in off-resonant conditions. It is clearly observed that the divalent peaks (located at a binding energy less than 5.6 eV) and the trivalent peaks (located at a binding energy greater than 5.6 eV) show resonance at different excitation energies.

5. Conclusions

We have succeeded in measuring soft X-ray spectra using the YB_{66} monochromator crystal at the DXM beamline BL7A of the UVSOR facility. The combination of the YB_{66} crystal and the wiggler at such a low-energy storage ring performs well in soft X-ray measurements. The YB_{66} crystal may be very valuable for use in future studies of soft X-ray spectroscopy at UVSOR. The YB_{66} crystal has already been used by some users. Photoabsorption and photoelectron spectroscopy experiments in such a photon energy region are now possible.

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