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# 637 nm cw Operation of Low Threshold Current AlGaInP Strained Single Quantum Well Laser Diodes

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Successful operation of a separate confinement heterostructure (SCH) AlGaInP/$(Al_{0.2}Ga_{0.8})_xIn_{1-x}P$ (x=0.43) strained single quantum well (SSQW) laser emitting 637nm has been achieved. Threshold current of 52mA at 25°C, the lowest value ever reported for AlGaInP lasers at this wavelength region was obtained by a $5\times230\mu m$ index guided laser diode.

## 1. Introduction

Shortening emission wavelengths of AlGaInP visible lasers is desirable for higher performances of optical information processing systems and the replacement of He-Ne gas lasers. There exist several difficulties in obtaining shorter lasing wavelengths due to two main reasons. First, the degradation of crystal quality with increasing Al contents of AlGaInP. Second, the small bandgap discontinuity between active and cladding layers which increases carrier overflow. Considerable effort has been devoted to shortening the emission wavelength of AlGaInP lasers[1)-9)]. The use of misoriented substrates which suppress the formation of the natural superlattice, incorporating with quantum well structures [5)] or AlGaInP active layer,[6),7)] were reported as an effective method in reducing the oscillation wavelength. Multiple quantum barrier (MQB) [8)] and high density p-doping into the cladding layer [9)] which increase the effective barrier height between the active and cladding layers have been demonstrated as the useful methods to suppress carrier overflow. The reduction of the threshold current (density) is also an effective approach in suppressing carrier overflow. Recently, we demonstrated the effective reduction of the threshold current (density) by introducing strained quantum well structures to the active region of the AlGaInP laser,[10),11)] and these structures were also applied to reduce the emission wavelength [12)-14)] and to increase optical output power [15)].

In this paper, we report on the low threshold current short wavelength continuous wave (cw) operation of the AlGaInP visible laser diodes. This has been achieved by incorporating the strained single quantum well (SSQW) structure consisting of AlGaInP with a high temperature growth which improves the crystal quality [16)] and increases the effective bandgap of this material system due to the suppression of the formation of the natural superlattice [17)].

## 2. Experimental

The epitaxial structure was grown by low pressure (60torr) organometallic vapor phase epitaxy (OMVPE) at 760°C on a Si-GaAs (100) substrate. It was found that high temperature growth improved optical quality of (Al)GaInP and increased the effective bandgap of (Al)GaInP. The photoluminescence (PL) peak energy of GaInP grown in our reactor increased about 50meV when the growth temperature increased from 700°C to 760°C. The PL peak intensity was also enhanced as the growth temperature increased.

Figure 1 shows the cross-section of the separate confinement heterostructure (SCH) SSQW laser. It consists of a 0.23 $\mu m$ Si-doped GaAs buffer layer, a 1.1 $\mu m$ Se-doped $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer, a 100Å undoped $(Al_{0.2}Ga_{0.8})_{0.43}In_{0.57}P$ SSQW active layer ($\Delta a/a=+0.65\%$) sandwiched between 800Å undoped $(Al_{0.5}Ga_{0.5})_{0.5}In_{0.5}P$ optical confinement layers, a 1.1 $\mu m$ Zn-doped $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer, and a 0.14 $\mu m$ Zn-doped $(Al_{0.1}Ga_{0.9})_{0.5}In_{0.5}P$ buffer layer.

$5\mu m$-wide stripe index guided lasers were fabricated by mesa etching and regrowth of a Si-doped GaAs blocking layer ($n=1.5\times10^{18}$ cm$^{-3}$) and a Zn-doped GaAs contact layer ($p=1.5\times10^{19}$ cm$^{-3}$). The p-side and n-side electrodes consist of Ti/Pt/Au and AuGe/Ni/Au, respectively. Laser facets were made by cleaving and the devices

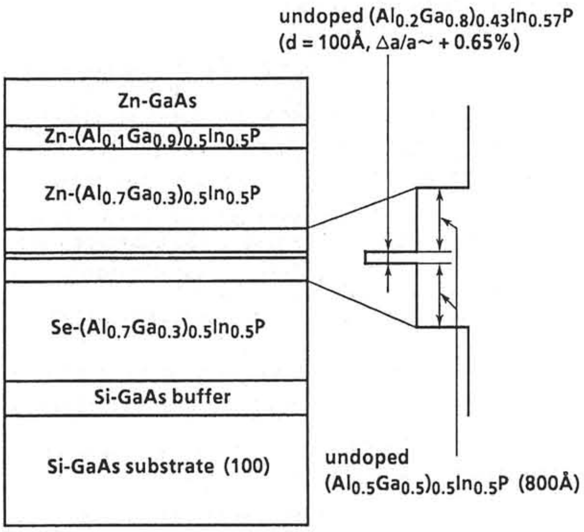


Figure 1 Cross-sectional view of the SCH-SSQW laser.

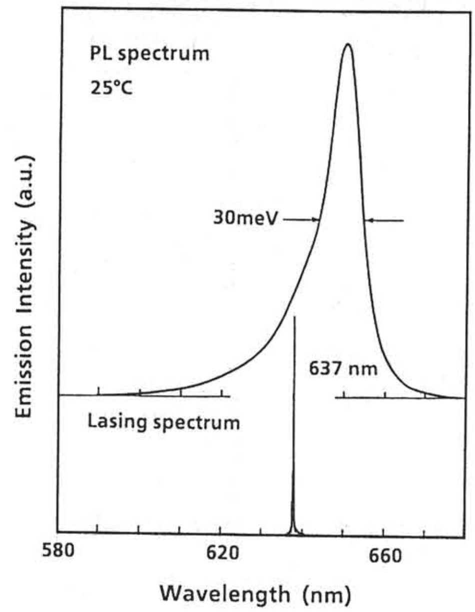


Figure 2 PL and the lasing spectra of the SSQW laser at 25°C

were mounted on a copper heat sink with Au/Sn solder in the p-side down configuration.

