FIBER BASICS AND FABRICATION (2022)

Keles, Yasin, *Istanbul Technical University*

***Abstract*— This article examines the basic components, types, fabrication processes, and applications of fiber optics. The importance of fiber optics in many areas such as medical, telecommunication, defence industry, and broadcasting emphasized.**

***Index Terms*— Applications, communication, deposition, fabrication, fiberoptic, oxidation**

I. INTRODUCTION

In today's digital age, access to information and communication are rapidly developing. At the center of these developments are fiber optic cables capable of carrying data at the speed of light. First discovered in the 1960s, fiber optics, although initially based on a simple principle, have become a revolutionary tool in the world of communication with the advancement of technology. Today, fiber optics play an indispensable role in many areas, from the health sector to telecommunications, from the defense sector to the broadcasting sector. In this article, the basic working principles, types, production processes and application areas of fiber optics will be examined in detail.

II. BASIC COMPONENTS OF A FIBER AND FIBER TYPES

Fibers have become the backbone of communications, enabling high-speed data transmission over vast distances nowadays. The major fiber types are plastic, glass, and photonic crystal fibers. Plastic fiber uses plastic materials but generally more challenging to install compared to glass fibers. Glass fibers that composed of fused metal oxides exhibit exceptional dimensional stability at both high and low temperatures without moisture absorption. Photonic crystal fiber guides light using a pattern of air holes in the fiber instead of only differences of refractive index. Common fabrication techniques for manufacturing fibers, involve vapor deposition processes and chemical vapor deposition processes within silica tubes to create soot layers which are drawn into fiber.

Optical fibers are widely used for high-speed transmission of data, voice, and video signals over very long distances, with capacities exceeding 10 gigabits per second [1].

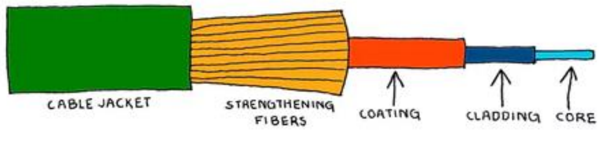

Image 1. Basic Components of a Fiber Optic Cable

Optical fibers consist of:

- Core
- Cladding
- Coating
- Strengthening fibers
- Cable jacket

A. Core

Corresponding their intended use, fiber cores can be used in a range of applications. The core size is different for different kinds of fiber optics. Single-mode fibers, commonly used in telecommunications, typically have core diameters ranging from 8 to 10 micrometers, while multimode fibers have larger cores, usually between 50 and 62.5 micrometers.

B. Cladding

The cladding, a thin layer surrounding the core, confines light waves within the fiber, enabling data transmission. This layer, with a lower refractive index than the core, is crucial for the fiber's functionality.

C. Coating

The essential protective layer, the coating, safeguards the fiber from physical damage, such as shocks, scratches, and moisture, acting as a protective barrier. This coating typically has an outer diameter of 250 or 900 microns.

D. Strengthening fibers (aramid yarn)

Aramid yarn serves as a crucial tensile strength member in fiber optic cables, ensuring the cable's resistance to stretching and breakage under tension. Additionally, it enhances the cable's protection against crushing and bending. Due to its inherent flame resistance and self-extinguishing properties, aramid yarn can also be employed as a fire-protection component.

E. Cable Jacket

The protective jackets encasing fiber optic cables play a crucial role in safeguarding the delicate fibers within from external damage, including physical impact and environmental factors.

Materials-based kinds of fiber

- Plastic Fibers
- Glass Fibers
- Photonic Crystal Fibers

A. Plastic Fibers

- Plastic Optical Fiber (POF) is a type of optical fiber manufactured from plastic materials.
- POF standardization is founded on multilevel PAM modulation, a frame structure, multilevel coset coding modulation and Tomlinson-Harashima precoding.
- Despite its complexity, glass optical fiber is the more widely used option in telecommunications.
- Due to the specialized handling and installation procedures required, the actual cost of glass fiber is significantly much higher.

B. Glass Fibers

- Glass is manufactured through the fusion of metallic oxides, sulfides, or selenite compounds.
- Even when exposed to extremely high or low temperatures, glass fiber does not undergo any dimensional changes.
- Glass fibers are resistant to water and maintain their physical and chemical properties.
- Due to its inorganic nature, glass fiber is non-combustible and maintains approximately 25% of its initial strength at temperatures as high as 1000°F.

Image 2. Glass Fibers

C. Photonic Crystal Fibers

- Photonic crystal fiber (PCF) is a type of optical fiber that based on features of photonic crystals.
- The applications of PCFs extend to various areas such as fiber-optic communications, high-power transmission, nonlinear devices and highly sensitive gas sensing and etc.
- PCFs guide light through a high index core surrounded by air holes.

