COMPACT BUILDING BLOCS FOR OPTICAL LINK ON SOI TECHNOLOGY

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SUMMARY

The paper describes the modelling and optical characterisation of the basic compact building blocks used for the realisation of optical functions compatible with the standard CMOS technology. Results on the loss characterisations versus the wavelength ($\lambda = 1275$ to 1625 nm) of basic components (submicronic strip waveguide, µbend, Y junction and MMI beam splitters) and the first experimental demonstration of an 1 to 8 optical link are presented.

KEYWORD

Optical interconnect, SOI photonics, waveguide, Y junction, MMI

ABSTRACT

INTRODUCTION

SOI photonics has been a growing subject this last decade [1-4]. Due to the high refractive index contrast between silica and silicon, the silicon waveguide on SOI allows a high level of integration compare to alternative optical technology such as doped silica [5], silicon nitride [6] or polymer waveguide [7] on silicon wafers. Moreover, the silicon material is transparent in the complete near infrared range (λ =1.25 to 1.65 µm) necessary for wavelength multiplexing techniques which increase the performance of the devices. As the technology is compatible with standard CMOS processing, massive production of low cost optical chips for future intra chip optical interconnections [8] or fiber to the home telecommunication applications can be envisioned.

Previous studies have addressed the coupling to SOI waveguiding devices which is a critical issue. Solutions based on the use of standard grating couplers [9-11], 3D tapers [12-13] and ARROW coupler [14] give an experimental coupling efficiency up to 50 %.

In this paper, we report the design, fabrication and measurement of losses in single mode SOI strip waveguide, µbend, Y junction and MMI beam splitters. Also, the demonstration of a 1 to 8 optical link in a compact chip of 1 cm side is given.

FABRICATION AND DESIGN

Devices were fabricated on SOI Unibond 200 mm wafer manufactured by SOITEC with 400 nm of Si on a 1 µm buried oxide (BOX) layer. The thick oxide of 1 µm is sufficient to reduce the substrate leakage losses and consequently to optically isolate the waveguide circuit from the substrate. Thinning steps with oxidation and etching are used to reduce the silicon thickness to 200 or 300 nm. The devices are manufactured with DeepUV (248 nm) lithography and and HBr etching process in a 200mm CMOS line at CEA/LETI. A 500 nm thick cap layer of silica is added by Plasma Enhanced Chemical Vapor Deposition (PECVD) process to encapsulate the optical circuit.

Two kinds of waveguide with different cross sections are studied. A 0.3x0.3 µm² waveguide (W_1) is used for telecommunication devices that require a polarisation insensitivity and a 0.5x0.2 µm² waveguide (W_2) for the optical clock distribution on CMOS.

Designs of the waveguide are performed by a Full vectorial mode solver [15] with transparent boundary conditions [16]. This solver gives the propagation constant of the guided modes and it is also used to calculate the propagation losses due to leakage in the silicon substrate and the cross talk effect occurring when two waveguide are closed to each other [17]. The modelling of the other devices is realised with 2D FDTD [18] method coupled with the effective index method [19]]. This method is less consuming in time and memory than a 3D FDTD [18] and conducts to the same results as regards with the devices optimisation. The 3D FDTD is only used for results validation and for the computation of the losses of the devices.

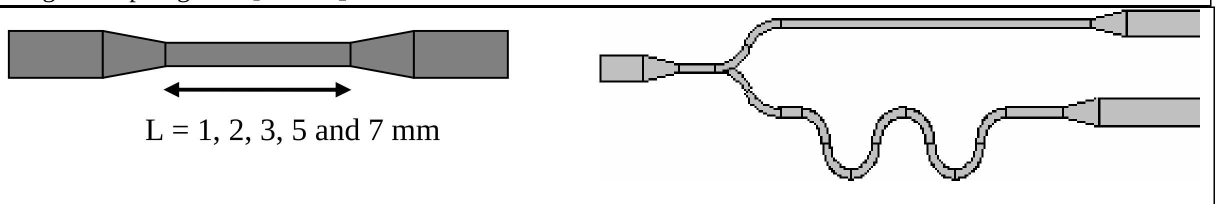
For the design of the 90° µbend, we considered bending with progressive radius of curvature for the goal of reducing the losses occurring in the transition region between the straight and the bending waveguides [20]. Simulations show that for such devices with high refractive index difference, the waveguide offset for transition loss optimization is close to zero. The main effect to overcome is the mismatch between the guided mode in the straight and bending waveguide region. The result is a backward reflection of the light that is the main part of the transition losses mechanism. The use of progressive radius allows to reduce slightly the transition losses.

