# A 20 µm-core polarization maintaining endlessly single mode photonic crystal fiber for delivery of high-power single frequency lasers

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**ABSTRACT**

We report on the development of a 20 µm-core polarization maintaining endlessly single mode photonic crystal fiber for the delivery of high-power single frequency lasers widely used in the quantum field. A complete numerical study is used to determine the optimal geometry of the fiber to be single mode over the 600-1700 nm spectral range with a polarization extinction ratio greater than 20 dB. Three versions of this fiber with different pitch and holes size ratios were fabricated and experimentally characterized at 780 nm, 1064 nm and 1550 nm. The Brillouin threshold was also measured at 1064 nm and compared to that obtained with commercial fibers.

***KEYWORDS*: *optical fiber; polarization maintaining; endlessly single mode***

## 1. INTRODUCTION

Since the appearance of the so-called endlessly single-mode fiber in the late 1990s, photonic crystal fibers (PCFs) and the exploration of the great variety of possible applications have attracted particular attention [1]. They have been successfully used in many fields such as optical communications, supercontinuum generation, or high-power fiber laser [2]. This is also an excellent solution for quantum applications [3]. Moreover, polarization maintaining (PM) PCFs maintain single-mode transmission of high-power, low noise single frequency lasers used for trapping and atoms cooling while keeping the initial linear polarization state. Since the realization of the first PM PCFs, having mode field diameters from about 4 to 6.5 micron, with stress applying parts outside the cladding region in 2004 [4], the development of this type of fiber is increasingly controlled. NKT Photonics (now part of Hamamatsu) is notably one of the world leaders in the supply of PCFs with a high degree of maturity with their "LMA-PM-xx" fiber series, the LMA-PM-15 being the reference for high power delivery with its core diameter of 15 µm [5]. At the same time, the enthusiasm for quantum physics, which requires more and more power, is motivating the development of increasingly powerful single-frequency low-noise laser sources around 1 µm [6] and in the visible via non-linear conversion [7]. With the emergence of these high-power sources which can deliver several hundred watts, current fibers are a limitation for beam delivery because the threshold of stimulated Brillouin scattering will be reached [8]. To give an order of magnitude and based on the theory presented in [8], the threshold is of the order of 12 W at 1064 nm for a 10m-long LMA-PM-15 fiber.

We report on the development of a 20 µm-core polarization maintaining PCF particularly suitable for delivering higher power. Based on a complete numerical study, we determine the optimal geometry of the fiber. Three versions of this fiber with different pitch and holes size ratios were fabricated and experimentally characterized at 780 nm, 1064 nm and 1550 nm. We measured a Brillouin threshold of around 25 W at 1064 for a 10m-long section, which justifies the interest of this fiber compared to existing fibers. We also verified the transport of more than 40W at 1064 nm with a 5m-long fiber without distortion.

## 2. EXPERIMENTAL QUALIFICATION OF OPTICAL FIBERS

After a complete numerical study, Photonics Bretagne manufactured 3 fibers with three *d/Λ* ratios (0.41, 0.43 and 0.45), *d* being the diameter of the air holes and *Λ* the spacing between the air holes, called pitch. A microscope image of the realized 20 µm-core and 260 µm-clad PM-PCF structure is shown in Figure 1, where we can observe 4 rows of holes and two stress zones on either side of the central zone at the periphery of the microstructures.

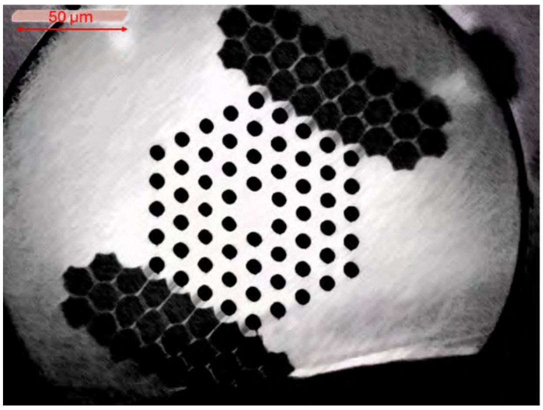


*Fig. 1. Microscope image of the 20µm-core and 260µm-clad PM-PCF fabricated*

ALPhANOV have fully characterized these three versions of the fiber at 1064 nm by measuring transmission, phase birefringence (with the support of Foton laboratory), PER and modal quality (see. Fig. 2).

