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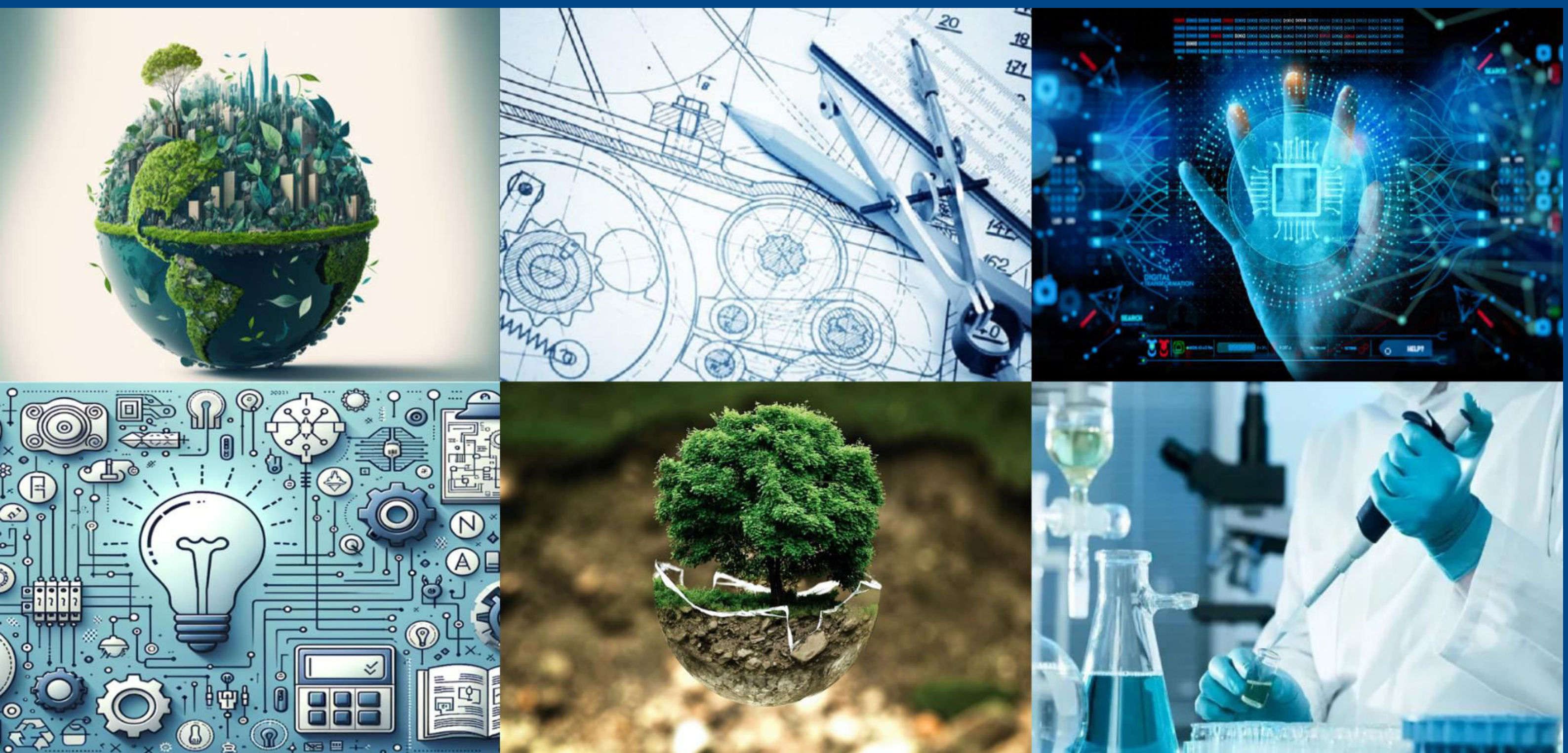

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Optical Fiber: Evolution, Mechanical Properties & Future Trends

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ABSTRACT: This research study explores the evolutionary progression of optical fibre, from its origin to its present form. The mechanical qualities essential for its functionality are examined. The study explores new developments and trends that are influencing the future of optical fibre communication, including higher bandwidth, improved data transfer speeds, and the use of innovative materials.

