High speed POF

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The status of the polymer optical fiber (POF) for high-speed data communication is reviewed. Very recently, the low-loss and high-bandwidth perfluorinated GI POF which has no serious absorption loss from visible to 1.3-μm wavelength was successfully prepared at Keio University. Since the core diameter (300-1000 μm) of the GI POF is much larger than that of the multimode silica fiber (62.5 μm), the serious modal noise in the conventional multimode silica fiber was virtually eliminated, resulting in stable giga bit order data transmission with inexpensive couplers and connectors.

1. INTRODUCTION

With increasing demand to access from home or office to Internet which is the most popular network in the world, high speed data communication even in the access area has been of great importance. The growing interests have been focused on high speed optical fiber communication. However, regarding the access area network, since the small core (5-10 μm diameter) of the single-mode fiber requires highly accurate connectors, serious increase of the cost of the whole system is expected. The large core (such as 500 μm or more) of the polymer optical fiber (POF) would make it possible to adopt injection-molded plastic connectors, which dramatically decreases the total cost of the system without any complicated lens alignment.

We have proposed a high bandwidth graded-index polymer optical fiber (GI POF), and have succeeded in a 2.5 gigabit per second (Gb/s) transmission in the 100 m GI POF link[1] using LD at 0.65-μm wavelength. However, the transmission distance was limited to less than 100 m due to the intrinsic absorption loss. In this paper, a new GI POF with low attenuation even at 0.7 - 1.3-μm wavelength region is presented.

2. GI POF FOR 1.3-μm WAVELENGTH USE

The attenuation of transmission of the PMMA-base POF is shown in Fig. 1. 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 of PMMA base POF was abruptly increased from about 0.7-μm wavelength to

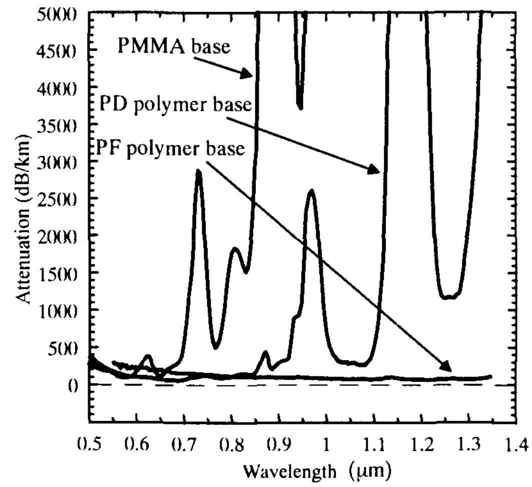

Fig.1 Experimental attenuation spectra of GI POFs.

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.

Very recently, 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. 1, 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 50 dB/km. The theoretical attenuation of this perfluorinated material at 1.3-μm wavelength estimated by inherent scattering and absorption losses is less than 0.4 dB/km

3. BIT ERROR RATE PERFORMANCE

Data transmission experiment was carried out by using high speed red LD with 0.647-μm wavelength developed by NEC. The LD can be modulated to about 4 Gb/s. The receiver sensitivity degradation (power penalty) caused by the dispersion of POF versus bit rate in 100 m SI and GI POF are shown in Fig. 2. The power penalty should be maintained less than 1 dB. Therefore, it was experimentally confirmed that the GI POF can be utilized in about 3 Gb/s data link which can sufficiently cover ATM LAN (156 and 622 Mb/s) standards or Fiber Channel (1 Gb/s), while less than 100 Mb/s in the SI POF link.

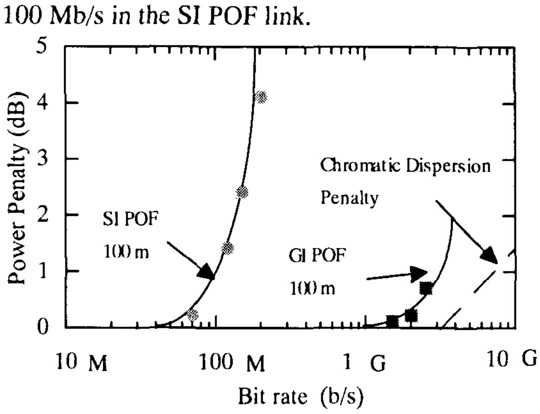

Fig. 2
Comparison of bit rate and power penalty in GI and SI POF links.

On the other hand, we also succeeded in the high speed transmission at 1.3-μm wavelength for the first time by the PF polymer base GI POF. Figure 3 shows the eye diagram of 622 Mb/s transmission in PF polymer base GI POF link. A good eye opening was observed even after 130 m transmission.

