BL3U

Construction of the 2m-Long in-Vacuum Undulator Beamline BL3U

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The undulator beamline BL3U has been designed and constructed for photoelectron spectroscopy (PES), soft x-ray absorption spectroscopy (XAS), and soft x-ray emission spectroscopy (XES) for the energy range from 60 to 800 eV. A soft x-ray emission spectrometer generally requires small beam size at the sample position, because a smaller opening of the spectrometer entrance slit is needed to achieve higher energy resolution. Such a beam is usually produced by refocusing optics downstream of the exit slit. In our case, the adoption of such refocusing optics is impossible, due to the very limited space. On the other hand, a monochromator with short arm lengths is utilized with a small exit-slit opening for obtaining practical resolution. It is feasible to carry out XES studies at the exit-slit position, if the monochromator has a constant exit-arm length. We have designed a varied-line-spacing plane (VLSP) grating monochromator in order to satisfy high energy resolution and small width of the exit-slit opening. Figure 1 represents the layout of the beamline BL3U at the UVSOR facility. The in-vacuum plane undulator composed of 50 periods of 3.8 cm period length is installed in a straight section, where the electron beam parameters are s_x=602 mm, σ_x'=49.9 mrad, σ_y=61.3 μm, and σ_y'=40.6 mrad. The brilliance and total flux calculated by using SPECTRA ver. 7.0.5 [1] are shown in Figure 2. The cylindrical mirror M0 vertically focuses the beam on the entrance slit S0 with the demagnification of 1/7.57. The typical beam size at the entrance slit S0 is a full width at half maximum (FWHM) of 22 μm. Due to the short arm length, the entrance-slit opening corresponding to the resolving power of $E/\Delta E=10^4$ becomes smaller than the beam size. This mismatch causes the beam loss of 12-63%. Varied-line-spacing parameters are calculated by minimizing the aberrations in the energy range of interest. The analytical solution of the aberrations for an S0-M1-VLSP-S1 optical system derived by Amemiya et. al. [2] is used. The obtained parameters give resolving power higher than $E/\Delta E=10^4$ in the photon energy range of 50-800 eV by using three interchangeable gratings with the center groove densities of 1200, 600, and 240 l/mm.

In the XES setup of Figure 1, the beam is horizontally focused on the exit slit by a plane-elliptical mirror M2X, which is located downstream of the VLSP gratings. A sample is placed at 5-10 mm downstream of the exit slit S1X. In the multi-purpose setup, the beam is focused on the exit slit S1 only vertically and then refocused in the both directions on the sample by a toroidal mirror M2. The M2X mirror and the exit slit S1X are designed to be easily interchangeable with the exit slit S1. In the XES setup, the beam on the sample is designed to have a gaussian distribution with FWHM of 60 μm horizontally. The vertical beam size is close to the opening of the exit slit S1X. Although the beam is diffracted by the exit slit S1X, the vertical size of the beam can be down to ~10 μm; in the multi-purpose setup, the beam size at the sample position is typically 30(v) x 170 (h) μm^2.

The commissioning has started from March 2004. The fitting of the N 1s →π* resonance spectrum (Fig.3) gives the monochromator resolution of 7200, where the Lorentzian width of 109 meV was assumed [3]. The resolution is lower than the designed value. The reason was found to be the misalignment of the gratings. Improvement of the alignment is now under progress.

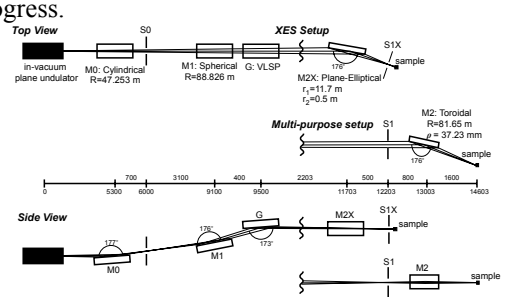

Fig. 1. Schematic layout of the BL3U.

