Grating Coupled Attachment of Optical Fiber Arrays for *in situ* Photonics Experimentation

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Abstract: We report a simple, vacuum-compatible fiber attach process for *in situ* study of grating-coupled photonic devices. The robustness of this technique is demonstrated on grating-coupled waveguides exposed to multiple X-ray irradiations for aerospace studies. © 2024 The Author(s).

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1. Introduction

In situ experimentation is essential to photonics research, allowing for real-time analysis of key properties and a deeper physical understanding of photonic integrated devices and circuits (PICs). For cross-over of photonics with other disciplines like microscopy, microfluidics, or tests in vacuum, the challenges of real-time, continuous fiber coupling become extremely difficult to manage. Often, devices must be probed repeatedly, monitoring between process steps or for repeatability. Spectral variation is inherent and must be considered when comparing results and the measure-step-measure approach is time consuming. Of the numerous approaches to coupling light on-chip, facet edge coupling and grating coupling are the most common. In general, grating couplers are more tolerant to fiber alignment but work only in a specifically designed, narrow wavelength band. Conversely, edge-couplers are easily designed and offer broadband coupling efficiency but require precise control over the fiber position to achieve coupling [1]. Further, while commercial fabrication of V-grooves to position fibers are well established and methods for secure attachment exist [2], V-grooves consume large footprints on chip and cannot be easily fabricated outside of commercial foundries. For *in situ* testing in academic settings, grating couplers provide key benefits of alignment stability, small footprint on-chip, and the ability to be fabricated in any photonic process comprised of a guiding medium and oxide substrate. Some solutions exist for commercial attachment of fibers to gratings, but these options are expensive and time-consuming, necessitating a straightforward and cost-effective approach that can be performed in the lab.

Here we report a simple, vacuum-compatible fiber attach process that couples optical I/O from a single mode fiber array to on-chip gratings with an additional insertion loss of only 2 dB on average compared to free-space alignment. We analyze the robustness of this attachment method through the lens of radiation effects research on integrated photonic components, where a fiber-attached, wire-bonded, fully-portable package opens the door to *in situ* studies of performance degradation mechanisms in harsh environments. Understanding sensitivities of photonics due to radiation is critical to enabling their application in space missions, high-energy particle colliders, and defense systems where radiation exposure is substantial. Notably, the fiber-attach process reported here is widely applicable and can also benefit molecular sensing, nanotweezing / trapping, waveguide-coupled quantum source characterization, near-field optical or atomic force microscopy, and heterodyned spectroscopy techniques [3–6].

2. Fiber Attach Methodology, Experimental Results, and 10-keV X-ray Irradiation

Fig. 1(a, b) shows 20x magnified photographs of an epoxy block fiber array attached to a photonic chip. As indicated in red, the device layout specifies grating positions 2 mm away from the device under test, ensuring that the device and its electrical contacts are uninhibited by the fiber array or the securing epoxy. Here, the fiber array is commercially sourced from Meisu Optics; the individual fibers are equally spaced to match the device under test grating coupler pitch (127 μm) and the encasing fiber block is cleaved to the angle of optimal grating coupling to rest normal to the chip surface. The fiber array is aligned to the desired adjacent I/O on-chip, maximum coupling is achieved by adjusting all six degrees of freedom, and the polarization is optimized using standard single mode paddles. At this point, the fiber is lifted directly upward, and a small bead of vacuum compatible epoxy (Masterbond UV10TKLO-2) is applied on the grating I/O using a Nordson EFD Ultimus I epoxy dispense system. The fiber is lowered again, and optimal alignment is achieved while the fiber array is submerged. Next, the fiber is tacked using an ultraviolet (UV) "pocket flashlight" spot cure, repeated in ~1 second intervals. Support epoxy is added adjacent to and behind the fiber array to provide structural integrity in steps (add epoxy, UV spot cure, repeat), taking care that the position of the fiber is kept stationary. Finally, the fiber array is baked in an oven at 100 ºC for one hour to remove remaining moisture.

