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THE BENEFIT OF USING PHOTONIC CRYSTAL FIBERS IN TELECOMMUNICATION SYSTEMS

Introduction

The transmission of light via a dielectric waveguide structure was first proposed and investigated at the beginning of the twentieth century. Although glass fibers were made in the 1920s [1], their use became practical only in the 1950s, when the use of a cladding layer led to considerable improvement in their guiding characteristics [2]. Before 1970, optical fibers were used mainly for medical imaging over short distances [3]. Their use for communication purposes was considered impractical because of high losses (1000 dB/km).The loss of optical fibers was reduced to below 20 dB/km [4]. Further progress resulted by 1979 in a loss of only 0.2 dB/km near the 1.55-μm spectral region [5]. In 1987, Yablonovitch and John - by using the tools of classical electromagnetism and solid-state physics - introduced the concepts of omnidirectional photonic bandgaps in two and three dimensions [6]. From then, the name A few years later in 1991, Yablonovitch and co-workers produced the first photonic crystal by mechanically drilling holes a millimeter in diameter into a block of material with a refractive index of 3.6 [7]. Other structures, which have band gaps at microwave and radio frequencies, are being used to make e.g antennas that direct radiation away from the heads of mobile phone users. There are typically three types of computational methods: time-domain "numerical experiments" [8] that model the time-evolution of the fields with arbitrary starting conditions in a discredited system ; definite-frequency transfer matrices [9] wherein the scattering matrices are computed to extract transmission/reflection through the structure; and frequency-domain methods [10] to directly extract the Bloch fields and frequencies by diagonalizing the eigenoperator.

The objective of the paper

These fibers are based on a new and very promising technology and could provide solutions to many optical problems in communications, light source manufacturing and has already revolutionized the field of frequency metrology. low bend sensitivity, to enable smaller coil inner diameters without compromising optical power as a result of increased bending loss. thermal stability, such that a wide temperature range can be supported and thermal gradients do not cause non-reciprocal index changes (Shupe effect). The polarization maintaining properties of a fiber should also be insensitive to temperature . Magnetic field insensitivity, as fibers sensitive to this (Faraday effect)

Photonic crystal fibres (PCFs)

Photonic crystals (PhCs) are inhomogeneous dielectric media with periodic variation of the refractive index. In general, (PhCs) have a photonic band gap. That is the range of frequencies in which light cannot propagate through the structure. (PhCs) are optical media with spatially periodic properties. Photonic-crystal fibres (PCFs) [11], also referred to as microstructure, or holey, fibres, are optical waveguides of a new type. In PCFs, radiation can be transmitted through hollow core see Figure (1), surrounded with a microstructured cladding, consisting of an array of cylindrical air holes running along the fibre axis. Such a microstructure is usually fabricated by drawing a perform composed of capillary tubes and solid silica rods.

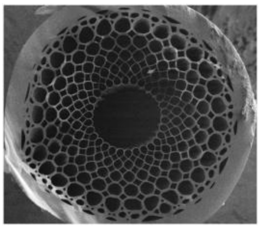

Fig. 1. Cross-section of photonic-crystal fibres

Along with conventional waveguide regimes, provided by total internal reflection, PCFs under certain conditions can support guided modes of electromagnetic radiation due to the high reflectivity of their cladding within photonic band-gaps (PBGs) or regions of low densities of photonic states [12], as well as by the antiresonance mechanism of waveguiding [13]. Such regimes can be supported by fibres with a hollow [14] core and a two-dimensionally periodic (photonic crystal) cladding. A high reflectivity provided by the PBGs in the transmission of such a cladding confines radiation in a hollow core, substantially reducing the loss, which is typical of hollow-core-guided modes in conventional, capillary-type hollow waveguides and which rapidly grow with a decrease in the diameter of the hollow core [15]. Unique properties of PCFs open up new routes for a long-distance transmission of electromagnetic radiation [11], as well as for nonlinear-optical transformation of laser pulses [16]. An increase in a fibre cross section is a standard strategy for increasing the energy of laser pulses delivered by fibre lasers. Standard large-core-area fibres are, however, multimode, making it difficult to achieve a high quality of the transverse beam profile. This difficulty can be resolved by using PCFs with small-diameter air holes in the cladding, which filter out high-order waveguide modes [17].

The photonic crystal fibers and conventional optical fibers technology

There is a difference between the conventional optical fibers and photonic crystal fibres technology ,we can be captured by a set of more specific performance parameters as described below in table (1).

