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Plastic Optical Fiber

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***Abstract*: Polymer optical fibre is an optical fiber which is made out of plastic. Traditionally PMMA (acrylic) is the core material, and fluorinated polymers are the cladding material. Since the late 1990s however, much higher-performance POF based on perfluorinated polymers (mainly polyperfluorobutenylvinylether) has begun to appear in the marketplace.POF has been called the "consumer" optical fiber because the fiber and associated optical links, connectors, and installation are all inexpensive. polymer fibers are commonly used for much higher-speed applications such as data center wiring and building LAN wiring. In relation to the future request of high-speed home networking, there has been an increasing interest in POF as a possible option for next-generation Gigabit/s links inside the house. Although the actual cost of glass fibers are lower than plastic fiber, their installed cost is much higher due to the special handling and installation techniques required.**

***Keywords*: Plastic optical Fiber PMMA, LAN connection, Fluorinated Polymer.**

I. INTRODUCTION

Plastic optical fiber (POF) (or **Polymer optical fibre**) is an optical fiber which is made out of plastic. Traditionally PMMA (acrylic) is the core material, and fluorinated polymers are the cladding material. Since the late 1990s however, much higher-performance POF based on perfluorinated polymers (mainly polyperfluorobutenylvinylether) has begun to appear in the marketplace.

In large-diameter fibers, 96% of the cross section is the core that allows the transmission of light. Similar to traditional glass fiber, POF transmits light (or data) through the core of the fiber. The core size of POF is in some cases 100 times larger than glass fiber.

POF has been called the "consumer" optical fiber because the fiber and associated optical links, connectors, and installation are all inexpensive. The traditional PMMA fibers are commonly used for low-speed, short-distance (up to 100 meters) applications in digital home appliances, home networks, industrial networks (PROFIBUS, PROFINET), and car networks (MOST). The perfluorinated polymer fibers are commonly used for much higher-speed applications such as data center wiring and building LAN wiring.In relation to the future request of high-speed home networking, there has been an increasing interest in POF as a possible option for next-generation Gigabit/s links inside the house. For telecommunications, the more difficult-to-use glass optical fiber is more common. Although the actual cost of glass fibers are lower than plastic fiber, their installed cost is much higher due to the special handling and installation techniques required.

II. STRUCTURE OF POF

POFs used for optical communications are highly flexible waveguides composed of nearly transparent dielectric materials. The cross-section of these fibers is circular and, generally, divisible into three layers, as shown in Fig. The three layers are called the core, cladding, and jacket, a protective cover. Within the core, the refractive-index profile can be uniform (step-index fibers, SI.) or graded (graded-index fibers, GI), while the cladding index is typically uniform.

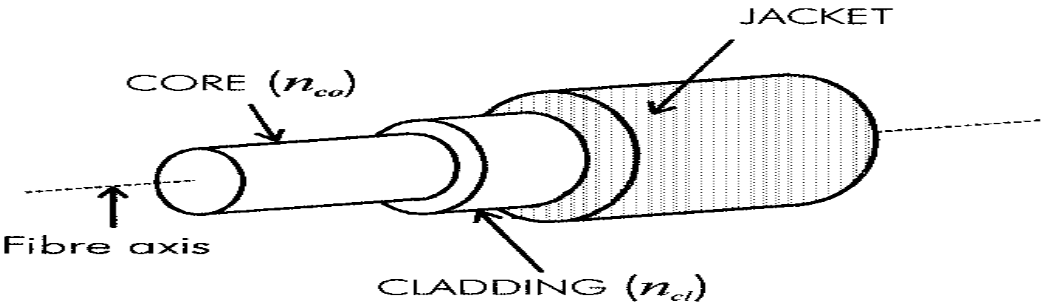


Fig. 1: Structure of a POF.

The basic configuration of an optical fiber and some important characteristics are shown in following figure.

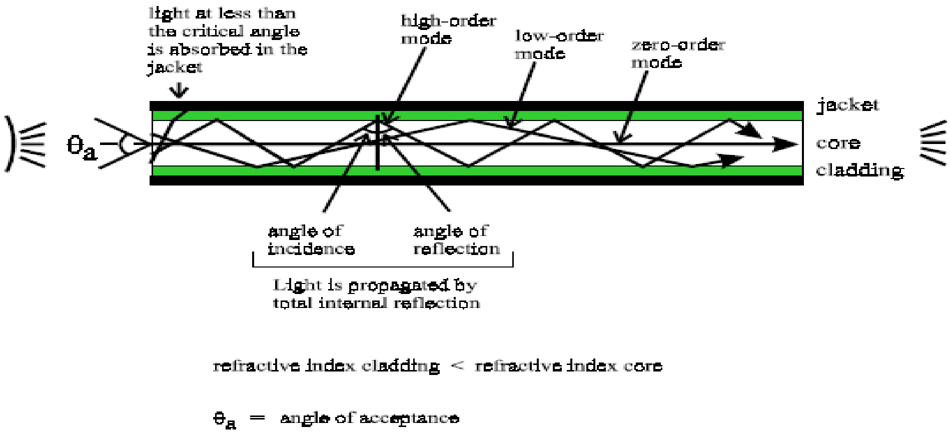


Fig. 2: Depiction of an optical fiber.

