Direct laser writing of tapered polymer probes for flexible fiber-to-device coupling and wafer-scale optical probing

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Progress in integrated photonics technologies has brought ultra-small devices, like photonic crystals and microring resonators, to the forefront of technology. In microelectronics, the use of metallic probes for in-situ wafer-scale testing can increase fabrication yields and enable rapid prototyping; yet attempts to emulate this functionality within standard top-down planar photonics fabrication processes have required a significant number of processing steps and usually suffer from high overall transmission losses[1]. In contrast to planar fabrication, direct laser writing (DLW) has become a popular fabrication technique for miniaturized three dimensional (3D) structures like freeform micro-optics[2], photonic wire bonds[3], and atomic force microscopy tips[4]. In this work, we use DLW to fabricate tapered polymer probes (TPP) with minimum diameters of $d \approx 1$ μm on the facets of optical fiber arrays. Our miniature TPP offers more design flexibility and control than alternatives like traditional dimpled pulled tapered fibers[5], without specialized fabrication steps. Due to its small size, our device is compatible with the rapid, flexible, and nondestructive optical characterization of on-chip devices.

The design of a TPP (Fig. 1) consists of two adiabatically tapered regions (green) that lead to a long suspended waveguide (red) of minimum diameter d, where d is chosen small enough (e.g., 1 μm) to enable evanescent coupling between the suspended waveguide and a device under test. While polymerization of the probe is straightforward, removal of uncured photoresist usually leads to structural deformation (Fig. 2a) of the suspended waveguide due to meniscuses (Fig. 2b) formed by the surface tension (σ) of the solvent between the suspended waveguide and the rest of the structure. To overcome this issue, two solutions are explored: (1) the use of auxiliary structures to prevent the formation of a meniscus (Fig. 2c), and (2) the use of low σ solvents to reduce the force exerted on the suspended waveguide. Probes with meniscus-breaking structures showed greatly reduced levels of distortion (Fig. 2d) and supported geometries with $d \approx 2$ μm. For $d < 2$ μm the low σ solvent Pentane was used to further reduce the geometric deformations. Doing so, we routinely create suspended waveguides with $d \approx 1$ μm, and the use of low σ solvents is being further explored to increase design flexibility (e.g., overhang length, $d < 1$ μm, etc.). At the smallest achieved $d \approx 800$ nm, geometric distortions arise due to the fragility of the thin waveguide (Fig. 3). Fabricated devices are currently being tested, and measurements will be presented.

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[1] Michels, T. & Aksyuk, V. *IEEE Photonics Technology Letters* **29**, 643–646 (2017)
[2] Dietrich, P.-I., *et al.*, *Nature Photonics* **12**, 241–247 (2018)
[3] Lindenmann, N. *et al. Optics Express* **20**, 17667 (2012)
[4] Glia, A., *et al. Advanced Science* 2201489 (2022)
[5] Michael, C. P., *et al.*, *Opt. Express, OE* **15**, 4745–4752 (2007)

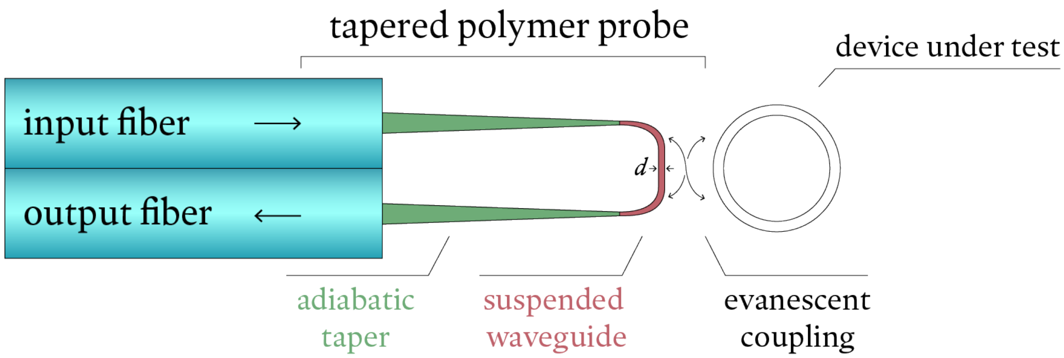

Figure 1: Schematic diagram of a tapered polymer probe (TPP) fabricated on the end facet of a 2-fiber array. The TPP is fabricated out of photoresist and consists of an adiabatic taper region (green) and a suspended waveguide (red) of small diameter (d) to enable evanescent coupling to an on-chip device under test. The resists used for the TPP in this study are IP-Dip and IP-S (certain commercial products or names are identified to foster understanding. Such identification does not constitute recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the products or names identified are necessarily the best available for the purpose).

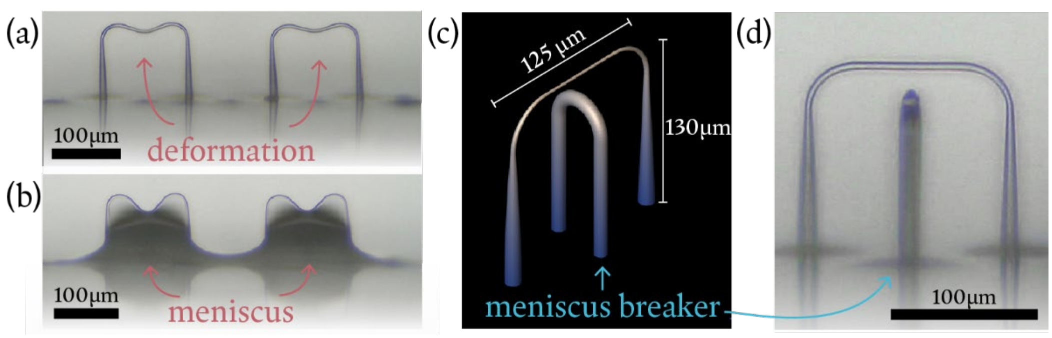

*Figure 2: **(a)** Using standard DLW development processing, long, thin, overhung features experience geometric deformation. **(b)** The distortions are caused by meniscuses formed by the surface tension of solvents between the suspended waveguide and the rest of the structure. **(c)-(d)** Using an auxiliary meniscus-breaking structure is effective at suppressing deformations.*

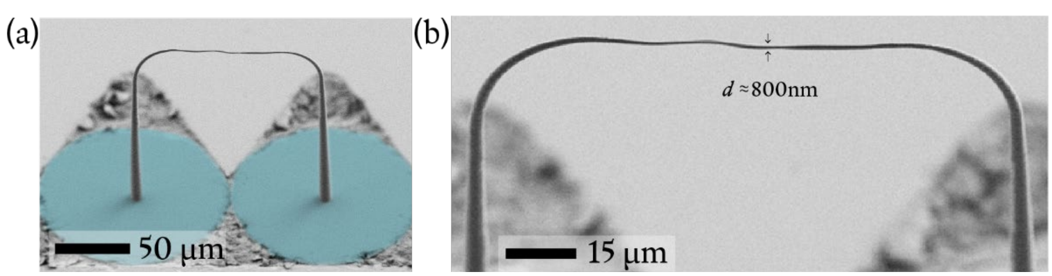

*Figure 3: **(a)** Scanning electron microscope micrograph of a tapered polymer probe fabricated on the end of two SMF-28 fibers (blue) held in place by v-grooves. **(b)** The suspended waveguide does not display the geometric distortions caused by meniscuses, but the small $d \approx 800$ nm leads to ribbon-like distortions.*