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One-Step-MOVPE-Grown Index-Guide GaInP/AlGaInP Visible Laser Using Simultaneous Impurity Doping

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We found simultaneous doping of AlGaInP with Zn and Se on differently orientated faces gave high carrier concentration layers of both p- and n-type in one process. We used simultaneous doping to fabricate a one-step-MOVPE-grown GaInP/AlGaInP visible laser with a real-index-guide structure. We achieved an effective self-aligned current-confinement structure in the AlGaInP cladding layer, and obtained a low threshold current of 18 mA. This laser also had stable transverse-mode oscillation and good reliability.

1. Introduction

Nonplanar growth on patterned substrates is a promising technique for fabrication of novel device structures. In this growth technique, lateral p-n junctions[1)-4)] enable to simplify growth procedures for device fabrication. Simultaneous doping with different impurities produces the lateral p-n junction due to the large differences in the orientation dependence of acceptor and donor dopant incorporation[4)]. A one-step-MOVPE-grown laser which used simultaneous-doping of InP has been demonstrated by Bhat et al.[5)]. The simultaneous doping technique on a patterned substrate is also useful for short wavelength lasers, because the lateral p-n junction on a patterned substrate gives a current blocking layer, and the patterned area forms a real index-guide structure. We reported strong dependences of Zn, Mg, and Se incorporation on substrate orientation in AlGaInP[6)]. We also found simultaneously doped AlGaInP had good optical and electrical qualities[7)]. In this paper, we report a one-step-MOVPE-grown visible laser using simultaneous doping of Zn and Se on a patterned substrate.

2. Simultaneous doping

We grew simultaneously doped layers using a vertical low-pressure MOVPE system. The growth temperature was 710 °C and the operating pressure was 50 Torr. The V/III ratio was about 300. The growth rate was 2 μm/hour. The source gases used for Zn and Se were DMZn and H_2Se. The substrate orientation were varied from (100) to (311)A. The carrier concentrations of simultaneously doped layers were characterized by C-V measurements.

Figure 1 shows carrier concentration dependences on substrate orientation for Zn singly doped, Se singly doped, and Zn and Se simultaneously doped layers. The conditions for simultaneous doping of Zn and Se were the same as for single doping. The Zn incorporation ratio increased with the offset angle, whereas that of Se decreased. For simultaneous doping, the conduction type was changed from n-type on a (100) plane to p-type on a (311)A plane by compensation of the p- and n- type impurities. Since there are the large differences between the Zn and the Se incorporation ratio on both the (100) plane and the (311)A plane, we can obtain high carrier concentration layers of both p-type and n-type at the same time with a low compensation ratio. Since the patterned substrate faces have different orientations, simultaneously doped layers on a patterned substrate can form lateral p-n junctions in AlGaInP.

3. Laser fabrication and structure

Figure 2 is a cross-sectional SEM image and a schematic of the laser structure. In this image, the dark region is an n-type region and the bright region is a p-type region. This laser has a inclined active layer on the (311)A face and this area forms a real-index-guide structure. The lateral p-n junctions using the simultaneous doping form a current blocking structure.
We fabricated the laser using following simple process. We chemically wet etched a Si-doped

n-type GaAs substrate into a terraced patterned substrate with a (311)A inclined face. Next, we grew an AlGaInP n-type cladding layer, GaInP active layer, AlGaInP p-type cladding layer with a simultaneous doped lateral p-n junction, and GaAs p-type contact layer.

The simultaneously doped layer produced a clear lateral p-n junction pattern reflected by the grown crystal's orientation. This lateral p-n junction formed an almost identical self-aligned current blocking structure without optical absorption loss. To obtain highly efficient current confinement, we also made a simultaneously doped layer on the active layer to form a remote p-n junction only on the (100) plane. This remote p-n junction assists carrier confinement because of the different built-in potential heights of the GaInP active layer and the AlGaInP cladding layer.

The (311)A inclined plane enabled us to reduce deep level (D3 level) density[8)9)] and natural superlattice concentration. We expected good optical quality in the (311)A inclined active layer.

