

Low-loss polystyrene core-optical fibers

Toshikuni Kaino, Michiya Fujiki, and Shigeo Nara

Plastic Molding Section, Ibaraki Electrical Communication Laboratory, Nippon Telegraph & Telephone Public Corporation, Tokai, Naka-gun, Ibaraki, 319-11 Japan.

(Received 10 April 1981; accepted for publication 19 August 1981)

Low-loss plastic optical fibers (POF) have been prepared with the attenuation loss of 114 dB/km at the wavelength of 670 nm employing polystyrene core and ethylene-vinylacetate copolymer cladding. The POF can allow the use for short-distance optical signal transmission. The theoretical loss limit of polystyrene core POF is calculated to be 70 dB/km at 670 nm.

PACS numbers: 42.80.Lt, 42.10.Qj, 78.20.Dj

I. INTRODUCTION

Plastic optical fibers (POF), which can be applied to transmit data, have many advantages such as low price, ease in handling because of good ductility, and light weight and ease in splicing to each other and to light sources because of large core diameter as well as high numerical aperture (NA).

It is expected to apply to optical signal transmission for certain computer-to-terminal data links. However, commercial POF have large losses, about 300 dB/km at least,¹ so their application is limited to extremely short distance use as in displays and image guides like light monitors in automobiles, endoscopes, and other medical devices.

As the core material of commercial POF, polystyrene (PS) or poly (methylmethacrylate)(PMMA) are used.² Among these, PMMA is superior to PS with regard to mechanical properties and chemical resistance. But PS has some features as a core material for low-loss POF as follows.

(1) PS can be obtained by thermal polymerization without any initiator as is needed in PMMA, which sometimes produces bubbles during the polymerization reaction.

(2) Hygroscopic coefficient of PS is one order lower than that of PMMA, so the loss due to O-H absorption is small even in humid environment.

(3) The refractive index of PS is 1.59, so the conventional transparent polymers can be used as a cladding.

PS core silicone resin cladding POF with the attenuation loss of 140 dB/km is reported in the previous letter.³

In this paper, the lower loss POF with PS core are de-

scribed and its transmission spectra are analyzed to clarify the cause of the losses and to estimate the theoretical loss limit of POF.

II. EXPERIMENT

Styrene monomer is prepared by the following processes.

Polymerization inhibitor is eliminated by alkali rinsing, then the residual alkali is washed by pure water until the pH of the monomer reaches to neutrality. After drying by Na_2SO_4 and CaH_2 , the styrene monomer is carefully distilled under vacuum and poured into the flask shown in Fig. 1. Commercial grade *n*-butyl mercaptan (20 mmol/l) as a chain transfer agent is poured into another flask of the apparatus. It can be distilled easily at a reduced pressure as the styrene monomer. The pressure in the apparatus is reduced to about 0.1 mm Hg so that dust and oxygen do not mix into the apparatus. The flask containing styrene is cooled with liquid nitrogen and remelted with hot water under vacuum to eliminate the dissolved oxygen.

Styrene monomer is distilled into the polymerization ampule and the ampule is washed to remove dust and other contaminants attached to the inner wall of the ampule. Then the monomer is transferred back to the flask by decantation.

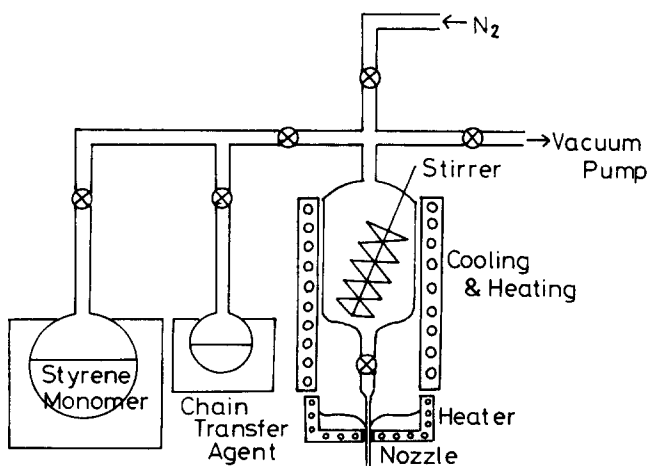


Fig. 1. Polymerization and fiber-drawing apparatus.