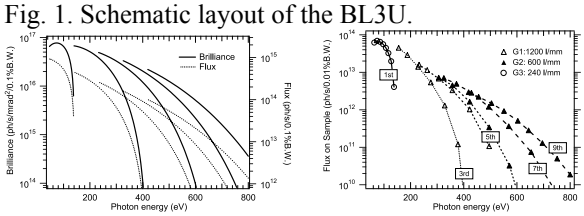

Fig. 2. Theoretical estimates of the undulator brilliance and flux, and the photon flux at sample position.

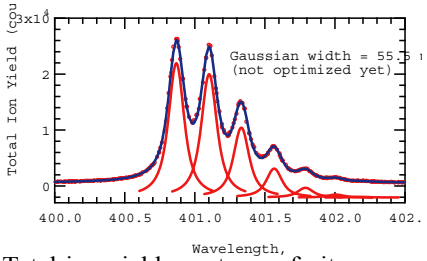

Fig. 3. Total ion yield spectrum of nitrogen molecule using the grating with groove density of 1200 l/mm.

[1] T. Tanaka, and H. Kitamura, J. Synchrotron Rad. 8, (2001) 1221.

[2] K. Amemiya, et. al., J. Synchrotron Rad. 3, (1996) 282.

[3] H. Ohashi et. al., Nucl. Instr. And Meth. A 467–468 (2001) 533.

BL3U

Design of a Transmission Grating Spectrometer for X-ray Emission Studies

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High resolution soft x-ray emission spectroscopy (XES) in combination with synchrotron radiation as incident soft x-rays has been extensively studied since the development of a high energy resolution spectrometer by J. Nordgren et. al [1]. The design of their grazing-incidence spectrometer is based on the Rowland circle mount. In this case, the horizontal acceptance angle is mainly limited by the detector size. In order to achieve higher resolution, the Rowland radius, R, or the spectrometer size, should be larger due to the relationship of $\lambda/\Delta\lambda \propto R$. The detector size is however limited. It is therefore desirable to design a novel optical system which can focus the emitted x-rays not only in the (vertical) dispersion direction but also in the other (horizontal) direction. In addition, recent advances make the charge-coupled devices (CCD) a promising soft-x-ray detector. It is however not a trivial problem to adopt it in the high resolution Rowland spectrometer, since the CCD detectors have low quantum efficiency at the small grazing-incidence angle. In this report, we propose a novel spectrometer design for high resolution soft x-ray emission studies.

Figure 1 shows the schematic layout of a transmission-grating spectrometer (TGS). In order to focus the emitted x-ray both horizontally and vertically, a Wolter type I mirror is introduced as the prefocussing mirror with a magnification of 10. The Wolter mirror consists of hyperboloidal and elliptical surfaces. The grazing-incidence angle of 1 degree gives a collection angle of 1.5 x 10^{-3} sr. A free-standing transmission plane grating with its groove density of 10 000 lines/mm is placed at 67 mm downstream at the edge of the Wolter mirror, in the normal incidence geometry. A back-illuminated CCD, of which the position is changed along the Rowland torus with scanning the photon energy, is located at 1400 mm downstream from the grating.

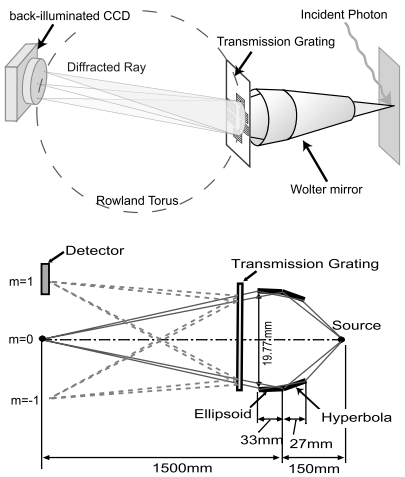

Fig. 1. Schematic layout of the transmission-grating spectrometer (TGS) (up). A cross sectional view is also shown (bottom).

