Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 123-126 **B-4-7**

Polarization-Dependent Optical Absorption in $(AlAs)_{1/2}(GaAs)_{1/2}$ Fractional-Layer Superlattice Grown by MOCVD

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The Fractional-Layer Superlattice (FLS), which has a compositional periodicity normal to the direction of crystal growth, represents a new class of superlattice structure. We report the first measurement of the optical absorption spectrum in a thick FLS, grown by metal-organic chemical vapor deposition. The purpose of this measurement is to investigate carrier confinement effects in the direction parallel to the grown surface. The anisotropic optical absorption, observed at the band edge of the FLS, confirms that the compositional periodicity is formed parallel to the grown surface.

1. INTRODUCTION

Recent advances in crystal growth techniques have made it possible to control on a nanometer scale the compositional distribution perpendicular to the direction of crystal growth. An $(AlAs)_{1/2}(GaAs)_{1/2}$ Fractional-Layer Superlattice (FLS), which has a compositional corrugation parallel to the grown surface, has been successfully grown by metal-organic chemical vapor deposition (MOCVD)[1,2]. In the MOCVD growth, the lateral compositional distribution is controlled by alternately supplying gas sources to a GaAs (001) substrate misoriented in the $[\bar{1}10]$ direction. The lateral-controlled MOCVD process appears to be the most promising method of growing FLS.

In this paper, we report on the optical properties of $(AlAs)_{1/2}(GaAs)_{1/2}$ FLS grown by MOCVD. So far, photoluminescence measurements at cryogenic temperature have been used to assess carrier confinement effects in lateral structures[3-5]. In the present experiments, optical absorption was directly measured to investigate the carrier confinement effects in FLS at room temperature.

2. FRACTIONAL-LAYER SUPERLATTICE SAMPLE

The FLS was grown by MOCVD on a (001) vicinal GaAs substrate, misoriented by 2° in the $[\bar{1}10]$ direction. Metal-alkyl sources, TEGa and TEAl, were alternately supplied to grow the $(AlAs)_{1/2}(GaAs)_{1/2}$ FLS. The details of the crystal growth system and growth conditions are reported elsewhere[1,2]. Figure 1 shows a TEM bright field image of the (001) surface, observed from the direction of crystal growth. The FLS has a periodicity in the $[\bar{1}10]$ direction. The clear contrast of GaAs and AlAs regions without fluctuation of the superlattice distance is obtained in a wide area (0.5 μm × 0.4 μm). The measured period of the superlattice is 8 nm, which agrees well with theoretical expectation for the 2° misorientation[2].

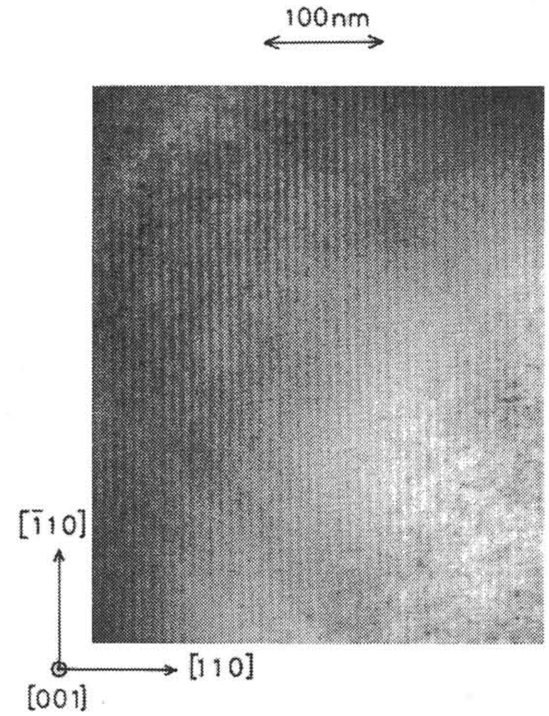

Fig. 1 Surface view of a TEM bright field image of an FLS. The observed area is 0.5 μm × 0.4 μm. The period of the FLS is 8 nm.

