Room-temperature Continuous-wave Operation of $\lambda/4$-shifted Membrane Distributed Feedback Lasers

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Abstract

We realized $\lambda/4$-shifted membrane DFB lasers for an ultralow threshold current operation. A threshold current of 280 $\mu$A was obtained for the cavity length of 30 $\mu$m 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 $\mu$A was achieved for membrane DFB lasers with the DFB section length of 50 $\mu$m [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 $\lambda/4$-shift region into the DFB cavity would be essential for the reduction of the threshold. In this paper, we report the realization of $\lambda/4$-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 $\lambda/4$-shifted membrane DFB laser, which has a surface grating in $p$-InP cap layer. In addition, the surface grating has a $\lambda/4$-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 $\lambda/4$ 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 $\mu$m, length: 20–300 $\mu$m) was formed by using CH₄/H₂ reactive-ion-etching (RIE) and wet chemical etching. Then, GaInAsP ($\lambda_g = 1.22$ $\mu$m) was regrown as a butt-jointed build-in (BJB) waveguide by organo-metallic vapor-phase-epitaxy (OMVPE) with a SiO₂ mask. After mesa (width: 7 $\mu$m) 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 $\mu$m-thick SiO₂ cladding layer by plasma CVD and BCB by spin-coating (approximately 2 $\mu$m 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 $\lambda/4$-shifted membrane DFB lasers with various cavity lengths under RT-CW condition. The stripe width and the grating period were 0.7 $\mu$m and 298 nm, respectively. As cavity lengths became shorter the threshold current density increased though the minimum threshold current of 280 $\mu$A was obtained for the cavity length ($L_{DBR}$) of 30 $\mu$m. As can be seen, the slope of the spontaneous emission...
DFB lasers without the BJB waveguide section. From the theoretical curve of an internal quantum efficiency, the stopband width of 35 nm was almost the center of the Bragg wavelength (1549 nm). A mismatch of the peak 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 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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### REFERENCES


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

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