Vertical Interconnection of SOI Photonic Integrated Circuits

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One of the important issues of System-on-a-package integration is the interconnection between independent Photonic Integrated Circuits (PICs). In this work, this issue is addressed by the use of Vertical Grating Couplers (VGCs) as the element for the interconnection between two Silicon-on-Insulator (SOI) PICs. Theoretical simulations using the finite-difference time-domain (FDTD) computational technique have shown that the coupling efficiency can be at least as good as 41%. In order to prove the principle, two SOI-PICs fabricated in ePIXfab have been stacked vertically via the foundry's standard VGCs.

Introduction

During the last years Silicon-on-Insulator (SOI) technology has emerged as one promising platform for integrated optics. One of the main reasons for this is the high refractive index contrast between the Si core ($n_{Si} \approx 3.45@1.5\mu m$) and the SiO_2 cladding ($n_{SiO2} \approx 1.45@1.5\mu m$). This refractive index difference allows for high density photonic integrated circuits (PICs) compatible with the fabrication process of standard complementary metal-oxide semiconductor (CMOS) technology. However it has a major drawback, which is the large mismatch in mode size and mode shape between the fundamental mode of a SOI waveguide and the mode of a given optical fiber. For that reason, one of the most researched issues in recent years has been the efficient fiber to chip coupling of SOI chips, partly in order to make feasible the hybrid integration of fiber coupled components, i.e. sources and detectors, but also to make possible the interconnection of independent photonic chips. The most accepted solution for this is the employment of Vertical Grating Couplers (VGCs) [2-4], with the great advantage that they can be placed anywhere in the chip and without the necessity of complex back-end process, i.e. end-facet polishing. Standard VGCs are already offered for fiber to chip coupling as building blocks provided by foundries, like *ePIXfab*. [5]

The principle of VGCs operation is beneficial also for other applications such as free-space alignment tolerant light coupling to the photonic sensor PICs [6]. VGCs may be also beneficial for vertical stacking of PICs as the light is vertically in- and out- coupled via VGCs.

In this paper such possibility is discussed by presenting the theoretical simulation study and experimental results on the vertical stacking of two SOI PICs, one against the other, using the VGCs as the interconnection element. The artistic vision of this operation is shown in fig. 1.

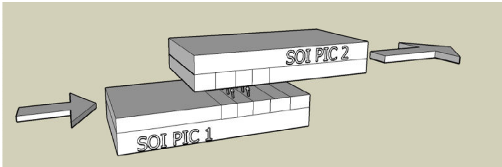

Figure 1. Grating to grating coupling between to PICs

Device simulations

In order to study the theoretical feasibility of the concept, finite-difference time-domain (FDTD) simulations have been performed using OptiWave^{TM} software package [7]. The simulated structure is shown in fig. 2.

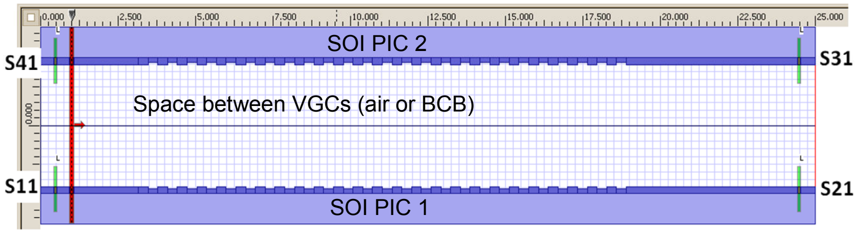

Figure 2. Simulated structure in Optiwave^{TM}. The port S11 (input port) indicates the reflections of light getting back from the VGC to VGC coupling structure and S31 is the transmission port of light coupled to the SOI PIC 2.

In fig 3. the scatering parameters indicated in fig. 2 are plotted as a function of the vertical separation between the SOI PICs. In order to make a more realistic simulation, the gap between the SOI PICs has chosen to be filled with Benzocyclobutene (BCB)-based polymer which is a standard material used for planarization of PICs. Such polymer has a refractve index of 1.541. In fig. 3 it can be noticed that for an optimal separation between the VGCs of 4.15um the transmission (S31) reaches its maximum value (3.8 dB, corresponding to 41% of coupling).