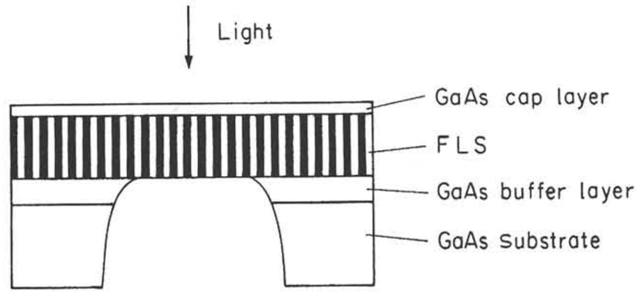

Fig. 2 Schematic cross-sectional view of the sample used in the optical absorption measurement. The thickness of the FLS is 250 nm.

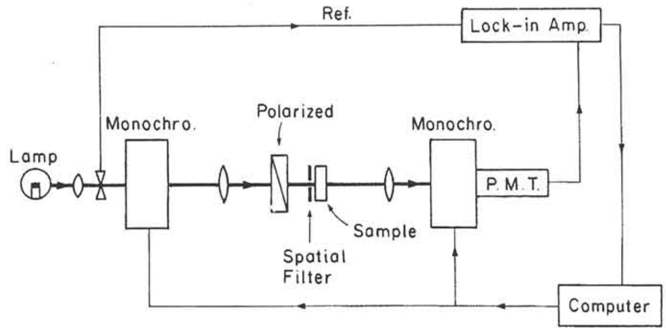

Fig. 3 Block diagram of experimental setup used in the optical absorption measurement.

3. OPTICAL ABSORPTION MEASUREMENT

An optical absorption measurement has been conducted to investigate the quantum confinement effect in the FLS. Figure 2 shows a schematic cross-sectional view of the sample used in the optical absorption measurement. The GaAs substrate was removed by selective etching to eliminate optical absorption from the substrate. The thickness of the FLS is 250 nm. The experimental setup used to measure the absorption coefficient is shown in Fig. 3. Light from a tungsten-halogen lamp, dispersed by a monochrometer with 1 nm resolution, is used as probe. The probe light is linearly polarized by a polarizer. The probe light illuminates the sample through a 200 μm aperture, normal to the surface of the epitaxial layer. The probe light transmitted through the sample was filtered by a monochrometer with a broad spectral width to suppress background light, and was then detected by a cooled S1-type photomultiplier tube. A lock-in detection method was used to improve the signal-to-noise ratio of the measurement.

4. RESULTS AND DISCUSSION

Figure 4 shows the transmission spectra at room temperature, measured by the probe field with electric vectors, parallel and perpendicular to the superlattice layers. The gradual undulations in the transmission spectra at wavelengths longer than 620 nm are caused by Fabry-Perot effects. At around 600 nm, the bandedge of the FLS is clearly observed as a sharp decrease in the transmission. A magnified view of the band edge region is shown in the inset of Fig. 4. The band edges for the orthogonal probe polarizations are spectrally separated.

The band edges associated with each polarization are shifted toward shorter wavelengths, compared with that calculated for an ideal $(AlAs)_{1/2}$ $(GaAs)_{1/2}$ FLS with rectangular compositional modulation. This is probably because of interdiffusion of Ga and Al at the interfaces.

Absorption spectra, calculated from the results in Fig. 4, are shown in Fig. 5. In the calculation, Fabry-Perot reflections were corrected for, taking into account the dispersion of the refractive index. Parameters used in the numerical calculation of Fabry-Perot effects are determined so that the calculated transmission spectra reproduce the experimental results in the transparent region with wavelengths longer than 620 nm.

The band edge for the polarization perpendicular to the superlattice layer shifts to the blue by 4 nm, compared with that for parallel polarization. This means that compositional modulation, deep enough to cause carrier confinement effects, is formed in the $[\bar{1}10]$ direction in this FLS. The band edge, assessed by optical absorption measurements, corresponds to the Γ-to-Γ transition. The absorption anisotropy observed at the band edge is attributable to the polarization dependence of heavy- and light-hole related transitions at the Γ minima.

