ADVANCED FIBRE DESIGNS FOR HIGH POWER LASER BEAM DELIVERY AND GENERATION

*John Hayes, Marco Petrovich, Franceso Poletti, Sonali Dasgupta, Xian Feng, Wei Loh, Neil Broderick, Kang Kang Chen, Shaif-ul Alam, Dejiao Lin, Andrew Malinowski and David J. Richardson*

*Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, UK*

## Introduction

Microstructured optical fiber (MOF) technology provides a powerful means to develop fibers with unique and enabling properties with potential uses spanning a very wide range of applications. Microstructuring of the fiber material allows access to properties unobtainable in the bulk. These include (a) the possibility to guide light in air (through photonic band-gap or low density of state effects) including spectral regions where the bulk is opaque; (b) single mode guidance over extended spectral ranges (referred to as endlessly single mode (ESM) guidance); (c) extended control of dispersion and (d) the fabrication of fibers with very much larger values of Numerical Aperture (NA) than possible using conventional fiber fabrication approaches. Furthermore these unique properties may be tailored to enhance wavelength generation in fibers through non-linear effects or in fibers containing rare-earth dopants. In the following sections we discuss recent progress in the design and fabrication of such fibers that exploit several of these opportunities.

## Photonic Bandgap Fibers

The primary benefits of photonic band gap fibers for power delivery relate to the low nonlinearity associated with air-core guidance and the prospects for reduced losses in wavelength regimes in which the inherent glass loss would make solid-core variants unusable. We have conducted extensive numerical and theoretical studies to identify fiber designs providing robust, broadband guidance [1-3] and to quantify the overlap of guided light with the surrounding glass. In Figure 1 we show two fibers fabricated in our facilities with a suitable choice of geometry according to the design rules derived. These pictures show fibers with two sizes of defect created by the omission of 3 and 19 central capillaries. Measurements confirm the broad usable bandwidths and show that the effective modal overlap with the solid regions of the fiber decreases steadily with increasing core size as predicted [4]. It is however to be appreciated that this is associated with a corresponding increase in the number of modes supported by the structure. Only by going to the smallest scale core is robust single mode guidance achievable, as reported in [4]. Exploiting the low overlap factors associated with 19-cell designs we have developed fibers operating at wavelengths >2.5 µm, well beyond the accepted transparency window of silica [2]

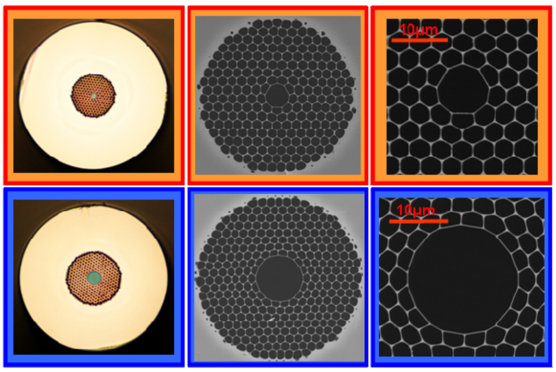


**Figure 1 3c (Top) single mode PBG fiber incorporating a 3-cell core; (Bottom) 19-cell PBGF for extended near-IR broadband transmission**

## Solid Core Fibres

Endlessly single mode (ESM) fibers are of interest for a range of potential applications and hexagonally stacked fibers with differing core structure have been developed and characterized in terms of their modedness, effective area, and bend-loss characteristics. In many single wavelength applications conventional doped fiber technology can arguably deliver fibers capable of similar performance. However, MOF technology offers potential advantage, when single mode guidance is required over extended wavelength ranges. For example, we have recently developed structures capable of delivering both fundamental and second harmonic radiation from a pulsed Q-switched Nd:YAG laser as required for various direct-write materials processing applications [5]. The use of ESM fibers in additional wavelength regimes has also become the focus of considerable attention with the first reports of such fibers being made in new materials such as Tellurite glass (transparent at wavelengths up to 5µm) [6] and in silver halides (capable of guiding light at wavelength beyond 20µm) [7]. As well as being of interest for high power laser delivery, such fibers are of use in applications such as modal filtering in space-borne astronomy [8], and broadband mid-IR supercontinuum generation [6].

## High NA JAC fibers

High-NA, large core Jacketed Air Clad (JAC) fibers are of relevance to a range of applications most notably in the context of fiber lasers and multimode laser diode beam delivery since they allow confinement of the guided light to a far smaller cross-sectional area than possible in either all-glass, or polymer-clad structures. This tighter optical confinement can be used to make shorter fiber amplifier and laser device, reducing the impact of fiber nonlinearities and/or dispersion. Numerical apertures approaching unity are now possible. In addition, the technology also allows for the ready implementation of fibers with different cross-sectional profiles.  For example, in Figure 3 we show an SEM of a square JAC fiber recently developed at Southampton for high power laser beam delivery in which the square near field profile is used to provide benefit in terms of pixel-definition in applications such as flat screen display manufacture [9], amongst others. In figure 4 we show a fibre having an actively doped core and a pump core NA>0.8 which is intended to reduce nonlinear broadening through tighter pump confinement.

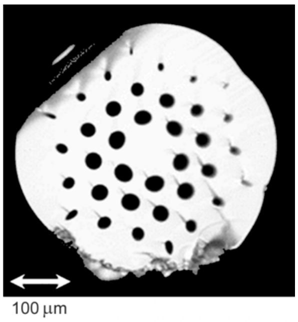


**Fig. 2 LMA Tellurite fiber with effective area of ~2000µm$^2$**

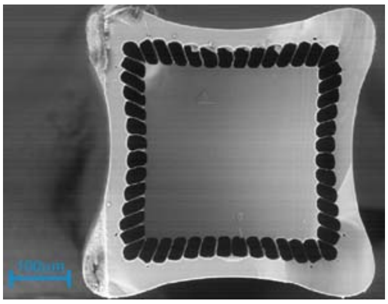

**Fig. 3 Square core JAC fiber for high power laser delivery.**

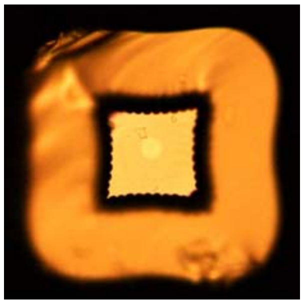

**Fig. 4 High NA JAC fiber with doped inner core**


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