Figure shows a step-index optical fiber, which means that the refractive index is constant along the fiber core cross-section and immediately changes (step-wise) to the refractive index of the cladding. An other possibility is a graded-index fiber, for which the refractive index gradually changes from a high value in the center toward a lower value at the perimeter of the core.

Light rays propagate via discrete paths through a fiber. Each distinct path is called a mode and corresponds to a certain angle of incidence. Consequently, different modes take different times to travel along the fiber. The total number of light modes which can be coupled in is defined by the numerical aperture (NA). The NA is limited by the refractive index difference between cladding and core. The NA is thereby directly related to the angle of acceptance and the latter is given by the formula:

$$\mathrm{NA} = (n_1^2 - n_2^2)^{1/2} = n_0 \sin(\theta_a / 2)$$

Where,

$n0$ = refractive index outer medium (usually air, $n = 1$)

$n1$ = refractive index of the core

$n2$ = refractive index of the cladding

The larger the difference in refractive index, the higher is the number of modes which can be guided through the fiber. In a step-index fiber, the number of possible modes N_m of wavelength N_m is related to NA and the fiber diameter (d) following Equation

$$N_m = 0.5 \left(\frac{\pi d \, \mathrm{NA}}{\lambda}\right)^2$$

In the situation that only one mode is available for the light rays, the fiber is called single-mode. Single-mode fibers are prepared by reducing the core diameter to dimensions well below the wavelength of the light used. Larger cores can accept more light modes and these fibers are, therefore, called multi-mode. The information-carrying capacity of optical fibers is largely determined by the level of signal dispersion and the refractive index profile along the core cross-section. Clearly, the initial modulation of light determines the starting pulse width and the pulse frequency and thus directly the bandwidth of the total system. However, most important for the bandwidth is the level of signal dispersion in the optical fiber. Through signal dispersion, pulses of light start to interfere (overlap of pulses), meaning that information will be lost and the bandwidth will thereby be reduced. The bandwidth is given in bits^{2}km/s or in Hz^{2}km. Signal dispersion is caused by modal, material and waveguide dispersion. Modal dispersion is the dominant factor and is caused by the different path lengths traveled by light modes with different angles of incidence.

Single-mode and Multimode Fibers

Optical fibers can be classified in two groups from the point of view of propagation: single-mode fibers, with a comparatively small core which requires the wave model of light, and multimode fibers, whose core is large enough to be analyzed with a geometric ray-tracing model. The frontier between the two groups is determined by means of the structural parameter *V*, which is given by

$$V = \frac{2\pi\rho}{\lambda}\left(n_{co}^2 - n_{cl}^2\right)^{1/2},$$

Where is the wavelength of the light that propagates through the fiber (typically 650 nm with PMMA POFs and 850 and 1310 with perfluorinated (PF). POFs.). When the value of the parameter *V*, called the normalized frequency, is higher than 2.405, it can be proved that the behavior of step-index fibers is multimode.

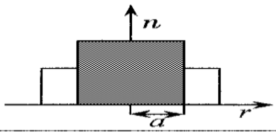
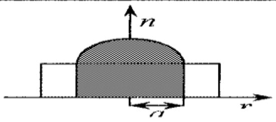
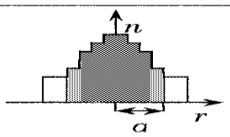
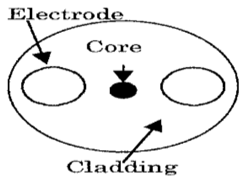
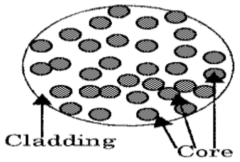
Index profile	Fiber type	Bandwidth*distance	Main features
	Single mode Multimode	3 MHz*Km	Step index profile; suitable for short haul communications High intermodal dispersion
	Multimode	600 MHz*Km	Graded index profile; suitable for short and medium haul communications Low intermodal dispersion
	Multimode	30 MHz*Km	Multistep index profile; suitable for short and medium haul communications. Low intermodal dispersion Well suited for mass production.
Transverse section	**Fiber type**	**Bandwidth*distance**	**Main features**
	Single mode Electrooptic	----	Single mode POF with embedded electrodes Specially indicated for the design of modulators
	Multimode	55 MHz*Km	Multicore SI POF. Tremendous stability against bending ; POFs winded round a stick of 3 mm radius shows 0.0 dB when NA=0.25 and the core diameter is 130 μm.

