BL46XU
Engineering Science Research III

1. Introduction

BL46XU is an industrial applications beamline with an undulator light source dedicated to promoting the utilization of synchrotron radiation by industry. A multi-axis X-ray diffractometer is installed in the first experimental hutch (EH1). In addition, the open space of EH1 is available for experiments of X-ray imaging and microfocus X-ray diffraction. The second experimental hutch (EH2) has two hard X-ray photoelectron spectroscopy (HAXPES) systems. The following instrumental improvements were carried out in FY2019: 1) the HAXPES system was equipped with a xenon light system to induce the surface photovoltage effect by band gap excitation and 2) the detector system for X-ray imaging was renewed to mitigate its deterioration and improve the detection of X-ray transmission images.

2. Optics and performance

The light source is a standard in-vacuum undulator at SPring-8 and the optics adopt a liquid nitrogen–cooled Si (111) double-crystal monochromator. The tunable energy range is 5.5–37.5 keV. To eliminate harmonics, two Rh-coated mirrors (70 cm length, horizontal reflection direction) are placed in the most downstream part of the optics hutch. The mirrors can be bent for horizontal light focus. A Si (111) channel-cut monochromator is placed between the monochromator and the mirrors to achieve incident X-rays with fine energy resolution. Figure 1 shows the beamline layout of BL46XU.

3. New equipment and developments

3.1 Xenon light system for the surface photovoltage effect in HAXPES

The HAXPES measurement system is a powerful surface analysis tool for the direct exploration of the electronic structure in deep regions, such as the interfaces of functional thin films, that are inaccessible by conventional XPS [1]. For example, the system is applicable to the evaluation of band bending at the interfaces of semiconductor devices buried in their gate stack structures. Band bending, which is caused by a localized level in the band gap, is an important parameter in the development of semiconductor devices because it affects the properties of the devices. The band bending can be

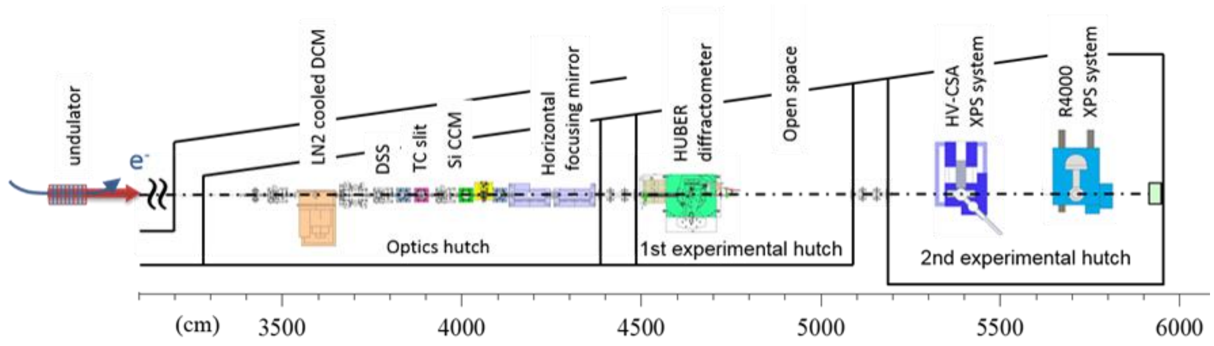

Fig. 1. Beamline layout of BL46XU.

evaluated by investigating the dependence of the peak shift of the inner shell excitation of XPS on the probe depth to compare with neutral spectra from deeper regions unaffected by band bending. However, in the case that the thickness of the region where band bending occurs is over a few hundred nm, even the probe depth of HAXPES is insufficient for evaluating the band bending. Therefore, to deal with such a case, we investigated the measurement technique of applying the surface photovoltage (SPV) effect to HAXPES. The utilization of the SPV effect can reduce the band bending with photoexcitation. A comparison of reduced and nonreduced spectra enables the band bending to be estimated [2]. As the light source for photoexcitation,

