Present and Future on POF

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The growing demands in fiber to the home (FTTH) for low cost broad band data communications are providing a major opportunity for further technology developments important to polymer optical fiber (POF) and devices. POF can satisfy requirements for high-bandwidth, quick-connect, fiber optics for short distance data transmission in data links, multi-media, and multi-noded bus networks. Recently, the graded-index (GI) POF having optical window at the wavelength of 0.7-1.3 μm regions has been developed. This GI-POF is anticipated long distance and high bandwidth data comunication using the laser diode developed for silica fiber.

1. INTRODUCTION

It has been about thirty years scince the step index (SI) type PMMA core polymer optical fiber (POF) was first introduced by Dupont in 1963, and significant developments were made in 1970s in Japan. Several makers entered in POF business in early 1970s. In present, Japan has been established the largest supplier in the world by the continuous effort to decrease transmission loss on the technology of mass-production for PMMA core POF.

Single-mode (SM) silica fiber whose core diameter is 5-10 μm requires highly accurate connectores, which seriously increases the cost of the whole system. The large core of POF would make it possible to adopt injection-molded plastic connectors which decreases the total cost of the system. Recently the growing demands in local area networks (LANs) for low cost broad band communications are providing a major opportunity for further technology developments important to polymer optical materials and devices. POF can satisfy requirements for high-bandwidth, quick-connect, fiber optics for short distance (100m) data transmission in data links, multimedia and multi-noded networks[1-4]. The bandwidth of the graded index (GI) type POF developed by Dr.Y.Koike[3] is superior to that of GI silica fiber. In Japan POF consortium also formed to study and apply POF to data comunication with Keio University and about thirty companies on February in 1994. After half a year, High Speed Plastic Networks (HPSN) consortium was also formed to specify, design, produce,and market POF based components and systems in USA.

This paper describes the technical trends of POF in present and future.

2. CHARACTERISITIC

2.1 Transmission loss

The infrared (IR) vibrational absorptions due to carbon-hydrogen bond are decisive loss factors in POFs, i.e., in CH absorption spectra of PMMA from near-IR to visible wavelength, there exists high harmonics vibration of IR stretching vibration and combination band of IR bending vibration and stretching one. Figure 1 shows the wavelength dependence of transmission loss of POFs. In the visible wavelength region, the most effect on the transmission loss is from the 5th to 7th high harmonics of CH vibrational absorption. In the visible wavelength region the minimum loss limit expects 35 dB/km at the wavelength of 568 nm for PMMA core POF and 69 dB/km at the wavelength of 672 nm for PS core POF, respectively[1]. Vibrational absorption of CH bonds the core material restricts the further improvement of the POF optical loss. Replacing the hydrogen of CH absorption in the IR region, as well as its overtones in the near-IR to visible region. Deuterium (D) atom was selected to replace the hydrogen in the core polymer which are considered to be effective not only for shifting optical windows but also for lowering the loss in the visible

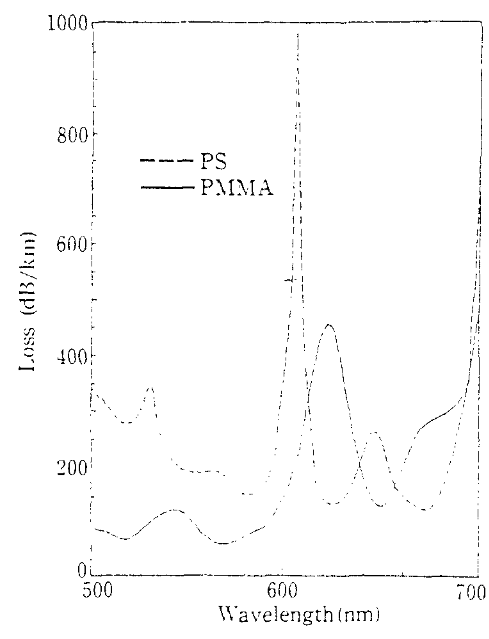


Figure 1. The wavelength dependence of transmission loss of POFs[18].

wavelength region shown in Fig.2.
The lowest transmission loss, 20 dB /km, was attained from 650 nm to 680 nm. However, the loss in this POF increases signifcantly with water absorption, i.e. in the 90% RH enviroment, the loss at 780 nm increases up to 100 dB/km higher than that at the dried state. So this fiber was not brought in the market. The history decreasing the transmission loss of POFs is shown in Fig.3.

