# Status and Dreams of Photonics Polymer for IT

*Yasuhiro Koike,* Takaaki Ishigure, Akihiro Tagaya*

Faculty of Science and Technology, Keio University, 3-14-1, Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan
Email: koike@appi.keio.ac.jp
ERATO Koike Photonics Polymer Project, Japan Science and Technology Corporation, $K^2$ Town Campus, 144-8, Ogura, Saiwai-ku, Kawasaki 212-0054, Japan

**Summary:** We have proposed a low-loss, high-bandwidth and large-core graded-index plastic optical fiber (GI POF) in data-com. area. The GI POF enables us to eliminate the "modal noise" problem which is observed in medium-core silica fibers. Therefore, stable high-speed data transmission can be realized by the GI POF rather than medium-core silica fibers. Furthermore, advent of perfluorinated (PF) polymer based GI POF network can support higher transmission than silica fibers network because of the small material dispersion of PF polymer compared with silica. In addition, we proposed a "highly scattering optical transmission (HSOT) polymer" and applied it to a light guide plate of a liquid crystal display backlight. The HSOT polymer backlight that was designed using the HSOT designing simulator demonstrated twice the brightness of the conventional taransparent backlight with sufficient color uniformity. Furthermore, we proposed the two types of zero-birefringence polymers synthesized by the random copolymerization method and the anisotropic molecule dopant method. Both of the polymers exhibited no orientational birefringence for any orientation of polymer chains.

**Keywords:** GI plastic optical fibers, HSOT, injection molding, material dispersion, zero-birefringence polymers

## Introduction

During the past several years, the IT industry was flourishing and leading the economic growth. However, in these days, it has gone into a temporary stall. The main cause of the stall should be a large difference between the current status of hardware and software. While the broadband Internet access has not penetrated into homes and offices yet, more and more expectations are placed on software including contents. In order to break through the situation surrounding the IT industry, a new development is required for the filed of information technology. And in order to make the new development, the biggest challenge will be how to install gigabit optical fiber to local area networks at homes and offices, and how to display the high quality motion pictures. In this article, a "high-speed graded-index plastic optical fiber (GI POF)", a "highly scattering


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optical transmission (HSOT) polymer", and "zero-birefringence polymers" for liquid-crystalline displays (LCDs) are described in detail.

# 1 Graded Index Plastic Optical Fiber (GI POF)

## 1.1 Modal Noise Elimination in GI POF Link

It was shown by previous works on the silica based multimode fiber (MMF) with 50 to 62.5 μm core diameter that the modal noise deteriorated the system performance.[1] The modal noise is observed in the MMF and a coherent light source such as laser diode or Vertical Cavity Surface Emitting Laser (VCSEL) systems. In such a system, "speckle" is formed on the output end face of the fiber by interference among the propagating modes. Therefore, if an offset connection between two fibers is included in the MMF link, the speckle power distribution is translated into the optical power fluctuation, which causes the modal noise. Therefore, the permissible misalignment in the connector of the silica based MMF is several micrometers, although MMF's larger core diameter than that of the single mode counterpart tolerates the misalignment in the fiber connection from the aspect of the connection loss.

On the other hand, in the case of the GI POF with much larger core than that of the silica based MMF, such a small misalignment in fiber connection is negligible in maintaining the low connection loss. In addition to the advantage in the connection loss, it was clarified that the modal noise was virtually eliminated in the large core (>120 μm) GI POF link, because of the huge number of propagating modes.

## 1.2 Bandwidth Achieved by GI POF

Despite the large modal noise problem mentioned above, the MMF networks have been expected to be a viable solution for the premises network, because it is still more cost effective than the use of single mode counterpart. Gigabit Ethernet and 10Gigabit Ethernet standards specify the use of MMF and an inexpensive VCSEL sources as a light source. However, the dispersion of the MMF is the serious problem particularly in the 10Gigabit transmission systems. When the refractive index profile of the MMF is optimized, a chromatic dispersion would be a dominant factor of the total dispersion.