Table 1 gives a comparison of the performance parameters for photonic crystal fibres and conventional optical fibers.

Feature	Conventional fiber	Hollow core fiber
Fiber diameter	Typ. 80 μm clad, 170 μm coating	Development fibers 125 μm clad, 240 μm clad
Fiber bend diameter	Typ. 2-3 inch	< 1 inch
Thermal stability	Shupe effect limits	Est. >7x better
Loss (PM fiber) 1550 nm	< 3 dB/km	< 15 dB/km
Loss (PM fiber) 1550 nm	< 3 dB/km	< 2 dB/km
Nonlinearities	Kerr effect limits	Est. >100x better
Polarization maintenance thermal stability	Poor if using stress parts for polarization maintenance	Better than stress part designs
Radiation sensitivity	Poor if using co-doped silica	Est. 50x better
Magnetic sensitivity	Faraday effect limits (less in a PM fiber)	Est. >100x better

Attenuation of photonic crystal fibres

In recent years, the typical attenuation level of photonic crystal fibers (PCFs) has been reduced dramatically. This is both true for fibers relying on index guiding [18,19] as well as those based on the photonic bandgab effect [20]. If the transverse scale of a photonic crystal fibres changes without otherwise changing the fibre's structure, the wavelength λ_c of minimum attenuation must scale in proportion [21]. Without recourse to the approximations of the previous section, the mean square amplitude of the roughness component that couples light into modes with effective indices between n and $n+\delta n$ is:

$$u^2 = \frac{k_B T}{4pg(n-n_0)} coth \int \frac{(n-n_0)kW}{2} \int dn \qquad (1)$$

where γ – the surface tension , k_B – Boltzmann's constant , T – the temperature.

The attenuation to these modes is proportional to u^2 [22] but the only other independent length scale it can vary with is λ_c. As attenuation has units of inverse length, it must therefore by dimensional analysis be inversely proportional to the cube of λ_c. If this is true for every set of destination modes, it must be true for the net attenuation α to all destination modes, so:

$$a(l_c) \text{ » } \frac{1}{l_c^3}. \qquad (2)$$

This equation [21], predicts the attenuation of a given fibre drawn to operate at different wavelengths. The result differs from the familiar $1/\lambda^4$ dependence of Rayleigh scattering in bulk media [23], and importantly applies to inhomogeneities at all length scales not just those small compared to λ. The fibres had 7-cell cores but were drawn to different scales, giving them different λ_c but otherwise comparable properties [21]. The minimum attenuation is plotted in Figure.(2) against λ_c on a log-log scale. A straight-line fit is shown and has a slope of 3.07, supporting the predicted inverse cubic dependence in Eq. (2).

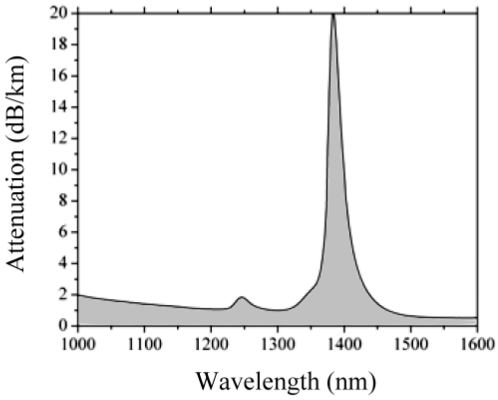

Fig. 2. Attenuation spectrum of a photonic crystal fibre

The minimum optical attenuation of ~0.15 dB/km in conventional fibres is determined by fundamental scattering and absorption processes in the high-purity glass [23], leaving little prospect of much improvement. Over 99% of the light in (PCFs) can propagate in air [21] and avoid these loss mechanisms, making (PCFs) promising candidates as future ultra-low loss communication fibres. The lowest loss reported in photonic crystal fibres is 1.7 dB/km [21], though we have since reduced this to 1.2dB/km. Since only a small fraction of the light propagates in silica, the effect of material nonlinearities is insignificant and the fibers do not suffer from the same limitations on loss as conventional fibers made from solid material alone.

