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Structures and Sensors of Polymer Optical Fibers for Last Mile Networks

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Abstract

Originating from distinct concepts for transferring information, sensing, or lighting efficiency, fiber characteristics vary greatly throughout their range. A substantial bandwidth-length product with acceptable attenuation characteristics is required for effective transfer of information. Since sensor fibers are typically used over short distances having considerably lower attenuation prerequisites. This paper presents polymer optical fiber (POFs) structures that are used as sensors over conventional fiber optics. An even broader spectrum of optical characteristics can be obtained by fabricating these fibers using polymer components rather than silica. A thick polymer fiber, as opposed to a glass optical fiber, will maintain its physical adaptability that is along with its large core, makes connecting the fibers during installation simple and reasonably priced. Diverse types of POF sensors are presented in this article with their possible application areas. POF is one of the technologies that could serve as the core of the crucial last mile of the telecom networks, also known as access network, which offers a fiber-optic substitute for copper that is simple to set up and has an excellent bandwidth. Further, optical access system is investigated for high transmission rate and longer span, and results are shared. Large numbers of subscribers share the communication facilities in the which allows supervisors to amortize deployment and operating costs much more financially.

Keywords: Polymer optical fiber, POF structures, POF sensors, optical access networks, attenuation

INTRODUCTION

An optical fiber is a nonconducting, cylindrical dielectric waveguide that utilizes the principle of total internal reflection to communicate information using light waves through its axis. The fiber is composed of dielectric materials, with a core encircled by a cladding layer. Optical fiber cable has many inherent advantages over traditional copper cables in terms of higher transmission speed with improved bandwidth, better reliability with data security and good durability. Optical Fiber is categorized as glass optical fiber and polymer optical fiber (POF). Glass optical Fiber is composed of glass and POF is made up of plastic or polymeric materials. Glass fiber is better for long-distance communication, while POF is better for short-range applications. Glass fiber is more fragile and susceptible to breaking than POF. POF is more robust under bending and stretching. POF is generally cheaper than glass fiber. POF is more flexible than glass fiber. Glass fiber is ideal for corrosive environments. POF can withstand vibration and unstable environments. Glass fiber is the preferred transmission method for

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telecommunications, while POF is preferred for cost-effective applications. POF is better suited for short-range applications, whereas glass fiber is more effective for long-distance communication. When compared to POF, glass fiber is more brittle and prone to breaking. POF is more resilient to stretching and bending. In general, POF is less expensive than glass fiber. Glass fiber works best in corrosive conditions. POF is resilient to unstable conditions and vibration and is preferred for applications that are more cost-effective.

Polymer Optical Fiber (POF) is translucent to visible beam and has a rope-like appearance. Polymer-based optical resources are utilized to build plastic optical fibers. Not just some buffer coatings and jackets, but polymers also create the core and the cladding. Plastic optical fibers are mechanically more strong and facilitate inexpensive fiber-optic solutions still matching the performance of glass fibers in vide range of application areas including propagation losses and data transmission capacity[1]. POF does not conduct electricity because it is composed of an insulating fabric which ensures immunity to electromagnetic interference (EMI), permits usage in combustible or explosive environments, and maintains the electrical isolation of associated connections [2]. Because of this, it is ideal for use in industrial settings, like machine control.

Its cladding substance is a fluorinated polymer, and its core is usually composed of Polymethyl Methacrylate Polymer (PMMA). A polymer optical fiber's cladding has an outer coating that creates the light-guiding outcome which ensures light to flow through the fiber's span, is where light travels within the fiber.

