High-resolution X-ray Microdiffraction System for Characterizing Selectively Grown Layers Using a Zone Plate Combined with a Narrow Slit

A microdiffraction system using a zone plate (ZP) is suitable for characterizing selectively grown semiconductor epitaxial layers and multi-quantum-well (MQW) structures [1,2]. This is because the hard X-ray microbeam produced by a ZP has both a sub-micrometer beam size and a relatively low angular divergence of the sub-mrad order. Using such a system, we were able to measure the lattice strain distribution in InGaAsP metal-organic vapor-phase epitaxy (MOVPE) layers selectively grown on 3- and 4-µm-wide InP stripe regions with a strain sensitivity of about 1×10^{-4} [2]. Although this strain sensitivity was fairly good, further improvement was desired to enable more precise strain measurements.

We have therefore developed a new high-resolution microdiffraction system [3], which enabled high-resolution X-ray microdiffraction experiments. The system (Fig. 1) was set up at beamline **BL24XU** using a newly developed apparatus for hard X-ray microimaging and microdiffraction [4]. The monochromatized beam (15 keV) was focused using a phase ZP, which was fabricated by NTT Advanced Technology. The diameter, outermost zone width, tantalum absorber thickness, and focal length of the ZP were, respectively, 180 µm, 50 nm, 800 nm, and 108.9 mm at a photon energy of 15 keV. A platinum 20-µm-diameter pinhole was used as an order-sorting aperture (OSA). To suppress the beam divergence, a 5-µm-wide slit was placed in front of the ZP. Since only one part of the ZP was used, the beam divergence became smaller as shown in Fig. 1. The center of the slit was off-placed from the ZP center so that the OSA would eliminate unfocused and going straight beams. The focused beam that passed through the OSA enabled us to perform high-resolution X-ray microdiffraction experiments using a precise $\theta - 2\theta$ goniometer with sub-100-nm-resolved *XYZ* sample-positioning stages.

We measured the focused beam size using the knife-edge scan method. The result was 0.32 µm horizontally and 1.3 µm vertically at the full width at half maximum. The measured photon flux at the sample position was about 1×10^7 photons/s at 100 mA. The horizontal angular divergence of the focused beam, estimated by measuring a Si 400 rocking curve, was about 70 µrad.

To confirm the capabilities of this system, we measured the spatial non-uniformity of the strain and the period in as-grown InGaAsP multi-quantum-well (MQW) structures selectively grown by MOVPE (see the inset of Fig. 2). Three rocking curves were taken at the center position and positions ±0.5 µm from the center position of the 1.8-µm-wide stripe region.

The measured rocking curves are shown in Fig. 2. The log of the diffraction intensity was plotted *versus* $\Delta q/q_{\mathrm{InP}} = \Delta\theta \cot \theta_B$ in percentages (×100), where $\Delta\theta = \theta - \theta_B$ is the goniometer angle relative to the InP 400 Bragg peak angle. Also, $q_{\mathrm{InP}} = 2\pi/d_{\mathrm{InP}}$ is the momentum transfer, where d_{InP} is the lattice spacing of the InP 400 diffraction. In all rocking curves, the 0th- and ±1st-order satellite peaks of the MQW superlattice were clearly observed in addition to a

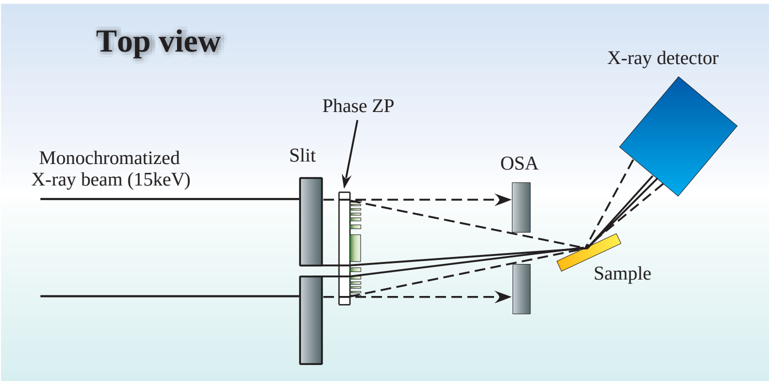

Fig.1. Schematic figure of the experimental arrangement. The monochromatized beam was focused by using a phase zone plate (ZP).

strong InP 400 peak at $\Delta q/q_{InP} = 0$. Since $\Delta q/q_{InP} = -\Delta d/d_{InP}$ from the Braggs' law, the strain perpendicular to the surface was directly determined from the 0th-order peak position. Also, the MQW period is proportional to the inverse of the separation between adjacent satellite peaks. We found that the spatial non-uniformity of the strain and the period in the MQW structure, i.e., the magnitude of the strain near the stripe edges, was greater than that at the stripe center, and the period near the stripe edges was longer than that at the stripe center. This indicates that the surface migration from the stripe edge to the stripe center is insufficient under these growth conditions [5].

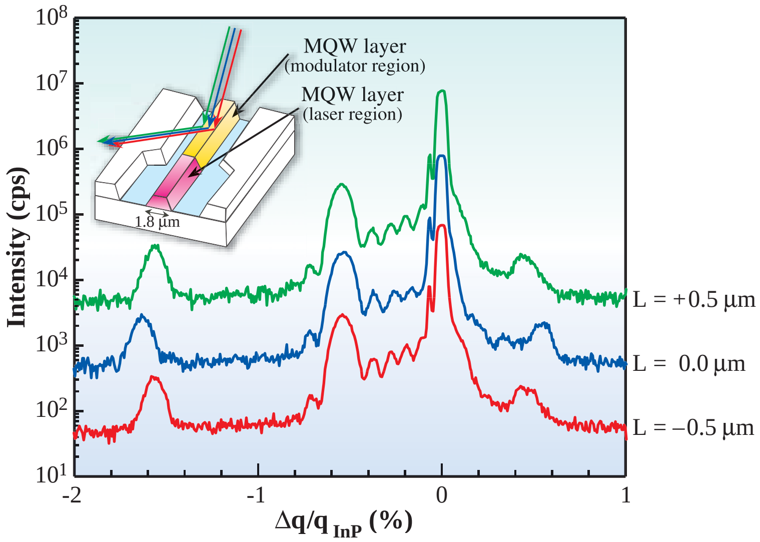

Fig. 2. A series of rocking curves taken at 0.5 µm intervals across the stripe region. The log of the diffraction intensity was plotted against $\Delta q/q_{InP}$. Note that the curves are vertically displaced for clarity.

Shigeru Kimura

SPring-8 / JASRI

E-mail: kimuras@spring8.or.jp

References

[1] Z. Cai *et al.*: Appl. Phys. Letters **75** (1999) 100.
[2] S. Kimura *et al.*: J. Jpn. J. Appl. Phys. **41** (2002) L1013.
[3] S. Kimura, Y. Kagoshima, T. Koyama, I. Wada, T. Niimi, Y. Tsusaka, J. Matsui and K. Izumi: Proc. of the SRI 2003, p.1275.
[4] Y. Kagoshima *et al.*: Proc. of the SRI 2003, p. 1263.
[5] Y. Sakata *et al.*: J. Cryst. Growth **208** (2000) 130.