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630 nm Wavelength GaInP/AlInP Multi-Quantum Well (MQW) Lasers Grown on Misorientation Substrates by Gas Source Molecular Beam Epitaxy (GSMBE)

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GaInP/AlInP MQW visible lasers emitting at the 630nm wavelength range were grown on misorientation substrates by gas source molecular beam epitaxy (GS-MBE). For the lasers, dependences of threshold current density on the lasing wavelength, the well number, and the substrate off-angle were investigated. It was found that the threshold current density, J_{th} decreased remarkably with increasing the substrate off-angle. Very low threshold current density operation as low as $2.0kA/cm^2$ was obtained with the lasing wavelength of 629nm, without any strain effects. But here the (100) 15°off-angle GaAs substrates toward [011] direction was utilized. What we believe is, the J_{th} value of $2.0kA/cm^2$ is the lowest one ever reported for the 630nm wavelength visible lasers.

1. INTRODUCTION

Short wavelength visible semiconductor lasers are one of crucial devices for realizing the high performance optical information processings. On the other hand, visible semiconductor lasers, with very high spectral-purity, also emitting at 633nm in wavelength, is of great worth from the aspect of optical sensing applications, due to the potential ability of the laser replacing He-Ne gas lasers. The 630nm wavelength AlGaInP lasers[1] were studied extensively using MO-CVD techniques thus far, but the threshold current density, J_{th} of these lasers was relatively high, typically to be $3{\sim}4kA/cm^2$. Very recently, however, by use of strained active layers, low J_{th} values of $1.7kA/cm^2$ and $1.2\ kA/cm^2$ were obtained for 634nm[2] and 637nm wavelength lasers[3], respectively.

In this study, the gas source molecular beam epitaxy (GS- MBE)[4], was employed to fabricate 630nm wavelength visible lasers. The 630nm GaInP/AlInP multi-quantum well (MQW) lasers were grown on the misorientation substrates resulting in the drastic reduction of J_{th}. By use of the large off-angle substrates (i.e. 15°off from (100) toward [011] direction), the very low J_{th} value of $2kA/cm^2$ was obtained for three quantum well (QW) type lasers, even without the strain effect. In this case the lasing wavelength was 629nm. Dependencies of threshold current density on the lasing wavelength, and the well number were also investigated. We found that the J_{th} was minimized for three QW lasers.

2. FABRICATION

In the GS-MBE system, molecular beams of the group III materials (Al, Ga, In) were supplied as conventional solid sources, while the group V phosphorus beam was obtained through the gas cracking cell using the 100% pure PH_3 gas[4]. The n and p type dopants were Si and Be, respectively.

Figure 1 shows a schematic diagram of GaInP/AlInP MQW lasers fabricated here, where the MQW active layers consisted of the GaInP well and GaInP(7Å)/AlInP(7Å) short period superlattice barrier (SLB) layers, all lattice-matched to GaAs substrates. The MQW active layers were covered, first by GaInP/AlInP superlattice cladding (SLC) layers[5], in order to reduce the interface non-radiative recombination. The thickness of p and n type AlInP cladding layers were

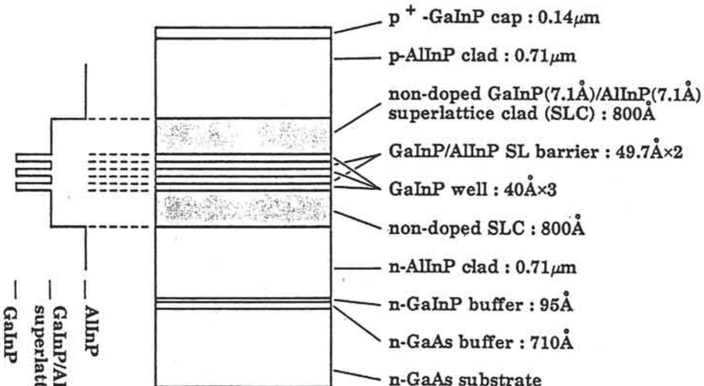

Fig.1. Schematic diagram of 630nm GaInP/AlInP MQW-SLC LDs.

both to be 0.71μm. The lasers were grown simultaneously on the (100) just, 7° off, and 15° off GaAs substrates, respectively, by mounting all substrates on the same Mo-block. Various MQW lasers with the different well width and well number were fabricated for the same barrier thickness (49.7Å). The growth temperature was 490~500°C, and the growth rate was 0.86μm/h.

