X-ray Interferometer of Separate Components

In the hard X-ray region most optical elements, such as monochromators, polarizers, collimators and beam expanders, are designed based on dynamical diffraction with perfect crystals. Interferometers, one of the most important optical elements, are also made of perfect crystals. For example, a skew-symmetric triple-Laue interferometer, which is an X-ray analogue of the Mach-Zehnder interferometer, has four thin blades making Laue case diffractions (Fig. 1(a)). First one acts as a beam splitter dividing the incident beam into two coherent beams. Two mirrors change the propagating directions of the two beams, and they meet on the last blade. The last blade is a recombinator, usually termed an analyzer, the periodic electron density of which analyzes a standing wave made by the interference between the two beams and yields Moire fringes. The spacing of the raw interference fringes is too small to be perceived directly due to the angstrom scale of the wavelength. So we can conclude that we need to achieve an angstrom scale stability for the operation of X-ray interferometers, otherwise the interference fringes will be smeared out. This is the reason why most X-ray interferometers are constructed on a single block of perfect crystal.

However we may need a separate component interferometer, which is more flexible and has a greater potential than the monolithic interferometer. For example, we can have a larger separation, say 1000 m, when the skew-symmetric interferometer is made from separate components. (Note that the two coherent beams propagate parallel to each other inside the interferometer.) Using a large skew-symmetric bicrystal interferometer, we are planning to detect the red-shift of X-rays due to the gravitational field of the earth in the 1-km-beamline **BL29XUL** [1]. Up to date, the separate component interferometers have been realized on a conventional static method, where the interference intensity oscillation was measured by scanning a phase plate or the image of interference fringes were taken after the separate components were extremely stabilized as if there were made of a single crystal block.

One big problem on the separate component interferometers is the stringent requirement of stability, which is estimated to be less than 10^{-10} m for translation and/or 10^{-10} radian for angle. The conventional approach to the separate component interferometers is suitable for a phase sensitive applications, such as phase contrast imaging, because the effect of instability on phase information is relatively smaller. However, the conventional static method cannot be applied to visibility sensitive applications. The visibility is subject to degradation by residual instability of the interferometer, so that the measured value may be lower than the true value. We need to compare the intrinsic values of visibility measured under different conditions of components, *e.g.*, coherence measurements by Young or Michelson interferometers.

Here we consider a new interferometric method to measure visibility [3]. Using this method, we can measure directly the intrinsic value of visibility and do not need to stabilize the interferometer. The principle is easy but somewhat tricky. We suppose the output intensity of the interferometer changes like $I(\phi) = \langle I_0 \rangle (1 + V\cos(\phi))$, where $\langle I_0 \rangle$ is the average intensity, V is the visibility, and ϕ is the phase variable which is related to relative translational and/or angular shifts among the components. Since ϕ is related to the angstrom scale, it varies rapidly due to mechanical vibration and thermal drift, if special care is not taken to stabilize the interferometer. When intensity correlation is measured, it will be averaged over ϕ

and become $<I^2>=<I_0>^2(1+V^2/2)$. Thus the visibility is determined from the intensity correlation.

We have investigated the relation between visibility and the intensity correlation using a skew-symmetric bicrystal interferometer. Figure 1(b) shows a schematic view of the experimental setup at BL29XUL [2]. This bicrystal interferometer consists of two separate Si blocks, one mounted on the splitter and the mirror-1, and the other mounted on the mirror-2 and the analyzer. The separation of the two blocks was 500 mm. We measured the intensity correlation of the output beam with two avalanche photo diodes (APD) using a coincidence technique. To verify interference, we also monitored the beam image by a CCD based beam monitor (not shown in Fig.1(b)).

Figure 2 shows the two dimensional map of normalized coincidence measured in the $\Delta\theta_1$-$\Delta\theta_2$ plane. Here, $\Delta\theta_1$ and $\Delta\theta_2$ represent rotation angles within the scattering planes of each crystal block. The coincidence rate was found to have a narrow peak along $\Delta\theta_1=\Delta\theta_2$ line. This suggests that only the narrow region where the two blocks are nearly parallel can be used for interferometry. Note that the two crystal blocks are exactly parallel on the $\Delta\theta_1=\Delta\theta_2$ line, as if the interferometer is made of a single crystal block. The reason why the coincidence was enhanced with the narrow range along $\Delta\theta_1=\Delta\theta_2$ was discussed in Ref. [4]. The beam images taken along the constant-$\Delta\theta_1$ line ($\Delta\theta_1$=0.5") show clearly that the interference fringes were observed within the same region where the

