- (Submitted to Electronics Letters) - revised version.

2077

Assorted Core Air-Clad Fibre

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October 5, 2000

Abstract

We present an optical fibre containing a selection of independently addressable air-clad cores with different dimensions. The intrinsic properties of such an *assorted core* fibre are studied and potential applications are reviewed. We explore the physical dimensions required for guidance at various wavelengths.

Introduction: When the core of an optical fibre is of a similar scale to the wavelength of light, properties of the guided mode(s) can be strongly wavelength dependent. This is particularly striking when the index contrast between core and cladding regions is large, the most extreme case being an *air-suspended* glass fibre. Of course, in practice it is not feasible to make such a structure. We demonstrate a new technique for fabricating an optical fibre with an array of independently addressable essentially air-clad cores of different dimensions. This relies on techniques developed in the production of holey optical fibres, which have a cladding formed by air holes running the full fibre length. The unusual refractive index profile of holey fibres leads to a host of novel optical properties, such as endlessly single-moded guidance, and many more [1],[2],[3].

Holey fibres are typically fabricated from a stack of silica tubes surrounding a single solid silica rod, drawn to a fibre using a conventional fibre tower [4]. In addition, some work has been presented on a dual core holey fibre in which two or more tubes are replaced by solid rods [5]. Here we present a fibre which contains many small cores of different dimensions (see Figure 1). This *assorted core* fibre contains a central core formed by the solid rod which is surrounded by a network of near air-suspended cores. When thin walled capillaries are stacked and drawn, additional cores can form at regions where several capillaries meet [6]. The differing sizes result from variations in tube thickness and diameter at the intersection points. A novel property of this fibre is the particular frequency range, determined by the width and length of supporting structures, over which light is guided in each core. Note that each core in the assortment may be selected individually. In this Letter we explore the properties of such a fibre and review potential applications.

Results: The assorted core fibre shown in Figs 1 and 2 was drawn from a stack of thin walled silica tubes surrounding a solid silica rod. Note that only the centre section of the fibre is shown and the outer fibre diameter is approximately 180 microns. We investigated the modes supported by the cores in this fibre, using a 30cm length of fibre at wavelengths of 488nm, 633nm, and 1500nm to obtain an understanding of the range of core sizes and support structures which permit the guidance of light. These results are given in Table 1.

The primary core (labelled A in Figure 2) is formed by the solid rod (as in a typical holey fibre) and is central to the structure. Core A is approximately $3.4\mu m$ in diameter and guides light over at least 488nm - 1550nm and it is few-moded over this range. In the surrounding region, junctions of relatively thicker glass are formed at points where several capillaries meet, creating a network of potential cores supported by thinner silica filaments. The subset of "potential" cores, called secondary cores herein, that guided light are shown in Figure 2. Note that for the whole of the wavelength range used all of the secondary cores were single moded. We obtain well isolated guided modes for a selection of the secondary cores, which range in dimensions from $1.20\mu m$ to $1.84\mu m$. Cores B, C, D, I, J and K support an isolated single mode at 488nm as do cores C, F, J and K at 633nm. For example, core F had a coupling efficiency of order 10% and could be completely isolated from the nearest adjacent core. Cores G and H together support a single spatially extended mode at both 488nm and 633nm. The joint nature of this guidance is either due to strong coupling between the two cores, or an inability to resolve the cores individually. At 1550nm none of the secondary cores guided light. It is interesting to note that cores with roughly similar support dimensions such as K and F guide light over different wavelength ranges. We find that this, and indeed all other observed guidance properties can be explained by geometrical arguments, as discussed below.

Discussion and Conclusion: By investigating the wavelengths over which each core geometry guides light, we infer some general rules relating the dimensions of the support structures to the observed guidance properties. We find that in order to guide light of wavelength λ, all support structures surrounding a secondary core must be longer than about 2λ and narrower than about 1.2λ. These are approximate rules which were deduced empirically, and they are physically reasonable as the range over which the field decays is of the order of the wavelength. The observed guidance properties of all the additional cores can be explained in this way. For example, core K guides efficiently at both 488nm and 633nm while core F only guides at 633nm. Although the regions surrounding both cores are similar, the lower support at F is wider than all those at K, thus permitting confinement at 633nm but not at 488nm. Similarly, I and B guide reasonably well at 488nm but not at 633nm due to the fact that two of the supports are very short, allowing a degree of confinement at 488nm but not for the longer wavelength. The fact that light of 1550nm was not guided within any of the secondary cores is explained by the rules outlined above, as all the secondary cores have support structures shorter than the length required for low loss confinement. As described above, this analysis leads to "rules of thumb" which should be a valuable tool for future fibre design.