2.2 Transmission bandwidth

Several large telecomunication companies in the world proposed the implementation of ATM (Ansynchronous Transfer Mode) which is a digital packet switch technology that integrates voice with video, and data transmission into an apparently seamless whole network. The basic requirement for an ATM system is high transmission speeds of 155-622 Mbps. The transmitted fiber length of conventional SI-PMMA core POF (NA=0.51) is limited until 30 m at the transmission speed of 155 Mbps for ATM ATM because the bandwidth is 3.5 MHz Km.

Dr. Y. Koike[5] invented the new fabrication of GI-POF by swelling and selective diffusion (SSD) method. This fiber resolved the problem of the transmission loss, the bandwidth, and the mechanical strength for ATM use.

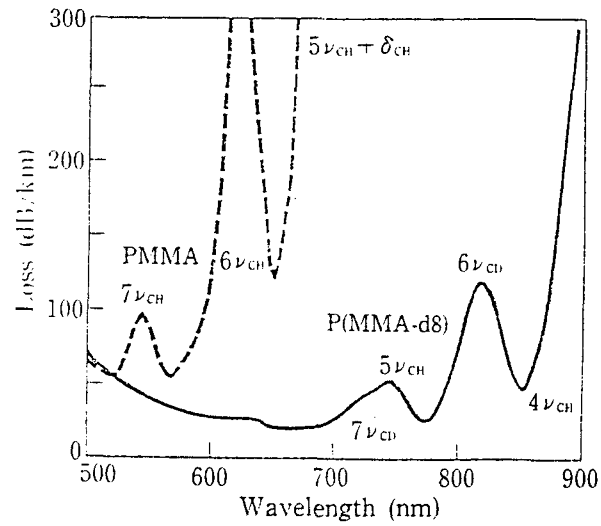


Figure 2. Loss spectrum for P(MMA-d8) and PMMA core POFs[18].

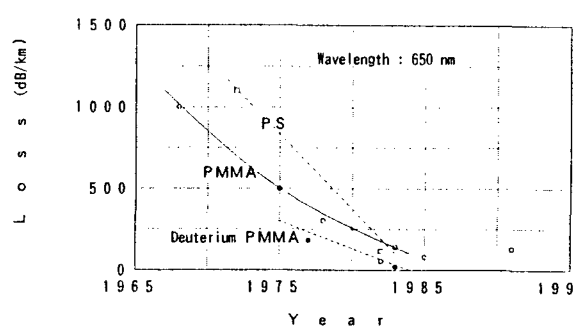
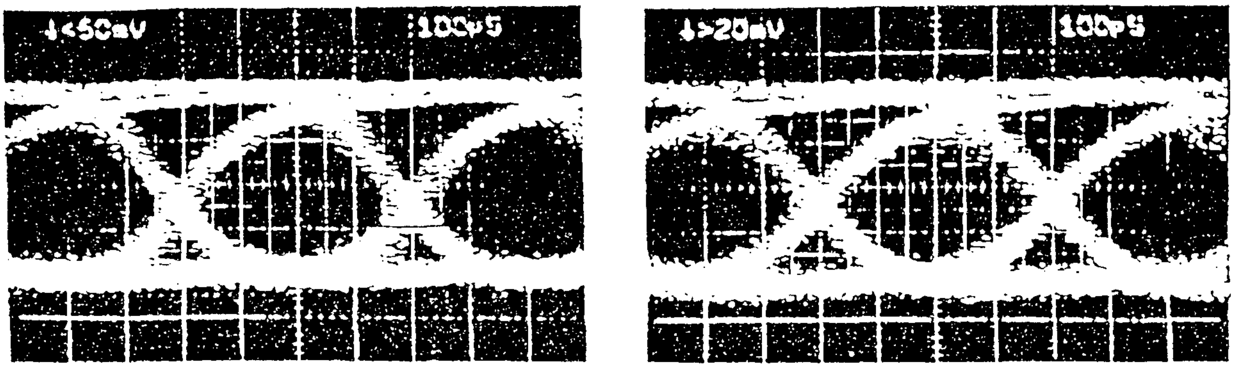


