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Long length/small core step-index silicon core fiber fabricated by improved powder-in-tube process

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The development of silicon-core fibers have drawn strong interest over the last decade. Indeed, silicon is a material offering interesting properties such as mid-wave infrared transparency (1-7 μm), high refractive index (3.48 @ 1.55 μm) and large third order non linearity ($\approx 1.5 \times 10^{-13} \text{ cm}^2/\text{W}$). Until now, three fabrication processes have been developed to achieve glass-clad silicon-core fibers: the high-pressure microfluidic chemical deposition method [1], the molten core method from silicon rods [2] and the powder-in-tube method [3]. This last one shows a very high potential to achieve hybrid optical fibers as it allows not only to use a wide range of materials but it is also compatible with the stack-and-draw process ; in this way, many different designs of fibers can be especially drawn. Unfortunately, fibers fabricated by this method are very short, only a few centimetres long because of the mechanical stresses accumulation at the interface between the two materials which have different thermal expansion coefficients (Si : $3 \times 10^{-6} \text{ K}^{-1}$; SiO_2 : $5 \times 10^{-7} \text{ K}^{-1}$), and because of the presence of air between the grains.

For the first time to our knowledge, we present the fabrication of a 50 meters long silicon core fiber with a 5 μm core, thanks to a modified powder-in-tube process: a consolidation step has been added during the process in order to control the expansion and the powder density of the silicon. This additional step consists in heating the silicon powder in the preform while controlling the pressure, in order to remove the air trapped between the grains. This consolidation step is carried out in situ, in the drawing tower furnace. The preform, which consists in a silica tube sealed at one end and loaded with silicon powder, is installed in the mandrel. The preform is then heated at a consolidation temperature which is set slightly above the melting temperature of the silicon ($T_{\text{conso}} = 1420^\circ\text{C}$) under 100 mbar pressure, while moving from the bottom up at a constant speed of 50 mm/min.

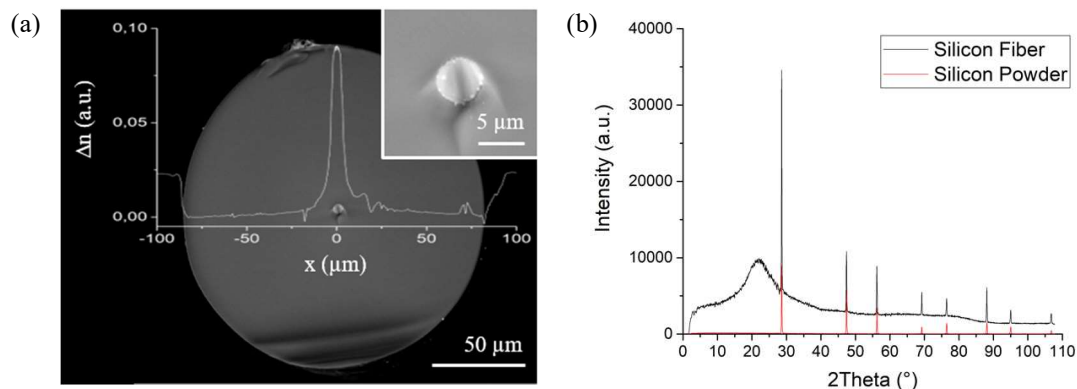


Fig. 1 (a) Scanning electron microscope (SEM) picture of a silicon-core/silica-clad optical fiber drawn using the modified powder-in-tube method (cross-section) with overlaid index profile. Inset: zoom on the core. (b) X-Ray Diffraction (XRD) pattern of silicon powder and of the as-drawn fiber crushed

The SEM picture (Fig. 1(a)) shows the cross-section of the as-drawn fiber. The fiber with a diameter of 170 μm exhibits a good core/clad concentricity, a good circularity of the core and a clean core/clad interface as can be seen in the inset. The index profile superimposed to the SEM picture matches perfectly the fiber geometry and confirms the index step between the two materials. Fig.1 (b) presents the XRD patterns of the drawn silicon fiber (black line) compared to the silicon powder (red line). On the black line, the amorphous hump around 20° corresponds to the silica clad. The results show that there is no 2θ shift between the two diffractograms. These values also fit those indexed in the JCPDS card 002.0561 corresponding to crystalline silicon. These results confirm that there is no residual stresses in the silicon core. Moreover, the narrowness of the peaks indicates a high degree of crystallinity of the core material composed of large grains.

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