KEYWORDS: Optical, communication, mechanical, future.

I. INTRODUCTION

Optical fibres are slender cylindrical filaments made of glass or polymer, with a transparent core surrounding by a cladding, similar in thickness to a human hair. The core possesses a greater refractive index compared to the clad. Light is transmitted along the core of the fibre through total internal reflection. Silica-based glass fibre can transport light over long distances, and by inserting short sections of amplifying fibre periodically, the light can propagate for thousands of kilometres. The incoming light is modified digitally by a signal, which can then be transmitted over hundreds to thousands of kilometres through the fibre optic cable.

Normal sand is the primary raw material used to create optical fibre, making it more cost-effective than copper wire in telecommunications. Optical fibres offer benefits over electrical transmission media such as minimal transmission loss, high bandwidth, compact size, and lightweight design. Currently, optical fibres serve as the foundation for local, national, and international telecommunication networks. Optical fibre technology is rapid and highly reliable.

A hair-like fibre may transport a remarkable quantity of information. The appealing characteristics of optical fibre transmission prompted significant research and development activities in the technological field, which became operational approximately twenty-five years ago. Optical fibres have mostly supplanted copper cable in optical communication networks since 1974, handling the majority of global telephone, data, and video traffic more affordably and dependably.

An erbium fibre amplifier used with optical fibre provides an improvement of around 50,000 times compared to copper cable over a span of around 10 years in signal transmission for telecommunications. This facilitates cost-effective and efficient communication across many mediums via fibre optics. Optical fibre technology has made remarkable progress over the last 30 years, with further advancements on the horizon. Photonic fibre architectures will usher in a new era of fibre optic communication.

II. EVOLUTION OF OPTICAL FIBER

During the mid-20th century, the demand for telecommunications grew so quickly that copper wire and electric current were unable to meet people's needs. Furthermore, the implementation of a telephone system capable of transmitting data, video, and other services had just commenced during that period. The current network struggled to handle the telephone demand, prompting exploration of alternatives to copper cable and electric power. The items mentioned were microwave cables, satellites, and outdated millimetre waveguides.

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Year:	1980	1990	2000	2010	2020
Channel rate	2.5 Gb/s	10 Gb/s	40 Gb/s	100 Gb/s	200/400 Gb/s
Modulation format (typical)	OOK (NRZ)	OOK (RZ)	DPSK DQPSK	PDM-QPSK	PDM-nQAM, CS, PAM4, DMT
System features (newly added)	Single-span, Single-channel	Multi-span with EDFAs, WDM	DWDM, Raman, ROADMs	1:N WSS, CDC-ROADMs	Flexible-grid WDM, M:N WSS, Super-C EDFA
System capacity (typical)	2.5 Gb/s (single channel)	400 Gb/s (40 WDM channel)	1.6 Tb/s (40 WDM channel)	8 Tb/s (80 DWDM channel)	16~32 Tb/s (Fixed-grid or flex-grid channels)
System reach (typical)	100 km (single span)	1000 km	1000 km @40G 3000 km @10G	4000 km @100G	2000(1000) km @200(400)G
Enabling technologies	Directly modulated laser	High-speed modulation, HD-FEC	Differential phase-shift-keying	Coherent detection with oDSP, SD-FEC	100Gbaud-class OE device and advanced oDSP

Fig 1: Advances in Fiber-Optical Transmission

Source: Liu (2019)

Numerous laboratories worldwide initiated studies on optical communication utilising lasers as a potential carrier wave source. The importance of a good transmission medium was also taken into account at that time. The gearbox was believed to be achievable by utilising a pipe lining made of a smooth, highly reflective substance. Some researchers proposed using a converging lens in a pipe to prevent light from spreading. Another proposal suggested directing light onto a thin polymer tape. All these concepts faced technical issues, were expensive, large, and lacked adaptability.In late 1966, Charles Kao and George Hockham proposed the concept of using optical fibres to carry light signals. It was discovered that when a light signal was transmitted across an optical fibre, certain portions of the signal were missing at the receiving end. A tiny layer of titania was found on the inner surface of a silica tube that had been crumpled and transformed into a fibre, as reported by Gambling in 2001. Tatania diffused into the silica surface during the drawing process, resulting in a TiO_2/SiO_2 centre core with a higher refractive index than the surrounding silica cladding. The fibre generated using this technique was excessively fragile for practical applications.

