Efficient fiber to SOI photonic wire coupler fabricated using standard CMOS technology

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***Abstract*— We present a Silicon-on-Insulator spot size converter fabricated using 248nm deep UV lithography. The loss of the taper structure is around 1dB over more than 60nm wavelength range while the overall coupling loss from a lensed fiber into a 590nm wide SOI waveguide was measured to be 1.9dB.**

I. Introduction

Silicon-on-Insulator (SOI) is a very promising platform to fabricate nanophotonic optical components on a wafer scale using standard CMOS processes [1]. Photonic wire waveguides in silicon-on-insulator confine light within submicron dimensions by total internal reflection. While efficient devices are being demonstrated, the coupling of light from a fiber in and out of the nanophotonic waveguide remains a problem due to the large mode mismatch between the fiber mode and the SOI waveguide mode. Different approaches are being used to overcome this problem. Grating couplers are good candidates due to the lack of the need for cleaved facets. 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] Optical bandwidth is typically very large (>100nm) and efficiencies are high (<1dB loss). However, to obtain this high efficiency the width of the SOI taper tip needs to be below 100nm 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 deep UV lithography machines. Therefore, the design of the spot size converter needs to be adjusted to be able to fabricate them on an industrial scale.

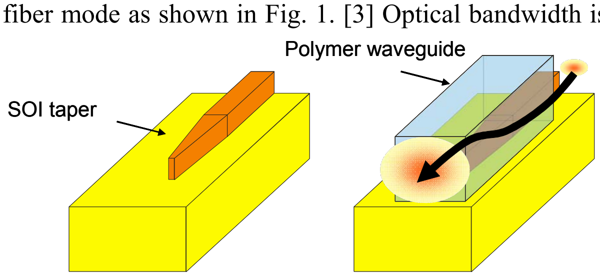

Fig. 1. SOI waveguide spot size converter for efficient coupling to a lensed fiber

II. Design of DUV definable SOI waveguide taper

The efficiency of the spot size converter was simulated using FIMMPROP 3D, a commercial fully vectorial eigenmode expansion tool. If we consider only the mode mismatch loss at the interface between the taper tip end and the polymer waveguide, we can calculate the upper limit of the achievable efficiency of the spot size converter. The polymer waveguide core was assumed to be 3µmx3µm (n=1.67) while the refractive index of the waveguide upper cladding is 1.54. The

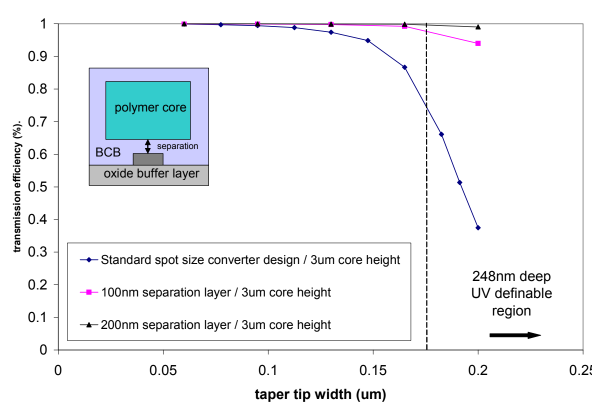

Fig. 2. Maximum spot size converter efficiency as a function of taper tip width

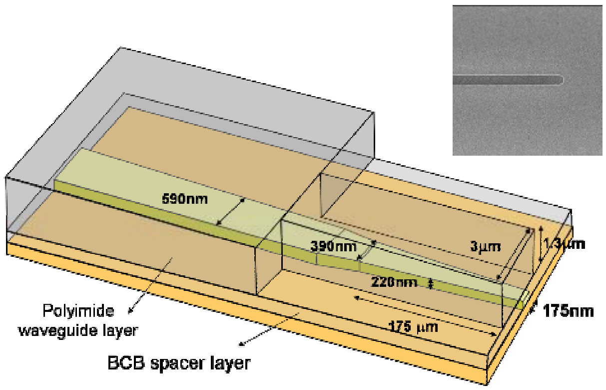

Fig. 3. Design of an SOI spot size converter and SEM picture of a fabricated taper tip

