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A Groove GaInAsP Laser on Semi-Insulating InP Using a Laterally Diffused Junction

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Abstract—Low threshold current GaInAsP/InP groove lasers have been fabricated on semi-insulating InP substrates. Three n-type layers are grown with a single liquid phase epitaxial (LPE) growth process, and the p-n junction is formed by a lateral Zn diffusion. The active layer inside the groove provides a real index waveguide. Threshold currents as low as 14 mA with 300 μm cavity length are obtained. A single longitudinal mode at 1.3 μm up to 1.4 I_{TH} is observed. The lasers operate with a single lateral mode when the active region width is less than 2.5 μm. This laser is suitable for monolithic integration with other optoelectronic devices.

INTRODUCTION

THE integration of semiconductor-based optical and electronic devices has gained considerable interest recently. Most of the demonstrations of such devices, so far, involve the GaAs/GaAlAs system. Since GaInAsP/InP lasers are most suitable for fiber communication systems, it is very desirable to develop monolithic integrated optoelectronic circuits in these quaternary systems as well. One of the major problems is the fabrication of a reliable low threshold current laser, especially one suitable for fabrication on semi-insulating (SI) substrates. One possible candidate for this is the transverse junction stripe (TJS) laser which has been fabricated so far in the GaAs/GaAlAs system [1]-[3]. In the quaternary system, to our knowledge, no reported structure with a transverse diffused junction has led to lasers with low threshold current. A previously reported TJS structure in a GaInAsP/InP system possesses a very high threshold current [4]. In this letter we report a low threshold current laser, which is fabricated on SI InP substrate, using a laterally diffused junction and a built-in real index waveguide for optical confinement. The resultant structure has the advantage of easy integration with
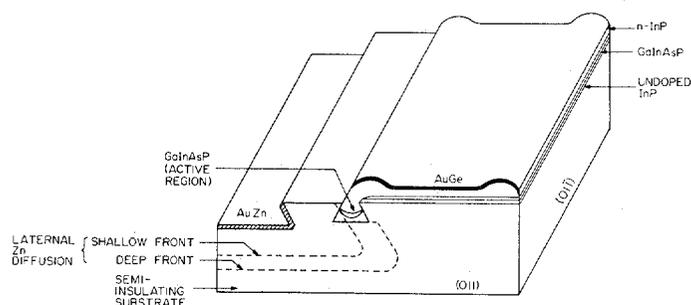
Fig. 1. A schematic cross section of the laser with diffusion touching the active region.

electronic devices, such as metal-insulator-semiconductor field-effect transistors.

The laser consists of three epitaxial n-type layers (double heterostructure) grown inside a groove on a semi-insulating substrate, and a lateral Zn diffused region as shown in Fig. 1. The current flows laterally from the p-type region across the junction to the n-type region above the groove. As the quaternary layer has a narrower bandgap than the InP, the carrier injection occurs predominantly in the quaternary layer. Current leakage through the InP-InP homojunctions is minimized due to the higher bandgap of the InP. Current leakage through the SI material is very small due to the high specific resistivity of the SI substrate. Optical confinement is obtained by the geometrical structure of the crescent shaped quaternary waveguide. As a result, a low threshold current and a single transverse mode can be obtained.

The preparation of the etched-groove structure on the substrate with Si_3N_4 as an etching mask has been reported recently by us [5]. In the previous structure, we have demonstrated a low threshold current laser with a grown horizontal junction (p-InP, quaternary, and n-InP are the LPE grown layers) in a groove on SI InP substrates. In the present structure, starting with the same grooved structure, we use the same growth

technique with three n-type LPE grown layers and the junction is formed by a lateral diffusion. Thus, similar processing steps are taken in the preparation of the substrates prior to the epitaxy. The fabrication process of this device begins with the chemical vapor deposition (CVD) of Si_3N_4 on the SI InP substrate. Then, grooves are made in the (011) direction of the SI InP substrate through 1.5–5 μm stripe openings. The Si_3N_4 is selectively removed from one side of the groove leaving 100 μm Si_3N_4 stripes on the substrate. These stripes act as masks on which no growth occurs during epitaxy. Three LPE layers are grown on the grooved wafer: an undoped InP (background electron concentration is 4–9 $\times$ 10^{16} cm^{-3}), a thin (0.1–0.3 μm) undoped quaternary GaInAsP layer and an n-type InP (2 $\times$ 10^{18} cm^{-3}, Sn doped) layer. The top n-InP is doped higher for low resistance and better electric contact. After the growth, a new Si_3N_4 is deposited and windows for diffusion are opened. The InP underneath these windows is etched down for several microns with 0.5 percent of bromine in methanol solution. Zn diffusion is then performed at 640°C for 20–30 min. The Zn diffuses laterally for a distance of 4–6 μm in the SI InP until it reaches the grooves. Fig. 2 shows a photograph of a laser with the Zn diffusion front touching the active region. After the diffusion, AuZn/Au and AuGe/Au contacts are evaporated and annealed on the p-side and n-side, respectively. For CW operation, the lasers are mounted upside up on copper heat sink with conductive epoxy.