A polymer is composed of natural or synthetic material and has a long chain of consecutive monomer units that are joined by a strong intermolecular bond. The polymers are classified as crystalline, semi-crystalline, or amorphous depending on the type of chain of monomers . Furthermore, depending on their natural source and manufacturing method, the polymers can be categorized as either natural or synthetic fibers. Increasing the crystalline nature of polymers can improve their mechanical properties, stiffness, surface roughness, and environmental stability. The performance of polymer optical fibers (POFs) is influenced by a number of structural factors, such as core size, cost, flexibility, and transmission losses. Particularly for large core sizes, POFs are more flexible than silica fibers. They can therefore be used to detect strain, bending, and cracks in composite materials. Because POFs don't need the costly fabrication process, they are less expensive than silica-based optical fibers. POFs are not as suitable for long-distance optical transmission as silica fibers due to their higher transmission losses. Different core sizes and core/cladding ratios are possible for POFs. For instance, the core of a large-diameter POF may comprise 95% of the cross-section.

An optical made up of POF is becoming more and more significant in sensor structure and local area networks in particular. The industrial and automotive markets support polymer optical fiber due its large core size, consistency, and moderate connectorization tolerances. The visible spectrum is utlized by POF transmitters and receivers, so if light is coming out of a fiber end which can be used to establish whether or not it is coupled. POF functions from -40°C to +85°C and is normally more strong than its substitutes, tolerating bending radius of less than 20mm. It has a minimum 20-year functional life, is resistant to oxidation, and can bear damp and saline environments.

Its cladding substance is a fluorinated polymer, and its core is usually composed of Polymethyl Methacrylate Polymer (PMMA). Attenuation tests on an unstructured fiber made from PMMA discovered absorption loss of 32 dB/m near 632 nm wavelength. This shows that the PMMA material had poor optical quality.

There are several other POFs that have been manufacturedthat includedeterminate POF, perfluorinated (PF) POF, polystyrene (PS) POF, and polycarbonate (PC) POF. PF-POF attenuation has been brought down to a level below 20 dB/km. To negate the losses various structured POFs has been recommended. One of them is microstructured polymer optical fibre (MPOF). It has the possibility of addressing every drawback of conventional POF, making it to be very important. In comparison with POF, the light directing system in MPOF is fundamentally different [3]. It is not caused by varying in the refractive index of the fiber fabric; rather, it is done by a pattern of tiny air channels that run along the entire span of the fiber. Recently, this mechanism is used in microstructured silica optical fibers, commonly known as photonic crystal fibers (PCFs). This mechanism provides a number of special new features including the potential to blend broad mode areas with single-mode behavior. Furthermore, transmission in air rather than in the fiber material is promised by newly proposed photonic band gap fibers, which allows the issue of absorbed losses of polymers to be addressed. The fabrication of MPOF is done using Extruded polymethyl methacrylate (PMMA) that is readily available in the market [4].

Recently, because of the advancements in optical fiber technology, the internet's capacity to transfer data and its related services has experienced a rapid growth in recent years. Infrastructure needed for these amenities has been modernized, starting with backbone networks and continuing to metropolitan area networks. However, the access network, which links end users to the backbone network, has not had the same rate of channel bandwidth growth. Active optical networks (AONs) or passive optical networks (PONs) can be used in optical access system configurations. While PON uses passive components like power splitters, AONs use active elements like power-driven Ethernet switches to function. Passive components demand very little power, which makes networks that use them cost-effective and energy-efficient. Therefore, PON is more economical than AON in terms of revenue prospects.In PON infrastructure, the consumer is linked in the downstream route to a point to multipoint configuration and in the upstream phase to a multipoint to point topology. Communication messages are sent in the downward from the central office (CO) of the service provider's optical line terminal (OLT) to a number of connected optical network units (ONUs).PONs are first created by using the time division multiplexing (TDM) methodology, also referred by TDM-PONs which broadcasts communication packets on a shared channel within a predefined amount of time [5,6]. Wavelength Division Multiplexing WDM-PONs and Hybrid TDM-WDM (TWDM) technique provide an additional option to TDM-PONs.WDM-PON is regarded as the ideal option for upcoming 5G access systems due to its ever-increasing capacity for multimedia information interchange. Creating innovative network architectures for next generation access systems that can achieve higher frame rate with longer transmission distance so as to accommodate more number of subscribers.

