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PHOTONIC CRYSTAL FIBERS : FABRICATION AND DESIGN PERSPECTIVES

Arun Prakash Singh
Department of Physics
Hindu College
Moradabad, U.P., India

Anuj Agarwal
Department of Physics
Hindu College
Moradabad, U.P., India

ABSTRACT

The creation of photonic crystal fibres and the examination of the wide range of prospective applications were pioneered by Philip St. J. Russell's research group in the 1990s. Research in this topic, which is one part of a larger field of photonic bandgap structures, is now among the most active in optics today. In part, this is due to the fact that these fibres may be designed to attain a wide range of unique qualities, making them suitable for a wide variety of applications. The field of Photonic Crystal Fibers (PCF) was first explored in the latter half of 1990's and quickly evolved into a commercial technology. photonic crystal fibers are generally divided into two main categories: Index Guiding Fibers that have a solid core, and Photonic Bandgap Fibers that have periodic microstructured elements and a core of low index material (e.g. hollow core). They can provide characteristics that ordinary optical fiber cannot, such as: single-mode operation from the UV to IR with large mode-field diameters, exceptionally high nonlinearity, numerical aperture (NA) ranging from very low to about 0.9, and optimized dispersion properties. Applications of PCFs are found in a wide range of research fields like spectroscopy, metrology, biomedicine, imaging, telecommunication, industrial machining, and military.

Keywords : Optical Properties and Photonic Crystals, Photonic Crystals, Taxonomy of Photonic Crystals

INTRODUCTION

A photonic crystal fiber (also called holey fiber, hole-assisted fiber, microstructure fiber, or microstructured fiber) is an optical fiber which obtains its waveguide properties not from a spatially varying glass composition but from an arrangement of very tiny and closely spaced air holes which go through the whole length of fiber. Such air holes can be obtained by using a preform with (larger) holes, made e.g. by stacking capillary and/or solid tubes (stacked tube technique) and inserting them into a larger tube. Usually, that preform is then first drawn to a cane with a diameter of e.g. 1 mm, and thereafter into a fiber with the final diameter of e.g. 125 μm.

Particularly soft glasses and polymers (plastics) also allow the fabrication of preforms for photonic crystal fibers by extrusion [1]. There is a great variety of hole arrangements, leading to PCFs with very different properties. All these PCFs can be considered as specialty fibers.

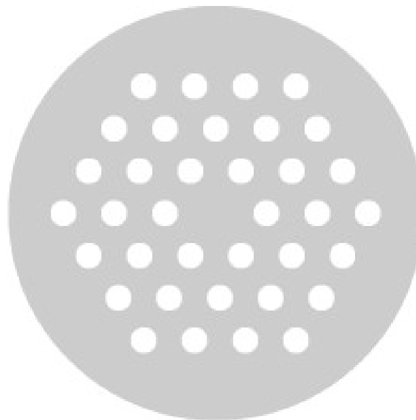

Figure 1 : Classical Photonic Crystal Fiber

Photonic Crystal Fiber Designs

Depending on the design, substantially different physical mechanisms providing the guidance of light may be obtained [2].

Triangular Hole Patterns

The simplest (and most often used) type of photonic crystal fiber has a triangular pattern of air holes, with one hole missing (see Figure 1), i.e. with a solid core surrounded by an array of air holes. The guiding properties of this type of PCF can be roughly understood with an effective index model: the region with the missing hole has a higher effective refractive index, similar to the fiber core in a conventional fiber. That guiding principle can work in a very wide range of wavelengths; even single-mode guidance may be obtained in a very wide spectral region (endlessly single-mode fibers) .

Photonic Bandgap Fibers

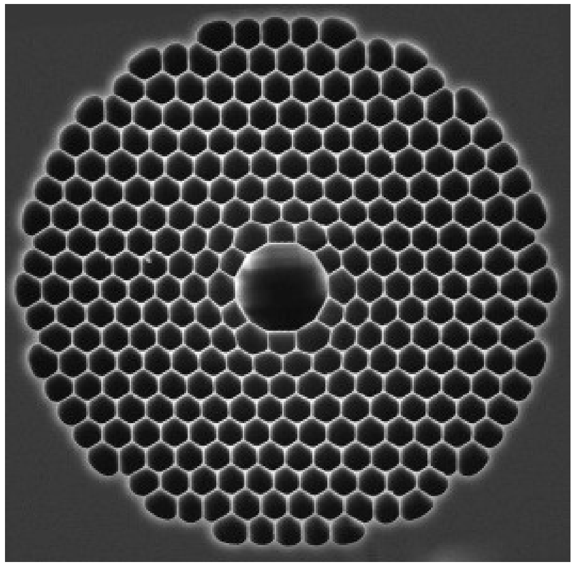

Figure 3: Hollow-Core Fiber

There are also so-called photonic bandgap fibers (PBG fibers) with a totally different guiding mechanism, based on a photonic bandgap of the cladding region, which is considered as a two-dimensional photonic crystal. Based on that mechanism, one can even obtain guidance in a hollow core (i.e. in a low-index region) (see Figure 2), such that most of the power propagates in the central hole (→ hollow-core fibers). Such air-guiding hollow-core photonic crystal fibers (or air core bandgap fibers) can have a very low nonlinearity and a high damage threshold [3].

