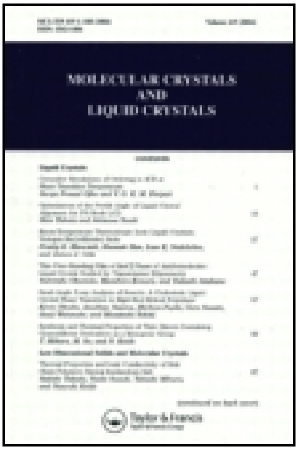

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Recent Progress in High-Speed Polymer Optical Fiber

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Version of record first published: 04 Oct 2006

To cite this article: Yasuhiro Koike (1998): Recent Progress in High-Speed Polymer Optical Fiber, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 315:1, 247-256

To link to this article: http://dx.doi.org/10.1080/10587259808044338

Mol. Cryst. Liq. Cryst., 1998, Vol. 315, pp. 247–256
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Recent Progress in High-Speed Polymer Optical Fiber

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Recent progress of the graded-index polymer optical fiber (GI POF) is reviewed. The low-loss perfluorinated (PF) polymer base GI POF experimentally achieved gigabit transmission for more than 200 m in the range of visible to near infrared region. In addition, improvement of the thermal and long-term stability of the bandwidth of the GI POF with using a new dopant material is described.

Keywords: Graded-Index polymer optical fiber; perfluorinated polymer; modal dispersion; material dispersion; modal noise

INTRODUCTION

Recent progress of the personal computer technology allows to access to Internet from home easily. In order to transmit the large number of data such as moving picture, the order of mega bit per second data rate is required. However, current data transmission rate in the premises area is limited by the bandwidth of the physical layer to the order of kilo bit per second (kb/s). With increasing demand of high speed information transmission, it is desired to introduce the optical fiber network even into the premises area.

We have proposed a large-core, high-bandwidth graded-index (GI) polymer optical fiber (POF) as a physical layer of short distance high data rate network.[1,2] We confirmed that giga bit order data transmission is capable in 100 m GI POF link. We also succeeded in preparing a low-loss GI POF even at near infrared region by using perfluorinated polymer (PF polymer).[3] The attenuation of PF polymer base GI POF is 50 dB/km at 1.3-μm wavelength which is widely utilized in the silica base optical fiber network in the trunk area.

Thermal stability and long-term reliability are key issues in order to utilize the POF link in the premises network. We developed the thermally stable GI POF by investigating the dopant characteristics. The glass transition temperature (Tg) of the polymer strongly influences the thermal stability of the POF. We focused on the plasticization effect of the dopant and selected the materials having the poor plasticization effect of the dopant added poly methyl methacrylate (PMMA) that is the typical polymer matrix of the POF.

HIGH-SPEED POF NETWORK

Figure 1 shows the high-speed POF network concept in the premises area. The backbone network is constructed with using the single mode silica fiber and the order of Gb/s signal is transmitted. On the other hand, current metallic cable system cannot transmit more than several hundred Mb/s in the access network. Therefore, high speed optical fiber network has to be extended even in the access network. However, since lots of signal distributions are required in the premises area as shown in Fig. 1, the small core diameter of the single mode silica fiber needs a precise fiber connecting technique, which increases the total network system cost. A large-core, high-bandwidth GI POF can decrease the total system cost by reducing the alignment technology in the fiber distribution and connection.

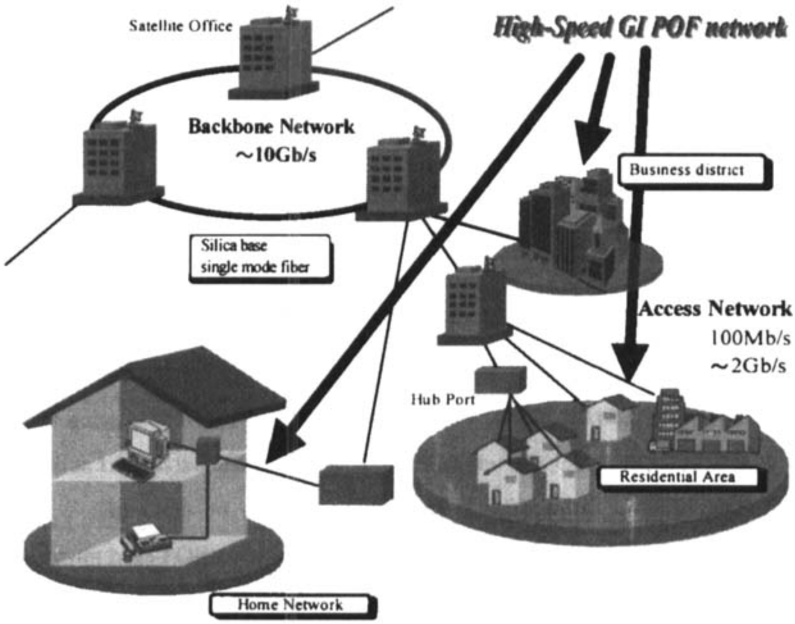


Fig. 1 High-speed POF network concept in the premises area.