For the premises network applications, we have proposed a low-loss perfluorinated (PF) polymer based GI POF.[2-3] The attenuation of the current PF polymer based GI POF is 10 dB/km in 0.8 – 1.3-μm wavelength range. In addition to the low attenuation, we have focused on the large advantage in the PF polymer based GI POF, that is lower material dispersion than that of silica.[3] This result means that the PF polymer based GI POF enables a higher data transmission rate than the conventional silica based MMF. Comparison of calculated bandwidth for 500-m length between the PF polymer based GI POF and silica based multimode fiber is shown in Figure 1 when their index profiles are optimised for 0.85-μm use. In this calculation, actually measured material dispersion was taken into account. It is noted that 10 GHz bandwidth for 500 m is achieved by the PF polymer based GI POF 1, which is approximately twice higher than that of silica based multimode fiber.

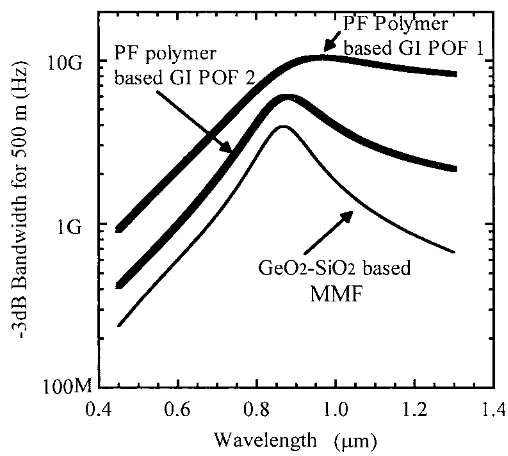


Fig. 1. Wavelength dependence of the bandwidth of PF polymer based GI POF compared to that of silica based multimode fiber (MMF). Spectral width of light source was assumed to be 1 nm.

In addition to the bandwidth advantage at 0.85-μm wavelength, it is noteworthy that the wavelength dependence of the bandwidth of PF polymer based GI POF is remarkably small. This indicates that if the index profile is optimized for 0.85-μm wavelength, the same fiber is also applicable at another wavelengths, such as 1.3-μm. Therefore, the same PF polymer based GI POF covers more than 10 Gb/s at almost any wavelength from visible to 1.3-μm regions.

## 2 Photonics Polymer for Display

### 2.1 Highly Scattering Optical Transmission (HSOT) Polymer

A display with high-visual quality and low energy consumption is one of the most important devices in the concept of the Ubiquitous Network. Liquid crystal displays (LCDs) are the mainstream flat panel display and have been widely used for a monitor of desktop computers and other portable devices, and a television. LCDs will be more important flat panel displays especially for portable devices in the coming highly-networked information society.

We proposed a novel photonics polymer, a highly scattering optical transmission (HSOT) polymer.[4-6] Light injected into the HSOT polymer is multiply scattered and homogenized, and then comes out as a directive illuminating light because of the microscopic heterogeneous structures formed by doping with spherical particles in the HSOT polymer. The scattering property of the HSOT polymer depends on the size and relative refractive-index of the heterogeneous structures. We applied the HSOT polymer to a light guide plate (LGP) in a backlight unit for LCDs and designed the heterogeneous structures by the multiple scattering simulator that we developed using the Monte Carlo method based on Mie scattering theory. Conventionally, before our proposal of the HSOT polymer, all LGPs in backlights were made of transparent polymers, and it was thought that polymers for the LGPs must be transparent without any contaminant, because the contaminant would absorb and scatter light. Even if the contaminant does not absorb light, it was supposed that the contaminant causes a decrease in brightness and degradation of color uniformity of the backlight, because scattered lights are distributed to all directions and the scattering efficiency depends on wavelength of the propagating light. On the other hand, the HSOT backlight demonstrated twice the brightness of the conventional one with sufficient color uniformity by optimizing the heterogeneous structures with using the multiple scattering simulator. This disproved the speculation that the LGPs must be transparent. Consequently, the HSOT backlight has become commercially used in some types of thin notebook computers because of its higher brightness.

