Realization of Fabry-Perot Resonators for Hard X-rays

Optical Fabry-Perot resonator has been frequently used in optics. In the case of X-rays, crystal resonators have long been thought of and proposed for nearly four decades [1]. The simplest two-plate crystal resonator has been mostly investigated theoretically. A variety of experiments in realizing X-ray resonators (cavities) have also been attempted.

An X-ray Fabry-Perot resonator, like the optical one, uses two crystal plates as reflecting mirrors. An incident X-ray beam is reflected back and forth coherently between the two plates via back diffraction, of which the Bragg angle is very close to 90º. Interference fringes due to cavity resonance are generated. In spite of that there have been many well documented theoretical studies of X-ray cavity resonance reported in the literature, the experimental conditions for such coherent interaction between the back-and-forth X-rays are however very difficult to be attained [2]. To overcome this difficulty, we first considered both the required temporal and spatial coherence of incident X-rays for cavity resonance in relation to the effective crystal gaps d, i.e., the longitudinal coherence length ℓ_L = [λE/ΔE] ≥ 2d and the crystal size $\ell_C \geq \ell_T$ (the transverse coherence length), where d is the sum of the thickness and gap of the crystal plate. We then designed the following experiments [3]: We prepared several two- and multi-plate crystal cavities of a plate thickness ranging from 25 to 150 μm and a crystal-gap of 40-150 μm from a four-inch Si (001) crystal wafer using the microelectronic lithography process. The size of the crystal plates is 800 μm wide and 200 μm high. Cavities with plate numbers up to 8 were manufactured. To fulfill the coherence conditions for cavity resonance, a Si (111) double-crystal and a four-crystal ultrahigh resolution monochromators used yield the energy resolution $\Delta E = 2.5 \times 10^{-8}$ at 14.4388 keV, i.e., ΔE = 0.36 meV [4].

The experiment was carried out at the Taiwan undulator beamline **BL12XU**. The incident X-rays, monochromatized by the monochromators mentioned hit at one of the cavities, which was sit at the center of an eight-circle diffractometer. The diffractometer allowed the crystal cavity to be rotated vertically and horizontally by adjusting the $\Delta\theta_v$ and $\Delta\theta_h$ angles, respectively, with a minimum step of 0.0005º. Energy scans were performed by tuning together the Bragg angles of the fourth-crystal monochromator with a minimum step of 0.005 arcsecond, equivalent to 58.548 μeV in energy.

The (12 4 0) reflection of silicon was used as the back diffraction. Both the forward-transmitted (000) and the back-reflected (12 4 0) beams were monitored by an ion chamber and a pin-diode detector, respectively. A 24-beam simultaneous diffraction, including (000) and (12 4 0), took place, because of the high energy X-rays used and the symmetry of the silicon crystal. These 24 diffractions belong to 9 sets of coplanar reflections of the same zone axes. Figure 1 shows the $\mu\theta_v$ -scans of (a) the forward-transmitted (000) beam and (b) the back-reflected (12 4 0) beam of the two-plate cavity at ΔE = 9 meV off the exact

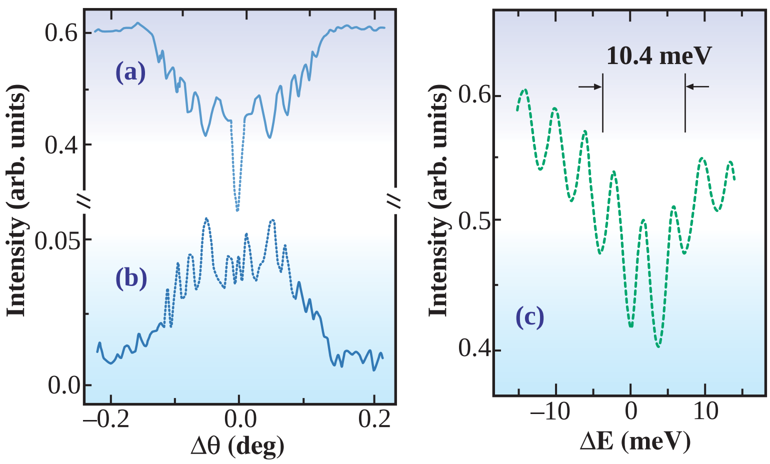

Fig. 1. Angle-scans of the forward-transmitted **(a)** and back-reflected beams **(b)**; **(c)** Energy scan [3].

