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Citation: Review of Scientific Instruments **66**, 2235 (1995); doi: 10.1063/1.1145716

View online: http://dx.doi.org/10.1063/1.1145716

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Synchrotron radiation time gate quartz device for nuclear resonant scattering

Carlos K. Suzuki
UNICAMP, University of Campinas, Faculty of Engineering, C.P.6122 13081-970-Campinas, SP, Brazil

Xiao W. Zhang and Masami Ando
Photon Factory, National Laboratory for High Energy Physics, Tsukuba, Ibaraki 305, Japan

Yoshitaka Yoda, Tetsuya Ishikawa, and Seishi Kikuta
Department of Applied Physics, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan

Taikan Harami, Hideaki Shiwaku, and Hideo Ohno
Japan Atomic Energy Research Institute, Office of Synchrotron Radiation Facility Project, Tokai, Ibaraki 319-11, Japan

(Presented 21 July 1994)

A synchrotron radiation time gate with X-cut quartz resonator has been constructed for use on nuclear resonant scattering at ultrahigh brilliance beam lines. The purpose is to discriminate the electronic scattered prompt (zero time) from the time delayed nuclear scattered photons. The special feature of this device is the possibility of adjusting the time modulation width of the gate without changing the frequency. © *1995 American Institute of Physics.*

I. INTRODUCTION

Very recently, the nuclear Mössbauer resonant scattering with synchrotron radiation (SR), which delivers an intense time delayed photons has originated a new problem on saturation effect of SR photon detection technique. Especially in the case of AR-NE3 beamline of the TRISTAN Accumulation Ring,[1] this problem has been critical due to the very high photon flux. Any kind of detector presently in use has a lack of counting the time delayed photons when both, the electronic scattered (zero time) plus the time delayed signals exceed a certain value. For example, with an avalanche photodiode detector, when the total number of photons composed by the zero time and the time delayed signals increases up to $\sim 10^4$ cps, miscounting of time delayed photons occurs.[2] This effect is more and more pronounced for higher photon flux. In particular, in the case of ns order nuclear forward scattering,[3] where the prompt beam cannot be separated, the need of fast time gating to suppress the zero time beam is fundamental. It is important to remember that either electronic gate or mechanical shutter are very difficult to use in this case.

Concerning time gate with diffraction techniques, many different types of x-ray and neutron shuttering mechanisms have been proposed. For example, the reduction of the Bormann transmitted intensity through the introduction of time-dependent strains of acoustic waves;[4] scanning Bragg reflecting crystal interferometer with a fast chopper caused by a phase sensitive switch;[5] and an ultrasonic chopping of two vibrating Si single crystals[6] with a period of ~ 100 μs. Various contributions trying to use neutron diffraction on moving crystal lattices,[7] especially with vibrating quartz crystals,[8–10] have also been reported. With synchrotron radiation, one of the first attempts was made with SAW-surface acoustic wave transmitted by $LiNO_3$ crystal.[11] But all of them were not suitable for our purpose for not providing an adjustable wave function.

We have then constructed a quartz device to discriminate in time the prompt beam diffracted by oscillating crystal lattices. The principle of this method is to use an X-cut quartz resonator crystal with the same frequency as SR single-bunch mode. In order to take the same phase, the resonator function generator is synchronized with the synchrotron rf trigger.

The oscillation frequency (f) of an X-cut quartz plate depends on the thickness (x_0) according to the relation[12]

$$f = 2840/x_0 \text{ kHz}, \tag{1}$$

with x_0 in millimeters. For the X-cut quartz oscillator vibrating in a resonance frequency, the displacement (Δx_0) varies as a function of applied field (V), according to the expression[13]

$$\Delta x_0 = \frac{2Qe_{11}}{\rho(\omega_0 x_0)^2} V, \tag{2}$$

where Q is the quality factor of quartz crystal resonance, e_{11} the piezoelectric constant, ρ the density, ω_0 the resonance frequency, x_0 the thickness of X-cut quartz plate, $\omega_0 x_0$ is equal to $\frac{1}{2}(c_{11}/\rho)^{1/2}$, and c_{11} is the elastic constant. Therefore,

$$V = c_{11}/8Qe_{11}\Delta x_0. \tag{3}$$

The substitution of the constants $c_{11} = 86.74 \times 10^9$ N/m^2, $e_{11} = 0.171$ c/m^2, and $Q = 10^4$ gives

$$V(\text{volts}) = 0.634 \times 10^7 \Delta x_0(\text{m}). \tag{4}$$

It can be observed that this expression is independent of the oscillation frequency, but it varies largely with the Q value.

