Compact grating couplers between optical fibers and Silicon-on-Insulator photonic wire waveguides with 69% coupling efficiency

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Abstract: We present efficient, compact and broadband grating couplers in Silicon-on-Insulator, for coupling between single mode fiber and nanophotonic waveguides. By adding a gold bottom mirror, the coupling efficiency is increased to 69%.

OCIS codes: (230.3120) Integrated optics Devices; (230.1950) Diffraction gratings; (250.5300) Photonic integrated circuits; (230.7370) Waveguides;

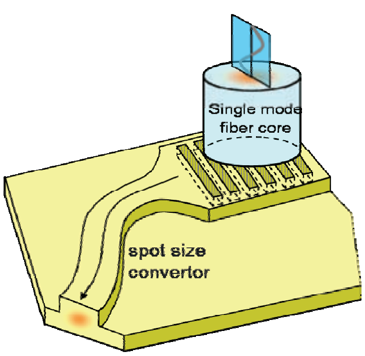
1. Introduction

High refractive index contrast materials are very well suited for ultra-dense photonic integrated circuits. An example of such a material is Silicon-on-Insulator (SOI), for which a lot of photonic-wire based components have been demonstrated [1]. Because of the large confinement, components can be very compact. However, the coupling with the outside world (optical fiber) remains an important problem, and shrinking the size of components makes the situation even worse. The reason is the huge mismatch between the fiber mode and the nanophotonic waveguide mode.

Several solutions have been proposed for solving this problem. By using an inverse taper approach, low loss and broadband operation was demonstrated, but these structures require lensed or special fibers with high NA [2, 3]. An attractive solution is provided by grating couplers, since they allow for wafer-scale testing. In this approach, light is coupled out-of-plane from fiber to waveguide. Traditional grating couplers use weak gratings and have a narrow bandwidth. We use strong and compact gratings in SOI for butt-coupling with the fiber. The principle is shown in Fig. 1 (left). A coupling efficiency of 33% for a 10x10 μm^2 grating coupler has been demonstrated in [4]. The coupling efficiency is limited by radiation towards the substrate. This type of coupler has a 1dB bandwidth of around 40 nm and good alignment tolerances (+/- 2µm for 1dB excess loss). A 2D-grating version can be used for getting polarization independence through polarization diversity [5].

In this paper, we avoid downwards radiation by adding a gold bottom mirror to the structure, using wafer bonding. We demonstrate a coupling efficiency from single mode fiber to waveguide of 69%.

2. Design



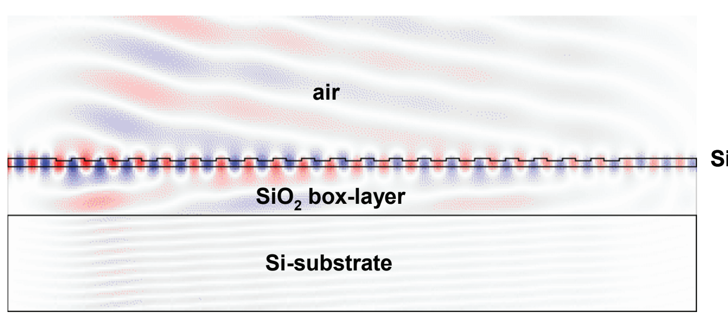
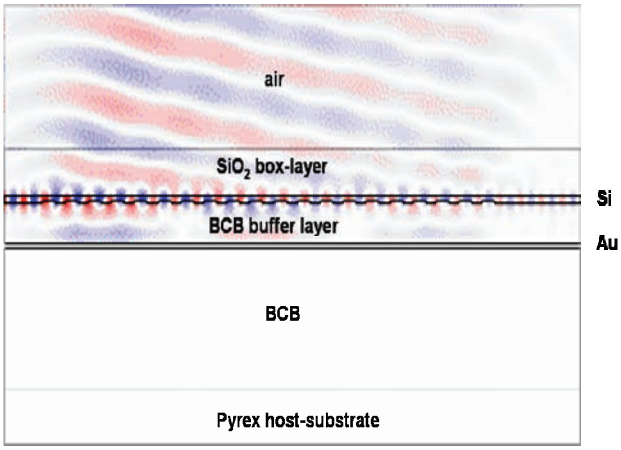


Fig. 1. (left) Principle of a grating coupler for coupling between SM-fiber and nanophotonic waveguide. (right) Field plot of such a grating coupler in Silicon-on-Insulator

The couplers were designed with CAMFR [6], an eigenmode expansion tool. All simulations are for TE-polarisation. Near vertical coupling at 10 degrees is used to avoid second order reflection. The simulation method is described in detail in [7]. We started from already existing SOI-grating couplers (box layer=1 µm, Si-core layer=0.22 µm) without bottom mirror and with following grating parameters: period=610 nm, filling factor =0.5 and etch depth=50 nm. The simulated coupling efficiency to fiber is 30%. A field plot is shown in Fig. 1 (right).

This structure was extended with a bottom mirror. First, a low index layer - in our case BenzoCycloButene (BCB) - has to cover the grating. The optimal thickness of this layer is 840 nm. Then a 50 nm gold mirror is evaporated, and the structure is bonded with another BCB-layer onto a host-substrate. Finally the Silicon-substrate is removed. The theoretical coupling efficiency to fiber is 72%. A field plot of the structure with bottom mirror is shown in Fig. 2 (left) together with the coupling efficiency curves of the different structures (Fig. 2 (right)).



