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Investigation of Strained GaInAsP Active Layer for AlGaInP Visible Laser

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We demonstrated the growth of GaInAsP/AlGaInP heterostructures by MOVPE at 710°C. The uniformity and controllability were good enough for laser fabrication. Integrated PL intensity showed that we could obtain longer wavelength by GaInAsP without serious degradation, rather than by GaInP. The time resolved PL and FWHM of 4K PL showed that the strained MQW had good interface qualities. An S^3 laser using our strained GaInAsP had a COD power of over 100 mW and good reliability at 30mW 50°C. The properties of the GaInAsP quaternary alloy are very well suited to visible lasers.

1. Introduction

To produce a high-power AlGaInP visible laser, we need a high COD level and a high characteristic temperature[1),2)]. These qualities need a long wavelength, near 690 nm with thin quantum well (QW) structures. Unlike GaInP ternary layers, GaInAsP quaternary layers allowed us to choose the active layer thickness, strain, and emission wavelength arbitrarily, but we have not seen any reports of GaInAsP active layers for AlGaInP visible lasers. In this study, we grew GaInAsP/AlGaInP heterostructures using high temperature metalorganic vapor phase epitaxy (MOVPE). We demonstrate the high-power operation of visible lasers with a strained GaInAsP active layer.

2. Crystal Growth and Characterization

We grew GaInAsP/AlGaInP double heterostructures by low-pressure MOVPE using a flow controlled stagnation point flow reactor system[3)]. Growth temperature was 710 °C and the operating pressure was 50 Torr. The V/III ratio was about 500 for active layers and about 300 for cladding layers.

We measured the uniformity of a GaInAsP epitaxial layer on a 2-inch wafer. Uniformity of thickness was ±1.5%, of photoluminescence (PL) wavelength was ±1nm, and of lattice mismatch was ±0.01% (Fig. 1). These uniformities are close to those for GaInP and good enough for fabricating optical devices.

Figure 2 shows the relationship between AsH_3/PH_3 flow ratio and As composition. The experimental As compositions were determined from the lattice mismatch and the Ga composition obtained from the vapor concentration of metalorganics. The experimental As compositions are well fitted by the logarithmic vapor-solid relationships[4)]. Figure 3 shows the relationship between wavelength and GaInAsP composition. The solid lines show calculated data considering the effect of strain and MQW shift. The experimental PL data are plotted using the As composition obtained from the vapor-solid relationship of Fig. 2. The experimental data are within ±3nm of calculated values. The GaInAsP allowed us to arbitrary choose the wavelength and strain with good controllability and reproducibility.

To examine the crystal quality, we investigated PL intensities, the full width at a half maximum (FWHM) of PL at room temperature, time resolved PL, and the FWHM of the 4K PL. We used a dye-laser (λ=590nm) as the PL excitation source and corrected the wavelength dependence of PL sensitivity using a tungsten lamp spectrum. We offset the (100) substrate orientation 6° toward (111)A to reduce natural superlattices. Figure 4 shows PL integrated intensities and thier FWHM versus wavelength at room temperature. Samples were all 9 nm thick double quantum well structures. The excitation power was about 10 kW/cm^2. We varied the strain for GaInP, and varied the As composition of GaInAsP while maintaining a constant compressive strain of 0.82%. The PL intensity of GaInP deteriorated significantly at wavelengths longer than 690 nm because of an excess strain over 1.1%. Although the integrated intensities of GaInAsP gradually decreased with increasing the wavelength, GaInAsP achieved wavelengths longer than 700 nm without serious PL degradation. The gradual decrease with highly excited PL may be caused by carrier overflow due to the band filling effect, because the FWHM of PL increases as shown in the figure. We can conclude that the GaInAsP has good optical qualities.

We looked at time resolved PL to measure the carrier lifetime (Fig. 5). The carrier lifetimes and interfacial recombination rate of the GaInAsP were close to those of GaInP.

We characterized the MQW's bandgap fluctuation, including interfacial roughness, by FWHM of 4K PL (Fig. 6). We varied As composition and strain to maintain a wavelength of about 690 nm. The FWHM gradually decreased with As composition. We can see that the GaInAsP has good interface qualities for strained MQW structures.

3. Application to a Laser

We tried a GaInAsP active layer in a one-step-MOVPE-grown real-index-guided laser[5] with excellent beam characteristics: small astigmatism and aspect ratio. This laser has a self-aligned current blocking structure made up of lateral p-n junctions[6] and has an inclined active layer nearly on the (411)A face on which natural superlattices are almost disordered. The active layer was a 9 nm thick GaInAsP double QW structure, with an As composition of about 0.12 and a compressive strain of 0.6%. We plotted the I-L characteristics of the laser (Fig. 7). The threshold current was 40 mA and maximum output power was over 100 mW at a wavelength of 688 nm. We conducted a preliminary APC aging test at 50°C and 30 mW (Fig. 8) and found no appreciable degradation over 500 hours. Our results demonstrate that GaInAsP quaternary layers have excellent qualities for visible lasers.

