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A Study of Photonic Crystal Fibers Properties and Applications

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Abstract:

The study summarizes that crystalline optical fiber (PCF) is a new class of optical fibers based on the optical properties of crystals, as these fibers are considered part of a broader class, which are optical fibers with a microstructure, which is characterized by the fact that light is directed by structural modifications in addition to changes in refractive indexes. Because of the ability of these fibers to trap light inside their core and with properties superior to those available in traditional optical fibers, these fibers have been used in many communications applications, fiber lasers, non-linear optical devices, and transmittance with high capacity. High sensitivity gas sensors, and other applications. The development of optical crystal fibers attracted manufacturers in this field as a result of exploring a large variety of possible applications. Therefore, they paid great attention to developing and manufacturing advanced fibers that, He is extensive in many technological applications that the world is witnessing today, after he invented the first types of J-Russell in the 1990s.Crystalline Optical Fibers The research team headed by Philip Saint, Therefore, this field can be considered to be part of the broader field of bandgap structures, Until this, Optical imaging is one of the most emerging areas in current optics research. Fibers offer many degrees of freedom in their design to achieve a variety of distinct properties, making them interesting for a wide range of applications. Therefore, the research dealt with a brief explanation of the types, design and advantages of optical crystal fibers with different, The structure of these fibers is such that the light

signal passes through them in a manner waveguide properties according to. Complete without loss or loss

Introduction

It Traditional fibers are made from special, pure glass, Optical fiber, or ultra-optical fiber, is is long and thin, no more than the thickness of a hair. Many of these fibers are bundled into optical cables, and are used . Its principle is based on the phenomenon of reflectionto transmit optical signals over very long distances. Overall, there are many uses of optical fibers, but connecting to the Internet is the most recent and most common. Optical fibers are based on the principle of directing light using refraction, and the physicists Daniel Colladon and Jacquet-Papin explained it in Paris in the early 1840s. It is scientifically known that during the passage of light from air to water, the incident ray will be refracted. Approaching the pillar on the surface of the water, John Tyndale then included an explanation of this principle John wrote about the property of total internal reflection during his public lectures in London 12 years later. In an introductory book on the nature of light in 1870: During the passage of light from air to water, the incident ray will be refracted approaching the column placed on the surface of the water. However, if the light ray travels from water into the air, it will refract away from the column, and if the angle between the incident beam and the erected, A where we will fully reflect inside column is less than 48 degrees, the light will not enter the air at all. This angle is called the angle limit (for the medium, water (there will be no refraction). 38 degrees in flint glass, and 23 degrees in diamonds. This angle is 48 degrees in water,

Components of optical fiber. Optical fibers consist of two concentric cylinders, the first called the core, surrounded by another cylinder called the cladding, then the protective covering (coating buffer) and the outer sheath of the cable. Jacket Core: It is a thin (cylindrical) glass through which light is transmitted and is made of silica inlaid (with germanium, for example. Silica-Ge). Cladding: A material that surrounds the glass core (another surrounding cylinder) and works to preserve the light in the center of the optical fiber. It is made of silica, so that the refractive index of the core is greater than the refractive index of the covering, which is the required condition for the phenomenon of complete reflection to occur, which is the basis of Directing light in optical fibers, as the light is completely reflected, and by repeating the reflection, the light spreads within the core of the optical fiber and reaches the other end. For fiber. Coating Buffer: A plastic cover that protects the optical fiber From moisture and protects it from damage and breakage.

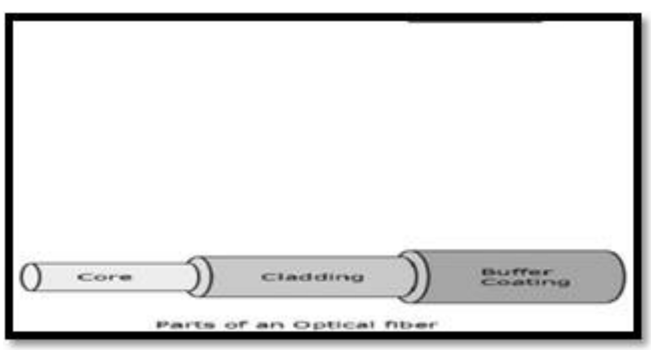

Figure (1) shows the parts of an optical fiber.