For evaluating the aberrations of TGS, a ray-tracing code TGSGUI is originally developed by one of the authors (T.H.). In the case of a rectangular source, the Wolter mirror has considerable amount of the aberration. Figure 4 presents a spot diagram at the detector position for the 0th order diffraction with a rectangular source of 1(v) x 200(h) μm^2. This result suggests that the aberration is negligible for this source size. Figure 4 (right) indicates a spot diagram of the 1st order diffracted rays of 320 eV at the detector with a rectangular source of 1x200 μm^2. Other aberrations arise from the plane figure of the grating [2]. The diagram however indicates that the present TGS has small amount of the aberrations. The resolving power better than 5000 is possible. The spatial resolution of the detector should be very high, which is estimated to be about 1 μm, in order to achieve such a high resolution.

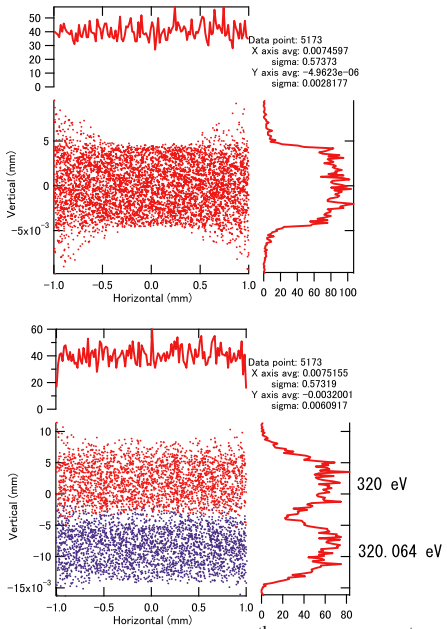

Fig. 1. Spot diagram of the 0th (top) and 1st (bottom) order diffraction at the detector with a rectangular source of 1(v)x200(h) μm^2 (top).

[1] Nordgren, et.al., Rev. Sci. Instrum. 60, 1690-1696 (1989).

[2] Beuermann, K.P. et.al., Applied Optics 17,2304-2309 (1978).

BL4B

X-ray Magnetic Circular Dichroism Measurements at BL4B

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X-ray magnetic circular dichroism (XMCD) is a powerful technique to investigate element-specific magnetization. Moreover, by using so-called sum rules, orbital and spin magnetic moments are separately obtainable, which are hardly derived by other conventional magnetic measurements. We have constructed a new ultrahigh vacuum (UHV) chamber for XMCD and surface XAFS (X-ray absorption fine structure) measurements at BL4B in upgraded UVSOR-II. Here, basic performance of our XMCD measurement system is described.

Apparatus

BL4B is a bending magnet station, where a varied-line-spaced grating monochromator is installed. Circularly polarized X rays are obtained by placing a newly installed slit (located in the upstream of the first mirror) upward or downward with respect to the electron orbit plane. A polarization factor P_c of ~0.70 was obtained with a reasonable photon intensity and an energy resolution $E/\Delta E$ of ~700 at the energy range of 600-1000 eV.

Figure 1 shows the inside of the UHV chamber. An Au-coated Fe electromagnet allows us to apply a static magnetic field of maximum 3000 G during XMCD measurements. The X ray is introduced through the holes at the center of the magnet poles, and its propagating direction is thus always parallel or antiparallel to the magnetic field.

The UHV chamber is evacuated by turbo molecular pumps, a non- evaporation getter and a Ti sublimation pump. The base pressure is around 1×10^{-10} Torr. Standard surface cleaning equipments such as an ion gun, a heater and a LEED/RHEED optics are installed. Metals and gases can be deposited by commercial evaporators and leak valves, respectively. A sample can be cooled down to ~100 K using liq. N_2. The sample can be rotated in both the polar and azimuthal directions with respect to surface normal.

