HIGH-RESOLUTION MICROBEAM X-RAY DIFFRACTOMETRY APPLIED TO NARROW-STRIPE SELECTIVE MOVPE GROWN InGaAsP/InP LAYERS

The fabrication of advanced integrated multi-quantum-well (MQW) waveguide devices and high-performance laser diodes requires extremely uniform device characteristics. The selective metal-organic vapor phase epitaxial (MOVPE) growth of InGaAsP layers between a pair of dielectric stripe masks on a narrow stripe region (*e.g.* 0.5 to 2 μm wide) in the [011] direction of an InP(100) substrate (Fig. 1) is an attractive methods to fabricate photonic integrated devices. The multilayer thickness, composition, and lattice strain can be varied between different regions of the same wafer through variation of the dielectric mask width. In addition, an ideal optical waveguide structure surrounded by (100) and (111) crystal planes, can be formed automatically without the necessity of semiconductor etching. Utilizing this growth technique, however, the lattice strain of the selective MOVPE layers is difficult to control. High-resolution X-ray diffraction (HRXRD), possessing a high-angle and/or high-reciprocal space resolution, usually used as a strain characterization tool for epitaxial layers grown onto full wafers, cannot be used here due to insufficient spatial resolution. HRXRD with micrometer-scale spatial resolution is needed.

Recently, we developed an X-ray microbeam, possessing low angular divergence and narrow energy bandwidth, through the use of perfect-crystal X-ray optics in conjunction with undulator radiation X-rays from the synchrotron light source [1]. These features of the X-ray microbeam are suitable for HRXRD measurements. We have applied this X-ray microbeam to the strain analysis of narrow-stripe selective (NS) MOVPE InGaAsP layers, grown on 1.7-μm-wide stripe regions of InP between a pair of SiO_2 mask stripes, varying width from 4 to 40 μm.

MOVPE growth was performed on a patterned substrate. Pairs of 100-nm-thick SiO_2 mask stripes

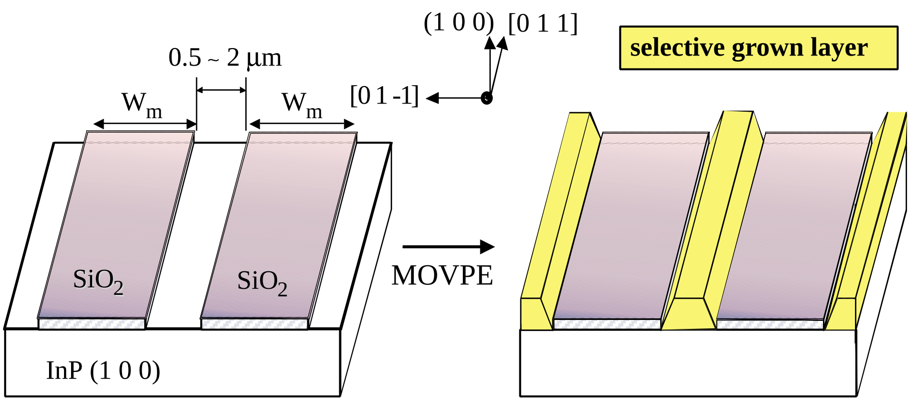

Fig. 1. Schematic figures of the InGaAsP layers grown by NS MOVPE.

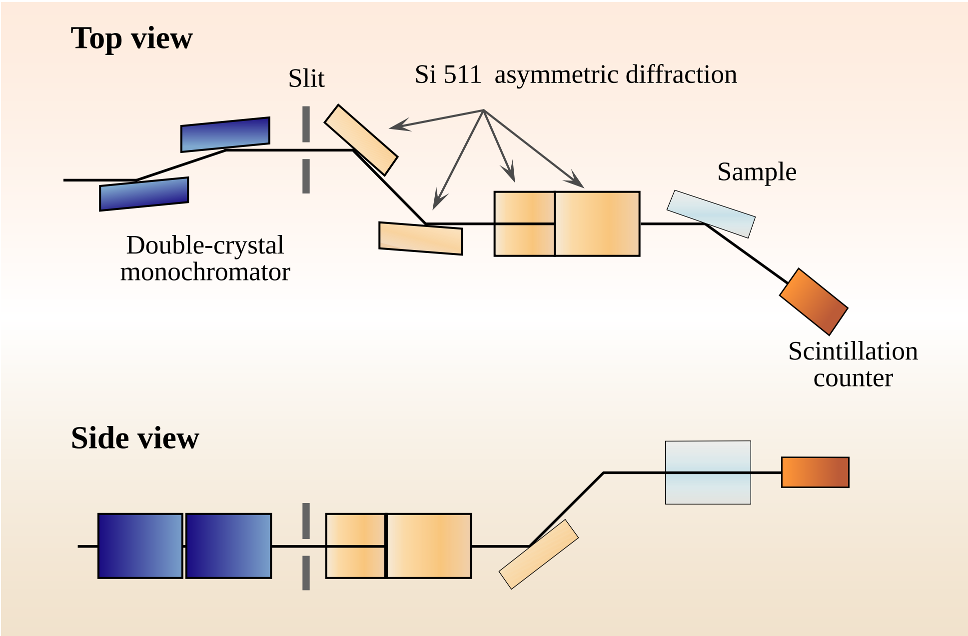

Fig. 2. The experimental arrangement of the optics set up at BL24XU.

were patterned along the [011] directions on an n-type InP(100) substrate. The mask stripe width (Wm) was varied from 4 to 40 µm while maintaining an open stripe width of 1.7 µm. Open stripe regions were separated by 300 µm. InGaAsP layers and InP cap layers were grown on the unmasked regions by atmospheric-pressure MOVPE.