Fig. 3: Types of refractive index profiles in POFs and their main features.

III. MATERIAL USED IN POF

➢ ***Polymethyl methacrylate(PMMA):***

Polymethyl methacrylate (PMMA) has a high transmission rate (98% over 3 mm) with a single window at 550-650 nm wavelengths suitable for optic fibre communication at theoretically 55 dB/km @ 570 nm, and typically 100-500 dB/km

(Table). As a homopolymer, PMMA has a refractive index of nD=1.492. Combining low molecular weight dopants (LMC) may affect the refractive index. Doping the system will evidently increase light scattering, and is a major risk for the long-term stability of the system. For details of the properties, given in Table.

Alternatively, copolymers of fluorinated MMA monomers can be utilised. The advantage of this is that the chemical structure is permanently defined, but the manufacturing procedure of the preform is decidedly more complicated and time consuming.

PMMA has favourable rheological properties for drawing the fibre out of a preform. The glass transition temperature for PMMA homopolymer is 105°C. The drawing can be done at reasonable temperatures of 175-220°C, depending on the composition. These properties even make direct extrusion process possible. PMMA is stable when used at up to +85°C in dry air. Higher temperatures, especially in humid conditions, cause rapid degradation of the polymer and reduce the service life to a few thousand hours. In the ambient conditions of normal premises, however, the service life expectation is predicted to be 20-30 years when copolymers are used.

Table: 1 Attenuation properties of typical PMMA fibre, core 980^{2}m

	650 nm				1300 nm
	α_1^{iso}, dB/km	α_2^{iso}, dB/km	α^{aniso}, B/km	α^{total}, dB/km	α^{total}, dB/km
Un-doped	12.5	0	6.2	18.7	1.2
Doped	15.4	75.6	70.6	161.6	10.1

Table: 2 PMMA modified fibre properties

POF	Draw T oC	Yield Strength kgf/cm2	Tensile Strength kgf/cm2	Elongation %
SI-POF	(220)	970	1040	67
MMA-BZMA	190-250	1060-712	1620-634	33-9
MMA-VB	190	737	638	7
MMA-BB	175-195	-1170	2050-1340	39-34
MMA-BBP	190-195	1260-960	1880-970	43-51
MMA-BEN	200	1052	1092	36

➢ ***Perfluorinated:***

Perfluorinated (PF) amorphous polymer materials nD=1.335-1.344 are based on totally fluorinated diene monomers or copolymers thereof. The excess carbon-hydrogen bonding means an attractive absorption window of between 650-800 nm and around 1300 nm, excluding 1170-1230 nm. The fibre losses in this region are theoretically 0.3 dB/km, and typically 5-10 times that. The most widely known PF is commercial CYTOPTM polymer, a chain with a serial ring structure on the backbone that leads to an amorphous structure and no diffraction on the crystals. The molecular orientation of the polymer is helical, providing excellent optical properties. The low attenuation of CYTOPTM means a marked improvement in bandwidth. See **Figure.**

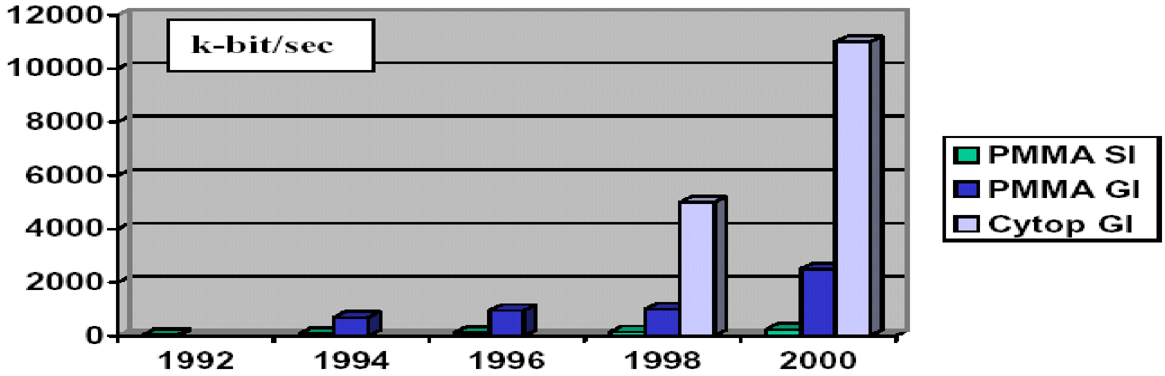


Fig. 4: CYTOPTM and graded index structure increased the POF band width from 150 k-bit/s up to 11.5 Gbit/s in one decade of time