GI POF FOR NEAR INFRARED USE

The attenuation of transmission of the PMMA-base POF is shown in Fig. 2. The minimum attenuation was about 150 dB/km at 0.65-μm wavelength which was almost the same as that of the step-index type POF commercially available. However the attenuation

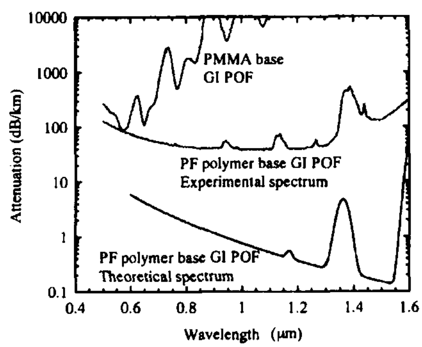


FIGURE 2 Total attenuation spectra of the PMMA-base and PF polymer base GI POFs.

of PMMA base POF was abruptly increased from about 0.7-μm wavelength to the infrared region due to the absorption loss of overtones of C-H stretching vibration.

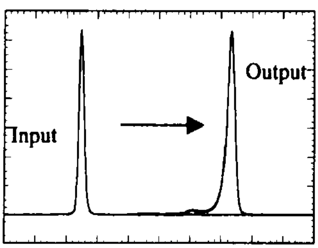
However, it is highly desirable to construct POF network system using commercially available LD and LED which operate in the range of 0.7 -1.5 μm of wavelength. Deuterated or fluorinated polymer base POF will be one of the promising candidates to eliminate the serious absorption loss in such a wavelength.

We have also succeeded in preparing both perdeuterated (PD) and perfluorinated (PF) polymer GI POFs whose attenuation spectra of 0.5-1.3-μm wavelength are shown in Fig. 2, compared with PMMA base GI POF. It is quite noteworthy that the attenuation of the PF polymer base GI POF even at 1.3-μm wavelength is about 40 dB/km.

In order to clarify the theoretical attenuation limit of this PF polymer base POF, total attenuation spectrum was estimated by calculating the inherent scattering and absorption losses with using Einstein's isothermal fluctuation theory and Morse potential energy theory,[4] respectively. Estimated result is also shown in Fig.2. It should be noted that the theoretical attenuation limit of the PF polymer base POF at 1.3-μm wavelength is 0.25 dB/km, which is much comparable with the conventional silica base fiber.

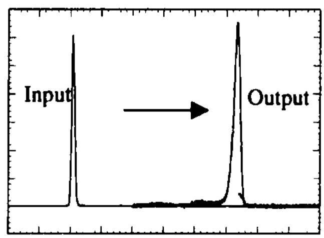
Bandwidth characteristic of the PF polymer base GI POF was investigated by a time-domain measurement method. A narrow pulse shaped input light signal was injected to the 100-m length PF polymer base GI POF, and the output pulse was detected by the sampling head. Used wavelengths were 0.65, 0.78, 0.85, and 1.3 μm. The results at 0.65-μm and 1.3-μm wavelength are shown in Figs 3 and 4, respectively. Although slight amount of pulse spread is observed, bandwidth of the GI POF estimated by Fourier transform was approximately 3 GHz at all wavelengths. Figure 5 shows the relation between the bandwidth and refractive index profile of the GI POF by using the WKB method with taking into account both modal and material dispersions.[3,5,6] The parameter g in Fig. 5 is called the index exponent when the refractive index profile of the GI POF is approximated by the power-law of the form.

In the case of the PMMA base GI POF, the maximum bandwidth of 100-m fiber at 0.65-μm wavelength is limited to approximately 3 GHz even when the refractive index profile is optimized, because of the large material dispersion of the PMMA. In this estimation, the source spectral width was assumed to be 3 nm.



500 ps/div.

Fig.3
Pulse broadening through 100-m PF polymer base GI POF at 0.65-μm wavelength.



500 ps/div.

Fig. 4
Pulse broadening through 100-m PF polymer base GI POF at 1.3-μm wavelength.

Plots in Fig. 5 signify the experimentally measured bandwidths. A good agreement in the theoretical and experimental values is observed, which indicates that the bandwidth estimation by the WKB method is effective in designing the refractive index profile of the GI POF. In the case of the PMMA base GI POF, the minimum attenuation window is located at 0.65-μm wavelength. Therefore, other wavelength at which the material dispersion decreases compared to that at 0.65 μm cannot be adopted. As shown in Fig. 5, the bandwidth of the PF polymer base GI POF is three times higher than that of PMMA base GI POF even in 0.65-μm wavelength use, and 100 GHz can be obtained at 1.3-μm wavelength.

