Fabrication of Microstructured Fibers Using an Effect of Pressure Self-Regulation in Sealed Holes

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Abstract: Theoretical aspects of drawing the holey preform with sealed holes at the top end are discussed. Experimental results on drawing in such a regime are presented.

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Microstructured fibers (MSF) are now becoming an integral part of high-end fiber lasers exploiting the unique properties of such highly nonlinear silica fibers with applications including compensation of material dispersion around 1 μm, generation of supercontinuum radiation and efficient four-wave mixing processes in both visible and IR spectral bands. All those effects rely heavily on thedispersion properties of MSF which are in turn dictated by the size, position and longitudinal uniformity of holes in MSF. Because of the effect of surface tension the holes tend to collapse during MSF drawing from a pre-arranged preform. The most widely used method to stop holes from collapsing is based on the use of external pressure to cancel out negative impact of the surface tension.

In this paper we discuss an alternative approach of self-regulated passive pressurization [1] when holes are sealed at the top end of the preform whereas the bottom end stays open to the air. In this arrangement the internal pressure within the MSF preform holes slowly builds up during the fiber drawing process and eventually prevents collapse. With improved understanding, we are able to produce long lengths of uniform MSF's.

At the beginning of the preform drawing, the internal pressure is low enough to prevent complete hole collapse. However during the drawing the volume of air in the preform decreases resulting in steady growth of internal pressure. This process continues until the pressure overcomes the surface tension and then starts to dominate resulting in expansion of the holes. This continues until the internal pressure and the surface tension effect balance each other. It can be shown that the internal hole pressure is self-regulating such that the ratio of the silica glass area to the area of the holes is constant.

This method of drawing MSF was modeled under the assumptions that the preform length is greater than the drawing furnace length, the draw temperature is $\boldsymbol{T_d}$ and the preform temperature outside the furnace is $\boldsymbol{T_p}$. Simple physical consideration indicates that in the steady-state condition, the volume of the holes in the drawn fiber exceeds the volume of section of the preform (from which the fiber was drawn) approximately by factor ($\boldsymbol{T_p/T_d}$). In other words when the sealed perform end situated over the entrance to the furnace is at room temperature (~300^{o}K) and the drawing temperature is ~2100^{o}K, then the ratio of relative cross-sectional area of the holes in the preform and in the fiber should be equal to ~7, i.e. relative diameter of the holes in the fiber should increase by factor $7^{1/2}$~2.7.

In order to verify the results of computer modeling we have drawn a fiber from a preform with 6 small holes in the center as it is shown in Fig.(1a) and compared it to cross-sections in the fiber at a length of 300 m (Fig.1b) and 700 m (Fig.1c). As it is seen the holes area in fiber is approximately seven times larger than that in the preform and the fiber cross section is constant over length greater than 300 m.

In conclusion, we have described a method of passive pressure self-regulation in fabrication of microstructured fibers. Our results demonstrate good uniformity of microstructured fibers drawn using this technique. This simple and practical approach can be also used when a fiber with different hole size is required.

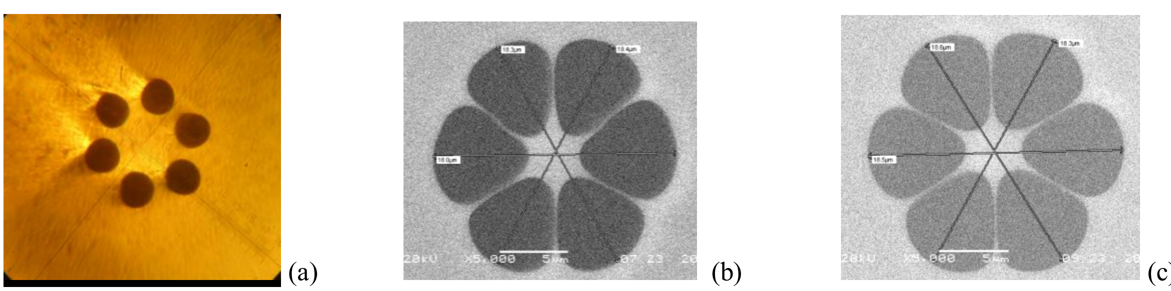

Figure 1. Central part of cross-sectional area of initial prefrom (a) and drawn fiber in different places (b) and (c)

References

[1]. D.J.DiGiovanni et al, US Patent 5,802,236, Sep. 1, 1998