10 Gb/s Operation of GaInAs/InP Top Air-Clad. Lateral Junction Waveguide-type Photodiode

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Abstract- **10 Gb/s operation of GaInAs/InP lateral junction-type photodiode was obtained by adopting a narrow stripe width of 0.85 µm. The responsivity of 0.39 A/W and the 3dB bandwidth of 8.8 GHz at a bias voltage of -2 V were obtained with the device length of 380 µm.**

I. INTRODUCTION

One of the promising solutions to overcome the problems of future Si-LSI such as global-wire signal delay and power dissipation is an introduction of the optical interconnection as substitute for electrical global wiring. For realization of the on-chip optical interconnection, low power consumption optical devices with small footprint are strongly required [1]. We proposed membrane distributed feedback (DFB) laser which consists of thin semiconductor core layers sandwiched by low refractive index cladding layers such as benzocyclobuten (BCB) or SiO_2. Since the membrane structure has strong optical confinement into the core layer, the membrane DFB laser is feasible for low power consumption operation and short cavity length [2]. In order to realize electrically pumped membrane lasers, lateral current injection (LCI) structure was adopted [3], and moderately high performance operation was confirmed by LCI-type lasers prepared on semi-insulating (SI)-InP substrate [4,5]. Recently LCI-membrane DFB laser by using BCB bonding process has been reported [6].

Toward photonic integrated circuits (PICs) based on the membrane structure, a lateral junction waveguide-type membrane photodiode, which has relatively thin core layer in common with the membrane laser, is suitable for monolithic integration with the membrane DFB laser. Since the device length can be reduced due to strong optical confinement effect, the membrane structure has also advantage for waveguide-type photodiode. In this paper, we would like to report a successful operation of GaInAs/InP lateral junction waveguide-type photodiode fabricated on a SI-InP substrate.

II. DEVICE STRUCTURE AND FABRICATION PROCESS

Figure 1 shows the schematic diagram of the fabricated lateral junction waveguide-type photodiode. The optical confinement factor in the GaInAs absorption layer (100 nm thick) was estimated to be about 19%, which was considerably increased compared with that of previously reported device consisting of 5 quantum-wells absorption layer [7]. Furthermore, our final target is the lateral junction

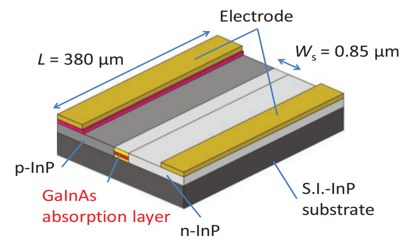

Fig. 1 Schematic device Structure

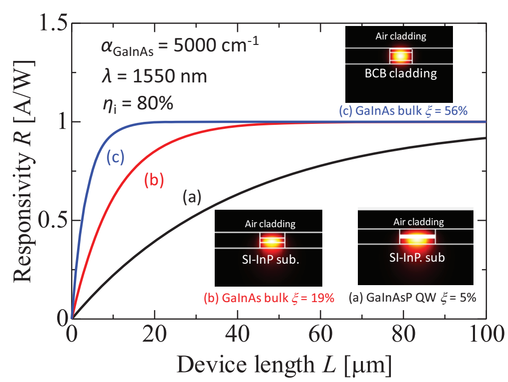

Fig.2 Responsivity dependence on the device length

waveguide-type membrane photodiode which consists of thin core layer sandwiched by low refractive index cladding layers and the total thickness of around 200 nm. The optical confinement factor in such membrane structure can be increased to more than 50%. Figure 2 shows the calculated responsivity of various photodiodes as a function of the device length with the various optical confinement factors. The internal quantum efficiency was assumed to be 80%. Figure 2 (a) and (b) represent the responsivity and a cross sectional optical mode field of the photodiode on SI-InP with the absorption layer of the GaInAsP-QW (previous work) and GaInAs bulk (this work), where the total core layer thickness is set to be 400 nm for both cases. Figure 2 (c) represents those for the membrane photodiode with the core layer thickness of 200 nm, where the optical confinement factor of the GaInAs bulk absorption layer can be enhanced to be 56% and the device length can be reduced to less than 20 µm.