Photonic bandgap fibers typically guide light only in a relatively narrow wavelength region with a width of e.g. 100–200 nm and can be used e.g. for pulse compression with high optical intensities [4], as most of the power propagates in the hollow core.

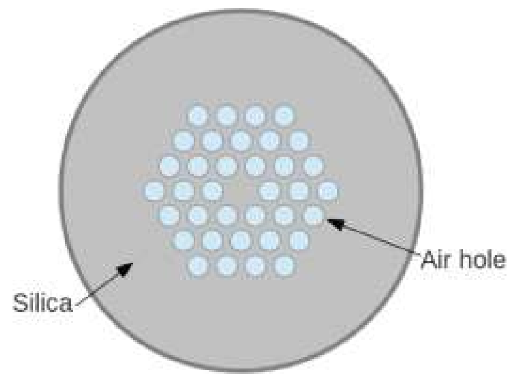

Figure 3 : Optical Microscopy View

Applications

Their special properties make photonic crystal fibers very attractive for a very wide range of applications. Some examples are:

- fiber lasers and amplifiers, including high-power devices, mode-locked fiber lasers, etc.
- nonlinear devices e.g. for supercontinuum generation [9, 28] (→ frequency combs), Raman conversion , parametric amplification, or pulse compression
- telecom components, e.g. for dispersion control, filtering or switching
- fiber-optic sensors of various kinds
- quantum optics, e.g. generation of correlated photon pairs , electromagnetically induced transparency, or guidance of cold atoms.

Some PCFs have a cladding refractive index that exhibits a strong wavelength dependence. Together with the inherently large design flexibility, PCFs allow for a whole range of novel properties to be explored. Such properties include endlessly single-mode fibers (F-SM Series), extremely nonlinear fibers and fibers with anomalous dispersion in the visible wavelength region (F-NL Series). A unique feature of PCFs is that a single fiber may support single-mode operation over a wavelength range from around 300 nm to beyond 2000 nm –

even for large mode field areas (of several hundred µm2). This allows PCFs to be utilized for transmission of very high powers with high beam quality without running into nonlinear or damage barriers (several hundred Watts for CW operation). On the other hand, the highly nonlinear fibers made as single-mode fibers have extremely small mode field areas (typically around 3 µm2) and confine light to the core region efficiently.

Even though PCFs have been around for a number of years, the huge range of possible applications is far from being fully explored [5]. It is to be expected that this field will stay very lively for many years and many opportunities for further. Based on their confinement mechanism, photonic crystal fibres have two modes of operation. For nonlinear optical devices, polarization-maintaining fibres, and other applications that require strong confinement, those with solid cores or cores with higher average indices than microstructured claddings can use the same index guidance principle as conventional optical fibres. However, the effective refractive index contrast between core and cladding can be much higher, and this can result in much stronger confinement (or they can also be made with much lower effective index contrast) [6].

Another option is the "photonic bandgap" fibre, which uses the microstructured cladding to confine light in a lower-index core or even a hollow (air) core, depending on how it is built. In the future, hollow core bandgap fibres may be used to construct fibres that can direct light at wavelengths where transparent materials aren't yet accessible, for example (because the light is primarily in the air, not in the solid materials). It is also possible to dynamically introduce materials into a hollow core, such as a gas that is to be tested for the presence of a specific component [7, 8]. A sol-gel coating can also be applied to the holes of PCF to improve light transmission.

Core and cladding of constant refractive index difference make up fiber-optic cables. Due to the difference in refractive index between the core and the cladding, light can flow through the core. Since the propagation loss of refracted light is so large, long-distance communications need the use of repeaters and amplifiers. Photons have a significantly better wave guidance in PCF because light is confined in the core rather than the outside sheath. Because PCF uses polymers instead of glass, the fibre is more flexible, making installation easier and less costly.

CONCLUSION

Fibers with photonic crystal cladding (PCF) are a unique kind of optical fibres that have microcapillaries arranged in a periodic pattern to create the fiber's outer cladding around the faulty core. Since the late 1990s, PCFs have gotten a lot of interest for their possible use in light propagation and other fields. Optical features like as modal area, chromatic dispersion, nonlinearity, and birefringence may be tailored to a great extent because to the PCF shape and the wide range of materials available for their manufacture. From large-mode-area, continuous single-mode fibres to dispersion correction, single-polarization and high birefringence guiding and nonlinear applications, PCFs can display remarkable performance. Supercontinuum generation and pulse shaping, hollow-core PCF pulse delivery, high-power fibre laser systems and fibre components for metrology and spectroscopy are only a few examples of the types of applications available.

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