40 Gb/s lateral vs vertical Ge-on-Si photodetectors integrated in silicon waveguides

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Abstract—**We report and compare results obtained on Ge-on-Si photodetectors in lateral and vertical configurations. A bandwidth of 120GHz was obtained for the lateral photodetector. Both types shown operation up to 40 Gb/s.**

Keywords-Silicon photonics; germanium; photodetector; integrated optics.

I. Introduction

Very fast optical telecommunications are technologically very challenging. The ever growing demand of faster transmissions and larger volume of information at high bit rates pushes forward research on high speeds and large bandwidths. Among building blocks necessary to achieve an optical circuit with such requirements, as sources [1] or modulators [2], photodetectors are the key component to convert optical signals into electrical ones. Currently, large bandwidth photodetectors are fabricated with III-V materials. III-V materials are however not fully compatible with the mainstream CMOS Si technology and III-V based components require expensive and challenging fabrication technologies. One alternative material is Ge, a Si compatible material which shows a strong absorption in the telecommunication wavelength range, and that allows to fabricate a photodetector monolithically integrated on a Si platform [3]. Such a technology is moreover compatible with CMOS circuitry. We present and compare in this work two different Ge-on-Si photodetectors, both showing large bandwidths and high speed operation.

II. Fabrication

The two detectors present different p-i-n diode geometries, as schematically shown in Fig. 1. Fig. 1a represents a lateral geometry where the p, i and n doped regions are on the same horizontal plane [4] whereas on the vertical configuration shown in Fig. 1b the p-i-n diode is in a vertical stack [5]. These devices were fabricated on 8 inch SOI wafers with 0.4µm thick Si layer and 1µm thick buried oxide. Passive circuitry was first realized by Deep-UV lithography and reactive ion etching. In particular rib Si waveguides were obtained by etching 110nm of Si. A recess at the end of the waveguide was then defined by etching Si down to a residual thickness of 50nm. In the case of the lateral configuration, the length and the width of the recess were 10µm and 0.5µm, respectively.

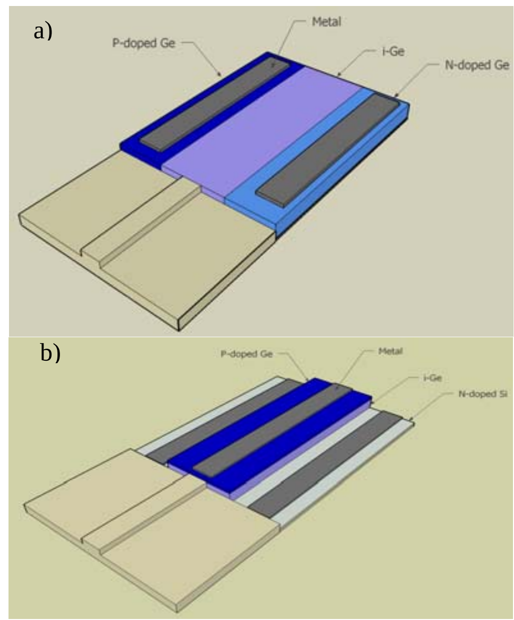

Figure 1. Schematic views of (a) lateral and (b) vertical p-i-n photodetector integrated in SOI waveguides.

Undoped Ge was then epitaxially selectively grown in the recess by Reduced Pressure-Chemical Vapour Deposition (RP-CVD). A photolithographic step was used to defining the first implantation area where boron ions were implanted. A second lithographic step with a phosphorus ion implantation permitted to define the n-doped region of the photodetector. In the case of Ge vertical photodetector, the 50nm thick Si layer at the bottom of the recess was first locally implanted with phosphorus ions to form the N+ ohmic contact. 340 nm of intrinsic Ge capped by 90 nm of in-situ boron-doped Ge are then selectively grown by RP-CVD in the silicon recess. Bottom contacts were defined by UV lithography followed by an etching step down to the N+ silicon region which defines a 3µm wide Ge mesa, whereas its length is 15um.

Ti/TiN/AlCu/Ti/TiN metal stack was then used to form contacts on p and n regions in both cases.

III. RESULTS

The dark current as a function of applied bias was measured at -1V bias for both Ge photodetectors. Dark current values of 4 µA and 18 nA were measured for lateral and vertical configurations, respectively. The relatively high value of the lateral detector dark current was probably due to dopant diffusion during annealing.

The optical responsivity of the Ge photodetectors was measured for a wavelength of 1550nm: 0.8 A/W in the lateral configuration and 0.9 A/W in the vertical configuration. Saturation value was obtained already at 0.1V and 0.3 V, respectively, showing a good collection efficiency of photogenerated carriers.