The signals were detected usually by a drain current from the sample, and a microchannel plate (MCP) is also available for the partial electron yield detection with a retarding field under the remanent condition. XMCD spectra are taken by changing the helicity of the X rays or the direction of the magnetic field. Most equipments such as the upstream slit, the monchromator, the magnet and the detection systems are controlled by the LabView software.

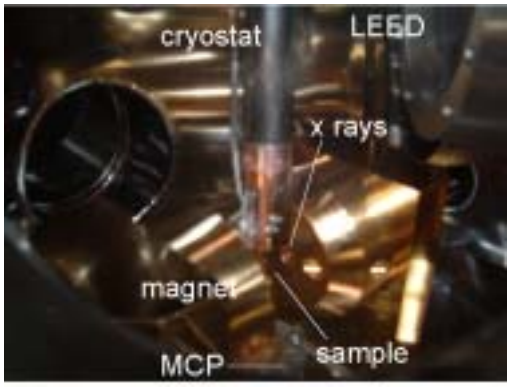

Fig. 1 Inside look of the UHV chamber.

Results

In order to show the performance of BL4B and the XMCD system, we have recorded Co $L_{III,II}$-edge XMCD of 3 monolayer (ML) Co on Cu(001). The substrate Cu(001) was cleaned by repeated cycles of Ar^+ sputtering and annealing to ~900 K (electron bombardment from the rear side). Cleanliness and order of Cu(001) were verified by XAFS and LEED, respectively. Co was deposited from the Omicron EFM3 evaporator. Co is known to grow epitaxially on Cu(001) with a layer-by-layer pseudomorphic fashion and to show the in-plane easy axis.

Figure 2 show the XMCD spectra, taken at the x-ray incidence angles of 30° (grazing incidence, close to the easy axis) and 90° (normal incidence, along the hard axis). It took around 12 min. to record a parallel or antiparallel spectrum. A signal-to-noise ratio is fairly well. The normal incidence spectra show much weaker XMCD signals because the magnetization is not saturated at 2000 G.

We have performed the sum rule analysis. The orbital moment m_l of 0.164 (μ_B) and the effective spin moment m_s of 1.65 (μ_B) for the θ=30° spectra, while m_l/m_s= 0.095 for the θ=90° ones. These values are consistent with previously reported values.

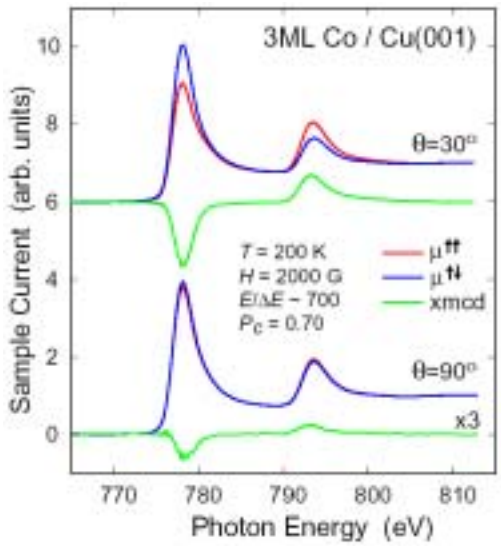

Fig. 2 Co $L_{III,II}$-edge XMCD of 3 ML Co/Cu(001) at the x-ray incidence angles of 30° and 90°.

BL5U

Present Status of High-resolution Angle-resolved Photoemission Spectroscopy Apparatus at BL5U

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Functionalities (superconductivity, magnetism, etc.) originating from the electronic structure near the Fermi level (E_F), especially the Fermi surface of solids, thin films and surfaces. To pursue the experimental investigation of the functionalities of materials, we have constructed a new high-energy-resolution photoemission apparatus for the helical undulator beam line BL5U.