energy, 14.4388 keV, and 0.002º per step for a two-plate cavity of 70 µm thickness with a 100 µm gap. Figure 1(c) shows the energy scan. The region of broad width shown in Fig. 1(a) is the total reflection region, which corresponds to the energy gap in energy scans. The intensity dip in the middle of Fig. 1(a) results from the 24-beam diffraction. Interference fringes due to cavity resonance are clearly seen. The expected cavity resonance fringes in the energy-scans are also observed. The energy range about 10.4 meV is the energy gap (Fig. 1(c)). The fringe spacing, namely the E_d is about 3.60 meV, in agreement with the calculated value 3.65 meV from the relation $E_d = hc/2d$, where E_d is the so-called free spectral range of a cavity.

Figure 2 shows the intensity distributions of resonance interference at ΔE = 12 meV off the exact photon energy: (a) Angular $\Delta\theta_v - \Delta\theta_h$ distribution of the transmitted (000) intensity I_T of the two-plate crystal cavity in a linear scale; (b) Two-dimensional contour map of Fig. 2(a); (c) Calculated map of (b) without angle and energy integrations. The three-dimensional plot, Fig. 2(a), reveals the interference intensity distribution. The two-dimensional fringes in Fig. 2(b) show concentric rings of alternating maxima and minima and the straight lines are due to the coplanar diffractions denoted as Lines L1 - L9.

In summary, we have realized Fabry-Perot resonators for hard X-rays. Interference fringes due to crystal cavity resonance are clearly observed.

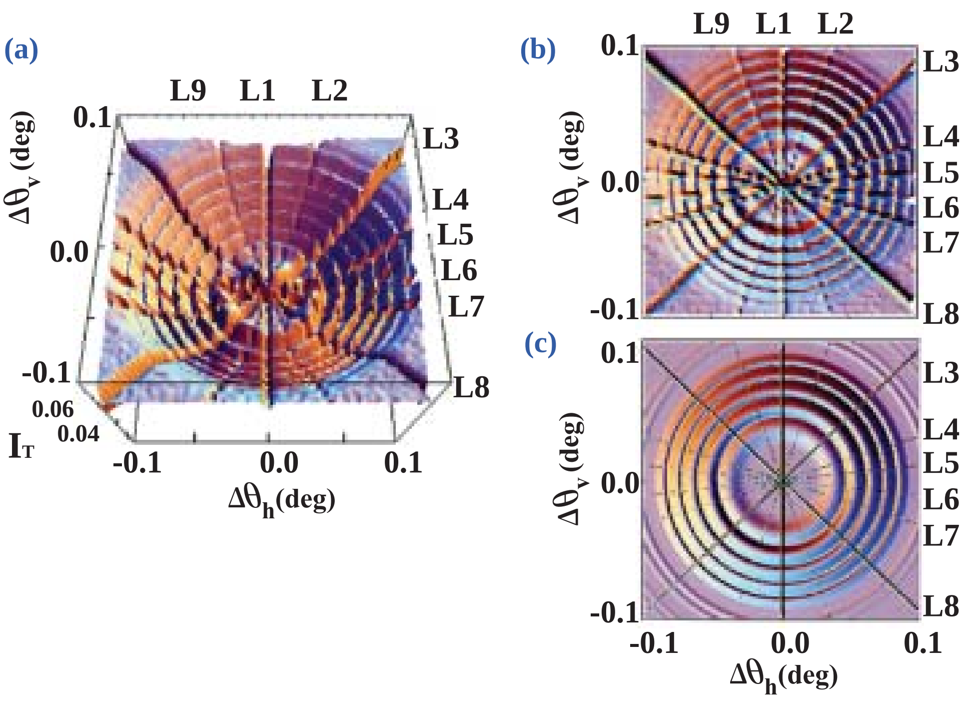

Fig. 2. Intensity distributions of resonance interference: **(a)** three-dimensional, **(b)** two-dimensional, and **(c)** calculated two-dimensional maps [3].

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