Two diffusion fronts are observed in the semi-insulating part of the diffusion path while only one front is observed in the n-layers. As pointed out by Ande et al. [6], for Zn diffusion, the shallow front corresponds to carrier density of 10^{17}–10^{18} cm^{-3}, while the deep front corresponds to carrier density of 10^{15} cm^{-3} or below. As a result, two fronts are observed in the SI InP which has very low carrier concentration and only one front is observed in the n-layers which are doped above 10^{16} cm^{-3}. Depending on the position of the diffusion front inside the upper n$^+$-InP layer, different laser threshold currents are obtained. For a diffusion front just touching the active region (see Figs. 1 and 2) the lowest threshold current obtained per unit active region width is 5 mA/μm for lasers with a cavity length of 300 μm and an active region thickness of ~0.2 μm. When the diffusion front is in the middle of the active region inside the groove (see Fig. 3), the lowest threshold current obtained per unit width is 10 mA/μm for lasers with the same cavity length and active layer thickness. The difference in the threshold current can be explained by the difference in the forward bias current leakage through the InP-InP homojunctions. When the diffusion front just touches the active region, the area of the high doping InP homojunction is minimal. When the diffusion front is in the middle of the active region, a large area p-InP/n$^+$-InP junction above the active region is created (see Fig. 3). The carrier leakage through this p-InP/n$^+$-InP junction at forward bias results in an increase in the threshold current of the laser.

The light output versus current characteristics of one of the lasers is shown in Fig. 4. The laser threshold current is 17 mA, with a cavity length of 350 μm. The lowest threshold current
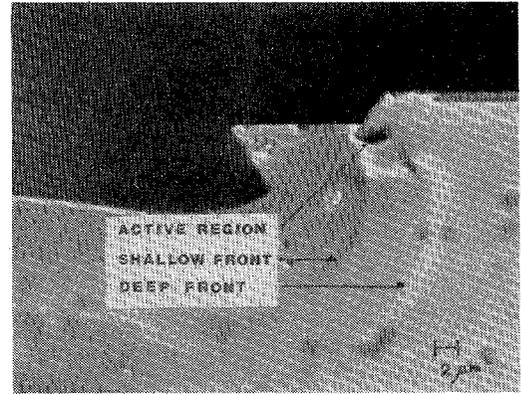

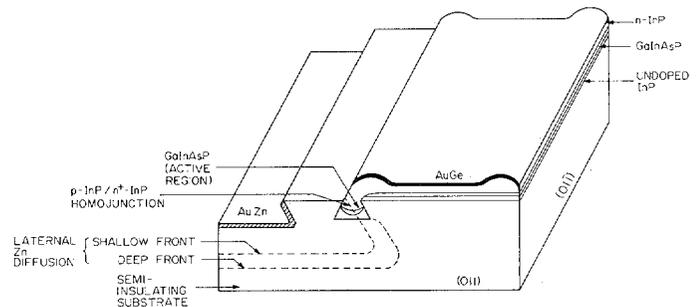Fig. 2. A photograph of a laser with diffusion performed.

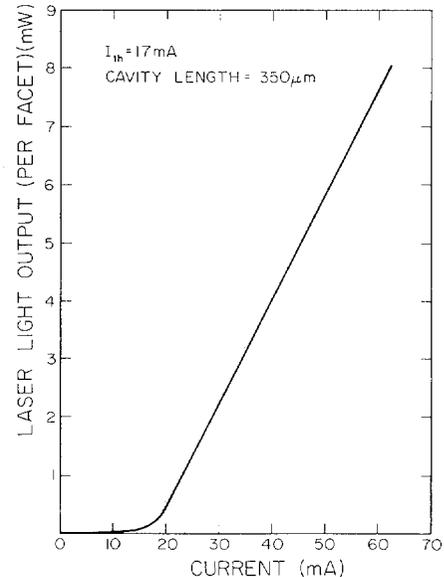Fig. 3. A schematic cross section of the laser with diffusion in the middle of the active region.

Fig. 4. L-I characteristics of a laser for pulsed operation; I_{TH} is 17 mA.

obtained is 14 mA for a laser with a cavity length of 300 μm. Room temperature CW operation of the lasers is obtained with threshold current as low as 15 mA. The lasers have a wavelength of 1.3 μm and have a single longitudinal mode at up to 1.4 threshold current. The external differential quantum efficiency of these lasers is about 30–40 percent for both facets. A far-field pattern at CW operation is shown in Fig. 5. A single
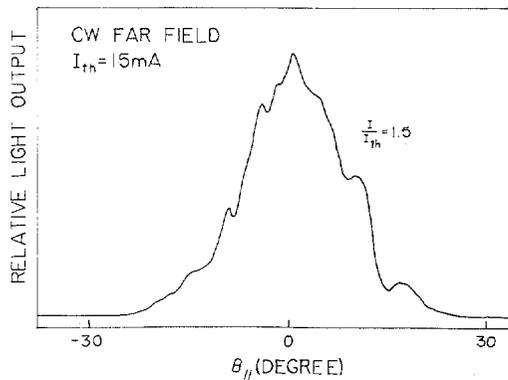
Fig. 5. A far-field pattern at CW operation of a laser with I_{TH} = 15 mA.

lateral mode pattern is observed for active region width of less than 2.5 μm.

CONCLUSION

In conclusion, we have successfully fabricated a low threshold current laterally diffused junction laser on semi-insulating InP substrate. The optical confinement is provided by the real index waveguide and single-mode CW operations is obtained.

These properties make this laser a potentially important light source for integrated optoelectronic applications.

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