Buried heterostructure laser diode on directly bonded InP/Si substrate

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Abstract: We report the successful lasing operation of MQW laser diode with buried heterostructure on the directly bonded InP/Si substrate. Buried heterostructure laser diode was fabricated two step MOVPE growth on silicon substrate.

1. Introduction

In recent years, with the widespread application of AI technology, big data, 5G, unmanned technology, etc., the amount and speed of information transmission have shown explosive growth. To satisfy the need of the better transportation and processing a large amount of information, people have put forward more requirements for the speed of signal processors. Therefore, the field of optical interconnection based on Si substrate, SOI substrate, and SiO2/Si substrate has also made considerable progress [1]. Lasers are still difficult to be fabricated directly using silicon materials, so how to integrate the lasers with III-V group materials on silicon or SiO2 materials has become the key technologies for optical interconnection. Using the hydrophilic bonding method, we bond the InP film on the Si substrate, and then made into the InP/Si substrate. After that, a semiconductor laser is grown on the InP film surface of the InP/Si substrate by the MOVPE method [2-4]. Adopting the integration method not only effectively solve the alignment problem of flip-chip bonding during high-density integration of the original device but avoid the thicker migration layer produced during wafer bonding as in the plasma bonding method. In addition, due to the large area of the InP film, selective growth methods can be used to grow various components by MOVPE equipment to achieve high-density integration [5,6]. After completing the integration of the LD on the InP/Si substrate, to reduce the threshold current of the LD to realize the long-term lasing of the CW power supply at room temperature. We have adopted wet etching to realize the mesa structure of the LD on the InP/Si substrate. The secondary growth has been carried out by the MOVPE method, and the BH LD structure realized on the InP/Si substrate. The threshold current has been reduced to a lower level successfully.

2. Growth Process

At the first growth of MOVPE, we grew an LD with a separate-confinement-heterostructure seven-quantum-well (SCH-7QW) structure directly on the InP surface of the InP/Si substrate by MOVPE. Fig.1 shows the schematic of LD with SCH-7QW structure grown on InP/Si substrate.

![Fig.1. Schematic layer structure](image1)

The active layers were composed of seven 10 nm Ga0.35In0.65As0.84P0.16 well layer separated by 10 nm Ga0.25In0.75As0.45P0.55 barrier layer. The well layer had a bandgap energy (Eg) of 0.83 eV and a photoluminescence (PL) wavelength of 1.49 μm, and the barrier layer had an Eg of 1.03 eV and a PL wavelength of 1.20 μm. The SCH layer had the same composition as the barrier layer (Ga0.25In0.75As0.45P0.55) and a thickness of 100 nm. The growth
conditions were a temperature of 650 °C and a pressure of 8 kPa. During the fabrication of this structure, solutions with a HCl and a H$_2$SO$_4$ were used to selectively etch several mesa waveguides with a width of 5 µm. After that, in the second MOVPE regrowth, the mesa waveguides were buried with i-InP. The structure was shown in Fig.2. The Si substrate was thinned near 50 µm after regrows. On the surface of the uppermost GaInAs layer of the waveguide, AuZn alloy was evaporated as a positive (P) electrode, and AuAl alloy was evaporated at the side of Si as a negative (N) electrode. Finally, the LD was cleaved manually, and edge-emitted light was observed. We have used H$_2$SO$_4$ to mark the active layer. Shown as Fig.3.

3. Experimental results

The lasing characteristics of the LDs were measured using a pulsed power supply. The duty ratio of the pulsed current was 0.05%, and the repetition time was 1 ms. The maximum lasing temperature of the LD with cavity length of 197.6 µm and the mesa width of 3.2 µm was 60 °C. The IL test results were shown in Fig. 4. Under the room temperature (20 °C) environment, the threshold current value was 118.8 mA.

![Fig. 4. I-L characteristics on InP/Si subs.](image1)

![Fig. 5. Temperature dependence of $I_\text{th}$ on different subs.](image2)

![Fig.6. Fabry-Perot Oscillation](image3)

As a comparison, the LD with the same structure was fabricated on an InP substrate. The dependence between threshold current and temperature of the LD grown on the different substrates was shown in Fig. 5. The threshold current of the LD grown on the InP substrate was lower than that of the LD grown on the InP/Si substrate. However, as the detection temperature increases, the gap of threshold current of the LD between two substrates was gradually decreasing. The EL spectrum of the BH LD grown on InP/Si substrate was obtained at 20°C at the injection current of 300 mA as shown in Fig.6. The peak wavelength in the EL spectrum was 1391.47 nm.

References


