Monolithically Integrated 16×10-Gb/s WDM Receiver on a Silicon-Silica-Germanium Photonic Platform

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1. Introduction

In wavelength-division multiplexing (WDM) optical network systems, various optical devices are being integrated to reduce cost and the footprint. The silicon (Si) photonic platform is attracted as the key technology for a highly integrated WDM network system. In previous work, we reported monolithic integration of a silica-based arrayed waveguide grating (AWG) and germanium (Ge) photodiodes (PDs) on a Si chip [1]. However, system bandwidth was limited to 16×1.25 Gb/s due to RC delay of Ge PDs. In this study, we have improved operation speed of Ge PDs and integrated them with the silica-based AWG for a 16×10 Gb/s WDM receiver.

2. Design and fabrication

Top-view images of an integrated AWG-PD chip are shown in Fig. 1(a). The AWG comprises Si-rich silica (SiOx) waveguides with a reflective index contrast of $\sim 3\%$ and core size of 3 μ m \times 3 μ m. The SiOx waveguides allow lower transmission loss and lower temperature dependence than Si waveguides [1]. Here, the channel spacing of the AWG is 200 GHz (wavelength of ~1.6 nm). The silica-based AWG is connected to a Si waveguide with Ge PDs using spot size converters (SSCs). A cross-sectional view of the Ge PD on Si waveguide is shown in Fig. 1(b). Ge PDs were designed to reduce RC delay with (1) an optimized G-S-G electrode layout, (2) the short p-Si slab length of 4.5 µm to reduce sheet resistance between the Ge mesa and p-Si electrode, and (3) a high boron concentration of 10²⁰ /cm³ at the p-Si/ electrode interface to reduce contact resistance. The size of Ge area is 10 μ m \times 50 μ m.

The fabrication process features thermal tolerance and CMOS compatibility for monolithic integration. First, Si waveguides with core size of 200 nm \times 400 nm were fabricated using electron-cyclotron-resonance (ECR) plasma etching. Next, boron implantation and Ge selective growth for Ge PDs were performed [2]. Here, a thin Si film was deposited on the Ge surface to prevent the Ge film from being damaged during CMOS process and form a stable contact interface between the metal electrodes and Ge. After that, a SiOx film was formed by using ECR

plasma-enhanced chemical vapor deposition (PECVD) for the silica-based AWG. This method enables us to form high-quality silica film at temperatures below 200°C and thereby prevent degradation of the Si waveguides and Ge PDs [3]. The SiOx film was then etched to form SiOx cores for the AWG and SSCs, and an over-cladding film was deposited. After that, contact-holes were formed and phosphine was implanted into Si/Ge layer on top of Ge PD. Finally, Ti/TiN/Al electrodes were formed.



Fig. 1. (a) Top-view images of integrated AWG-PD device. (b) Cross-sectional view of the Ge PD on a Si waveguide.

3. Performance of monolithically integrated AWG-PD

We examined performance of the monolithically integrated AWG-PD device. Transmittance of Si and SiOx waveguides for the TE mode is shown in Fig. 2. Propagation losses of the Si and SiOx waveguides are 2.8 and 1.0 dB/cm, respectively. Low-loss Si and SiOx waveguides were successfully integrated.



Fig. 2. Transmittance of Si and SiOx waveguides.

Next, the performance of a stand-alone Ge PD with Si/SiOx waveguide was evaluated. Current-voltage curves of the Ge PD in the dark and illuminated state are shown in Fig. 3. Input light power was 1.26 mW at the SSC before the Ge PD. Dark current was 245 nA and photocurrent was 1.27 mA at DC bias of -2V. Here, the responsivity is about A/W. Relationship between photocurrent 1.0 and wavelength is shown in Fig. 4. Ge PDs show flat wavelength dependence in C-band input light. Series resistance at DC bias of 2V is ~140 Ω . This value is 20 times lower than that of previous work. The Ge PD design and fabrication process in this study successfully reduce the RC time constant of the Ge PD. Frequency characteristics of the Ge PD are shown in Fig. 5. The 3-dB cutoff frequency of the Ge PD at DC bias of -2 V was estimated to be over 20 GHz. The Ge PDs operate fast enough for 25-Gb/s WDM receivers.



Fig. 3. Current-voltage curves of Ge PD.



Fig. 4. Relationship between photocurrent and wavelength.



Fig. 5. Frequency characteristics of Ge-PD.

Finally, we evaluated performance of the integrated AWG-PD device. We input TE mode light into the silica-based AWG and obtained demultiplexing spectra from all 16 channels of Ge PDs at DC bias of -2V. Demultiplexing spectra are shown in Fig. 6. The spectra show a channel spacing of ~1.6 nm as designed, and interchannel crosstalk is less than -16 dB. Here, the total insertion loss of the AWG was about 6 dB. An eye diagram of photocurrent with 10 Gb/s signal input into the AWG is shown in Fig. 7. Input signal was PRBS 2³¹-1, signal wavelength was 1564.6 nm, and DC bias of the Ge PD was -2 V. The eye diagram shows sufficient eye opening for 10-Gb/s receivers. From these results, we conclude that the performance of the monolithically integrated silica-based AWG and Ge PDs on a Si chip is high enough for 16 \times 10 Gb/s WDM receiver operation.



Fig. 6. Demultiplexing spectra of integrated AWG-PD device.



Fig. 7. Eye diagram of Ge PD with 10 Gb/s input signal.

4. Conclusion

We monolithically integrated a silica-based AWG and Ge PDs on a Si chip. We achieved the Ge-PD cutoff frequency of ~20 GHz and 10-Gb/s receiver operation. These results show that the silicon-silica-germanium photonic platform is a promising candidate for highly integrated WDM systems.

References

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