Characterization of Optical Devices using a Pigtailed Fiber

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Abstract:

The hope of achieving integrated optical devices on-chip deals with how to couple light from off-chip sources into the optical devices. The coupling efficiency between off-chip fibers and on-chip waveguides was investigated in this project. We designed a small acrylic plastic base-holder to permanently hold the on-chip waveguides and two optical fibers with room curing epoxy, enabling a strong fiber-waveguide coupling. To minimize loss, the facets of the SU-8 waveguides were polished using aluminum oxide polishing paper. The waveguide and fibers were aligned and the coupling efficiency was measured using a cutback method. We found, for a wafer without the base holder, a coupling loss of 1.26 dB for a polished facet, 3.0 dB for an unpolished facet. Using these losses as a reference, we successfully pigtailed the wafer and fiber using the base holder with a loss of more than 20 dB.

Introduction:

Much of optical devices research focuses on the area of using on-chip waveguides to transport signals and information. The success of such devices relies on coupling these waveguides with minimal losses to off-chip fibers [1]. While low coupling losses using various tapering methods between the waveguide and fiber have been achieved [2, 3], we desire a device that can permanently couple the fibers onto the waveguide without inducing significant losses.

Losses due to coupling depend on the amount of overlap between the two propagating modes in the fiber and on-chip waveguide. By using a Gaussian description for the propagating modes, Joyce [4] found analytical approximations for misalignment. The misalignment tolerances (losses up to 1 dB) were calculated to be on the order of less than a few microns [5]. This important result drove much of the design and preparation of our fiber pigtailing device.

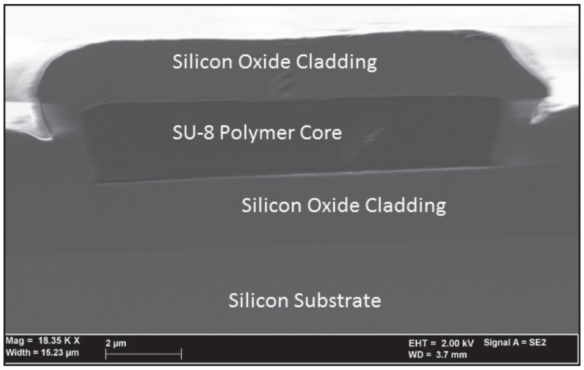


Figure 1: Polished waveguide facet.

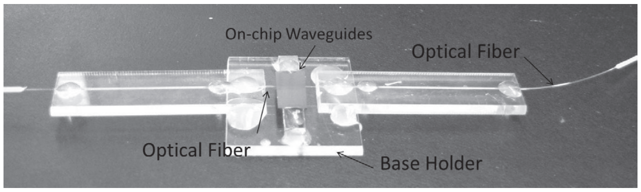


Figure 2: Fiber pigtailing device.

Methodology:

In order to measure the effectiveness of pigtailing, we fabricated on-chip waveguides. We used plasma enhanced chemical vapor deposition (PECVD) for silicon oxide deposition, and photolithography to define the shapes. The waveguides contained four layers: 1) a silicon substrate, 2) 2 μm silicon oxide layer, 3) 2.5 μm height SU-8 photoresist waveguide, and 4) a 2 μm top layer of protective silicon oxide. The chip was cleaved to reveal the edges of the waveguide for coupling and then the facets were polished down to produce smoothness on the micrometer-scale. Silicon carbide polishing paper of particle sizes 25.5 μm, 6.5 μm, 2.5 μm, and aluminum oxide paper of particle sizes

1 μm, 0.3 μm, and 0.05 μm, were used, from large particles to small. The resulting edge is seen in Figure 1.

The coupler itself is a simple plastic holder that secures in place the waveguide and the fibers on both ends. As shown in Figure 2, the chip and fibers rest on top of the plastic base with all components held down by a room temperature curing epoxy.

We glued down the silicon substrate, aligned the optical fibers for minimum transmission loss, applied epoxy under the fibers and realigned during the curing process. The measuring apparatus is described in Figure 3 and monitored in real-time. Once all the epoxy cured, the device can be detached from the laser and transported as a mobile device.

In order to determine how well the plastic holder held the silicon sample and fibers, we first determined the coupling losses of the on-chip waveguide to the optical fiber without the plastic holder. A cut-back method was employed to find the coupling losses for both a polished and unpolished sample.

Results:

We used a 100 μW mid-IR laser at 1540 nm wavelength to determine the coupling loss of the fiber and waveguide. Four different lengths of polished waveguides were measured and linearly fitted to find the propagation loss and coupling efficiency. A single length of unpolished waveguide was also measured and extrapolated to find the unpolished coupling efficiency using the same value for the propagation loss as found in the polished waveguides.

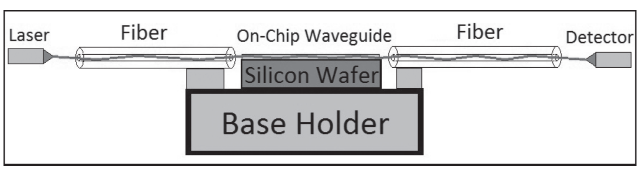
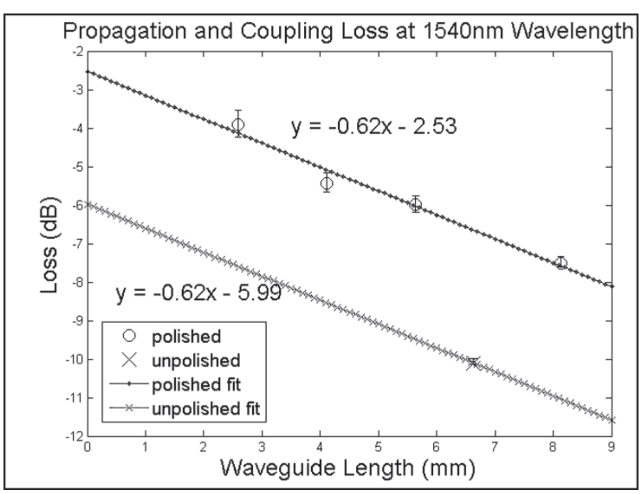


Figure 3, above: Measurement setup.

Figure 4, below: Cut-back data results.



The results, seen in Figure 4, show a propagation loss of 0.62 dB/mm and total coupling losses of 2.53 dB and 5.99 dB, or 1.26 dB and 3.0 dB per each of the two coupling sides, for the polished and unpolished samples respectively. We then successfully pigtailed our device using the plastic holder with a coupling loss faring two times worse than that of an unpigtailed device.

The misalignment during the epoxy curing is still significant, as we have found the epoxy dries to a point where alignment maneuverability was limited, yet still displaced the fibers during curing shrinkage.

Conclusions:

We successfully demonstrated the effectiveness of polishing waveguide facets in reducing coupling loss and a pigtailing device. The loss for a permanently pigtailed device is worse than a bare sample, but mobility and utility are invaluably gained, allowing for more complex experiments. Future work can address the misalignment problem in greater detail.

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