The GaInP grown on the (311)A plane was thicker than on the (100) plane. We believe this stabilizes the optical confinement of the laser.

4. Laser characteristics

Figure 3 shows the I-L and the I-V characteristics at room-temperature under CW operation. The active layer thickness was 23 nm with 0.5 % compressive strain. The cavity length was 300 μm and the stripe width was 3.5 μm. We obtained low threshold current of 18 mA and a series resistance of 10 ohm for as-cleaved sample. These value suggest that the simultaneously doped lateral p-n junction layer effectively confined the driving current with low resistivity.

The laser operated in short wavelength of 664 nm (Fig.4), because the GaInP inclined active layer was disordered by the off orientation. The maximum output power was 20 mW for as-cleaved sample and 40 mW for AR-HR (10%-90%) coated sample They were lmited by COD of the facet.

Figure 5 shows the far-field pattern of this laser under CW operation. The beam divergence parallel to the inclined junction plane was 10° and perpendicular to it was 33°. We obtained stable fundamental mode oscillation.

We conducted aging test at 50°C and 5mW. The operation current remained low for over 500 h (Fig.6). We conclude there is no significant degradation by simultaneously doped AlGaInP. These results demonstrate simultaneous doping is useful for fabricating a visible laser.

5. Conclusion

We demonstrated a simultaneously doped index-guide one-step-grown visible laser. The laser had a low threshold current and a stable transverse-mode oscillation with good reliability.

References

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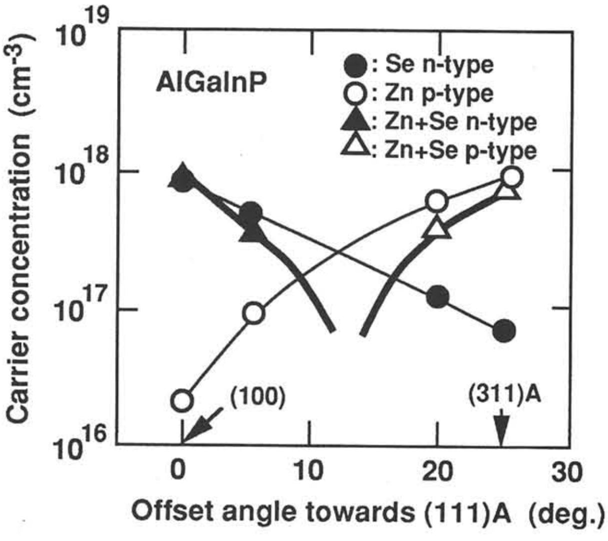
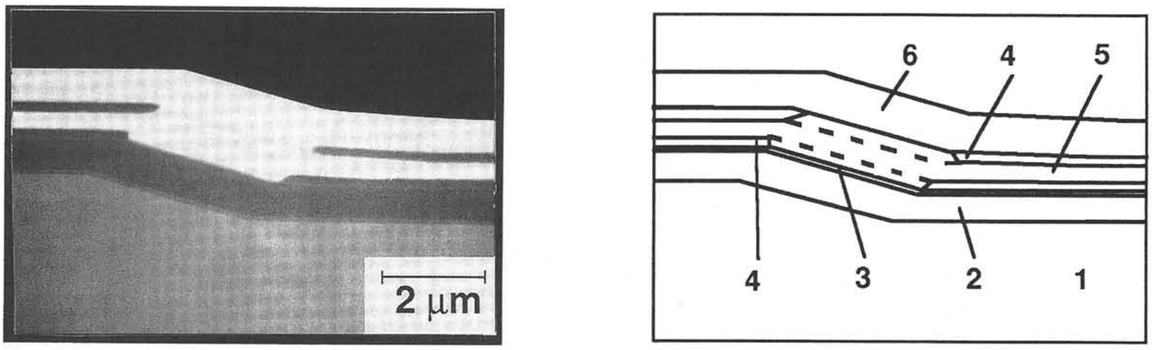


