Physica E 41 (2009) 1076–1081

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Performance of Ge/Si receivers at 1310 nm

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A R T I C L E I N F O

Available online 14 August 2008

PACS:
85.30.De
85.60.BT
85.60.Gz

Keywords:
Germanium
Photodetector
Silicon photonics

A B S T R A C T

We have studied three types of these detectors; normal incident illuminated p–i–n detectors (NI-PD), waveguide p–i–n detectors (WG-PD), and avalanche photodetectors (APDs) operating over a wavelength range of 850–1550 nm. NI-PDs have achieved −14.5 dBm sensitivity at 10 Gb/s and 850 nm, which is comparable to similarly commercially packaged GaAs devices. Unlike GaAs detectors, however, the Ge detectors scale well out to 1310 nm, because Ge has a much smaller bandgap. WG-PDs have achieved bandwidths of approximately 30 GHz at 1550 nm with internal quantum efficiencies of 90%, and similar, or better, performance is also expected at 1310 nm. Normal incident APDs operating at 1310 nm have achieved a primary responsivity of 0.54 A/W with a 3-dB bandwidth of 9 GHz at a gain of 17. A gain-bandwidth product of 153 GHz has been measured which generally exceeds that of a commercial InP-based APD.

1. Introduction

Si-based photodetectors operating at 1310 nm are important in the larger field of silicon photonics, because they are compatible with the use of silicon modulators ($\lambda > 1100$ nm) without pushing the envelope of the absorption band edge of germanium ($\lambda < 1600$ nm). Research has shown a progression of improvement in Ge/Si photodetectors in the near-IR [1–8], and it is clear that responsivity at 1310 nm will not be a challenge for these devices. Liu [2] has reported a responsivity of 0.6 A/W at 1310 nm for a normal incident illuminated p–i–n detectors (NI-PD) without a proper anti-reflection coating, and predicted 0.98 A/W is achievable with such a coating. This is comparable to an InP-based device. Dark current is an area of concern for Ge/Si detectors since it is at least two orders of magnitude higher than GaAs or InP-based devices. However, when packaged in a receiver the input referred noise current of the transimpedance amplifier ($\sim 1\,\mu$A) typically is the limiter for sensitivity, not the detector dark current. Ge/Si photodetectors have also demonstrated bandwidths high enough to support the applications of interest. NI-PDs have achieved 10 Gb/s operation with sufficient sensitivity at 850 nm and they should be able to scale to 1310 nm without sacrificing the data rate [7]. Waveguide p–i–n detectors (WG-PDs) have bandwidths of 30 GHz with internal quantum efficiencies near 90% and dark currents below 500 nA [8].

Another interesting type of Si-based receiver uses avalanche photodetectors (APD) instead of a simple p–i–n. Research on Ge/Si APDs has just started and the goal is to combine the successes of the work on GeSi p–i–ns with the excellent multiplication properties of Si. The heart of the device is the high-field gain region in Si where a chain reaction of impact ionization events occurs when a photogenerated electron enters from an adjacent absorbing Ge film. This process amplifies the photocurrent and makes for a more sensitive photodetector. Silicon is the best semiconductor to use in the gain region because it essentially allows only the electrons, and not the holes, to initiate impact ionization events. This works to constrain the random nature of the gain process and reduce what is called excess noise. By

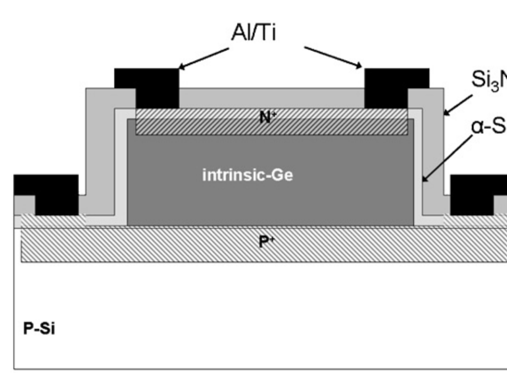

Fig. 1. Schematic representation of the normal incidence Ge/Si detector.

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doi:10.1016/j.physe.2008.08.017

switching from the commonly used InP gain region to a Si region, a 3–5 dB improvement in sensitivity has been shown [9,10].

2. Detector fabrication

2.1. NI-PDs

The Ge p–i–n detectors were fabricated on (1 0 0) p-type Si, with a resistivity of 20 Ω-cm [7]. The Ge film was deposited in a CVD reactor at 400 °C, after which the temperature was raised to 670–700 °C for the rest of the Ge growth. In this case, the nominal total Ge thickness after growth was 1.5 µm to optimize performance at 850 nm. For operation at 1310 nm, a Ge film thickness slightly larger than 2 µm is used. Circular mesas were then formed by etching the patterned films down to the Si substrate. The Ge layer was passivated with an α-Si film, annealed at 900 °C for 100 min, then implanted to form the contact regions. Following the deposition of a 740 nm thick Si_3N_4 film, metal contacts were formed with a Ti adhesion layer, followed by a 0.4 µm thick aluminum layer. The Si_3N_4 film serves as both an insulator and anti-reflection coating, reducing the surface reflectivity to <5% at 850 nm. A cross-sectional schematic representation of the Ge detector can be seen in Fig. 1.

