

FEASIBILITY STUDIES OF THE THREE-DIMENSIONAL DETECTOR FOR SOFT X-RAY EMISSION SPECTROSCOPY

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A time-resolving two-dimensional position-sensitive detector was applied to soft X-ray emission spectroscopy (SXES) and its feasibility was successfully studied by using synchrotron radiation. A soft X-ray emission spectrum synchronously acquired with bunch signal of the storage ring has elucidated that a threefold higher signal-to-noise ratio could at least be achieved. By adopting a pump-probe technique to SXES, we have preliminarily studied the effect of the electron-hole plasma (EHP) on the Si 2p soft X-ray emitting processes of Si crystal. A meaningful change in the excitation curve for the elastic scattering yields near the 2p thresholds was found to be probably due to the many-body interactions caused by the EHP.

1. Introduction

SXES using synchrotron radiation (SR) is a powerful tool^{1–4} for studying the electronic structure of matter and the relaxation processes of excited states with a localized core hole. SXES also allows us to separate the angular momentum components of the valence states because of a clear selection rule due to the dipole nature of the X-ray transitions. Furthermore, since the mean free path of the soft X-rays is much longer than that of the electron, SXES enables us to study the electronic structure of bulk of the materials as well as the buried structure, such as the multi-quantum well.

Recently, we have adopted a time-resolving two-dimensional (2D) position-sensitive detector,⁵ i.e. 3D detector, to the SXE spectrometer in order to study the relaxation dynamics of the core hole states. Such a 3D detector has successfully demonstrated its feasibility for measuring charged particles in recoil ion momentum spectroscopy.^{6,7} By utilizing a time sensitivity of the 3D detector for SXES, we expect we can pioneer new applications in spectroscopic studies. In the following sections, we briefly describe the experimental setup and preliminary results of the recent feasibility studies, in which SR-bunch gated SXES as well as SXES with simultaneous irradiation of SR and laser were carried out.

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2. SXE Spectrometer with 3D Detector

The SXE spectrometer,⁸ which is installed at the BL19B revolver-undulator beamline⁹ of the Photon Factory (KEK), had been used for studying the solid state physics by means of SXES and resonant Raman scattering.^{10,11} Figure 1 shows a schematic drawing of the SXE spectrometer equipped with the 3D detector. The details of the SXE spectrometer are given in Ref. 8; we describe here the 3D detector and its basic performance.

The 3D detector consists of a triple stack (Z-stack) of selected rimless microchannel plate (MCP) and a 2D position-sensitive delay line anode (helical wire pair). The typical performance and the characteristics of the 3D detector are summarized in Table 1. The position of the detected soft X-ray is independently encoded by the signal-arrival-time-difference at both ends for each parallel pair

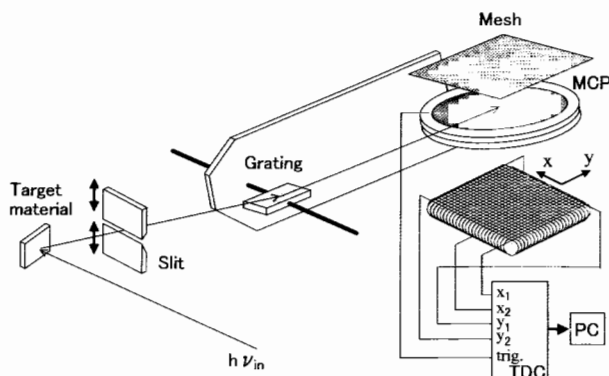


Fig. 1. Schematic drawing of the SXE spectrometer equipped with the 3D detector.

Table 1. Typical performance and characteristics of the 3D detector used as a photon detector for the time-sensitive SXES.

Position resolution	< 100 μm
Timing resolution	\sim 500 ps
Overall linearity	200 μm
Rate capability	1 MHz
Multihit pulse pair resolution	10 ns
Active diameter	83 mm
Operating temperature range	-50 to 70°C
Operating pressure	< 2×10^{-4} Pa

delay line. The four signal pairs from both delay line ends are fed into a differential amplifier by twisted-pair cables (equal length). The time sequence of the signals is measured by the time-to-digital converter (TDC), and the signal on the MCP back or front side is used as a time reference.

The surface of the front MCP of the Z-stack is coated by CsI in order to achieve enhanced soft X-ray quantum detection efficiency. In addition, a retarding wire mesh is mounted in front of the stack so that the secondary electrons ejected from CsI to the vacuum reflect back to the detector. Figure 2(a) represents the applied mesh-voltage dependence of the SXE yields of 100 eV photons and clearly shows the negative bias against the MCP front drastically increase the detection efficiency. Figure 2(b), on the other hand, shows the mesh-voltage dependence of the widths of the time- and position-spectrum. The time-spectrum was obtained using the signal on the MCP front and the bunch signal of the storage ring. The timing resolution became worse significantly when the mesh-voltage was close to that of the MCP front in contrast to the weak

