High characteristic temperature of 1.3 μm crescent buried heterostructure laser diodes

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Abstract. Two-step liquid phase epitaxy and preferential etching technique have been used to fabricate 1.3 μm InGaAsP/InP buried crescent laser. The p-n-p-n thyristor-like structure is used as the blocking layers. The leakage current is very small even at high temperatures. The characteristic temperature T_0 at room temperature is as high as 79 K. This value is higher than those ever reported.

Keywords. Liquid phase epitaxy; InGaAsP/InP; 1.3 μm laser diodes; crescent buried heterostructure; characteristic temperature.

1. Introduction

Semiconductor lasers based on the InGaAsP system emitting at 1.1–1.6 μm wavelengths are of considerable interest due to the development of very low-loss and low-dispersion optical fibre at these wavelengths. Heterostructure lasers contain two heterojunctions forming boundaries around the light-emitting active region and providing proper refractive index step to form a dielectric waveguide and also to provide a potential barrier that confines the injected carriers to a small volume. The laterally defined device structures with both the vertical and lateral carriers as well as optical confinement being the most useful laser structure in optical fibre communications. Because of its excellent electrical and optical properties such as low threshold current, single stable fundamental transverse mode, narrow beam divergence, high output power and high temperature operation. To achieve this purpose, buried heterostructure (BH) and buried crescent (BC) heterostructure are the two typical laser structures (Kirkby and Thompson 1976; Oomura *et al* 1981, 1984; Ishikawa *et al* 1981, 1982; Cheng *et al* 1985, 1987; Cheng and Renner 1986).

In fabricating these structures, either a two-step LPE growth or a critical Zn diffusion following a one-step LPE growth process on preferential etching channelled substrate is required. Unfortunately, the required sophisticated etching technique and a second LPE growth apparently will easily degrade the interface of the heterostructures (the exposed p-n junction). Especially, in the InGaAsP/InP system, the characteristics of lasers due to the thermal surface decomposition of InP substrate in a high temperature ($\sim 650^\circ\text{C}$) hydrogen ambient before the melt contact of the LPE regrowth, will result in the irregular far-field pattern (FFP), peak shift (Ishikawa *et al* 1981) and a reliable device (Hirono *et al* 1983). To get rid of the degradation, a new “displaced” buried crescent (D-BC) laser structure in which the p-n junction is displaced from the exposed surface by means of Zn diffusions from P-InP blocking layer to the n-InP cladding layer during and after the second growth was proposed by Hirano *et al* (1983). The lasing characteristics of the BC

lasers are obviously improved (Oomura *et al* 1984) to make InGaAsP/InP lasers a suitable light source for optical fibre communications.

In this paper, the etch- and fill two-step LPE technique and the countermeasure by displacing the p-n junction from the exposed surface have been introduced for studying these InGaAsP/InP BC lasers. The growth and characteristics of the BC lasers emitting at $1.3\ \mu\text{m}$ wavelength with high characteristic temperature T_0 are reported.

2. Experimental

Two growth cycles are introduced in fabricating the laser devices. Details on the growth system and procedure were reported in earlier papers (Su *et al* 1984; Wu *et al* 1985a, b, 1986; Su *et al* 1986, 1987). In the first growth, a four-layer structure was sequentially grown on InP substrates: the Sn-doped n-type InP buffer layer ($\sim 5 \times 10^{17}\ \text{cm}^{-3}$); the undoped n-type InGaAsP blocking layer ($0.3\ \mu\text{m}$ thick, $E_g = 0.96\ \text{eV}$); the Zn-doped p⁺-InP blocking layer ($2\text{--}3\ \mu\text{m}$ thick, $\sim 2 \times 10^{18}\ \text{cm}^{-3}$), and the undoped n-type InGaAsP mask layer ($0.3\ \mu\text{m}$ thick, $E_g = 1.13\ \text{eV}$). Selective etching is used to define the channel stripes by standard photolithography. After preferential etching, the regrowth cycle is introduced. Sn-doped InP cladding layer ($\sim 2 \times 10^{18}\ \text{cm}^{-3}$); $0.2\ \mu\text{m}$ crescent-shaped undoped InGaAsP active layer; Zn-doped InP confining layer ($\sim 2 \times 10^{17}\ \text{cm}^{-3}$) and p⁺ InGaAsP cap layer ($> 1 \times 10^{19}\ \text{cm}^{-3}$) are successively grown on the substrate. Figure 1 shows the SEM photograph of the cleaved cross-section of the BC laser diodes after regrowth. Au-Zn (5 wt%) and Au-Sn (10 wt%) alloys are used as ohmic contact for p-type layer and n-type substrate respectively. Gold films are plated onto both p- and n-sides. The laser size is typically $300\ \mu\text{m}$ long and $6\ \mu\text{m}$ wide.

3. Results and discussions

The lattice mismatch between the epilayers and InP substrate measured by X-ray diffraction is $< 0.03\%$. Photoluminescence (PL) measurement shows $1.30\ \mu\text{m}$ emission at room temperature. The I-V characteristics of a p-n-p-n thyristor-like current blocking structure for various temperatures is shown in figure 2. Good blocking layers can be obtained with this structure even at a high temperature. The light output power vs bias current under CW operation at different temperatures is shown in figure 3. Threshold currents at room temperature are in the range 15–40 mA, corresponding to current densities $0.83\text{--}2.22\ \text{kA/cm}^2$. Output power in the range 7–20 mW/facet at 100 mA biased current can be obtained for CW operation at 300 K and no significant kink is observed. The maximum power obtained at 100 mA is 20 mW. The threshold current density I_{th} is approximately (Botez *et al* 1976) $I_{\text{th}}(T) = I_0 \exp(T/T_0)$, where T_0 is the characteristic temperature. The temperature dependence of the threshold current I_{th} is shown in figure 4. The 79 K of T_0 value can be obtained from this temperature relation. This value is higher than the values reported earlier for 50–70 K (Horikoshi and Furukara 1979; Nanory *et al* 1979; Ano *et al* 1979; Thompson and Denshall 1980; Cheng *et al* 1987).

The spectra of the InGaAsP/InP BC laser at several driving currents above threshold ($I_{\text{th}} = 23\ \text{mA}$) are shown in figure 5. The operating wavelength does not

Figure 1. a. Schematic structure and b. SEM photograph of cleaved cross-section of the BC laser diode.

Figure 2. Temperature dependence of I-V characteristics of p-n-p-n thyristor-like blocking layer.

Figure 3. Light-current characteristics (CW operation) at different temperatures.

Figure 4. Threshold current (I_{th}) vs heat-sink temperature.

Figure 5. Optical spectra of BC laser at A. 20 mA B. 50 mA C. 75 mA and D. 100 mA driving current ($I_{th} = 23$ mA).

change significantly with current above the threshold. The peak of emission spectrum is around $1.3 \mu\text{m}$ wavelength. It belongs to longitudinal multimode laser.

4. Conclusions

A two-step liquid phase epitaxy and preferential etching technique have been used to fabricate $1.3 \mu\text{m}$ InGaAsP/InP buried crescent laser. The p-n-p-n thyristor-like structure is used as the blocking layers. The leakage current is very small. The threshold currents for a $300 \mu\text{m}$ long device at room temperature are in the range of 15–40 mA, corresponding to current densities of 0.83 – 2.22 kA/cm^2 under CW operation. A maximum output power of 20 mW per facet under CW operation can

be obtained. The characteristic temperature T_0 at room temperature is as high as 79 K. This value is higher than those ever reported. A emission spectra of 1.3 μm can be obtained. The operating wavelength does not change significantly with the current above threshold.

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