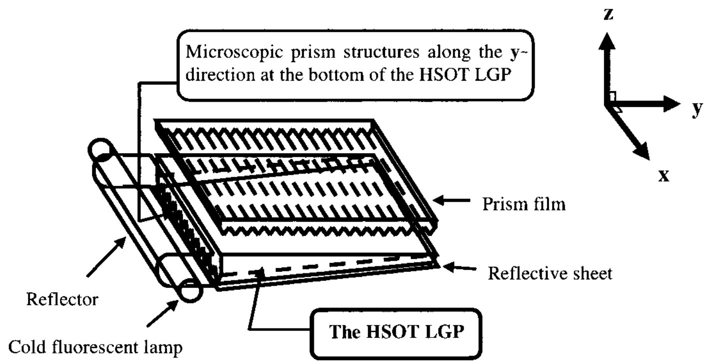


Fig. 2. Schematic diagram of the advanced HSOT backlight, in which the wedge-shaped HSOT LGP has the microscopic prism structures at the bottom in the y-direction.

Details of the optimization using the multiple scattering simulator are described in Ref. [5-6]. Here we describe the relation between scattering efficiency and wavelength. Scattering efficiency against the diameter of the spherical heterogeneous structure at 615, 545, 435nm corresponding to red, green and blue (RGB) lights are shown in Figure 3. Generally, we tend to think that blue light is always scattered stronger than red light based on Rayleigh scattering theory. However, it is not always true and depends on the size of heterogeneous structures. By injecting white light from a typical cold fluorescent lamp or a white LED into the scattering medium containing the heterogeneous structure (A), yellowish transmitted light with a lower color temperature was obtained because blue light was scattered stronger than red light. This is the same phenomenon as the red sunset. However, bluish transmitted light with a higher color temperature was obtained in the scattering medium containing the heterogeneous structure (B), because red light was scattered stronger than blue light. By controlling the diameter of the heterogeneous structure to give almost the same scattering efficiencies for RGB, output light having almost the same color temperature as that of injected light can be obtained. We realized sufficient color uniformity by using particles having almost the same scattering efficiencies.

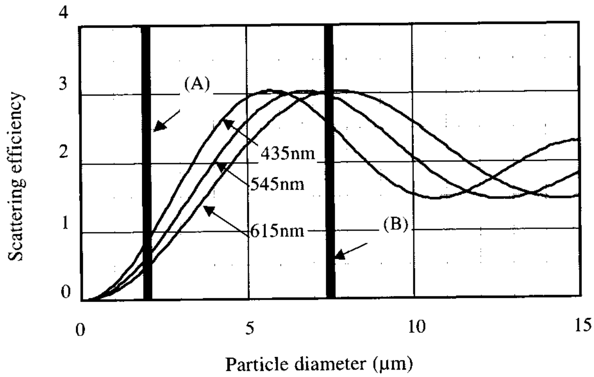


Fig. 3. Scattering efficiency curves of a single particle for 435, 545 and 615 nm-wavelengths, respectively. Typical cold fluorescent lamps have spectral peaks around these wavelengths. Relative refractive index: m = 0.965. (A) and (B) mean particle diameters of 2 μm and 7.5 μm as the heterogeneous structures, respectively.

### 2.2 Zero-Birefringence Polymer

Optical polymers have been widely used as key-materials for a variety of optical devices in recent optical technology, for example, polymer optical fibers, optical films for LCDs, optical disks and lenses because of their easy processing, easy handling, light weight, high transparency, and low cost. Although most polymers are composed of monomers exhibiting an anisotropic polarizability, they exhibit no birefringence in a perfectly amorphous state. However, the optical polymers tend to exhibit birefringence caused by the orientation of polymer chains in the process of injection-molding or extrusion, which restricts their application in optical devices that handle polarized light. Optical polymers that exhibit no birefringence for any orientation of polymer chains are desirable to realize high performance optical devices for handling polarized light. We define such polymers as “zero-birefringence polymers” in this article.

We developed the zero-birefringence polymers by the random copolymerization method[7] and by the anisotropic molecule dopant method.[8-9] In the random copolymerization method, negative and positive birefringence monomers are randomly copolymerized with the specified composition in order to compensate polarizability anisotropy in a polymer chain as shown in Figure 4(a). We demonstrated some types of zero-birefringence polymers having sufficient transparency for some optical devices such as pick-up lenses of optical disks by using the random copolymerization method. Figure 5(a) shows the data of poly(methyl methacrylate(MMA)-co-benzyl methacrylate(BzMA)). In the case of uniaxially drawn polymer samples, the orientational birefringence $\Delta n$ is defined as $\Delta n = n_{//} - n_{\perp}$, where $n_{//}$ and $n_{\perp}$ are refractive-indices for light polarized in a parallel direction and a perpendicular direction to the drawing direction, respectively. Positive polymers show orientational birefringence $\Delta n > 0$ and negative polymers show $\Delta n < 0$. When the copolymer was synthesized with the composition MMA/BzMA = 82/18 (wt./wt.), the orientational birefringence was always zero at any draw ratios.