However, that issue has been resolved. Some oxides are included with silica to regulate the refractive index of both the core and clad, as stated by Acharya (2001). TiO_2, GeO_2, P_2O_5, and Al_2O_3 raise the refractive index, while B_2O_3 and F decrease it. Currently, there are two steps involved in the commercial production of optical fibre. The preform is created in the initial stage using silica together with the specified oxides. In the second process, the fibre is pulled from the preform at a high temperature of 2000 degrees Celsius. When preparing the performance, the refractive index for both the core and clad is maintained as needed. A typical performer is approximately one metre in length and has a diameter of a few centimetres. System engineering identifies three primary components of an optical fibre communication system. The system includes an electrooptic transmitter (such as LED or Laser), an optical transmission medium (fibre), and an optoelectronic receiver (PIN or APD-photodetector).

III. MECHANICAL PROPERTIES OF OPTICAL FIBER

Optical fibres are mostly utilised as the transmission medium in optical communications systems, but their use in sensing technology is also expanding. While the mechanical properties of optical fibres, such as bending radius, are crucial for optical communications, they are much more significant in sensing applications. The physical qualities of the optical fibre are crucial for characterising sensors in sensing technology. Many optical fibre sensors depend on the distortion of the optical fibre to measure the external parameter being monitored. When an optical fibre is mechanically disturbed, it will experience a deformation that is directly proportional to the force of the disturbance.

Hooke's law defines the relationship between the applied force and resulting deformation, with the proportionality determined by the material's elastic constant. The Hooke's law is expressed along the longitudinal axis of the fibre.

$$K = \frac{|F|}{|\Delta L|} \qquad (1)$$

K represents the elastic constant and Δl is the relative deformation caused by the perturbation force, F.

The fibre Young-modulus, EG, represents the relationship between the force applied per unit area and the resulting deformation.

$$F = E_G A \frac{\Delta l}{l} \qquad (2)$$

In equation (2), A represents the area and l represents the length of the optical fibre under perturbation. The elastic constant is determined by formulas (1) and (2).

$$|K| = \frac{E_G A}{l} \qquad (3)$$

IV. FUTURE OF OPTICAL FIBER COMMUNICATION

Fibre optics communication is undoubtedly the future of data transmission. Technological advancements and growing demand have propelled the evolution of fiber optic communication. It is anticipated to persist in the future due to the advancement of new and more sophisticated communication technology. Here are some anticipated future trends in fibre optic communication:

Fig 2: Future Trends in Optical Fiber Communication

- All Optical Communication Networks
- Multi – Terabit Optical Networks
- Improvements in Glass Fiber Design and Component Miniaturization
- Improvement in WDM Technology
- Advancement in Network Configuration of Optical Submarine Systems
- Improvement in Optical Amplification Technology
- Improvements in Optical Transmitter/Receiver Technology
- High – Altitude Platforms
- Polymer Optic Fibers
- Laser Neural Network Nodes
- Improvements in Laser Technology
- Ultra – Long Haul Optical Transmission
- Intelligent Optical Transmission Network

Source: Idachaba et al. (2014)

V. CONCLUSION

Optical fibre has evolved via tremendous technological and material developments, resulting in remarkable enhancements in communication networks. The future of optical fibre communication shows promises due to continuous research and development leading to advancements including higher bandwidth capacity, faster data transmission speeds, and the incorporation of new materials and technologies. By continually advancing the capabilities of optical fibre, we can expect enhancements in network efficiency, reliability, and scalability to meet the increasing needs of modern telecommunications.

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