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INHIBITED-COUPPLING HOLLOW-CORE FIBERS : NEW HORIZONS

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ABSTRACT

This communication will *review* our recent developments in inhibited-coupling hollow-core fibers, ranging from understanding the optical guiding mechanism to new state-of-the-art performances. These results are expected to have strong impacts in a new landscape of research and technology.

KEY WORDS : *hollow-core fibers ; photonic crystal fibers ; inhibited-coupling.*

1. INTRODUCTION

The recent advances in inhibited-coupling (IC) hollow-core photonic crystal fibers (HCPCFs) science have much contributed to the comprehension of their guidance mechanism and provided new insights on fiber design activities. Such efforts entailed remarkable results on IC HCPCFs performances and consolidated them as an enabling technology for both fundamental and applied fields [1]. Today, several emerging fields are making a call for the advent of such HCPCFs and its gas-filled form to develop a new research landscape spanning from optical telecommunications, nonlinear and ultrafast optics, atom and quantum optics to plasma photonics to cite a few.

Light guidance in IC HCPCFs relies on reducing the coupling between the core and cladding modes, which is accomplished by minimizing the spatial overlap between their fields and by obtaining a strong mismatch between their spatial phases [2]. Recently, our research on IC HCPCFs identified different limiting factors for loss performances depending on the spectral range. For IC HCPCFs guiding in the infrared, the loss is limited by the confinement loss (CL) which is determined by the fiber design. Instead, the loss decreasing of fibers guiding at shorter wavelengths ($\lambda < 750$ nm) is hindered by the surface scattering loss (SSL), which stems from the IC HCPCFs core surface roughness that, in turn, arises from frozen-in thermal surface capillary waves induced during the fiber draw. Therefore, improving the loss levels in IC HCPCF will rely on controlling the roughness of the hollow-core surfaces for the short-wavelength spectral range [3] and improving the fiber designs for the infrared domain. Additional optical properties have also to be now considered such as single mode guidance, polarization purity and advanced post-processing.

Here, we present recent developments that allowed us to attain ultralow loss in both CL- and SSL-limited spectral ranges. We firstly report on a new IC HCPCF, the hybrid Kagome-tubular (HKT) HCPCF, which associates Kagome and tubular lattices to obtain ultralow loss and robust single mode operation. Secondly, we report on single-ring tubular-lattice (SR-TL) HCPCFs with record loss in the short-wavelength range and specific modal operation. Finally, these new advances provide a new panorama IC HCPCFs working in ultraviolet, visible and infrared wavelengths.

2. THE HYBRID KAGOME-TUBULAR LATTICE HCPCF

Fig. 1a shows the HKT HCPCF concept. The HKT HCPCF has a 6-tube (6T) inner cladding embedded in a Kagome outer cladding. The 6T cladding filters the core LP₁₁-like modes by coupling them to the fundamental air mode of the cladding tubes. In turn, the Kagome cladding significantly reduces the CL. The potential of the HKT HCPCF to provide ultralow loss is displayed in Fig. 1b, where the CL of different fiber designs (FD) has been plotted as a function of the normalized frequency, $F = (2t/\lambda) (n_g^2 - 1)^{1/2}$ (t : cladding tubes thickness; λ : wavelength; n_g : glass refractive index; FD #1, #2, #3, and #4: jacketless tubular fiber, a SR-TL HCPCF, a Kagome fiber,

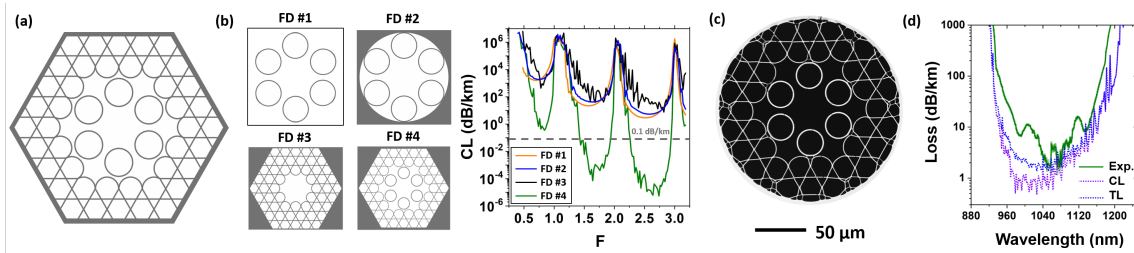


Fig. 1 : (a) HKT HCPCF structure. (b) CL as a function of F for tubular, Kagome, and hybrid FD. (c) Experimental HKT HC-PCF. (d) Measured loss and simulated CL and TL.

