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GaInAsP/InP Membrane DFB Lasers Directly Boded on SOI Substrate with Rib-waveguide Structure

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Abstract

Membrane GaInAsP/InP distributed feedback lasers were realized on an SOI substrate integrated with rib-waveguide structure and continuous-wave operation under optical pumping was obtained up to 85°C. The characteristics temperature was 65 K and the thermal resistance was estimated to be 11 K/mW.

I. Introduction

It has been predicted that the continued growth of silicon LSI technology will soon hit the interconnect bottleneck such as the ohmic heating and the RC delay due to the metal lines. One of methods to solve this problem is a replacement of the metal line by an optical line.

Since a silicon on insulator (SOI) substrate has a high index contrast between the silicon core (n=3.45) and the oxide buffer layer (n=1.45) and it makes ultracompact optical circuits at the low-loss fiber communication wavelengths, integrations of functional photonic devices such as lasers and optical amplifiers on SOI platforms are very attractive. Room-temperature continuous-wave (RT-CW) operations of semiconductor lasers fabricated on a silicon substrate by heteroepitaxial growth [1] and direct wafer-bonding [2] have been reported, however, it is difficult to couple light outputs to a silicon waveguide because of their thick cladding layers. Membrane-based lasers are very attractive for low threshold operation as well as integrations to an SOI waveguide [3]. Recently, we have reported RT-CW operations of optically pumped GaInAsP/InP membrane buried-heterostructure (BH) distributed feedback (DFB) lasers on an SOI substrate using direct wafer bonding [4],[5]. An injection type semiconductor laser fabricated on an SOI substrate was achieved by BCB/SiO_2 bonding [6] and plasma assisted bonding [7].

In this paper, we would like to report relatively high temperature CW operation of GaInAsP membrane DFB lasers on an SOI substrate rib-waveguide structure with narrow stripe width.

II. Device Structure and Fabrication

The device structure of GaInAsP/InP membrane lasers on an SOI waveguide is shown in Fig. 1. A five-quantum-well, consisting of a $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ 1% compressively-strained well (6 nm thick) sandwiched by 2-step optical confinement layers of $Ga_{0.22}In_{0.7d8}As_{0.48}P_{0.52}$ (λ_g=1.2μm, 10 nm thick) / $Ga_{0.14}In_{0.86}As_{0.31}P_{0.69}$ (λ_g=1.2 μm, 55 nm thick) were grown on a (100) n-InP substrate as an initial wafer by an OMVPE technique. The DFB structure was fabricated on the initial wafer by using an electron-beam lithography, CH_4/H_2 reactive ion etching (RIE) and OMVPE regrowth [4]. The SOI and the GaInAsP/InP substrates were dipped in a H_2SO_4:H_2O_2:H_2O solution to make these surfaces hydrophilic, which is important for self-adhesion at room temperature. These substrates were loaded into a furnace and heated at 250 °C for 3 hours [5]. After bonding, the membrane structure was formed by selective wet chemical etching of the InP substrate side. Then the stripe geometry was formed by photolithography and RIE dry etching as shown in Fig. 1. Typical (wirelike) active region width and the period of the first-order grating were around 110 nm and 250nm, respectively. The cavity length and the stripe width were 140 μm and 1.5 μm, respectively. The waveguide length and the stripe width in the waveguide region were 500 μm and 1.5 μm, respectively.

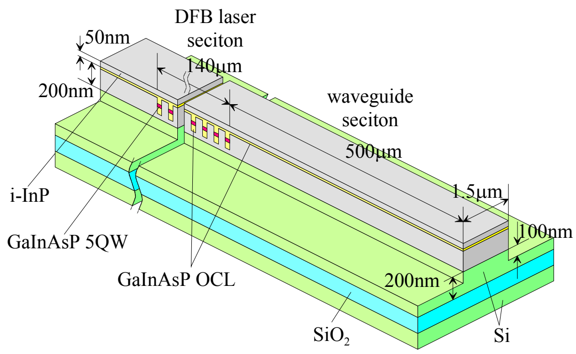

Fig. 1 Schematic structure of GaInAsP/InP membrane DFB laser and InP/SOI waveguide.