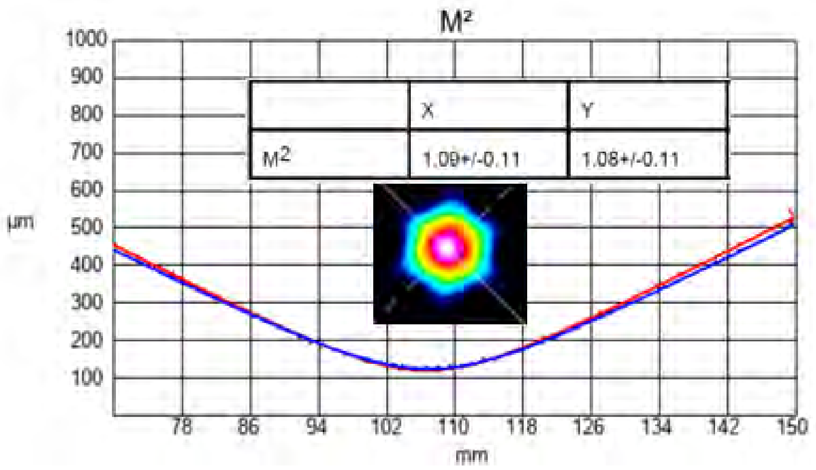


*Fig. 2.* Spatial profile and $M^2$ measurement at 1064 nm for a 30m-long PM-PCF.

We also measured the threshold of appearance of the Brillouin effect at 1064nm which is the first non-linear effect limiting the delivering power in single frequency regime. We have shown that our fiber has a much higher threshold than existing commercial fibers (see Fig. 3) and we demonstrated the transport of more than 40 W at 1064 nm with a 5m-long fiber without distortion. Thanks to our study, we proved that the theory existing for all-silica fibers could describe the behavior of large-core PCF and that we could therefore extrapolate our results to other wavelengths.

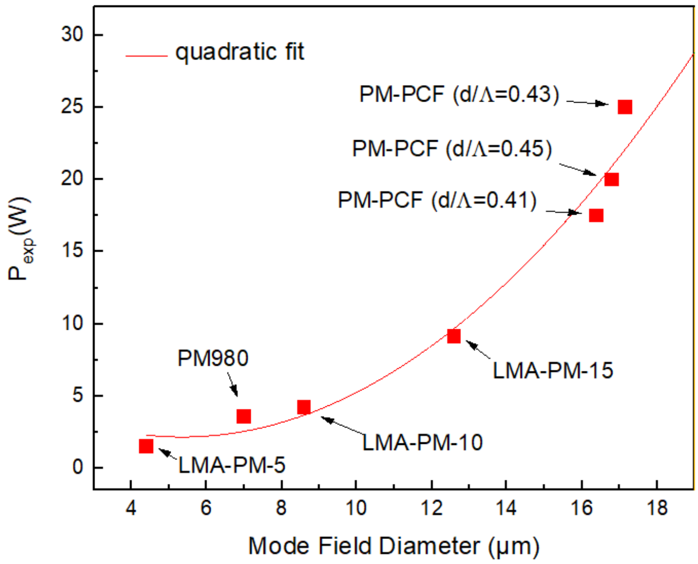


*Fig. 3. Experimental Brillouin threshold power, $P_{exp}$, at 1064 nm for the 10m-long tested fiber*

Additional measurements at 780 nm and 1550 nm demonstrated endlessly single mode behavior as well as the conservation of PER. 780 nm is widely exploited for cooling Rubidium atoms and 1550 nm is also very useful in quantum physics to create dipole traps and for optical communications. It is therefore a serious advantage to have an endlessly single-mode fiber capable of delivering high optical power in these spectral.

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