Dispersion of photonic crystal fibres

In a homogeneous medium the dispersion relation between wave vector k and frequency ω of the propagating light is given through the refractive index of the material $\omega=c|k|/n$. In a PCF it is the combined effect of the material dispersion and the band structure arising from the 2D photonic crystal that determines the dispersion characteristics of the fiber. For propagation in fibers it is the dispersion for the wave vector component along the z-direction kz that is the interesting parameter. In the fiber optics literature kz is referred to as the propagation constant β. It is then reasonable to define an effective refractive index as

$$n_{eff} = \frac{\beta c}{\omega_{fund}}, \tag{3}$$

where ω_{fund}. denotes the frequencies of the lowest lying mode in the fiber. The higher derivatives of the propagation constant are given as

$$\beta_n(\omega) = \frac{\partial^n \beta}{\partial \omega^n}, \tag{4}$$

and the second order dispersion $D = -\frac{2\pi c}{\lambda^2}\beta_2$ is just another way of expressing β_2. The zero-dispersion wavelength (λ_{ZD}) is defined as the free space wavelength $\lambda = \frac{2\pi c}{\omega}$ where $\beta_2 = 0$.

A cross-section of an index guiding PCF is shown in Fig.(3) a calculation of the dispersion properties and effective area of this fiber will be sketched. The dispersion given by $\beta_2(\lambda)$ is shown in Fig. (3) and the fiber has λ_{ZD} = 721 nm, whereas the zero dispersion wavelength for bulk silica is found around 1300 nm.

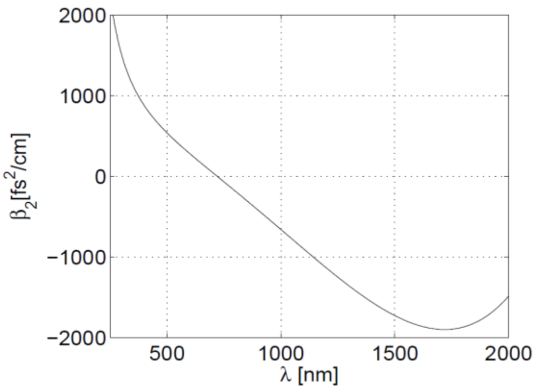

Fig. 3. Dispersion characteristics for the fundamental frequency mode of the 1.7μm core diameter PCF

The zero dispersion wavelength for this fiber has consequently been shifted into the visible regime due to the micro-structuring. This widely tunable group velocity dispersion is an extremely valuable property of the PCFs. The dispersion can be tuned by a proper choice of the size of the air holes, the distance between the holes (pitch) and the size of the central defect. A general tendency is that the zero dispersion wavelength is found at a shorter wavelength when the fraction of air filling is increased and the central defect is decreased [24]. It is possible to manufacture fibers with zero dispersion wavelengths between 500 and 1500 nm. Another general trend is that decreasing either the pitch or the hole-size leads to a higher curvature of the dispersion profile, eventually leading to two closely lying zero dispersion wavelengths. The fibers can be made with cores down to 1μm in diameter. Due to the small core areas huge intensities can be obtained in the cores of the fibers. Consequently, such fibers will exhibit a highly nonlinear response. Another very useful property of the fibers is that they can be made endlessly single mode. Only one mode should have a propagation constant between the effective propagation constants for the cladding and the core i.e. $n_{core}k > \beta > n_{clad}k$, where k is the free space propagation constant. The restriction corresponds to only one solution to Maxwell's equations propagating in the core and evanescent in the cladding. The effective frequency parameter is given by [25]

$$V_{eff} = (\frac{2\pi\rho}{\lambda})\sqrt{n_{core}^2 - n_{clad}^2} \tag{5}$$

where ρ is the core radius. For the fiber to be single mode Veff should be below 2.405. As λ decreases, the effective index of the cladding n_{clad} increases, because more intensity of the light will be confined to the silica part of the cladding. Consequently, Veff can be kept below 2.405 for a wide range of wavelengths and the fiber is said to be endlessly single mode. In this way fibers, even with a very large core, can be made endlessly single mode [26]. As the mode area of the fiber increases the relative intensity in the core will decrease. Hence the fibers can be used for linear propagation, where a lot of power can be delivered without going into a nonlinear propagation regime.

