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X-ray Optics with Small Vertical Divergence and Horizontal Focusing For an X-ray Standing-wave Measurement

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An x-ray optics was proposed for dynamical diffraction measurements of a non-ideal crystal. It was composed of a pair of channel-cut Si (004) crystals and a one-dimensional focusing lens system. Vertical angular divergence values were measured as FWHM's of ca. 1.3 arc secs for an incident photon energy of 12.4 keV during a rocking scan around the analyzer sapphire 0006 reflection when the second channel-cut crystal was fixed at five deviation angles. The experimental angular resolution deconvoluted is about 1.3 arc secs at the deviation angle of ca. 0.7 arc sec. A typical photon flux was around 10^9 photons /s as a peak value of the rocking scan for an incident slit of 0.2 x 0.1 mm. The horizontal beam size measured at the focal distance of ca. 200 mm was 4.3 μm.
Key words: optics, dynamical x-ray diffraction, channel-cut crystal, horizontal focusing

1. INTRODUCTION

A feedback control system for stabilizing an incident x-ray intensity from a beamline monochromator was designed by Krolzig et al.[1, 2]. A dynamic combination of a micrometer positioner driven by a piezoelectric element and monitoring the diffracted x-ray intensity enabled an angular control of the monochromator with sub-arcsec precision. This was a key instrument for conducting a synchrotron measurement; consequently, many beam lines at synchrotron facilities adopted the system. Further, recent improvement of the system has added a new function of stabilizing the beam position of the incident x-rays[3] and was useful for extended x-ray absorption fine structure spectroscopy measurements[4].

The x-ray standing wave (XSW) technique allows us to perform element-specific and structural analysis of surface adsorbed atoms as well as buried hetero-interfaces with high spatial resolution. A yield profile of secondary emissions like fluorescence x-rays, here called an XSW profile, is recorded during a rocking scan of a sample in case of using hard x-rays. The angular width of the rocking curve is intrinsically several arc secs when calculated for a perfect crystal on the basis of dynamical diffraction theory. Bedzyk et al. have introduced a postmonochromator optics[5], which is an upgrade feedback control system, to prepare the incident beam in a way that avoids angle and photon energy averaging effects that would smear the XSW profile. Here we report on a combined system of a one-dimensional focusing lens plus the postmonochromator optics for performing measurements of dynamical diffraction of a non-ideal single crystal like an oxide material.

2. REQUIREMENTS FOR XSW MEASUREMENTS

XSW measurements of a non-ideal crystal require the followings:
1) a beam of a small angular divergence should be incident because of the narrow angular width abovementioned of the intrinsic rocking curve for hard x-rays and
2) a small area on a sample should be irradiated as much as possible because its crystalline domain is small. In addition, recording the yield profile of weak secondary emissions takes long time; hence,
3) the optics necessitates stabilizing the intensity and angle of the incident beam.
In the following section, we discuss advantages and disadvantages of three setups that have already used and propose our optics.

3. DESIGN CONSIDERATIONS

The non-dispersive parallel setting, which usually employs an identical reflection of the same material for the two crystals of a monochromator and sample, meets requirement 1). We inconveniently need to change the arrangement of the monochromator when a different reflection of the sample is investigated. The postmonochromator optics uses a non-dispersive pair of channel-cut crystals and can substitute for the non-dispersive parallel setting to generate quasi-plane waves even if the optics is not changed.

A different solution is to use a combined setup[6] which is composed of a one-bounce capillary and a miniature Si (400) channel-cut crystal as Kazimirov et al. proposed. The setup fills the three requirements mentioned above. Example parameters written in ref.[6] for 12.5 keV x-rays were
a) beam sizes of 10 μm after the capillary and 6 μm for Si(400) collimating crystals,
b) the (004) rocking curve width of 14 μrad from the standard Si(001) wafer, and
c) intensities from 0.9 x 10^6 to 3 x 10^6 photons / s.
The small divergence and small size of the beam consisted; however, the setup was considerably at the cost reducing the x-ray intensity in the scattering plane.

