Soft X-ray Emission Spectrometer Equipped with a Multilayer Rotating Analyzer for Study of the Polarized Emission

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Soft x-ray emission spectrometer equipped with a multilayer rotating analyzer for study of the polarized emission

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A soft x-ray emission spectrometer equipped with a multilayer rotating analyzer has been made. The spectrometer covers an energy range of 50–500 eV with a resolution power of about 300. Using the rotating analyzer we have measured the polarization of the B *K* emission of *h*-BN, and have found that it is dominantly polarized perpendicularly to the *c*-axis, which agrees well with the experimental result. © *1995 American Institute of Physics.*

I. INTRODUCTION

Soft x-ray emission (SXE) spectroscopy is a useful method for studying the electronic structure of occupied states of solids and the relaxation process of the inner core states. Recently Ma *et al.*[1] found definite dependence of the C *K*-emission spectra of diamond on the excitation energy, and proposed from the crystal momentum conservation that the absorption-emission process should be treated as a coherent inelastic scattering process. This is essentially identical with the resonant Raman scattering process. In analogy to the ordinary Raman scattering we should examine the polarization of the SXE's with linearly polarized incident photons. On the other hand, the large majority of the 1*s* holes of low *Z* elements are subject to the nonradiative Auger decay. Their lifetime is as short as the order of femtosecond, which suggests that the radiative decay will exhibit unrelaxed intermediate states. Besides, anisotropic structure of a valence band will show polarized emission. Therefore, the challenging SXE polarization measurements will provide new information on the relaxation processes.

We have so far developed multilayer mirrors for SXR's, and are able to fabricate those practically applicable at about 180 eV. We ascertained that the multilayer coatings are the most useful polarizing elements in the SXR region in the vicinity of 45° angle of incidence, i.e., the Brewster angle.[2] Kimura *et al.*[3] have successfully applied a rotating analyzer mounted with a SXR multilayer for evaluating precisely the polarization properties of synchrotron SXR's emerging from a monochromator. Though intensity of the SXE would be considerably low, we can measure its polarization degrees owing to the advantage of the SXR multilayer reflectors.

In order to study the polarized emission, we recently made a new instrument composed of a SXE spectrometer and a multilayer rotating analyzer. Using this instrument we carried out experiments for the B *K* emissions of some boron compounds, and observed definite polarization. In the following sections the details of the SXE spectrometer and the rotating analyzer are described, and preliminary results of the SXE experiments for *h*-BN are also presented.

II. SXE SPECTROMETER

Figures 1(a) and 1(b) show plane view and side view schematics of the SXE spectrometer equipped with a rotating analyzer. For convenience the spectrometer and the analyzer are illustrated to work simultaneously. During the mode of spectrum measurement the analyzer was shifted upward with a rotation/translation feedthrough. The details of the analyzer are given in the following section. The spectrometer consists of a slit, a varied-spacing concave grating, and a multichannel detector, all fixed to an optical base made of aluminum. The sample was slightly pushed against the slit from its left-hand side with a manipulator. As is shown, the sample was irradiated at an angle of incidence of 45° through the slit of 0.25-mm width, and the emission was observed in the normal direction. The slit was thus an effective source for the spectrometer. Excitation beam should be incident into the slit opening, which made the optical alignment quite easy. In practice, we measured SXE of the sample with the slit, and that without the sample as the background, and then obtained a spectrum for the sample by background subtraction. The concave grating (Hitachi 001-0437) is specifically designed for a grazing-incidence flat-field spectrograph.[4] It has a 1200 grooves/mm density at the center on a 5649 mm radius of

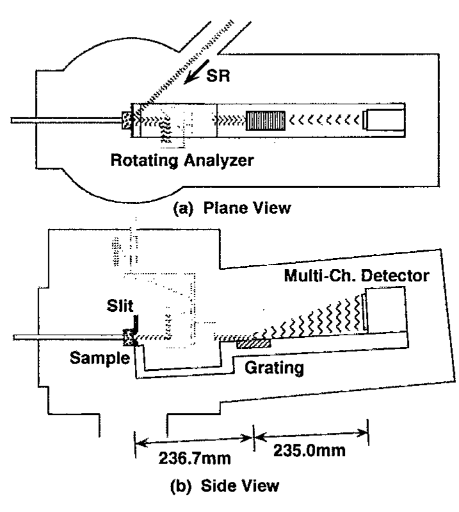

FIG. 1. Plane view (a) and side view (b) schematics of the spectrometer equipped with the rotating analyzer.