Optical fiber communication system

Fiber optic communication is a communication technology that uses light pulses to transfer information from one point to another through an optical fiber.. A block schematic of a general communication system is shown in Figure (4) ,

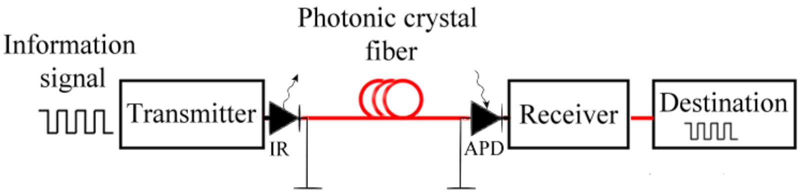

Fig. 4. General communication system

the function of which is to convey the signal from the information over the transmission medium (photonic crystal fiber) to the destination. Fiber optic communication systems consists of an optical transmitter to convert an electrical signal to an optical signal for transmission through the photonic crystal fiber and a receiver at the destination point. For optical fiber communications the information source provides an electrical signal to a transmitter comprising an electrical parte which drives an optical source to give modulation of the light wave carrier. The optical source which provides the electrical–optical conversion may be either a semiconductor IR . The transmission medium consists of an photonic crystal fiber and the receiver consists of an optical detector which drives a further electrical parte and hence provides demodulation of the optical carrier and an optical receiver to reconvert the received optical signal back to the original transmitted electrical signal. Thus there is a requirement for electrical interfacing at either end of the optical link and at present the signal processing is usually performed electrically.

The propagation in the photonic crystal fibers

To consider the propagation of light within an optical fiber utilizing the ray theory model it is necessary to take account of the refractive index of the dielectric medium. The refractive index of a medium is defined as the ratio of the velocity of light in a vacuum to the velocity of light in the medium. The spacing between the air holes in a photonic crystal structure with air holes embedded in dielectric material is given roughly by the wavelength of the light divided by the refractive index of the dielectric material. The problem in making these small structures is enhanced because it is more favorable for a photonic band gap to form in dielectrics with a high refractive index, which reduces the size of the lattice spacing even further. The emitting power of the light (IR) from the transmitter may take many reflected and refracted paths before arriving at the receiver. The receiver in a optical communication system is the light detector (photodiode) . The large size of the photodiode with respect to the wavelength of the light provides a degree of inherent spatial diversity in the receiver which mitigates the impact of multipath fading . Multipath fading is not a major impediment to optical communication , temporal dispersion of the received signal due to multipath propagation remains a problem. This dispersion is often modelled as a linear time invariant system since the channel properties change slowly over many symbol periods [27]. The impact of multipath dispersion is most noticeable in diffuse infrared communication systems . Unlike conventional fiber optical systems, multipath fading is not a major impairment in photonic crystal fiber transmission. The multipath propagation of light produces fades in the amplitude of the received electromagnetic signal at spacings on the order of half a wavelength apart.

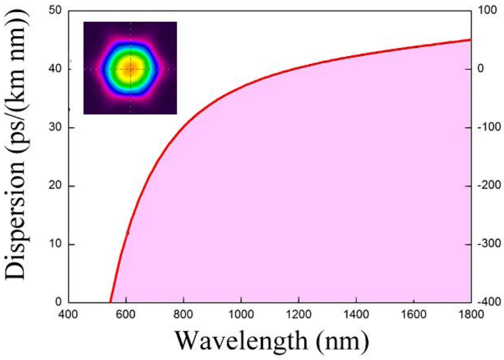

Fig. 5. Distribution of the output power of photonic crystal fibers

The figure 5 shown the results of an experimental determination of the optical emission intensity distribution in the cross-sectional center of the defect and the results of numerical calculation of the distribution of power density in cross-section.

Conclusion

For photonic crystal fibers to realize their potential and advantages over conventional fibers in fiber optic communication . In communication the fibers could provide many new solutions. The photonic crystal fibers offer the possibility of low losses and dispersion, a possible competitor to conventional fibers . Photonic crystal fibres offer new solutions for laser physics, nonlinear optics, and optical technologies, as they combine dispersion tuneability and a high degree of light-field confinement in the fibre core. The maximum laser fluence in an optical system is limited by the laser damage of material of optical components. The availability of low-loss fibers led to a revolution in the field of light wave technology and started the era of fiber-optic communications . Photonic crystal was created and led to many subsequent developments in their fabrication, theory, and application. photonic crystal fibers compressors in fibre-laser systems allow the generation of output light pulses with a pulse width on the order of 100 fs in the megawatt range of peak powers. Thus, PCFs play the key role in the development of novel fibre-laser sources of ultrashort light pulses and creation of fibre-format components for the control of such pulses.

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