Over-67-GHz-bandwidth Membrane InGaAlAs EADFB Laser on Si Platform

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Abstract: A membrane InGaAlAs electro-absorption modulator with an over 67-GHz bandwidth is integrated with a DFB laser on a Si platform. The integrated device shows a dynamic extinction ratio of 3.8 dB for 100-Gbit/s non-return-to-zero signals.

1. Introduction

The demand for large-capacity optical transceivers is increasing with the rapid growth of data center traffic. In the transmitter, a directly modulated laser, Mach-Zehnder modulator, and electro-absorption modulator (EAM) are respectively required for appropriate applications. Among them, the EAM has attracted much attention due to its small footprint and large EO bandwidth. EAMs using InP-based multiple-quantum wells (MQWs) have been widely used because of the wide range of operation wavelength (O, C, and L bands), high modulation efficiency, and easy integration with laser diodes (LDs) and semiconductor optical amplifiers (SOAs) [1, 2]. A state-of-the-art InP-based traveling-wave EAM integrated distributed feedback (EADFB) laser showed the EO bandwidth of exceeding 100 GHz and 204-Gbaud non-return-to-zero (NRZ) modulation [2, 3]. Recently, large EO bandwidth was also demonstrated using a membrane EAM with a lumped electrode on a Si photonics platform [4, 5]. Because of their large optical confinement and low capacitance compared to those of typical InP-based EAMs, GeSi EAMs on Si platforms for the C band and L band exhibit 100-Gbaud-class operations and EO bandwidths of more than 67 GHz without 50 ohm termination, providing a simple and energy-efficient drive architecture. For data center interconnects, there is a strong desire to fabricate O-band EAMs on a Si platform and integrate them with lasers.

As a solution, we focus on a membrane InP-based EAM integrated with a laser on a Si platform. In our previous work, by employing wafer bonding and epitaxial regrowth on a silicon-on-insulator wafer, we fabricated a 300-μm-long membrane InP-based EAM with a lateral p-i-n diode that demonstrated the EO bandwidth of 50 GHz in the L band [6]. Thus, the next challenge is to achieve O-band operation, laser integration, and 100-Gbaud-class operation, which is becoming increasingly important not only for data center interconnects but also for beyond 5G applications using millimeter-wave communications. In this work, we fabricated a high-speed membrane EADFB laser, which has an MQW layer designed for the O-band operation. By increasing the optical confinement in the MQW, we successfully reduced the EAM length to 100 μm and achieved the EO bandwidth of over 67 GHz without 50-ohm termination. Using the fabricated EADFB laser, we demonstrated 100-Gbit/s NRZ operation with an extinction ratio (ER) of 3.8 dB.

2. Device structure

Fig. 1(a) and (b) show cross sections of the membrane EAM and DFB laser, Fig. 1(c) shows a cross-sectional transmission electron microscope (TEM) image of the EAM, and Fig. 1(d) shows a top view of the EADFB laser on Si. The EAM has a 400-nm-wide InGaAlAs MQW core buried in a 230-nm-thick InP layer. The photoluminescence (PL) peak wavelength of the MQW is 1.23 μm for the O-band operation. By applying reverse bias voltage, a lateral electric field is applied to the MQW layer, and the absorption coefficient is changed by the Franz-Keldysh effect [6]. The number of MQW periods is nine, which is larger than that of the previous device [6]. By increasing the number of MQW layers, both the total absorption area and optical confinement factor are increased. The design is beneficial for reducing the length of the EAM while maintaining a large extinction ratio and low density of photogenerated carrier per well layer and thus obtain a large EO bandwidth even at high optical power. The absorption length of the EAM is 100 μm, which is one third of the length of the previous EAM. The DFB laser is also buried in the 230-nm-thick InP layer. In this work, for a feasibility check, the MQW layer of the laser was the same as that of the EAM for ease of fabrication. The DFB laser has a uniform SiN grating on the top surface of the InP layer, and a width-modulated Si waveguide under the MQW [7]. Since the effective refractive indices of the III-V and Si layers are close, the MQW and Si cores can be optically coupled to reduce the mode overlap with the large-loss p-InP. In addition, optical mode field is easy to transfer between the DFB laser and Si waveguide using InP taper waveguides. The DFB laser and EAM are electrically isolated by the low-loss Si waveguide section between them. These features are important for achieving high modulation rates in EADFB lasers. The length of the active region is 300 μm. One of the two outputs from the DFB laser is coupled to a Si waveguide though a 50-μm-long InP taper and then coupled to an SiOx core through an inversely tapered Si layer (laser monitor). The other output light from the DFB laser is coupled to a Si waveguide then enters the EAM through an InP/Si taper (EAM output).

