Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 604–605

E-8-2

Fabrication of InGaAsP/InP Twin-Guide Laser Diode with Rectangular Ring Cavity

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1. Introduction

Semiconductor ring lasers have recently received attention because they can be used as sources in photonic integrated circuits and have the beneficial characteristics such as mode purity and the potential of unidirectional operation.

In these devices, the output couplers such as Y-branch coupler[1], evanescent coupling[2], multimode interference coupler [3] have been used to efficiently couple ring laser with output waveguide, through which many optical devices can be interconnected for implementation of photonic integrated circuits. Because most of ring lasers have the same epitaxial structure with optical waveguide for interconnection, however, they need additional current injection into interconnection optical waveguide for its transparency.

In this paper, we have proposed and fabricated the twin-guide structure which consists of active waveguide with rectangular ring cavity and transparent output waveguide coupled to each other as a directional coupler.

2. Experiment

Fig1. shows the schematic of twin-guide laser diode with rectangular ring cavity. Four straight waveguides and total internal reflection(TIR) mirrors construct a ring cavity which set up the traveling wave. Lasing light is coupled to the transparent passive output waveguide by vertically evanescent coupling. Normal mode analysis[4] was utilized for optimal design of epitaxial structures and mask layout. The system is designed so that only two modes(TE_o,TE_1) can propagate. Because the optical power at TIR mirrors changes according to the propagation length as the two modes beat, the reflected optical power at each TIR mirror and transmission into the waveguide can be controlled by changing propagation lengths (L1,L2) between TIR mirrors. L1,L2 are set to be 280μm and 183μm, respectively, for high power transmission (~90%) into the transparent output waveguide and maximum power reflection at TIR mirrors. The line width is about 6μm.

Grown twin-guide laser diode epitaxial layers using LP-MOCVD are n-doped InP cladding layer (1.5μm) on (100) InP wafers, n-doped InGaAsP layer (0.43μm, Eg=1.0eV) for passive waveguide, n-doped InP layer (0.9μm) for spacer, unintentionally doped InGaAsP(0.2μm, Eg=0.81eV) for active layer, p-doped InP cladding layer (2 μm) and highly p-doped $In_{0.53}Ga_{0.47}As$ for P-ohmic contact layer(0.1 μm).

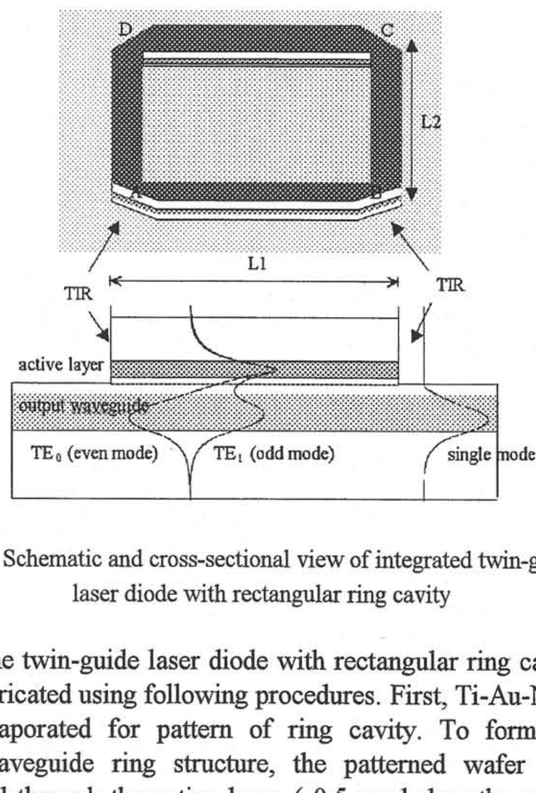


Fig. 1 Schematic and cross-sectional view of integrated twin-guide laser diode with rectangular ring cavity

The twin-guide laser diode with rectangular ring cavity is fabricated using following procedures. First, Ti-Au-NiCr is evaporated for pattern of ring cavity. To form the rib-waveguide ring structure, the patterned wafer was etched through the active layer (0.5 μm below the active layer) by Cl_2 – based reactive ion beam etching(RIBE). Polyimide is spun on and cured for planarization and etched by plasma to expose the rib waveguide for electrical contact. The large-area Ti-Au is evaporated for pad pattern. The wafer is lapped into 100 μm and N-ohmic is alloyed.

