Room-temperature Continuous-wave Operation of λ/4-shifted Membrane Distributed Feedback Lasers

Takahiro Tomiyasu[1], Daisuke Inoue[1], Takuo Hiratani[1], Yuki Atsuji[1],
Tomohiro Amemiya[2], Nobuhiko Nishiyama[1], and Shigehisa Arai[1,2]
[1]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Japan
[2]Quantum Nanoelectronics Research Center, Tokyo Institute of Technology, Japan

Abstract

We realized λ/4-shifted membrane DFB lasers for an ultralow threshold current operation. A threshold current of 280 µA was obtained for the cavity length of 30 µm under room-temperature continuous-wave condition.

I. Introduction

It was predicted that the performance of large scale integrated circuits (LSIs) will be limited by increment of RC delay and power consumption in the global interconnects of electric wiring. In order to overcome this problem, an introduction of optical interconnection has been proposed for their attractive performance such as low delay, low power consumption, and wide-bandwidth data transmission [1]. However, light sources for optical interconnections are required to operate with power consumption of less than 100fJ/bit [2].

To realize such light sources, we have proposed and demonstrated GaInAsP/InP membrane distributed feedback (DFB) lasers [3]. A low threshold current of 230 µA was achieved for membrane DFB lasers with the DFB section length of 50 µm [4]. However, much smaller cavity volume and lower threshold current will be required for on-chip optical interconnections.

In order to meet such requirements, an introduction of λ/4-shift region into the DFB cavity would be essential for the reduction of the threshold. In this paper, we report the realization of λ/4-shifted membrane DFB lasers under room-temperature continuous-wave (RT-CW) condition.

II. Device Structure and Fabrication Process

Fig. 1 illustrates the schematic of a λ/4-shifted membrane DFB laser, which has a surface grating in *p*-InP cap layer. In addition, the surface grating has a λ/4-shift at center, because threshold current becomes lower for the strongly confined electric field at phase shift position and it becomes lowest for the shift-amount λ/4 and phase-shift position at center.

The fabrication process of the device is as follows. First, an initial wafer was grown on an *n*-InP substrate by gas-source molecular-beam-epitaxy (MBE). Next, an island pattern (width: 10 µm, length: 20–300 µm) was formed by using CH_4/H_2 reactive-ion-etching (RIE) and wet chemical etching. Then, GaInAsP (λ_g = 1.22 µm) was regrown as a butt-jointed build-in (BJB) waveguide by

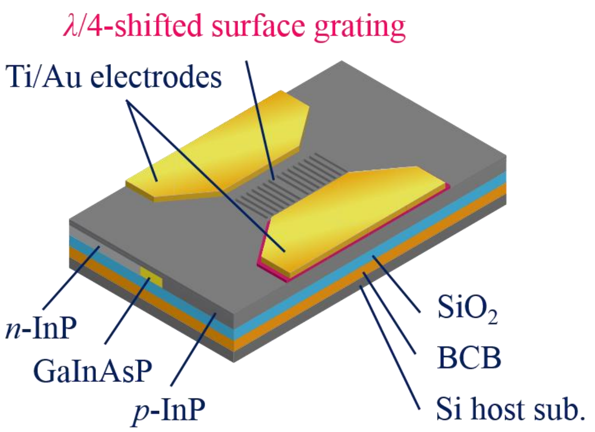

Fig. 1. Schematic of a λ/4-shifted membrane DFB laser.

organo-metallic vapor-phase-epitaxy (OMVPE) with a SiO_2 mask. After mesa (width: 7 µm) was formed by the similar etching process, an *n*-InP layer was regrown at both sides of the mesa. Then one side of the *n*-InP was removed, and a *p*-InP layer was regrown to form a *p-n* junction for lateral current injection. Next, depositions of 1 µm-thick SiO_2 cladding layer by plasma CVD and BCB by spin-coating (approximately 2 µm after hard curing) onto a Si host substrate, the laser wafer and the Si-host substrate was bonded under vacuum at temperature of 130°C for 70 min. The *n*-InP substrate and etch-stop layers were removed by polishing and wet chemical etching. The p^+-GaInAs contact layer except the *p*-electrode region was removed and Ti/Au electrode was evaporated onto the *p*-InP region. Similarly, the *p*-InP cap layer of *n*-electrode region was removed and Ti/Au electrode was evaporated onto the *n*-InP region. Finally, surface grating pattern was formed by electron beam lithography (EBL) and wet chemical etching.

