Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp626-627

Waveguide InGaAs Metal-semiconductor-metal Photodetector Monolithically Integrated with InP Grating Coupler on III-V CMOS Photonics Platform

Yongpeng Cheng[1, 2], Yuki Ikku[1, 2], Mitsuru Takenaka[1, 2] and Shinichi Takagi [1, 2]

[1] Department of Electrical Engineering and Information systems, The University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[2] JST-CREST, Japan
Phone: +81-3-5841-6733, E-mail: ypcheng@mosfet.t.u-tokyo.ac.jp

Abstract

A waveguide InGaAs metal-semiconductor-metal (MSM) photodetector (PD) monolithically integrated with an InP grating coupler has been demonstrated using the III-V CMOS photonics platform. The grating coupler gives approximately 28% coupling efficiency, which allows wafer-scale testing with better coupling and alignment tolerance than edge-fire coupling. Integrated with the demonstrated grating coupler, the waveguide InGaAs PD gives a peak responsivity of approximately 0.19 A/W with a spectrum conforming well to the integrated grating coupler characteristics. The demonstrated PD on a III-V-on-insulator wafer enables compact receiver chips for optical interconnects.

1. Introduction

As photonics enters fields from telecommunications to short-reach optical interconnects in data centers and high-performance computers [1, 2], photonic integrated circuits (PICs) are intensively researched for the integration of laser diodes, modulators, photodetectors (PDs), and passive waveguides. With a long researching and developing history, the conventional III-V photonics still has unchallenging positions especially for lasers. But in the integration view of III-V photonics circuits, the low two-dimensional optical confinement in ridge waveguides and deeply-etched waveguides prevents us from developing high-density and compact InP PICs because sharp bending causes substrate leakage of optical fields [3].

In order to develop compact III-V PICs, we have proposed the III-V CMOS photonics platform using the III-V-on-insulator (III-V-OI) wafer which can be fabricated by the direct wafer bonding of InP-based layers on a SiO_2/Si wafer [4]. Owning to the buried oxide layer, the strong two-dimensional optical confinement and compact InP-based photonic-wire devices are feasible. In addition, III-V materials are also considered as next-generation metal-oxide-semiconductor (MOS) transistors because of their high electron mobility. Hence, the III-V CMOS photonics platform ultimately enables high performance electronic-photonic integrated circuits (EPICs). On this platform, we have already demonstrated microbends, ultrasmall arrayed waveguide gratings [4], optical switches [5]. We have also demonstrated InGaAs metal-semiconductor-metal (MSM) PDs monolithically integrated with an InP photonic-wire waveguide [6]. However, the edge-fire coupling of the input optical signal resulted in a low coupling efficiency between a lensed fiber and the InP photonic-wire waveguide. In this paper, we present a waveguide InGaAs MSM PD on the III-V CMOS photonics platform monolithically integrated with an InP grating coupler, as shown in Fig. 1.

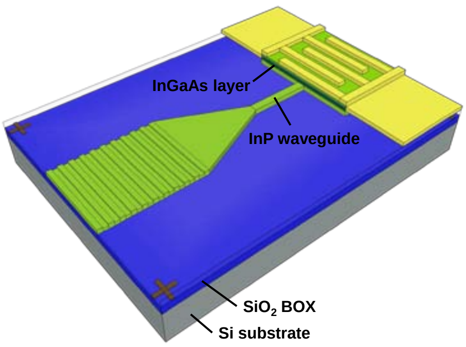

Fig. 1 Schematic of waveguide InGaAs MSM PD with grating coupler on the III-V CMOS photonics platform.

2. InP grating couplers on the III-V CMOS photonics platform

Figure 2 shows a schematic of an InP grating coupler fabricated on a III-V-OI wafer. At first, we bonded a 350-nm-thick InP waveguide layer to a 2-μm-thick SiO_2 buried oxide layer (BOX) as described in [6]; and then, we used two electron-beam lithographies (EBL) to form grating patterns and waveguide respectively. The InP layer was etched by reactive ion etching with CH_4/H_2 gases. The grating etching depth was 100 nm. The InP epitaxial wafers were provided by Sumitomo Chemical Co.,Ltd.

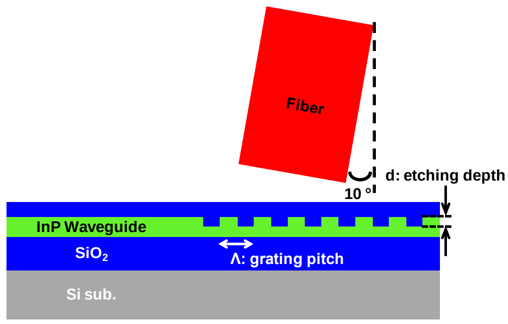

Fig. 2 Schematic of InP grating coupler on III-V-OI wafer

Figure 3 shows the transmitted power through the two grating couplers with 660 nm grating pitch (Λ) and a

500-µm-long InP photonic-wire waveguide. We used two cleaved single-mode fibers for the optical input and output. In Fig. 3, we obtained a transmitted power of -11.6 dBm at 1555 nm when the input power was 0 dBm. And the full width at half maximum (FWHM) for the grating coupler is 40nm. By taking into account the propagation loss of 1.2 dB/mm for the InP waveguide [6], the coupling efficient of a single grating coupler was estimated to be -5.5 dB.

