Functionalized optical fiber tips for ultra-short range interconnections

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Miniaturization is one of the big trends that we can identify across many scientific and technological research domains. This is also the case in the world of optics and photonics, where a reduction of the footprint and cost of components is often desired. One particular application area is that of optical interconnections. Single-mode optical fibers are widely used in optical communication and sensor systems for their small size, immunity to electromagnetic interference, low signal loss and high capacity. At the input and output of such fibers, different types of optical components can be used to guide the light into the right direction as efficiently as possible. Examples of such components that have been developed are gratings (to split different wavelengths into different directions, used in wavelength division multiplexing systems), couplers (to couple or split the light to other fibers and components), lensed components (to focus or collimate the light beam for better free-space propagation and coupling performance), tapered components (to expand or decrease the beam size) and many more. Mostly, these components are made from several discrete optical elements put together to obtain the desired functionality. In recent years however, a 3D direct laser writing fabrication technology based on two-photon polymerization (2PP) is gaining interest due to the combination of full 3D design freedom and sub-micrometer resolution [1]. In this work, we present the design, direct laser fabrication, and proof-of-concept demonstration of various optical elements such as mode conversion tapers, micro-lenses, and diffractive elements directly integrated on the fiber tip, resulting in extremely compact components with high optical performance for short-range optical interconnections.

We used dedicated optical simulation tools (i.e. Lumerical Mode and FDTD solvers) to model a standard telecom single-mode optical fiber and design adiabatic mode conversion tapers that can efficiently increase or decrease the mode size over an order of magnitude (i.e. reaching mode-field diameters > 20 µm and < 1.8 µm, respectively, starting from the standard telecom fiber mode-field diameter of 10.4 µm at a wavelength of 1550 nm) by optimizing the taper's geometry. As such, we developed a range of step-index and microstructured waveguide geometries, with linear or nonlinear taper profiles (see Fig.1 (a)) and demonstrated that their optical performance in alignment-tolerant fiber-to-fiber connections and fiber-to-chip coupling to various generic photonic integrated circuit platforms (see Fig.1 (b)) was in line with our simulation results [2,3]. Next, we developed an alternative fiber beam expansion and collimation strategy based on micro-lens components, of which the lens profile was optimized using beam propagation simulations in the Zemax software, to reach a relaxation of the 3 dB lateral misalignment tolerance from 4.5 µm for a standard single-mode fiber connection, to 29.8 µm for our expanded beam lensed fiber connection (see Fig.2). Finally, we investigated the creation of an ultra-short-range fiber optic beam splitter by directly printing a diffractive optical element (DOE) on the fiber tip. By using the Iterative Fourier Transform Algorithm, we were able to optimize an 8-level quantized diffractive optical element for the 1-to-7 beam splitting of an input Gaussian beam emitted by a standard single-mode fiber over a short distance of only 61 µm. In order to reach the desired power splitting performance, we needed to increase the resolution of the diffractive element (i.e. the amount of phase modulating pixels). To this end, we used our microstructured up-taper components to increase the mode size at the input as shown in Fig.3, allowing to increase the size of the diffractive element. The pixel size on the other hand is determined by the minimal feature size that can be obtained with our printer system (i.e. about 200 nm).

As illustrated by our beam-splitting component, the two-photon polymerization technology allows to monolithically integrate multiple optical elements on the fiber tip in a single fabrication process. Our developed taper, lens, and diffractive structures can therefore be used as fundamental building blocks for the development of more complex functionalized fiber tips and other interfacing components for short-reach interconnects.

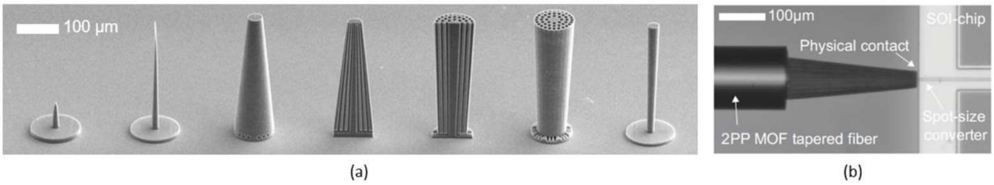

Fig. 1. (a) Scanning electron microscope image of the tapered waveguide elements fabricated by two-photon polymerization (2PP)-based direct laser writing on a glass substrate. From left to right: nonlinear air-clad down-taper, linear air-clad down-taper, microstructured (MOF) down-taper, cross-section of the MOF down-taper visualizing the internal air hole distribution, cross-section of the MOF up-taper, MOF up-taper, and linear air-clad up-taper. (b) Microscope image of a MOF down-taper printed on a fiber tip and coupled to a silicon-on-insulator (SOI)-chip with spot-size convertors.

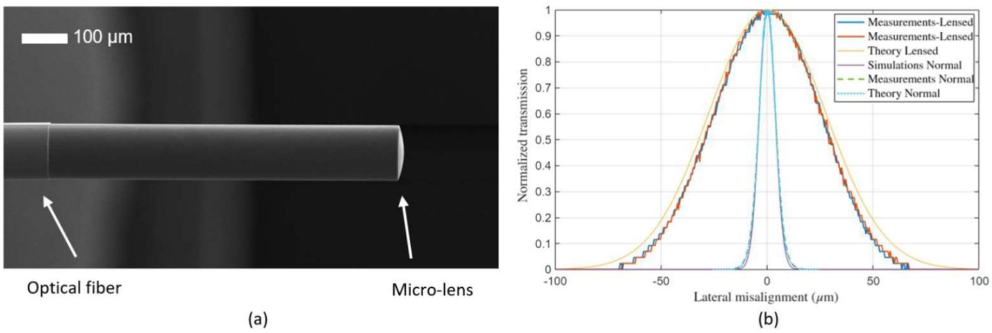

Fig. 2. (a) Scanning electron microscope image of a micro-lens fabricated by (2PP)-based direct laser writing on the tip of a standard optical fiber. (b) Measurement results of lateral misalignment tolerance experiments, comparing a normal fiber connection between 2 standard optical fibers with our expanded beam lensed fiber connection.

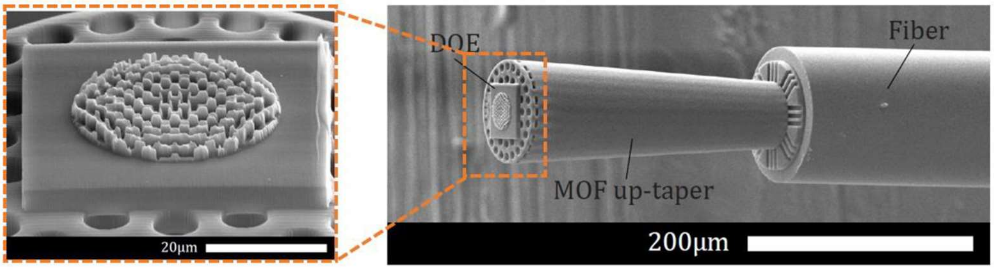

Fig. 3. Scanning electron microscope image of a diffractive optical element (DOE) on top of a microstructured (MOF) up-taper, monolithically printed on the tip of a standard optical fiber for beam splitting applications.

References

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