3-1 Optical fiber divisions

1-3-1 single mode fiber: Through it, light signals are transmitted in a uniform pattern in each optical fiber in the bundle, and it is used in telephone networks and television cables. This type of fiber is characterized by a small glass core radius. It reaches about 9 microns, and infrared laser rays of short wavelength pass through it nm 1.55-1.3. Multi-mode fiber: With it, many types of optical signals are transmitted through a single optical fiber, which makes its use better for computer networks. This type of fiber has a larger radius, reaching 62.5 microns, through which infrared rays are transmitted. In Table

No. (1) a comparison between single-mode optical fiber and multi-mode optical fiber Some important technical parameters for optical fibers - Numerical aperture of an optical fiber: (NA (aperture numerical).

The numerical aperture of penetration, in addition to the angle of acceptance, is one of the important parameters that express the extent of the ability of light to penetrate through the optical fiber, and the formula by which the numerical aperture is given (without a unit of For the refractive indices of the core and shell: measurement) according to, The acceptance angle is given by the following formulaAcceptance angle = sinÿ1

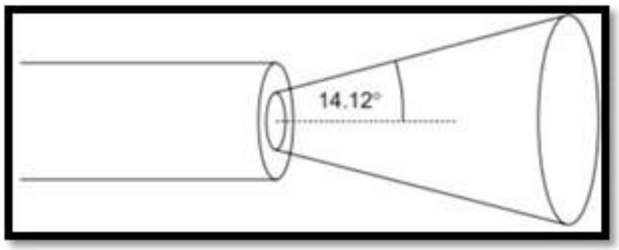

Figure (2) Acceptance cone, which shows the angle Acceptance with a value of 14.12

The acceptance angle ÿ is one of the numerical values that must be known about the optical fiber, and its concept can be summarized as follows: It is the angle at which the incoming ray must enter at an angle equal to or less than it in order to achieve total internal reflection and then spread through the fiber correctly and with the least possible loss, in When the angle of the entering ray is greater than the angle of acceptance, part of it is refracted through, The circumference of the fiber will then be lost, and what remains of it will be reflected inside the fiber, and here we get a reflection of that. In order for the light to be sent for the longest possible distance, we must take into account the introduction of partial light, not value of Cone at total light. It forms something like a cone According to the value of the acceptance angle. Vacuum at an angle not exceeding the, The front of the fiber, which is called the cone of acceptance, as in Figure (2). The cone of acceptance is expressed as the angle through which light is confined to the core and is able to travel along the optical fiber , 4-1 Physical phenomena in optical fiber:

It shows the transmission of light inside an optical fiber according to the cross-section of an optical fiber

A clip Figure (3) shows the phenomenon of total refraction. Application of this in the field of optical communications systems (as a carrier of information). The most important physical phenomena that appear in the optical fiber can be clarified, taking into account that light, Electromagnetic wave - Using Wave Theory by considering light as a line or ray. - Also, using Geometric Optics, by considering that light is a packet of photons, using Quantum Theory, and in order to understand the behavior and work of light. In fiber optics, we will use the second consideration and study light as a beam moving in a specific direction and angle, and the basic laws in optical optics will be applied to it: such as Snell’s laws and reflection. And brokenness. Whenever the angle of incidence changes, it is accompanied by a change in the angle of refraction. In the case of, according to Snell’s law: the angle of incidence of the ray at the entrance to the fiber is greater than the critical angle. Therefore, the critical angle is the special case of the value of the angle of incidence of the ray when its angle of refraction is 90 degrees, then the light It is completely reflected within the core of the optical fiber, and this phenomenon is called total internal reflection, It is also known as waveguide, and if the light falls at an angle less than the critical angle, part of the light will be reflected inside the core of the fiber (partial internal reflection), and another part will be refracted across the perimeter of the fiber, leading to its exit from the fiber and then leading to increased loss. phenomenon of refractionIt shows the transmission of light inside the optical fiber according to the figure 2.