Because of the carrier confinement effects, ground state energy levels of heavy- and light-holes, which are degenerate in bulk material, separate into individual levels in the quantum well structure. The heavy- and light-hole related transitions are known to have different polarization dependences[6]. The bandedge wavelength for the probe light with the electric field parallel to the quantum well layers is determined by the heavy hole-related transition, while that for the perpendicular probe field is determined by the light-hole related transition. The observed separation in the band edge wavelengths corresponds to the difference in the heavy- and light- hole confinement energies.

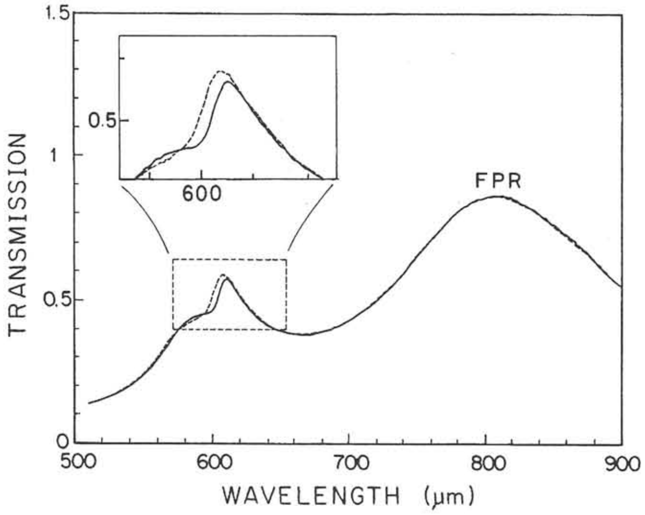

Fig. 4 Optical transmission spectra, measured by probe field, with electric vectors parallel (solid curve) and perpendicular (broken curve) to the FLS layers. The undulation in the transmission spectra at wavelengths longer than 620 nm is due to Fabry-Perot reflection oscillations.

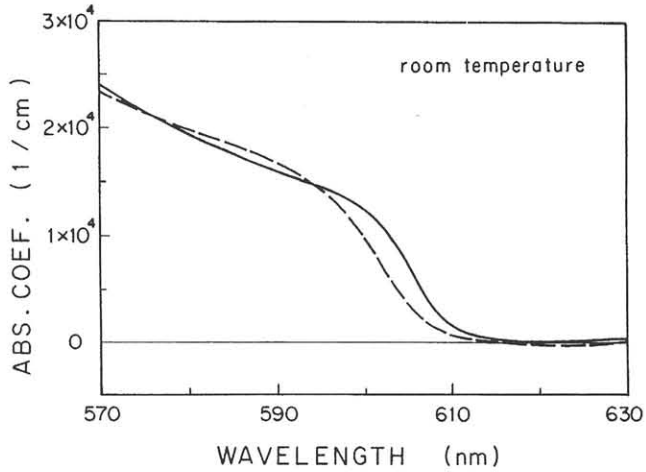

Fig. 5 Optical absorption spectra for probe lights with electric vectors parallel (solid curve) and perpendicular (broken curve) to the FLS layers, calculated from the experimental transmission spectra shown in Fig. 4.

5. CONCLUSION

An optical absorption measurement has been carried out to study carrier confinement effects in $(AlAs)_{1/2}(GaAs)_{1/2}$ FLS grown by MOCVD. Anisotropy in optical absorption has been observed perpendicular to the grown surface. This confirms the formation of a compositionally periodic structure parallel to the grown surface. The lateral-controlled MOCVD method appears to be a very promising technique for fabricating lateral corrugation of nm-scale on the semiconductor surface.

ACKNOWLEDGMENT

The authors would like to thank Drs. Hiroshi Kanbe and Arturo Chavez-Pirson for valuable discussions.

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