Phase Modulation of ^{181}Ta Nuclear Resonant Synchrotron Radiation

In nuclear γ-ray resonance spectroscopy, ^{181}Ta stands for the highest energy resolution at low energies, and the ^{181}Ta nuclear resonant elastic scattering with synchrotron radiation has been successively observed at beamline **BL09XU** utilizing a stroboscopic detection technique and the heterodyne setup [1,2]. In the stroboscopic detection technique and the heterodyne setup, two Ta foils are placed in the beamline and one of these foils is given a variable velocity, and the Doppler effect shifts the resonance energy. The spectra are then taken as a function of Doppler velocity between the two Ta foils. When the Doppler-shifted resonance energy is equal to the energy in the other foil, an enhanced intensity of the delayed forward scattered photons is observed and a Mössbauer-like spectrum is created. The propagation of the synchrotron radiation through the ensemble of the resonant nuclei is a single-photon event and it is possible to observe phase modulation due to the change in optical path length or the deflection of the radiation or the small angle diffraction of the radiation for nuclear resonance in ^{181}Ta.

As shown in Fig. 1, a rotating Lucite wedge, which has periodic positive and negative slopes in the thickness change, is inserted between the two Ta foils and the Mössbauer-like spectra have been observed as a function of rotation speed from 0 to 10,000 revolutions per minute (RPM). When the thickness of the Lucite wedge is D and its refractive index is $N = n + i\,K$, the phase change by the variation in D is given by:

$$\phi = \phi_0 + \frac{(1+N)\,\omega_0}{c} \cdot \frac{dD}{dt} \cdot t \ ,$$

where c is the speed of light. Time dependent phase change induces a slight shift in resonance frequency that is given by $[(1-n)\omega_0]/c \times (dD/dt)$ [3]. Since the positive and negative slopes in the thickness of the Lucite wedge induce the positive and negative time dependences of the phase change, the 0th order resonant Mössbauer-like spectrum splits into two resonant peaks depending on the rotation speed and the refractive index of the Lucite wedge. Figure 2 shows the Mössbauer-like spectra as a function of the rotation speed of the Lucite wedge. When the rotation speed of the Lucite wedge is zero, the 0th order stroboscopic resonance is shown as a single peak at zero Doppler velocity. When the rotation speed of the

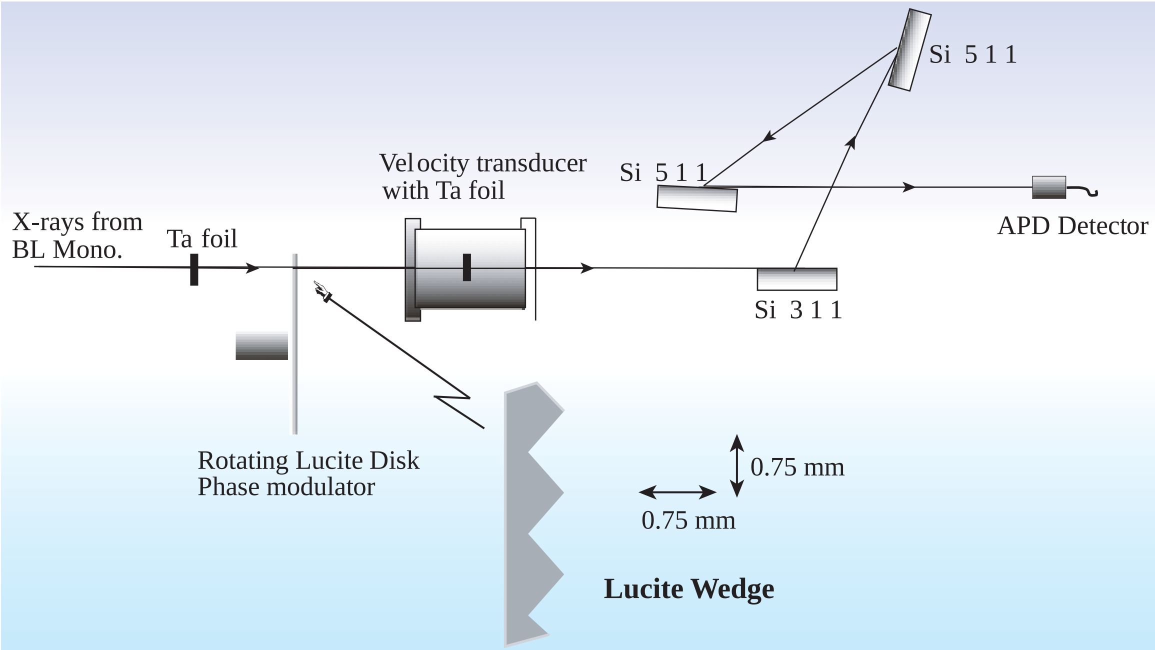

Fig. 1. Experimental setup for the phase modulation of the ^{181}Ta nuclear resonant synchrotron radiation. Rotation lucite disk is inserted between two Ta foils and the optical path length D for the 6.21 keV ^{181}Ta resonant radiation depends on the rotating speed.