The wavelength dependence of the effective cladding index (n_{cl}) and thus of associated optical properties is particularly striking when the structure is small and the air fill fraction is large, as in this fibre. Such fibres display highly unusual dispersive properties, such as anomalous dispersion at short wavelengths and high optical non-linearity [2]. Also, evanescent field devices could be made by exploiting the overlap between the modal field and the air [3]. For example, the overlap between the modal field and the air has been calculated for a core with the same dimensions as K by modeling a typical holey fibre with an equivalent air fill fraction and core size. At 633nm the overlap is 5% and at 1550nm is 17% which demonstrates that these cores are small enough to be relatively efficient evanescent devices.

The optical fibre described here possesses an assortment of small cores ranging in dimension from 1.2μm to 3.4μm. All of the applications mentioned above depend critically on the size of the fibre core. This selectable assortment of cores therefore provides a wide range of optical properties, contained within a single fibre, from which it is possible to pick and choose. In future it should be possible to design optical fibres with an even greater range of core sizes by increasing the range of tube dimensions, allowing great flexibility in device design.

References

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Core	Smallest dimension [μm $\pm$ 0.05μm]	Shortest support [μm $\pm$ 0.05μm]	Widest support [μm $\pm$ 0.05μm]	488nm	633nm	1550nm
A	3.40	-	-	G	G	G
B	1.20	1.13	0.53	G	L	N
C	1.47	2.10	0.60	G	G	N
D	1.24	1.13	0.60	G	L	N
E	1.43	1.05	0.60	L	L	N
F	1.50	1.56	0.68	L	G	N
G	1.35	1.28	0.60	L	G	N
H	1.24	1.28	0.60	L	G	N
I	1.43	1.13	0.49	G	L	N
J	1.20	1.65	0.64	G	G	N
K	1.43	2.40	0.60	G	G	N
L	1.58	2.03	0.79	N	L	N

Table 1: Details of the small cores and surrounding support structures dimensions and light guidance properties. G = Guidance, N = No guidance, L = Leaky guidance.

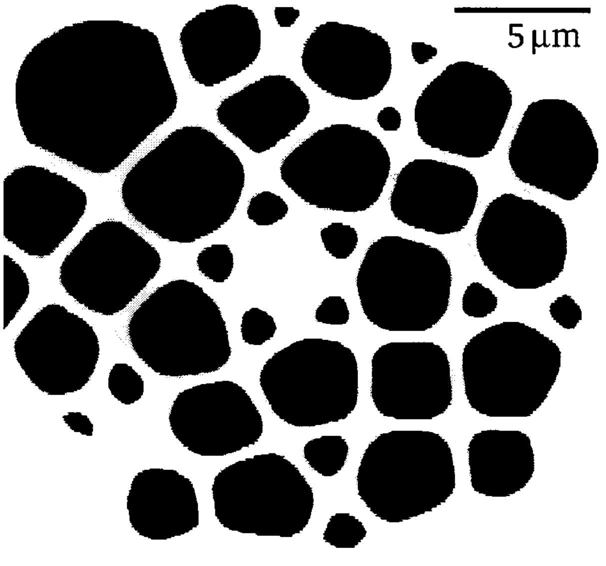

Figure 1: SEM photograph of assorted core holey fibre cross-section.

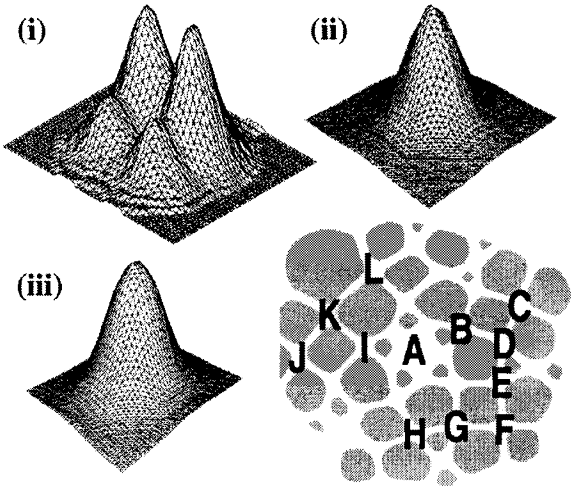

Figure 2: SEM of fibre with (i) mode profile of core A at 488nm, (ii) mode profile of core K at 488nm and (iii) mode profile of core F at 633nm.