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600nm Range GaInP/AlInP Strained Quantum Well Semiconductor Lasers Grown by GSMBE on Misorientation Substrates

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GaInP strained single quantum well (SSQW) lasers emitting in 630-700nm wavelength range were grown on misorientation substrates by gas source molecular beam epitaxy (GSMBE) using a shutter control method. The annealing and substrate misorientation effects of 633nm tensile SSQW lasers were investigated. The threshold current density (J_{th}) was decreased by annealing, with the resultant low J_{th} value of $555A/cm^2$.

1. INTRODUCTION

AlGaInP/GaAs red-light semiconductor lasers emitting in 600nm wavelength range are crucial devices for high capacity optical information storage, high speed printing, and so on. Recently, strained quantum wells were introduced into AlGaInP lasers[1] to realize very low threshold current density[1-3] and high light output[4], but which lasers were fabricated by metal organic chemical vapor deposition (MOCVD). Meanwhile, by gas source molecular beam epitaxy (GSMBE)[5], strained GaInP single quantum well (SSQW) lasers were prepared by use of a novel shutter control method[6]. And then it was clarified that the substrate misorientation was effective to improve the lasing performance of 660nm AlGaInP lasers with unstrained GaInP active layers[7].

In this paper, 630-700nm wavelength SSQW lasers with strained GaInP active layers are described, which were grown by GSMBE on misoriented (100) GaAs substrates[7,8]. Effects of annealing and substrate misorientation on the lasing performance of SSQW lasers are also discussed. By annealing 633nm tensile SSQW lasers after the growth, the threshold current density (J_{th}) was reduced from $850A/cm^2$ to $555A/cm^2$. Finally, the J_{th} performance of 633nm SSQW lasers are discussed in comparison with the reported J_{th} data[2,3].

2. FABRICATION OF STRAINED QUANTUM WELLS

Figure 1 shows a schematic diagram of strained single quantum well (SSQW) lasers fabricated here, which lasers consisted of the strained GaInP well and GaInP/AlInP superlattice cladding layers [9] and p- and n-AlInP cladding layers. Three types of lasers with 10nm thick GaInP active layers were grown on the (100) just and misoriented GaAs substrates with misorientation angle of 7, 15 and 25 degree from (100) toward [011] direction, respectively. That is, tensile and compressive SSQW lasers with the strain amount of -0.9% and +0.9%, respectively, and unstrained quantum well lasers were fabricated.

Strained GaInP quantum wells were grown without growth interruption by the shutter control method[6]. In this technology, the opening time of Ga

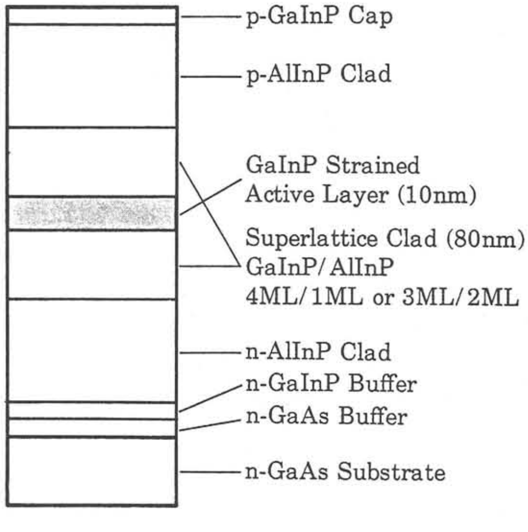

Fig.1. Schematic diagram of GaInP strained single quantum well (SSQW) lasers.

and In shutters was separately controlled during each one-monolayer growth period, as shown in Fig.2. Figure 2 shows the shutter time schedules for the growth of compressive and tensile strain and unstrain GaInP layers. For compressive strain case (see Fig.2(a)), for example, only Ga shutter was closed for a certain time span in every one-monolayer growth period, producing In-rich compressive-strain composition. Therefore, the strain amount can be controlled by the opening time ratio of Ga and In shutters.

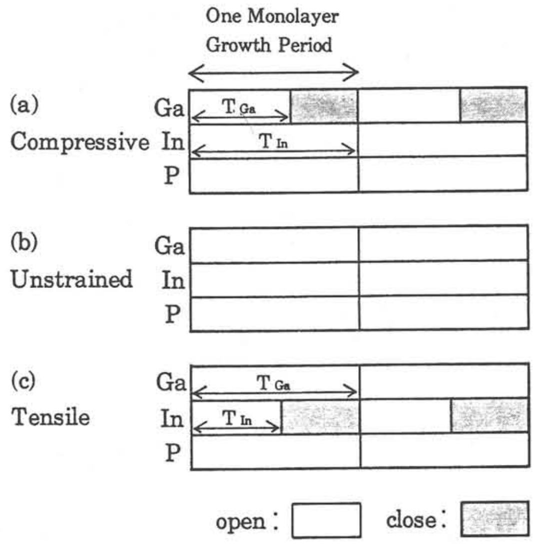

Fig.2. Time schedules of opening and closing Ga, In and P shutters for growth of GaInP compressively, unstrained and tensile strained layers.

