Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp811-812

High Speed Optoelectronic Devices in Silicon

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1. Introduction

Silicon-based photonics has generated an increasing interest for several years with a focus on applications like optical telecommunications or optical interconnects in microelectronic circuits. Furthermore, some promising solutions provide by the use of silicon photonics is offered for biophotonics. The main objectives of silicon photonics are the reduction of photonic system cost, the increase of the number of functionalities on the same integrated chip by combining photonic and electronic together and the reduction of the power consumption [1]. Numerous developments on passive and active building blocks have been made including waveguides [2,3], modulators [4-5], lasers [6] and photodetectors [7,8].

In this paper, we will focus on recent results on ultrafast optical modulators and germanium photodetectors integrated in silicon on insulator (SOI) waveguides. These building blocks are essential for the fabrication of high speed optical links for optical telecommunications and interconnects.

2. Optical modulator

Several physical effects can be used to obtain light modulation in silicon. Recently, quantum confined Stark effect (QCSE) in Ge/SiGe multiple quantum wells (MQW) has been demonstrated to achieve electro-absorption modulation [9,10]. However, the more efficient effect to achieve high speed optical modulator is to use carrier depletion in PN or PIN diodes.

The modulator presented here is based on a 400nm thick PIPIN diode (figure 1). The considered silicon rib waveguide height and width are 400 nm and 660 nm, respectively, while a 100 nm etching depth. A p-doped slit is inserted in the intrinsic region of the lateral pin diode and acts as a source of holes. High p and n- doped regions are placed apart from the rib region to define the pin diode. As a large part of the waveguide is not doped and the metallic contacts are deposited on both sides of the waveguide, low propagation loss is obtained whilst keeping a high modulation efficiency. Such a design is favorable to high speed operation as the capacitance and the access resistances are low. The principle of such a modulator is the following: at equilibrium, holes are confined in the doped slit inside the rib waveguide. A good overlap between the carrier density variation zone (doped slit) and the guided mode then occurs. Under a reverse bias, holes are swept out which leads to an effective index variation. This index variation creates a phase shift of the guided mode. The phase shifter is inserted in both arms of a 4-mm long asymetric Mach-Zehnder interferometer and electrodes are used to bias one arm.

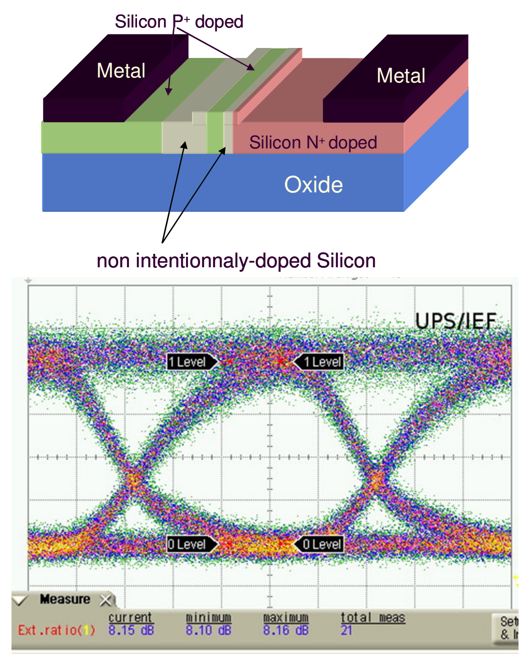

Fig. 1: Schematic view of the PIPIN diode and the open eye diagram at 10GBit/s

The measured insertion loss is about 5 dB and high DC and dynamic extinction ratio was obtained. A data transmission operation higher than 10 Gbit/s was also achieved.

3. Germanium photodetectors

The second main building block is the photodetector. The monolithic integration of photodetectors in SOI waveguides requires an active material compatible with the IV/IV semiconductor technology. In this context, germanium (Ge) compounds are natural candidates for light absorption around λ=1,55µm.

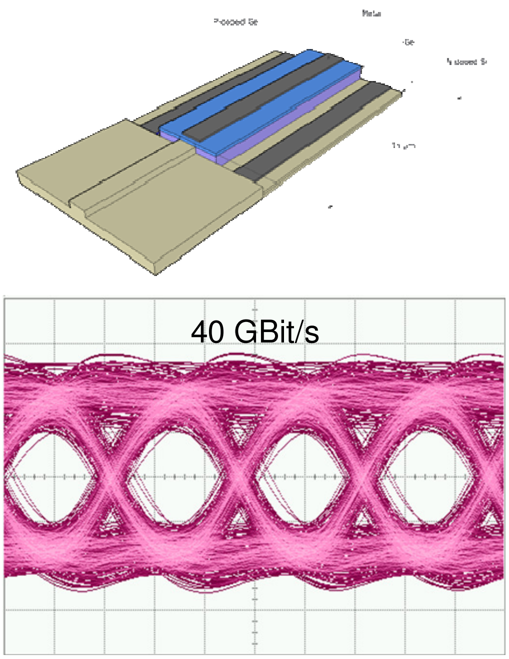

Figure 2: Vertical Ge photodetector integrated in silicon waveguide and 40Gbit/s open eye diagram at the wavelength of 1.55µm

In our approach, Ge is selectively grown at the end of the waveguide in a silicon recess in order to address butt coupling integration. Such configuration allows a very short absorption length: 95 % of the light intensity is indeed absorbed over about 4 µm at 1.31 µm and less than 7 µm at 1.55 µm. Several configurations have been studied to achieve high speed operation at telecom wavelengths. Table 1 summarizes the results we obtained on Ge photodetectors integrated in SOI waveguide. Very high bandwidth and responsivity can be obtained with all kinds of photodetectors. As an example, figure 2 reports the open eye diagram at 40Gbit/s obtained with a vertical waveguide germanium photodetector at a wavelength of 1.55µm.

		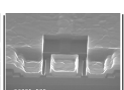	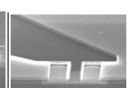
structure	MSM	PIN	PIN
Dark current at -1V	~100 µA	~ 20 nA	~ 1 µA
Responsivity	> 1 A/W	~ 1 A/W	~0.8 A/W
Bandwidth	25 GHz	42 GHz	~ 130 GHz
Data transmission		40 Gbit/s @ -4V	10 Gbit/s @ 0V

Table 1: Results obtained on Ge waveguide detectors.

4. Conclusion

In conclusion, we report recent results on optical modulators and photodetectors integrated in silicon waveguides. Now, 40Gbit/s optical modulator and germanium photodetectors integrated in silicon waveguide are available using silicon –based platform.

Acknowledgement:
The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 224312 HELIOS and from ANR (Agence National pour la Recherche) under SILVER and MICROS projects.

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