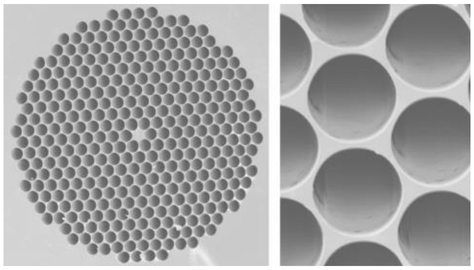

Image 3. Photonic Crystal Fibers

III. FIBER FABRICATION

The two primary techniques employed by fiber manufacturers for fabricating single mode and multimode glass fibers are vapor phase oxidation and direct-melt processes.
The popular vapor-phase oxidation process involves reacting highly pure metal halide vapors, such as SiCl4 and GeCl4, with oxygen to produce a white powder of SiO2 particles, commonly known as soot.
Manufacturers deposit soot onto a glass substrate (mandrel) or within a hollow tube using one of the following four methods during the vapor phase oxidation process:

- Outside Vapor-Phase Oxidation (OVPO)
- Vapor-Phase Axial Deposition (VAD)
- Modified Chemical Vapor Deposition (MCVD)
- Plasma-Activated Chemical Vapor Deposition (PCVD)

A. Outside Vapor-Phase Oxidation (OVPO)

First layer of SiO2 particles, known as soot, is deposited onto a rotating graphite or ceramic mandrel using a burner.
The glass perform is constructed layer by layer using glass soot. The preforms are typically 10-25 mm diameter and 60-120 cm long from which fibers are drawn.
Glass halide vapor is precisely controlled to form the core and cladding.
Following the deposition process, the glass rod is removed, and the porous tube is verified by heating it to a high temperature of 1400°C.
The central hole, which is present initially, reduce during the drawing process.

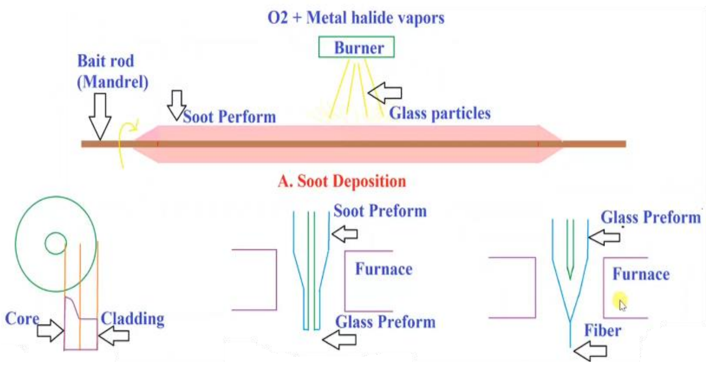

Image 4. Outside Vapor-Phase Oxidation Process

B. Vapor-Phase Axial Deposition (VAD)

A porous preform is created and grown axially by moving the rod upward.
The rod is continuously rotated to hold cylindrical symmetry during particle deposition.
As the preform moves upward, it undergoes a transformation into a solid state.
The resulting solid preform can then be drawn into a fiber by heating it in a separate furnace.

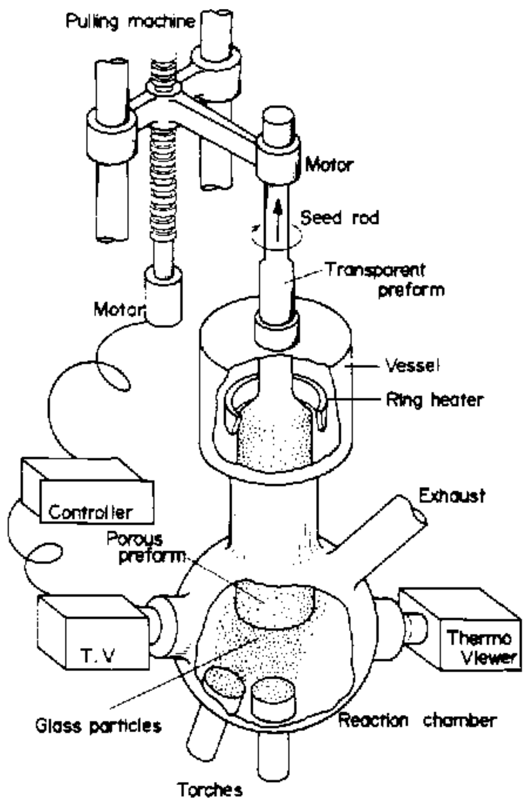

Image 5. Vapor-Phase Axial Deposition Process

C. Modified Chemical Vapor Deposition (MCVD)

A rotating silica tube is filled with glass vapor particles produced by the reaction of metal halide gases and oxygen.
As SiO2 particles accumulate, they are sintered into a clear glass layer by a moving oxyhydrogen torch.
After reaching the target glass thickness, the vapor flow is terminated, and the tube is subjected to intense heating to form a solid preform.
The fiber, drawn from the preform rod, will feature a core consists of the vapor-deposited material and a cladding derived from the original silica tube.

