67 GHz uni-traveling carrier photodetector on an InP-membrane-on-silicon platform

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Abstract: An InP membrane-based uni-traveiling carrier photodetector, heterogeneously integrated on silicon, is realized using double-sided processing. A responsivity of 0.7 A/W at 1.55 μm and a 3 dB bandwidth beyond 67 GHz are demonstrated.

OCIS codes: (230.5160) Photodetectors, (130.3120) Integrated optics devices.

1. Introduction

Heterogeneous integration emerges as a promising technology for the realization of photonic integrated circuits (PICs) on silicon. It not only allows for the integration of high-performance InP-based lasers on Si [1], but also provides photodetectors (PDs) with high efficiency and low dark current. InP-based uni-traveling carrier photodetectors (UTC-PDs) promise high speed and high saturation power due to the high electron velocity in InP [2]. Recently, InP-based modified UTC-PDs on Si showed good DC characteristics and excellent power handling capabilities [3]. Its 3 dB bandwidth, however, is lower than that reported for Ge-based p-i-n PDs [4], primarily due to a relatively large device area and the associated large capacitance.

In this paper, we present a novel type of UTC-PD on Si with a 3 dB bandwidth beyond 67 GHz. This is the highest value reported so far for heterogeneously integrated PDs on Si, and is comparable to the highest bandwidth of Ge-based PDs. By integrating the PDs and passive waveguides (WGs) in the same InP membrane using a butt-joint coupling, PDs as short as 10 μm can be made with a reasonable responsivity, allowing for a low junction capacitance, which is desirable for high bandwidth operation. In addition, a new double-sided process scheme is used to optimize the design.

2. Design and fabrication

The cross-sectional design of the UTC-PD is shown in Fig. 1.(a). A 150 nm thick p-type doped InGaAs layer is used both as the absorption layer and as the contact layer to the metals at the p-side. The photon-generated holes are collected directly by the p-contact while the electrons travel to the depletion region in the i-InP layer. The p-InGaAs layer has a graded doping profile to enhance the transport of electrons in it. The i-InP layer is used both as the collector for electrons and as the passive WG layer. As can be seen from Fig. 1.(b), the input InP WG is connected to the UTC-PD through a simple butt-joint coupling. The thickness of the i-InP WG layer allows for single-mode strip WGs. It is also a trade-off between the transit-time constant and the RC-time constant, resulting in bandwidth limits beyond 100 GHz from both. The device is fabricated using double-sided processing, allowing for p- and n- contacts to be defined at either side of the membrane, which leads to a substantial reduction of resistance at the p-side. A 2 μm benzocyclobutene (BCB) layer is used for bonding the processed InP sample to the Si wafer. Ground-signal-ground (GSG) transmission lines are landed on a planarized polyimide surface.

3. Experimental results

The characteristics of a 3×10 μm^2 UTC-PD are presented in this section. Fig. 2.(a) shows the measured dark current of 153 nA at -4 V. In order to determine the internal responsivity, the coupling loss from fiber to WGs is first measured on test WGs using a standard setup described in [5], and calibrated out. The responsivity versus wavelength is plotted in the inset of Fig. 2.(a), showing a value of 0.7 A/W at 1.55 μm. The responsivity is above 0.6 A/W over the entire C-band. The frequency response, as measured using a commercial Agilent 67 GHz lightwave component analyzer (LCA), is shown in Fig. 2.(b). At -2V the 3 dB bandwidth is 15 GHz, while at -4V it exceeds 67 GHz (the upper limit frequency of the LCA). The bias dependence might be related to the carrier trapping of electrons due to the conduction band discontinuity at the InGaAs/InP interface.

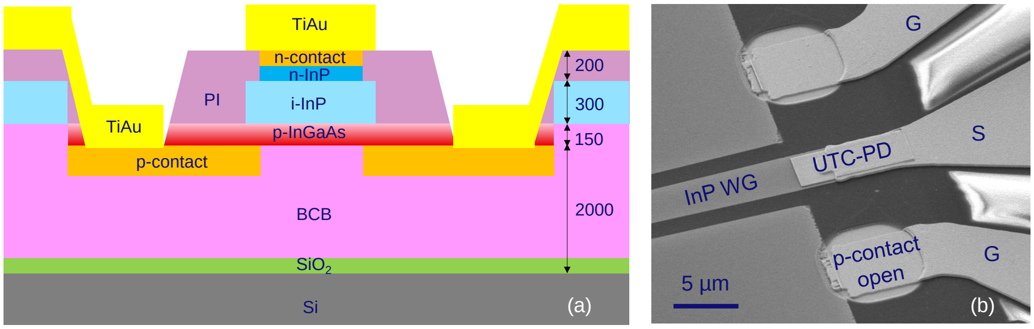

Fig. 1. (a) Cross-section of the UTC-PD. Thickness in nm. (b) SEM photo of the fabricated device.

4. Conclusions

We demonstrate a WG-coupled UTC-PD integrated on an InP-membrane-on-silicon platform. The device shows a 3 dB bandwidth of beyond 67 GHz, which is the highest value reported in heterogeneously integrated PDs on silicon. The responsivity is 0.7 A/W at 1.55 μm, and the dark current is 153 nA at -4 V. These results are promising for high speed applications in optical interconnects and wireless applications.

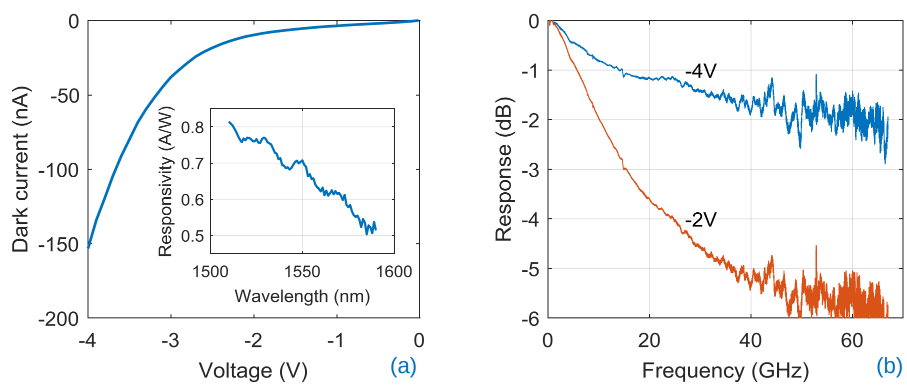

Fig. 2. (a) Measured dark current of a 3×10 μm^2 PD; the inset shows the responsivity versus wavelength measured at -4 V. (b) Frequency responses of the PD measured at -2 V and -4 V.

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