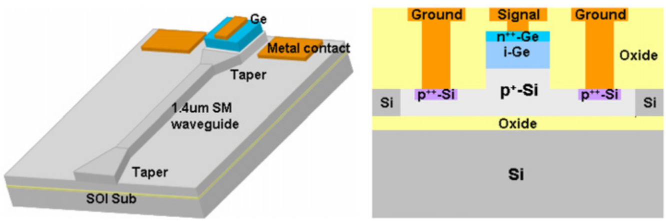

Fig. 2. The device schematic on the left (a) shows the waveguide running into the detector region. A cross-section is shown on the right (b).

2.2. WG-PDs

The schematic representation of the waveguide photodetector and corresponding cross-section are shown in Fig. 2(a and b), respectively. As the light propagates from the rib waveguide to the photodetector region, the light evanescently couples up into the

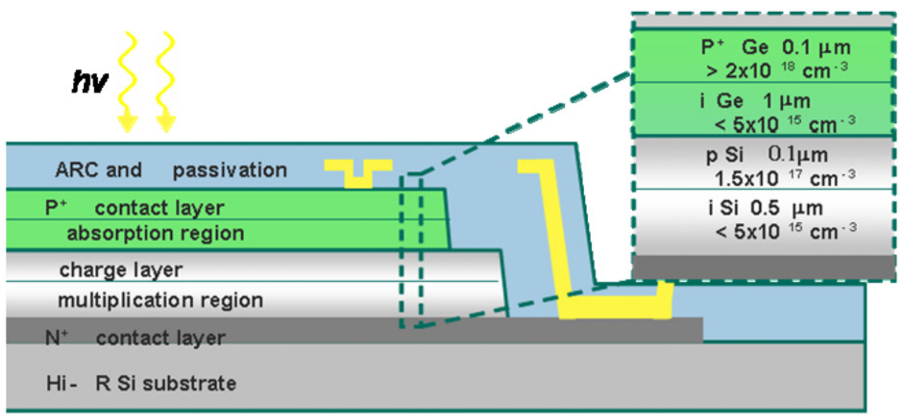

Fig. 3. Schematic cross-section of a GeSi SACM APD. The GeSi PIN PD used for primary photoresponsivity calibration has the same device cross-section except for the p-type charge layer.

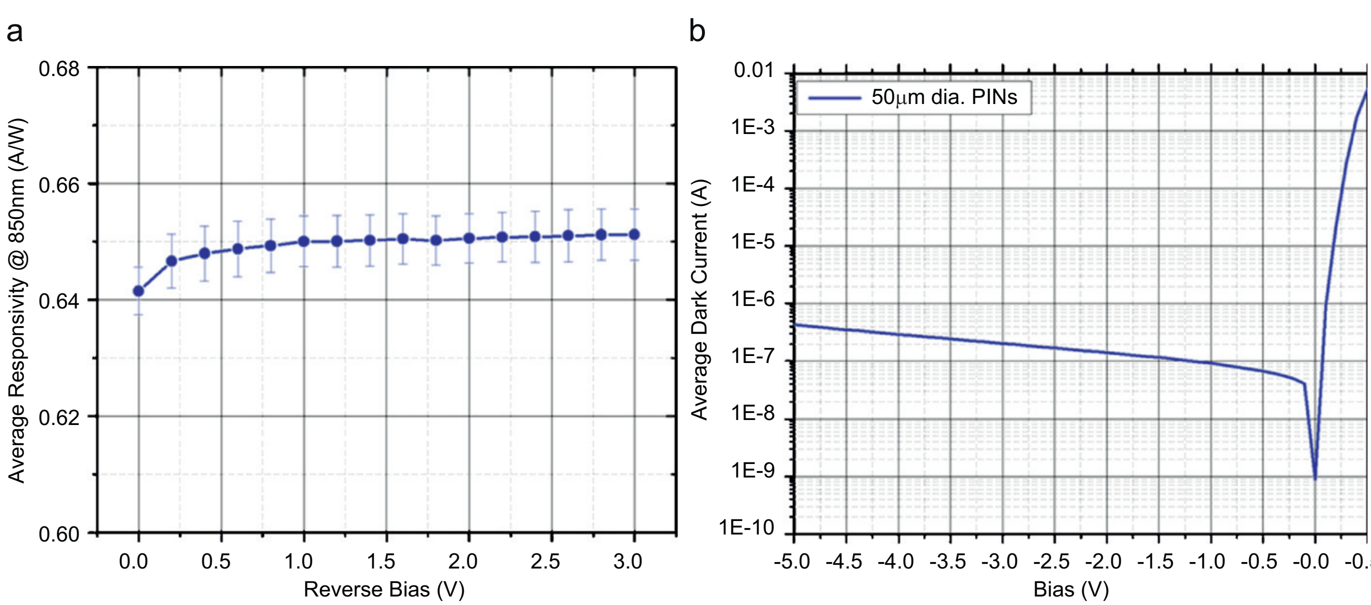

Fig. 4. (a) Responsivity of NI-PD detector with 1.5 µm thick Ge film at 850 nm. (b) Dark current at room temperature of a 50 µm-diameter device as a function of bias.