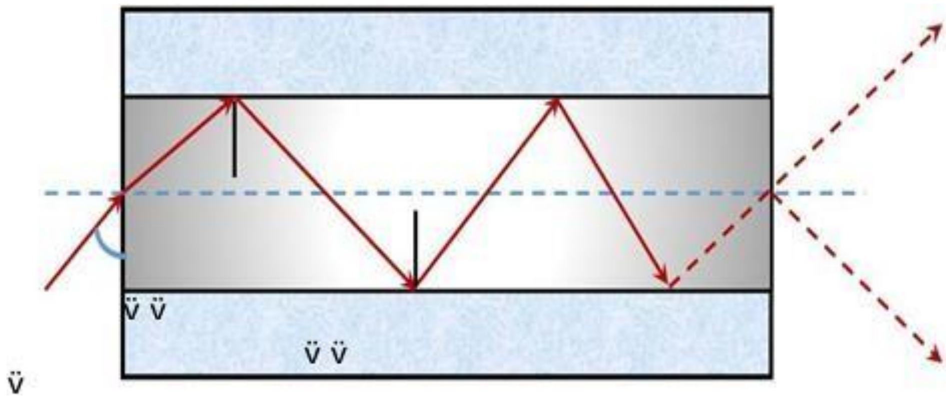

Figure (3) shows a cross-section of a total optical fiber.

5-1 Properties of fiber optics: Optical fibers have revolutionized the world of communications due to their superiority over regular connection wires. They are: 1 - More capable of carrying information. Because optical fibers are thinner than regular wires, a large number of them can be placed within one bundle, which increases the number of telephone lines or the number of television broadcast channels in one rope. It is enough to know that the bandwidth of optical fiber reaches 50THZ, while the largest bandwidth needed by television broadcasting does not exceed 6Mhz. - Smaller in size, as its radius is less than half the diameter of traditional copper wires. For example, a copper wire with a diameter of 7.62 cm can be replaced with another optical fiber whose diameter does not exceed 0.635 cm. This represents special importance when laying wires underground. 3 - It is lighter in weight. Copper wires weighing 94.5 kg can be replaced with optical fibers weighing only 3.6 kg. 4- Less loss of transmitted signals 5- It is not possible for signals transmitted through adjacent fibers in one rope to interfere, which ensures the clarity of the transmitted signal, whether it is a telephone conversation or a television broadcast. It is also not exposed to electromagnetic interference, which makes the signal transmitted completely confidentially, which is of particular importance for military purposes. 6- Non-flammable, which reduces the risk of fires 7- It requires less power in generators because the loss during the connection process is small, Because of these advantages, optical fibers have entered many industries, especially communications and computer networks. It is also used in all types of medical imaging, as well as high-quality sensors for changes in temperature and pressure, which have applications in underground exploration.

6-1 Problems with optical fibers.

Methods of interference: Noise in optical fibers is also known as the loss during the transmission process. It is a reduction in the intensity of the optical beam (signal) that is transmitted through the transmission medium. The interference coefficient in optical fibers is measured in decibels/km through the medium due to the relatively high quality of transparency of the optical transmission media. The physical medium is usually fibers of silica glass that trap the light beam inside. Distortion is an important factor that determines the process of transmitting digital signals over long distances. Therefore, most research revolves around reducing interference and increasing the amplification of the optical signal. Experimental research has shown that interference in optical fibers is caused by scattering and absorption. -28SMF can be manufactured, Low loss single mode optical fiber. The Coring optical fiber, which is considered the reference wavelength for communications, has a loss rate of 0.17 dB/km over 1550 nm. For example, when using 8 km of optical fiber, 75% of the light is transmitted over a distance of 1550 nm. It has been observed that if ocean water were as pure as fiber optics, we would be able to see all the way down to the Mariana Trench in the Pacific Ocean, 36,000 feet deep. - Scattering of light