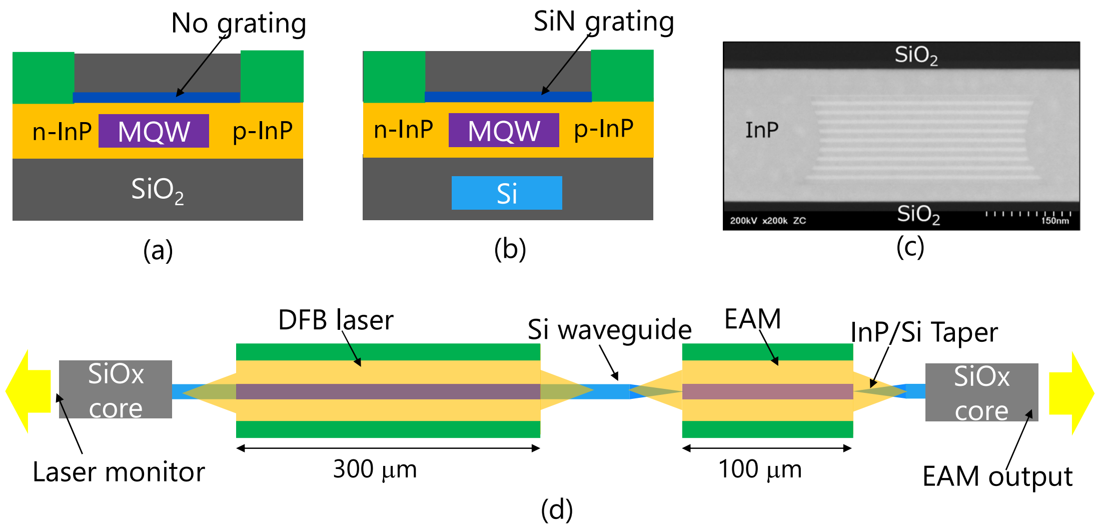

Fig. 1. Cross-sectional images of (a) EAM and (b) DFB laser. (c) Cross-sectional TEM image of EAM. (d) Top view of EADFB laser.

3. Measured results

We first measured the output power of the fabricated EADFB laser. We measured the output power from the laser monitor and EAM output ports by using a lensed fiber. The measured fiber-coupled output power at the laser monitor and EAM output were around +2.0 and -2.0 dBm with an LD current of 40 mA and without applying voltage to the EAM. Fig. 2(a) shows a measured lasing spectrum at the LD current of 40 mA. The lasing wavelength was near 1260 nm with the side-mode suppression ratio of around 47 dB. Note that the output power can be increased by increasing the active length and reducing the optical confinement factor in the MQW layer [7].

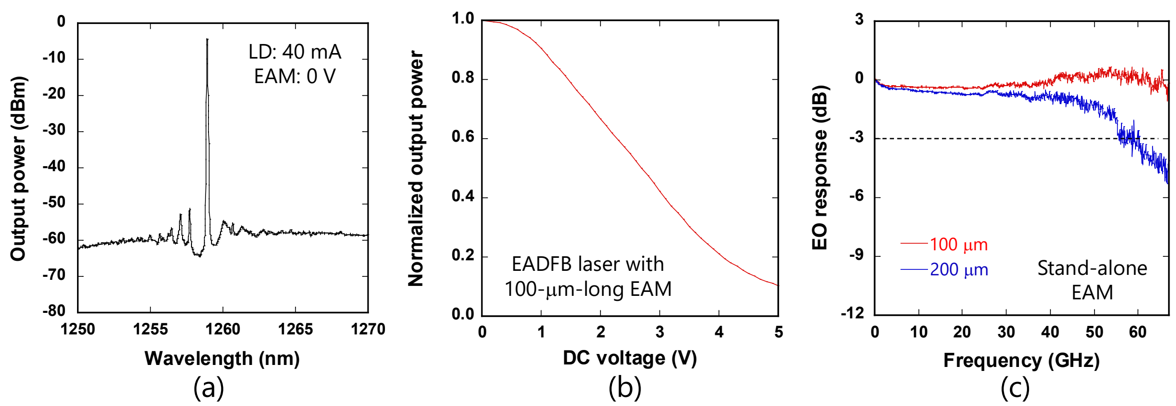

Fig. 2. (a) Lasing spectrum of EADFB laser. (b) Normalized output power of EADFB laser. (c) Measured EO response of stand-alone EAMs.

