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Next Generation of Optical Fibers

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Abstract: *In present situation, applications of optical fibers have considerably reached with great levels of research which having been focused on the development of not only new generations of optical fiber materials and designs, but also on new processes for their preparation. Here the latest developments in advanced materials for optical fibers ranging from silica, to semi-conductors, to particle-containing glasses, to chalcogenides and also in process-related innovations are discussed.*
Keywords: *Total internal reflection, Step Index & Graded Index, Silica-based optical fibers; Nanoparticle-doped glasses; semiconductor core optical fibers; chalcogenide optical fibers.*
Optical Fiber- Communication may be defined as the transfer of information from one point (Source) to another (destination).For the information to be transmitted over a distance, a communication system is usually required.

I. Fiber-Optic System-

Communication system that uses light as the carrier of information from a source to a destination through a guided cable (glass or plastic) are called Fiber-optic system.

Optical fiber is the technology associated with data transmission using light pulses traveling along with a long fiber which is usually made of plastic or glass. Metal wires are preferred for transmission in optical fiber communication as signals travel with fewer damages. Optical fibers are also unaffected by electromagnetic interference. The fiber optical cable uses the application of total internal reflection of light. The fibers are designed such that they facilitate the propagation of light along the optical fiber depending on the requirement of power and distance of transmission. A single mode fiber is used for long-distance transmission while multimode fiber is used for shorter distances. The outer cladding of these fibers needs better protection than metal wires.

Types of Optical Fibers-

The types of optical fibers depend on the refractive index, materials used and mode of propagation of light.

The classification based on the refractive index is as follows:

- **Step Index Fibers:** It consists of a core surrounded by the cladding which has a single uniform index of refraction.
- **Graded Index Fibers:** The refractive index of the optical fiber decreases as the radial distance from the fiber axis increases.

The classification based on the materials used is as follows:

- **Plastic Optical Fibers:** The polymethylmethacrylate is used as a core material for the transmission of the light.
- **Glass Fibers:** It consists of extremely fine glass fibers.

The classification based on the mode of propagation of light is as follows:

- **Single Mode Fibers:** These fibers are used for long-distance transmission of signals.
- **Multimode Fibers:** These fibers are used for short-distance transmission of signals.

The mode of propagation and refractive index of the core is used to form four combination types of optic fibers as follows:

- Step index-single mode fibers
- Graded index-Single mode fibers
- Step index-Multimode fibers
- Graded index-Multimode fibers

How Does an Optical Fibre Work-

The optical fiber works on the principle of **total internal reflection**. Light rays can be used to transmit a huge amount of data but there is a problem here – the light rays travel in straight lines. So unless we have a straight long wire without any bends at all, harnessing this advantage will be very tedious. Instead, the optical cables are designed such that they bend all the light rays' inwards (using TIR). Light rays travel continuously, bouncing off the optical fiber walls and transmitting end to end data. Although light signals do degrade over progressing distances, depending on the purity of the material used, the loss is much less compared to using metal cables. A Fibre Optic Relay System consists of the following components:

- The Transmitter – It produces the light signals and encodes them to fit to transmit.
- The Optical Fibre – The medium for transmitting the light pulse (signal).
- The Optical Receiver – It receives the transmitted light pulse (signal) and decodes them to be fit to use.
- The Optical Regenerator – Necessary for long distance data transmission.

Because of their attributes (high reliability over long distances, low attenuation, low interference, high security, very high information capacity, longer life span and ease of maintenance), optical fibers have had a profound impact on telecommunication where they transport light pulses from one point to another. The first commercially-relevant fibers, made from silica (SiO_2) glass, were developed in the 1960s. Shortly thereafter, the first low loss optical fibers were realized .

