

High-Speed Heterogenous Photodiodes on Silicon Nitride for Integrated Microwave Applications

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Abstract: We demonstrate InGaAs/InAlGaAs/InP waveguide photodiodes on Si₃N₄ with up to 81 GHz 3-dB bandwidth, 0.76 A/W responsivity, and -1.8 dBm and -9 dBm output RF power at 50 GHz and 100 GHz, respectively.

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1. Introduction

Photonic generation of low-noise radio frequency (RF) signals and microwaves in integrated platforms has the potential to transform communications, radar, and sensing applications [1–3]. Using discrete components, we have recently shown that integrated microresonator solitons on Si₃N₄/Si combined with a high-speed InP-based photodiode (PD) can provide microwave signals at 100 GHz with excellent spectral purity [4]. However, for ultimate system miniaturization and elimination of fiber interconnects, it is desirable to integrate the high-speed PD on the Si₃N₄/Si platform on a wafer-scale. Using an adhesive die-to-wafer bonding technique, we have previously demonstrated integrated PDs on Si₃N₄/Si with 20 GHz bandwidth and balanced PD pairs with 30 GHz bandwidth [5, 6]. In this paper, we demonstrate heterogeneous PDs with up to 81 GHz bandwidth and only 5 dB power roll-off at 100 GHz. The PDs are integrated onto 800-nm thick Si₃N₄ waveguides, making them ideal candidates for the integration with microresonator solitons and on-chip photonic microwave generation [4].

2. Experimental results

The PD layer structure was an InGaAs/InAlGaAs/InP modified uni-traveling carrier (MUTC) PD, and we bonded the unprocessed PD die (4×3 mm²) onto the pre-fabricated Si₃N₄/Si chip using a 90-nm thick layer of SU-8 as the adhesive (Fig. 1(a)). This PD design has a calculated transit-time limited bandwidth of 167 GHz [7], and more details about the MUTC PD can be found in the references [6, 8]. After substrate removal, we fabricated double-mesa PDs using conventional dry and wet etching processes, electron beam metal deposition, and Au electro-plating [6]. Fig. 1(b) and (c) show microscopic images of the fabricated heterogeneous PDs with compact and extended RF probe pads designs, respectively. The latter was designed to provide inductive peaking to enhance the bandwidth. For efficient light coupling into the PD absorber, the 1 μm-wide waveguide was tapered to 750

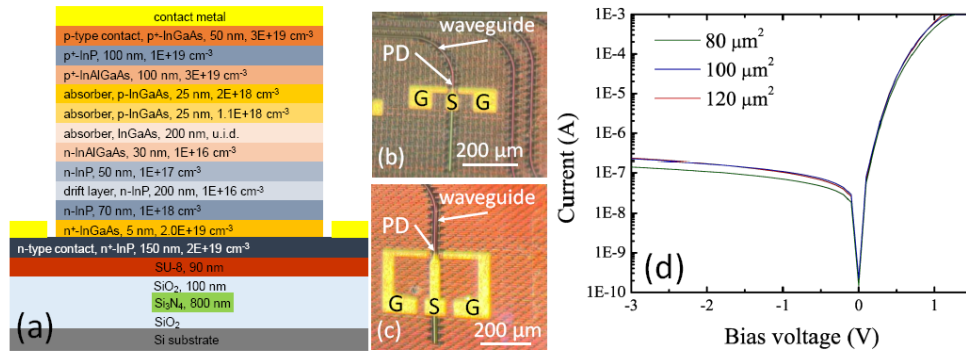


Fig. 1. (a) Cross-sectional view of the PD epitaxial structure bonded to the waveguide. Microscopic images of the heterogeneous PD with (b) compact ground-signal-ground (GSG) RF probe pad, and (c) extended GSG RF probe pad. (d) Measured dark currents.

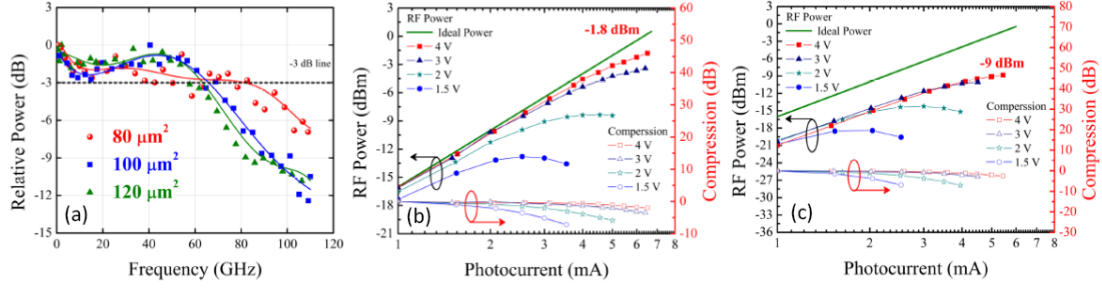


Fig. 2. (a) Relative frequency responses at -2 V and 1 mA. The solid lines show polynomial fitting curves. Measured RF power and RF compression at different reverse biases at (b) 50 GHz for a 120- μm^2 PD, and (c) at 100 GHz for a 100- μm^2 PD.

nm underneath the PD active area. The measured dark currents versus voltage are depicted in Fig. 1(d). The dark current at -3 V is as low as 230 nA, 224 nA, and 140 nA for PDs with areas (width $\times$ length) of $8\times 15\ \mu\text{m}^2$, $10\times 10\ \mu\text{m}^2$, and $8\times 10\ \mu\text{m}^2$, respectively. The responsivity at 1550 nm wavelength was 0.76 A/W for 10 μm -long PDs. The frequency response was measured with an optical heterodyne setup and an RF power meter. RF losses in the setup from the RF probe, cable, and bias-T were subtracted from the measured powers, and we estimated the accuracy of this method to be ± 0.5 dB. While the 100- μm^2 and 120- μm^2 PDs with extended RF probe pad design reached 3-dB bandwidths of 66 GHz and 63 GHz, respectively, the 80- μm^2 PD with compact RF probe pad had a 3-dB bandwidth of 81 GHz, however, the roll-off in its frequency response at 100 GHz was only 5 dB due to lack of inductive peaking (Fig. 2(a)). The results indicate that all PDs are limited by their resistance-capacitance time constant, and that extended RF probe pad design and down-scaling of the PD area can further enhance bandwidth. The maximum output RF power of a 120- μm^2 PD measured at 50 GHz is -1.8 dBm at 6.5 mA and -4 V as shown in Fig. 2(b). The photocurrent at 1-dB compression is 5 mA. A 100- μm^2 PD reaches -9 dBm at 100 GHz and 5.5 mA at -4 V with a photocurrent at 1-dB compression of 3.8 mA (Fig. 2(c)). Maximum output power was limited by thermal failure, that occurred at -5 V and 6 mA for the 120- μm^2 device.

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