One way to divide the signal in N part is to use MMI splitter [21]. Figure 3 a) shows the contour mapping of the field in a 1 by 2 MMI. Simulations are performed with a 3D FDTD method. The size of a 1 to 2 MMI is 2x5.4 µm2. This method gives also the spectral response of the device (fig. 3 b)). Simulations shows that the use of tapers on the input and output waveguides of the MMI reduces the backward reflection and then decreases the radiation losses and increase the flatness response versus the wavelength of the devices. 3D simulations of the Y junctions shows that the radiations losses are a 0.5 dB greater than the MMI but the device are less chromatic.

CHARACTERISATION

In order to evaluate the propagation losses of strip waveguides, as well as the losses of the 90° µbends, we performed a series of test devices shown in figure 1 a) and b).

The input and output part of the test device is constituted by a waveguide of 2 µm width for optimizing the injection of the tapered fiber light in the component. An adiabatic transition is used to reduce the size of the strip waveguide with minimum losses. The test device for the measure of the propagation losses are constituted in their central part by a strip waveguide of variable length (fig.1 a)). The basic test device for the measurement of the transmission of basic integrated optics elements contains an Y junction with 2 arms at the output: the first arm being a reference waveguide and the second arm containing the elementary component to be studied. Figure 1 b) shows the test devices for the measure of the losses of the 90° µbend. This device contains 40 bends on the lower arm. Light of 4 SLED sources is injected on the test devices by the butt coupling method with a tapered fiber and a linear polariser in line to get TE or TM polarisation. The spectral response is collected by an output tapered fiber coupled with a spectrum analyser. A linear infrared camera is used to observe the light which is diffracted on the rough side wall of the waveguide. Measurements are performed on the devices for the 2 strip waveguide topologies W_1 and W_2.

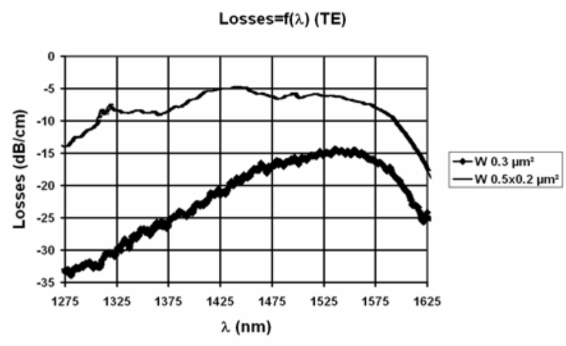


a) b)

Figure 1 : *Schematic view of the test sample. a) Test devices dedicated to the waveguide propagation losses measurements and b) test devices for the spectral response measurements of basic integrated optics elements.*

The propagation and µbend losses measurements are reported respectively on figure 2 a) and 2 b). The W_1 waveguides have acceptable losses of 15 dB/cm on a range of 50 nm around 1550 nm. Their applications will be limited to discrete devices lower than one mm. The W_2 waveguides have losses of about 5 dB / cm on a wide range of wavelength (1425 nm to 1575 nm) and so introduction of WDM may be considered for optical clock distribution applications in a 1 cm² chips. We can notice that the losses of the µbends are relatively weak on all the spectral range (less than 0.35 dB for 40x 90° bend) and can be considered as unimportant (0.05 dB/bend) in the case of the W_2 waveguides for radius greater or equal to 5 µm.

The characterization of the MMI was realized with the same type of test devices. On the figure 3 b), we have reported the theoretical and experimental losses of one of the output waveguide of the MMI for both configurations of guides. We can notice that the theoretical curves are in good agreement with the experiment. The minimum of the MMI transmission occurs for the design wavelength of 1300 nm. These losses are lower than those of a conventional Y junction. The diffraction losses of the MMI (W_1) are weaker than for the MMI (W_2). For the MMI (W_1), the increase of the losses versus the wavelength is 1 dB. We can consider that it is chromatic. For the MMI (W_2), we can consider that the component is useful on a spectral range of 100 nm. The imbalance between the 2 outputs of the MMIs does not exceed 0.5 dB.



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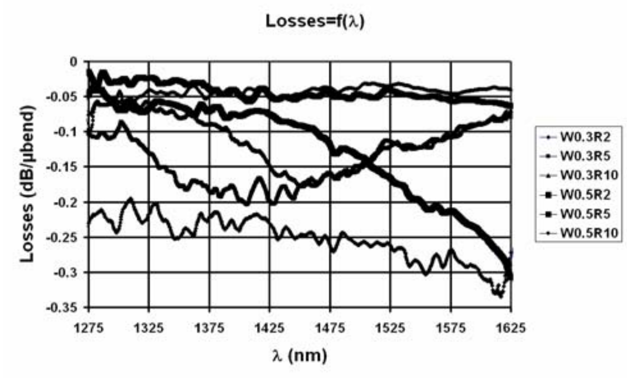
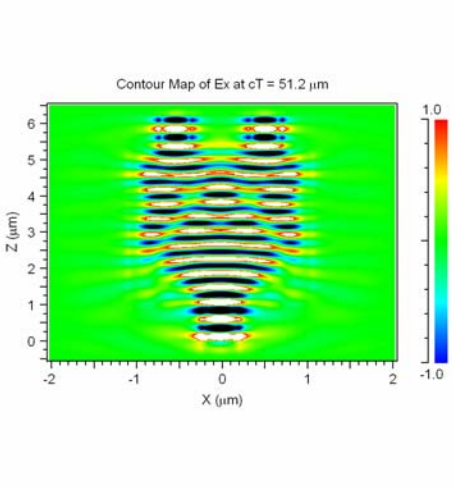


b)