Normalized optical bandwidths at 1550 nm wavelength are plotted in Fig. 2. In the case of the lateral configuration -3 dB cutoff frequency was estimated to be as high as 120 GHz at -2V bias. The bandwidth was measured with three different techniques and only the one using the beating of two near optical lasers coupled with a 110GHz electrical spectrum analyzer could reach the required frequency range. On the other side the vertical configuration shows a bandwidth of 42 GHz with a reverse bias of 4V. The larger bandwidth of lateral photodetectors compared to vertical photodetectors is likely due to the dopant diffusion during the annealing step, thus reducing the intrinsic region of the diode.

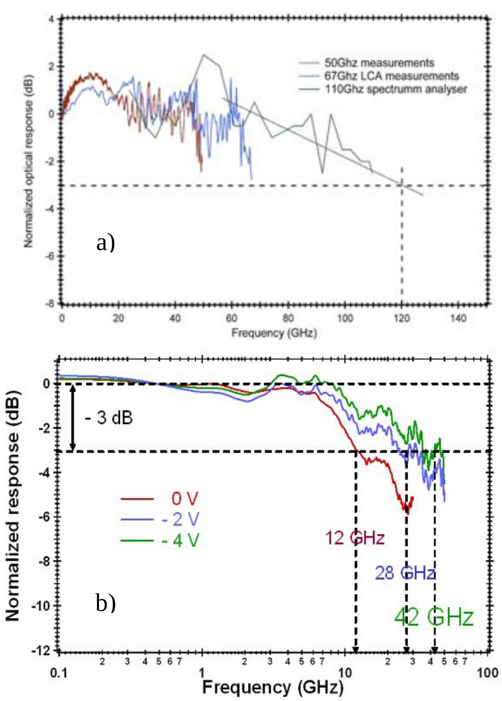

Figure 2. Normalized optical response at 1550 nm wavelength of the (a) lateral and (b) vertical Ge photodetector as a function of frequency for 2V reverse bias voltage and 0, 2 and 4V reverse biases, respectively.

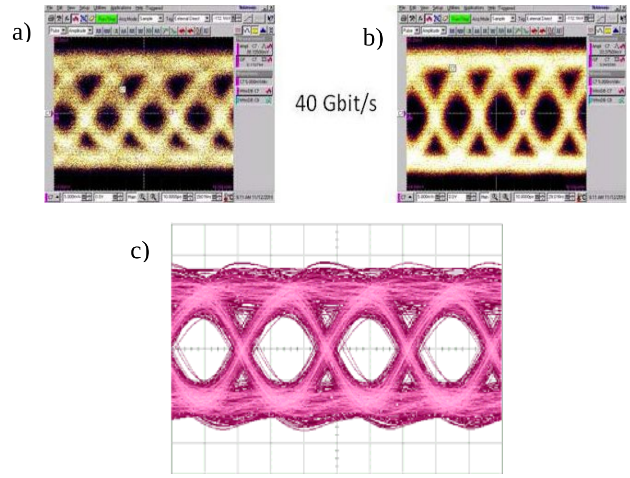

Figure 3. Open eye diagram at 40 GBit/s and at 1550 nm wavelength for lateral photodetector at 0V bias (a) and -1V bias (b) and for vertical photodetector at -4V bias (c).

The data transmission at 40 Gb/s of these Ge waveguide photodetectors were finally checked. Open eye diagrams were obtained for both types of detectors already at zero-bias for lateral configuration (see Fig. 3a and 3b) and at 4V reverse bias for the vertical configuration (see Fig. 3c).

These results demonstrate that very high bandwidths and operation up to 40 Gb/s can be obtained for Ge-on-Si integrated photodetectors. These performances of an important building block in silicon photonics will help in merging integrated optics and electronics for ultra-fast data transmission.

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REFERENCES

[1] J. Liu, X. Sun, R. Camacho-Aguilera, L. C. Kimerling, and J. Michel, “Ge-on-Si laser operating at room temperature,” Opt. Lett., vol.35 (5), pp. 679–681, 2010.

[2] D. Marris-Morini et al., “Recent Progress in High-Speed Silicon-Based Optical Modulators,” Proc. IEEE, vol. 97(7), pp. 1199–1215, 2009.

[3] J. Michel, J. Liu, and L. C. Kimerling, “High-performance Ge-on-Si photodetectors,” Nature Photonics, vol. 4, pp. 527–534, July 2010.

[4] L. Vivien et al., “42 GHz p.i.n Germanium photodetector integrated in a silicon-on-insulator waveguide,” Opt. Express, vol. 17(8), pp. 6252–6257, 2009.

[5] L. Vivien et al., “Zero-bias 40Gbit/s germanium waveguide photodetector on silicon,” Optics Express, vol. 20 (2), pp. 1096-1101, 2012.