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Hollow-core photonic crystal fibers as platforms for Power-over-Fiber applications

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Abstract: We report on the first power-over-fiber experiment using an inhibited-coupling guiding hollow-core photonic crystal fiber. A tubular-lattice hollow-core fiber has been employed to deliver a 976nm laser beam onto a photovoltaic converter and power up a representative electric circuit and display. We understand that the demonstration reported herein identifies the first step towards the utilization of hollow-core fibers as promising platforms for new power-over-fiber systems potentially able to circumvent the fundamental power limitations imposed by silica-core fibers.

1. Introduction

The current framework in photonics identifies hollow-core photonic crystal fibers (HCPCFs) as building blocks for the next developments in the field. The recent research endeavors have allowed the achievement of technological breakthroughs (with remarkable reduction of the loss figures [1-3]) as well as the demonstration of a myriad of applications ranging from the development of optical sources [4] to the study of sensing opportunities [5, 6].

In HCPCFs, the optical mode is guided through an empty core, and with minimal interaction with the microstructure that demarks the fiber core contour. Indeed, this property is even more salient for HCPCF guiding via the inhibited coupling (IC) mechanism, for which the power fraction of the core mode overlapping the silica surrounding can have values as low as 10^{-6} [7]. The tiny overlap between the core mode and the silica microstructure unlocks the possibility of using HCPCFs to transport high-power beams at levels at which solid-core fibers cannot withstand. This capability of HCPCFs has been proven when dealing with both pulsed [8] and continuous-wave (CW) laser beams [9]. Remarkably, and very recently, a HCPCF has been demonstrated to be capable to transmit, for 1 km, a CW laser beam with 1kW power level at 1075 nm [10].

In a different context, and via the use of solid-core fibers, power-over-fiber (PoF) systems have been widely studied in the past years [11, 12]. PoF systems can convert the optical power emitted from a light source (and transmitted through an optical fiber) to electrical power thanks to the utilization of a photovoltaic (PV) converter. As typical PoF systems employ silica-core fibers, the utilizable optical power levels are inherently limited by silica properties. Indeed, approaches using large-core and double-clad fibers [13, 14] have been reported as alternatives for increasing the power levels in silica-based PoF systems. Still, such systems remain fundamentally limited by the power levels that silica can withstand.

Thus, considering the potential of HCPCFs to deliver high-power laser beams, we here propose the utilization of this class of optical fibers for PoF applications. Hence, we employ a single-ring tubular-lattice (SR-TL) HCPCF

to deliver a 976 nm laser beam onto a photovoltaic converter and activate a representative electrical circuit and display. To the best of our knowledge, this is the first application of a HCPCF in PoF. We consider that the demonstration reported herein identifies a promising path for the development of future PoF systems that can potentially lift the fundamental limitations which hinder the increase of the practicable power levels in PoF configurations based on silica-core fibers.

2. HCPCF structure and loss characterization

Fig. 1a shows the cross-section of the fiber we use herein. It stands for a SR-TL HCPCF whose 39 μm -diameter core (identified as a yellow circle in Fig. 1a) is demarked by eight 720 nm-thick untouched silica tubes with 20 μm diameter. The fiber transmission spectrum alternates high- and low-attenuation regions, which are set by the cladding tubes' thickness, t , and the refractive index of the core and cladding tubes, n_1 and n_2 , respectively. The high-loss regions occur at wavelengths $\lambda_m = (2t/m)(n_2^2 - n_1^2)^{1/2}$, where m is an integer. Fig. 1b inset shows the transmission spectrum of a 3m-long section of the fiber used here and Fig. 1b main plot exhibits the fiber loss spectrum between 850 nm and 1350 nm. The fiber minimum loss figure is 1.0 dB/km at 1120 nm. At 976 nm (wavelength of the laser in PoF experiments), the fiber loss amounts to 4.0 dB/km.