The lasers fabricated here were evaluated under room temperature pulsed condition with the pulse repetition rate of 1kHz, and width of 100ns. The lasing wavelength and threshold current density of the GaInP SSQW lasers are shown in Fig.3, as a function of the strain amount. Compressive strain and unstrain lasers operated in TE mode with minimum J_{th} value of $330A/cm^2$ and $450A/cm^2$, respectively, and tensile strain lasers in TM mode with J_{th} of $850A/cm^2$.

3. ANNEALING AND SUBSTRATE MISORIENTATION EFFECTS

Annealing Zn doped AlGaInP layers grown by MOCVD can enhance the electrical activity of p type doping[10]. However, the annealing effect on Be doped AlInP layers grown by GSMBE was still not investigated. So, in order to clarify that, the Be doped AlInP layers, which were grown on various misorientation substrates, were annealed at $550^{o}C$ for 30min in a H_2/N_2 (H_2 5%) blend-gas atmosphere. The carrier density was evaluated by use of the Semiconductor Profile Protter (PN4300:BIO RAD MICROSCIENCE DIVISION) using $1HCl:20H_2O$

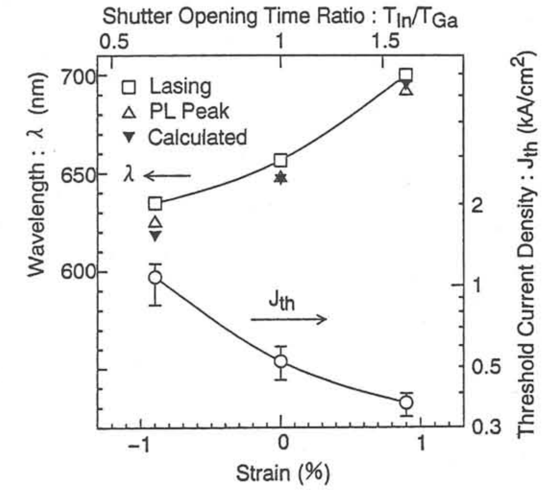

Fig.3. Lasing, PL peak and calculated wavelength and threshold current density (cavity length of 1mm) of GaInP SSQW lasers as a function of strain amount of GaInP strained active layers.

electrolytes. Figure 4 shows the carrier density for annealed and as-grown Be-doped AlInP layers, as a function of substrate misorientation angle (SMA). We note in Fig.4 that both annealing and substrate misorientation were effective to improve the electrical activity of Be acceptors.

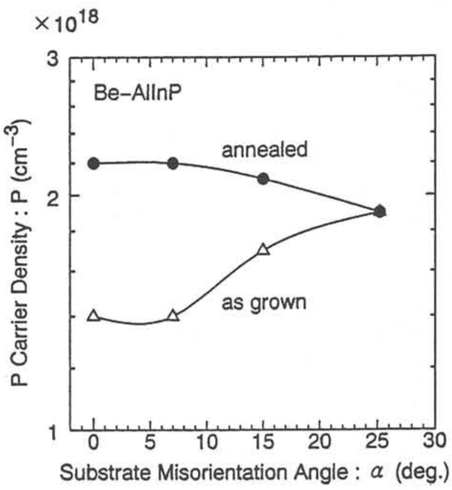

Fig.4 Carrier density of as-grown and annealed Be doped AlInP layers as a function of substrate misorientation angle.

Next, the annealing effect of 633nm GaInP tensile SSQW lasers was investigated. Figure 5 shows the J_{th} value for cavity length of 0.5mm and lasing wavelength of the as-grown and annealed lasers. Here, after annealing, the remarkable reduction of J_{th} was observed. On the other hand, for 660nm unstrain GaInP lasers, however the J_{th} value did not change by annealing. This fact can be explained as follows. The increase in carrier density of p-cladding layers by annealing pushed up the hetero-barriers to suppress the leakage current. This suppression was much more effective to reduce the J_{th} value for shorter wavelength 633nm lasers with smaller heterobarriers.

Figure 6 shows the injection current versus light output (I-L) characteristics and lasing spectrum of annealed 633nm tensile SSQW lasers. The J_{th} value of 555A/cm^2 was obtained for the cavity length of 1mm.