Lucite wedge increases from 0 to 10,000 RPM, the split of the 0th order stroboscopic resonance has been observed clearly and the magnitude of the splitincreases with increasing rotation speed. Figure 3 shows the magnitude of the split of the 0th order stroboscopic resonance as a function of the rotation speed of the Lucite wedge. The split of the 0th order stroboscopic resonance depends linearly on the rotation speed. From the gradient of the line, the refractive index of the Lucite wedge ($1-n$) was determined to be (7.11 ± 0.14) × 10^{-6} for 6.21 keV of ^{181}Ta nuclear resonance energy.

The present investigation clearly shows the phase modulation of the nuclear resonant synchrotron radiation for ^{181}Ta nucleus and will open a new field for exploring the fundamental properties of the radiation in the X-ray and γ-ray regions. We have available sufficient frequency resolution to reveal the spectral changes produced by variously generated modulation frequencies, just as we have at radio frequencies, and also now in the X-ray and γ-ray regions where quantum effects predominate.

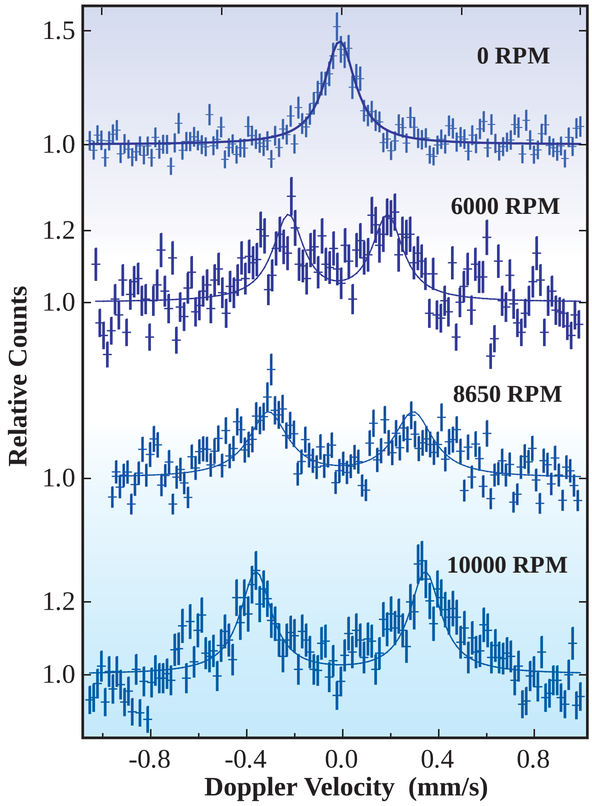

Fig. 2. Rotating Lucite wedge, which has periodic positive and negative slopes in the thickness change, has been inserted between two Ta foils and the 0th order stroboscopic spectra of the Ta foils have been shown as a function of the rotating speed (RPM) of the Lucite wedge. Doppler velocity is given for one Ta foil and the other foil is stationary.

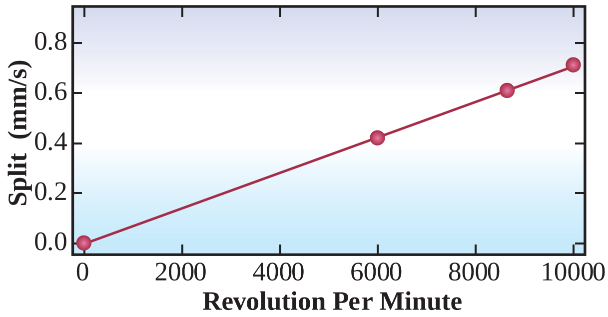

Fig. 3. Magnitude of split of 0th order stroboscopic resonance line as function of rotating speed (RPM) of the Lucite wedge. The magnitude of the split is twice that of the resonant shifts induced by the time dependent phase modulation.

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