Packaging Process for Efficient Coupling Using a Grating Coupler with Backside Mirror

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***Abstract*—We present the packaging process for permanent efficient coupling to silicon photonic waveguides using angle-polished fibers and aperiodic grating couplers with backside mirrors. The functional principle is based on the total reflection at the fiber-air interface and results in a compact and stable fiber-to-chip transition. A record value of -1.38 dB is achieved for the coupling efficiency utilizing gratings in a 250 nm silicon-on-insulator platform. The influences of the grating width and the optical adhesive are analyzed. This work demonstrates the suitability of grating couplers with backside mirrors for compact and permanent fiber links.**

I. Introduction

In the field of integrated silicon photonics the grating coupler is an important passive component, which can be used for on-wafer measurements realizing the optical transition of silicon waveguides to single mode fibers (SMFs) [1]. Aperiodic grating couplers with backside reflectors achieve a coupling efficiency of -0.58 dB at a wavelength of 1550 nm [2]. For the efficient coupling the used fibers are cut and arranged in a nearly vertical way with an usual angle of about 9° to the normal of the chip surface [3]. For the use of the efficient grating couplers in commercial products, a more compact way for the fiber alignment is presented in [4]. Here the fibers are polished with a specific angle, horizontally aligned and fixed by an adhesive. A coupling loss of 4.5 dB is achieved with a periodic 12 µm wide grating coupler. This method is also demonstrated by another group and presented in [5]. Nevertheless, there is a need to improve the achieved coupling efficiencies with the goal to fabricate compact devices with optical insertion losses better than 3 dB. In 2014 our group presented a CMOS compatible coupler with a record coupling efficiency of -0.62 dB utilizing a backside etching process and a metal layer below the grating coupler. Based on the mechanical sensitivity of the membrane, the contraction of an adhesive on top of the grating can lead to unwanted mechanical deformation. Due to this fact, the implementation of the described method is investigated in this work. Moreover, a closer look to the coupling scheme in Fig. 1 illustrates the enhanced distance between the fiber core and the grating coupler due to the fiber cladding, which usually has a diameter of 125 µm. To investigate the influence of the beam expansion and possible deformations, the dependency of the coupling efficiency on the grating coupler width is outlined for this coupling method.

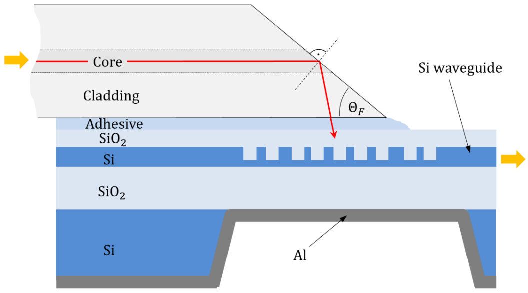

Fig. 1. Schematic coupling between single mode fiber SMF 28 and a silicon waveguide with the help of special grating couplers with back side reflector.

II. Packaging Process

SMF-28 fibers are cleaved with the commercial high precision cleaver CT-30 from Fujikura with an angle Θ_F of 90° after removing the outer jacket. After clamping the fiber in a special Al mounting (see Fig. 2(a)), the fiber end facets are grinded and polished in two steps with the help of two lapping sheets to receive a facet angle Θ_F of 40.6°. The fiber coating is removed by a hot jacket stripper (HJS-02) in the following step. A typical resulting fiber end is depicted in Fig. 2(b). With the

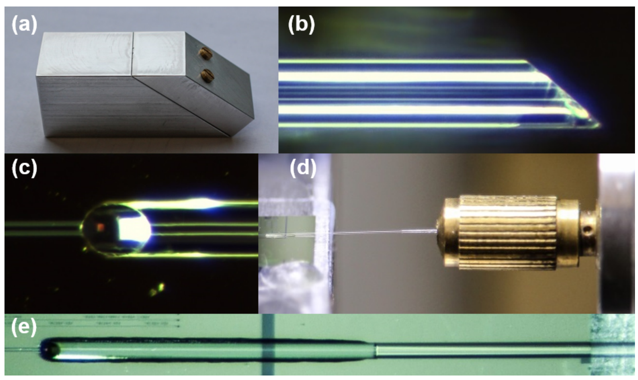

Fig. 2. (a) Al mounting for defining a specific fiber angle. (b) Microscopic image of the polished fiber (side view). (c) Top view of the fiber on top of the grating coupler. (d) Mounted fiber in the positioning system. (e) Top view of the glued fiber on the Si chip.