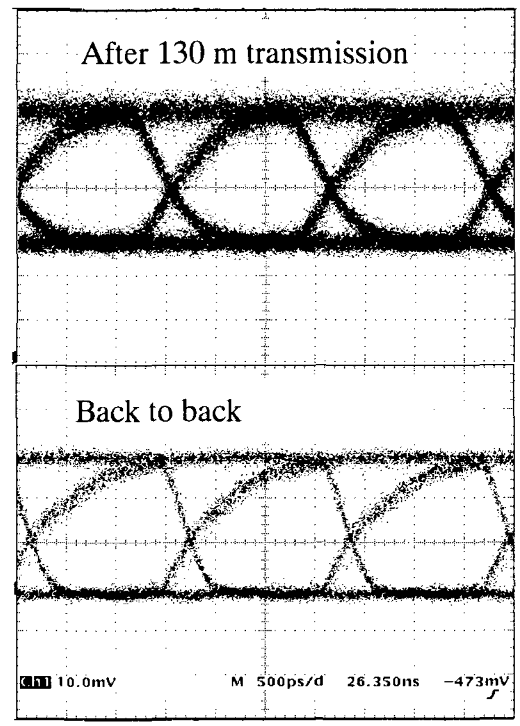

Fig. 3
Received waveform of 622 Mb/s transmission at 1.3-μm wavelength by PF polymer base GI POF.

Optimization of the refractive index profile of the GI POF should be the key technology in order to minimize the modal dispersion. The possible bit rate in GI POF link was theoretically calculated considering both modal and material dispersions by using WKB method. The detail estimation methods are shown in elsewhere[2]. Figure 4 shows the relation between the possible bit rate and refractive index profile of the GI POF which was approximated by the index exponent g in the power law of the following equation:

$$n(r) = n_1\left[1 - \left(\frac{r}{a}\right)^g \Delta\right] \quad (1)$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \approx \frac{n_1 - n_2}{n_1} \quad (2)$$

Here, n_1 and n_2 are refractive-indices at center axis and cladding of the fiber respectively, "a" is radius of the core, and Δ is relative difference of the refractive-index. In Figure 4, the results of the partially fluorinated polymer (PHFIP 2-FA) base GI POF are compared with those of PMMA base GI POF. The light source was assumed to be an LD with 2-nm spectral width. It should be noted that the bit rate in PMMA base GI POF link is limited to less than 5 Gb/s even when the index profile is optimum because of the large material dispersion[2], while smaller effect of the material dispersion can be observed in the PHFIP 2-FA base GI POF link.
Thus, the low material dispersion is another advantage in the fluorinated polymer.

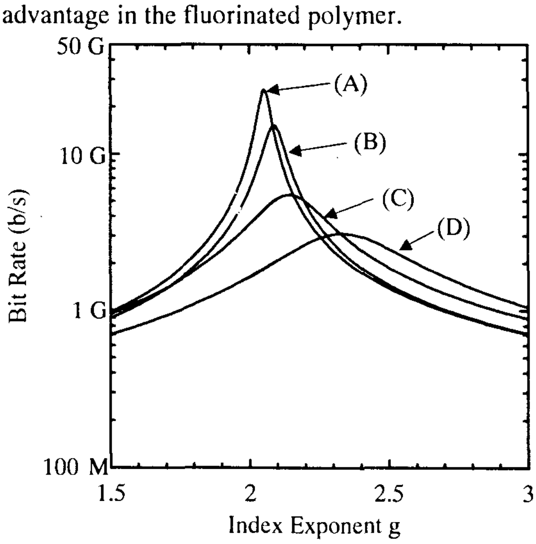

Fig. 4
Relation between index exponent of GI POF and bit rate in 100-m link.
(A): PHFIP 2-FA base at 0.78-μm wavelength.
(B): PHFIP 2-FA base at 0.65-μm wavelength.
(C): PMMA base at 0.78-μm wavelength.
(D): PMMA base at 0.65-μm wavelength.

Furthermore, since the PF polymer base GI POF can utilize the signal wavelength of 1.3 μm, much smaller effect of material dispersion is expected because the material dispersion decreases with increasing wavelength.

The required bit rate and the possible bit rate achieved by several media is summarized in Fig. 5. Although conventional metallic cables such as twisted pair is useful because of easy handling, it takes additional cost for their system to transmit such a high bit rate for ATM LAN standards (155, 622 Mb/s). On the other hand, GI POF can cover most network protocols and applications. Figure 6 shows the data transmission capacity of the PMMA base and PF polymer base GI POF, compared with coaxial and twisted pair cables and low NA SI POF.