Figure 2 : *a) Propagation losses versus the wavelength of the two strip waveguide in a TE polarisation. b) Losses of the µbends versus the wavelength for 3 different radius (2, 5 and 10 µm) in the two strip waveguide cross sections (TE polarisation).*



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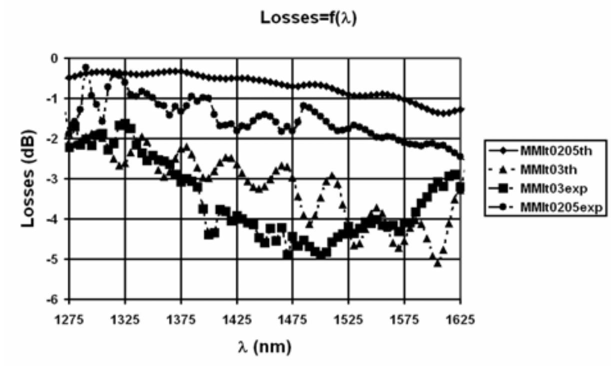
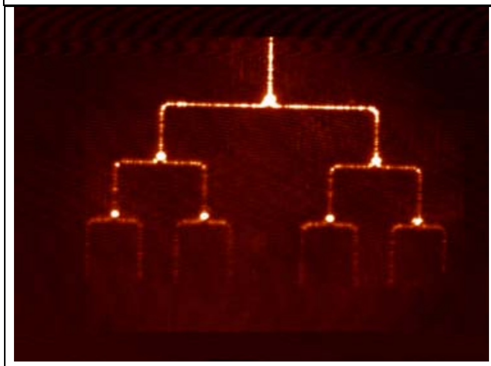


b)

Figure 3 : *a) Mapping of EM field that propagate of the 1 to 2 MMI splitter. b) Theoretical and experimental spectral losses of the MMI output for the two strip waveguide cross sections (TE polarisation).*



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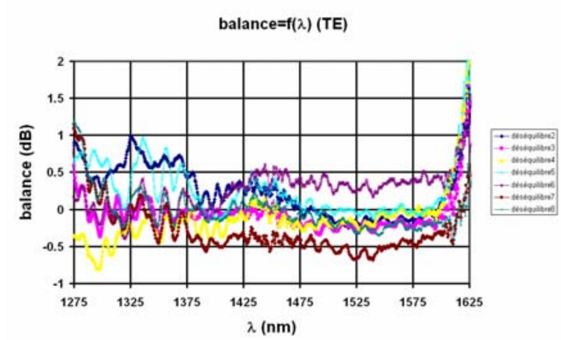

b)

Figure 4 : *a) Infrared red image of the 1 to 8 optical distribution with 7 Y junctions splitters. b) Spectral balance of the 8 output.*

The figure 4 a) shows the infrared image of the light which propagates in a 1 to 8 optical distribution tree constituted by 7 Y junctions, µbends (radius of curvature = 5µm) and W_1 waveguides. The propagation of the light is achieved on 1 cm length. On the figure 4 b), we have plot the spectral response of 7 outputs normalized with regard to the first output. We notice that the imbalance of the distribution remains lower than 0.5 dB on all the spectral range.

CONCLUSION

The design and characterization of very compact passive devices based on Silicon On Insulator (SOI) were investigated. We use 2 kinds of strip waveguides having various cross sections (0.5x0.2 µm² and 0.3x0.3 µm²). Measurements of propagation losses show that the first strip waveguide have very low losses (5 dB/cm) and it's more suitable for optical clock interconnect application.

Ninety degrees µbends with progressive radius of curvature reduce the losses occurring in the transition region between the straight and the curved waveguides. These µbends exhibited only negligeable losses (0.04 dB/µbend). Very compact MMI devices have been modelled with a compact size of 2x4.2 µm2 for a 1 to 2 MMI. Experimental results are in good agreements with the computed results and show that the MMI devices are the most chromatic basic elements of an optical circuit for the W1 topology. This drawback vanishes for the W2 topology. Very well balanced 1 to 8 optical distribution on a 1 cm² chip was demonstrated experimentally.

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