Figure 1 shows a present status of the apparatus installed at BL5U [1]. The most striking point is a new type hemispherical photoelectron analyzer, MBS-Toyama 'Peter A-1', with which we have achieved the world record of the experimental energy-resolution ΔE~1.2 meV, which has been evaluated from the fitting of the PES spectrum near E_F of Au by temperature-dependent Fermi-distribution-function broadened by Gaussian (Fig. 2).

To evaluate the improvement of the photoemission spectrometer for BL5U, the XPS spectrum of Si(111) 7x7 surface obtained by the present apparatus is compared with that by the previous one (Fig. 3). In Figure 3, the present spectrum seems to have some advantages to the previous one, *i.e.*, the better *S/N*, the sharper double peak structures originating from Si 2p spin orbit splitting, in spite of the compatible experimental conditions (photon energy, temperature, sizes of slits, surface preparation). The observed differences strongly suggest the improved efficiency as well as the energy resolution of the present spectrometer, though the upgrade of UVSOR is responsible for the better *S/N*.

Finally, we will briefly comment on the future issues for the experimental study of the functional materials at BL5U. After the upgrading UVSOR and the replacement of the photoemission apparatus, some weak points were revealed. Then, we plan the upgrade of BL5U in April 2004; (1) change of the spherical-mirror adjuster with high efficient water cooling, (2) installation of new spherical grating for normal incident region (hν=5~30 eV), and (3) installation the cooling system at the entrance slit.

[1] S. Kimura *et al.*, UVSOR Activity Report 2002, 75.

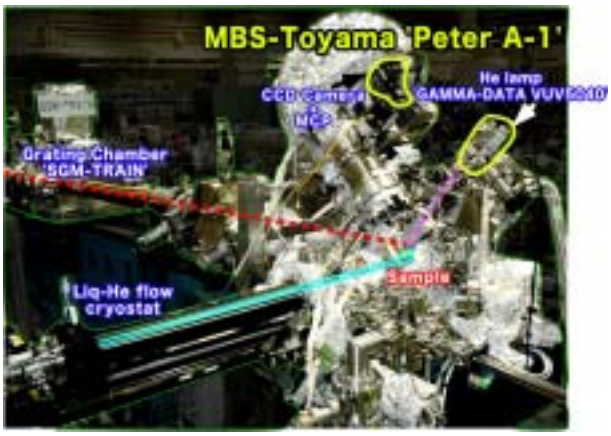

Fig. 1 High-resolution photoemission spectroscopy apparatus at BL5U.

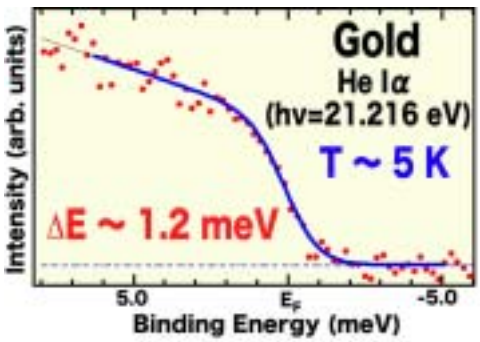

Fig. 2 PES spectrum around E_F of Au film obtained by using He Iα photons at 5 K (red circles). The results of fitting is superimposed (blue line).

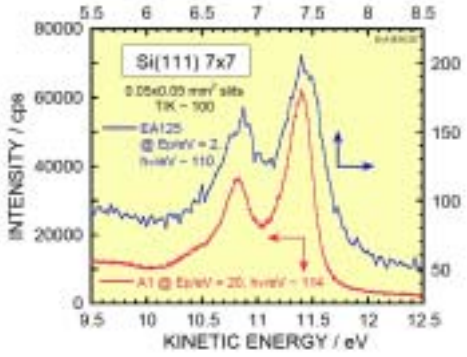

Fig. 3 Si 2p photoemission peaks obtained with the previous (blue) and present (red) apparatus installed at BL5U.