The experimental arrangement (Fig. 2) was set up at the Hyogo beamline **BL24XU**, using a high-precision goniometer system with both horizontal and vertical rotation axes [1]. Producing an X-ray microbeam with low angular divergence and narrow energy bandwidth, we adopted the two-dimensional condensation of undulator radiation 15 keV X-rays, through successive asymmetric diffraction. This method obtained a beam of approximately 7.3 µm and 6.4 µm at the sample position in the horizontal and vertical directions, respectively. The estimated angular divergence was 7.7 µrad in the horizontal and 5.3 µrad in the vertical directions, respectively, with an estimated energy bandwidth of 66 meV. We performed HRXRD measurements using the microbeam in conjunction with a high-precision θ-2θ goniometer with submicron-precision XYZ sample positioning stages. Rocking curves around the InP 400 diffraction peaks were measured using angular steps of 0.004°.

The rocking curves from the NS MOVPE grown regions and the non-selective growth region of the sample revealed clear peak shifts in the InGaAsP layers as the mask width increased from the higher angle side to the lower angle side of the substrate peaks (Fig. 3). Analysis of these rocking curves enables the precise determination of strain ($\Delta d/d$) (Fig. 4), important for creating a well-controlled waveguide structure with excellent crystal quality.

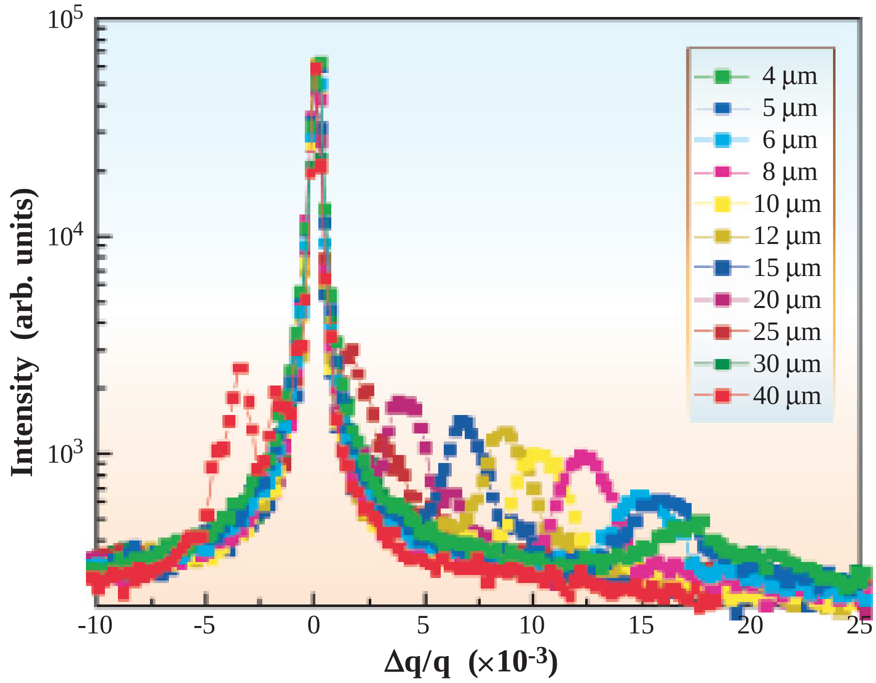

Fig. 3. A series of the rocking curves from the NS MOVPE growth regions.

Shigeru Kimura

Fundamental Research Laboratories,
NEC Corporation

E-mail: s-kimura@bl.jp.nec.com

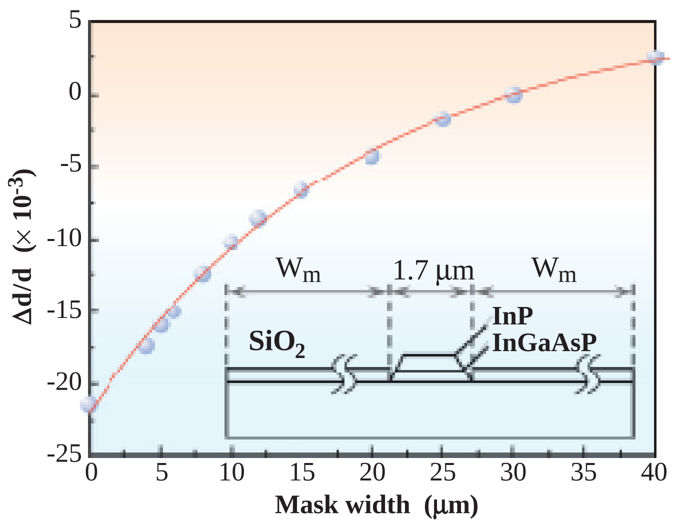

Fig. 4. Mask width dependence of the perpendicular strain $\Delta/\Delta d$.

References

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