Figure 3 shows the cross sectional SEM view of the fabricated device. The lateral junction structure was formed

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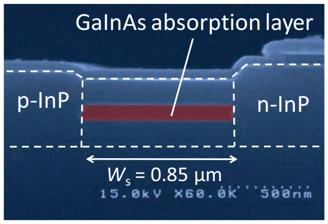

Fig. 3 Cross sectional SEM view of the lateral junction structure.

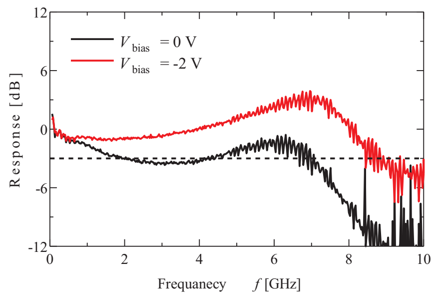

Fig. 4 Frequency response with various bias voltage.

by using two step OMVPE regrowth method [4]. The total thickness of the core layer, which consists of a lower optical confinement layer (OCL, λ_g = 1.2 μm, 155 nm), GaInAs bulk abosorption layer (100 nm thick), and an upper OCL (λ_g = 1.2μm, 155 nm), was designed to be 400 nm. First, a mesa structure was formed with a SiO_2 mask and dry etching process. After removing plasma damaged sidewall, n-InP (N_D = 4 × 10^{18} /cm^3) was selectively regrown at both sides of the mesa. Next, by etching the part of the wide mesa and the one side of the buried n-type layer in the similar way, narrow (0.85-μm-wide) stripes were formed. Then, p-InP (N_A = 4 × 10^{18} /cm^3) cladding and p-GaInAs contact layers were regrown in the same way. Finally, Ti/Au electrode was deposited on both the p-GaInAs contact and the n-InP sections. The stripe width and the device length of the fabricated lateral junction waveguide-type photodiode were 0.85 μm and 380 μm, respectively.

III. Device Characteristics

The responsivity of the fabricated device was estimated to be about 0.37 A/W at the wavelength of 1550 nm, which was 37% larger than that (0.27 A/W) of previously reported device with MQW absorption layer [7]. The frequency response of the fabricated device is shown in Fig.4. An electrical signal from a network analyzer was converted into a light signal with a network performance tester in which a LN modulator and a DFB laser were built, then the light signal was converted into an electrical signal with the fabricated lateral junction photodiode mounted on an alumina submount with a co-planer circuit. The increased response at around 7 GHz might be due to the impedance mismatching between the device and submount. The 3dB bandwidth was observed to be 1.9 GHz at non-bias condition and 8.9 GHz at the bias voltage of -2 V. This 3dB bandwidth at a bias voltage of -2 V was 6 GHz in the previously reported device with the stripe width of 1.4 μm, hence the reduction of the stripe width resulted in faster response.

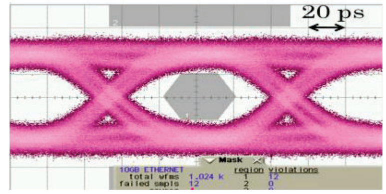

Fig.5 Eye diagram at 10 Gb/s(V_{bias} = -2 V).

Figure 5 shows the eye diagram at 10 Gb/s operation. The pseudo random bit sequence (PRBS) non-return-to-zero (NRZ) signal with the word length of 2^{31}-1 from a pulse pattern generator was converted into light signals and input to the fabricated photodiode. As can be seen, a clear eye opening at 10 Gb/s with the bias voltage of -2 V was observed.

IV. Conclusion

In order to realize a high speed operation, narrow stripe lateral junction waveguide-type photodiode with GaInAs bulk absorption layer was demonstrated. By adopting the GaInAs bulk absorption layer, the responsivity of 0.39 A/W was obtained. The 3dB bandwidth of 8.8 GHz at a bias voltage of -2 V was realized for the stripe width of 0.85 μm and device length of 380 μm, and a clear eye opening was obtained up to 10 Gb/s.

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