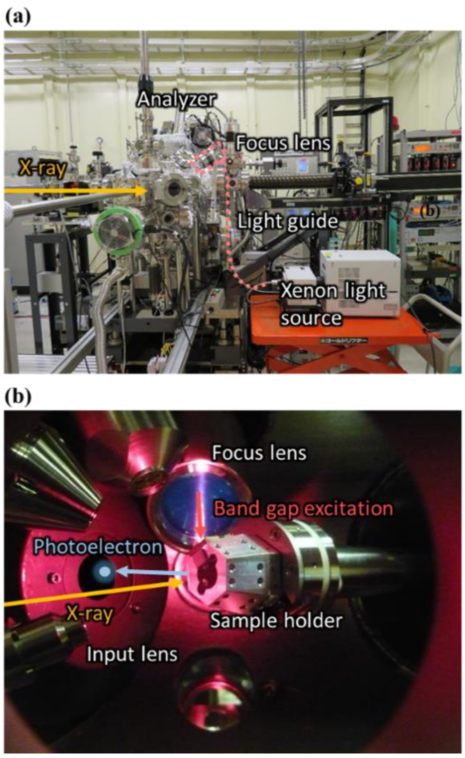

Fig. 2. (a) Exterior view of the HAXPES and xenon light systems in the second experimental. hatch of BL46XU. (b) Internal view of the measurement chamber.

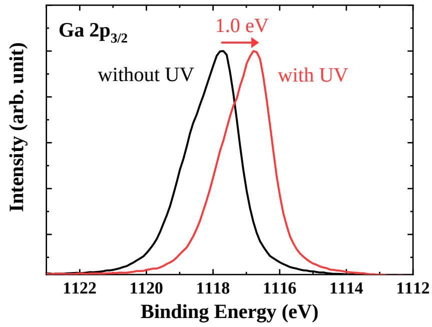

Fig. 3. Ga $2p_{3/2}$ spectra of p-type GaN semiconductor measured with (red) and without (black) UV light.

we installed a xenon light system with MAX-303 (Asahi Spectra Co., Ltd.). In this system, the wavelength range of 400 to 1200 nm can be used. Figure 2 shows the overview of the HAXPES and xenon light systems. This xenon light system consists of a xenon source, a band-pass filter changer, a continuously variable neutral density (ND) filter, a quartz lightguide and a focusing lens compatible with an ultrahigh vacuum. The light spot size at the sample position is 4.5 mm.

Here, the results obtained with this system for a p-type GaN semiconductor are shown in Fig. 3. Two spectra of Ga $2p_{3/2}$ measured under different conditions, with and without the irradiation of ultraviolet (UV) light of 360 nm wavelength, are shown. It can be seen in this figure that the spectrum measured with UV irradiation shifted by 1.0 eV to a binding energy lower than that measured without UV irradiation. This means that this energy shift was caused by the reduction of band bending by the SPV effect. Thus, this result suggests that a depletion layer is formed at the surface of the p-type GaN semiconductor. The combination of HAXPES measurement and the SPV effect has successfully enabled the characterization of band bending. This xenon light system is already available for user experiments.

3.2 New detector systems for X-ray imaging

The detectors for X-ray imaging have been updated. The new detector consists of a camera and an imaging unit, as shown in Fig. 4(a). The new camera is ORCA-Lightning from Hamamatsu Photonics. The frame size of this camera is 4608 × 2592 pixels. This camera features a high frame rate of 121 fps. This feature successfully improves the speed of measurements. The phosphor of the new imaging unit (made by Sigma Kouki Co., Ltd.) is LuAG:Ce (Ce-doped $Lu_3Al_5O_{12}$) with a thickness of 15 µm. This imaging unit features the high radiation resistance of the phosphor because it is bonded to the substrate without using an adhesive [3]. Therefore, the high flux beam from the undulator can be irradiated to the phosphor without attenuation. This feature shortens the exposure time required for detecting transmission images. These features of this new detector system improve the quality of the X-ray CT data obtained in the on-the-fly mode. Figure 4(b) is a cross-sectional image of a piece of wood measured with this detector in the on-the-fly mode. This figure shows that there were no serious defects such as artifacts.

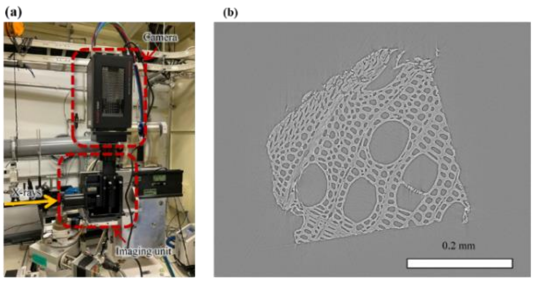

Fig. 4. (a) Photograph of the new detector and (b) CT image of a piece of wood.

The new detector has been put into service for user experiments. The control system of the user interface is unchanged, allowing users to control the CT apparatus regardless of the camera differences.

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References:

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