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Double heterojunction Si-Ge-Si pin waveguide photodiodes for high-speed communications at 1550nm wavelength

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Abstract

We studied the performances of our new double heterojunction Si-Ge photodiodes for high-speed communications at telecom wavelength. Thanks to highly integrated design, the photodiodes exhibit high performances under low bias. Bit-error-rate at 10^{-9} is demonstrated at 10, 20 and 25Gbps data rates, with sensitivities of -13.9, -12.7 and -11.3 dBm, respectively.

1. Introduction

As silicon photonics has developed in the last decade, Germanium (Ge) has become the material of choice for the photodetectors thanks to progresses in heteroepitaxy on Silicon (Si) [1], [2]. Different configurations of waveguide integrated Ge on Si p-i-n photodiodes have been demonstrated, mainly using lateral homojunction or vertical junction, evanescently coupled to the waveguide [3]–[5]. However, by using a lateral double heterojunction Si-Ge-Si, with both contacts on Si, the integration complexity can be reduced without compromising the performances [4], [6], [7].

In this paper we report on high-bit rate operation of double heterojunction Ge on Si photodiodes at 1550nm wavelength, under low bias.

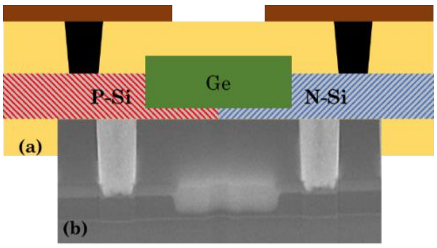

Fig. 1 Cross sectional view of a Si-Ge-Si double hetero-junction photodiode. (a) Schematic and (b) SEM.

2. Design and fabrication

The design of those new double heterojunctions photodiode has been guided by the will to keep the integration complexity at its minimum while offering high performances for optical communication applications. By using Si for the doped regions of the p-i-n photodiodes, it allows easy integration with others active components also making use of doped Si such as p-n Si modulators. Moreover, the butt coupling approach allow high coupling efficiency between the waveguide and the photodiode, independently of the thickness of the Ge region, thus no optimization of the thickness is needed, and the absorption region can be made shorter than with evanescent coupling. A schematic view of such photodiode is depicted in the Fig. 1(a). To study the performances of such photodiodes, several length and width of the Ge region have been designed, i.e. 0.5, 0.8 and 1µm wide Ge cavity, with length of 5, 10, 20 and 40µm, for operation at 1550nm wavelength.

The presented devices have been fabricated using 220nm Silicon On Insulator (SOI) wafers with 2µm Buried Oxide Layer (BOX) on the 200mm CEA-Leti technological platform. The Ge is grown inside a Si cavity partially etched across p and n doped Si regions. A ~60nm Si layer serves as the seed layer for the heteroepitaxy, and the Ge layer is thinned down by Chemical Mechanical Polishing (CMP) to roughly 260nm. A final Scanning Electron Microscopy (SEM) view of the device is shown on Fig. 1(b). A more detailed process flow is described elsewhere [6].

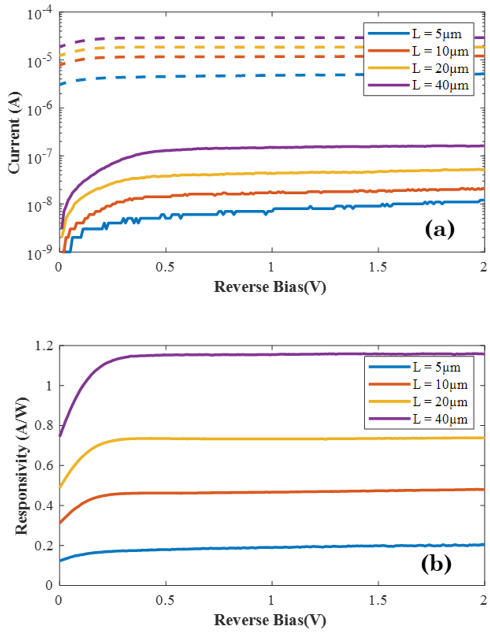

Fig. 2 DC characteristics of a 1µm wide photodiode with different lengths (a) Dark current (solid lines) and photocurrent (dashed lines) and (b) Responsivity function of the reverse bias.

