Efficient Silicon-On-Insulator fiber coupler fabricated using 248nm deep UV lithography

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***Abstract*—We present a Silicon-on-Insulator waveguide to fiber coupler fabricated using 248nm deep UV lithography. The loss of the taper structure is around 1dB while the coupling loss from a lensed fiber into a 590nm wide SOI waveguide was measured to be 1.9dB.**

I. INTRODUCTION

In the last years, Silicon-On-Insulator (SOI) is emerging as a very promising platform for photonic integration. Due to the high omnidirectional index contrast very compact wavelength scale components can be fabricated. Moreover one can use the standard CMOS technology to mass manufacture these optical devices [1]. However the viability of integrated optical components depends just as much on the capability to provide them with manufacturable low-loss interfaces to an optical fiber. In this paper we demonstrate that CMOS technology can also play a key role for these interfaces.

II. FIBER TO WAVEGUIDE COUPLING

The coupling of light from an optical fiber into an SOI waveguide is made difficult by the small overlap of the SOI waveguide mode and the fiber waveguide mode. Several approaches are proposed in literature to tackle this problem. Grating couplers are good candidates due to the lack of the need for cleaved facets.

Manuscript received July 2005. This work was supported partly by the European Union under the IST project PICMOS (FP6-2002-IST-1-002131) and the IST Network of Excellence ePIXnet. G. Roelkens and W. Bogaerts acknowledge the Fund for Scientific Research (FWO) for financial support and the support of the IAP-Photon network. P. Dumon thanks the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT Vlaanderen) for a scholarship. D. Van Thourhout acknowledges the Federal Science Policy Office for a return grant. G. Roelkens, P. Dumon, W. Bogaerts, D. Van Thourhout and R. Baets are with the Department of Information Technology (INTEC) at Ghent University – IMEC, B-9000 Gent, Belgium (e-mail address: gunther.roelkens@intec.ugent.be).

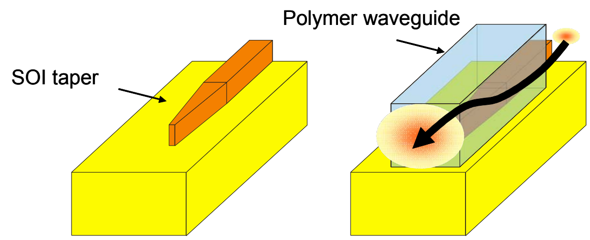

Fig. 1. SOI waveguide spot size converter for efficient coupling to a lensed fiber

However they intrinsically suffer from a compromise between efficiency and optical bandwidth, making them unsuitable in some applications [2]. Another approach presented in literature is to use a spot size converter to transform the SOI waveguide mode to a polymer waveguide mode which matches a lensed fiber mode as shown in Fig. 1 [3] [4]. The optical bandwidth is typically very large (>100nm) and efficiencies are high (<1dB loss). To obtain this high efficiency the SOI taper needs to taper accurately to widths below 100nm for high efficiency due to the strong optical confinement in the SOI waveguide. While this is not a problem for an e-beam lithography system in a research environment, this is much more difficult to achieve for the standard industrial CMOS 248nm deep UV

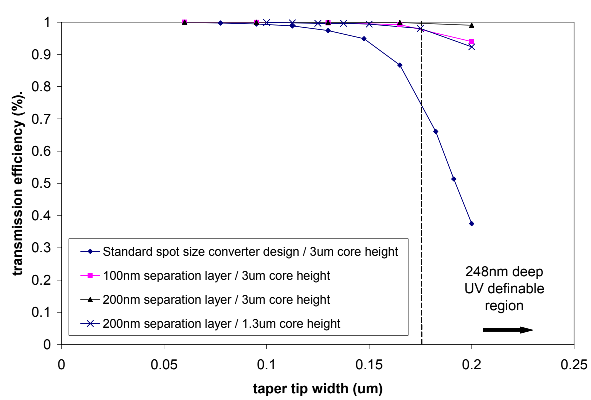

Fig. 2. Simulated efficiency of the spot size converter as a function of SOI taper tip width. Simulations are for TE polarization and a wavelength of 1.55μm.

lithography machines. In Fig. 2 we present the achievable efficiencies of the standard spot size converter design as a function of the taper width at 1.55µm wavelength. In this simulation the only source of loss is considered to be the mode mismatch at the SOI tip / polymer waveguide interface. Simulations are performed for TE polarized light. FIMMPROP-3D, a commercially available fully vectorial eigenmode expansion tool, was used [5]. The required tip width depends on the properties of both the SOI waveguide and polymer waveguide. The SOI waveguide core is assumed 220nm high while the polymer waveguide is assumed to have a refractive index of 1.67 and core dimensions of 3µm x 3µm. A benzocyclobutene (BCB) top cladding (n=1.54) is assumed.