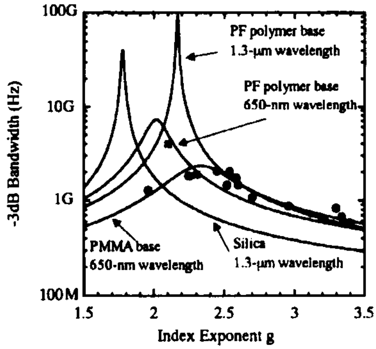


Fig.5 Relation between the index exponent g and the bandwidth of 100 m GI POF.
●: Experimental value of PMMA base GI POF at 0.65-μm
■: Experimental value of PF polymer base GI POF at 0.65-μm

MODAL NOISE

It has been concerned that the modal noise degraded the bit error rate in the case of multi mode fiber with laser diode in the fiber-optic links.[7] However, we confirmed that the large core (300 - 1000 μm diameter) of GI POF which transmits more than 30,000 modes causes no such degradation of bit error rate even if a laser diode with high coherency was used.[8] We investigated the modal noise effect on the bit error rate in GI POF link as follows: a Fabry-Perot LD at 644 nm with 1 nm spectral width was used as the light source, and the bit error rate of 156 Mb/s system in which one fiber-to-fiber joint had been deliberately misaligned was measured. Figure 6 shows the results of PMMA base GI POF with a 600-μm core

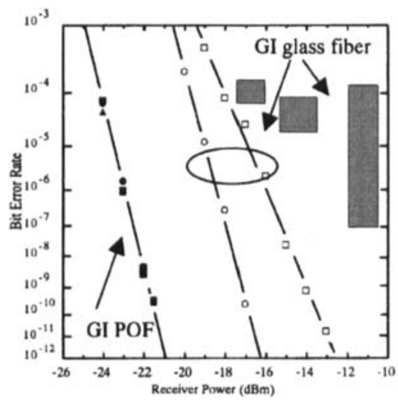


FIGURE 6 Modal noise effect on bit error rate in PMMA base GI POF link.
Misalignment:
GI POF
●: 0 μm ■:100 μm ▲:200 μm
GI glass fiber
O: 0 μm □:10 μm ■ : 20 μm

diameter. Even when 200-μm misalignment is occurred, no significant degradation is observed. On the other hand, in the case of the conventional GI glass fiber whose core diameter was 62.5 μm, it was observed that a 10-μm of displacement caused large bit error rate degradation, and that it was impossible to obtain the accurate bit error rate curve in the case of 20-μm displacement because of a serious fluctuation of the output power from the fiber.

It is concluded that the large core of the GI POF offers low modal noise as well as low coupling loss. The large core of GI POF enables the usage of inexpensive connector made by injection molding which tends to cause 20 to 50-μm misalignment.

THERMAL STABILITY OF GI POF

Thermal stability of the refractive-index distributions of triphenyl phosphate (TPP) doped and diphenyl (DP) doped GI POFs are shown in Figs 7 and 8, respectively. It is noted that profile stability strongly depends on the used dopant. In the case of TPP doped GI POF, no profile change was observed after 5000 hours aging at 85 °C, where the aged fiber is naked fiber . On the other hand, in the case of DP doped GI POF, only after 10 hours aging at 85°C, the index profile significantly degrades. The Tg distributions are also shown in Figs. 7 and 8, respectively. It is revealed that the Tg at core center of DP doped GI POF is lower than 75 °C. This lower Tg than the aging temperature is considered the main reason of the refractive index profile degradation at 85 °C. On the contrary, the TPP doped GI POF has 85 °C of Tg at the core center. Therefore, it can maintain the same refractive index profile at 85 °C aging more than 5000 hours. As shown Figs.7 and 8, TPP and DP doped GI POFs have 0.2 and

0.25 of the numerical aperture, respectively, which attribute to the difference of the refractive index of used dopants. So, in order to obtain the same numerical aperture as the TPP doped GI POF, feed concentration of DP can be lower than that of TPP. Therefore, we selected the diphenyl sulfide (DPS) which has much higher refractive index as 1.63. By decreasing the feed concentration of DPS, we can obtain the GI POF which