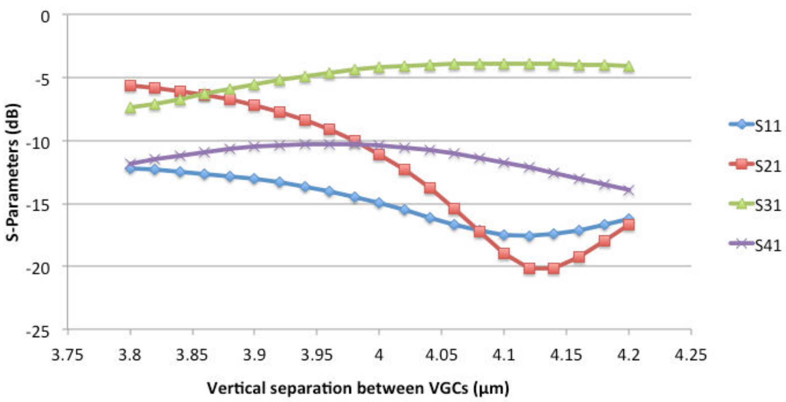

Figure 3. Variation of SOI-SOI coupling with respect to vertical distance for 1140-nm-long gratings and the gap between the structures filled with BCB.

Experimental set-up and characterization

A first prototype for a SOI PIC to SOI PIC coupling was fashioned, as shown in fig. 4. Two models of SOI PICs consisting on a straight waveguide equipped with two VGCs were used in the experiment. In order to facilitate the characterization, fibers were coupled to one of the VGCs in each of the SOI PICs using a glass cube in order to fix its position, as also can be observed in fig. 4. Such post-processed two SOI PICs were carefully aligned one against the other using two separated 3 axis nano-positioning stages. Once the maximum of transmission was reached, UV curable polymer glue with a refractive index n ≈ 1.5 was used to fix their position.

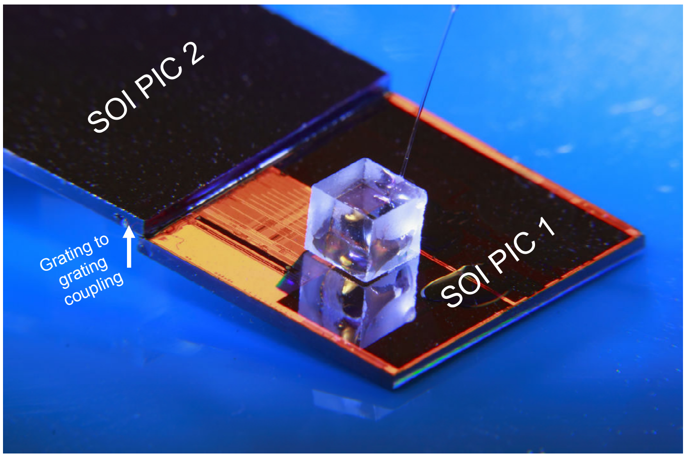

Figure 4. Picture of two SOI PICs stacked vertically against each other using VGCs as the element for the interconnection. The cube on the SOI PIC 1 is used to facilitate the fiber to chip coupling.

For the characterization of the prepared device, the transmission spectrum was measured using a broadband super-LED source and an optical spectrum analyzer. The obtained result is shown in fig. 5.

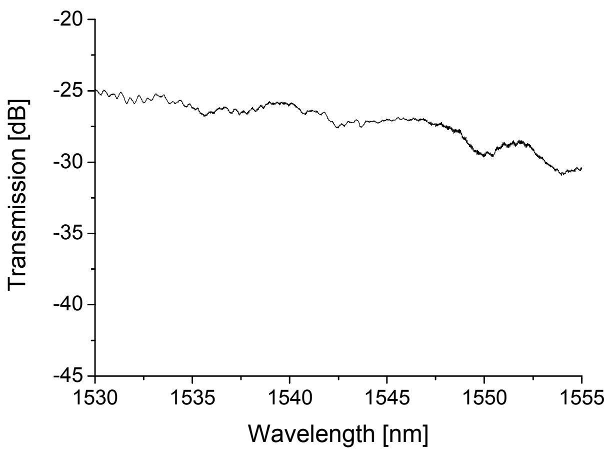

Figure 5. Experimental spectrum of two vertically stacked SOI PICs.

In fig. 5 the transmission spectrum of the characterized device is presented. This spectrum was produced by subtracting the spectra of the source from the output. As one sees the transmission is rather low varying from -30 dB to -25dB. However there are many elements that contribute to the overall loss and they need to be considered. Namely the glass cube assisted fiber to chip coupling which losses could be estimated as not lower than 6dB and the transmission loss through the straight waveguides that could be estimated as 1 to 2 dB. Consequently the transmission efficiency of VGC to VGC coupling could be estimated as -17 to -11 dB.

Conclusions

In this work, the vertical coupling between two PICs has been studied from the theoretical and experimental point of view. FDTD simulations were employed to find the maximum coupling efficiency, resulting with a theoretical value of 41% transmission efficiency. The preliminary experimental studies were performed in order to prove the concept of VGC to VGC coupling.

In further work the alignment tolerance will be evaluated as well as losses will be measured with higher accuracy.

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