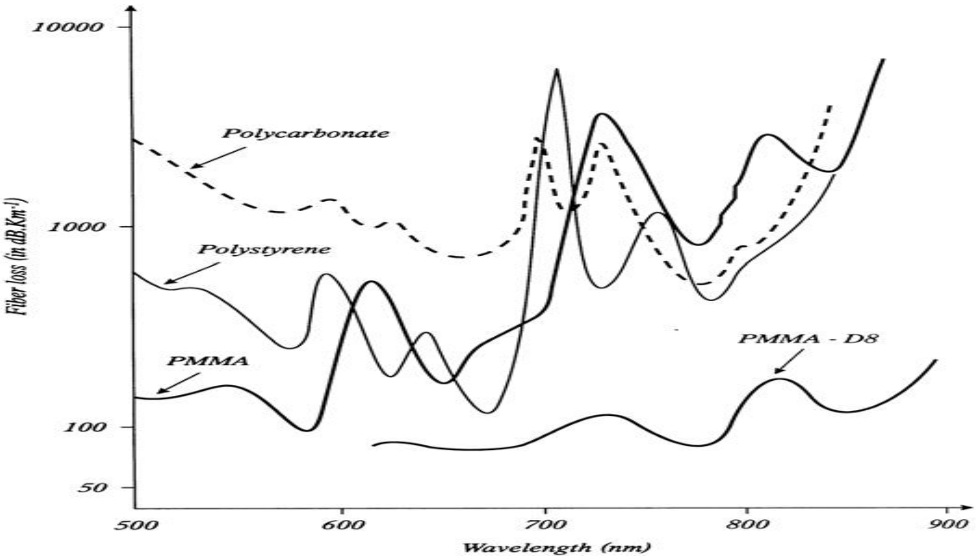
The melt processing of PF is a highly delicate task, while the processing window for fluorinated polymers is narrow. Additionally, the products of degradation processes are both corrosive and toxic. For this reason manufacturing process takes place under highly controlled conditions typically in the interfacial gel polymerisation. PF has minimum water diffusion. The fibre does not absorb water, and consequently increases its attenuation. Neither is its chemical structure affected by moisture, and thus does not degrade in a humid environment. Furthermore, PF materials have excellent chemical resistance to substances like sulphuric acid, sodium hydroxide and benzene. The only drawback in comparison with PMMA is in the case of freon, e.g. CFC-113. The mechanical properties of different PF materials are insufficiently reported, but they do resemble those of PMMA systems, or 20% less tensile strength at typical usage temperatures of -40 to +85 °C.

- ***Polycarbonate:***

Polycarbonate (PC) (polymers and copolymers of bis-phenol A) with refractive index n_D=1.58 and glass transition temperature of 150 °C can be utilised at higher temperatures than PMMA; say, – 40- 120 °C. PC is also less sensitive to moisture than PMMA. However the attenuation properties are worse; say 700 dB/km at 570 nm. This limits its use in special applications such as outside the passenger compartment in an automobile. Mechanically PC is as durable as PMMA, with break strength of 17.7 k Psi at 10.8% elongation (6.3% for PMMA).

- ***Polystyrene:***

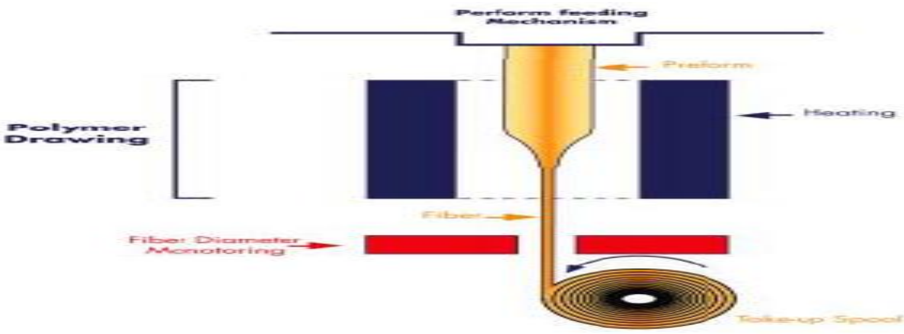
Polystyrene is less attractive for data applications than PMMA, due to its rather worse attenuation of 90 dB/km, compared to 55 dB/km at 570nm. Glass transition is very much the same, namely 105°C, but the refractive index of nD 1.59 is closer to the typical value for PC. See attenuation profiles in **Figure**.