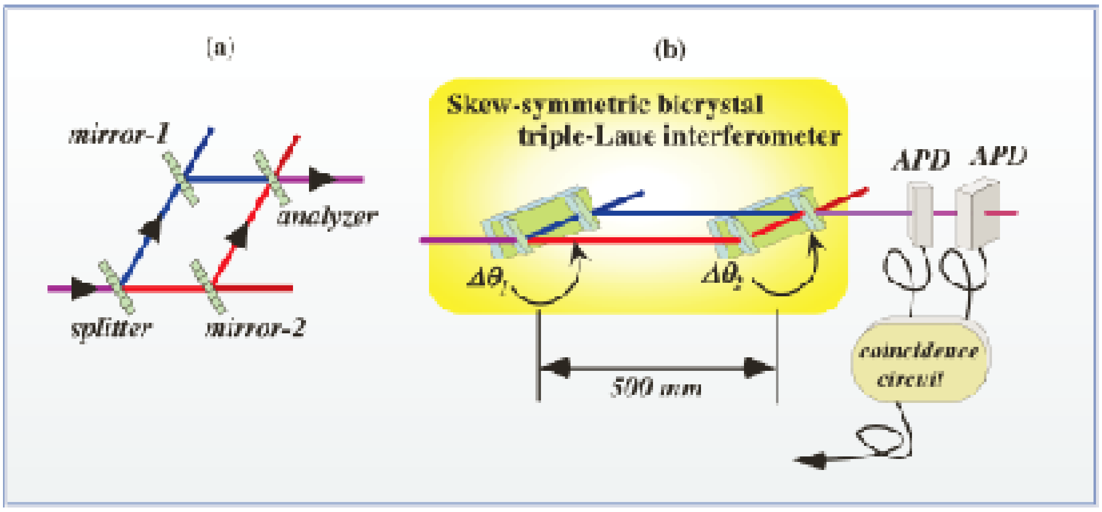

Fig. 1. ***(a)*** *Schematic view of a skew-symmetric triple Laue interferometer, which is an optical X-ray of Mach-Zehnder interferometer. Laue case diffractions take place at the four thin blades, splitter, two mirrors, and analyzer (recombinator).* ***(b)*** *Schematic side view of the experimental setup. The interferometer consists of two Si crystals separated by 500 mm. The output intensity was monitored by two APD detectors in transmission geometry, which were connected to the coincidence circuit to measure the intensity correlation.*

coincidence had a peak (Fig. 2(b)). Thus the theoretical relation, $\langle I^2 \rangle \sim 1+V^2/2$, was confirmed semiquantitatively.

We overviewed briefly the interferometry with separate components and intensity correlation, using the skew-symmetric interferometer. The intensity correlation technique was found to be a good measure of visibility and may be useful in visibility sensitive applications by separate component interferometers, such as Young or Michelson interferometers.

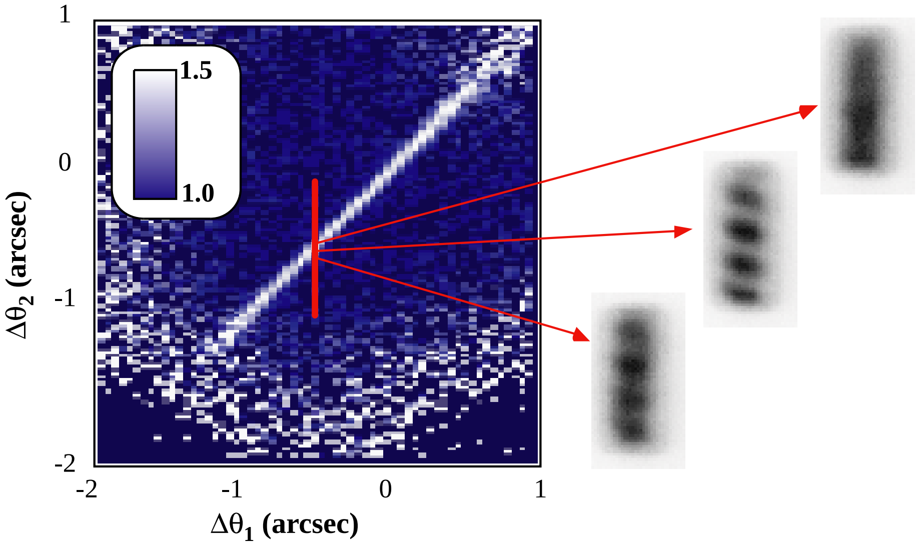

Fig. 2. Two-dimensional map of the normalized coincidence, and the beam images taken along the constant-$\Delta\theta_1$ line (red line). The normalized coincidence had a sharp peak along $\Delta\theta_1 = \Delta\theta_2$ line, where the interference fringes were observed clearly in the beam images.

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