BL6B

Construction of the new IR and THz beam line BL6B

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At the beginning of FY2004, the new infrared (IR) and terahertz (THz) beam line BL6B is constructed. The design concept and the expected performance have been already reported. [1,2] In this paper, the configuration of the Fourier interferometers and the end stations and the future plan are reported.

The configuration of the beam line is shown in Figure 1. IR-synchrotron radiation (IRSR) is collected by a perfect focusing mirror, so-called "magic mirror" set in the bending duct B6. IRSR is guided by two plane mirror and is focused at the first focusing point. The polarization is changed from horizontal at the emission point to vertical by the two plane mirrors. The first focusing point was shifted about 300 mm to the outside of the storage ring because of the installation of a newly installed radiation shield.

The ultra-high vacuum in the storage ring and in the front-end part is separated at the window exchanger with a diamond and a z-cut-quartz windows before the first focusing point. IRSR is guided to two interferometers, one is old Michelson FT-IR (Bruker IFS66v) and the other newly installed Martin-Puplett FT-FIR (JASCO FARIS-1). Since the new FT-FIR is rapid-scan type, higher accuracy of intensity is expected. The covering wave number range is from less than 10 cm^{-1} up to 20,000 cm^{-1}.

The IRSR after two interferometers is guided to the free port. Before the upgrading, a conventional sample chamber was located at the position. To support higher level experiments, users can set their own chambers to the port. The old conventional sample chamber and the old infrared magneto-optical apparatus can be also located, of course.

In the near future, a commercial IR microscope will be installed. The microscope will cover not only IR region but also THz region because the brilliance in the THz region is much higher than conventional light sources. The THz microscope will be a good probe for vibrations of large molecule in a small region and a metal-insulator imaging.

[1] S. Kimura *et al.*, UVSOR Activity Report 2002, *p.* 78 (2003).
[2] S. Kimura *et al.*, Proc. SRI2003.

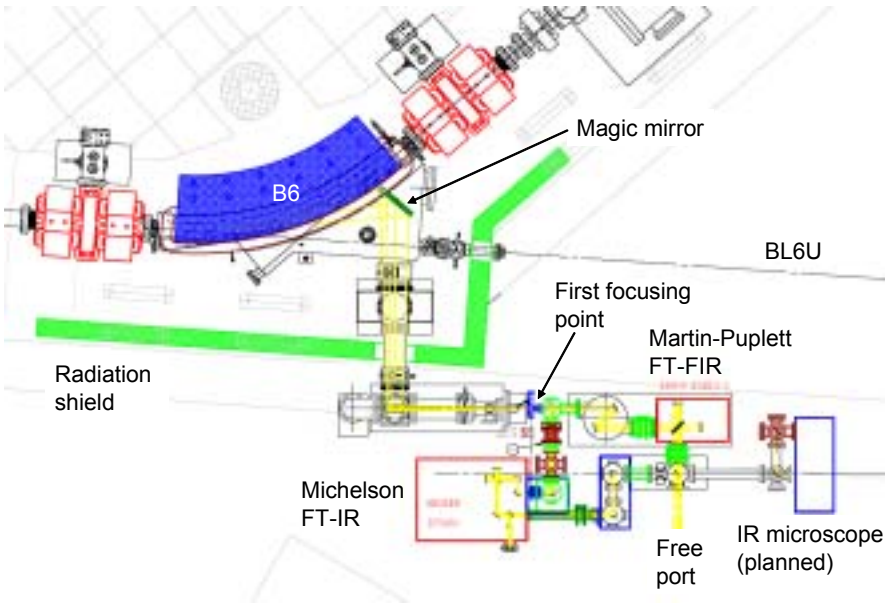

Fig. 1. Schematic figure of top view of the new infrared and terahertz beam line BL6B.

