

Receiver-less silicon-germanium avalanche p-i-n photodetectors

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On-chip avalanche photodetectors (APDs) are attractive pick for a sensitive detection of high-speed light signals with low intensities. Silicon-germanium (Si-Ge) APDs are foreseen as leading candidates for building reliable short-reach optical links. Appeal for Si-Ge APDs stems from larger (lower) gain-bandwidth (excess noise) at reduced voltages, CMOS-compliant production, and monolithic integration as compared to their III-V alternatives [1-5]. Typically, Si-Ge APDs are realized in a form of metal-semiconductor-metal (MSM) [3], separate absorption charge multiplication (SACM) [4], or p-i-n structures [5] - each of them having own bright aspects and specific shadows [1]. Albeit many Si-Ge APDs provide appealing performances, they are followed by additional electronics, which however, prevents power-aware and low-cost detection on Si chips.

In this work, APDs were developed within a Si-foundry facilities as compact p-i-n structures with a double Si-Ge-Si hetero-junction (Fig. 1a-b) [2]. All devices feature a fixed 260 nm thick Ge film epitaxially grown on 60 nm deep Si cavities, with varying widths and lengths on fabricated chips. Si-Ge-Si p-i-n APDs capitalize on intrinsic multiplication gain via an impact ionization phenomenon under high electric fields. Hetero-structured p-i-n APDs benefit from strongly localized impact ionization process. Impact ionization takes place at the Si-Ge interface instead of the Ge diode centre. Unique design of Si-Ge-Si p-i-n's favors simultaneous high-speed and low-noise operation APDs, importantly, without subsidiary amplification stages [4]. Figure 1c-f shows essential photodiode characteristics for 0.5 μm wide and 40 μm long device, measured at 1.55 μm wavelength. The dark current at -1V was ~ 50 nA, which then increased up to 600 μA at -11V, most likely caused by combined effects of multiplication noise and tunneling. Nominal device responsivity was 0.5 A/W, which was increased up to 4.2 A/W thanks to an avalanche gain of 8.3, as shown in Fig. 1c. The maximum 3-dB cut-off frequency was 33 GHz under carrier saturation and low operating gains, while gain of 8.8 reduces the device bandwidth down to ~ 20 GHz due to intrinsic avalanche built up time (Fig. 1d). The gain-bandwidth product of 175 GHz and low avalanche excess noise with an effective ionization ratio of about 0.25 were obtained on hetero-structured APDs. The 40 Gbps eye diagrams (Fig. 1e) were seamlessly retrieved under -10V bias and low input powers of -14.2 and -17.2 dBm, respectively. Si-Ge-Si p-i-n APD senses low input powers with sensitivity of -11 dBm for 40 Gbps transmission bit rate characterized under an error-rate threshold of 10^{-9} .

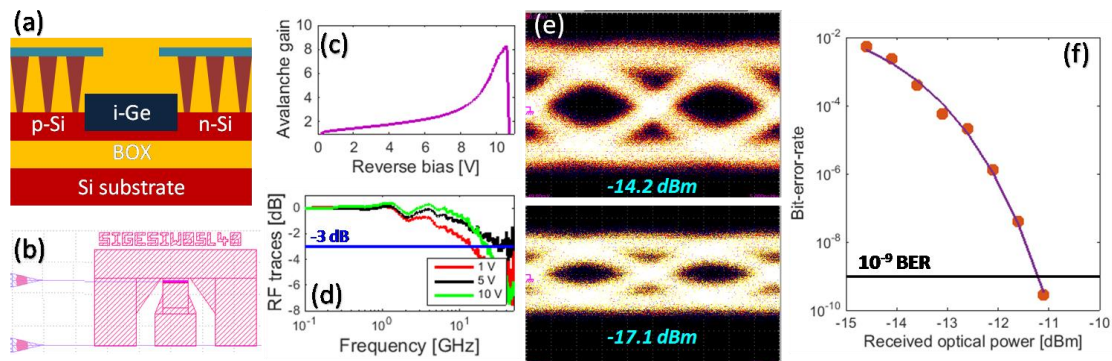


Fig. 1 Hetero-structured Si-Ge-Si p-i-n APDs: (a) cross-sectional schematics and (b) device layout. (c) Avalanche gain versus reverse bias under an optical power of -14.2 dBm. (d) RF diode characteristics under different biases. High-speed diode measurements: (e) electrical eye diagrams and (f) bit-error-rate acquisition.

This work opens up new prospects for monolithic Si-Ge photo-receivers, enabling a range of short-reach and chip-scale applications as diverse as data centres, interconnects or high-performing clouds, servers and computing.

Acknowledgements

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