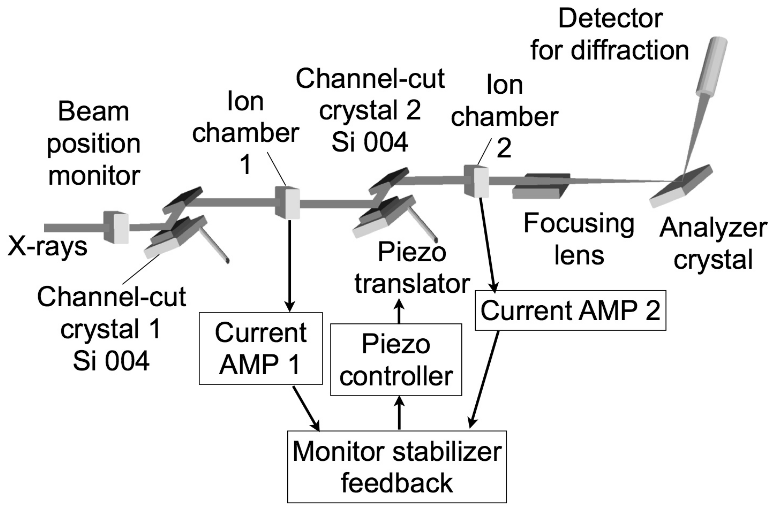

Fig. 1: Schematic of experimental setup and feedback loop of an electric stabilizer unit.

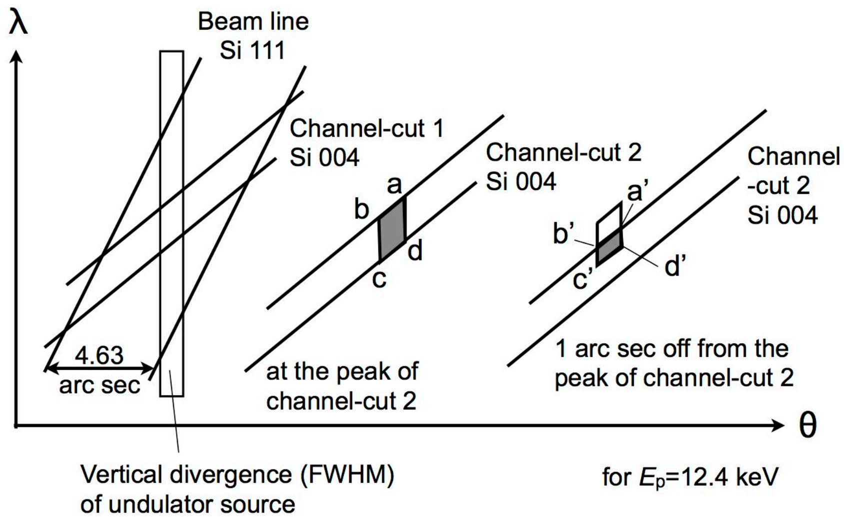

Fig. 2: DuMond diagrams of the optics. The optics admits x-rays represented by parallelograms abcd and a'b'c'd'.

We here propose a modified optics (Fig. 1) that provides us with a small divergence in the scattering plane and a small beam in the horizontal direction. In other words, the 1D focusing element is added to the postmonochromator optics. Figure 2 shows the DuMond diagram for the undulator source, the beam line Si (111) monochromator, and the pair of Si (004) postmonochromator reflections at E_p = 12.4 keV. The FWHM vertical divergence of the undulator source is estimated using the vertical beam size 1.02 arc secs of σ =6 μm and vertical divergence of σ =1 μrad. The parallelogram abcd or a'b'c'd' shows x-ray divergences of angle and wavelength that the optics generates. The divergences will smear a dyanamical rocking curve and XSW profile. We can detuned the second channel-cut crystal to change the range of the wavelength dispersion.

4. EXPERIMENTAL

We prepared the setup (Fig. 1) at BL13XU, SPring-8. The channel-cut crystal was fine-tuned using a piezo-driven rotary stage with a leaf spring (Fig. 3(a)). The piezo-translator controller received a signal from a monitor stabilizer. X-ray intensities in front of / in the rear of the channel-cut crystal were monitored with ion chambers and converted to voltages from currents through current amplifiers; successively the voltages proportional to the x-ray intensities came in the stabilizer. A voltage to stable a ratio of the voltages was applied to the piezo translator through a division amp. To achieve performance to fill requirement 1) and 2), a strain-free mount of the crystal is crucial. Accordingly, the channel-cut crystals had two grooves at the bottoms (Fig. 3(b)).

The 1D focusing lens system used was made from an SU-8 resist on a Si wafer substrate fabricated by Forschungszentrum Karlsruhe. The system consists of 26 micrometer-size lenses of which aperture was 320 μm. The focal distance calculated was 200 mm. We used the lens to focus x-rays in the horizontal direction.