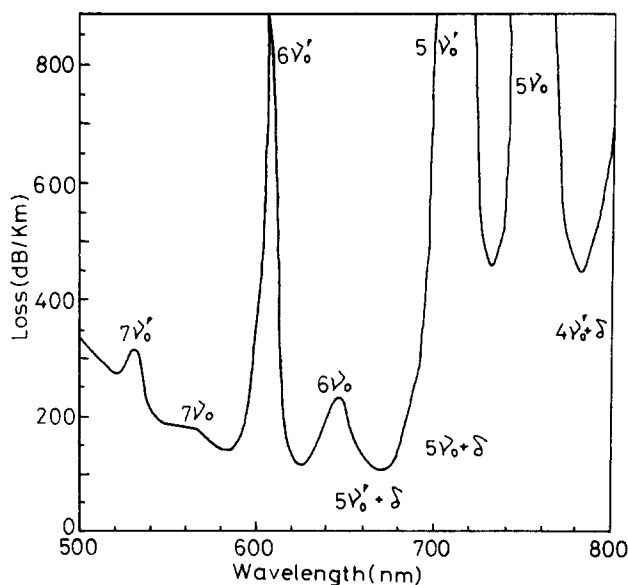


Fig. 2. PS core POF transmission-loss spectra.

TABLE I. Loss factors of POF.

Absorbing loss	{	Intrinsic	{ Infrared (IR) vibrating absorption
			{ Electronic transition
Scattering loss	{	Impurities	{ Transition metals
			{ Other organic contaminants
	{	Intrinsic	Rayleigh scattering due to density fluctuations
			{ Core-cladding boundary imperfections
			{ Variation in core diameter
	{	Imperfections in waveguide structure	{ Dust and micro voids
			{ Orientational variation in refractive index

Such washing and distillation are repeated until the glittering from dust detected He-Ne laser is not observed at any point in the ampule. Then the chain transfer agent is distilled into the polymerization ampule and the ampule is heated in an electric furnace at 130 °C for 16 h to polymerize the styrene monomer. The temperature is raised gradually to 180 °C and settled at the temperature for 16 h to complete the polymerization. After that, the pressure of the apparatus is raised to the atmospheric pressure and the nozzle which is set at the bottom of the ampule is opened.

The ampule is heated to 190 °C and the melted PS is pressed from the upper end of the ampule by dry nitrogen gas at 1.75 atm of gas pressure and fibers are drawn out from the nozzle at the rate of 2 m/min. The fiber diameter is controlled to 1.0 mm by regulating the drawing velocity and the gas pressure. Ethylene-vinylacetate copolymer (EVA) is clad immediately by coating to the core fibers at about 0.3 mm in thickness. This EVA contains 25 % of vinyl acetate and has the softening point of 90 °C.

The refractive indices of the core and the cladding are 1.590 and 1.485, respectively. Therefore, the ΔN is 6.9 % and the NA is 0.58.

The transmission loss spectra of the POF are measured using a grating monochromator and halogen-tungsten lamp detected by a silicon photo-diode. The scattering loss is measured on the optically polished another ampule of the polymerized styrene using He-Ne laser by comparing the loss of the dust-free benzene and carbon-tetrachloride poured into the ampule using the same way as the styrene monomer. The scattering losses of benzene and carbon-tetrachloride are 56.5 dB/km and 23 dB/km, respectively.⁴

III. RESULTS AND DISCUSSIONS

The transmission loss spectra of the PS core POF are shown in Fig. 2. The optimum transmission loss is 114 dB/km at 670 nm. It shows the lowest attenuation at longer wavelength than the PMMA core POF, where the lowest attenuation is 570 nm.⁵