A half-century after the development of the first optical fibers, enabled by the ubiquity of telecommunication-grade glass fibers, optical fibers have found numerous other applications in laser-based manufacturing (e.g., precision cutting, drilling and welding), illumination, sensing and imaging, to cite just a few. Optical fibers also are well suited to biomedical applications. They can be used to view inside the body without having to perform surgery, as the optical fiber can be easily inserted—due to their small size and flexibility—into veins, arteries, lungs and other accessible parts of the body. They can be used as physical sensors of temperature, pressure and radiation; and also as chemical sensors of pH, partial pressure of blood gases and glucose, as reviewed. Those many new applications have initiated a global search for new material- and process-oriented innovations, as the wavelength of the light used in the application dictates the selection of enabling materials and designs.

Here is an overview of the advanced materials and processing innovations employed for the preparation of next generation optical fibers. This overview is divided in five parts. The first section presents the recent progresses in the development of **silica-based fibers**. The latest developments in fibers with nanoparticles contained within the core and semiconductor core fibers.

1. Silica-Based Optical Fibers

Rare-earth (RE)-doped fiber-based lasers are a very active area of present research and development due to their compactness, excellent beam quality and handling capability. Accordingly, the fabrication of new RE-doped fibers has attracted considerable attention with improvements in lasing performance being a prime motivation. Silica glass remains the main glass host for fiber lasers due to its excellent transparency, high mechanical strength and thermal robustness.

Rare-earth (RE)-doped fibers have often been fabricated using a combination of modified chemical vapor deposition (MCVD) and solution doping, given the simplicity and versatility of these processes in the manufacturing of single or low-moded fibers

2. Nanoparticle-Doped Glasses and Fibers

Two types of fluorescent nanocrystals (NCs)—upconversion nanocrystals (UPNCs) and nanodiamond (ND)—have attracted particular interest for photonics applications in recent years. Lanthanide ions doped into UPNCs enable emissions in the ultraviolet to visible spectral range due to the upconversion of two or more near-infrared excitation photons. Recently, highly concentrated active lanthanide ion-doped UPNCs were found to emit high brightness upconversion by excitation enhancement. This new generation of UPNCs is particularly promising for various applications, such as, for example, biological sensing, anti-counterfeiting, photon energy management and volumetric displays.

3. Semiconductor Core Optical Fibers

Another significant area of optical fiber materials' development involves the fabrication, optimization and application of glass-clad fibers comprising semiconductor cores. Semiconductors, the work-horse of the optoelectronics industry, enable all modern electronic conveniences, as well as a growing number of photonic devices; i.e., silicon photonics. attention to this new field. A number of papers reviewing the advances on this topic have been

It is also important to note that, unlike traditional glass fibers, additional solid-state and liquid-phase chemistry not only can take place during the fabrication of these fibers, but can be strategically employed. Two excellent examples are the fabrication of zinc selenide (ZnSe) fibers using Zn and Se compounds and silicon fibers realized from aluminum in both cases, reactions occur in-situ during the draw, opening the door to an even richer range of materials and chemical/process routes to intriguing new fibers not possible using conventional methods.

Though considerable progress has been made over the past decade, glass-clad semiconductor core optical fibers generally perform on par with their planar waveguide analogs; at least in terms of optical attenuation with losses on the order of dB/cm levels; for a comparison of loss values, see. While the exact loss

mechanisms that dominate are still a source of debate and investigation, a number of studies have begun to narrow down the most critical.
In addition to the aforementioned efforts to develop semiconductor core fibers from a wider range of core materials and cladding compositions, significant work has also gone into the processing of the fibers in order to both understand the science of the crystal formation and to optimize its single crystallinity.

4. Innovative Chalcogenide Glasses and Optical Fibers

This section discusses important advances in chalcogenide glasses and fibers. In recent years, applications have increased for fibers operating in the mid-infrared (mid-IR) region, which can be defined as the 2–20-µm electromagnetic spectral range. Indeed, this spectral region covers the atmospheric transmission windows (3–5 µm) and (8–12 µm) in which thermal imagery (military and civilian) is routinely employed. Furthermore, the mid-IR window corresponds with the molecular fingerprint region where molecules have strong absorption bands. In this context, the development of mid-IR transparent materials and optical fibers is essential. Consequently, numerous research activities for developing innovative mid-IR optical fibers and, more particularly, chalcogenide optical fibers have been reported. In this section, the transmission window of different chalcogenide fibers will be presented and discussed depending on the composition and purification process as will be ordinary and original fiber designs. Finally, applications in mid-infrared spectroscopy based on passive or active chalcogenide fibers will be discussed.

