High-Speed Photodiodes on Silicon Nitride with a Bandwidth beyond 100 GHz

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Abstract: Next-generation telecommunication systems will rely on photonic integrated circuits. However, Silicon Nitride (SiN) photonic platforms do not natively provide high-speed photodiodes. We integrated a waveguide-coupled UTC photodiode on a SiN platform using the scalable micro-transfer-printing technology. These diodes show a responsivity up to 0.45 A/W, a dark current below 10 nA and a 3 dB-bandwidth beyond 100 GHz, even at zero-bias. As such, high-performance photodetectors are available on silicon-nitride photonic platforms. © 2022 The Author(s)

1. Introduction

Digital communication systems, from long-haul fiber links to short-range wireless networks, are increasingly reliant on photonic integrated circuits. But the pursuit of even higher bandwidths is pushing current solutions to their limits. Silicon-photonic platforms – praised for their scalability and cost-effectiveness – rely on solutions like heteroepitaxy of III–V on Silicon [3], or germanium fins on top of SOI-waveguides [1] for very high-speed applications. Of all silicon-photonic technologies, Silicon Nitride (SiN) material platforms offer some distinct advantages: they provide very low-loss waveguides, feature very good filters – thanks to very high-Q resonators – and can handle very high powers – due to the absence of two-photon absorption compared to silicon. On SiN however, no direct growth is possible. One possible solution is wafer-bonding III–V on SiN-waveguides [2]. In this work, we present a versatile and scalable approach of creating waveguide-coupled photodetectors on SiN by micro-transfer-printing (µTP) uni-travelling-carrier (UTC) photodiodes.

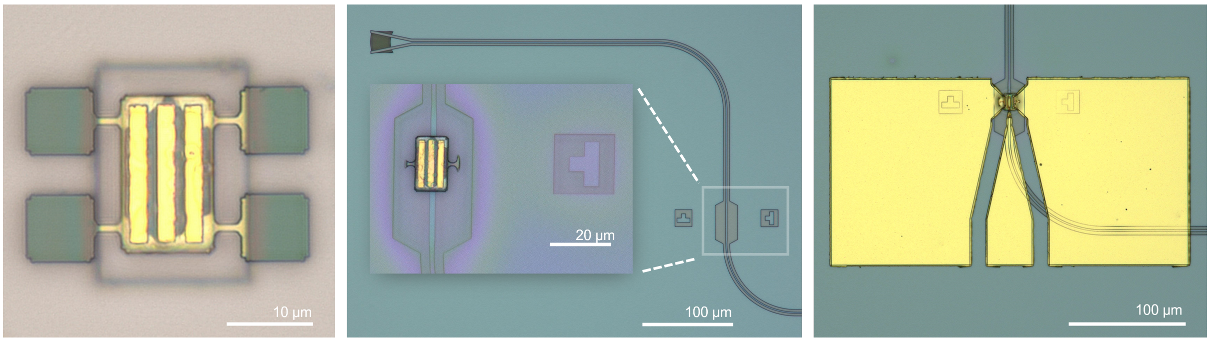

Fig. 1: A waveguide UTC photodiode coupon is first created in the source III–V wafer (left), before being transfer-printed on a SiN-waveguide (middle) and post-processed to include a CPW (right)

2. Materials and fabrication

To transfer-print chiplets from the source III–V wafer to a target SiN chip, we first created suspended UTC photodiode coupons using the fabrication procedure reported in our previous work [4]. For this, the III–V epitaxial layer stack has been modified to include a 500 nm sacrificial InAlAs release layer between the substrate and active layers. In contrast to wafer bonding, the photodiodes are first fabricated on the source wafer. Next, the release layer is anisotropically etched using a hard mask, followed by a deposition of a new SiN passivation layer that is patterned to create tethers to the InP-substrate. Finally, the chiplet is under-etched (isotropically) to create a suspended coupon. (Figure 1, left)