3. Measurements

The devices were cleaved and measured under the pulsed conditions (1 μsec pulse width, 0.1% duty cycle).

Fig.2 shows the light-current curve of ring laser. The threshold current is about 230mA, corresponding to a threshold current density of $4kA/cm^2$. High threshold current density may be originated from surface recombination, etching damages, and scattering losses caused by dry etching process. The incorporation of quantum-well for higher gain and optimization of process parameters will improve the performances of the device.

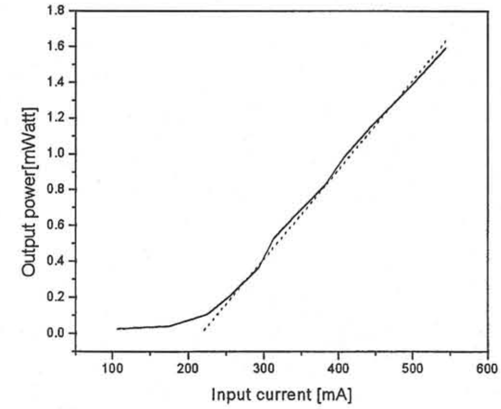
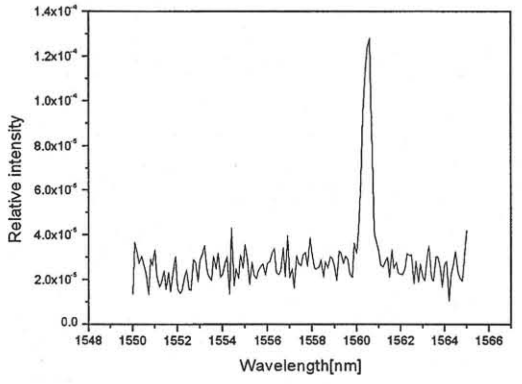
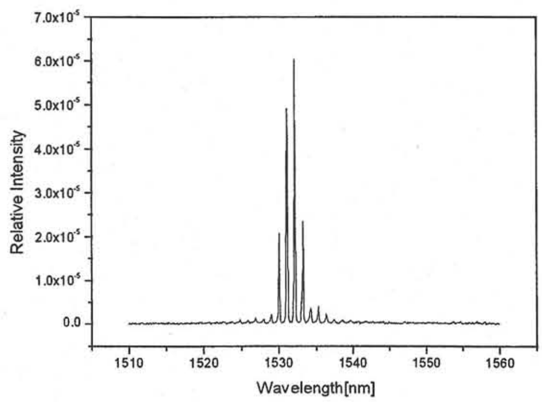


Fig. 2 Light-Current curve of integrated twin-guide laser diode with rectangular ring cavity



(a)



(b)

Fig.3 Spectrum characteristics of integrated twin-guide laser diode with rectangular ring cavity (a) and broad-area Fabry-Perot laser diode (b).

The emission spectrum at 340mA ($1.4 \times I_{th}$) is shown in Fig.3(a). The emission peak wavelength is about 1.56μm. It shows the single mode operation. For comparison, we have also fabricated the broad area Fabry-Perot laser diode from the same wafer. The spectrum is also displayed at Fig.3(b). The emission peak wavelength is measured to be 1.53 μm. Although we used the index-matching oil to reduce the reflection from cleaved output waveguide, it is not enough to completely suppress the external resonance.

Therefore, the emission peak wavelength shift may be caused by interference with the resonance in the ring cavity and weak external resonance of cleaved output waveguide[5].

4. Conclusions

We have proposed and fabricated the InGaAsP/InP twin-guide laser diode with rectangular ring cavity fabricated by Cl_2-based RIBE. Four straight waveguides and TIR mirrors construct a ring cavity. Lasing light is coupled to the transparent passive output waveguide by vertically evanescent coupling. The threshold current was measured to be 230mA. The emission peak wavelength is about 1.56 μm. The fabricated device shows single mode operation at $1.4 \times I_{th}$.

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