A VUV beamline (ABL-3B) for real-time photoelectron spectroscopy at the NTT synchrotron radiation facility

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A VUV beamline (ABL-3B) for real-time photoelectron spectroscopy has been developed at the normal-conducting accelerating ring (NAR) of the NTT synchrotron radiation facility. To accept the incident synchrotron radiation beam with the wide horizontal divergence angle of 20 mrad, a 1.38-m-long cylindrically bent front mirror was devised. This mirror was composed of four plane mirror blocks connected together and mounted on a steel holder beam having a C-shaped cross section. The mirror holder can be bent by a novel bending device with a momentum of 1388 kg cm to achieve the optimum radius of the curvature of 63.9 m. The focused spot of 3.5 mm (H)×1.8 mm (V) was preliminarily obtained on the sample position by bending the front mirror. When the stored electron beam current was 50 mA and the “grasshopper” monochromator was tuned at 130 eV, a photon flux of 1.5×10^{19} photons/s was obtained with the energy resolution of 0.5 eV.

1. Introduction

Synchrotron radiation (SR) photoelectron spectroscopy (SRPES) has been one of the most powerful tools for studies of solid state physics and chemical state analysis of surfaces and interlayers [1]. In particular, real-time SRPES measurements can provide direct information about crystal growth processes. To improve the advantage of real-time SRPES, it is essential to make a beamline that can provide a sufficiently intense monochromatized beam. For real-time SRPES of various samples of semiconductor materials such as GaAs and Si, an incident photon flux of more than 5×10^{10} photons/s has been estimated to be necessary in order to obtain a photoelectron signal intensity of 1000 cps by means of a hemispherical analyzer with a time resolution of 100 ms.

To investigate the crystal growth process of semiconductor materials, we have designed and constructed a vacuum ultraviolet (VUV) beamline, ABL-3B, for real-time SRPES at the normal-conducting accelerating ring (NAR) [2] of the NTT synchrotron radiation facility [3]. This NAR can be considered to be a compact SR ring, because the stored electron beam energy is 0.8 GeV and the critical photon energy is about 600 eV. One of the advantages of a compact ring is that the front focusing mirror can be located closer to the SR source. This means that a wide horizontal acceptance of SR beam can be achieved using a 1-m-long front mirror even with a grazing incidence.

This paper describes the design and the initial operation of the beamline, focusing on the devised front focusing mirror.

2. Beamline layout

A horizontal view of the beamline and a schematic drawing of the beamline optics are shown in Fig. 1. The beamline was designed to be as compact as possible, because of spatial restrictions. The main components are a front-end section of the bending magnet source, a front focusing mirror, a “grasshopper” monochromator, a rear focusing mirror, and an apparatus for optical evaluation. In the front-end section, an absorber and a water-cooled beam mask are located upstream of a radiation shielding wall installed at the 1.9-m position from the source center. The beam mask limits the divergence angle to 20 mrad horizontally and 1 mrad vertically. A pneumatic valve acting as a beam shutter and a fast-closing valve is placed downstream of the shielding wall. The acoustic delay line usually installed in the front-end section of ordinary beamlines can be eliminated, because the vacuum chamber of the front focusing mirror has a large volume of 2.2×10^{5} cm^3 and functions as the acoustic delay line. The front focusing mirror (M0) is a cylindrically bent mirror installed at the 3.3-m position, as 1:1 configuration between the source center and the exit slit (S2) in order to suppress horizontal coma aberration. The
incident beam is horizontally deflected, and the γ-ray beam generated from the mirror can also be separated from the SR beam by the M0 mirror. To accept a wide horizontal divergence angle of 20 mrad with an incident angle of 87°, the length of the M0 mirror should be 1.38 m. The radius of curvature can be optimized to 63.9 m by a novel bending device to focus the incident beam onto the exit slit. The mechanical details of this front focusing mirror and its bending device are discussed in the next section.

After the SR beam passes through the adjustable aperture at the 4.7-m position, it enters into a "grasshopper" monochromator [4] at the 6.0-m position. The front mirror (M1) in the monochromator is an elliptically bent mirror to vertically focus the beam onto a codling slit (M2/S1) without any vertical coma aberrations. A conventional 2-m spherical replica grating is mounted on the monochromator. A toroidal mirror (M3), 300 mm (L) × 30 mm (W) × 10 mm (T), is located at the 7.7-m position as a rear focusing mirror. This M3 mirror is placed in the 1:1.2 configuration between the exit slit and the sample position to obtain a well-focused beam spot on the sample position. Its radii of curvature are 57 mm for horizontal focusing and 20800 mm for vertical focusing. All of the mirrors are platinum-coated mirrors with fused quartz substrates. A gold-mesh beam monitor (10) and a gas cell for resolution measurements are installed downstream of the M3 mirror. The gas cell consists of a nozzle for gas injection and a channeltron for photoionization ion detection. We used photoionization yield spectra of rare gases measured with this gas cell to evaluate the energy resolution of the monochromatized SR beam.

The gas cell also functions as a differential pumping system. An experimental apparatus for real-time SR-PES and for molecular beam epitaxy (MBE) will be connected to the beamline. The vacuum of the apparatus during MBE and of the gas cell during the photoionization yield measurements reaches the order of 10^-7 mbar.

