Picosecond X-ray Stroboscopy Probing Crystal Lattice Deformation Induced by Pulsed Laser Irradiation

When the surface of a semiconductor crystal is irradiated by a femtosecond pulsed laser, the crystal lattice close to the surface is transiently deformed. The deformation propagates as a wavepacket toward the backside of the crystal, and is reflected and then comes back to the surface. This phenomenon is called acoustic pulse echoes, the technique of which has, for example, been anticipated as a tool for investigating the underlying structures in materials such as thin layers and defects, similar to sonar which can detect underwater objects. The optically induced acoustic pulse has been detected mainly by optical pump-probe methods with picosecond time resolution, which give integrated effects of deformation such as slope and displacement of the surface. However, the transient lattice strain in the material had not been directly observed by X-ray diffraction.

The pulsed nature of the synchrotron radiation (SR) and the synchronization technique between SR pulse and ultrashort laser pulse can take snapshots of X-ray diffraction profiles of crystal lattice motion with 40 ps resolution. The 27-m-long undulator beamline **BL19LXU** is equipped with a femtosecond pulsed laser system synchronized with the SR pulse timing. The time evolution of X-ray diffraction intensity can be obtained by changing the delay between the laser and X-ray SR pulses. The high repetition rate of the SR envisaged as a quasi-continuous wave is also useful for surveying the wide time range profile of target phenomenon using the multichannel scaling (MCS) technique. The use of both the multichannel scaling and the pump-probe technique offers the efficient time-resolved experiments such as pulsed echo observation, requiring picosecond time-resolution at large delay time.

Transient lattice strain produced by ultrashort laser pulse light generally includes inclination of lattice planes (i.e. shear strain) as well as dilation and contraction (i.e. longitudinal strain). The strain with both longitudinal and shear components cannot be quantitatively analyzed from the rocking curve measurement using a monochromatic and parallel incident X-ray beam. In the triple crystal diffractometry (TCD), the Bragg diffracted beam from the sample is angularly resolved by an analyzer crystal, so that the distribution of diffracted intensity in a reciprocal space is measured with high momentum resolution. The centroid shift of the diffracted intensity distribution in the direction parallel to the reciprocal lattice vector represents the longitudinal strain; the

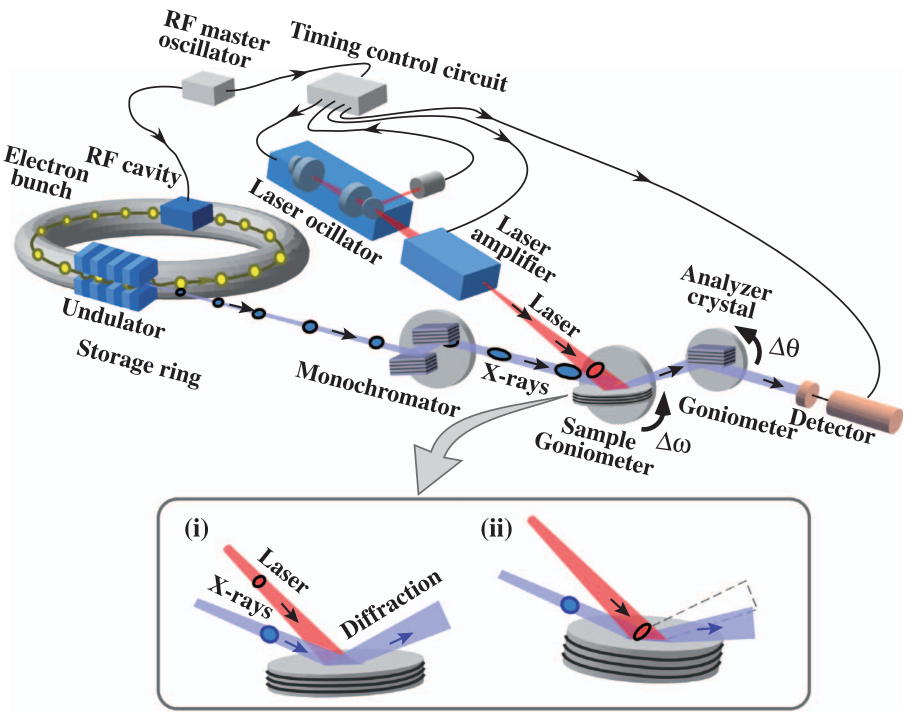

Fig. 1. Schematic illustration of experimental setup for picosecond time-resolved triple crystal diffraction.

shift in the perpendicular direction corresponds to the shear strain.