The propagation of light through an optical fiber depends on the total internal reflection of the light beam. Rough and irregular surfaces, even at a partial level, can cause rays to reflect in random directions. This is what we call reflected propagation or dispersion, and can be characterized by a wide range of light scattering angles depending on the length. The wavelength of the scattered light beam, therefore, creates boundaries for the reflection areas. The spatial dimension of vision, depending on the frequency of the sharp light wave and the physical dimension (or spatial scale) of the scattering center, which is usually in the form of small, specific structural features. Since visible light has a wavelength on the order of one micrometer (millionth of a meter), the scattering centers have dimensions on a spatial scale. Similar. Distortion results from the scattering of light at the outer surface and the inner surfaces. In crystalline materials such as metals and ceramics, in addition to pores, most of the inner surfaces or outer surfaces are in the form of boundaries that separate small regions of the crystal system. It has recently been shown that when the size of the scattering center decreases Within the limits of the wavelength of the scattered light, scattering no longer occurs to a significant extent. This phenomenon has led to the production of transparent ceramic materials. Also, the scattering of light in optical fibers is due to molecular irregularities (compositional fluctuations) in the glass structure In fact, one of the emerging schools of thought is that glass is simply a limiting solid state and in this context, it becomes "spheres".

Showing different degrees of short-range order are the building blocks of both metals and alloys, as well as glasses and ceramics. Distributed between and within these areas are small structural defects that provide the most ideal locations for light scattering. This same phenomenon is considered one of the factors that limit the transparency of infrared rays. Dispersion can also be the result of nonlinear optical processes in the fiber. Ultraviolet and infrared rays. In addition to light scattering, distortion or loss in the wave, also due to selective absorption of specific wavelengths, in a manner similar to that responsible for the appearance of color. Raw materials include: Electrons and molecules are as follows: At the electronic level, it depends on whether the electronic orbitals are spaced apart (“quantized”) such that they can absorb an amount of light (or “photon”) of a particular wavelength or frequency in the ultraviolet or visible ranges. Optical crystal fibers, Photonic Crystal Fibers, introduction ,Crystal Photonic Fibers (PCFs) are among the advanced types that have come into use in many contemporary technological applications and in many wide fields. The simplest (and most widely used) type of optical crystal fibers contains a triangular pattern of holes With one hole missing, that is, with a solid core surrounded by a group of air holes. Air, the indicative properties of this type of PCF can be roughly understood using an effective indicator model: the area in which Missing holes have a higher effective refractive index, similar to the core in conventional fibers. There is also something It is called a bandgap fiber (6 fibers) (PBG fiber) [with a completely different routing mechanism, based on a gap. Optical scope of the cladding area. The latter mechanism even allows routing in a hollow core (i.e. in a low-index region), such that most of the energy is propagated in the central hole (ÿ hollow-core fibre). Such air-guided hollow photonic crystal fibers (or air-bandgap fibres) can have Very low level of nonlinearity and high damage threshold They usually only direct light In a relatively narrow wavelength region of width e.g. 100-200 nm and can be used for example for pulse compression at high optical density, as most of the energy is scattered in the hollow core. Most PCFs are made of pure fused silica (ÿ silica fibres), which is consistent with the manufacturing techniques mentioned above. Most notably of heavy metal Many PCFs made of other materials have been shown, That and yet soft glass and polymers (plastic optical fibres), which are sometimes even used for terahertz radiation.