## 3. Results and Discussion

Figure 2 shows the PL spectrum obtained from the SSQW laser epitaxial wafer after removing the Zn-GaAs contact layer and the lasing spectrum of the SSQW laser at 25°C. The PL peak energy agrees with the calculated transition energy between conduction band (n=1) and heavy hole band (n=1). The sharp PL linewidth of 30meV also suggests that the $(Al_{0.2}Ga_{0.8})_{0.43}In_{0.57}P$ layer is coherently strained without the generation of misfit dislocations and no significant Zn diffusion from the p-cladding layer to the active region occurs. Continuous wave (cw) operation was obtained at 637nm. This is among the shortest wavelengths reported for AlGaInP lasers operating at room temperature. The emission wavelength is 13nm shorter than the peak wavelength of the PL spectrum due to the band-filling effect.

Figure 3 shows the temperature dependence of output power against cw current characteristics for the SSQW laser (5×230$\mu$m). The threshold current at 25°C was 52mA, which is, to our best knowledge, the lowest threshold current ever reported for AlGaInP lasers with emission wavelength shorter than 640nm. Lasing was observed up to 42°C. The thermal resistance estimated by the pulse measurements was about 39°C/W. The improvement of the maximum operating temperature can be expected by using a heat-sink having a high thermal conductivity such as diamonds and increasing the cavity length [18]. The slope efficiency was 0.24 W/A and the characteristic temperature was 46K (15-30°C).

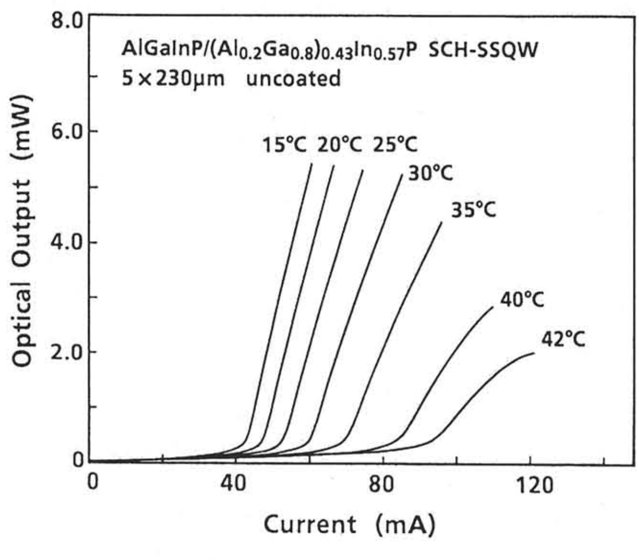


Figure 3 Temperature dependence of I-L characteristics of the SSQW laser (5×230$\mu$m)

Several devices having the same structure as that shown in Figure 1, except for the active layer which consists of different Al contents, have been processed as broad contact devices with a dimension of 80$\mu$m×500$\mu$m, to investigate the dependence of threshold current density ($J_{th}$) on oscillation wavelengths. Figure 4 shows the relationship between the $J_{th}$ measured under pulsed conditions (800nsec, 2kHz) and oscillation wavelengths. Although, the $J_{th}$ tends to increase rapidly at wavelengths

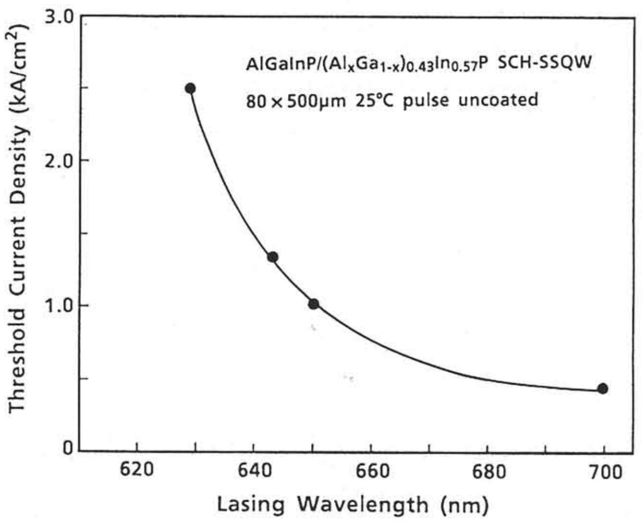


Figure 4 Relationship between threshold current densities of SSQW lasers and their lasing wavelengths.

below 640nm, the $J_{th}$ still remains relatively low ($J_{th}$=2.5kA/cm$^2$ at 629nm) compared with those of conventional DH structure devices (3~4kA/cm$^2$). These results indicate that strained quantum well structure incorporated with an AlGaInP active layer grown at high temperature is very effective in reducing the threshold current density even at shorter wavelength.

## 4. Conclusion

AlGaInP SCH-SSQW lasers consisting of the AlGaInP compressive strained single quantum well have been fabricated. Successful room temperature cw operation at 637nm with a threshold current of 52mA was obtained. The combination of high temperature growth which improves the crystal quality, and the strained quantum structure which contributes to the reduction of the threshold current, is a promising approach in shortening the oscillation wavelength of AlGaInP lasers. Further improvement of the device performance at shorter wavelengths will be made by optimizing the device structure and introducing the strained multiple quantum well active layers.

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