ePIXpack - Advanced Smart Packaging Solutions for Silicon Photonics

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Abstract. *We introduce two Silicon photonics packages to be used in future applications requiring multiple optical & electrical i/o. One package is based on a fiber array to assure small footprints. The other package provides configurable optical & electrical connectivity. Both packages are built using commercially available parts.*

Introduction

Silicon photonics is a rapidly advancing field with a strong potential for applications in integrated photonics. These applications comprise a wide spectrum ranging from optical sensors to optical data & telecom sub-modules. The most prominent merit of Silicon photonics is the use of highly advanced microelectronics process technologies. This allows for the fabrication of ultra-compact and low loss Silicon waveguide devices (photonic nanowires) in a CMOS-compatible fashion, opening the way for a true convergence of electronics and photonics.

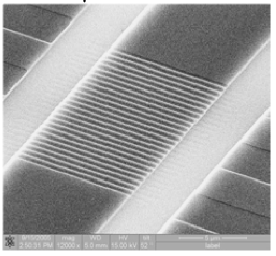
Nanowires pose a challenge for optical coupling to the outside world due to the large mismatch in mode size between conventional single-mode fibers (SMF) and the waveguides. Conventional butt-coupling techniques yield insertion loss figures in excess of 20dB, rendering such approaches infeasible in real applications. The problem has been researched intensively and various solutions have been proposed and demonstrated. Our work is based on coupling via waveguide gratings. Gratings offer clear advantages such as compatibility with planar processing, the possibility for wafer-level testing, and relatively large alignment tolerances. However, gratings also evoke the need for entirely new smart packaging solutions due to the effect of out-of-plane coupling. New approaches are required to handle issues of mechanical stability, and reliability while preserving at least partially the compactness of the underlying devices. At the same time, these approaches should be derived from micro-electronic packaging to keep costs as low as possible.

To be clear, the goal of this work was not the development application specific packages, but rather to study some generic aspects that will become of central importance in Silicon photonics packaging. In the following paper we shall introduce two new Silicon photonic packages. The first package offers a compact solution for an 8-port fiber array interface. The second package provides a generic and configurable optical & electrical interface to a standardized Silicon photonic chip. This chip is offered by the Silicon Photonics Platform of the European Network of Excellence ePIXnet [1]. Both packages are under development by the Photonic Packaging Platform ePIXpack [2], which is also one of the activities of ePIXnet.

Optical coupling to photonic wire waveguides via gratings

Coupling to silicon photonic wires through high-index contrast gratings is attractive because of the relaxed alignment tolerances compared to facet coupling while using standard single mode fibers. Because of the high index contrast, the grating can be short (25 periods) and achieve a relatively large bandwidth.

Simple one-dimensional grating couplers with a uniform fill factor, etched into a broad waveguide, achieve a coupling efficiency of around 30% with a 40nm 1dB bandwidth (per coupler) for a single polarization [3]. Detuned gratings with a coupling angle of 8º to 10º are used in order to avoid coupling to the wrong direction. The alignment tolerance for a 1dB loss penalty is over ±2µm.



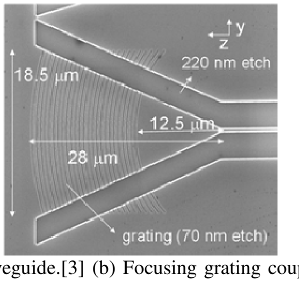
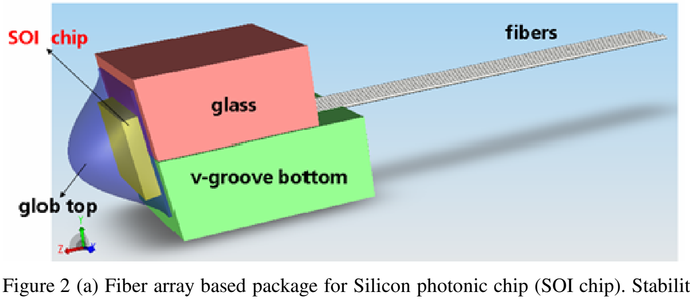


