Optical Fiber Tips for Nanoscopic Applications

Jörg Bierlich, Jens Kobelke, David Brand, Konstantin Kirsch, Jan Dellith, Hartmut Bartelt

Institute of Photonic Technology
Albert-Einstein-Str. 9, 07745 Jena, Germany

mailto: joerg.bierlich@ipht-jena.de

In this work, we present technological studies on the preparation and characterisation of chemically etched predefined optical fiber tips for spectroscopic and micro-/ nanoscopic applications.

1 Introduction

Silica-based metal-coated fiber tips (tapers) are used in a variety of spectroscopic and micro-/ nanoscopic applications (e.g. AFM, SNOM, TERS). The optical resolution of such measurement systems is dependent on the diameter of the tapered fiber end, which allows only a few 10 nm. In addition to taper drawing processes the tip shaping of the multimode glass fibers is done primarily by wet-chemical etching usually in hydrofluoric acid [1-3].

In the present study we investigated the possibility of the preparation of geometrically predefined, nanoscaled fiber tips by taking advantage of the step- and gradient-shaped concentration profiles of highly doped silica fibers. For this purpose a gas phase etching process using hydrofluoric acid (HF) vapor was applied. The advantage of this approach is that all reaction products are obtained in a gaseous form and therefore surface condensation which often leads to etching inhomogeneities can be avoided.

2 Influence on the etching kinetics

The shaping of the fiber tips base on very different etching rates depending on the etching treatment and doping characteristics of the optical fibers. Technological investigations on the influence of the etching gas atmosphere on the time course of the tip shaping and the final geometry were performed on undoped silica fibers. For this purpose, the glass fiber samples with a typical diameter of 125 µm were positioned in the gas phase 2 mm above the fluid level of 40 % hydrofluoric acid (Fig. 1 inset). The reaction vessel was separated from the environment by an adjustable gas orifice to realize different opening states and thus etching gas atmospheres.

Independent of the gas orifice setting the etching rate has a maximum at the origin of the fiber tip and decreases specifically along the fiber with opening the orifice as well as deaeration of the etching gas atmosphere (Fig. 1). By enlarging the gas orifice, the formation of the fiber shaft geometry from decreasing linearly to parallel-running and fiber tip angles of 0.05° to 5° can be adjusted reproducibly (Fig. 2). Thereby, the etching time (t_e) to form a fiber tip varies significantly from 3 h to 12 h. With an increasing process time, a growing damage of the fiber surface was observed leading to the deterioration of the mechanical stability of the already fragile fiber tip.

3 Influence of the doping characteristics

The influence of the doping characteristics was investigated in phosphorus-, germanium-, fluorine- and boron-doped glass fibers. The fiber samples were drawn from doped MCVD-performs which differed in doping profile and dopant concentration. As an example Fig. 3 shows the refractive index

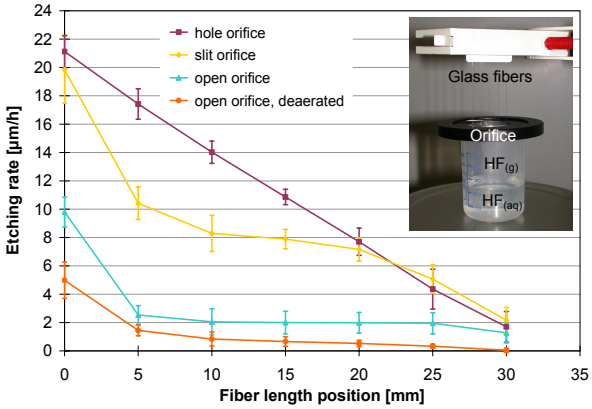

Fig. 1 *Different etching rates along the axial fiber position depending on the gas orifice setting. Experimental etching setup (inset).*

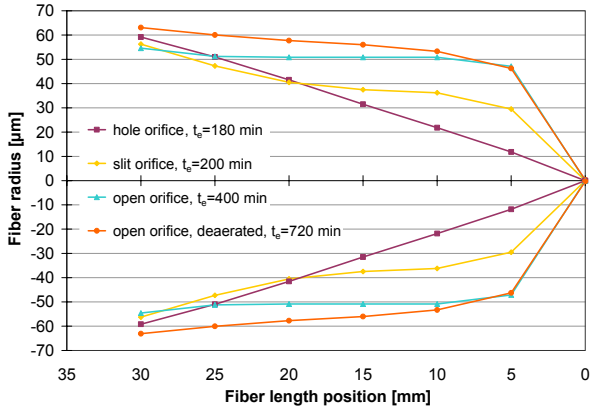

Fig. 2 *Various fiber tips shapes depending on the etching conditions. Thereby, the process time (t_e) to shape a fiber tip varies significantly from 3 h to 12 h.*

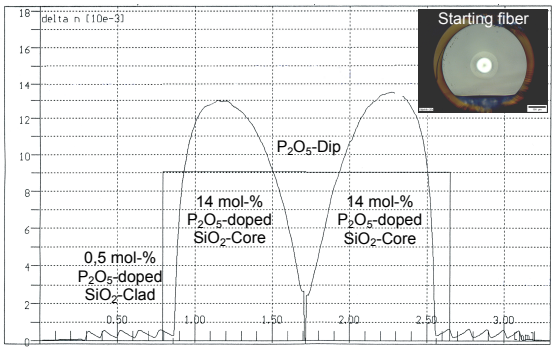

Fig. 3 *Radial step index profile of a phosphorus-doped glass prefrom showing the typical central dip. Cross section of the resulting glass fiber sample (inset).*