In the 1990s, a new type of fiber, the microstructured optical fiber (MOF), attracted much interest. Since then, this new fiber design has been made using many glasses and, since 2000, has been extended to chalcogenide glasses. Here, the interest is to combine the properties of microstructured fibers with those of chalcogenide glasses (mid-infrared transmission and high nonlinear properties). In most cases, only one material is required to guarantee the light propagation in the core. The inclusions surrounding the core are generally filled with air. Contrary to the fabrication of standard fiber, there is no need to control precisely the index of refraction difference between core and cladding. Due to their mid-IR

The principle of the FEWS method can be compared to the attenuated total reflection (ATR) spectroscopy. In an optical fiber, the light propagates by total internal reflection. When a sensate is in contact with the surface of a chalcogenide fiber, the evanescent wave can be partially absorbed. The optical signature of the sensate will be observed at the output of the fiber. The first experiments using chalcogenide fibers have reported the detection of different chemical substances, such as butanone, acetone and ethanol. Later, the chalcogenide fiber has been used in more complex media, in order to achieve environmental and biomedical purposes. Often used with liquids, the FEWS method can be also used for tissue analysis and gas analysis. Before 2014, all of the fibers used were selenide based. With selenide fibers, the longer wavelengths that can be detected are around 11–12 µm. Indeed, as illustrated in, the attenuation losses of selenide-based fibers such as $As_{40}Se_{60}$ fiber or $As_{20}Te_{30}Se_{50}$ fiber are too strong for wavelengths longer than 11 µm.

II. Conclusions and Future Opportunities

Over the past decade, considerable progress has been achieved in the development of glasses and processes for the manufacture of advanced optical fibers. Given the material attributes, existing manufacturing infrastructure and commercial success of optical fibers, it is without question that work will continue to further improve fiber compositional and design flexibility, process simplicity, and the spectroscopic efficiencies of active fibers. Fabrication technologies for optical fibers are constantly evolving, driven by economic motives, and will favor the most cost-effective technologies for larger scale preforms.

Continued research into ND-doped and UPNC-doped tellurite glasses and fibers to date suggests that the direct doping method is a powerful technique to add NCs in a glass matrix. Future work is anticipated to comprise the use of other NCs and glasses to advance the understanding of the interaction of NCs with the glass matrix during the doping step to reveal the impact of NC and glass composition on the dissolution and dispersion of the NCs in a glass. Future NC-doped glasses and fibers with improved dispersion and enhanced control of dissolution are expected to pave the way for practical applications ranging from photonic sensor, photonic memory, single photon sources, to microcavity lasers, as well as full-color display systems. The direct doping method can be further investigated so that other NCs with photonic, electronic and magnetic properties of interest could be added, leveraging the performance and functions of the new NC-doped glasses and fibers enabled by the direct doping approach.

Areas of note for future research and development include continued efforts to realize fibers from new/different compositions (e.g., GaAs and other binary and ternary semiconductors; particularly ones exhibiting $\chi^{(2)}$ nonlinearities), tailoring of cladding glasses in order to better match semiconductor thermomechanical properties and IR transparency, single-mode fibers, possibly based on tapering, which exhibit enhanced nonlinearities, and novel in-fiber junction and photovoltaic devices. These seem particularly to be where the greatest value arises from the marriage of semiconductor physics and fiber optics. Lastly, the growing interest for the mid-IR wavelengths and mid-IR spectroscopy analysis will motivate and enhance the development of new mid-IR materials and fibers, such as chalcogenide glasses and fibers.

Advantages of Optical Fibre Communication

- Economical and cost effective
- Thin and non-flammable
- Less power consumption
- Less signal degradation
- Flexible and lightweight

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