In this paper, various types of polymer optical fiber sensors with their application areas are elaborated. Further, in order to achieve the goals of next-generation optical access networks, the work previously published in the literature is improved upon in this study by providing a novel optical access network model that is tested.

The paper is further organized as follows, in section II; details of optical fiber sensors with their application areas are described. In section III, novel architecture of optical access networks is presented and simulated results are depicted in section IV. Section V carries the conclusion made for this article.

OPTICAL FIBER SENSORS

Technological fields like fundamental, aviation, and space engineering, as well as vehicle, manufacturing, and healthcare engineering now heavily rely on sensing. But most of the earlier sensors in use today still rely on electricity technology. Optics and POF-based sensors have multiple benefits over traditional ones and have wide ranging applications in the field of human health care. Optical fiber sensors are a new sensor technology that offers inherent benefits like chemical stability, multiplexing mechanism, compact size, resistance to electromagnetic fields, and small size. Because of these benefits, optical fiber sensors are a technologically environmentally friendly solution for use in commercial, healthcare, and structural health monitoring settings. The construction and operation of fiber-optic sensors can be based on a variety of methods and concepts, such as fiber Bragg gratings (FBGs), interferometry, evanescent wave absorption (EWA), fluorescent-based, opto-electronic, chemi-luminescent, and vibrational spectroscopic sensors. The basic components of every fiber-optic sensor are identical, which includes an illumination source, the optical sensing component, and a photodetector. The FBG is an extremely popular method for creating an optical technology-based textile-integrated single sensor. When Ultraviolet (UV) light is illuminated using a phase-mask, the index of refraction in the core of the fiber is periodically modulated, and this is known as an intrinsic fiber element in photosensitive fibers defined as FBGs [7]. The sensitivity of the reflected wavelength to variations in strain or temperature forms the basis of the signal assessment concept in FBG sensors. UV light modulates the refractive index at surfaces, reflecting wavelengths that match to the limit given in equation below

$$\lambda_B = n_{eff}.2\wedge \quad (1)$$

Where $n_{eff}$is the effective refractive index, $\wedge$is the bragg grating period on which bragg wavelength λ_B depends as shown in figure 1 below,

Positive interference between two or more waves is the fundamental idea behind using an interferometer to measure fluctuations in the surrounding environment. For instance, a MachZehnder interferometer (MZI) using a collimated beam split by a beam splitter is depictedin Figure 2 below,

A second beam splitter combines the "sample beam" and the "reference beam," which are both reflected by a mirror. The output interference is registered by two detectors. Relative phase shift brought on by the sample or a modification in the sample beam's path duration is what this system depends on.

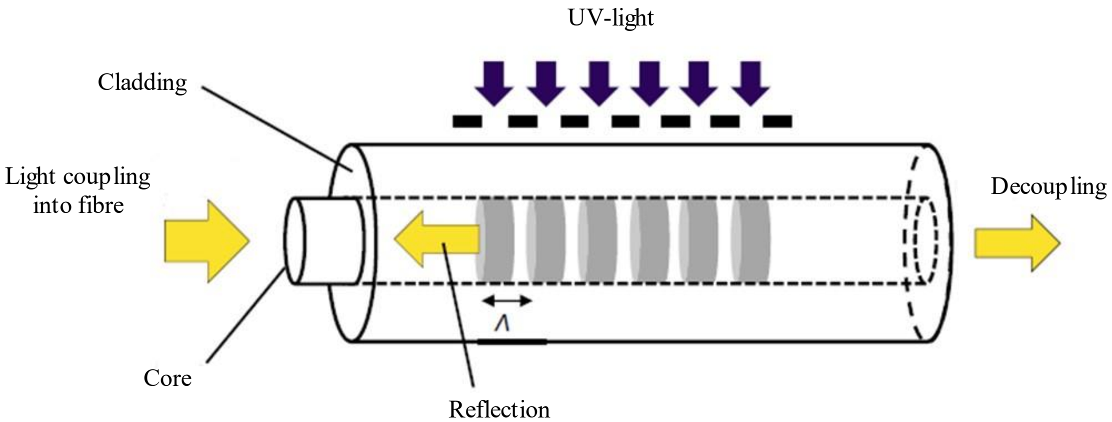

Figure 1. FBG Principle [7].