An $X[2\bar{1}\bar{1}0]$-cut 766.95 kHz quartz resonator was prepared from pure Z synthetic quartz with Au electrodes. The dimensions along $Y[01\bar{1}0]$ and $Z[0001]$ directions were 30 and 20 mm, respectively. If we consider an applied field $V_{\text{max}} = 20$ V, the displacement $\Delta x_0 = 31.5 \times 10^{-7}$ m, and $\Delta x_0/x_0 = 0.85 \times 10^{-5}$ (the resonator thickness $x_0 = 3.70$ mm). According to the Bragg law, this interplanar variation of the

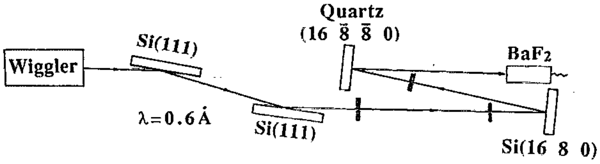

FIG. 1. X-ray optical representation for the experiment with quartz resonator diffraction (plane view).

crystal lattice is equivalent to the shift of the diffraction angle $\Delta\theta = \Delta x_0/x_0 \tan\theta_B$, where θ_B is the Bragg angle. For $\lambda=0.6$ Å, $\Delta\theta=8$ arcsec for $(16\bar{8}\bar{8}0)$ reflection.

II. EXPERIMENT AND RESULTS

The x-ray optical arrangement for diffraction on quartz resonator is presented in Fig. 1. The interplanar spacings $d_{1680}=0.3036$ Å (Si) and $d_{16\bar{8}\bar{8}0}=0.3070$ Å (quartz) form in practice an almost parallel (+,−) setting. The experimental setting for time measurement with a BaF_2 fast detector is represented in Fig. 2. Figure 3 shows the rocking curves of $(16\bar{8}\bar{8}0)$ profiles of static crystal ($V=0$) and oscillating crystal ($V_{max}=2.5$ V). The signal-to-background rate decreases and the integrated intensity increases with the applied field. Two main effects can be considered in X-ray diffraction by the vibrating crystal: (i) The variation of the interplanar spacing with time, $d=d(t)$, where elongation and compression movements take place, and there are two positions of d spacing satisfying the Bragg law for an oscillation period; (ii) the movement of diffracting planes with velocity $v=v_0 \sin \omega t$, which implies in broader diffraction profiles; the variation of the applied field V has no contribution on time positioning of diffraction profiles, but it does influence the broadening of the diffraction profiles.

In terms of x-ray diffraction, the periodical variation of d spacing with time is equivalent to the periodical variation of diffraction angle θ with time, which means an x-ray diffracted intensity modulation with time. If the alignment is set on the peak position (just at the Bragg angle of $\delta=0$), for an oscillation period T, it is possible to scan the angular interval $\pm\Delta\theta$ around this peak. The diffracted intensity will oscillate with time according to Fig. 4(a), where each pair corresponds to one oscillation period T. On the other hand, for the alignment set out of the peak position ($\delta\neq0$), the oscillation

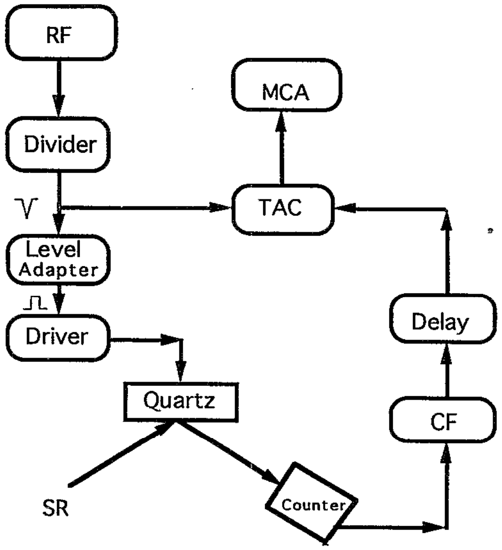

FIG. 2. Schematic arrangement of time measurement.

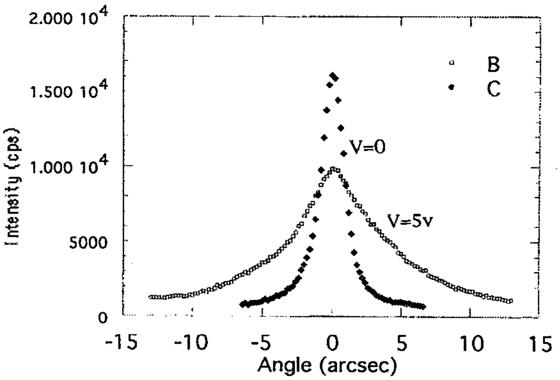

FIG. 3. Rocking curves of quartz resonator $(16\bar{8}\bar{8}0)$ reflection for static ($V=0$) and oscillating ($V_{max}=2.5$ V or $V_{peak\ to\ peak}=5$ V) crystal. The vertical scale intensity of profile B has to be multiplied by 0.5 due to the double counting time.