IV. MANUFACTURING PROCESS

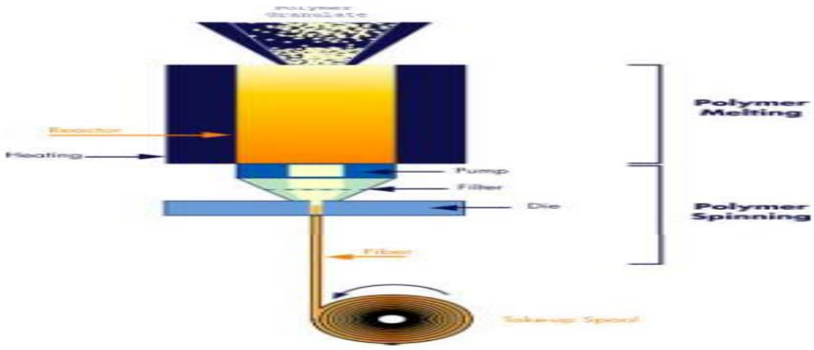
1. Drawing from a perform(Fibre drawing):

The actual fibre drawing takes place in an induction oven at 160-280 °C. The drawing procedure is controlled by a diameter control unit, which regulates the tension rollers. The process is thus remarkably similar to glass fibre drawing. Originally 35-50mm preforms are used, but possibilities up to 100mm have been studied. No fraction of a preform is allowed to have monomer conversion lower than 99.5%, while too high a free monomer concentration in the fibre drawn process would cause gas disclosures. The drawing oven is typically an electrically heated open resistor type of round oven. It has also been proposed to replace this with an infrared oven, in order to overcome problems related to the poor thermal conductivity of the plastics. The diameter of the perform, as well as the fibre drawlength after it, are limited due to the insulating properties of the optic polymer preform. Our experience with a special IR oven is promising, while the melting time constant is in magnitude of 50-70 seconds with 40mm preforms and 2-2.5 kW input power. When 1.2 micron wavelength is used, radiation penetration depth is more than 10mm, which reduces the heat transfer and conduction limitations. The possibility of shutting down the heating power increases the safety.



2. Melt spinning process:

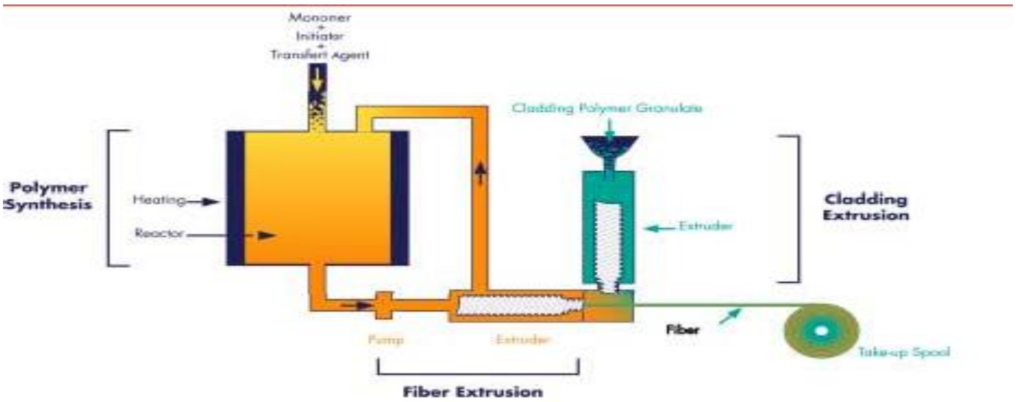
Step-index POFs are manufactured by means of a melt spinning process in which fibers are obtained by either continuous or batch extrusion. In the continuous extrusion process, a monomer, an initiator, and a chain transfer agent are continuously fed into the reactor and the fiber is continuously withdrawn from the die. This is an efficient process since high production rates are possible. This process gives high drawing speed.



3. Continuous Extrusion of core and cladding:

Extrusion is sensitive to contaminations and variations in layer thickness of the fibre construction .Thus; the process is suitable for less demanding applications. With a single extruder, it is simple to produce a single fibre, typically with a monofilament spinrette. Step-index fibres are produced with centre core-cladding tooling. A typical performance level for POF of kind is 400 Mbit/sec at distances of up to 100m, but not limited to that. In the extrusion process the fibre can be directly formed close to its final diameter. However, the extrusion process is limited through tooling pressure with the small fibre dimensions. Simultaneously the fibre draw-down has to be kept in reasonable limits, while a draw-down ratio >4 may affect the optical properties trough crystal formation. Thus the dual step drawn process (Peachtree) is favorable.