3. Results and discussion

Photoluminescence (PL) spectra from the MQW active layers were measured at room temperature. Figure 2 shows the PL peak intensity for five-QW type lasers as a function of the substrate off angle. Note that the increased PL peak intensity was brought about by increasing the substrate off angle. Such increase in PL intensities can be explained by two growth mechanisms given as follows: It was known for the AlGaAs quantum wells that the hetero-interface sharpness was improved by use of misoriented substrates through the promoted step flow growth. Furthermore, the increased step number may enhance the epitaxial growth, reducing the impurity incorporation into the crystal, with the resultant improvement in crystal quality.

On the other hand, we should notice that the possible increased electrical activity of dopants on misorientation substrates can enhance the hetero-barrier height, and as the result the lasing performance can be improved.

The PL peak intensity of the above samples is also plotted as a function of the PL peak wavelength, as shown in Fig.3. The rapid decrease in the intensity occurred below 600nm in wavelength may be caused by the reduced emission efficiency going down to the Γ-X cross over point. But in the wavelength range

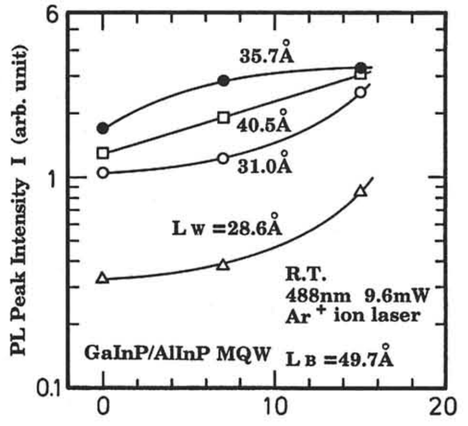

Fig.2. PL peak intensity as a function of the substrate off angle for GaInP/AlInP MQW active layers with various well widths.

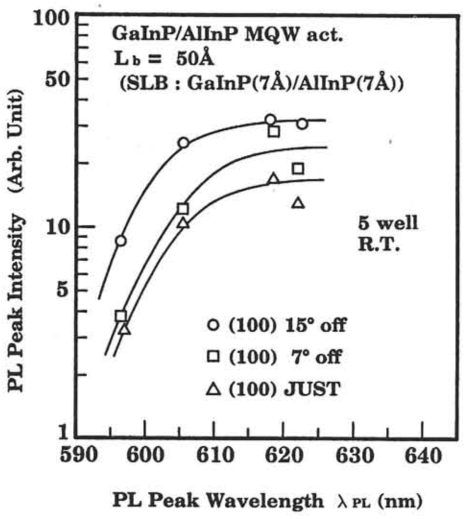

Fig.3. PL peak intensity from GaInP/AlInP MQWs as a function of PL peak wavelength.

above around 605nm, the PL intensity did not change so much, indicating the similar optical quality.

The lasers were evaluated as the broad contact type chips with the cavity length of ~400μm, under the pulsed condition (1kHz, 100nsec) at room temperature. For the lasers grown on the (100) 15° off substrates, the threshold current density were reduced as a factor of 1.4~2, compared with those on (100) exact substrates. Thus, in the following discussions, only the lasing performance of the lasers on 15° off substrates will be described.

Figure 4 shows the threshold current density as a function of the lasing wavelength, for five and three QW type lasers. As shortening the lasing wavelength, the J_{th} was increased exponentially. This rapid deterioration of J_{th} may be caused, mainly by the increased current leakage over hetero-barrier[6], and possibly, in part by the reduced emission efficiency due

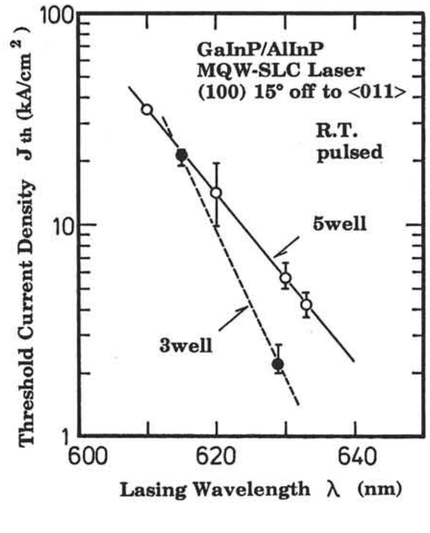

Fig.4. Lasing wavelength dependency of the threshold current density of five-QW type lasers.

