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# High-speed silicon-germanium photodetectors for chip-scale photonic interconnects

(Invited paper)

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**Abstract**—We present our latest advances in the development of compact and high-performing photodetectors based on unique p-i-n silicon-germanium-silicon heterostructure. We demonstrate their credible high-speed performance, showing that these devices worthily become key building blocks within next-generation chip-integrated photonic interconnects.

**Keywords**—silicon photonics; germanium; photodetectors; optical interconnects; chip-scale communications

## I. INTRODUCTION

Optical photodetectors are essential for many applications ranging from sensors to communications. Conveniently, photodetectors benefit from crystalline semiconductor technology to perform efficient optoelectrical conversion. In modern industries of computation, communication, and optoelectronics, III-V compounds and group-IV materials are broadly used to build up high-performance detectors. Although optoelectronic properties of silicon (Si) prevent realization of faster detectors at commercial communication wavebands, high-quality epitaxially grown germanium (Ge) films provide a good solution for reliable light detection on Si chips [1-5].

Si-Ge photodetectors have steadily evolved into well-mastered building blocks. Nowadays, monolithically integrated Si-Ge devices leverage seamless and versatile production with cost effectiveness of Si-foundry environment. Advances in design and technology reached the point, beyond which Si-Ge diodes now offer advantages over dominant III-V-based detection bearers [1]. We report on our latest achievements in the development, realization and characterization of compact Si-Ge-Si photodetectors with double p-i-n heterojunctions operated at mainstream 1.55  $\mu\text{m}$  wavelength [2-5].

## II. P-I-N PHOTODETECTORS

The p-i-n diodes were fabricated on 200 mm silicon-on-insulator (SOI) wafers using existing fabrication infrastructure. P-i-n devices exploit a waveguide-integrated scheme combined with a lateral Si-Ge-Si

heterojunction. This simple and unique integration brings a range of levers on the device board. This includes better modal confinement, improved control over the intrinsic region, and easier the fabrication flow compared to the full-Ge architectures [1-5]. As a result, compact devices with judiciously controlled layout and enhanced performances are available on the chip along many other photonic devices. From a technological perspective, better manufacturing flow decreases contact access resistance, reduces fabrication steps in optical interconnect process, and helps improving hybrid opto-electronic integration.

Measured p-i-n diodes have low dark-currents, typically of 10 nA for the smallest geometries and of 100 nA for the largest devices. The photo-responsivity ranges from 0.2 to 1.2 A/W at 1.55  $\mu\text{m}$ . The responsivity maximum is typically reached at low operating voltages of about -0.5 V. This shows a great diode capability to sweep out the vast majority of generated photo-carriers within their lifetime [2-5]. High-speed tests showed up operation at low voltages up 40 Gbps bit rates [4]. Moreover, p-i-n photodiode sensitivities, at a error-rate of  $10^{-9}$ , of -14 and -11 dBm were achieved for conventional 10 and 25 Gbps transmission bit rates, respectively [3].

### III. AVALANCHE P-I-N PHOTODETECTORS

Operation of Si-Ge-Si p-i-n device under higher voltages enabled an impact ionization effect to take place, and thus making the same diode work in an avalanche mode. Impact ionization allows generation of multiple electron-hole pairs, and enabling to boost the light signal [1]. Under an avalanche operation with a gain of 6, the device responsivity improved to 3 A/W compared to its reference of 0.5 A/W [4]. The device speed reached maximum of 33 GHz at low gains and started to drop down to 19 GHz as the gain raised up. The device had gain-bandwidth product up 210 GHz. Low impact ionization coefficient of 0.25 was obtained thanks to the localized impact ionization occurring at the Si-Ge interface. High-speed signal traffic was maintained for 40 Gbps speeds at input power levels down to -20 dBm. Power sensitivity of -11 dBm was measured under avalanche operation for 40 Gbps signals [5].

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