The extruder can be fed with pelleted polymer, but polymer formed in-situ in a special feeding device reduces contamination level. As an exception to conventional extrusion, this technology enables multiple concentric polymer layers to be extruded with a compact machinery solution. One potential application arising from this capability is the production of graded index POF. See **Fig.**



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To our knowledge, there is currently no commercially viable method for the continuous production of graded index plastic optical fibres. Theoretically it has been calculated that the number of layers needed to successfully imitate the graded index is around 15-20 layers. Two conical extruders with 3 rotor extruders in cascade are able to produce up to 12 layers. In practice, a core with only 3 claddings has been made, but the construction is sufficient up to 1 Gbit/sec at 100m. In our TUT Fibre Material Science, an SI fibre with conical extruder cascade has been made. The extruder used is shown in **Fig.**

V. WHY WE GO FOR POLYMER OPTICAL FIBER?

Polymer fibre with revolutionary properties which are suitable for broadband data transmission and telecommunications. In relation to the future request of high-speed home networking, there has been an increasing interest in POF as a possible option for next-generation Gigabit/s links inside the house. For telecommunications, the more difficult-to-use glass optical fiber is more common. Although the actual cost of glass fibers are lower than plastic fiber, their installed cost is much higher due to the special handling and installation techniques required.

The telecom and datacom industries have opened the door for novel technologies that enable unique functions and/or unconventional high-yield manufacturing without sacrificing high performance. Advanced planar polymer technologies can fit the bill in every aspect. Today, glass optical fibers are routinely used for high-speed data transfer. Although these fibers provide a convenient means for carrying optical information over long distances, they are inconvenient for complex high-density circuitry. In addition to being fragile, glass fiber devices are difficult to fabricate—especially when they have a high port count and as a result are quite expensive. Polymeric materials permit the mass production of low-cost high-port-count photonic circuits in parallel on a planar substrate. In addition, they provide the possibility for a much higher degree of ruggedness. Work carried out in a number of laboratories has demonstrated these advantages.

Properties of POF Material

1) Young’s modulus for a POF is nearly two orders of magnitude lower than that orders of magnitude lower than that of silica fiber 2.1Gpa for a PMMA POF

2) SO even a1mm diameter POF is sufficiently flexible to be installed

3) Minimum bend radius for POF_S is smaller

4) POF can operate at temperatures up to 80-100 above this POF lose their rigidity and transparency

5) High bandwidth GIPOF lose have a high thermal stability

6) POF is high chemical & good aging resistance in nature

Optical Fiber Cable Testing

Performance verification forms an integral part of the manufacturing of optical fibre. The capability of each length of optical fibre to meet the required optical, geometrical, mechanical and dispersion characteristics is determined for each length of fibre before it is cabled. The optical attenuation is rechecked after cabling, in order to verify that it has not been significantly altered by the cabling process.

The capability of the cable to withstand the rigours of installation and use are determined using a wide range of mechanical tests that include bending, flexing, torsion, impact resistance and crush tests. This is done using specially designed equipment that simulates field conditions according to international standards. Special emphasis is placed on tensile strength and environmental performance. ATC uses holistic approaches to achieve an integrated cable/clamping system for aerial self-supporting cables. Special test facilities and test methods are used to ensure long-term system reliability.

Application

Integrating electronic equipment into textile products may mean some revitalisation of the industry. Essential for POF in the field is whether consumer electronics apply the optic data channels to a greater extent. With POF, the data transmission systems may be manufactured in a markedly more robust manner than today's standard solution. The application spectrum of POF has increased, and is developing towards technically more demanding solutions simultaneously with continuing improvements in the performance of the materials and their manufacturing methods. New polymeric materials have even been introduced, such as the previously mentioned amorphous PF in data communication fibre, or polycyanurenate as an alternative for UV curable fluor-acrylate in optical wave-guide devices. See table for three different application areas. As for communication applications, the actual growth potential in the fields of the automotive industry, consumer electronics, and later in local networks have been indicated. Special applications such as optodes and photonic sensors may also find some advanced technical applications.

Table: 3 POF application areas

	Illumination	Commercial	Communication
Diameter (µm)	100-5000	250-2000	500-1000
Diameter tolerance	25 %	<10 %	<10 %
Cladding	Not critical	Critical	Very critical
NA	Not critical	0.3-0.65	0.5
Attenuation	3-5 dB/m	0.5 dB/m	0.25 dB/m
Heat resistance	60 °C	70 °C	85 °C

Illumination and wave-guide applications

Fibre optic systems are used today for lighting, decoration and sign applications. It is thus simple to show different colours of light in a tight screen area, when the actual light source that emits heat can be located separately. Some POF systems emit light along the entire cable. Materials that emit visible light through fluorescence or scattering can be added to the fibre. Side-emitting fibres are commonly used in the lighting of architectural and contour buildings, hotels and entertainment centers. In public premises and leisure areas, there is a need for light guides due to complicated routing or limited lightning. Today many of these solutions are based on bulky lamp rows or less effective taping solutions. Optical fibre makes it possible to build this function into carpets and suchlike in a most sophisticated and space-saving manner. Light guide illumination is useful in hazardous and explosive environments. High-voltage tube devices can be replaced with fibre, thick fibre or rods. Changing particle size and concentration can even control light emission in large core-size 10mm bulky rods of POF. The material is manufactured by means of adding micro-spherical beads during the synthesis of the rods. To a certain extent illumination fibre material can be added to fabric structures. Weaving the POF into the fabric makes light leak out of the fibre, and planar flexible lighting elements can be fabricated. See **Figure.**