Figure 3. The history of decreasing the transmission loss of POFs.

NEC[6] also developed the high speed reddish laser diode (LD) having the emitted wavelength of 647 nm and the modulation up to 2.5 Gp/s. This GI-POF can transmit until approximately 3 Gb/s by the transmission experiment by using this LD. Figures 4(A) and (B) show the eye



(a) Back to Back (b) After 100 m GI POF transmission

Figure 4. 2.5 Gb/s eye pattern with 100 m of GI POF at 647 nm wavelength[6].

diagram before and after 2.5 Gb/s 100 m length transmission. This experiment was the first success in the world for the transmission speed of above 1.2 Gb/s and the fiber length of 100 m at POF. This experimental result also clarified to be available to multimedia communication.

2.3 Heat resistivity

It is expected that POF will be widely used as a short distance optical trasmission medium in the engine compartment of automobile, cleaning the boilling water for medical instruments, and attaching immediately to the light source of light guide. Conventional PMMA core POF with a glass transition temperature of 105℃. In automobiles, this fiber can be used as optical data link only in areas where the temperature dose not exceed 80℃ such as in the passenger compartment. For applications in the engine compartment, the data links must operate at temperature of up to 125 ℃, according to USA standards. The POF composed of a polycarbonate (PC) core with a glass transition temperature of 150 ℃ having high thermal stability up to 125 ℃[7]. This fiber is also superior to mechanical shock and bending. However, the PC core POF is not sufficient for long thermal stability more than 2000 hr at 125℃ because the decomposition of a polymer chain of PC takes place by oxidation. Furthermore, the PC core POF becomes yellowish due to electronic transition of chemical bond and impurity for long fiber length.

The POF composed of a thermosetting polymer, such as polysiloxane[8] and a copolymer composed of methylmethacrylate and ethylene glycol methacrylate[9], high thermal stability up to 150℃ was developed. However, those fibers have a limit in mass production because the hardening time about 1 hr need the fabrication to the optical fiber.

Recently the heat resistive POFs made of the thermoplastic resin superior to mass production have been developed. POF[10] composed of the hydrogenerated ring-opening polymer having ester group substituted tetracyclododecene derivatives is available to the temperatures up to 150

Table 1. The history of the heat resistive POFs.

Year	Maker	Core Material	Attenuation Loss (dB/km)	Wavelength (nm)	Heat Resistivity (℃)
1986	Fujitsu	PC	800	765	125
	Asahi Chemical	PC	600	770	125
	Idemitsu Petro Chem.	PC	560	650	120
	Teigin	PC	600	770	120
	Mitsubishi Rayon	—	1000	770	135
1987	Sumitomo Elec.	polysiloxane	1000		150
	Hitachi	Linked PMMA	1000	650	150
1992	Bridgestone	Liquid polysiloxane	150	590	150
1993	Furukawa Elec.	new PC	380	760	145
1994	JSR*	Poly-nolvolnene	800	680	150
	Toray	Copolymer PMMA	218	650	125

* Japan Synthetic Rubber

℃ and good transparency in the visible wavelength region. POF[11] composed of a specially formulated heat-resistant thermoplastic resin is available to the temperatures up to 145℃ and significantly low transmission loss of 0.36 dB/m at the wavelength of 760 nm. POF[12] composed of a copolymer of methylmethacrylate and iso-propylmaleimide with a glass transition temperature of 135 ℃ is available to the temperatures up to 125 ℃ and significantly low transmission loss of 0.25 dB/m at the wavelength of 650 nm. Table 1 lists the the history of the development for heat resistive POFs.

