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Picometer-resolution and high dynamic-range profilometer for hollow-core fiber surface roughness characterization

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While the cladding design of inhibited-coupling hollow-core photonic crystal fibers (IC-HCPCF) sets their transmission performance in the infrared wavelength range ($\lambda > 1 \mu\text{m}$), the limiting factor in their transmission loss at shorter wavelengths is set by surface scattering loss (SSL) [1]. As the SSL depends on the HCPCFs' core surface roughness (SR) arising from thermally-induced surface capillary waves (SCW) occurring during fiber drawing, the characterization of its core surfaces, achieved by either atomic force microscopy (AFM) [2] or optical profilometry [3], becomes of paramount importance.

Here, we report on surface roughness results obtained by a picometer-resolution and high dynamic range profilometer with the ability to assess the surface of selected sections from different HCPCF microstructures. In particular, we measure the roughness of the inner and outer surfaces of the cladding silica core surround of different HCPCF designs and tubular IC-HCPCFs fabricated by the novel method reported in [4]. Fig. 1(Ia) shows schematically the optical "pico-profilometer" [5]. Our profilometer shows a sensitivity of $2 \text{ pm}/\sqrt{\text{Hz}}$ (Fig. 1(Ib) and Fig. 1(Ic)) and a dynamic scanning range of more than 2.5 mm (Fig. 1(Id)) and (Fig. 1(Ie)). Fig. 1(II) summarizes the measurement of longitudinal SR of the two sides of glass membrane of a core-surround of different HCPCF as illustrated in Fig. 1(IIa). The inner surface of cladding hole is shown in blue and the outer surface in green. The discrimination between the two sides was achieved by filling the fiber core or the cladding holes allowing us to measure the inner or outer surfaces of the cladding elements, as identified Fig. 1(IIb) shows in box chart format the measured RMS of the SR of the two surfaces of a glass membrane of a tubular, Kagome and photonic bandgap (PBG) HCPCF respectively. The results show comparable RMS with an average in the range of 0.3-0.4 nm, in consistency with the thermodynamic limit [2]. Fig. 1(IIc) shows the case for tubular HCPCFs fabricated by a new process which allows roughness reduction by increasing shear stress on the surface [4]. The results corroborate this effect for both sides with RMS average of 0.25 nm for inner side and of 0.15 nm for the outer side. The difference in SR between the two side is due to the difference in the shear stress during the draw. Fig. 1(II d) displays the record low loss values attained by these HCPCFs (symbol) to illustrate the impact of such SR reduction. Noteworthy, they lie beneath the silica Rayleigh scattering limit (dashed line) and stand out as the lowest loss fiber optics in the visible and ultraviolet ranges [3], opening the way to new applications.

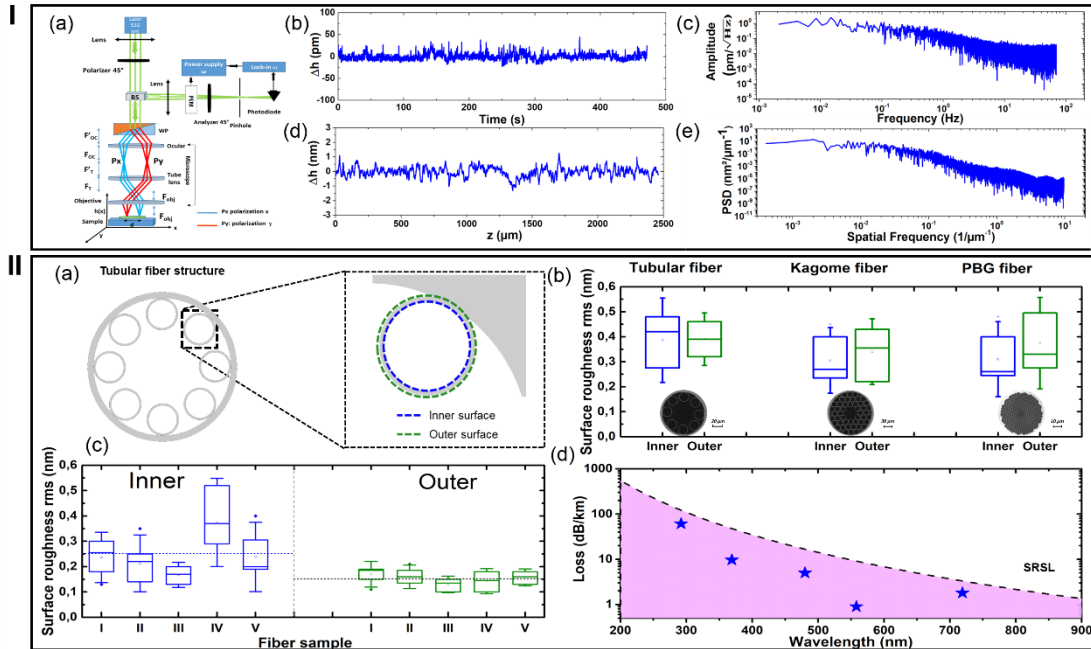


Fig. 1 I(a) Optical profilometer system; I(b,c) sensitivity of the optical profilometer in time and frequency domain; I(d) Typical core surface roughness profile (Δh : roughness height variation); (e) Power spectrum density of the profile; II(a) Identification of inner / outer surfaces of a cladding tube in a tubular HCPCF; II(b) rms roughness of different HCPCF designs; II(c) of different samples of tubular HCPCFs and II(d) New state-of-the-art IC HCPCF loss.

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