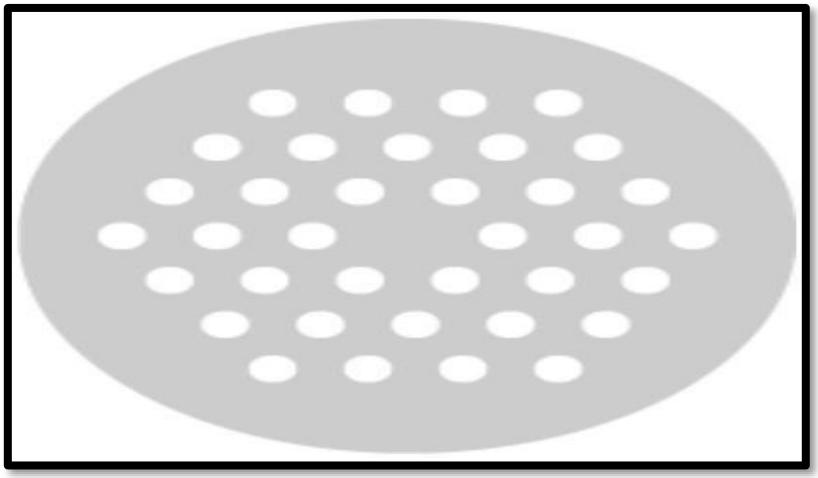

Figure (4) shows a model of an optical crystal fiber.

2 Types of optical crystal fibers

1-1-2 PCFs Mode Single Endlessly: Endless single-mode crystalline optical fibers are thin silica glass fibers that possess a regular array of microscopic holes that extend along the entire length of the fiber [2]. led discovery PCFs offer many possibilities, from directing light in a vacuum, to achieving scattering properties. Extraordinary, from enhancing nonlinear effects to high light confinement and minimizing nonlinear effects themselves through the very large mode area of single-mode fibers [1] - [4]. In addition,

PCFs have the amazing property of being single-mode and endless [5]. In other words, it can remain in single mode across all wavelengths. These led to the unusual properties of PCFs has led to increased interest in their application in areas such as sensing, signal processing, and optical , that communications systems [6]. patternInfinite single-mode photonic crystal fibers are non-doped silica fibers that use a triangular A of air holes to form the cladding. Since the anisotropy index between the core and the shell, n, is determined solely by the geometry of the air holes, it is possible to fabricate fibers with a very small and precise fin, and thus, Having very low numerical apertures and very large placement areas.

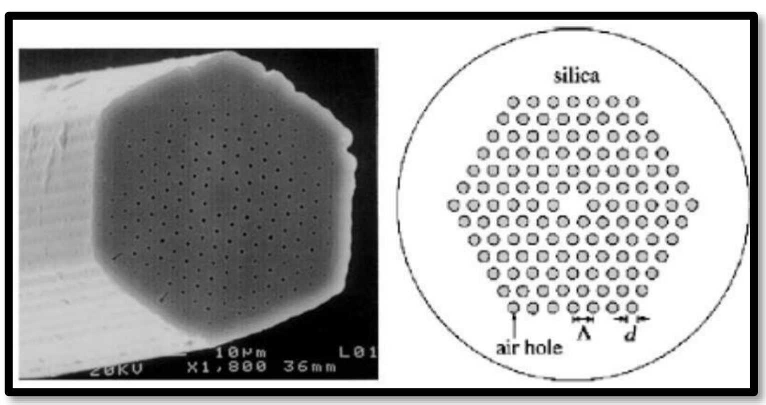

Figure (5) shows a PCFs Mode Single Endlessly crystalline optical fiber

The most important features of this type of fiber are:

- ✓ Low fiber loss over a wide wavelength range
- ✓ Single mode at all wavelengths
- ✓ Radiation of solid silica fibers

✓ Wavelength independent MFD

2-1-2 Hollow Core PCFs:

Hollow Core PCFs[37] is an optical fiber that essentially directs light into a hollow area, so that only a small portion of the light energy is propagated through the solid fiber material (usually Given the standard physical mechanism for directing light in a fiber, it should not be possible:Glass). According, Normally, the refractive index of the fiber core must be higher than the surrounding cladding material, and there is no way to get the refractive index of glass lower than that of air or vacuum. At least in the region, another guiding mechanism could be used: one possibility is to exploit a gap that Optical spectroscopy. With the photonic range, it can also be achieved in photonic crystal fibers with a specific structure. These fibers are also called bandgap fibers. (Note that not all optical fibers are gapped, The bundle has a hollow core.) A particularly simple design (also resulting in simplified production) is the fiber Hexagonal hollow cores [12, 21] contain a pattern of silica rings (with a circular or elliptical cross section) around the hollow core; these do not use an optical band gap and cannot. Think of them as photonic crystal fibers. The fiber preform can be made relatively simply by arranging a number of Silica whiskers, resulting in thin glass films after drawing into the fibers. The finer version has additional smaller rings nested within the larger rings [20, 30], and can provide more low propagation loss. Real loss reduction can also be achieved by decoupling Pipe slightly, avoiding nodes touching each other. The term negative curvature fibers refers to the boundary curvature in the opposite direction to the annulus around the heart. Other terms, which contain the attribute anti-resonant, emphasize the aspect of reducing loss through the design of the glass structure of the optical anti-resonant, i.e. relative phase changes suitable for reflection at different interfaces.

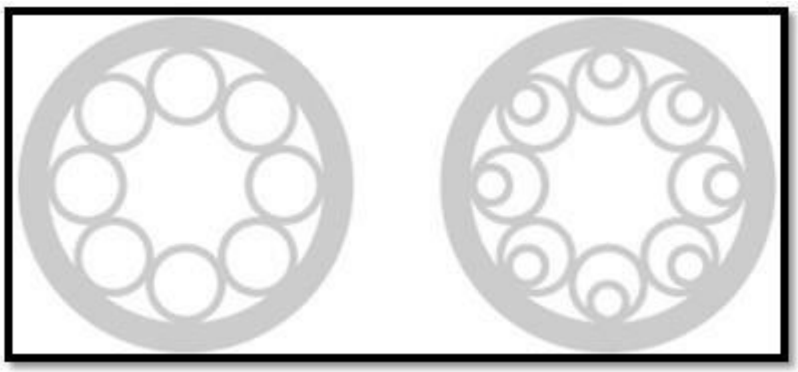

Figure (7) shows a Hollow Core PCFs

- Propagation losses: Propagation losses for hollow fibers are usually much higher than those for solid fibers – especially when: There are ways to mitigate that trade-off that single-mode guidance is required. And with [15]. Recently, some hollow fibers with low losses have been achieved - almost by comparison

With modern hard-core silica fibers in the optimum wavelength region of about 1.5 µm, [32]. Likewise low losses appear to be possible in the wider wavelength region, where silica absorption or scattering is much higher. With glass it is even possible to direct light at wavelengths where the low overlap of the intensity profile makes the transparency of the glass material relatively weak. For example, this has been demonstrated using high- energy pulses from an Er:YAG laser at 2.94 ÿm [13]. Even the light from a dioxide laser Carbon at 10.6 µm can be guided by these fibers [3]. Hence, hollow fibers are interesting for delivering high-energy beam in a wide range of wavelengths. - Nonlinearities Weak with weak spatial overlap in the glass The fact that the light is directed mainly in air, with only structure, reduces nonlinear effects (especially for ultrashort pulses with high peak power) and makes possible a high damage threshold. Note that the Kerr effect in air is about That's mostly down to low density.

Three times of the glass, and it returns - Dispersion Chromatic, Especially for bandgap fibers, the chromatic dispersion of such fibers can be engineered by designing optical fibers with a small mode area. This is also particularly interesting for superimpulse routing, Short, where large amounts of chromatic dispersion and nonlinearity can lead to severe pulse distortions.