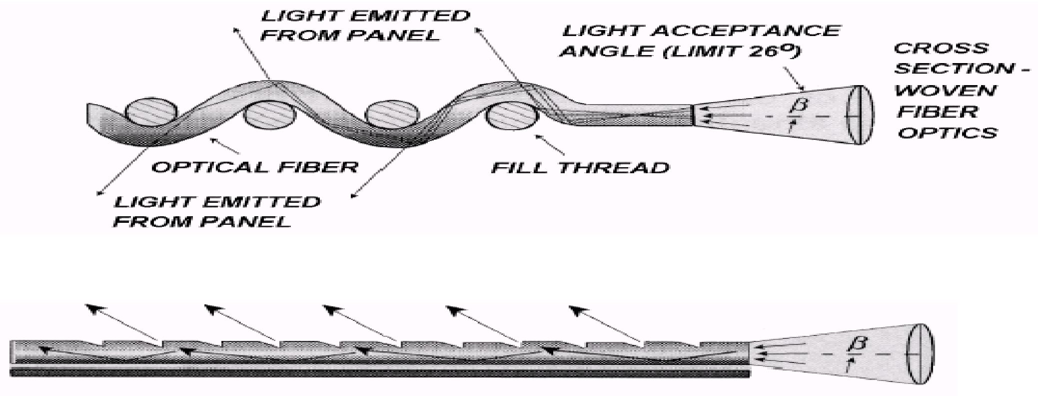


Fig. 5: POF in weaving emits light, and fabric with light emission can be made, or alternatively the surface may have an abraded construction

Automotive applications

Although Mercedes Benz has been the pioneer in this field, within a few years most producers will adopt the technology, mainly in top-end vehicles. The automotive industry has applied the D2B standards to provide noise-free infotainment inside the passenger compartment, and has adopted the MOST standards. A typical requirement is 150 Mbit/s and 30 m, but 500 Mbit/s will come as IEEE1394automotive standards are introduced. Flat flexible cable hybrid design is one area of interest. The development opens the door for fabric integrated solutions as an alternative to FFC. It would then be easy to integrate the data bus connection into the decorative textiles on the car body. The targets for this are installation simplicity, weight savings and integration. The need for different kinds of flat displays and illuminations is also increasing.

Multimedia & telecom applications

POF in multimedia and telecom are applicable to the final of the data highway. The competing technologies in the home and office network are RF copper cables and specific OF (miniature glass fibre cables). POF's advantages include their low weight, inexpensive costs, and simple installation. Disadvantages are related to limited bandwidth, such as 400 Mbit/s over 100m. As an optic media the POF is insensitive to electrical and magnetic noise, thus competing with copper. There is additionally an application in data connections, when the silica OF is a technical overkill.