3. Results and discussion

All devices were characterized under DC and RF conditions in order to evaluate their performances in terms of dark current, responsivity and opto-electrical bandwidth. Fig. 2(a) and (b) show typical dark and photo current curves and responsivities for a 1µm wide photodiodes. For the longest device, i.e. 40µm, the dark current stays below 200nA at -2V and the responsivity reaches over 1.1 A/W at only 0.5V reverse bias, whereas for the shortest device, i.e. 5µm long, the dark current is of the order of 10nA and the responsivity is only about 0.2A/W. For the widths of 0.8µm and 0.5µm, the maximum measured responsivity is about 0.75 and 0.45 A/W respectively, for 40µm long devices. Those flat responsivities at low bias were observed consistently over the whole range of devices independently of the length and the width of the photodiodes.

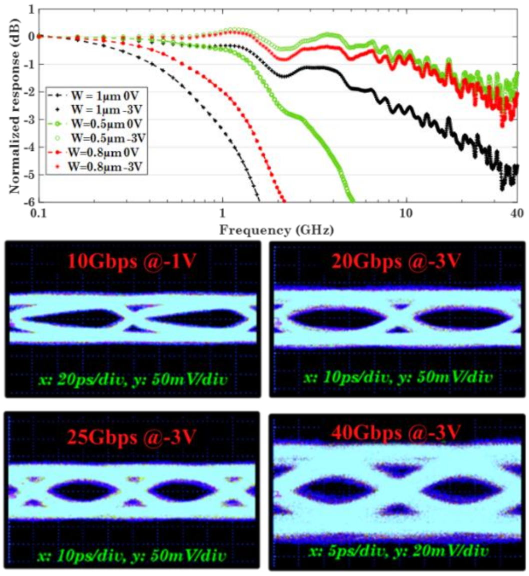

Fig. 3 (a) Normalized frequency response of 40µm long photodiodes and (b) Eye diagrams for a 1µm wide and 40 µm long photodiode at 10 Gbps, 20 Gbps, 25 Gbps and 40 Gbps.

The electro-optic bandwidth has been characterized using a Lightwave Component Analyzer (LCA), with its internally built laser and modulator. At 0V, the measured -3dB bandwidth for 40µm long photodiodes is about 1 GHz, 1.5 Ghz and 2.5 GHz for width of 1µm, 0.8 µm and 0.5 µm respectively. This low bandwidth can be explained by the low build in electric field, limited by the heterojunction barrier in the band diagram, which also explain the low responsivity below -0.5V. The measurement at -3V are also represented on the Fig. 3(a). No significant trend function of the device length were observed for the frequency response, even for the narrowest devices, i.e. 0.5µm, thus indicating that the high speed operation is only limited by the transit time across the intrinsic Ge region. Increasing the reverse bias allowed the photodiodes to be operated at 10, 20, 25 and 40Gbps data rates, with open eye diagrams as shown on Fig. 3 (b) for a 1µm wide and 40µm long photodiode.

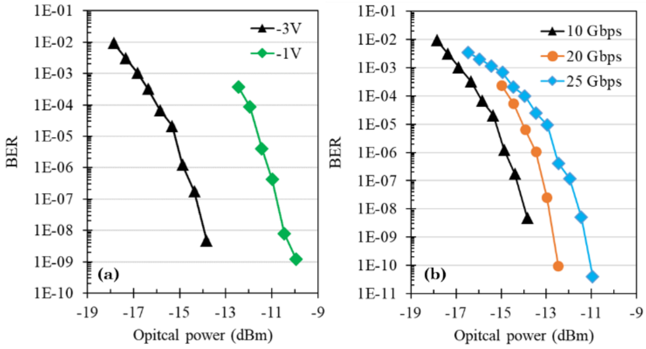

Fig. 4 Bit Error Rate measurements for 1µm wide and 40µm long photodiode. (a) At -1V and -3V bias, for 10Gbps data rate and (b) at -3V bias for 10, 20 and 25 Gbps.

The sensitivity of the 1µm wide and 40µm long photodiodes has also been characterized using Bit Error Rate (BER) measurements in Non-Returning to Zero (NRZ) modulation format. The Fig. 4(a) show the results for -1V and -3V bias at 10Gbps where for a BER of 10^{-9}, the corresponding optical power are -13.9dBm and -10dBm, respectively. Additionally, the Fig. 4(b) show the BER at -3V for 10, 20 and 25Gbps. The corresponding sensitivities for a BER of 10^{-9} are about -13.9dBm, -12.7dBm and -11.3dBm, respectively.

3. Conclusions

We presented our latest results on Si-Ge-Si double heterojunction p-i-n photodiodes for high-speed optical communications at 1550nm wavelength. Such structure, associated with efficient waveguide butt-coupling configuration demonstrated low dark current, high responsivity close to theoretical maximum and high-speed operation up to 40Gbps data rates.

Acknowledgements

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