3-1-2 Multi-core crystalline optical fiber (PCFs-Multi). A unique type of optical crystal fiber known as (core-multi). A composition can be made great prospects for developmentP. CFs). This can greatly improve the power output, so it has For example, using a basic binary PCF, we show mode coupling between cores. The clip appears, The transverse two-core PCF in Figure (8)

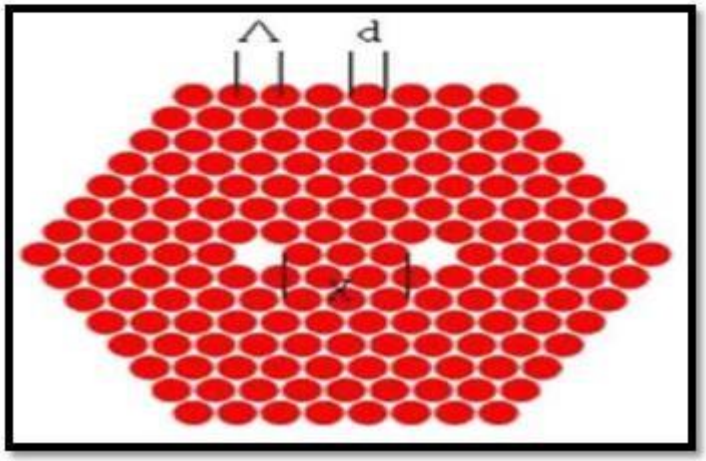

Figure (8) shows a cross-section of a PCF core.

Light PCF photonic crystal fiber can provide large mode area and low numerical aperture, meanwhile, provide propagation activation rate, good beam quality, and effective dispersion control. Coherent fusion is an effective way to increase the output power of fiber lasers. Hence, it is very advantageous to develop a high-energy fiber laser using coherent fusion through multi-inversion PCF. In this work, using multi-core PCF design and cohesive combination technique, there are air holes surrounding them uniformly to form the cladding. Between these cores the solid glass is filled.

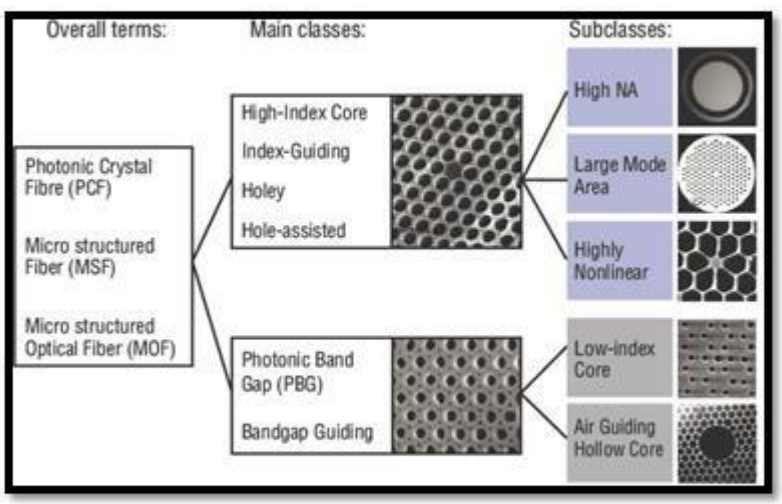

Figure (9) shows the classification of optical crystal fibers [37].

3-2 Active fibers for amplifiers and lasers

1- Propagation modes in optical crystal fiber: In most cases, photonic crystal fibers either have only single-mode propagation or support a small number of guided modes (few-mode fibres). The density profiles of the guided modes are concentrated, The fundamental modes are largely in the core, while higher order modes tend to expand more in the cladding region. Normally, mode fields extend to the air openings only by a very small amount; The intensity pattern is "squeezed" between the holes. Calculating style profiles for these fibers is relatively difficult, (a) because it does not... radial symmetry is given, as is the case for most all-glass fibres, and (b) due to the large refractive index contrast between air and glass. Advanced mode solver software is required, which generally requires much longer computation times than simple mode solvers that are limited to modes LP. Characteristics that can be achieved by design Photonic fibers with different hole pattern designs (with respect to the underlying geometry of the mesh, displacements) can have very fine properties, the relative size of the holes, and perhaps small depending strongly on the design details: - It is possible to have a very high numerical aperture such as 0.6 or 0.7 of multi-mode fiber (also for pump cladding of multi-mode fibre) double(Single-mode guidance is achieved over very wide wavelength regions (single fiber). Endless mode) for small ratios of hole size and hole spacing , Mode areas can be very small or very large (perhaps with a lower NA than is possible using conventional fibres).