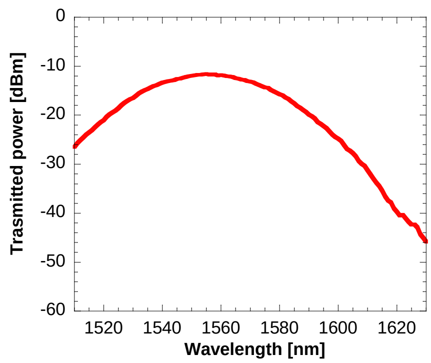

Fig. 3 Measured transmitted power of InP grating coupler on III-V-on-insulator wafer.

3. Waveguide InGaAs MSM photodetectors integrated with grating coupler

We also integrated the InP grating couplers to the waveguide InGaAs MSM PDs on a III-V-OI wafer. The 200-nm-thick InGaAs absorbing layer was stacked on the InP waveguide layer. To reduce the dark current, we prepared an InAlAs Schottky barrier enhancement layer with a 25-nm-thick InP cap layer on the InGaAs layer. After fabricating the III-V-OI wafer, we fabricated the device by the following procedure: at first, we defined the InGaAs PD mesa by wet etching. After the formation of the grating, InP waveguides were etched by dry etching. Finally, the SiO_2 surface passivation layer and interdigitated electrodes were deposited. Figure 4 shows plan-view microscopic images of the fabricated device.

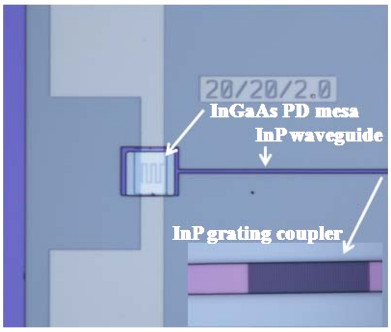

Fig. 4 Plan views of waveguide InGaAs MSM PD integrated with grating coupler.

Figure 5 shows the InGaAs PD wavelength dependence by the responsivity measured at 4 V bias. Here, the optical input at the InP grating coupler is 0 dBm. The responsivity exhibits a spectrum of 1554 nm peak wavelength and 81nm FWHM. Here, the comparably wider FWHM in Fig. 5 than Fig. 3 is because only one grating coupler is used for PD integration. At the peak wavelength of 1554 nm, we attain an intrinsic responsivity of approximately 0.19 A/W by taking into account the coupling loss of the grating coupler and the 1.4 dB propagation loss of the InP waveguide. The responsivity is relatively low because the SBE layer blocks the photogenerated carriers. By introducing a gradually component-changing InAlAs SBE layer [7], the responsivity can be improved.

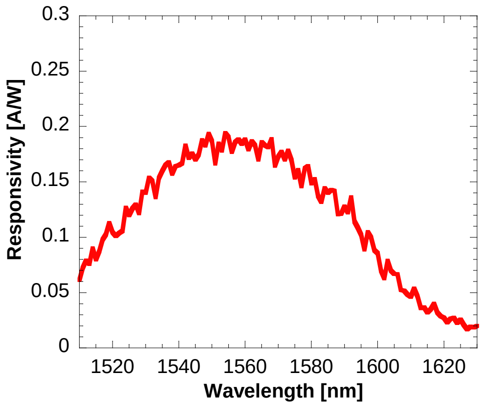

Fig. 5. Wavelength dependence of responsivity measured at 4 V.

4. Conclusions

We successfully integrated an InP grating coupler and a waveguide InGaAs MSM PD on a III-V-OI-on-Si wafer. The InP grating coupler exhibited a coupling efficiency of approximately 28% at a wavelength of 1555 nm. After the monolithic integration of the InP grating coupler to the InGaAs PD by the InP photonic-wire waveguide, the PD also shows a reasonable spectrum with 0.19 A/W responsivity at the 1554 peak wavelength. Thus, the demonstrated waveguide InGaAs PD can be used for compact receiver chips for the optical interconnects.

Acknowledgements

This work was supported by a Grant-in-Aid for Young Scientists (A) from MEXT. The authors would like to thank Osamu Ichikawa, Hisashi Yamada, Sumitomo Chemical Company Ltd., Tsukuba, Japan, for their technical supports.

References

[1] R. G. Beausoleil, M. McLaren, and N. P. Jouppi, IEEE J. Sel. Top. Quantum Electron. **19** (2013) 458.

[2] S. Rumley, D. Nikolova, R. Hendry, Q. Li, D. Calhoun, and K. Bergman, J. Lightwave Technol. **33** (2015) 547.

[3] Robert J. Deri and Eli Kapon, IEEE J. Quantum Electron. **27** (1991) 626.

[4] M. Takenaka, M. Yokoyama, M. Sugiyama, Y. Nakano, and S. Takagi, Appl. Phys. Express **2** (2009) 122201.

[5] Y Ikku, M. Yokoyama, O. Ichikawa, M. Hata, M. Takenaka, and S. Takagi, Opt. Express **20** (2012) B357.

[6] Y. Cheng, Y. Ikku, M. Takenaka, and S. Takagi, IEICE Electron. Express **11** (2014) 1.

[7] E. Sano, M. Yoneyama, T. Enoki and T. Tamamura, Electron. Lett. **28** (1992) 1220.