We then transfer-printed the coupon on a SiN target chip with a thin adhesive layer of benzocyclobutene (BCB) using an X-Celeprint transfer printer. The SiN-target chip consists of focused grating coupler and a printing area with alignment markers. (Figure 1, middle) This approach only requires minimal post-processing: vias were etched in the SiN passivation layer and a metal coplanar waveguide (CPW) was created for characterization. (Figure 1, right)

3. Results

The fabricated waveguide-coupled photodiodes have sizes between $2{\times}12\,\mu\mathrm{m}^2$ and $2{\times}20\,\mu\mathrm{m}^2$. The SiN waveguides are verified to have low losses (<1 dB/cm). Considering the on-chip optical power, corrected for grating-coupler losses (9 dB/coupler), these diodes show a responsivity between 0.2 A/W and 0.45 A/W. This variation corresponds to the different sizes and variation in printing accuracy. All further results correspond to a device of $2{\times}16\,\mu\mathrm{m}^2$ with a responsivity of 0.35 A/W. These diodes also feature very low dark currents: 10 nA at a bias voltage of -1 V. (Figure 2, left) The frequency response was measured using a heterodyne setup consisting of two DFB-lasers and a thermal power meter (Rohde&Schwarz NRP-Z58). For all bias voltages the devices show a bandwidth well beyond 100 GHz. By extrapolating the results up to 110 GHz, a 3 dB-bandwidth of 149 GHz and 119 GHz is found for -1 V bias and zero-bias respectively. (Figure 2, right). At zero-bias a 1 dB-saturation photocurrent of 2.8 mA can be achieved with a RF power output of -12.5 dBm at 100 GHz. At -1 V bias this even increases to a saturation photocurrent of 4.5 mA with a RF power output of -6.9 dBm.

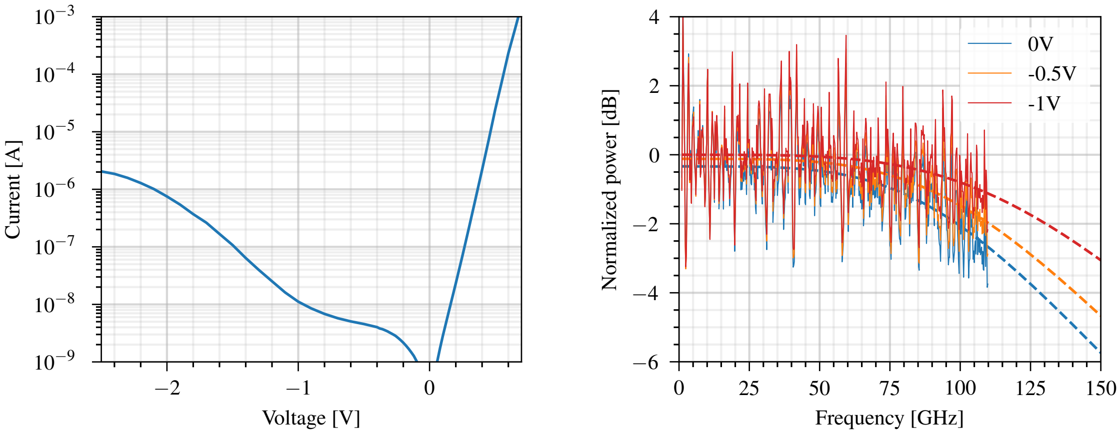

Fig. 2: A 2x16 µm transfer-printed waveguide UTC photodiode shows very low dark current (left) and a bandwidth (right) well beyond 100 GHz.

4. Conclusion

We have shown the integration of waveguide-coupled UTC photodiodes on a SiN-platform using micro-transfer-printing. This proves to be a flexible approach that results in a high-performance photodetector with a decent responsivity (up to 0.45 A/W), low dark current (below 10 nA) and high bandwidth (beyond 100 GHz). This high-speed operation will be further investigated in frequency bands beyond 100 GHz.

References

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