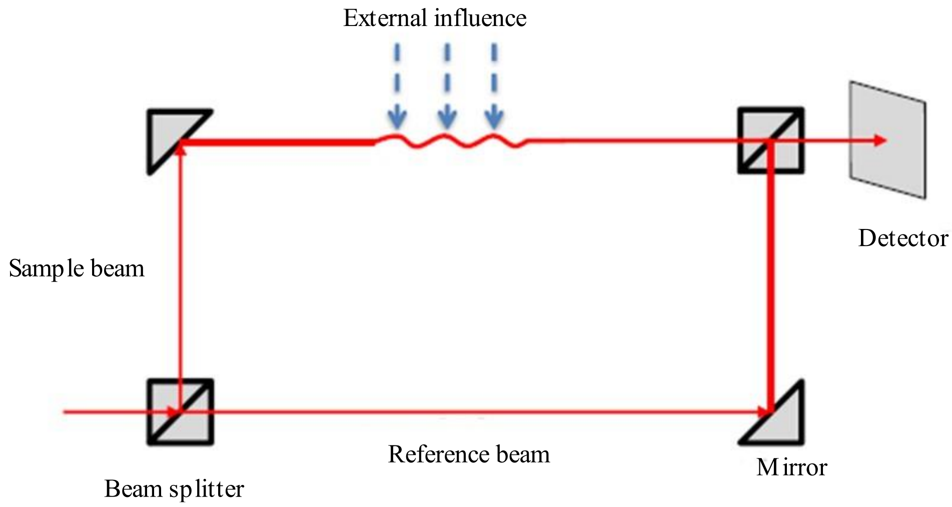

Figure 2. MZI Principle.

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Light in optical fibers does not suddenly become zero in intensity at the interface among the two mediums when it is fully internally reflected. A certain amount of light breaks through the surface and diffuses into the substrate below.As a result, an electromagnetic field known as the evanescent field is produced [8]. As one gets farther away from the user interface its intensity drops exponentially as shown in Figure 3.

SYSTEM MODEL

Figure 4 shows the system model of the hybrid WDM/TDM optical access system in a 32x1024 configuration. The system architecture that is being presented uses thirty two user transmitters situated at the Central Office (CO) of the service provider to facilitate communication with 1024 users at different data rates. WDM multiplexers combine the generated data and send it to subscriber optical network units (ONUs) via optical fiber cables that range in length from 100 to 180 km. At the receiving terminal, power splitters are used to send data signals to 1024 ONUs after they have been separated by a WDM (de)multiplexer. An external modulator, an electrical signal generator, a continuous wave (CW) laser, and an information source make up the WDM transmitter. The photo-detector at ONU receives the data signal from the optical splitter. It is the main component of the receiver that transforms the incoming optical signal into an electrical output. The signal then passes through a filter circuit before being examined by different test instruments. The system is analyzed using Eye diagram [9].

Eye Diagram is an important parameter to evaluate the effectiveness of POFs for last mile network. An eye diagram shows the quality and integrity of a digital signal in optical fiber communication through a visual illustration. It is a visual representation illustrating the changes in voltage levels of a signal over a period of time. The graph looks like an eye, with the crucial part being the gap between the top and bottom signal traces. Creating an eye diagram involves connecting the signal from the receiving end of a serial link to an oscilloscope and adjusting the sweep rate to show one or two bit time periods. Essentially, the eye diagram is a tool used to assess the performance of digital communication systems, especially in the realm of high-speed data transfer and reception. It is utilized for assessing signal quality, such as noise, jitter, and intersymbol interference [10]. It indicates the maximum eye width and height, representing signal distortion. The network's sensitivity is determined by how quickly the eye closes. As the distance increases, it becomes clear from the figure that both eye width and eye height decrease, showing a loss of signal deformation with the same power levels as OLT.