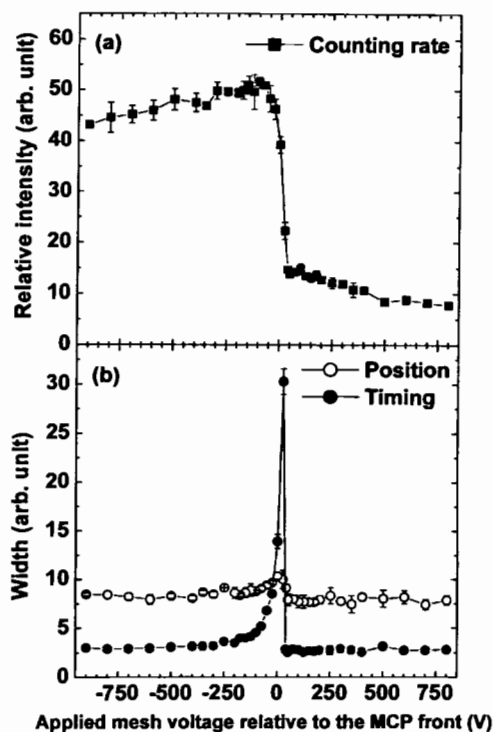


Fig. 2. Applied mesh-voltage dependence of (a) the SXE yield and (b) the widths of the time- and the position-spectrum.

mesh-voltage dependence of the position resolution. From these dependences, we found that the negative mesh-voltage of several hundred eV relative to the MCP front gives rise to higher quantum efficiency with reasonable timing resolution for the soft X-ray detection.

3. Feasibility Experiments

In this study, we have employed ZnSe and Si crystals as target materials. ZnSe target was chosen to test a feasibility of SR-bunch gated SXES by measuring the weak satellite structure due to the shake processes^{12,13} in the $L_{2,3}$ emission spectrum of Zn. On the other hand, Si target was used to explore new applications in spectroscopic studies by means of SXES with simultaneous irradiation of SR and laser.

Experiments were performed at the Photon Factory during a single-bunch operation of the storage ring. The SXE spectra were excited by photons from the VLM19 monochromator¹⁴ with a varied-line spacing plane grating. The energy of the photon beam was set to 1072 eV for ZnSe and 98–103 eV for Si, respectively.

The SXE spectrometer was tuned using the fluorescence emitted from the standard sample. The grating had 1200 grooves/mm. The 3D detector was oriented at the correct position on the relevant Rowland circle by adjusting the computer-controlled actuators. The $L_{2,3}$ emission spectra of Zn were recorded in second order diffraction and those of Si were acquired with the geometry of first order diffraction.

4. Results and Discussion

4.1. SR-bunch gated SXES

If we could achieve further enhancement in the signal-to-noise (S/N) ratio for the soft X-ray detection, an observation of the very weak transition is expected to become possible. Such a situation gives rise to opportunities to study the multielectron processes by measuring the weak satellite lines.^{12,13}

With the advent of the recent synchrotron radiation sources, measuring an evolution of the intensities for shake processes especially near their threshold has become possible.^{15–18} Such systematic studies will give us deeper insight into understanding

the dynamic electron–electron correlations in photo-ionization processes.

Figure 3 shows the timing spectrum of which prompt peak represents the SR-arrival time. By adopting the information of the SR-bunch signal¹⁹

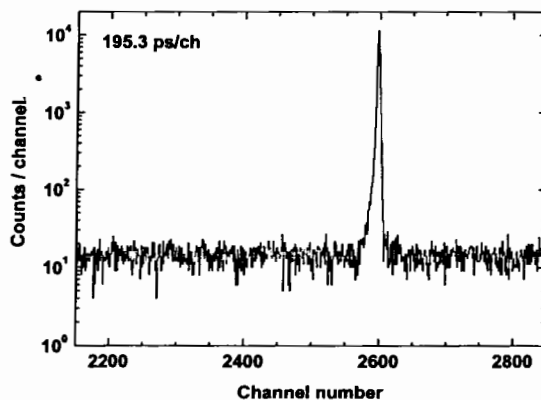


Fig. 3. Timing spectrum obtained using the signal on the MCP front and the bunch signal of the storage ring.

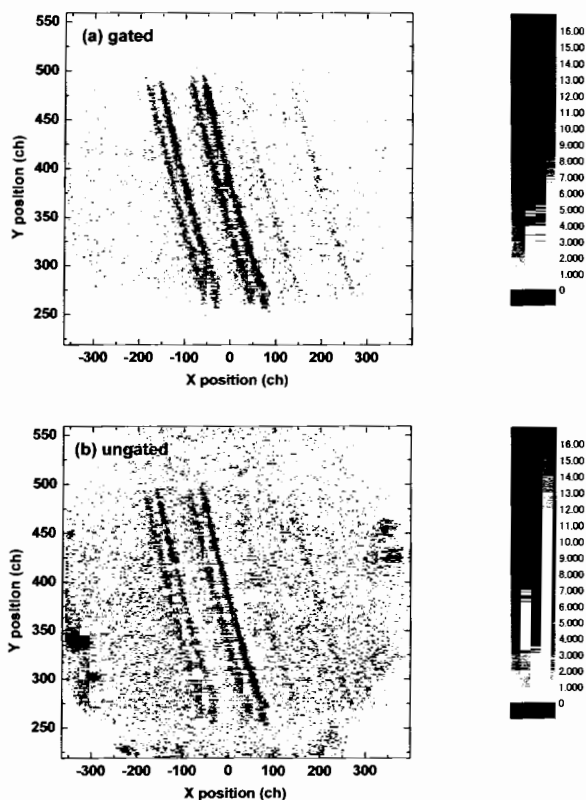


Fig. 4. Two-dimensional position spectra of the wavelength dispersed Zn 2p fluorescence in the condition of (a) gated and (b) ungated.

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