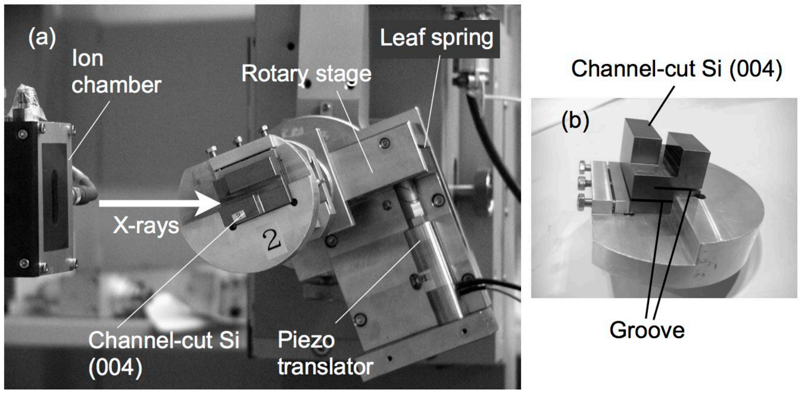

Fig. 3: Photos of channel-cut crystal. Part of optics (a). The holder for the strain-free mount of the crystal (b).

5. RESULTS

We measured divergences and intensities that the optics generated. Fig. 4 plots observed vertical divergence angles. The FWHM divergence angles were measured when an analyzer crystal was rocked at a fixed deviation angle of the second channel-cut crystal. On the other hand, a photon flux (the right axis in Fig. 4) was a peak value of the rocking scan.

We intentionally chose a sapphire crystal (0001) grown by the heat-exchange method (HEM) as the analyzer crystal. The 0006 reflection was used. The incident slit was located between ion chamber 1 and channel-cut crystal 2. The slit aperture used was 0.2 (horizontal) x 0.1 (vertical) mm. The intrinsic FWHM calculated is 0.4 arc secs; simply, the experimental angular resolution deconvoluted is about 1.3 arc secs at the deviation angle of ca. 0.7 arc sec. Other intrinsic widths calculated are, for example, 3.32, 2.46, and 2.54 arc secs for the 1 0 -1 4, 2 -1 -1 3, and 0 1 -1 2 reflection, respectively. By comparison with these values, the resolution obtained is enough small for performing a dynamical diffraction measurement. While Fig. 2 implies the angular divergence is independent of any deviation angle of the second channel-cut crystal, observed FWHM values were as a function of the deviation angle. This might be ascribed to the dispersion effect of wavelength. We will use the deviation angle of ca. 0.7 arc secs which gives an enough small divergence angle as well as a reasonable intensity to perform XSW measurements.

The lateral beam size measured at the analyzer position was 4.3 μm using a knife-edge scan (shown in Fig. 5). The knife was made of a Au foil. The reduction ratio was 0.002.

6. SUMMARY

We made a setup of the optics composed of a pair of channel-cut Si (004) crystals and a 1D focusing lens system. The vertical divergence and photon flux were evaluated using the 0006 reflection of the sapphire crystal. The horizontal beam size was also measured at the focal distance.

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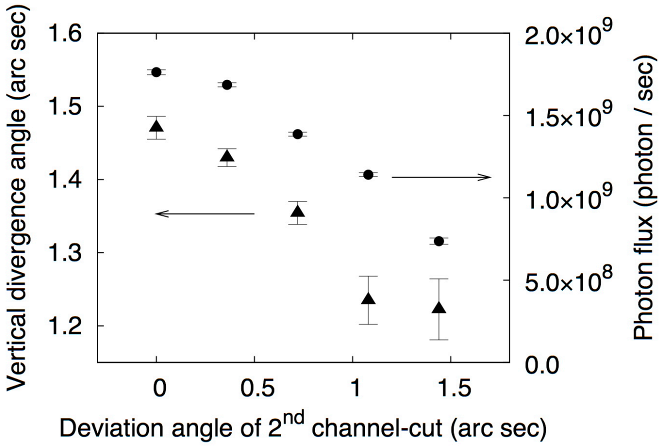

Fig. 4. Vertical angular divergence (▲) and intensity (●) as a function of the deviation angle of the second channel-cut crystal. An analyzer crystal used was a HEM sapphire single crystal.

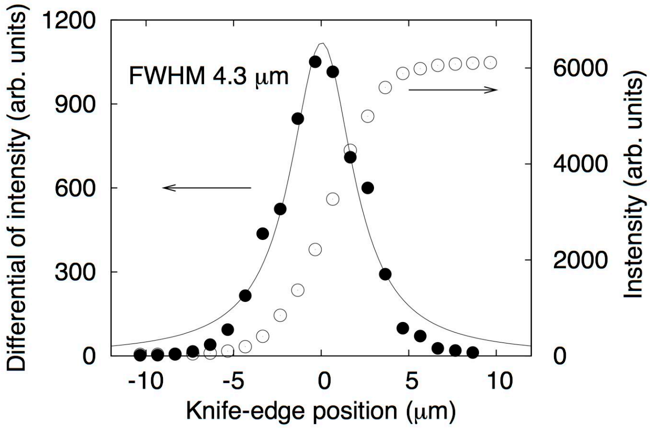

Fig. 5: Knife-edge scan and lateral beam size.

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