To assess the possibilities of a 248nm deep UV lithography system to fabricate the taper tips an ASML PAS5500/750 stepper was used. Using a standard resist mask process taper tips down to 175nm could be fabricated. As can be seen in Fig. 2, this achievable tip width limits the efficiency of the device. To increase the efficiency the design of the spot size converter was changed by adding a low index BCB spacer layer as shown in Fig. 3 to reduce the coupling of the waveguide

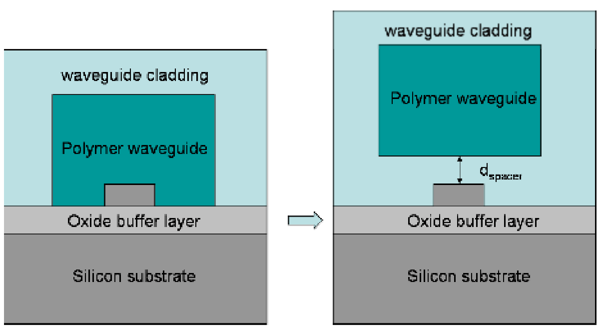

Fig. 3. Modified taper design for fabrication using a 248nm deep UV lithography system

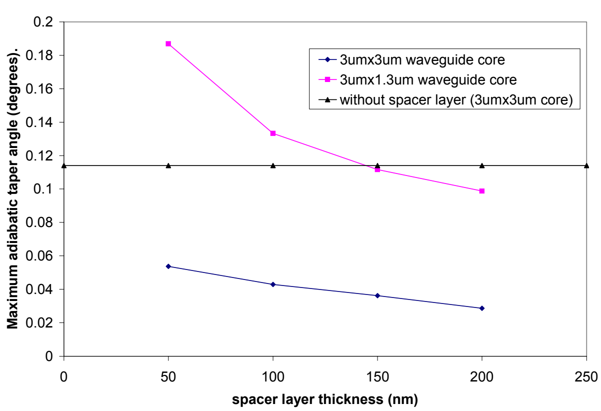

Fig. 4. Influence of the spacer thickness on the spot size converter maximum adiabatic taper angle for the modified design.

modes. The simulated efficiency of the taper device for a spacer layer of 100nm and 200nm is also shown in Fig. 2. This graph shows that adding this spacer layer increases the achievable efficiency using deep UV lithography to about 100%. The influence of the spacer layer thickness on the maximum adiabatic taper angle of the spot size converter is shown in Fig. 4. It is clear that without altering the polymer waveguide dimensions, the spot size converter length drastically increases by adding a spacer layer. This can however be overcome by reducing the polymer waveguide height without reducing the efficiency for deep UV definable taper tips as can be seen in Fig. 2 and Fig. 4 where respectively coupling losses and maximum taper angle for a 1.3µm polymer core height are plotted. As is shown in Fig. 5, there is however a small reduction in the coupling efficiency between the polymer waveguide mode and the lensed fiber spot for reduced polymer waveguide height. It is clear that the choice of polymer waveguide height is a trade-off between device length and coupling efficiency.

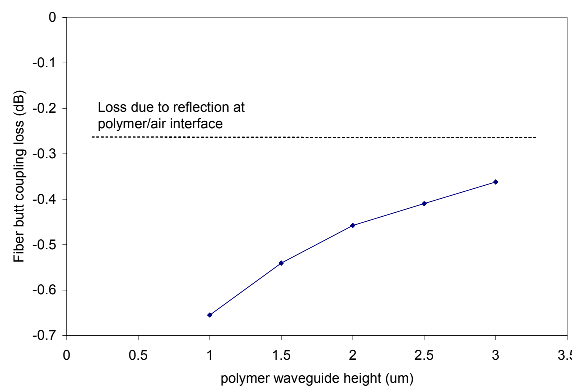

Fig. 5. Influence of the polymer waveguide height on the coupling efficiency to an optical fiber. A Gaussian lensed fiber spot of 2.5µmx2.5µm is assumed. Simulations are performed for TE polarization at a wavelength of 1.55µm.