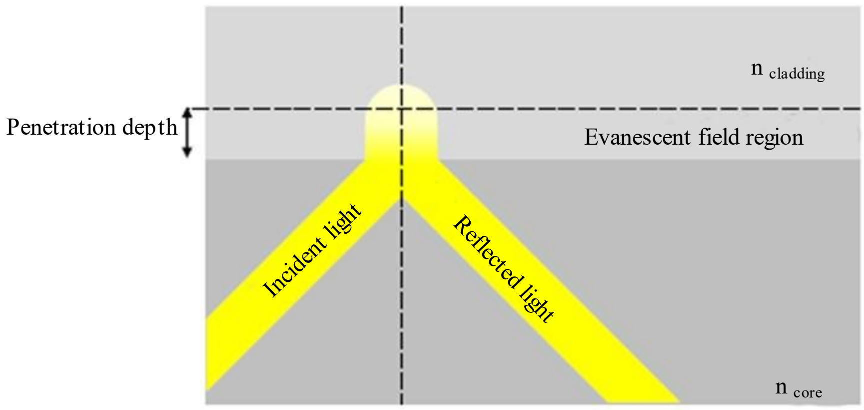

Figure 3. The Evanescent field.

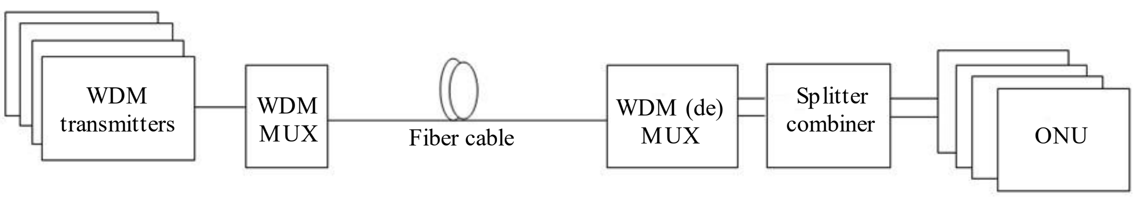

Figure 4. System architecture.

RESULT AND DISCUSSION

Figures 5(a) and (b) depict the eye diagram of the system model that is being presented when the received information signal is analyzed at a distance of 160 km and 180 km, respectively. An essential parameter for estimating the properties of information signals in optical transmissions is the eye diagram.