Fig. 1(c) shows the transmission spectra of a fiber-attached grating pair configured in a loopback scheme. These devices were taped out using the GlobalFoundries Fotonix™ process design kit [7]. Three repeated measurements are taken after each process step: pre-cure, submerged in epoxy (blue), after the UV spot cure exposure (orange), and after the 100 ºC thermal bake (green). While no transmission intensity is lost during the spot cure, approximately 2 dB of loss is noted after the thermal bake. Since the epoxy constricts and expands to naturally fill space as it is cured, this loss in transmission is somewhat stochastic, but generally remains within 1-3 dB. Before the fiber is attached, more than 5% variation in the maximum transmission intensity is noted across the three sequentially repeated measurements (taken across ~6 minutes total), which can be attributed to drift of the fiber position over time and the use of standard single mode fibers. This variation is effectively removed after the curing process, as seen by the overlapping spectra.

Figs. 1(d-e) show the cumulative effects of total ionizing dose using 10-keV X-ray exposure on the fiber attached loopback. Stepwise spectral measurements at four different total ionizing doses (Fig. 1(d)) as well as continuous measurements at a single wavelength (1550 nm) during X-ray exposure (Fig. 1(e)) were carried out with the fiber attached chips inside the X-ray chamber. Due to space constraints, these measurements would not be possible without employing a fiber-attach method. For both types of measurements, the total experimental variation was much less than 1%. We derive two important conclusions from these results. First, by comparing Fig. 1(c) and Fig. 1(d), the transmission variation intrinsically associated with non-packaged fiber-to-chip coupling is essentially removed. Second, building from prior work that suggests silicon waveguides and optical fibers are very tolerant to ionizing effects [8], we can now additionally conclude that our fiber-attach approach is tolerant to ionizing effects. Because the fiber attach scheme employed here drastically reduces experimental variance and is not affected by X-ray irradiation, any radiation-induced changes in the performance metrics of fiber-attached photonic integrated circuits in future studies can be exclusively attributed to the specific active photonic devices on the chip.

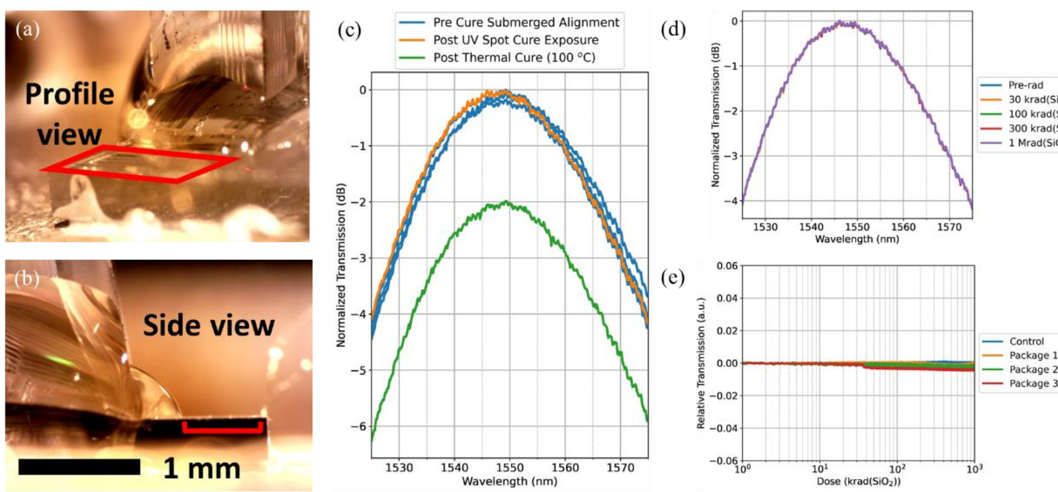

Figure 1. Photographs of (a) the profile view and (b) the side view of a fiber attached grating coupled photonic die. (c) Transmission spectra from a loopback taken during alignment (blue), after ultraviolet spot cure (orange), and after thermal cure (green). Three repeated measurements are plotted for each step and show a marked decrease in experimental uncertainty with only 2 dB of additional loss noted from the curing process. (d) Step-stress and (e) continuous 10-keV X-ray irradiation experimental results with (d) the loopback wavelength spectrum and (e) the change in transmission at 1550 nm tracked up to 1 Mrad(SiO_2) at a dose rate of 28 krad(SiO_2)/min. for a total of 35.5 minutes.

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