Laser-fabricated ball lens optical interface for back side coupling to a silicon photonics sensor chip

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***Abstract*—We propose a simple optical interface for coupling between a single mode fiber and a grating on a Photonic Integrated Circuit (PIC), by coupling from the back side using a ball lens. This way, the top side of the PIC remains accessible for sensing.**

Keywords—back side, ball lens, coupling, fabrication, femtosecond laser, optical interface, silicon photonics

I. Introduction and Optical Interface Concept

Conveniently coupling light in and out of a silicon Photonic Integrated Circuit (PIC) remains a challenge because of the mismatch in mode field diameter (MFD) between a silicon waveguide and a single mode optical fiber used for interfacing. A popular solution for fiber-to-chip coupling is the use of grating couplers [1]. However, usually grating couplers are interfaced from the top side of the chip, where also the optical circuit is situated. For PIC-based optical sensors, this is an issue since an optical fiber attached to the top side unavoidably causes mechanical hindrance during sensing. Here we introduce a solution in which the (sensor) PIC is interfaced from the bottom side using a ball lens, aligned in a precisely fabricated fused silica holder, thereby obtaining a compact PIC package while maintaining the front side of the chip flat and clear for sensing.

The general concept is depicted in Fig. 1(a): making use of a 300 µm diameter sapphire ball lens, the beam emitted by the fiber is imaged onto the grating coupler. In this paper, we demonstrate this for the particular case of coupling between an SMF28 single mode fiber, through a 725 um thick Si substrate to a grating coupler which is optimized for accepting a 10.4 um spot size at 1550 nm wavelength and at 10° coupling angle. Upon optimization using the Gaussian beam propagation module in Zemax OpticStudio (Fig. 2(b)), the maximum coupling efficiency of the lens system was found to be 98%, and the 1 dB lateral positioning tolerance of the fiber+ball lens assembly was found to be +/- 2.5 µm. To achieve this high coupling efficiency, the position of the ball lens (in x,y,z) with respect to the fiber facet and PIC is critical. We show that this can be achieved using fused silica-based holders, precisely fabricated using the FLICE (Femtosecond Laser Irradiation followed by Chemical Etching) technique [2].

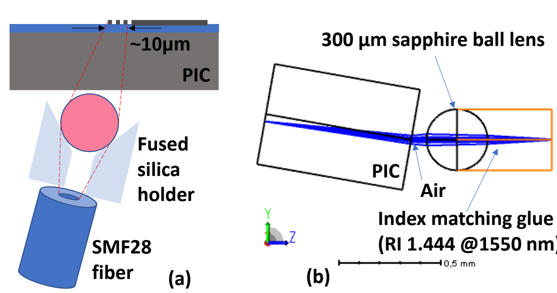

Fig. 1. Proposed optical interface: (a) concept and (b) OpticStudio

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II. Results and discussion

A. Optical coupling performance

The concept of using a ball-lens based optical interface was experimentally verified on a test PIC having short straight waveguides with TE grating couplers (1550 nm wavelength, 10° coupling angle) at both ends. The PIC substrate was thinned down and polished to a final thickness of 100 µm and a silicon nitride anti-reflection coating was applied. The thinned substrate allowed coupling from the back side directly using an SMF28 fiber and as such allows comparing coupling efficiency with and without ball lens from the back side, as shown in the inset of Fig. 2. At the other grating coupler, light was coupled from the top side using an SMF28 fiber in both cases. It should be mentioned that in case (i) an additional loss of 0.3 dB due to the ~100 µm separation between fiber and grating coupler and in case (ii) an additional loss of 0.4 dB due to the absence of an antireflection coating on the ball lens is expected. The difference in substate thickness used for the experiments, compared to the design in Fig. 1(b) does not have an impact on the coupling efficiency but only requires a larger separation between the ball lens and PIC. A broadband, (Erbium-Doped Fiber Amplifier) EDFA with an emission spectrum between 1520 nm and 1610 nm was used as a source, while the transmitted optical power was recorded using an optical spectrum analyser (OSA). Fig. 2 indicates that the use of a ball lens does not increase the loss, since the experimentally obtained maximum coupling efficiency is virtually identical in both cases, although there is a slight reduction in bandwidth when the ball lens is used. The absolute coupling efficiency (-16 dB) was relatively low because the used grating couplers were not optimized for back side coupling; this can easily be improved by adding a metal mirror on top of the grating coupler for improving the directionality [3].

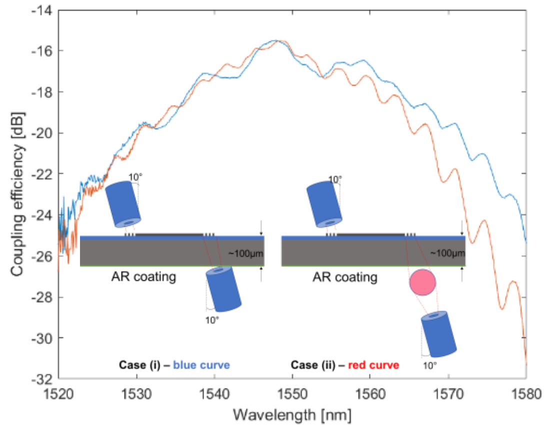

Fig. 2. Comparison of the fiber-to-fiber coupling efficiencies for back side coupling without or with ball lens. The schematics in the inset illustrate the two test configurations investigated.

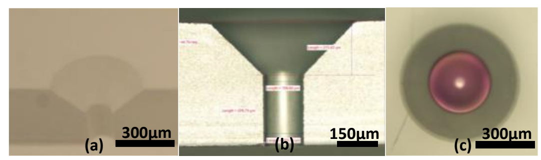

Fig. 3. Microscope images of the realised fused silica holders: (a,b) cross-sectional view, (c) top view with ball lens inserted.

B. Ball lens holder fabrication using FLICE

We have previously demonstrated V-grooves for precise fiber alignment, realized using the FLICE technology [4][3]. Based on this process and with an adapted design, a miniature funnel-like fused silica holder was realized which allows positioning the ball lens at the designed (x,y,z) position above the fiber facet. The dimensions of the holder were optimized to achieve the desired ball lens – fiber separation (284 µm for the current design) and alignment markers were applied to allow lateral alignment with respect to the fiber facet. Fig. 3 shows a cross-section of the realized holder (a, b) and a top view image of a holder with 300 µm ruby doped sapphire ball lens inserted (c). The currently achieved vertical position of the ball lens was within 5 µm of the designed value which can further be improved by optimizing the FLICE process.

In the current proof-of-concept demonstrator, only 1 of the interfaces was realized from the back side. This can however be extended to an array of interfaces and by employing slightly smaller ball lens diameters, coupling to standard 250 µm pitch fiber arrays is feasible. Furthermore, to facilitate packaging, it is more convenient to mount the fiber perpendicularly to the chip instead of at the commonly used 10° angle. This can be achieved by laterally displacing the ball lens with respect to the optical fiber axis. As such, an off-center positioned ball lens can ensure the proper 10° light deflection required for interfacing the grating coupler.

III. Conclusions

We have experimentally shown that an efficient optical interface for back side coupling between a single mode fiber and a silicon grating coupler on a PIC can be obtained employing a sapphire ball lens. This approach requires only 2 additional post-processing steps on the PIC, i.e. back side polishing and application of an anti-reflection coating. Accurate positioning of the ball lens with respect to the fiber and PIC can be achieved using a funnel-like holder realized in fused silica glass using Femtosecond Laser Irradiation followed by Chemical Etching.

References

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