The intense synchrotron radiation produced at the beamline has enabled us to combine the time-resolved technique and the TCD [1]. The time-resolved TCD (TR-TCD) has been applied to the detection of acoustic pulse echoes that are generated in silicon and gallium arsenide semiconductor plates by femtosecond laser irradiation (Fig. 1) [2]. In Fig. 2, the obtained time-dependent longitudinal strain component for the pulse echoes showed that the polarity of the strain pulse was dependent on the optically induced initial stress, and that the bipolar pulse waveform was gradually deformed and broadened in the course of propagation. The pulse duration broadening was consistent with a boundary roughness for an unpolished plate (Fig. 3). This implies that the method can provide a new non-contact method to probe the roughness of optically inaccessible internal boundaries in materials.

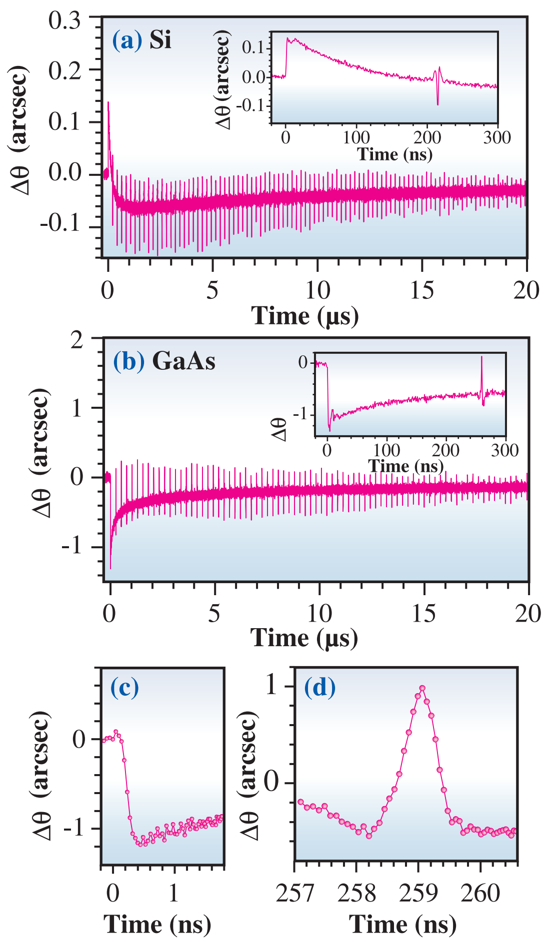

Fig. 2. Acoustic echoes for Si **(a)** and GaAs (**(b)**, **(c)** and **(d)**) wafers observed by multichannel scaling (**(a)** and **(b)**) and pump-probe technique(**(c)** and **(d)**).

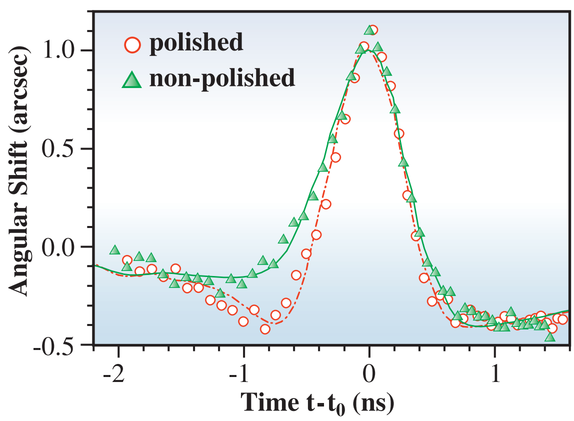

Fig. 3. Angular shift of the time-resolved X-ray diffraction profile of 1st echo pulse dependent on the back surface roughness.

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References

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