III. Fabrication and Measurements

Piecewise linear Silicon-on-Insulator spot size converters were fabricated using an ASML 248nm PAS5500/750 stepper. The SOI waveguide dimensions are shown in Fig. 6, together with an SEM picture of the taper tip. After waveguide fabrication a 200nm BCB film was spin coated on top of the SOI waveguide structure. To achieve this very thin layer thickness, BCB was diluted using mesitylene [6]. After curing, a polyimide waveguide core layer of 1.3µm thick was applied and the waveguide core was etched using a 100nm Ti mask and ICP plasma etching. After removal of the Ti mask using diluted HF a thick BCB topcladding was applied. The refractive index of the polyimide and BCB for TE polarization at 1.55µm is

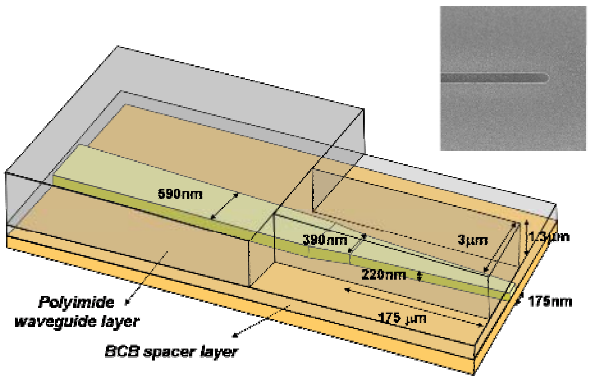

Fig. 6. SOI spot size converters: design and fabricated SOI taper tips. BCB top cladding is not shown for clarity

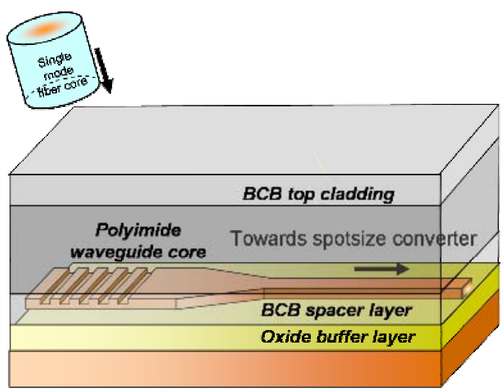

Fig. 7. Light injection using an SOI grating coupler

1.67 and 1.54 respectively, characterized using a Metricon 2010 prism coupling setup. The structure used to characterize the spot size converters is shown in Fig. 7. A grating coupler was used to inject light into the fundamental TE waveguide mode of the SOI waveguide, while a lensed fiber with a spotsize of 2.5µmx2.5µm or an objective lens was used to collect the light at the polymer waveguide facet. The lensed fiber had a specified loss of 0.5dB while the loss of the objective collection was negligible. The grating coupler used in the experiments was characterized to have 7dB loss and a 60nm 3dB bandwidth. Fig. 8 shows a transmission spectrum measured by light collection using an objective. The coupling efficiency of the grating coupler is superimposed. This implies that the SOI spot size converter itself shows 1dB loss. Transmission experiments using a lensed fiber were also carried out. A coupling loss from lensed fiber to a 590nm wide SOI waveguide of 1.9dB was measured. This 0.9dB extra loss is caused by the mode mismatch between the polymer waveguide mode and the lensed fiber mode and the additional 0.5dB loss of the lensed fiber.

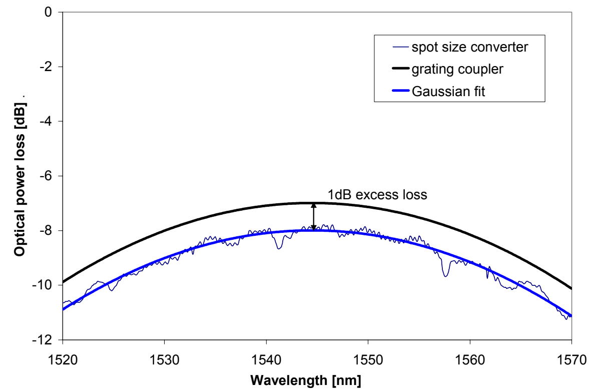

Fig. 8. Measured transmission spectrum using an objective collection lens. The grating transmission spectrum is superimposed.

IV. Conclusion

A spot size converter for efficient coupling between an optical fiber and an SOI waveguide circuit was designed for and fabricated by 248nm deep UV lithography. A tradeoff has to be made between fiber chip coupling efficiency and compactness of the spotsize converter. Experimentally, 1.9 dB coupling loss was measured between a lensed fiber and an 590nm wide SOI waveguide.

V. References

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