Causes of the optical attenuation losses of the plastic fibers are shown in Table I. The visible spectrum of the PS core POF are dominated by the high harmonics of the aliphatic C-H stretching vibrations, $n\nu_0$, at 758, 646, and 562 nm and the aromatic C-H stretching vibrations, $n\nu'_0$, at 714, 608, and 532 nm, where n is the vibrational quantum number. These spectral absorption peaks are inherent to the material and do not arise from impurities. Their strength becomes one order weaker when the degree of the n increases by one. Shoulders in the region of lower wavelength of each peak are assigned to the combination bands $n\nu_0 + \delta$ and $n\nu'_0 + \delta$, where δ is the fundamental aliphatic C-H bending vibration.

The UV absorption tails resulting from $\pi \rightarrow \pi^*$ electronic transitions of phenyl groups are recognized in the short-wavelength region below 600 nm. The loss of this fiber α_e at an arbitrary wavelength λ can be calculated by the following equation,⁶

$$\alpha_e(\text{dB/km}) = 1.1 \times 10^{-5} \exp\left(\frac{8000}{\lambda}\right).$$

The amount of transition metal ions in the POF measured by flameless atomic absorbance analysis is too small to influence the loss spectrum of the visible region.

The scattering loss before fiber drawing is 55 dB/km at

TABLE II. Loss limits of PS core POF.

Wavelength (nm)	552	580	624	672	734
Rayleigh scattering (α_s , dB/km)	95	78	58	43	30
UV absorption (α_e , dB/km)	22	11	4	2	1
IR absorption (α_a , dB/km)	0	4	22	24	390
Imperfections in waveguide structure (α_i , dB/km)	45	45	45	45	45
Loss limits (dB/km)	117	93	84	69	421

633 nm. This Rayleigh scattering loss is inversely proportional to the fourth power of the wavelength. So the losses, α_s , of this fiber at an arbitrary wavelength is calculated by applying the value at 633 nm to the following equation⁷

$$\alpha_s(\text{dB/km}) = 55 \times \left(\frac{633}{\lambda}\right)^4.$$

An excess loss is considered to be brought by imperfections of the waveguide structure.

To avoid dust and other contaminants, using of this closed-type polymerization and fiber-drawing apparatus is very effective.

Therefore, the loss factors and the losses of the PS core POF are considered as shown in Table II.

The loss limits of the POF are composed of the intrinsic vibrating absorption loss, intrinsic electronic transition UV absorption loss, and the intrinsic Rayleigh scattering loss, so the loss limit of the PS core fibers is about 70 dB/km at 670 nm, and attenuation loss less than 100 dB/km can be realized at 580 and 624 nm.

These characteristics can allow the use of cheaper light sources, such as display-grade red gallium phosphide light-emitting diodes (LED), which has higher luminous efficiency than the green LED which is fit for the PMMA core POF as reported before.⁵ The loss of the reported POF are sufficiently low to use for fiber-optics signal transmission systems.

ACKNOWLEDGMENTS

The authors wish to thank Y. Katayama and S. Oikawa for their helpful discussion.

¹H. M. Schleinitz, *Int. Wire and Cable Symp.* **25**, 352 (1977).

²B. Crist, M. E. Marhic, and M. Epstein, *J. Appl. Phys.* **51**, 1160 (1980).

³S. Oikawa, M. Fujiki, and Y. Katayama, *Electron. Lett.* **15**, 829 (1979).

⁴M. Kerker, *The scattering of light*, (Academic, New York, 1969), p. 499.

⁵T. Kaino, M. Fujiki, S. Oikawa, and S. Nara, *Appl Opt.* **20**, 2886 (1981).

⁶F. Urbach, *Phys. Rev.* **92**, 1324 (1953).

⁷K. Inada, *Opt. Commun.* **19**, 434 (1976).