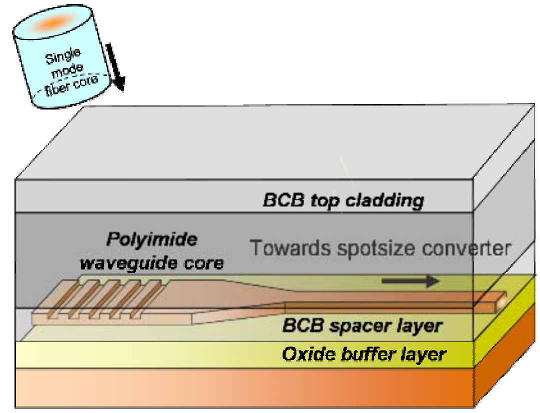

Fig. 4. Spot size converter measurement setup – fundamental mode excitation by grating coupler

results are shown in Fig. 2. Because the minimal achievable taper tip size using a 248nm deep UV lithography system is around 175nm, there is a substantial efficiency reduction compared to the sub 100nm taper tips achievable using e-beam machines. To overcome this problem, an additional spacer layer is added to reduce the coupling between the waveguide modes as shown in the inset of Fig. 2. The influence of the spacer layer thickness on coupling efficiency of the spot size converter is also shown. It can be seen that the efficiency of the taper can be enhanced by adding this spacer layer.

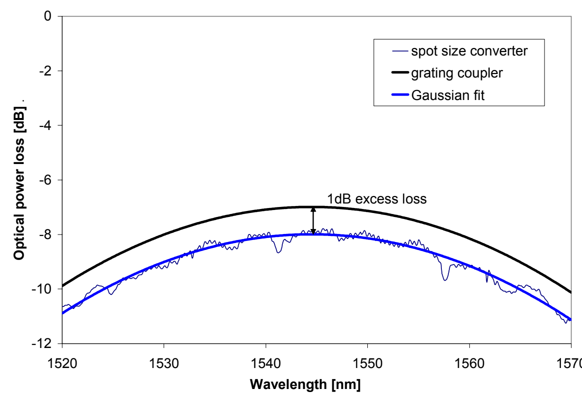

Fig. 5. Measured transmission spectrum with a superimposed grating transmission spectrum

III. Fabrication and Measurements

Piecewise linear Silicon-on-Insulator spot size converters were fabricated using an ASML PAS5500/750 stepper. The SOI waveguide dimensions are shown in Fig. 3, together with an SEM picture of the taper tip. After waveguide fabrication a 200nm benzocyclobutene (BCB) film was spin coated on top of the SOI waveguide structure. After curing, a polyimide waveguide core layer of 1.3µm thick was applied and the waveguide core was etched through using a 100nm Ti mask and ICP plasma etching. After removal of the Ti mask a thick BCB top cladding was applied. The refractive index of the polyimide and BCB for TE polarization at 1.55µm is 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. 4. 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 grating coupler used in the experiments was characterized to have 7dB loss and a 60nm 3dB bandwidth. Fig. 5 shows a transmission spectrum measured by light collection using an objective lens. The coupling efficiency of the grating coupler is superimposed. This implies that the SOI spot size converter itself shows 1dB loss. The coupling loss from a lensed fiber into a 590nm wide SOI waveguide was measured to be 1.9dB. The 0.9dB extra loss is caused by the mode mismatch between the polymer waveguide mode and the lensed fiber spot and the additional specified 0.5dB loss of the lensed fiber used.

IV. References

[1] W. Bogaerts, R. Baets, P. Dumon, V. Wiaux, S. Beckx, D. Taillaert, B. Luyssaert, J. Van Campenhout, P. Bienstman and D. Van Thourhout, "Nanophotonic waveguides in silicon-on-insulator fabricated with CMOS technology", *Journ. of Lightwave Technology*, Vol. 23(1), pp. 401 – 412, Jan 2005

[2] D. Taillaert, W. Bogaerts, P. Bienstman, T.F. Krauss, P. Van Daele, I. Moerman, S. Verstuyft, K. De Mesel and R. Baets, "An out-of-plane grating coupler for efficient butt-coupling between compact planar waveguides and single-mode fibers", *Journal of Quantum Electronics*, Vol. 38 (7), pp. 949 – 955, July 2002

[3] T. Shoji, T. Tsuchizawa, T. Watanabe, K. Yamada and H. Morita, "Spot-size converter for low-loss coupling between 0.3um square Si wire waveguides and single mode fibers", *15th annual meeting of the IEEE Lasers and Electro-Optics Society*, vol. 1, p.289-290, 2002