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Micro-transfer printing of O-band InP-InGaAs photodiodes on a silicon nitride photonic platform

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***Abstract*—We present the heterogeneous integration of O-band InP-InGaAs photodiodes on a silicon nitride photonic platform using micro-transfer printing technology. The devices exhibit a responsivity of 0.9 A/W at 1310 nm with an applied bias voltage of -3 V.**

***Index Terms*—photodiode, heterogeneous integration, micro-transfer printing, silicon photonics**

I. INTRODUCTION

Photonic integrated circuits (PICs) play an important role in the realization of transceivers, LiDAR systems, optical sensing and computing systems. Compared with the conventional silicon-on-insulator (SOI) silicon photonics (SiPh) platforms, silicon nitride (SiN) has the advantages of low propagation loss, broad transparency window and high power handling capability making it an ideal platform for these applications. However, active components cannot be provided on a low-pressure chemical vapor deposition (LPCVD) SiN platform. Micro-transfer printing (μTP), as an emerging heterogeneous integration technology, can enable this. The technique shows great versatility. A series of III-V [1], [2], silicon [3] and lithium niobate [4] devices have been introduced to SiN platforms by using this technology, which brings a great functional extension to SiN PIC platforms.

In this work, we present a waveguide-coupled O-band InP-InGaAs photodiode on an LPCVD SiN photonics platform, which was realized with μTP technology. The measured responsivity is up to 0.9 A/W at the wavelength of 1310 nm, under a -3 V bias voltage. The dark current for a device with an active region of 6×25 μm^2 is 47.5 nA at -1 V bias voltage and 0.5 μA at -3 V bias voltage.

II. FABRICATION USING μTP

The whole fabrication process can be divided into 3 parts: the fabrication of transfer-printable photodiode coupons, μTP, and the post-printing process. As illustrated in Fig. 1(a), photodiodes are fabricated on an InP-InGaAs layer stack, with an additional sacrificial InGaAs layer to release the device coupons from the InP substrate. A SiN layer is deposited and patterned for passivation and to create tethers to anchor the photodiodes on the substrate, after which the devices are released. When laminating the PDMS stamp to the fabricated device coupon, the SiN tethers break and the devices are picked-up. The photodiode is then transfer-printed onto a prepared SiN PIC (300 nm SiN waveguide layer thickness, 1.1 μm waveguide width). The post-printing process includes spin-coating BCB cladding and final metallization for GSG electrodes. Fig. 1(b) shows the microscope image of a resulting waveguide-coupled photodiode. The device has a pair of grating couplers for light input and GSG electrodes for electrical probing. A reference waveguide is set next to the device to calibrate the input optical power.

III. SIMULATION AND CHARACTERIZATION

IV curves were measured to investigate dark currents of the fabricated photodiodes. For a photodiode with a 6×25 μm^2 active region, as presented in Fig. 2(a), the dark currents are found to be 47.5 nA and 0.5 μA at -1 V and -3 V bias voltages, respectively. Fig. 2(b) is the simulated side-view of the fundamental TE mode launched into a photodiode with a 25 μm long active region. The optical power is evanescently coupled from the SiN waveguide into the mesa of the photodiode and is rapidly absorbed without much propagation. Therefore, the simulated responsivity at 1310 nm keeps at 0.9 A/W when the active region length increases from 11 μm to 25 μm, as shown in Fig. 2(c). Responsivity measurements were carried out on photodiodes with different active region lengths at a wavelength of 1310 nm at -3 V bias voltage. The input optical power was calibrated with reference waveguides. The responsivity measurement results are plotted in Fig. 2(c), which go up to 0.9 A/W. Compared with the simulation results, the responsivity varies across different device lengths, which can be attributed to the difference in coupling efficiency between grating couplers.

IV. CONCLUSION

Waveguide-coupled O-band InP-InGaAs photodiodes were integrated on an LPCVD SiN photonic platform using micro-transfer printing, showing responsivity up to 0.9 A/W at 1310 nm wavelength and at -3 V bias voltage.