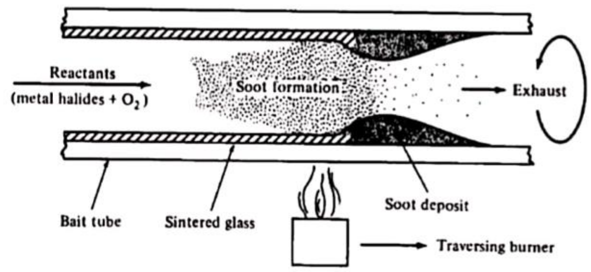

Image 6. *Modified Chemical Vapor Deposition Process*

D. Plasma-Activated Chemical Vapor Deposition (PCVD)

To alleviate mechanical stress in the growing glass films, the silica tube is maintained at temperatures between 1000°C and 1200°C. A moving microwave resonator, operating at 2.45 GHz, generates a plasma inside the tube to initiate chemical reactions.

This process directly deposits clear glass material directly on the tube wall without soot formation. Hereby, no sintering is required. Once the desired glass thickness is reached, the tube is collapsed into a preform, similar to the MCVD process.

The direct-melt process involves melting multicomponent glass rods to form the core and cladding of a fiber.

A common technique, the double-crucible method, involves two different glass rods for core and cladding are used as feedstock for two concentric crucibles. Molten core glass is held in the inner crucible, and cladding glass is held in the outer crucible. Fibers can be drawn from the molten glass through orifices in the bottom of the two concentric crucibles [2].

IV. APPLICATIONS

The following areas can be given as examples of the applications of fiber optics.

A. Medical Industry

Optical fibers, due to their thin and flexible nature, are integral to various medical instruments. Fiber lasers power a range of medical applications, including surgical procedures, endoscopic examinations, microscopic analysis, and biomedical research [3].

B. Communication

Optical fibers form the backbone of modern communication systems, enabling rapid and accurate data transmission. By employing fiber-optic cables for both transmitting and receiving signals, networks can achieve significantly higher speeds and improved performance compared to traditional copper-based systems.

C. Defence Industry

Optical fibers' use in high-level data security systems, SONAR hydrophones, seismic applications, and aircraft wiring ensures robust and confidential communication channels, safeguarding sensitive information.

D. Broadcasting

Their high bandwidth capacity enables the transmission of high-quality video and audio content. Broadcast companies widely utilize fiber-optic cables to deliver a range of services, including HDTV, cable TV, and video-on-demand [4].

V. CONCLUSION

Fiber optics, which was introduced about 60 years ago, forms the basis of today’s communication technologies. Each of the different fiber types, such as plastic, glass and photonic crystal fibers, is effectively used in certain applications with its own advantages. The importance of fiber optic technology is increasing in applications such as high-speed data transmission and long-distance transmission of audio and video signals.
Various manufacturing techniques, including Outside Vapor-Phase Oxidation (OVPO), Vapor-Phase Axial Deposition (VAD), Modified Chemical Vapor Deposition (MCVD), and Plasma-Activated Chemical Vapor Deposition (PCVD), offer flexibility in optimizing fiber properties for different applications. These techniques ensure the production of fibers with the necessary dimensional stability and performance required for high-speed communication systems.
In the future, with the further development of these technologies, faster and more efficient communication systems are expected to be made possible through more innovative manufacturing techniques.

VI. REFERENCES

[1] “What is the maximum speed of fibre optic cable? | Prysmian Group,” *uk.prysmian.com*. https://uk.prysmian.com/media/news/what-is-the-maximum-speed-of-fibre-optic-cable

[2] D. Khadka, “Optical Fiber Communication.” Accessed: Dec. 12, 2024. [Online]. Available: https://elxcompacme.wordpress.com/wp-content/uploads/2014/03/fiber-optic-as-a-communication-medium.pdf

[3] “Posts - HOLIGHT Fiber Optic’s Latest Updates and Insights,” Jan. 07, 2023. https://www.holightoptic.com/optical-fiber/

[4] H. Gaurav, “Definition, Types and Applications of Optical Fiber,” *STL Tech*, Jun. 17, 2022. https://stl.tech/blog/types-of-optical-fiber/