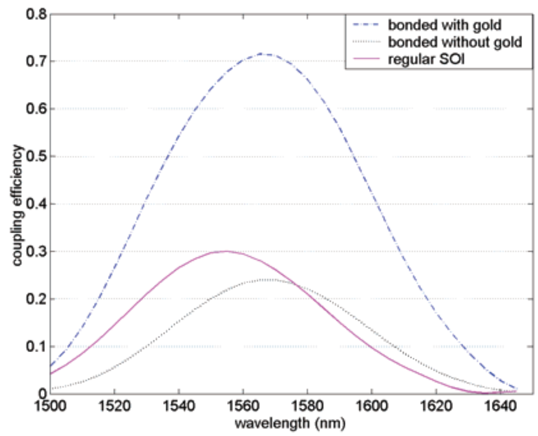
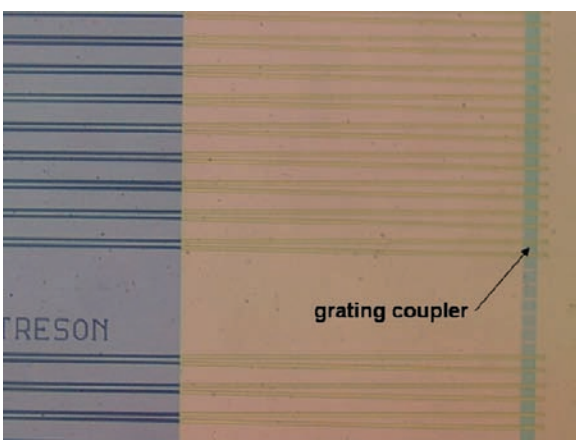


Fig. 2. (left) Field plot of a bonded SOI-grating coupler with bottom mirror. (right) Simulated coupling efficiency of the different couplers

3. Fabrication

The SOI-structures were defined with 248 nm DUV lithography [8]. The waveguides are 10 µm wide. We use BenzoCycloButene (BCB), a spin-on polymer from Dow Chemical, both as a low index dielectric and as a bonding agent. First, a BCB-layer with target thickness of 840 nm was spin coated onto the SOI-die and cured for 40 minutes at 210 degrees. Then, only the grating area was covered with a 50 nm evaporated gold layer using lift-off. The die was then bonded under vacuum onto a pyrex-substrate using an approximately 3 µm thick BCB-layer [9]. The BCB was cured for 1 hour at 250 degrees and the silicon substrate was removed using lapping, SF_6 plasma etching and wet etching in KOH. A picture of the fabricated structure and a FIB cross-section is shown in Fig. 3.



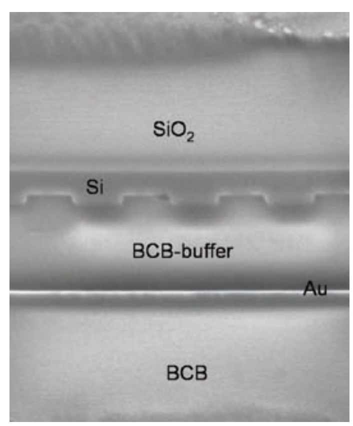


Fig. 3. (left) Picture of the bonded sample. Only the shaded area (with the gratings) is covered with gold.
(right) FIB cross-section of the fabricated structure

4. Measurements

We have determined the coupling efficiency from a fiber-to-fiber transmission measurement. The structures consist of an input coupler and an output coupler, connected by a waveguide. Only the input coupler has a gold mirror and on the sample, we also have bonded reference structures without gold mirror. In this way, we are able to evaluate the performance of the coupler with bottom mirror. A fiber, connected to a tunable laser, is positioned above the input grating at an angle of 10 degrees. Another fiber, connected to a power detector, is positioned (also at 10 degrees) above the output grating. By characterizing the losses in our setup, we are able to calculate the coupling efficiency reliably. For the bonded couplers without mirrors, we assumed that input coupler and output coupler are the same, and the coupling efficiency is determined to be 26%. We used this value for extracting the coupling efficiency of a grating coupler with bottom mirror (input coupler). The coupling efficiency is increased to 69% and the 1dB bandwidth is 40 nm. The measurement results are shown in Fig 4.

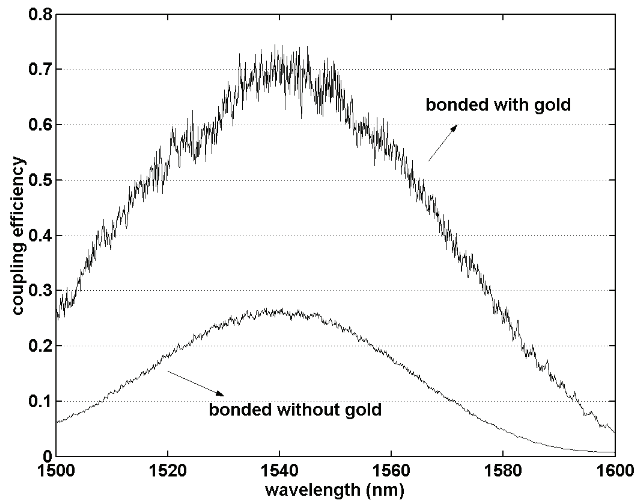


Fig. 4. Measured coupling efficiency of bonded SOI-grating couplers without and with bottom mirror

5. Conclusion

We have demonstrated highly efficient and compact grating couplers in Silicon-on-Insulator, for coupling between single mode fiber and waveguides on chip. We have measured a coupling efficiency of 69% on bonded SOI-grating couplers with a gold bottom mirror. The combination of compactness, low insertion loss, relatively broadband operation, and the possibility of wafer-scale testing has high potential for application in future telecommunication networks.

6. References

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