High-Speed InGaAs/InAlGaAs Waveguide Photodiodes Grown on Silicon by Heteroepitaxy

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Abstract: We demonstrate III-V on silicon waveguide photodiodes with 200 nA dark current, 0.27 A/W fiber-coupled responsivity, and over 25 GHz 3-dB bandwidth.

OCIS codes: (040.5160) Photodetectors; (040.6040) Silicon

1. Introduction

Silicon photonics has become one of the most promising technologies for photonic integrated circuits due to its compatibility with mature CMOS technology and infrastructure [1]. To integrate high-performance III-V devices on Si, several integration methods have been proposed [2, 3], among which direct epitaxial growth of III-V compound materials on Si is a true wafer-level solution. Using this method, several photodiodes with bandwidths up to 14 GHz have been reported in the literature [4-8].

In this work, we present a high-speed waveguide photodiode (PD) grown directly on a Si template. To achieve high responsivity, we utilized a dual-integrated waveguide-depletion layer. In this design, the core layer of the passive feeding waveguide serves simultaneously as the electron drift layer in the PD [9]. Our PDs show low dark current, a 3-dB bandwidth of over 25 GHz and high external responsivity of 0.27 A/W.

2. Device design

The epi-layer structure of the PD is shown in Fig.1 (a). The epi-layers were heteroepitaxially grown by molecular beam epitaxy on a Si template similar to the one reported in [8]. From top to bottom, the PD structure consists of a 50 nm highly doped InGaAs P-contact layer, 60 nm graded bandgap InAlGaAs smoothing layer, 300 nm InAlAs electron blocking layer, 60 nm InAlGaAs smoothing layer, 150 nm undepleted and 100 nm depleted InGaAs absorber, 15 nm InAlGaAs smoothing layer, and 450 nm InAlGaAs un-doped electron drift layer. A highly-doped InP layer on top of the Si template was used as the N-contact layer. The waveguide was fabricated using the $In_{0.52}(Al_{0.3}Ga_{0.7})_{0.48}As$ electron drift layer as shown in the schematic of the PD in Fig.1 (b) to improve the light coupling efficiency from the waveguide into the absorber. A two-step double mesa dry etching process was used to form the PD structure. Radio frequency (RF) pads were deposited on a 2 µm-thick layer of SU-8 which was used to isolate the RF pads and reduce the RF loss. An air bridge was fabricated by electroplating to connect the top contact of the device and the center pad. Finally, the chip was diced to expose the waveguide facets. A SEM picture of a device after fabrication is shown in in Fig.1 (c).

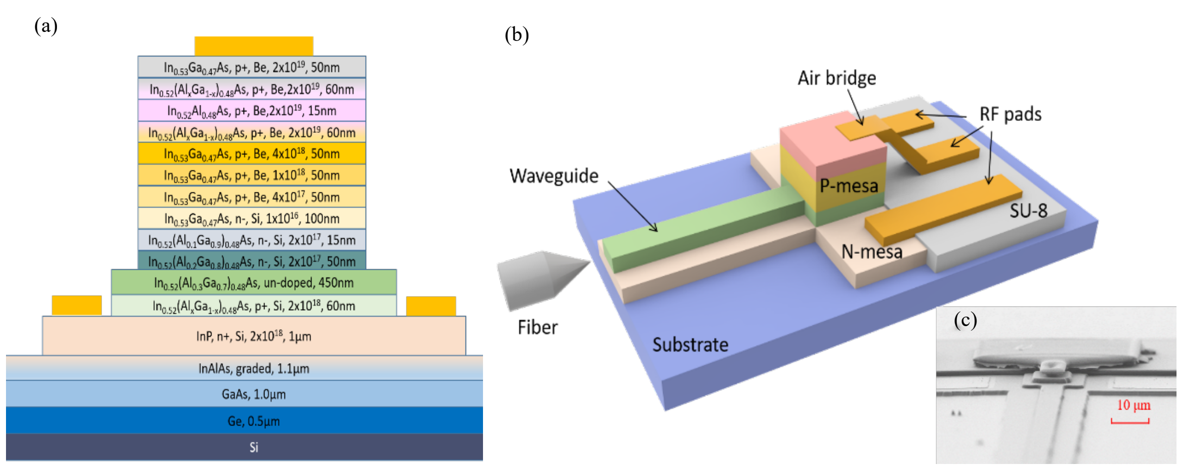

Fig.1 (a) Epi-layer structure of the PD. (b) Schematic of the PD, and (c) SEM picture of a fabricated device.

3. Experimental results

The I-V characteristics of fabricated waveguide PDs are shown in Fig.2 (a). Under a reverse bias of 3 V, the dark current is as low as 200 nA for a PD with an active area of 100 μm^2 corresponding to a dark current density of 200 mA/cm^2.

The external (fiber-coupled) responsivity was measured with a lensed fiber and was 0.27 A/W at 1550 nm wavelength without an anti-reflection coating. Since the waveguide facet showed considerable roughness after the dicing process we expect a significantly higher internal responsivity once the facet is polished and the fiber-chip coupling loss is taken into account. The polarization dependence of the responsivity was measured to be 1.6 dB.

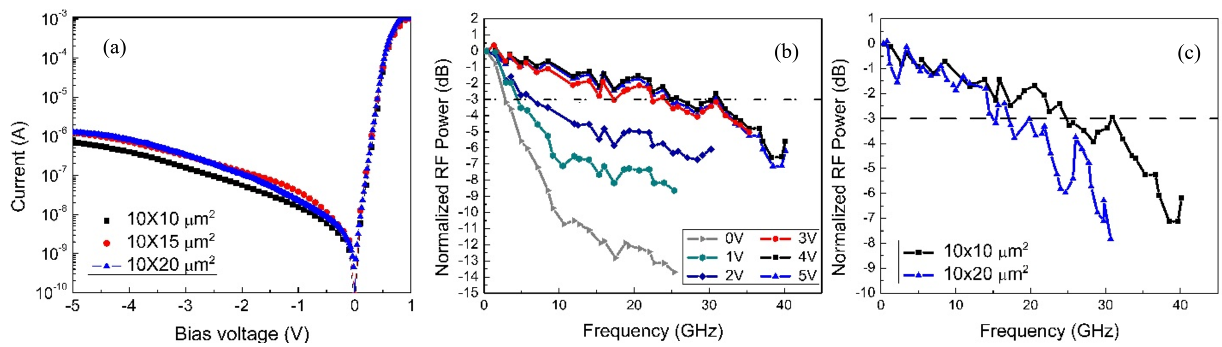

Fig.2 (a) Dark I-V characteristics of PDs with different active areas. (b) Normalized bandwidth of 10×10 μm^2 PD under different reverse voltages. (c) Measured frequency responses at -5 V.

The frequency responses of the photodiodes were measured at different voltages using an optical heterodyne setup. As shown in Fig.2 (b), when the reverse voltage is larger than 3 V, the PD is fully depleted and reaches its maximum bandwidth. Fig.2 (c) compares the frequency responses of 10×10 μm^2 and 10×20 μm^2 PDs with 3 dB bandwidths of 25 and 19 GHz, respectively, indicating that the bandwidth under large reverse bias is RC-limited.

4. Conclusion

Waveguide PDs based on heteroepitaxy of III-V material on Si with low dark current and over 25 GHz bandwidth are demonstrated for the first time.

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5. References

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