InP-based Membrane-type Semiconductor Lasers

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Abstract—**With an aim of ultra-low power operation, membrane-type distributed-feedback (DFB) lasers consisting of wirelike active regions are realized with an InP-based high index-contrast waveguide by using benzocyclobutene (BCB) as well as direct boding on a silicon-on-insulator (SOI) substrate. Lateral current injection (LCI) type lasers on a semi-insulating (SI) InP substrate are also presented.**

Keywords-semiconductor laser; distributed feedback laser; BCB bonding; wafer bonding; silicon on insulator

I. INTRODUCTION

To solve the bottle neck problem of Si-LSIs, i.e. speed and power consumption limit, due to transmission time delay caused by long total global transmission line distance, an introduction of optical interconnects / on-chip optical wirings became a very important and challenging issue in next generation electronics [1],[2]. At the same time another research trend to realize not only LSIs but also photonic integrated circuits (PICs) on the same platform with matured CMOS technologies became very active [3], and very low-loss Si waveguides [4],[5] and a very high-Q cavity [6] were achieved on an SOI substrate. Ultrahigh speed detectors and modulators based on Si or Ge/Si on SOI substrates have been demonstrated [7]-[10]. Si Raman lasers on an SOI substrate as well as Ge on Si laser [11]-[13], and hybrid materials system lasers based on AlGaInAs/InP directly bonded on an SOI substrate were also realized [14]-[16].

Looking at the requirements for the light source of optical interconnects [1],[2], the capability of low-power consumption is considered to be essential, hence vertical cavity surface emitting lasers (VCSELs) [17], micro disk lasers [18], and 2-D photonic crystal (PC) lasers [19], which can operate with very low threshold current, have been intensively investigated. A very low threshold current operation of micro disk lasers integrated with Si wire waveguide on an SOI substrate was also demonstrated [20],[21]. On the other hand we have been investigating single-mode lasers, i.e. DFB and distributed-reflector (DR) lasers with strongly index-coupled gratings, which can be operated with very low threshold current, and demonstrated sub-mA threshold currents [22]-[24].

For further reduction of the threshold current, we proposed a membrane buried-heterostructure (BH) DFB laser to enhance an optical confinement factor of the active layer by adopting a high index-contrast waveguide and obtained a room-temperature continuous-wave (RT-CW) operation under optical pumping [25]. In this paper, research activities on InP-based membrane lasers and lateral current injection lasers formed on a SI-InP are presented.

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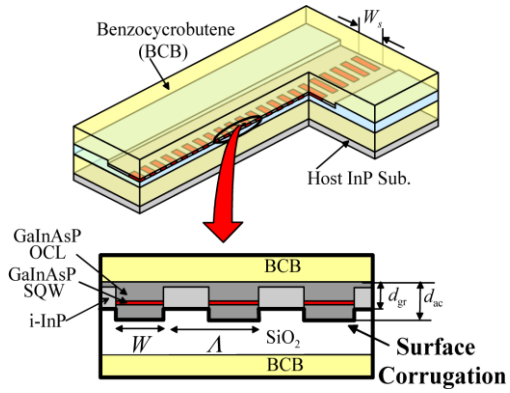

Fig. 1 Schematic of membrane BH-DFB laser with surface corrugations [27].

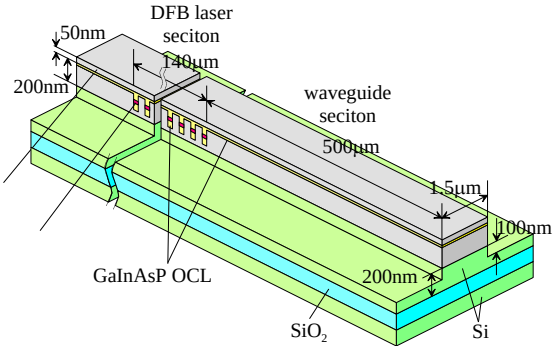

Fig. 2 Schematic of membrane BH-DFB laser directly bonded on SOI with rib-waveguide [30].

II. MEMBRANE BH-DFB LASERS

A. Low Threshold Operation Capability

Due to a strong index-contrast as well as a very thin (only 150 nm) waveguide, an optical confinement factor of the active layer is enhanced by a factor of 3. Furthermore by adopting a DFB structure with wirelike active regions, a threshold current of less than 50 μA for the stripe width of 1 μm was predicted [26], and a low threshold operation was confirmed under an optical pumping (threshold pump power P_{th} = 0.34 mW for W_s = 2 μm and L = 80 μm) with RT-CW condition (Fig. 1)[27]. By thinning the semiconductor core so as to cancel the temperature coefficient of the core by that of the BCB, temperature coefficient of the lasing wavelength was reduced to 1/5 of that of conventional lasers emitting at 1.5-1.6 μm [28].

B. Direct Bonding on SOI Substrate

Aiming at an integration with low-loss Si waveguides, a direct bonding of a membrane BH-DFB laser wafer on an SOI substrate was carried out. P_{th} of 2.8 mW for W_s = 2 μm and L =

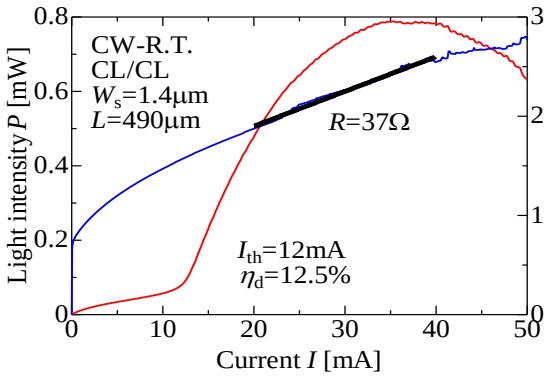

Fig. 3 Light output and voltage-current characteristics of LCI-BH laser grown on SI-InP substrate [33].

120 μm was obtained at RT-CW condition [29]. Similar BH-DFB lasers directly bonded on an SOI with a rib-waveguide structure was fabricated (Fig. 2) [30]. As a step toward current injection of this type of lasers, BH-DFB lasers with 2 μm-thick InP cladding layer was realized and a threshold current density of 400 A/cm^2 was obtained [31].

III. Lateral Current Injection (LCI) Lasers

Since a current injection operation is essential for optical interconnects, we fabricated LCI type lasers with 400-nm-thick GaInAsP core layer grown on a SI-InP substrate [32]. Recently a moderately low threshold operation was achieved (Fig. 3)[33], hence an extremely low threshold current operation can be expected with the membrane BH-DFB laser in near future.

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