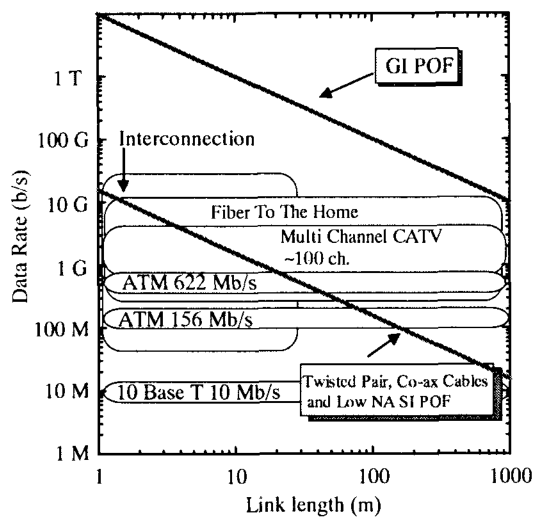

Fig. 5

Application area of POF link.

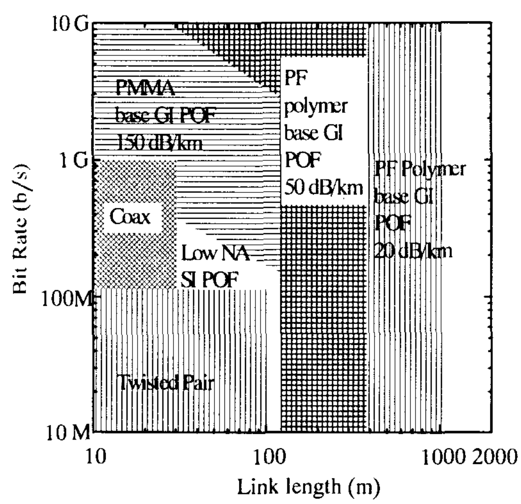

Fig. 6
Relation of data rate and link length of several physical media.

4. 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. 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. 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 has been deliberately misaligned was measured.

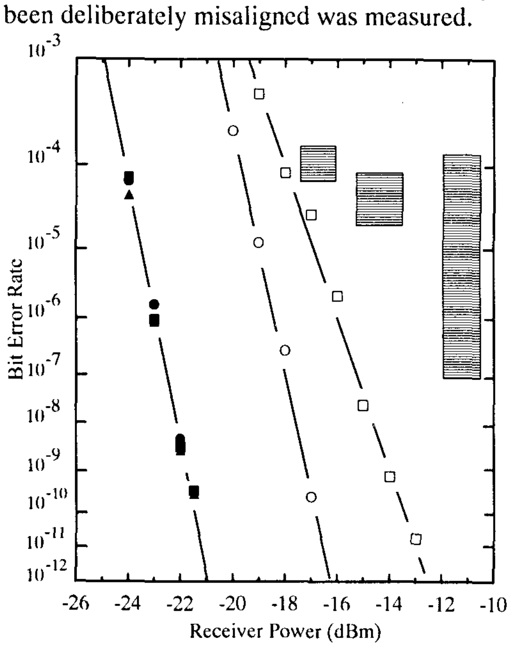

Fig. 7
Modal noise effect on bit error rate in PMMA base GI POF link.
Misalignment:
GI POF
●: 0 μm ■:100 μm ▲:200 μm
GI glass fiber
O: 0 μm □:10 μm ▒: 20 μm

Figure 7 shows the results of PMMA base GI POF with a 600-μm core diameter. Even when 200-μm misalignment was 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.

5. CONCLUSION

We demonstrated the low loss GI POF even at 1.3-μm wavelength. The perfluorinated polymer base GI POF has many advantages: one is no serious absorption peak in the range of 0.5-1.3-μm wavelength in its attenuation spectrum, and the attenuation at 1.3 μm where the LD for silica fiber operates is about 50 dB/km. Another is low material dispersion compared with PMMA and silica, which allows more than 10 Gb/s transmission even in 500 m link. In addition, no modal noise in the GI POF link permits the coherent LD usage. We believe that these experimental and theoretical aspects suggest that the PF polymer base GI POF will be one of the promising candidates for "the last one mile".

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2. T. Ishigure, E. Nihei, and Y. Koike, *Appl Opt.*, **35**, 2048 (1996)