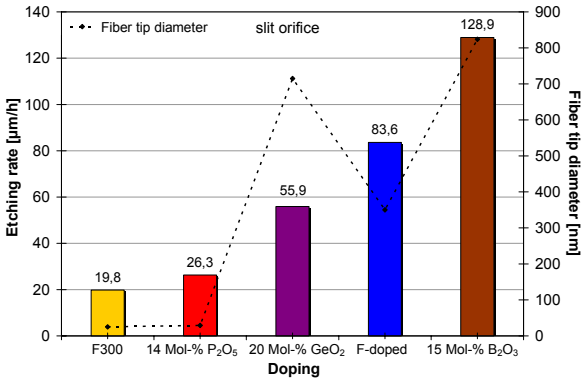

Fig. 5 *Influence of different fiber core dopants on the etching rate in comparison to an undoped glass fiber (F300) and the achieved fiber tip diameters.*

profile and the associated doping characteristics of a P_2O_5-doped step index perform and the starting fiber, respectively. The highly P_2O_5-doped SiO_2-core shows an undoped central dip due to the finial perform collapsing step during the manufacturing.

The predefined geometric shaping of the fiber tips are based on the specific etching rates of the differently doped glass structures. Here, the etching behavior correlates with the doping-dependent refractive index profile of the fibers (Fig. 3). Pure silica glass (F300) shows a low etching rate whereas the tested dopants increase the etching rate significantly (Fig. 5). Strong etching gradients take effect in the region of the central index-dip, since the dopant concentration is reduced to zero and therefore the etching rate is minimized. The achieved fiber tip diameters and tip angles tend to decrease with a lower etching rate (Fig. 5).

Narrow fiber tips in various shapes and tip radii down to less than 15 nm were achieved with pure silica and P_2O_5-doped glass fibers. Exemplary Fig. 4 and Fig. 6 show different prepared fiber tips from P_2O_5-doped fiber samples. The protected internal fiber tip structures are being considered as a fiber micro-reactor coupled with a tip sensor.

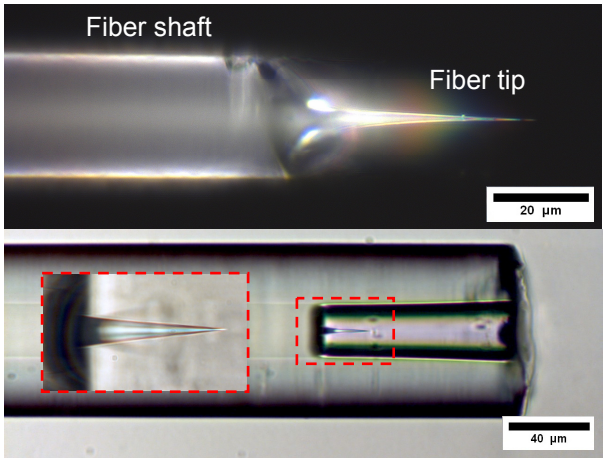

Fig. 4 *Optical micrographs of etched fiber tips. Typical exposed glass tip (above) and an optical fiber probe with a protected internal fiber tip (below).*

4 Metallisation of the glass fiber tips

For investigations on coating of planar surface plasmon resonance structures the fiber tips were coated with nanometer-sized silver layers (40 nm in thickness) by means of vapour deposition. Finally the metal layers were subjected to a high temperature annealing treatment to convert them into a droplet structure (Fig. 6 inset). Characterized by heated probe microscopy the droplet formation occurs at temperatures above 900 °C due to surface tension effects of the melting phase. However, silver has low adhesion to glass and is therefore easily removable. To improve the adhesion, a TiO_2 intermediate adhesive layer is conceivable.

Acknowledgment

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References

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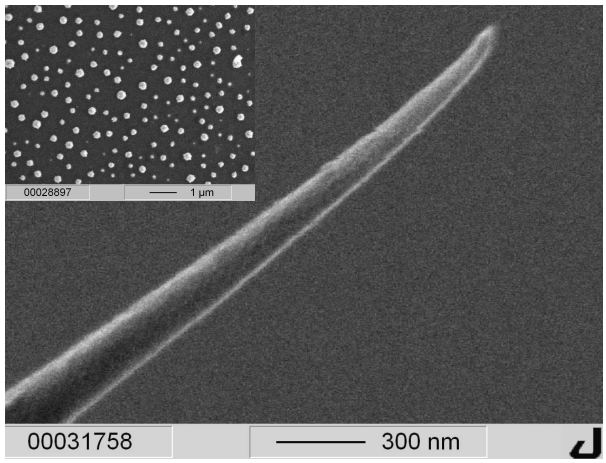

Fig. 6 *SEM image of a narrow glass tip etched from a P_2O_5-doped fiber sample. Droplet structure on the fiber surface after annealing of a 40 nm thick Ag layer (inset).*