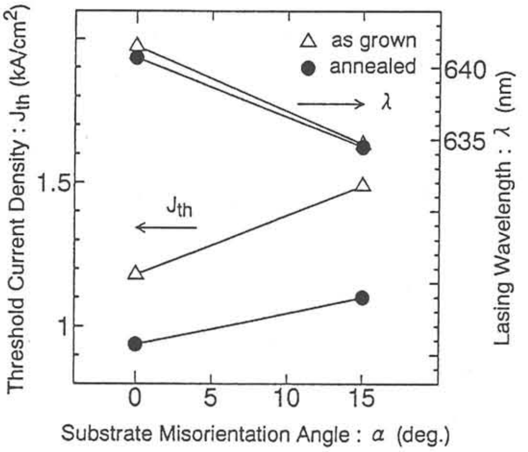

Fig.5. Threshold current density and lasing wavelength of as-grown and annealed GaInP tensile SSQW lasers as a function of substrate misorientation angle.

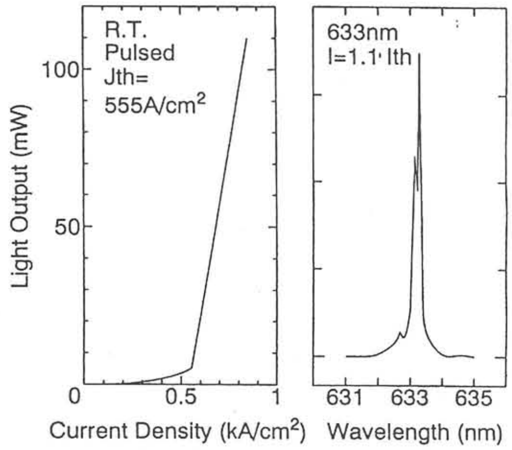

Fig.6. Injection current versus light output (I-L) characteristics and lasing spectrum of annealed GaInP tensile SSQW lasers.

The J_{th} data of 633nm range strained quantum well lasers including reported data[2,3] are summarized in Fig.7, where the data except for us were obtained by MOCVD. From this figure, we note that the GSMBE stands on the same technological stage as MOCVD in the fabrication of AlGaInP strained quantum well lasers.

4. CONCLUSION

630nm-700nm GaInP SSQW lasers were grown on misorientation substrates by GSMBE using a novel shutter control method. The annealing and substrate misorientation effects on SSQW lasers

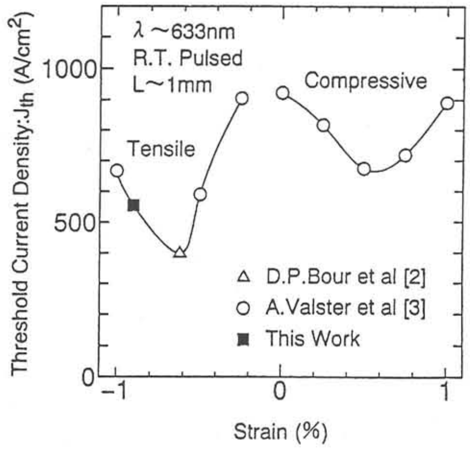

Fig.7. Threshold current density data of 633nm range strained quantum well lasers.

were investigated. Annealing crystals at 550°C for 30min in H_2/N_2 blend gas, can enhance the electrical activity of Be in p-AlInP layers, contributing to the reduction of threshold current density (J_{th}). The J_{th} value of 633nm SSQW lasers as low as 555A/cm^2 was obtained, which is comparable to the best data reported for the 633nm lasers grown by MOCVD.

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REFERENCES

[1] J.Hashimoto, T.Katsuyama, J.Shinkai, I.Yoshida, and H. Hayashi, Appl.Phys.Lett., 58 (1991) 879.

[2] D.P.Bour, D.W.Treat, R.L.Thornton, T.L.Paoli, R.D.Bringans, B.S.Krusor, R.S.Geels, D.F.Welch, and T.Y.Wang, Appl.Phys. Lett., 60 (1992) 1927.

[3] A.Valster, C.J.van der Poel, M.N.Finke, and M.J.B.Boermans, Conf.Digest of 13th IEEE Semiconductor Laser Conf. (1992) 152.

[4] H.B.Serreze, and C.M.Harding, Electron.Lett. 28 (1992) 2115.

[5] A.Kikuchi, K.Kishino, and Y.Kaneko, J.Appl.Phys., 66 (1989) 4557.

[6] I.Nomura, K.Kishino, and Y.Kaneko, Electron.Lett. 28 (1992) 851.

[7] A.Kikuchi, and K.Kishino, Appl.Phys.Lett., 60 (1992) 1046.

[8] A.Kikuchi, and K.Kishino, J.Cryst.Growth, 127 (1993) 9.

[9] A.Kikuchi, Y.Kaneko, I.Nomura, and K.Kishino, Electron. Lett., 26 (1990) 1668.

[10] H.Hamada, S.Honda, M.Shono, R.Hiroyama, K.Yodoshi, and T.Yamaguchi, Electron.Lett., 28 (1992) 585.