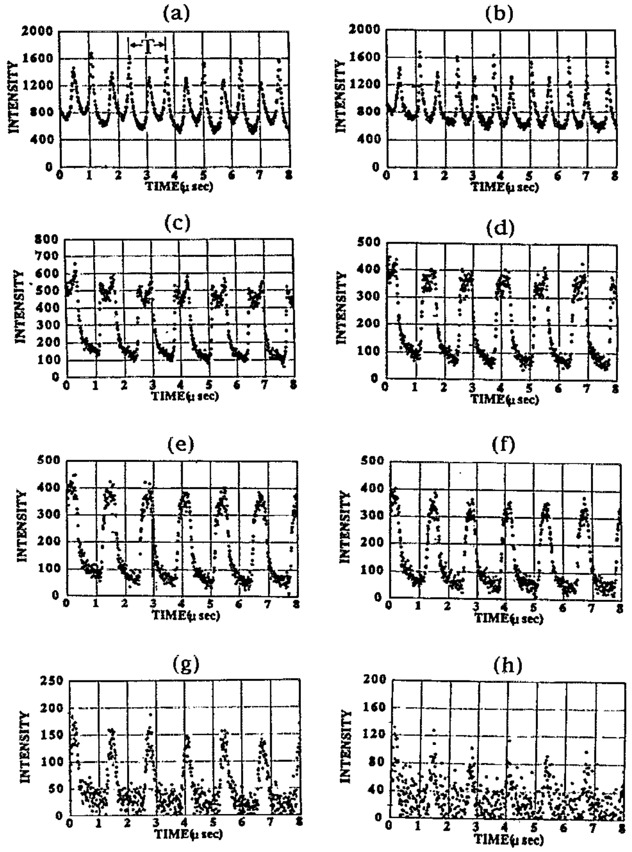

FIG. 4. Time modulation of SR diffracted by a 766.95 kHz resonator for a sequence of (a) $\delta=0$ (peak), (b) $\delta=1$ arcsec, (c) $\delta=2.5$ arcsec, (d) $\delta=3.5$ arcsec, (e) $\delta=4.5$ arcsec, (f) $\delta=6.0$ arcsec, (g) $\delta=9.0$ arcsec, and (h) $\delta=12$ arcsec.

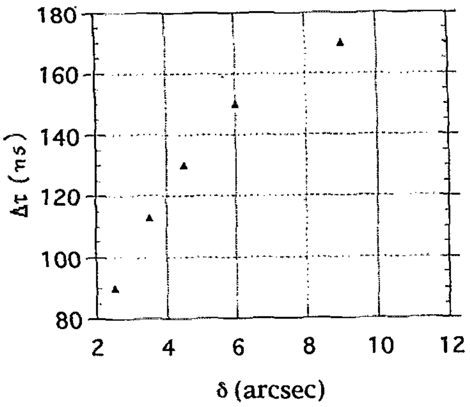

FIG. 5. Dependence of the interval of time for the intensity decay $\Delta\tau$ with δ.

profiles will shift in time. If we consider one period oscillation, the peaks forming a pair will shift to closer positions, towards each other. For δ=2.5 arcsec [Fig. 4(c)], the two profiles in a period are close enough to form a single-wave function. Figures 4(b)–4(h) show a sequence of SR time modulation for the alignment set at δ=1, 2.5, 3.5, 4.5, 6, 9, and 12 arcsec, respectively. We observe that the more distance from the peak the alignment is set, the closer the oscillation profiles for each pair become. The main characteristics observed from these data are: (i) for δ=4.5 arcsec, the peaks of the two profiles forming a single signal become coincident, (ii) the plotting of the signal/noise ratios of diffracted oscillation profiles as a function of δ reveals a maximum value around 7.2 for δ=8 arcsec; (iii) the time modulation width decreases as a function of δ values from ~600 ns (δ=2.5 arcsec) to ~260 ns (δ=9 arcsec); (iv) the ideal time gate should decay instantaneously, but in this case the time delay $\Delta\tau$ depends on the δ values with its minimum value around 90 ns for δ=2.5 arcsec (Fig. 5). $\Delta\tau$ was estimated from 80% of the maximum intensity to the background level. Obviously, these characteristics depend on the resonator diffraction planes and the magnitude of applied field. The signal-to-background ratio can be improved by using lower field amplitudes and also more perfect dislocation-free and high-Q value crystals. The present data were observed with $V_{\max}$=20 V, but for $V_{\max}$=1.5 V, when resonation starts, the signal/background ratio of the rocking curve increases by a factor of 5. A relevant point for use on SR time gate for nuclear resonant scattering is the possibility of adjusting the width of the signal, while maintaining the frequency constant.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Professor K. Kohra for his support and continuous encouragement, and Dr. K. Hamaguchi, Dr. M. Seya, and Dr. K. Nagai, Tokyo Communications Co. Ltd., for their helpful discussions.

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