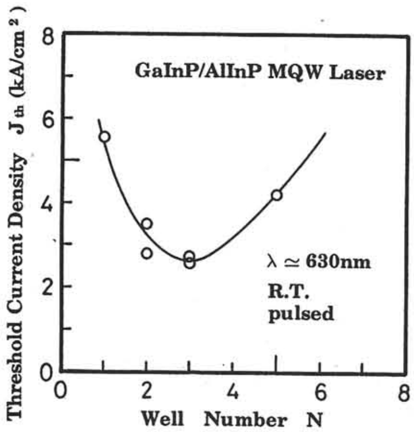

Fig.5. The threshold current density versus well number for GaInP/AlInP MQW lasers.

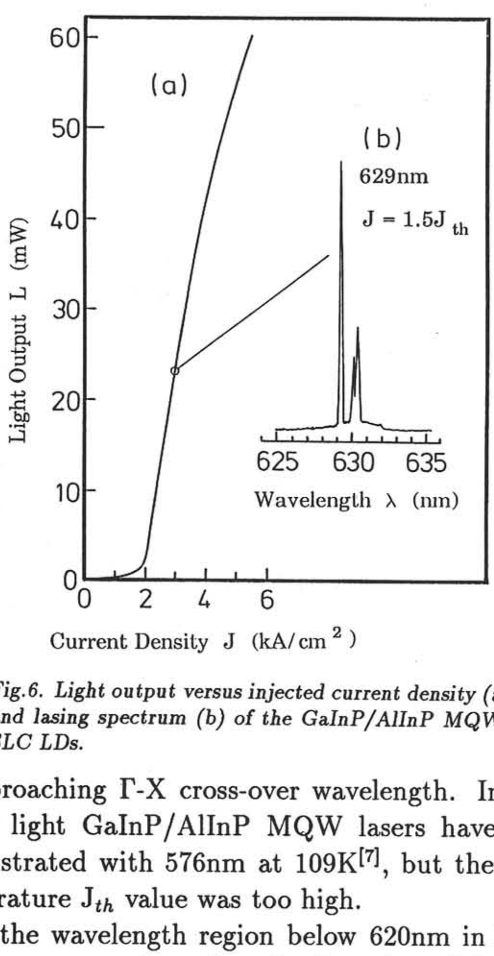

Fig.6. Light output versus injected current density (a) and lasing spectrum (b) of the GaInP/AlInP MQW-SLC LDs.

to approaching Γ-X cross-over wavelength. In fact, yellow light GaInP/AlInP MQW lasers have been demonstrated with 576nm at 109K[7], but the room temperature J_{th} value was too high.

In the wavelength region below 620nm in Fig.4, two curves crossed, so that the J_{th} value of five-QW lasers seemed to be lower than that of three-QW lasers. It suggested that the reduced optical confinement factor for the small well-number lasers pushed up the J_{th} in the narrow well-width (i.e. the shorter wavelength) region.

The well number dependency of the threshold current density was investigated, for 630nm MQW lasers, as shown in Fig.5. The threshold current density was minimized at three quantum-wells, i.e., to be 2.6kA/cm^2 on average. And the minimum threshold current density was 2.0kA/cm^2, and in this case the wavelength was 629nm. On the other hand, note that the minimum J_{th} for the (100) just substrate was 2.9kA/cm^2.

Figure 6 (a) and (b) show the light output versus current (L-I) characteristics and lasing spectrum of the lasers with J_{th} = 2.0kA/cm^2, respectively.

4. Conclusion

GaInP/AlInP MQW lasers were grown on the misoriented (100) GaAs substrates toward [011] direction by GS-MBE. The substrate off angles dependencies of PL peak intensity and the threshold current density were investigated. With increasing the substrate off angle, the laser performance such as threshold current density was improved (at least up to 15° off). The reduction of threshold current densities owing to the substrate misorientation may relate to the crystal growth mechanism, concerning the doping activation characteristics and suppressed spontaneous ordering of crystals, and the improved crystal quality due to the step flow growth. The threshold current density for the MQW lasers was exponentially increased as shortening the lasing wavelength. The lowest threshold current densities of 2.0kA/cm^2 was obtained for 629nm wavelength lasers with three quantum wells grown on 15° off angle substrates.

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