4. Conclusion

We grew GaInAsP/AlGaInP heterostructures by MOVPE at 710°C. Uniformity and controllability were good enough for practical applications. The integrated PL intensities of GaInAsP showed long wavelengths with good optical qualities. The time resolved PL and FWHM of 4K PL showed good quality interfaces in strained MQW structures. A laser using GaInAsP with an As composition of 0.12 and a low compressive strain of 0.6% had a high COD with high-power operation of 30 mW. We can conclude that GaInAsP quaternary layers have excellent qualities for visible laser applications.

References

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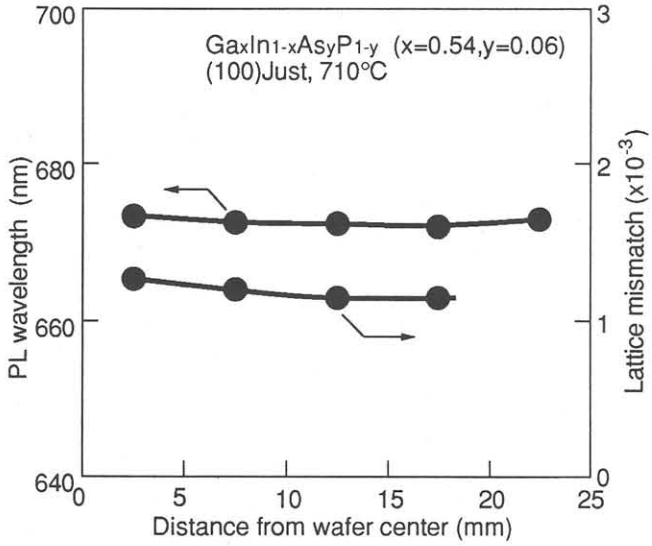