Figure 1: (a) Uniform fiber couplers etched in a 10µm wide SOI waveguide.[3] (b) Focusing grating coupler with similar efficiency but more compact footprint [5]

In addition, a two-dimensional grating coupler simultaneously splits the two incident polarizations and can be used in a polarization diversity scheme [4]. Simple 2D couplers achieve similar efficiency and bandwidth as one-dimensional couplers, but have a more strict alignment tolerance in order to achieve polarization independent circuits.
The grating couplers can be optimized in various ways to improve the efficiency or size. Focusing couplers achieve the same efficiency on a much smaller footprint, as with the regular coupler one still has to taper down the broad waveguide [5]. By using non-uniform fill factors, much lower coupling losses can be obtained. The efficiency can be further boosted by decreasing the vertical symmetry of the structure or adding bottom mirrors [3]. With an overlay, highly efficient couplers can be obtained that even couple light vertically instead of detuned [6].

Examples of optical & electrical packages

As packaging is necessary to achieve a reliable device on basis of the silicon photonic chips the challenge is to couple in the light into a fiber array maintaining the advantage of size and coupling efficiency. This so called interconnection bottleneck has to be overcome by a packaging concept providing standard optical interfaces. Alignment, reliability, standardization, and mass production suitability are the most important issues. Two first approaches using the standard sized chips described above are described in the following sections compact fiber array package. The compact fiber array package is a smart packaging approach for all optical functionality of the chip without any need of electrical wiring. The optical fibers are arranged in one row and serve as input and output fibers for the chip. A central requirement for Silicon photonics packages is compactness. Our first package focuses on this aspect. The concept is depicted in Fig. 2.



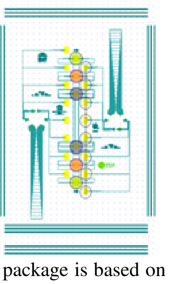
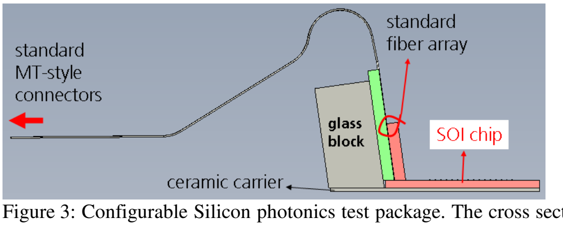


Figure 2 (a) Fiber array based package for Silicon photonic chip (SOI chip). Stability of the package is based on the actual fiber array mount, which consists of a V-groove bottom & a glass lid. The SOI chip contains a number of equally spaced grating couplers (optical i/o-ports). An example of a corresponding layout is shown in (b). The couplers are indicated by the circles shaded in color.

The package uses a commercial fiber array connector as a base to mount the Silicon photonic chip. Such arrays provide up to 32 i/o-ports without the need for a dedicated fiber array design. Glass lid and V-groove bottom are polished to provide the correct angle for coupling. The chip is sealed by an appropriate glob top encapsulation. A very compact package with multiple optical ports can be realized in this way.
A less compact but very flexible approach is taken for the second Silicon photonics package, which is depicted in Fig. 3.



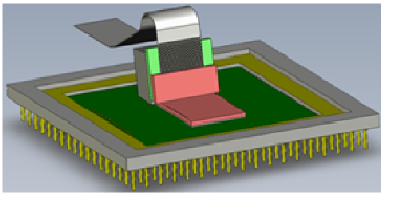
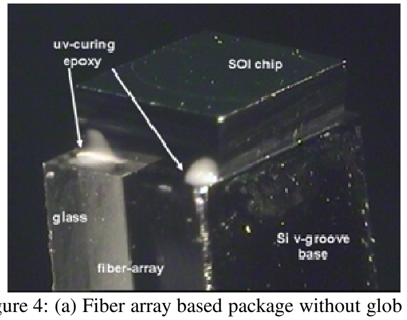


Figure 3: Configurable Silicon photonics test package. The cross section in (a) shows the ceramic carrier that acts as a base for the fiber array connector & the SOI chip. The carrier also contains the respective electrical fanout structures that route the connection to the underlying standard PGA (b).