Figure 1. Carrier concentration dependence on substrate orientation



1. GaAs n-substrate
2. AlGaInP n-clad (Se)
3. GaInP active layer
4. AlGaInP simultaneous doping (Zn + Se)
5. AlGaInP p-clad (Zn)
6. GaAs p-contact

Figure 2. Cross-section of the one-step-grown laser structure

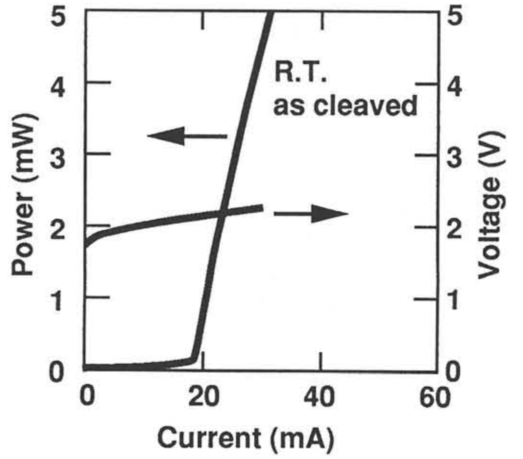


Figure 3. I - L and I - V characteristics

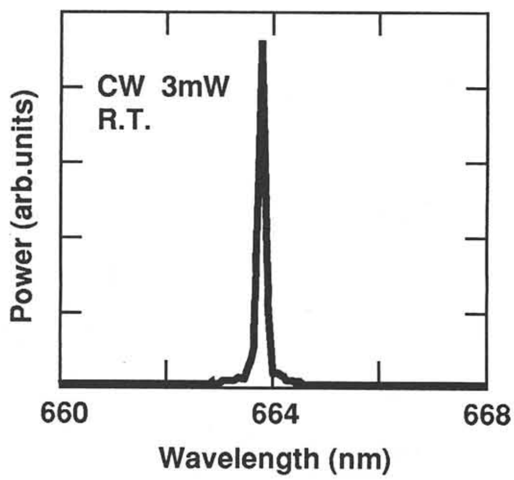


Figure 4. Lasing spectrum

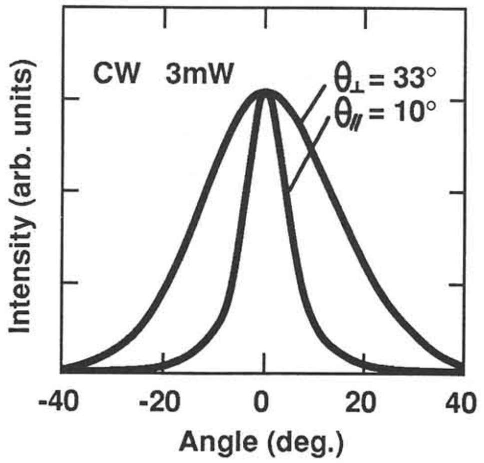


Figure 5. Far-field patterns in directions parallel and perpendicular to junction plane

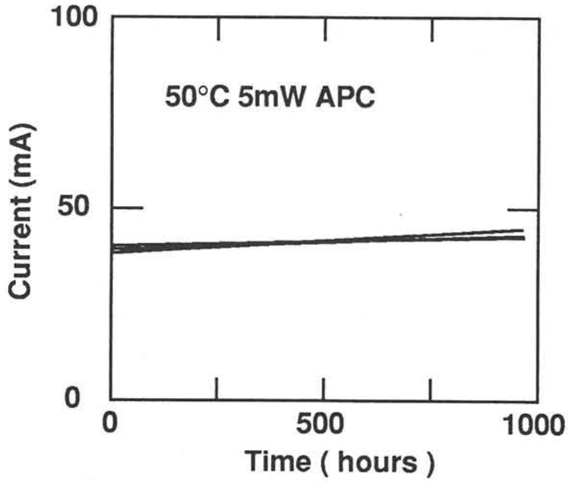


Figure 6. Life test