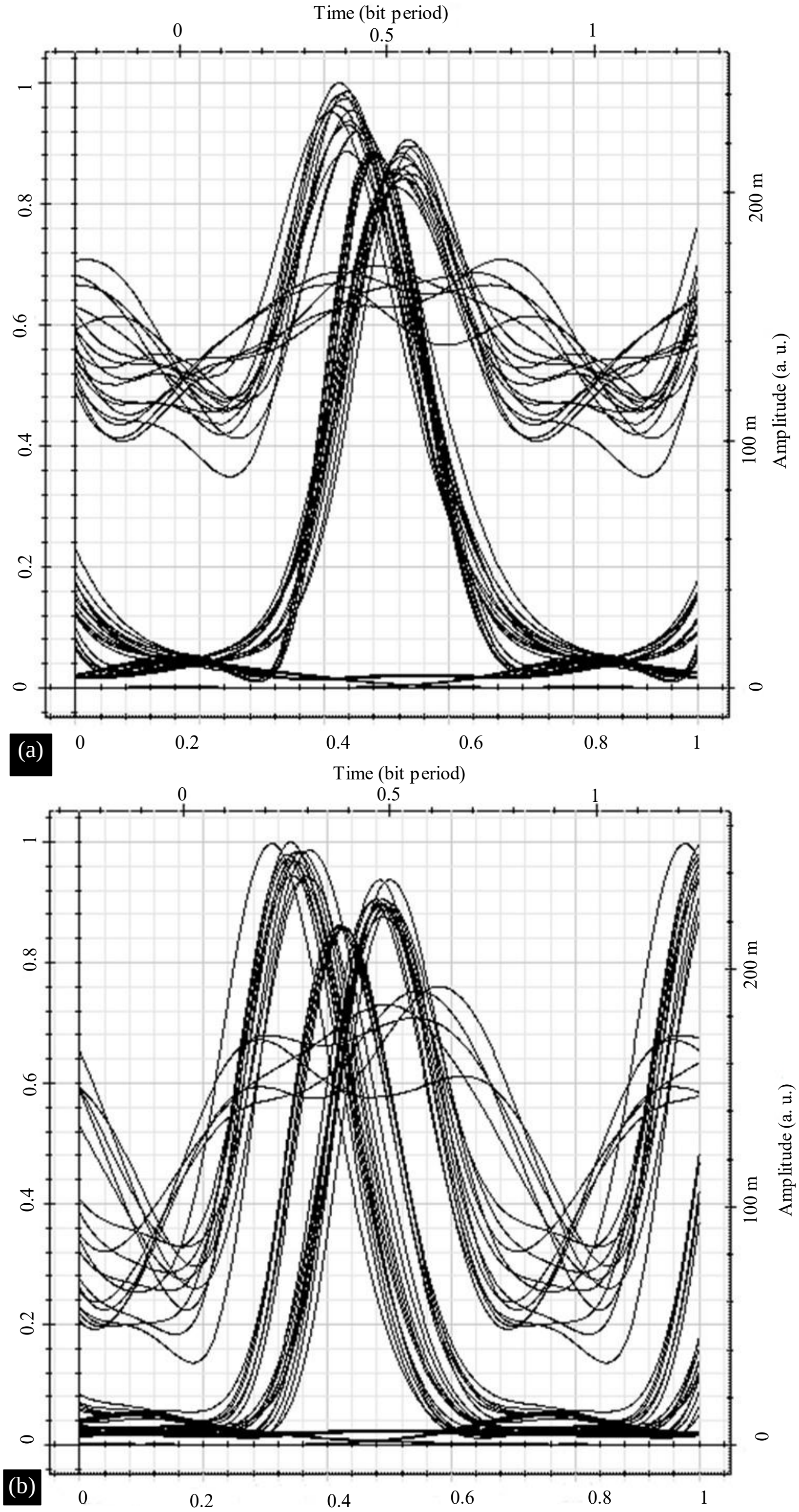

Figure 5. (a) & (b) Eye diagram measured at160 Km and 180 Km.

It measures the noise level at the receiver and displays the received signal graphically in relation to time. The diagrams show that as transmission distance increases, signal distortion increases as well.

CONCLUSION

Over the span of decade or so, fiber-optic communication has advanced significantly. The need for rapid information speeds and smart system designs that adjust rapidly to varying capacity utilization is linked to the phase-out of copper cables and the integration of optical fibers with wireless applications. Polymer Optical Fiber (POF) are better alternative over conventional fiber optics. A cost-effective option for short-distance transmission up to 100 meters is provided by POFs, which combine all the benefits of optical technology. This paper has deliberated on the various types of POF sensors, principle of operation and their application areas. Sensors based on POFs are presented. Due to their inherent mechanical qualities, PFBGs can be a good substitute for conventional FBGs. Recent developments with the POF endface make it possible to prepare the fiber quickly, easily, and reproducibly. Further, a novel system configuration of optical access networks is shared that serves to 2048 users combined in TWDM technology. The system infrastructure is shared by 1024 subscribers, allowing for remote placement at a rapid pace with recurring costs are also decreased because reach extender devices, such as amplifiers, are not needed to achieve network architecture performance. This allows for an affordable amortization of the installation and operating expenses. Compared to the other system frameworks, the hybrid system under investigation is the best option for access networks in the future.

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