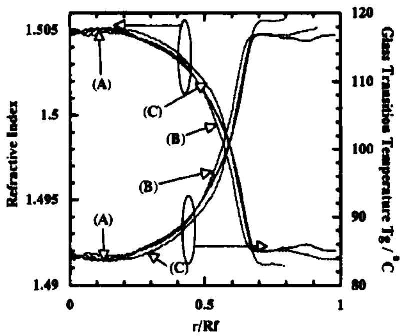


Fig.7 Thermal stability of the refractive index profile of 20 wt. % TPP doped GI POF through 85 °C aging compared to the glass transition temperature profile.
(A): Original (B): after 3000 hours (C): after 5200 hours

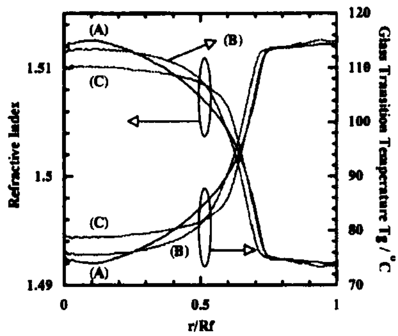


Fig.8 Thermal stability of the refractive index profile of 20 wt. % DP doped GI POF through 85 °C aging compared to the glass transition temperature profile.
(A): Original (B): after 10 hours (C): after 48 hours

has higher Tg at the core center and the same numerical aperture as the TPP doped GI POF. Thermal stability of the DPS doped GI POF was investigated by direct measurement of bandwidth stability through 85 °C aging. The result is shown in Fig. 9. No output pulse degradation was observed even after 3000 hours aging. It was also confirmed that little attenuation increment is observed after 3000 hours aging, which can cover the required thermal stability described in Bellcore standard.

High numerical aperture is also required property for GI POF to increase the coupling efficiency and to decrease the bending loss. So, we selected a new dopant with high refractive index. By using new dopant A, higher Tg than 90 °C was maintained at the core of the GI POF even though

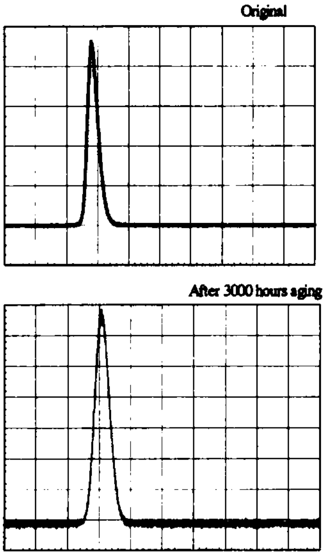


Fig.9 Thermal stability of bandwidth of 11 wt. % DPS doped 100-m GI POF through 85 °C aging. The bandwidth was measured at 0.65-μm wavelength.

the fiber numerical aperture is approximately 0.25. The refractive index profile of the GI POF adopting the dopant A was maintained after more than 600 hours aging at 85 °C. Furthermore, these GI POFs have the thermal stability at high humidity. We tested the attenuation stability at high temperature and high humidity. At 70 °C, 80% RH, no attenuation increment was observed after 400 hours aging in the GI POF adopting any kind of dopants used in this study. In the case of dopant A doped GI POF, the low attenuation was maintained even at 80 °C, 80% RH. It is concluded that the newly developed GI POF can be used at 80°C, 80%RH for giga bps data transmissions.

CONCLUSION

High-bandwidth in wide wavelength range of the PF polymer base GI POF was confirmed theoretically and experimentally. The PF polymer base GI POF can adopt not only the light source at 1.3-μm wavelength but those at 0.98, 0.85, 0.78, or 0.65-μm wavelengths. The high bandwidth stability at high temperature (85 °C) for 1000 h was also experimentally confirmed. The glass transition temperature of the fiber core is maintained to be as high as 90 °C by using a new dopant. Figure 10 summarizes the bit rate performance and link length of the GI POF compared to those of other physical layers. The PMMA base GI POF link is limited within 100-m length because of the attenuation limit. On the other hand, the PF polymer base GI POF can extend both link length and bit rate performance as shown in Fig. 10. We believe that these high potentials of the POF can realize a new network concept in the termination area of access network and in the premises wiring.

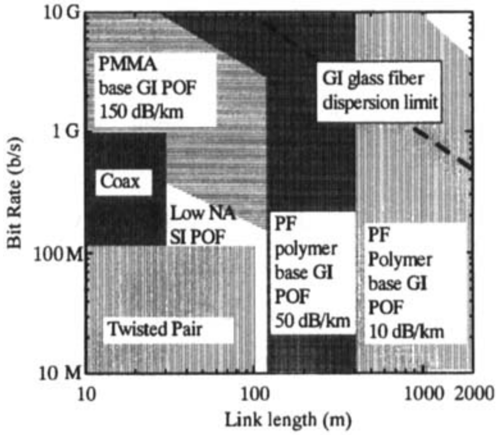


Fig.10 Bit rate performance and link length of POF compared to other physical layers.

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