Fig. 2. Mounting of the mirror blocks on the C-shaped holder beam.

Fig. 3. Schematic drawing of the front focusing mirror and the bending devices.
of $10^{-6}$ Torr, so a differential pumping system is needed to maintain the beamline vacuum of $10^{-9}$ Torr and to protect the ultrahigh vacuum of $10^{-10}$ Torr in the NAR.

3. The front focusing mirror and its bending device

The 1.38-m-long front focusing mirror is composed of four plane mirror blocks, connected together and mounted on a steel holder beam having a C-shaped cross-section as shown in Fig. 2. A conventional H-shaped holder [5] is not suitable for accepting the wide horizontal divergence SR beam, because the flexural stress of the H-shaped holder exceeds the allowed stress of the stainless steel when the horizontal acceptance angle is more than 10 mrad and the radius of the curvature is less than 100 m. The blocks of the plane mirror are 342.5 mm (L) × 50.0 mm (W) × 5.0 mm (T), and the surface roughness is less than 5 Å. The cross-sectional size of the C-shaped holder beam and the thickness of the mirror was determined in order to make the flexural rigidity ratio between the holder beam and the mirror more than 200. The mirror blocks are clamped on the holder by steel rods on which a cooling-water pipe made of copper is attached.

Fig. 3 shows a schematic drawing of the bending device of the front focusing mirror. The mirror holder including the mirror blocks can be bent by equal but opposite moments which are produced by two pairs of fulcrum rods. The mirror holder is supported on a stage by the fixed fulcrums (a, a') located behind the both ends of the holder. A T-bar rod on which other fulcrums (b, b') are attached is placed in front of the holder. The SR beam passes between the T-bar rod and the mirror holder. The mirror holder can be pressed by the T-bar rod driven by a pulse motor through a steel wire. By using 1388 kg cm for the momentum between the pair of fulcrums (a-b and a'-b'), we can calculate that the mirror holder can be bent to a cylindrical shape with the optimum radius of the curvature of 63.9 m. The stage can be moved by

![Diagrams showing beam spots before and after bending](image)

**Fig. 4.** Beam spots on the sample position (a) before and (b) after bending of the front focusing mirror, including the horizontal and vertical profiles measured with an optical densitometer.
horizontal translation, roll, and pitch by pulse motors to align the mirror. The bending and alignment motions can be fully computer-controlled.

4. Initial operation of the beamline

Fig. 4 shows SR beam spots of the zeroth-order diffraction on the sample position, including the horizontal and vertical profiles measured with an optical densitometer. Before the front focusing mirror is bent, the horizontal spot size (FWHM) is 10 mm and the vertical is 3.7 mm. The horizontal size directly reflects the exit slit length. After the bending with the optimum radius of the curvature, the horizontal size narrows to about 3.5 mm and the vertical size narrows to 1.8 mm. The horizontal profile shows that the SR beam is concentrated on the center of the optical axis. Although the focused spot size has not been thoroughly optimized yet considering the horizontal source size of $\sigma_x = 0.45$ mm, the obtained spot size seems to be sufficiently small for the real-time SRPES measurements. The profile also indicates that there is no scattering at the joints between the mirror blocks. The narrowing of the vertical size might be explained by the focusing of the toroidal M3 mirror. It is well known that vertical focusing is coupled to horizontal focusing in a toroidal mirror system. The arrangement of the M3 mirror is optimized to focus the exit slit image on the sample position. Therefore, the well-focused vertical spot would be obtained when the SR beam is focused horizontally on the exit slit by the M0-mirror-bending. The photocurrent of the beam monitor after bending was 5.5 times larger than before bending. These results show that the front focusing mirror is nearly cylindrical and that the SR beam is well focused on the exit slit.

Fig. 5 shows the spectral response of the “grasshopper” monochromator obtained over the full scanning range from near the zeroth-order diffraction to 250 Å with a grating groove density of 1200 lines/mm and 50 μm slits. The contribution of the zeroth-order diffraction to the spectrum decreases linearly as the wavelength increasing front $10^{-2}$ Å to about 10 Å. The broad swelling in the region between $10^{-2}$ Å and $10^{-1}$ Å might be due to defocusing of the zeroth-order diffraction on the exit slit. The monochromatized SR beam of the first-order diffraction appears in the photon energy range from 50 eV to above 300 eV. The background level in the available photon energy range is four orders of magnitude lower than the zeroth-order diffraction peak. Therefore, the monochromatized beam is well separated from the zeroth order diffraction, and strays are also well suppressed. A slight CK-absorption edge caused by carbon contamination on optical elements was observed. Due to the blaze effect of the grating, the maximum intensity was obtained at 150 eV. The maximum photon flux, was estimated to be $1.5 \times 10^{10}$ photons/s with a measured energy resolution of 0.5 eV during storing of the 50-mA electron beam, based on a transmission in the gold-mesh beam monitor of 67% and a quantum yield of 0.06 electrons/photon [6] with gold. From the viewpoint of the photon flux, it seems reasonable to conclude that if an electron beam of more than 100 mA could be stored in the NAR, we could obtain a photon flux large enough for real-time SRPES measurements with a time resolution of the order of 100 ms.

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References