BL8A

Carbon Contamination of SR Mirror

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Carbon contamination on SR irradiated mirror was investigated as a series of the BL8A experiment Vacuum pump oil was checked as one factor as contamination to the mirror surface in the experiment of the preceding year.[1] We experimented by putting in oil in a vacuum in order to advance contamination on the surface of a mirror. Moreover, since it was assumed that oil dissociated to a carbon simple substance by irradiation, it tried how to apply an electric field to the processed thing. The effect of the electric field was investigated in this experiment by using the carburizing technique.

Although much time was spent on experiment preparation, the very interesting result was given. In the environment where electric fields differ, the result from which the amount of generation of a carbon contamination differs was obtained.(fig.1) The progress of the carbon contamination was measured under oil molecule existence that was apply the SR for 4 hours. Fig.2 shows the reflectivity reduction of the surface of the mirror in each condition. The reflectivity reductions were 73% for +1.5kV, 65% for without high voltage and 50% for -1.5kV, respectively. Fig.3 shows the profile of the SR irradiation mirror as a contour color plot. The clear electric field dependence was confirmed. From this result, we can conclude that the electric field at mirror surface is effective for reduce the carbon contamination. However, since there is few measurement data, the quantities talk is not made.

In this experiment, it is not experimenting in changing voltage etc. Change of the reflectance accompanying voltage change is an interesting point. It expects that the same data is obtained also in pure vacuum environment. More exact investigation is needed about dependence of the strength of an electric field, and dependence of vacuum conditions. Although this time was only found out delaying condition, things were not made to removing contamination. We need the further experiment for find out the other method of the carbon contamination.

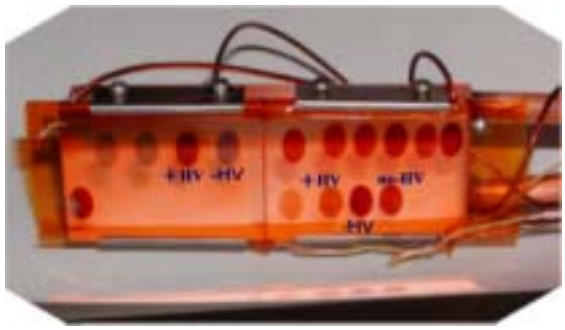

Fig.1. Picture of the contaminated copper mirror.

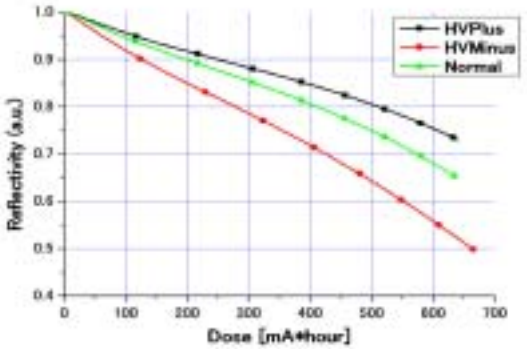

Fig.2. Reflectivity of irradiated mirror.
upper line: Plus High Voltage,
middle line: No High Voltage,
lower line: Minus High Voltage.

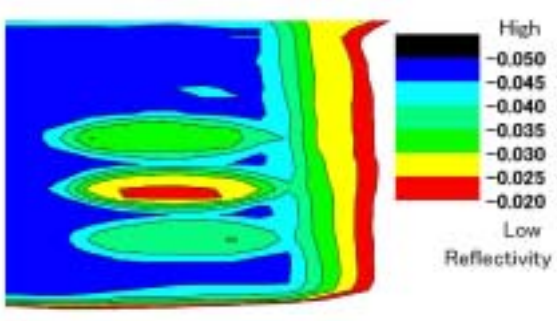

Fig.3. Mirror surface scan at after experiment.
upper round area: No High Voltage,
middle round area: Minus High Voltage,
lower round area: Plus High Voltage.
(unit at the time of measured [Volt].)

[1] M.Tadano et.al. UVSOR Activity Report2002 P80
[2] T.Naito et.al UVSOR Activity Report2000,P63