Fig. 1 GaInAsP uniformity over a 2-inch wafer

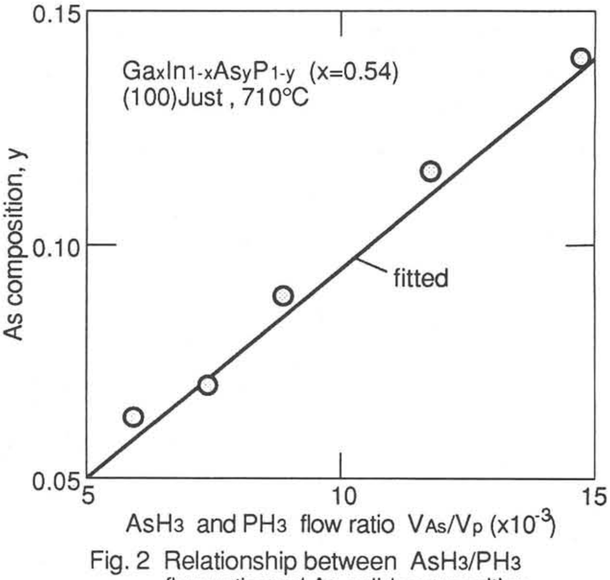

Fig. 2 Relationship between AsH3/PH3 flow ratio and As solid composition

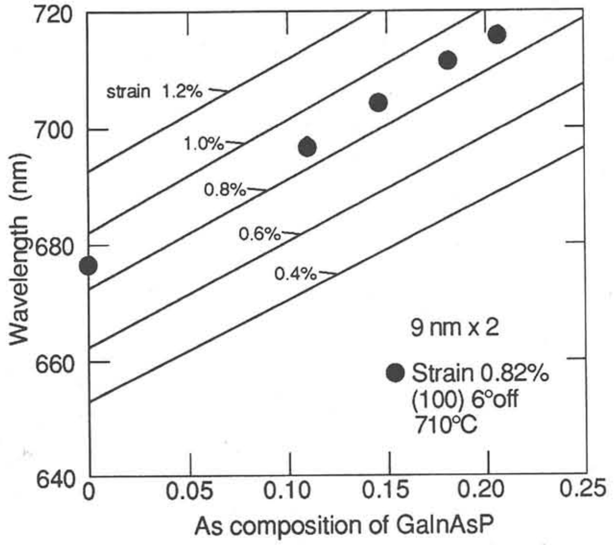

Fig. 3 Relationship between wavelength and As composition for GaInAsP

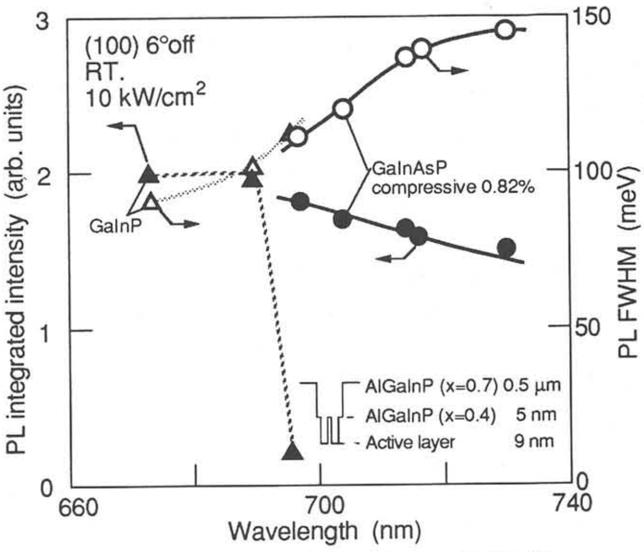

Fig. 4 PL integrated intensities and FWHM

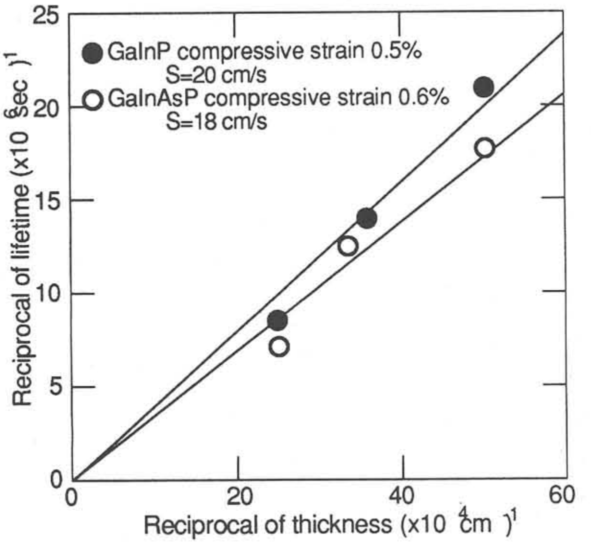

Fig. 5 Reciprocal of lifetimes from time resolved PL

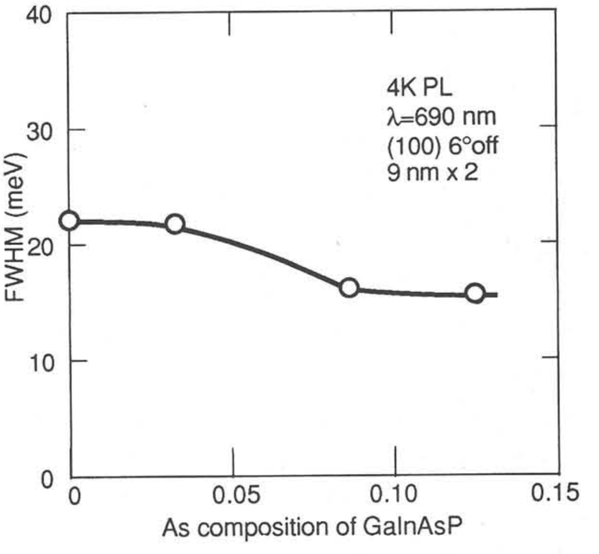

Fig. 6 FWHM of 4K PL for GaInAsP

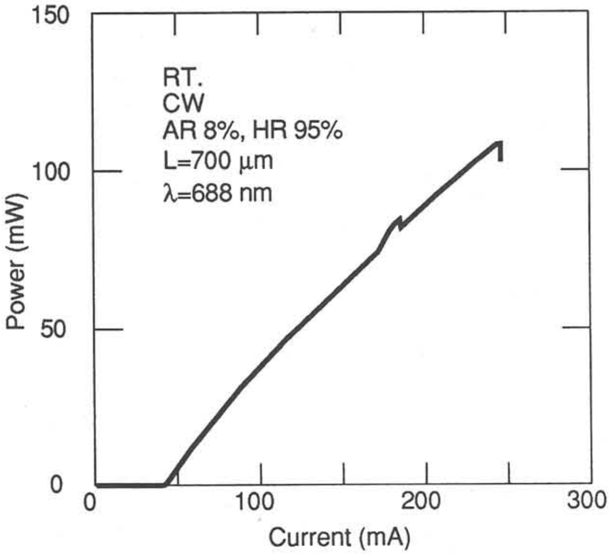

Fig. 7 I-L characteristics

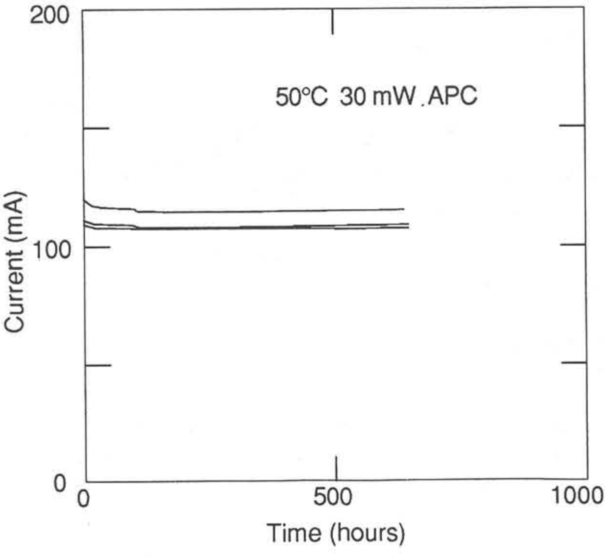

Fig. 8 Aging characteristics