GaInAsP/InP Membrane Lasers

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Abstract: Recent advances of GaInAsP/InP membrane lasers will be presented. A high index-coupling grating structure enabled very-low threshold current (230 μA) as well as high-speed modulation with a record modulation current efficiency (9.9 GHz/mA$^{1/2}$).
OCIS codes: (230.0230) Optical devices; (250.5960) Semiconductor lasers

1. Introduction

Since optical interconnects consisting of optical/photonic devices with low-power consumption and high-speed operation have been matured technologies in recent supercomputers, further development of ultra-low power consumption devices for on-chip optical interconnects will be an important issue. For this purpose, we have been investigating so-called "membrane semiconductor lasers" [1]-[4], whose modal gain is 3-4 times higher than that in conventional semiconductor lasers consisting of quantum-well active region. Photonic crystal lasers consisting of the membrane structure revealed their superior operation characteristics over conventional lasers [5].

Recently, low threshold-current and high-speed modulation characteristics of the membrane lasers with a surface grating structure, namely membrane distributed-feedback (DFB) lasers [6],[7] and distributed-reflector (DR) lasers [8] as shown in Figs. 1 and 3(a), respectively, were demonstrated. Furthermore an in-plane integration with a p-i-n photodiode (PD) was also demonstrated [9].

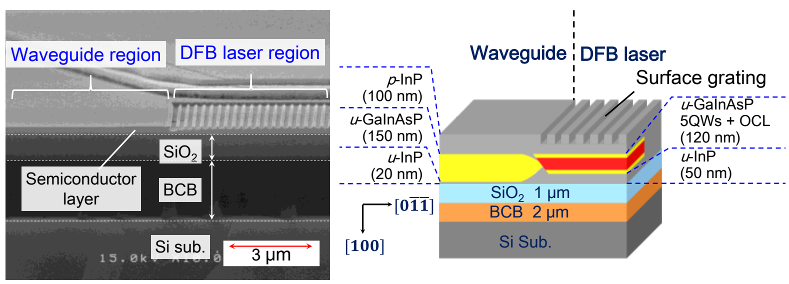
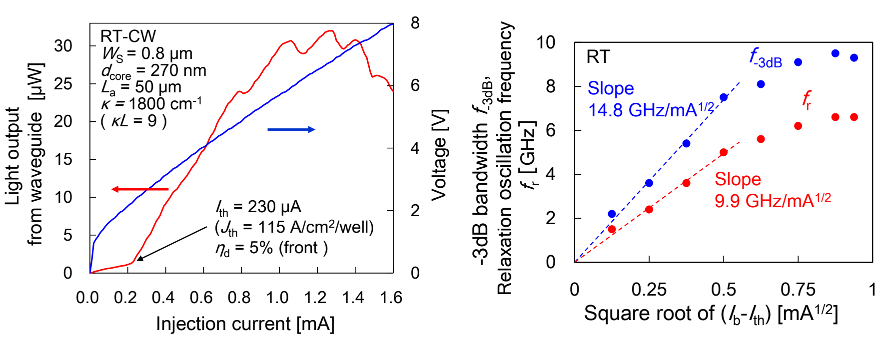


Fig. 1. Schematic structure of a membrane DFB laser

2. Membrane distributed-feedback (DFB) lasers

Figure 1 shows a cross-sectional SEM view and its schematic structure of GaInAsP/InP membrane DFB laser emitting at 1.55 μm wavelength bonded on a Si-substrate, where the total thickness of the GaInAsP/InP structure was 270 nm and the grating coupling coefficient corresponded to 1800 cm^{-1} for the surface grating depth of 60 nm. Thanks to an enhanced optical confinement effect in the membrane structure, a low-threshold current of I_{th} =230 μA (J_{th} =115 A/cm^2/well) was obtained with the DFB cavity length of 50 μm and the stripe width of 0.8 μm [6] as



(a) (b)

Fig. 2. (a) Light-output and voltage–current characteristics of a waveguide-integrated membrane DFB laser and (b) its relaxation oscillation frequency and −3 dB bandwidth frequency as a function of square root of the bias current.

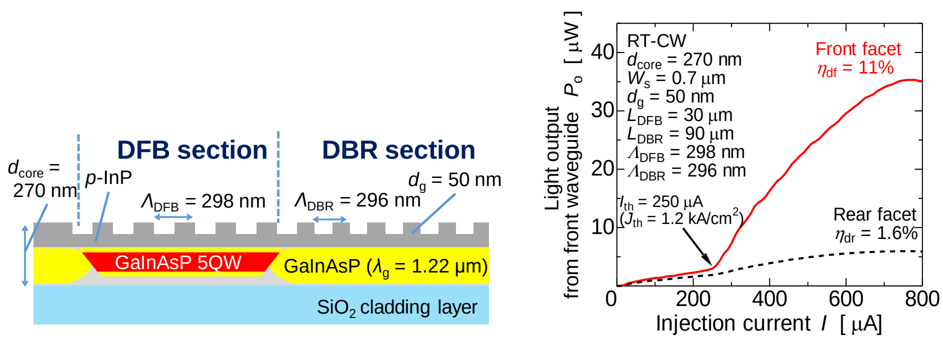
shown in in Fig. 2(a). A differential quantum efficiency measured from the front side facet was only 5%, this poor value can be attributed to an optical loss in 500-µm long GaInAsP passive waveguide section.

The enhancement of the optical modal gain in the membrane structure was expected to lead to high-speed direct modulation property under a relatively low injection current, in other words, higher modulation efficiency. From small-signal modulation measurements, a relaxation oscillation frequency was observed to be proportional to the square root of the bias current above the threshold, and its slope was interpolated to be 9.9 GHz/mA$^{1/2}$ [7] as shown in Fig. 2(b). This value is, to our knowledge, a record high value than that reported for 1.5 µm wavelength lasers.

3. Photonic integrated devices based on the membrane structure

In on-chip optical interconnection where it is desired that the light source has high power conversion efficiency as well as one directional output property, hence the distributed-reflector (DR) laser consisting of a DFB section with a DBR section will be a most promising candidate as an in-pane light source. Figure 3(a) shows a cross-sectional structure of a DR laser with a surface grating [8]. A low-threshold current of I_{th} =250 µA (J_{th} =240 A/cm^2/well) was obtained with the DFB section length of 30 µm and the stripe width of 0.7 µm as shown in in Fig. 3(b). Since the differential quantum efficiency measured from the front side facet was 11% which was almost 2 times higher than that obtained by the previous DFB laser and the output from the rear side was considerably suppressed, the DBR section worked as a high-reflection mirror for high output efficiency operation based on one directional output feature.

An integration of a 30-µm long phase-shifted membrane DFB laser with a 200-µm long pin-PD was also demonstrated [9], where very-low dark current of 0.8 nA at a bias voltage of -1 V and enough high responsivity were obtained. In future, an extremely short PD utilizing "slow-light effect" will be promising as an optical to electrical conversion device with high output voltage.



(a) (b)

Fig. 3. (a) Cross-sectional structure of the membrane DR laser and (b) its light output characteristics.

Acknowledgment

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