3. TECHNICAL TRENDS

3.1 Decreasing technology of transmission loss

It is expected to lower the attenuation loss of POF in the wavelength where high speed, high output power optiported presources are available. For the purpose, CH vibrational absorption should be lowered and the possibility has been investigated whether the substitution of hydrogen atoms and by fluorine atoms opens the way to core materials with lower attenuation.

Recently Dr.H.Koike[5] reported precisely the massive atoms effect to shift the absorption wavelength at conventional acrylate polymer in a longer wavelength region. It should be noted that a dramatic decrease in the absorption loss can be found by substituting the hydrogen bond as shown in Fig.5. For example, the transmission loss at the wavelength of 780 nm decreases from 2000 dB/km at C-H vibration to 10^{-5} dB/km at C-F vibration. This caluculation suggests that the attenuation loss of the fluorinated POF is near to silica fiber if another loss factor is controlled. However, the fluorination of core material results in the decreasing of the refractive index, i.e. the difference of the refractive index between core and

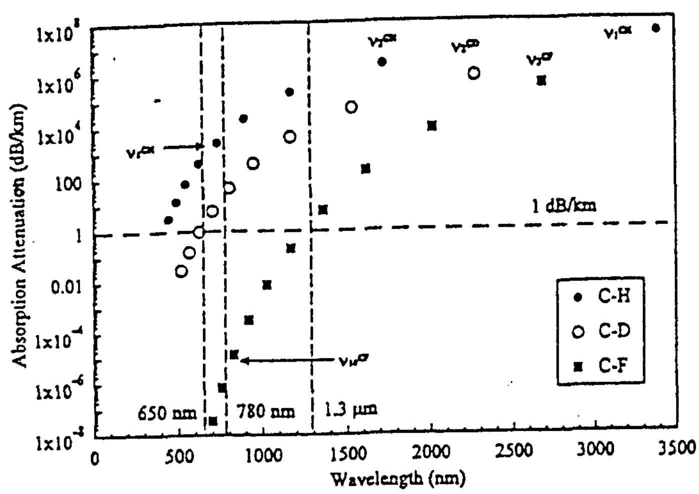


Figure 6. Spectral over-tone positions versus absorption loss of different C-X vibrations in conventional acrylate polymer[5] .

cladding. As a result, the bending loss extremely increased with the SI-POF.

The fluorinated technology is avilable to only GI-POF because the difference of the refractive index between core and cllading for GI-POF is the order of 0.015[3]. In last years, Keio University groups[13] have succeeded in preparing both perdueuterated and perfluorinated GI-POF whose attenuation spectra of 500-1300 nm wavelength is shown in Fig.6. It is quite noteworthy that the attenuation of the perfluorinated GI-POF even at 1300 nm wavelength is less than 60 dB/km. The theoretical attenuation of this perfluorinated material estimated by inherent scattering and absorption losses is less than 1 dB/km. By the improvment of the purification technics for monomer, the polymerization process, and the fabrication thechnologies, the attenuation loss of this will be near at the theoretical loss limit.

3.2 Infrared transmission

The reddish light emitting diode (LED) corresponding to the optical window of POF has been widely used as a light source because they are high emmision power, low in price, and easy in handling. LED is limitted in the high speed data communication because the rise and fall time is the order 10 ns. The transmission of the speed at 155 Mbps and the length of 100m for PMMA POF was obtained by the specially signal treatment of the driven current[4]. The reddish LD whose rise and fall time is near 1 ns is available to the transmission speed above 155 Mbps.However, it is difficult to apply the visible LDs to the components using high speed data communication which life times needs to more than 100,000 hours because the mean life time of these LDs is the order of 10,000 hours in the present stage. The GaAs infrared LD whose emitted wavelength is 780 nm using widely the light source for compact disc is applicable for this purpose[14]. This LD was also recognized the device of fiber channel applied to the high speed communication standard in ANSI whose transmission speeds are 226, 531, and 1063 Mbps. We[15] recognized by the transmitted experiment which the transmission speed of 700 Mbps (NRZ signal) and the fiber length of 50 m using new polycarbonate core POF with the diameter of 0.5 mm developed by Furukawa Electric Industry Co. Ltd[11]. PIN silicon photodiode which cutoff frequency is 1.5 GHz was used in this experiment.