III. Lasing Characteristics

The device was optically pumped from the top with a 980 nm wavelength CW laser diode through a single-mode optical fiber connected to a micro-PL setup. The pumping light was focused through a cylindrical lens to a spot size of 4 μm ×176 μm. The output power was coupled into a multi-mode fiber connected to an optical spectrum analyzer. This laser was oscillated up to 85 °C. The characteristic temperature T_0 of 64K was obtained. Although both sides of this mesa stripe was surrounded with air which is very low thermal conductive material compared with semiconductor, the characteristic temperature was higher than the value of the laser on SOI [7].

Figure 2 shows the temperature dependence of lasing wavelength. The incremental temperature coefficient of the lasing wavelength was 8.9×10^{-2} nm/K, which is approximately 20% smaller than that of conventional 1.55 μm wavelength lasers because an optical field penetrates into air cladding regions [8] and exists in silicon layer whose temperature coefficient of the refractive index is almost a half of that of InP.

Figure 3 shows the pump power dependence of lasing wavelength. The lasing wavelength increased linearly with the pump power above the threshold because the carrier density clamps at the threshold and the incremental coefficient against pump power $d\lambda/dP_{\mathrm{pump}}$ was 2.2×10^{-2} nm/mW. By assuming the absorption coefficient of GaInAsP OCL to be 10,000 cm^{-1} and all absorbed power was changed into heat, the thermal resistance R_{th} can be estimated from the temperature coefficient of the lasing wavelength to be 9.3 K/mW, which is slightly small value (11 K/mW) of the previously reported air-bridge type membrane BH-DFB laser due to better heat pass through SOI layer [9].

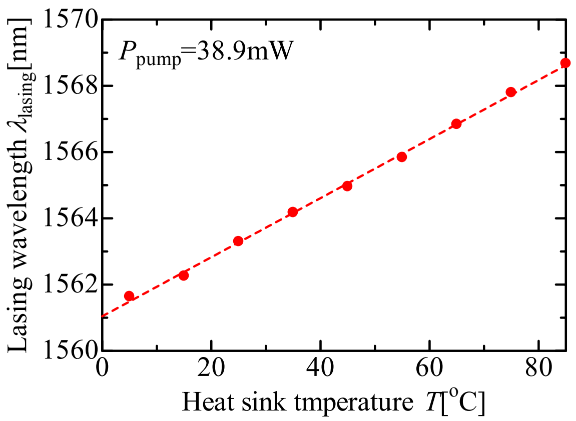

Fig. 2 Temperature dependence of lasing wavelength.

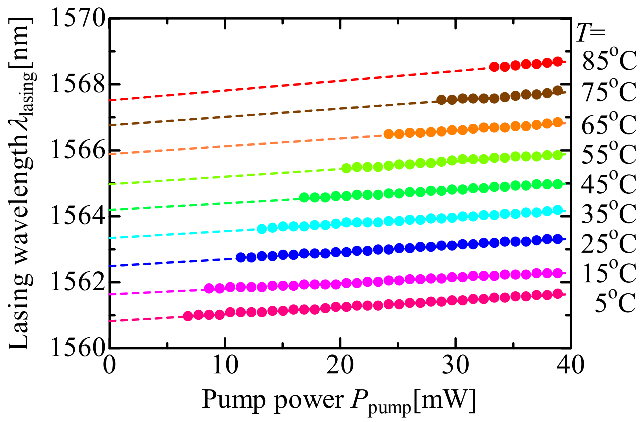

Fig. 3 Lasing wavelength as a function of pump power.

IV. Conclusion

CW operation of GaInAsP membrane DFB lasers integrated with SOI rib-waveguide was demonstrated up to 85 °C. The characteristic temperature of 64K was achieved with the stripe width of 1.5 μm, the cavity length of 140 μm and the waveguide length of 500 μm. This device structure can be applied to realize photonic integrated circuits (PICs) consisting of lasers, modulators, amplifiers, detectors and SOI passive components.

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