and the ideal HKT HCPCF, respectively). Given the potential of the HKT HCPCF, we endeavored to fabricate it. Fig. 1c exhibits the cross-section of the experimentally achieved fiber. The thickness of the cladding tubes is $1.27 \mu\text{m}$, and the core diameter is $37.1 \mu\text{m}$. The ratio between the core and cladding tubes diameters ($D_{\text{tubes}}/D_{\text{core}}$) is 0.62. Fig. 1d shows the measured loss, where a minimum value of 1.6 dB/km at 1050 nm has been obtained. Fig. 1d also exhibits the simulated CL and total loss ($TL=CL+SSL$), which have been calculated by considering the experimental structure. Finally, we evaluated the fiber modal content. A higher-order modes extinction ratio of 47 dB have been measured for a 10 m-long fiber resulting for the first time in a robust single mode operation [4].

3. TUBULAR-LATTICE FIBERS WITH ULTRALOW LOSS IN THE SHORT-WAVELENGTH RANGE

Here, we report on new state-of-the-art HCPCFs for short wavelengths exhibiting loss of 61.0 dB/km at 292 nm, 9.7 dB/km at 369 nm, 5.0 dB/km at 480 nm, 0.9 dB/km at 558 nm, 1.8 dB/km at 719 nm, 2.5 dB/km at 733 nm. Fig. 2a presents a typical SR-TL HCPCF, the measured loss values, and the bulk silica Rayleigh scattering limit (dashed line). To accomplish such ultralow loss in SSL-limited region, we improved on the quality of the fiber core surfaces. Moreover, our recent research showed that the modal properties of SR-TL HCPCFs can be tailored by modifying their structure. Fig. 2b shows SR-TL HCPCFs acting as mode shapers and polarization discriminators; the different fiber output profiles have been obtained by altering the polarization angle (θ) of the input light [5].

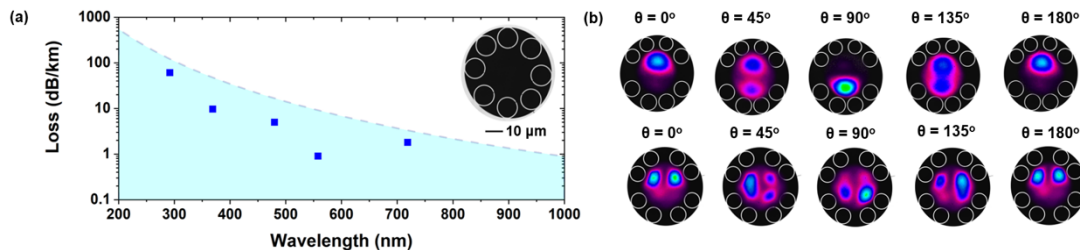


Fig. 2 : (a) Typical cross-section and measured loss of new state-of-the-art SR-TL HCPCFs. Dashed line: bulk silica Rayleigh scattering limit. (b) Alternative SR-TL HCPCFs with specific modal operation.

4. CONCLUSION

We presented recent advances in IC HCPCFs technology and new state-of-the-art fibers. In the infrared, ultralow loss could be obtained by using the new HKT HCPCF design. In the short-wavelength range, new record loss could be obtained thanks to an amelioration of the fibers core surface quality. Finally, we demonstrated single mode guidance and specific modal properties. We envisage these developments will impact on the next generation of HCPCFs for both scientific and applied fields. *This research was funded through PIA program 4F and la région Nouvelle Aquitaine.*

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