III. Measurements Results

Fig. 2 shows light output characteristics of λ/4-shifted membrane DFB lasers with various cavity lengths under RT-CW condition. The stripe width and the grating period were 0.7 µm and 298 nm, respectively. As cavity lengths became shorter the threshold current density increased though the minimum threshold current of 280 µA was obtained for the cavity length (L_{DFB}) of 30 µm. As can be seen, the slope of the spontaneous emission

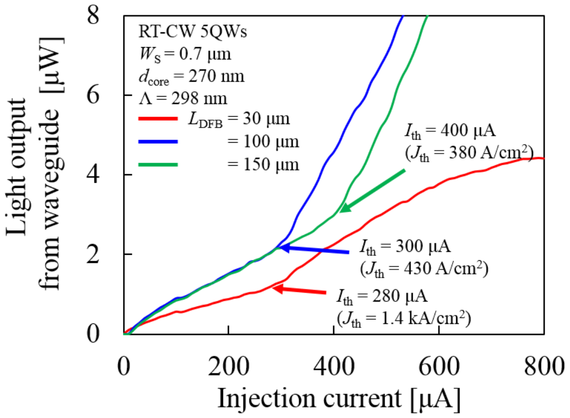

Fig. 2. Light output characteristics of λ/4-shifted membrane DFB lasers.

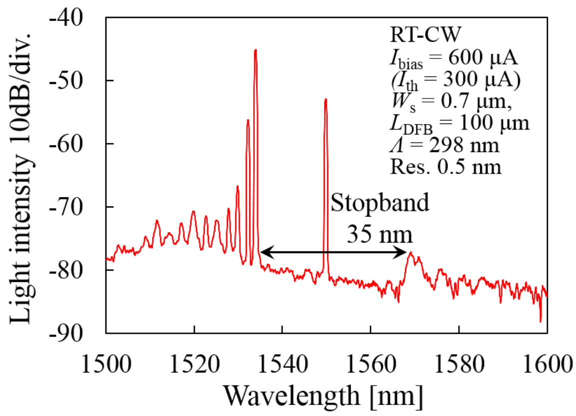

Fig. 3. Lasing spectrum of a device with L_{DFB} of 100 μm.

intensity below the threshold of short cavity device (L_{DFB} = 30 μm) was about half of longer cavity devices (L_{DFB} = 100 μm and 150 μm,) though that was almost identical for longer cavity devices. While at the same time, the threshold current density became higher as L_{DFB} became shorter. These facts indicate that an internal quantum efficiency was degraded when L_{DFB} became shorter, this can be attributed to the leakage current at the interface between the DFB and the BJB waveguide sections.

The lasing spectrum of a device (L_{DFB} = 100 μm) is shown in Fig. 3. The lasing mode was clearly observed at almost the center of the stopband due to the λ/4-shifted grating, while several modes were observed in the shorter wavelength side of the stopband that may be attributed to a mismatch of the peak gain wavelength (at around 1520 nm) from the Bragg wavelength (1549 nm). From the stopband width of 35 nm, the index-coupling coefficient κ_i of the grating was estimated to be about 1600 cm^{-1}.

Fig. 4 shows theoretical threshold current dependency on the cavity length of λ/4-shifted membrane DFB lasers and measurement results. As can be seen, even though threshold current decreases with the shortening of cavity length (L_{DFB}), it seems to gradually getting away from a theoretical curve of an internal quantum efficiency (η_i) of 75 % which was evaluated from our previous report of DFB lasers without the BJB waveguide [5], hence we think there is a leakage current of around 50 μA at the interface. When the internal quantum efficiency is

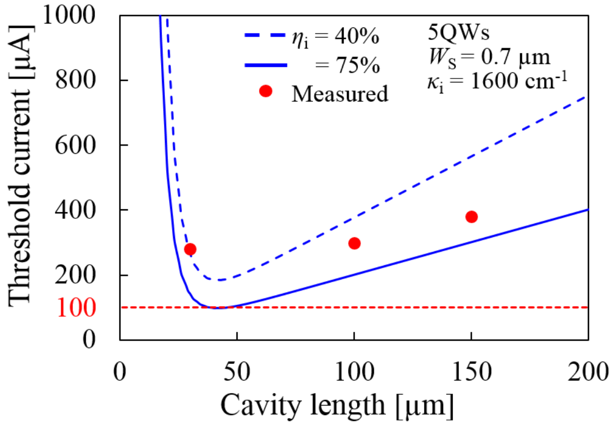

Fig. 4. Theoretical threshold current as a function of the DFB section length and measurement results.

improved to 75%, the minimum threshold current will be 100 μA for L_{DFB} = 40–50 μm when κ_i = 1600 cm^{-1}.

IV. Conclusions

λ/4-shifted membrane DFB lasers were demonstrated for the first time and a threshold current of 280 μA was achieved for 30-μm-long cavity length under RT-CW condition. Even though there was gain wavelength mismatch from the Bragg wavelength and a problem of leakage current at the interface between the DFB and the BJB waveguide sections, further reduction of the threshold current by shortening the DFB section and by adopting higher index-coupling coefficient of the grating, will be very important for future light sources for on-chip optical interconnections.

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