These lead to very strong or very weak optical nonlinearities. PCFs have low sensitivity to bending losses even for large mode areas. Some arrangements of holes lead to an optical bandgap (ÿ optical bandgap fiber), where guidance is possible even in a hollow core, since a higher refractive index is no longer needed in Inner part. Such hollow fibers directing air are interesting as an example for dispersive pulse compression at high pulse energy levels. Especially for large holes, there is a possibility of filling gases or liquids into the holes. Gas-filled PCFs can be exploited for fiber optic sensors, for nonlinear spectral broadening at very high power levels, or for variable power attenuators. Asymmetric hole patterns can lead to very strong refraction of the fibers that maintain polarization. larger placement areas. This can also be combined with - Strong polarization-dependent attenuation (polarized fibre) can be obtained in different ways. For example, there can be a fundamental polarization-dependent cutoff, such that the fiber directs only light with one polarization in a given wavelength range. Likewise, it is possible to prevent Raman scattering by strongly attenuating the longer-wavelength light. Highly unusual chromatic dispersion properties, e.g. abnormal dispersion in the visible wavelength region results, in particular from PCFs with small mode areas. There is design freedom that allows different combinations of desired parameters, Great, which, Coreless end caps can be manufactured by simply fusing holes near the end of the fiber with a heat treatment. Sealed end sides allow larger mode areas on the fiber surface and thus a higher damage threshold, for example for amplification of intense nanosecond pulses eg with a regular pattern of core structures in a single fiber - multi-core designs are possible, where there may or may not be coupling between the cores

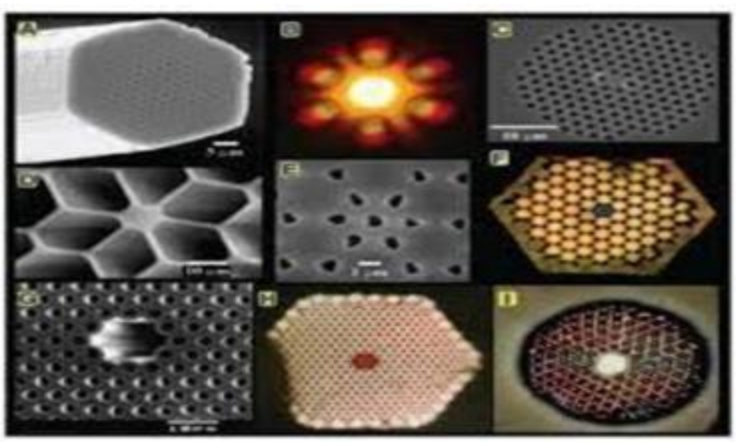

Figure (10) shows microscopic images of the types of optical crystal fibers.

4-2 The main application areas of crystalline optical fibers, They can be used to deliver laser radiation, for example with high average energy in the broad wavelength regions from the ultraviolet to the mid-infrared, or for radiation in the form of ultrashort pulses with high peak energy. They may be useful for data transmission, especially in situations where there is very low latency (delay (time) is vital. Also, one can exploit low-loss data transmission in spectral regions where absorption losses of solid silica fibers are very high. By transmitting light with a Significantly larger optical range, one can achieve higher transmission capabilities in terms of data rate. Miniaturized gas-based Raman lasers can be achieved, because the interaction of an optical beam directed by a hollow fiber is much more intense than the interaction of a free-space beam in a multi- compartment gas cell. Likewise, a number of other nonlinear functions can be achieved using gas- filled hollow fibers [31].

Conclusions

Based on the above, PCF photonic crystal fiber has large mode area and low numerical aperture, meanwhile, it provides light propagation activation rate, good beam quality, and effective dispersion control. This is the result of high-quality wave guidance as a result of the unique features provided by advanced manufacturing techniques for this type of fiber. The multi-core optical crystal fiber provides an effective way to increase the output power of the fiber laser. Therefore, in this study, these types of fibers were defined and distinguished from traditional fibers.

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