All-optical de-multiplexing of 10Gbps data using III-V/SOI microdisk resonators

R. Kumar,[1, 2] T. Spuesens,[1,2] P. Mechet,[1,2] J.-M. Fedeli,[3] N. Olivier,[3] P. Regreny,[4] G. Roelkens,[1,2] D. Van Thourhout,[1,2] and G. Morthier[1,2]

[1]Photonics Research Group, INTEC Department, Ghent University-IMEC, Sint-Pietersnieuwstraat 41, 9000 Ghent, Belgium
[2]Center for Nano- and Biophotonics (NB-Photonics), Ghent University, 9000 Ghent, Belgium
[3]CEA-LETI, Minatec Campus, 17 Rue des Martyrs, 38054 Grenoble, France
[4]Université de Lyon, Institut des Nanotechnologies de Lyon INL-UMR5270, CNRS, Ecole Centrale de Lyon, Ecully, F-69134, France

We present the demonstration of all-optical de-multiplexing of non-return-to-zero 10Gbps data controlled by a 2.5 GHz and 5 GHz clock in a 7.5 micron diameter III-V-on-silicon microdisk resonator. The fabrication of the III-V/SOI chip having several microdisk resonators is carried out in a 200mm CMOS pilot line. This demonstration of an all-optical de-multiplexer with a small footprint (7.5µm x 7.5µm) is an important step towards the realization of compact multifunctional photonic integrated circuits on the III-V/SOI hybrid platform.

Introduction

Silicon-on-insulator (SOI) is a promising platform for photonic integrated circuits (PICs) due to its CMOS compatibility. It provides a high-index-contrast environment enabling the fabrication of miniaturised silicon optical circuits. The SOI waveguide platform has proved itself as a versatile platform for several optical functions such as filters [1], splitters and combiners [2], waveguide crossings [3], directional couplers [4], switches [5], modulators [6], wavelength convertors [7] and wavelength (de)multiplexers [8]. The advantage of mature CMOS fabrication technology has also been exploited to realize SiGe or germanium-on-silicon based devices such as photodetectors [9] and modulators [10]. To realize the fully functional PICs certain active functionalities such as lasers, memory elements (generally optical flips-flops) are a must. This gives rise to the question of choosing between the silicon or III-V platform [11] for future PICs. Since silicon has a cost advantage while III-V has the advantage of active functionalities, a hybrid integrated platform where III-V is integrated on top of the SOI waveguide circuits is the most promising way forward to realize complex and fully-functional PICs. Here, it is important to note that there have been demonstrations of lasing in silicon [12-13] as well as in germanium [14]. But for the application in fully-functional PICs, the performance of these lasers is still far below the acceptable level for different metrics including modulation speed, footprint and power consumption.

In the recent past, using III-V microdisks heterogeneously integrated onto SOI waveguide circuits, a lot of work has been reported on advanced optical functions such as all-optical flip-flops [15], optical gates [16], electro-optic modulators [17], optical switches [18], and wavelength convertors [19]. Here, we report an experimental demonstration of bias-free time domain all-optical de-multiplexing in a 7.5 µm diameter III-V (InP-InGaAsP)/SOI microdisk. Non-return-to-zero (NRZ) data at the rate of 10Gbps is demultiplexed using clock rates of 2.5GHz and 5GHz. The III-V/SOI chip consisting of several microdisks is fabricated in a 200mm CMOS pilot line. The details of device design and fabrication can be found in ref. [20].

Working Principle

The effect of refractive index modulation caused by the free carrier generation in a pump-probe configuration can be exploited to realize an all-optical de-multiplexer in a microdisk resonator. The modulation of the refractive index results in the modulation of the transmission characteristics of the microdisk resonator. In a pump-probe configuration, a probe is tuned to one resonance wavelength while the pump is tuned to another. For the implementation of the de-multiplexer in microdisk resonators an optical clock is used as a pump and the optical data signal is used as a probe. If the wavelength of the optical data signal is chosen to be on- resonance of the microdisk resonator then in the absence of the optical clock pulses, the optical data signal will be coupled into the microdisk. In the presence of the optical clock pulses, free carriers will be generated

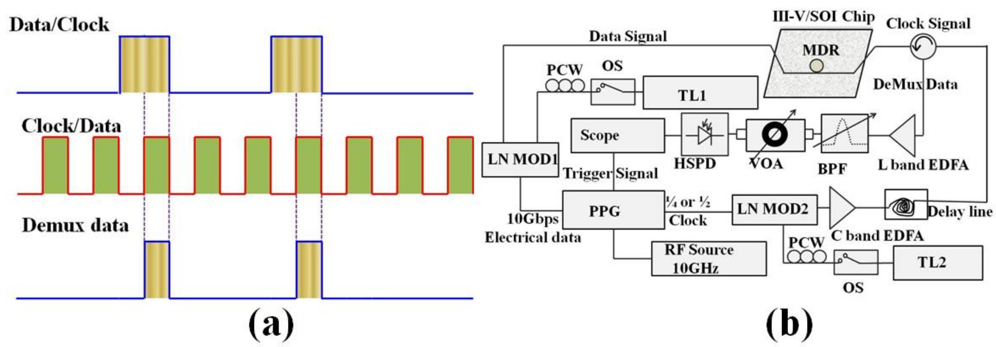

Fig.1. (a) Illustration of the concept of all-optical de-multiplexing; (b) Schematic of experimental set-up

which will result in a blue shift of the resonance and the optical data will become off-resonance for the duration of the optical clock pulses. This way the optical data output from the microdisk will be high or low depending upon the presence or absence of the optical clock pulses. This is illustrated in figure 1(a). The combination of the input optical data rate and the optical clock rate will decide the data rate of the de-multiplexed output.