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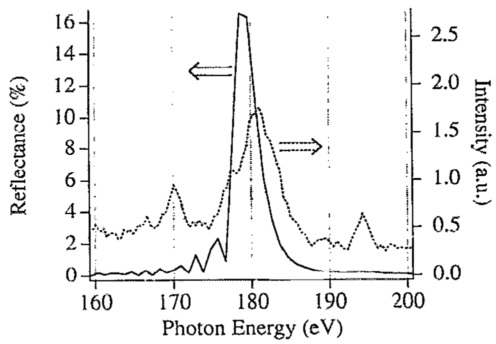

FIG. 2. Spectral reflectance of the Ru/B_4C multilayer measured at 45° angle of incidence (solid curve) and the B *K* emission spectrum of *h*-BN excited at 194 eV (dotted curve).

curvature. It was fixed to the optical base so that its face might exactly coincide with the upper face of the base. For the incidence angle of 87.0° the distance from it to the slit and that to the detector is 236.7 and 235.0 mm, respectively. As is seen from these dimensions the spectrometer was designed to be very compact. The detector was a vacuum-compatible VUV multichannel detector (Hamamatsu Photonics, C2321-01) composed of a microchannel plate (MCP), a fiber optic, and a plasma-coupled device. The device has 1024 channels along the active area of 51.2 mm length by 5 mm width. Thus its spatial resolution is about 50 μm. Based on the channel density we estimated the resolution power of the spectrometer. It was found that using the second-order spectrum the resolution power was about 300 over the spectral range of 50 to 500 eV. It would be enough to examine the SXE spectra for the polarization studies.

III. SXR MULTILAYER ROTATING ANALYZER

The outline of the rotating analyzer unit is illustrated in Fig. 1. The unit is composed of a SXR multilayer tilted at 45° to its rotation axis,[3] which was directed towards the emission point. The azimuth angle was defined with the rotation around the axis driven with a vacuum-compatible stepping motor. In order to raise the accuracy of the 45° angle of incidence, a 4- mm-diameter slit was attached at the entrance of the analyzer. The distance from the sample was about 30 mm, providing an accuracy of 4°. The analyzer is movable around the sample in the horizontal plane. The polarization of the emission was measured when positioned in front of the sample, as is shown in Fig. 1, while that of the incident beam, passing through the slit, was measured when positioned on its path. A Ru/B_4C 199 layer coating fabricated using a magnetron sputtering system was used in this study. Its spectral reflectance measured for *s* polarization at 45° angle of incidence is shown in Fig. 2 with a solid curve. The peak reflectance was found to be 16% at 180 eV and the FWHM was ~4 eV. In Fig. 2 is also shown with a dotted curve the B *K*-emission spectrum of *h*-BN obtained in this study. The peak at 194 eV is due to the scattered excitation light, which is filtered off with the multilayer.

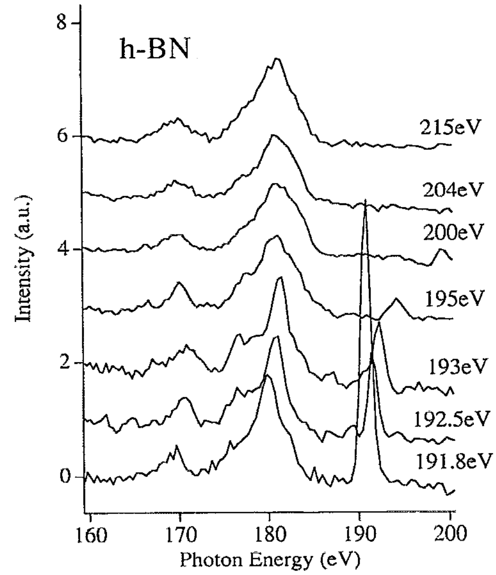

FIG. 3. B *K* emission spectra of *h*-BN excited at several photon energies.