The package can be configured to provide only electrical, only optical, or both electrical and optical connectivity. It is based on an SOI chip design, which uses standardized pitches for grating couplers and bond pads. The necessity of more generic & flexible test packages arises mainly in the R&D environment, where configurable electrical & optical connectivity is preferred to compact & qualified packages.

Experimental results

Fig. 4 shows a fiber array based package without and with glob top encapsulation. The SOI chip is mounted face down on the fiber array. The chip alignment is optimized by active alignment using two monitoring ports on the SOI chip. After active alignment the position of the chip is fixated by a UV-curing epoxy.



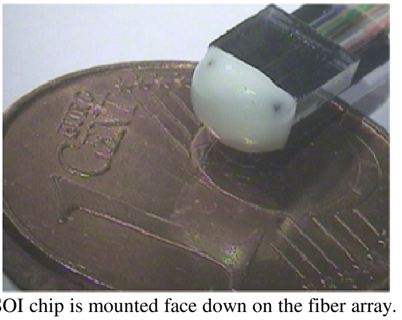
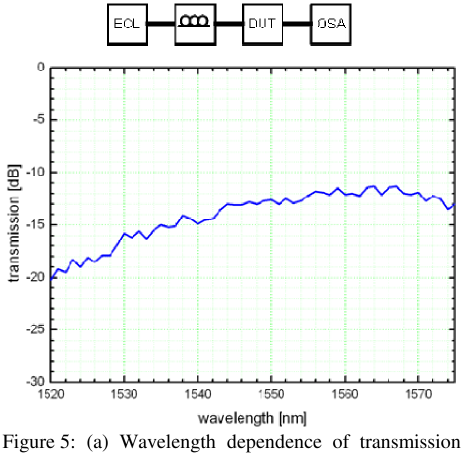


Figure 4: (a) Fiber array based package without glob top. The SOI chip is mounted face down on the fiber array. (b) Encapsulated SOI chip on fiber array (8 fibers) in comparison to 1 Euro Cent coin.

Our first experiment coupled to an array of 6 couplers that were cross-connected (i.e. shortened) in pairs by photonic wire waveguides. This configuration allowed for a simple test of the optical coupling concept. Fig. 5 (a) depicts the coupling characteristics of an aligned fiber in the package as a function of wavelength, which shows the wavelength dependence of the grating coupler. Fig. 5 (b) shows the transmission characteristics of the fiber-chip coupling in the dependence of lateral displacement of fiber array to the chip. Due to the fiber core/cladding concentricity <0.5µm and due to tolerances within the v-groove ±1µm, the coupling uniformity is expected to be <0.5dB.



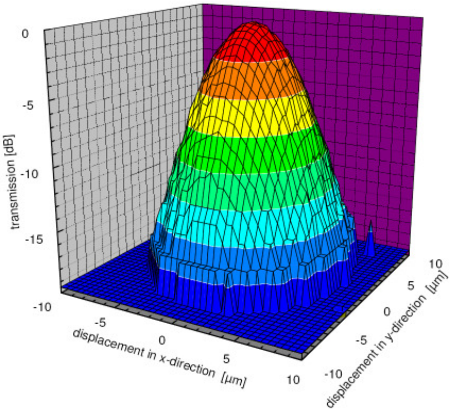


Figure 5: (a) Wavelength dependence of transmission through 2 shortened grating couplers. (b) Transmission characteristic of fiber-to-grating coupler in the dependence of lateral displacement.

Conclusions

Two new Silicon photonic packages have been presented. Both packages provide a solution for fiber array coupling to high-index contrast photonic wire waveguide gratings. Using standardized SOI chip designs and commercial assembly parts, the packages allow for small footprint or flexible use in an R&D environment.

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