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help of a customized positioning and fiber mounting system, the fibers are coarsely adjusted parallel to the chip surface (see Fig. 2(c) and Fig. 2(d)). Norland optical adhesive 68 is dropped on the Si chip at a distance of about 5 mm with respect to the grating coupler. To avoid the adhesive covering the polished fiber facet, a reproducible very small volume about 0.01 µL is essential and can be adjusted by an Eppendorf micropipette. After dipping the fibers in the drop, the adhesive flows between the fibers and the chip surface to the fiber end and to the chip edge. A final positioning procedure with the help of piezo actuators is necessary to achieve an efficient coupling. The adhesive is cured by UV exposure in the final step. The glued fiber on the Si chip is depicted in Fig. 2(e).

III. Analysis

In this work, aperiodic grating couplers fabricated on the 250 nm SOI platform at IMS CHIPS Stuttgart are used. Here, Al backside reflectors enhance the coupling efficiency to record values of -0.62 dB. The fabrication process and the results for near-vertical coupling are presented in [6]. Fig. 3(a) depicts a comparison of the near-vertical and the horizontal coupling method with an identical grating coupler using a fused silica matching oil. Here, the achieved difference in transmission of 0.03 dB for a grating width of 15 µm is close to the measurement accuracy and repeatability. The spectrum of the horizontal coupling method holds a red shift of several nanometers in comparison to the near-vertical coupling method because of an additional fiber to chip surface inclination angle. This angle is necessary for proper positioning due to friction effects between fiber and matching liquid and could be compensated by reducing the facet angle Θ_F proportionally. Using the packaging procedure presented before, the achieved coupling efficiency versus wavelength is shown in Fig. 3(b) for different states of the used adhesive. A small difference in the resulting transmission spectra of 0.12 dB occurs comparing the coupling with the matching liquid to the coupling with the glued fiber. The effect of the adhesive curing is relatively small. Following the measurement results, the expectation in [4] of achieving coupling efficiencies better than -1.4 dB using the presented compact coupling method can be confirmed. Due to larger viscosity of the Norland adhesive, a larger inclination angle is needed for proper positioning and therefore a further red shift in the measured spectrum occurs. Analyzing the measured influence of the grating coupler width (see Fig. 4), results in an optimal grating coupler width of 17 µm, which is quite close to the simulated maximum of 13.7 µm for the near-vertical coupling [6]. Here, the slightly enlarged value can be

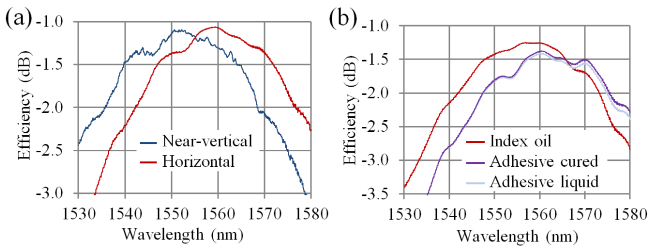

Fig. 3. (a) Transmission spectra of an aperiodic grating coupler with backside reflector for both coupling methods. (b) Influence of the adhesive on the transmission spectrum.

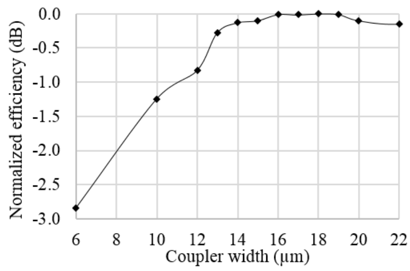

Fig. 4. Dependency of the maximum coupling efficiency on the grating coupler width for a periodic grating coupler without backside reflector at 1566 nm.

explained with the beam expansion in fiber cladding (distance about 63 µm) and the adhesive. Adapting a Gaussian beam characteristic with a mode field diameter w, which can be described by

$$w = w_0 \sqrt{1 + \left(\frac{4\lambda_0 z}{\pi n w_0^2}\right)^2} \tag{1}$$

where z is the traveled distance of the beam with the vacuum wavelength λ_0 in the medium with the refractive index n and w_0 is equal to 10.4 µm for the SMF-28 fiber, results in an enlargement factor w/w_0 of about 1.27. This is in good accordance to the enlargement of the optimal width, following the measurements presented in Fig. 4.

IV. Conclusion

The presented packaging process allows the realization of compact, stable and efficient fiber links to silicon photonics. By using aperiodic grating couplers with backside reflectors fabricated in a 250 nm silicon on insulator technology, a record coupling efficiency of -1.38 dB is achieved. This is to the best of the authors' knowledge the highest presented coupling efficiency for a stable and compact optical interface using grating couplers and demonstrates the compatibility of the gratings to the customized coupling method. Analyzing the dependency of the coupling efficiency on the grating coupler width, results in an optimal width of about 17 µm, which is in good accordance to the measurements.

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