Experiments and Results

The transmission characteristics of the microdisk resonator are found by scanning the power as a function of wavelength using a continuous wave tunable laser. Two azimuthal mode resonances, one at 1550.1nm while another at 1580.9nm, are found. The all-optical de-multiplexing experiments are carried out using the set-up as shown in figure 1(b). A 10Gbps NRZ optical data signal is generated using a pulse pattern generator (PPG), a first electro-optic $LiNbO_3$ modulator (LN MOD1) and a first tunable laser (TL1) tuned around a longer wavelength (1580.9nm) resonance of the microdisk. An optical clock signal having a repetition rate of 2.5GHz and 5 GHz is generated using a second tunable laser (TL2) tuned around a shorter wavelength (1550.1nm) resonance, a second electro-optic LiNbO3 modulator (LN MOD2) and the electrical clock from the PPG. An optical delay line is used for the synchronization of the optical clock with the optical data signal. A circulator is used to collect the de-multiplexed data and an EDFA is used to amplify the de-multiplexed data. A band pass filter (BPF) is used to suppress the ASE noise generated from the EDFA. A variable optical attenuator (VOA) is used to control the input power to the high-speed photodiode (HSPD) connected to the scope. The waveform of the optical data signal at 10Gbps with alternate 0s and 1s is shown in Figure 2(a) while 2(b) shows the waveform of the optical clock signal at 2.5GHz.

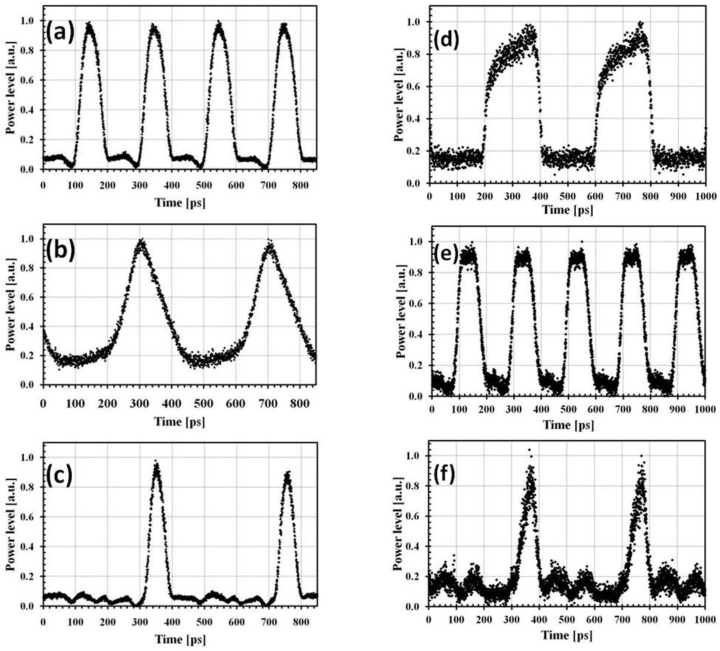

Fig.2. Waveforms of (a) 10Gbps 01010..optical input data, (b) 2.5GHz optical clock, (c) De-multiplexed output as a result of (a) and (c), (d) 10Gbps 001100..optical input data, (e) 5 GHz optical clock and (f) De-multiplexed output as a result of (d) and (e)

To de-multiplex the optical data signal, the wavelength of the data signal is tuned to the longer resonance wavelength while the wavelength of the clock signal is tuned to the shorter resonance wavelength. In the absence of the clock signal, the data signal remains coupled into the microdisk and a low dc power level is seen on the scope. In the presence of the clock, the resonance of the microdisk shifts, because of the plasma-dispersion effect due to generated free carriers, causing the data signal to go out of resonance and therefore the de-multiplexed data is seen on the scope for the duration of the clock pulses. Figure 2 (c) shows the de-multiplexed output. Comparing the figures 2(a) and 2(c), it can be seen that the logic 1 levels which are originally separated by 200 ps become separated by 400ps after de-multiplexing. The experiment is repeated for the data pattern of 001100…. and an optical clock at the rate of 5 GHz. Figure 2(d) and 2(e) shows the waveform of the optical data and the optical clock respectively. The output after de-multiplexing is plotted in figure 2(f).

In conclusion, we have demonstrated all-optical de-multiplexing in a small foot-print III-V/SOI microdisk resonator without using any bias. This kind of de-multiplexer forms an important building block for fully-functional and compact PIC chips.

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