The perfluorinated based GI-POF can be transmitted the wavelength of 1300 nm using the optical communications of the SM fiber. This outstanding aspect is many advantages like holding components in common and so forth and will be one of the promising can didates for the last one mile on FTTH.

3.3 Polymer optical fiber amplifier[16]

POF amplifier is studyed by Keio Uiversity groups[16] for the PMMA base GI-POF which is transparent at visible wavelength range. Sample preform rod was also prepared by the same processing as GI-POF preparation with the interfacial sol-gel polymerization. In the experiment of the GI-POF Amplifier (GI-POFA) the four kinds of dyes, Rhodamine 6G, Rhodamine B and Perylene Red. Excitation pumping was carried out by frequency doubling: Second Harmonic Generation: SHG (532 nm) of Nd:YAG laser (1064 nm). A large core diameter with Rh B dye which emission wavelength is 570 nm gave high level power amplification up to 30 dB for one watt input signal as shown in Fig.7. For optical communication application, the pulse operation by the greenish LD as the exitation pumping is requested.

4. SUMMARY

Comparing to silica fiber, POF has following advantages such as a large core diameter and potentiality of low cost for fiber fabrication. On the other hand, transmission loss is still high level. Therefore, the most promising application field for POF will be relatively short distance LAN or data commmunications. Based on these advantages, the new SI- POFs improved bandwidth[6, 17] have been developed and have been tried to apply to several high speed POF LAN sysytems, such the ATM-LAN and Fast Ethernet. For example, a 156 Mbps 100m transmission[6] was successfully demonstrated using low NA SI-POF and new LED.

The perfluorinated GI-POF which can

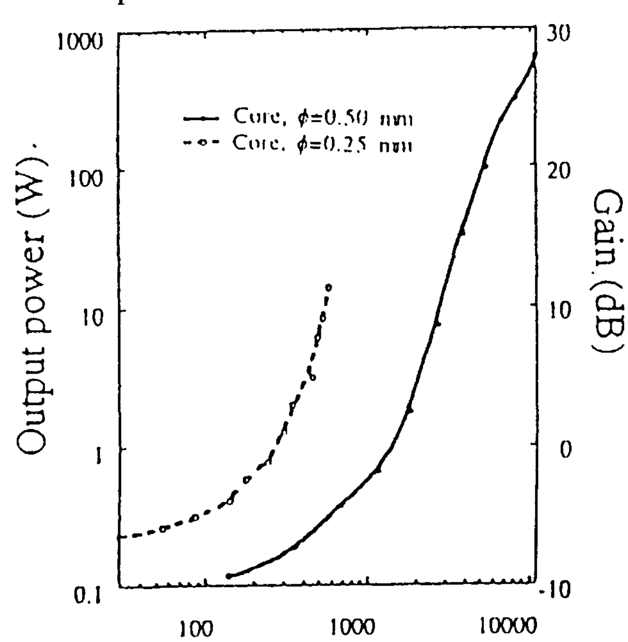


Figure 7. The pumping power dependence of output power and gain for GI-POF amplifier doped Rhodamine B[16].

transmit the infrared wavelength is most anticipated to apply the high-speed data transmission because the components used in silica fiber areavailable in common. Furthermore this POF is possible to transmit the fiber length of near 1 km, so called last one mile, by decreasing the transmission loss below 10 dB/km. To make an advatage of component a low cost of POF, not only the cost reduction of POF itself, but also other related components are necessary.

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