We also measured the output power from the EAM output port with various DC voltages applied to the EAM. Fig. 2(b) shows the measured output power normalized at 0 V. The LD current was set to near the threshold current to suppress the temperature increase at the EAM by photocurrent. The EAM showed relatively good linearity. From 0 to 3 V, the ER of the EADFB laser was 3.7 dB.

Next, to evaluate the EO bandwidth of the EAM, we fabricated and measured stand-alone EAMs with various absorption lengths on the same wafer. Fig. 2(c) shows the measured EO response of the stand-alone EAMs with the lengths of 100 and 200 μm. The input wavelength and DC voltage were 1280 nm and 2 V, respectively. In the measurements, we didn't use a 50-ohm termination at the EAM. Even with the longer one (200-μm-long EAM), we achieved the EO bandwidth of around 60 GHz, which is larger than that of our previous EAM [6]. By reducing the EAM length to 100 μm, the EO bandwidth increased thanks to the reduction of device capacitance and reached over 67 GHz. The EO bandwidth of the 100-μm-long EAM is expected to be much larger than that of the state-of-the-art InP-based EADFB laser [8], even without 50-ohm termination. From the results, we confirmed the EO bandwidth was successfully increased and it is large enough for 100-Gbaud-class operation.

Finally, we measured eye patterns of the EADFB laser with the 100-μm-long EAM. The experimental setup is shown in Fig. 3(a). The NRZ signals from a pulse pattern generator (PPG) were amplified by an RF amplifier, whose bandwidth was around 66 GHz. The peak-to-peak voltage of the input signal was around 2.6 V, which was measured by a 50-ohm system. Here, we input the RF signal to the EAM through an RF probe without 50-ohm termination at the EAM. The output light from the chip was fed into an O-band SOA and then detected by a p-i-n photodiode (PD). The eye patterns were measured by a sampling oscilloscope. Fig. 3(b) and (c) show the eye patterns of the input and output waveforms for 100-Gbit/s NRZ signals with a DC bias voltage of 2 V. The LD current was 44 mA. We obtained eye openings with an ER of 3.8 dB for the 100-Gbit/s NRZ signals. Note that, in our experimental setup, the maximum symbol rate was limited by the bandwidths of the RF amplifier and p-i-n PD.

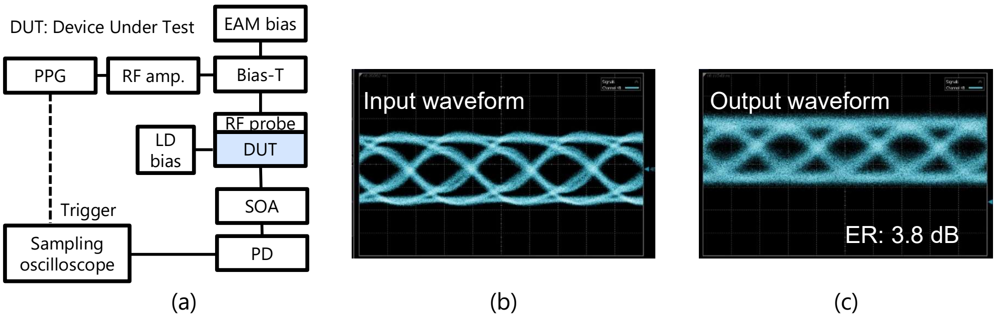

Fig. 3. (a) Experimental setup and measured (b) input and (c) output eye patterns for 100-Gbit/s NRZ signals.

4. Conclusion

A membrane InGaAlAs EAM, whose bandwidth is over 67 GHz, was integrated with a DFB laser on a Si platform. The integrated device showed 100-Gbit/s NRZ operation with an ER of 3.8 dB. This technology is a key to fabricating a compact, low-power-consumption, and low-cost optical transceiver.

References

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