3. Power-over-Fiber demonstration

To demonstrate the use of the above-mentioned HCPCF in a PoF configuration, light from a 976 nm laser (SkyEra TY976) has been launched into a 7 m-long HCPCF by butt-coupling its fibered output (62.5 μm core diameter) to the HCPCF – a schematic diagram of the experimental setup is presented in Fig. 2a and a picture of the butt-coupling site is shown in Fig. 2b. Optimization of the fibers' relative positions entailed a maximum transmitted power of 130 mW at the HCPCF output. Although the attained power level allows demonstrating a HCPCF-based PoF operation, there is considerable still room for improvement of the coupling efficiency between the laser output and the HCPCF, which is currently lower than 10%. Future work will, therefore, focus on improving such coupling efficiency, and, also, on using optical sources

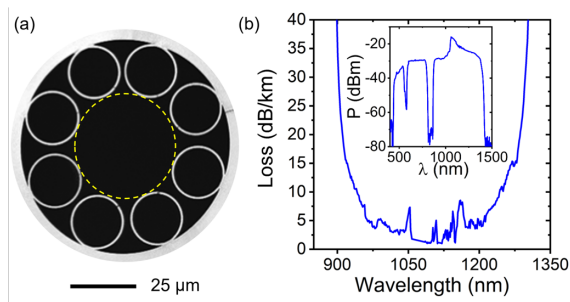


Fig. 1. HCPCF (a) cross-section and (b) loss spectrum (inset: 3m-long fiber transmission spectrum).

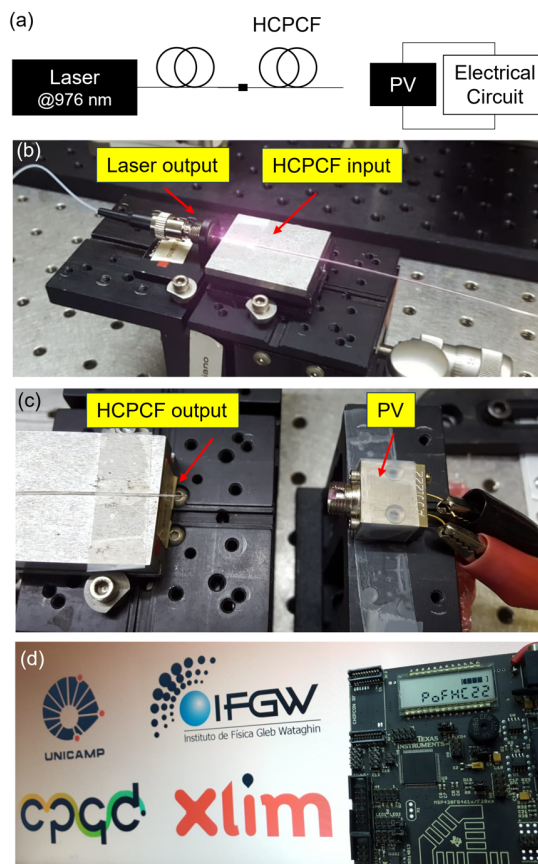


Fig. 2. (a) Setup diagram. Pictures of the (b) input coupling site, (c) the HCPCF output placement in front of the PV converter, and (d) the representative electrical circuit and display used in the PoF demonstration.

with higher power levels.

For the PoF demonstration, a silicon-based photovoltaic (PV) converter optimized for 915 to 980 nm sources (MH GoPower YCH-L200-06-FC) has been placed in front of the HCPCF end-face (Fig. 2c). Due to the small numerical aperture of the HCPCF (which, typically, has the order of 0.02 [15]), the tip of the HCPCF has been placed 2.5 cm away from the window of the PV converter so to achieve adequate illumination on the latter. When shining a 130 mW-optical power level on the PV converter, a 1.39 mA current intensity have been

measured between the terminals of the same. To illustrate the capability of using a HCPCF as a transmission channel in a PoF application, a representative electrical circuit (Texas Instruments MSP430) was connected to the PV converter. Fig. 2d shows that the light delivered by the HCPCF has been able to power up the tested display.

4. Conclusion

In this paper, we have proposed the employment of HCPCFs for PoF applications and described an experiment in which a 976 nm laser beam, after being transported by a 7 m-long HCPCF, has been used to activate a representative electrical circuit and display. To our knowledge, this is the first time that a HCPCF has been used to deliver light within a PoF context.

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