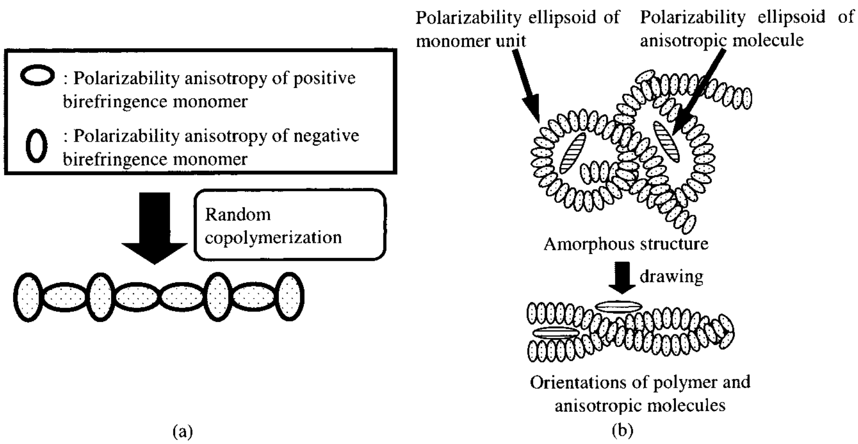


Fig. 4. Mechanism of the compensation for orientational birefringence by (a) the random copolymerization method and (b) the anisotropic molecule dopant method.

In the anisotropic molecule dopant method, molecules which have an anisotropic polarizability and rod-like shape such as *trans*-stilbene are chosen and doped into polymers. The mechanism of the compensation for orientational birefringence by the anisotropic molecule dopant method is shown in Figure 4(b). When the polymer chains are oriented in processing, the molecules are also oriented because of their rod-like shape. Negative birefringence of the polymer can be compensated by doping with positive anisotropic molecules which have a positive polarizability anisotropy with respect to direction of orientation. Figure 5(b) shows the orientational birefringence of *trans*-stilbene-doped PMMA and PMMA films at 590 nm wavelength as a function of the draw ratio. Negative birefringence ($\Delta n < 0$) of the drawn PMMA film was compensated by doping with *trans*-stilbene which was the positive anisotropic molecule. The birefringence was completely eliminated for any draw ratios at the concentration of 3.0 wt% of *trans*-stilbene. Based on these results, the zero-birefringence polymers will, we believe, open the way for the great advantages in various photonics polymers in display and storage.

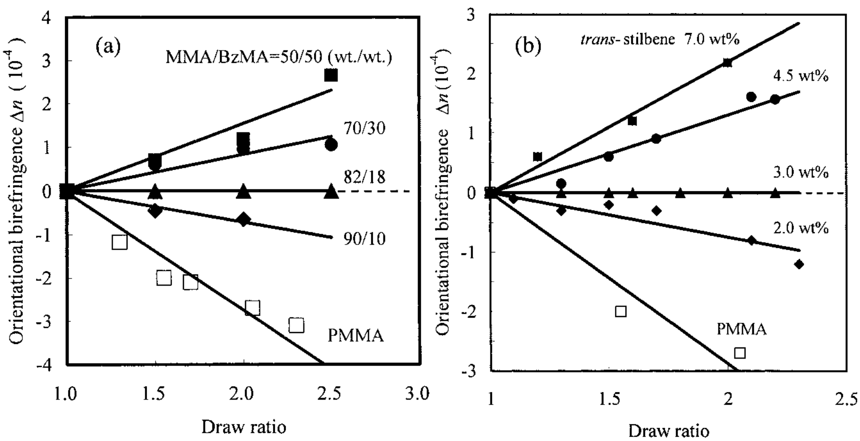


Fig. 5. Compensation for orientational birefringence of (a) poly(MMA-co-BzMA) and (b) *trans*-stilbene-doped PMMA films.

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