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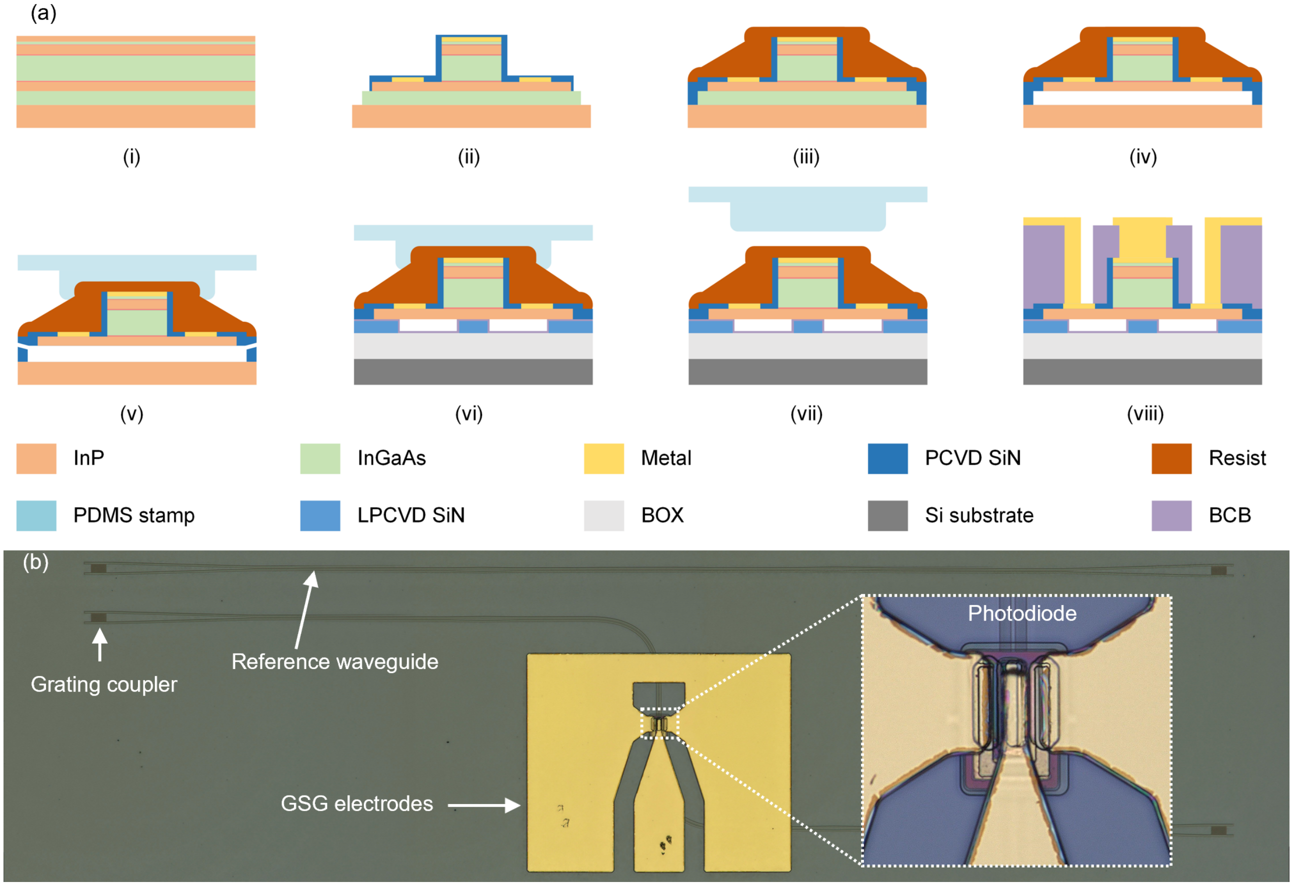

Fig. 1. (a) Simplified fabrication process flow, (b) Microscope image of a resulting waveguide-coupled photodiode.

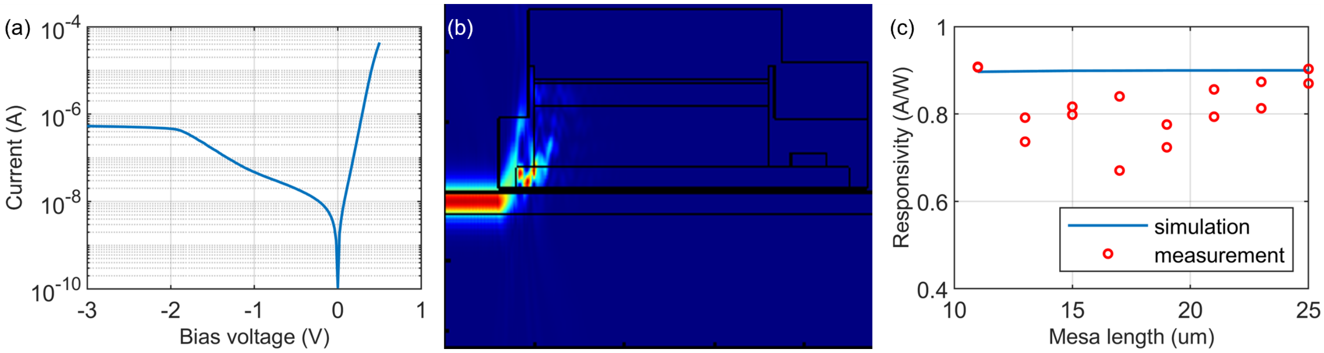

Fig. 2. (a) IV curve for a photodiode with a 6 × 25 μm^2 active region, (b) The side-view of the fundamental TE modelaunched into a photodiode with an active region length of 25 μm, (c) The measured responsivities of photodiodes with active region length varying from 11 μm to 25 μm at -3 V bias voltage at 1310 nm wavelength, compared with the simulation result.

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