IV. EXPERIMENTS FOR THE B *K* EMISSION OF *h*-BN

We chose hexagonal BN in this study because *h*-BN has been well studied for its layer structure.[5–7] *h*-BN samples were prepared by hot press from original powder of 99.7% purity. Using an x-ray diffractometer the highly oriented *c* axis was ascertained. The luminescence experiments were carried out on BL-3B at the Photon Factory, where the radiation from a normal bending magnet was monochromatized with a 24 m spherical grating monochromator.[8] It provided 10^{11}–10^{12} photons/s with ΔE=0.5 eV. The degree of linear polarization of the emerging beam was optimized up to ~67% (horizontal to vertical polarization=~5:1) at 180 eV using the multilayer analyzer.

V. RESULTS AND DISCUSSION

A. B *K*-emission spectra

Figure 3 shows the B *K*-emission spectra of *h*-BN excited at several photon energies. For profile comparison the height of the emission spectra is made equal to each other. The large peak at about 180 eV is due to the B 2*p*, while the peak at 170 eV is due to the N 2*s* component. The emission spectrum of 193 eV excitation shows sharp peaks at 182 and 178 eV, which agrees well with the result of the calculation.[9] The peaks become broad with increasing excitation energy. This result might be explained using the coherent inelastic scattering model.[1] Quantitative investigation on the joint density of state[10] is needed. From the aspect of the excitation to π orbitals the 193 eV region is interesting. However, no spectra have been measured because of the low emission intensity.

B. Polarized emission

In the upper part of Fig. 4 is shown the output of the rotating analyzer as a function of its azimuth angle measured for the B *K*-emission of *h*-BN when excited at 194 eV with

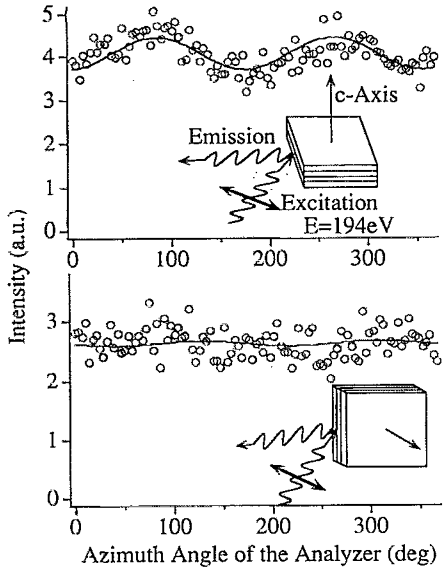

FIG. 4. Output intensity of the rotating analyzer vs azimuth angle measured for the B K emission of h-BN with the c axis oriented as shown in the insets.

the c axis vertically oriented as is illustrated in the inset. As is seen, the emission is definitely polarized, ~10%, in the same phase with the incident SXR's. The polarization originates most probably from the p_{xy} orbitals of the valence band experimentally studied by Tegeler *et al.*[5] Besides, we observed that the polarization increases with increasing excitation energy up to 70 eV above the absorption threshold. This fact confirmed that we observed no scattered light. The excitation energy dependence seems to arise from modulation of the core-hole lifetime. On the other hand, polarization was not observed when the c axis was oriented horizontally as is shown in the lower part of Fig. 4. One possible reason would be that the dominant polarization due to the p_{xy} orbitals was cancelled with that due to the p_z orbitals enhanced by the effect of the coherent inelastic scattering proposed by Ma.[1] The origin has been still under investigation.

IV. SUMMARY

We have made a compact-size SXE spectrometer equipped with a multilayer rotating analyzer. The spectrometer covers the energy range from 50 to 500 eV with the resolution power of about 300. Using this instrument we have studied the B K emission of h-BN and have obtained the following results.

(1) The K emission spectrum shows a sharp structure just above the absorption threshold, which agrees with the calculation.

(2) The K emission is dominantly polarized perpendicularly to the c axis.

(3) The polarization increases with increasing excitation energy.

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