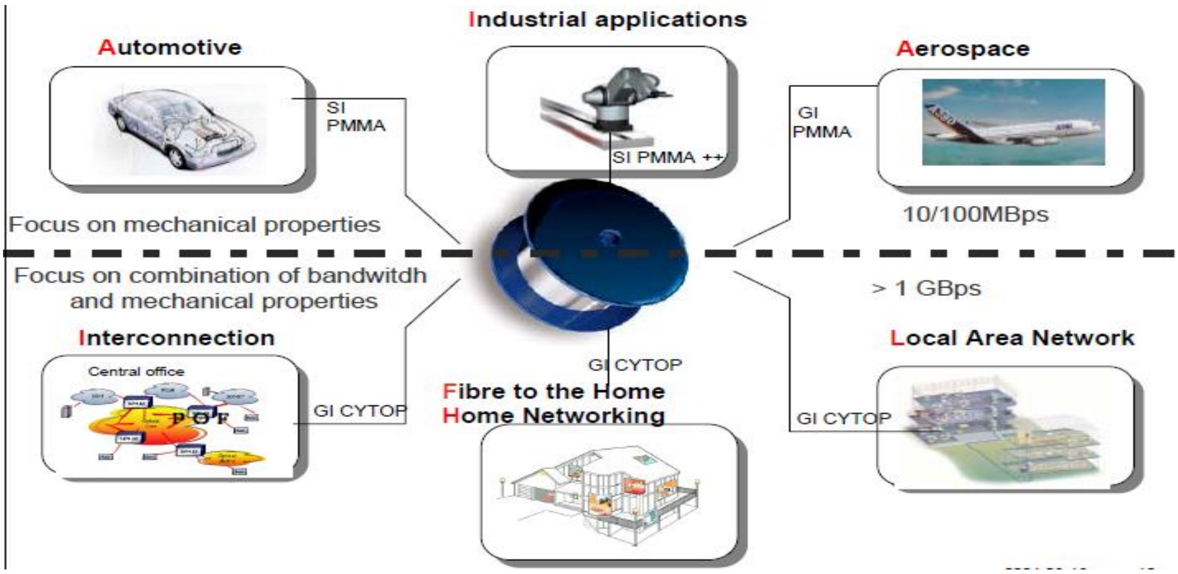
Optical fibre application in textiles

There is active research related to intelligent clothing. The applications combine electronics and information technology with textiles. This began with military applications, but later the solutions have been combined into leisure products and safety clothing. Wearable computing additionally makes it possible to integrate data and telecommunication devices, play consoles, or even full time control of life functions. Polymer optic fibre applications can reasonably be expected in interior textile integration, typically in automotive vehicles and public buildings, where the data channels are to be hidden. In lighting, the new LED sources may reduce indication light use of POF, and niche architecture solutions are left. However, the most attractive future applications are in field of para-textiles, such as chemical measurements in filters in use. As another example, we may refer to measurements integrated in different insulation constructions. When in combination with the technical textiles there is a need to measure very small volumes and aggressive environments on-line, especially chemical states, the optodes provide solutions.

Local area network

Integration and miniaturization have always been the dream for engineers. They offer the path to low cost, high reliability and modularized products. Optical integration has not progressed as fast as electronic integration in the past years. One of the main reasons is that for integrated optics it is difficult to use only one material system to fabricate optimal devices with a wide range of functions. Polymer waveguide devices are attractive because they offer the potential of fairly simple and low cost fabrication based on low-temperature processes and low cost packaging based on passive alignment [1-3].

The optical loss of optical polymers has been reduced to less than 0.1dB/cm recently [4]. Polymer optical waveguide device can provide a convenient integration platform including optical waveguide devices and optoelectronic chips. In this paper, a PLC based optical transceiver and minispectrometers are addressed. The transceiver is shown schematically in Fig. 1. The coupling from the polymer waveguide to the photodiode (PD) as well as from the laser diode (LD) to the polymer waveguide is accomplishhed via a 45° mirror (vertical coupling). The light from the LD can also be coupled to polymer waveguide by butt-joint coupling. For reducing cost, passive alignment of fibre-chip coupling is possible by U-grooves. These main issues will be discussed.



VI. ADVANTAGES OF POLYMER OPATICAL FIBERS (POF)

1) Small size: The other diameter of optical fiber is generally small 0.125 the other diameter remains about 1mm even if the fiber is coated with plastic

2) Lightweight: The specific gravity of silica is 2.2 and that of copper 8.9 further as the dimension of the fibers are small the weight of optical fiber cables is one third to one tenth that of conventional cables with the same transmission capacity

3) Good flexibility: In general below 3mm in diameter and optical fiber does not break even if it is bent

4) Free from rust: Glass materials such as silica are stable chemically and optical fiber are entirely improves to rust which is not the case with metals

5) Very large information: Transmitter capacity per unit cross sectional area of the fiber broad bandwidth of transmission and very large capacity of transmitting information produce an extremely high density of information capacity of optical fiber cable

6) Free from electromagnetic induction & lightning damage: Glass in generally a good dielectric and is immune to electromagnetic induction and lightning

7) Resistance to high temperature: the melting point of silica is about 1900 far above that of copper of plastics therefore cables made with silica are resistant to high temperature

8) Fibers do not generate sparks: No discharge spliced points of optical fiber be used in potentially inflammable on explosive environments

9) The optical fiber in glass: The optical fiber is nothing other than silica on compound glass it is generally little and has an elongation of only 5% when the fiber is used this little characteristics must be fully taken into account

10) Material for optical fiber is not copper: copper resources are limited optical fiber are primarily made of silica which is abundant

VII. CONCLUSION

- POF capacity for improving usefulness of multimode optical fiber has been demonstrated
  - Simplified termination
  - Superior resistance to mechanical stress
  - Improved bandwidth
- Combined advantages of MMOF and Copper
- Practical and relevant POF components development is underway
  - Supports 850nm
  - Supports gigabit networking
  - Wider distance scalability

POF technology is developing in step with the advances in electronics and communication technology. As a communication application, the actual growth potential in the fields of the automotive industry, consumer electronics, and later in local networks is indicated. There are also separate developments in the fields of sensors and illumination. Special applications such as optodes and photonic sensors may also find some advanced technical textile applications.

Essential for POF is the question of whether consumer electronics apply the optic data channels to a greater extent. With POF, the data transmission systems may be manufactured in a markedly more robust manner than today's standard solution. Advanced systems will be integrated with decorations, upholstery and automotive interiors, where POF is flexible and compatible with these constructions. The driving force should be higher user-comfort, which enables seamless use of the technology in everyday activities.

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