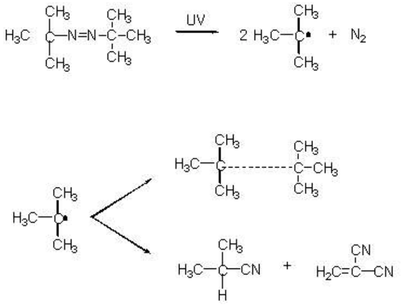


Fig 1. Azo compound decomposition by UV energy

In a multiple-fiber unit one would expect to use materials having larger elastic moduli and in considerably greater thickness. Moreover, when a multiple-fiber unit is bent, the individual fibers will generally each experience different bending forces and will tend to move relative to each other. In addition, the larger diameter of multiple fiber units means that for a given bend radius the outer surface of the outer coating is exposed to greater tensile and compressive stress than in a single-fiber unit. The polycarbonate back-born materials satisfy these requirements.[1-2]

In this paper, the photochemical (Ultra Violet) reaction is employed to foam gas bubbles trapped in the coating film for optical fiber bundle.[8-10] The gas bubbles trapped in the film lower the density of the coating significantly down to one half of that of the solid film.

2. Experiment and result

Test compounds, adding azo group blowing agents and metal complexes reagents as catalyst in the UV curable polycarbonate compounds, are prepared for fiber coating. To figure out the efficiency of blowing agents, four other compounds, which have different contents of blowing agent each other- 0.5 wt%, 1.0 wt%, 1.5 wt%, 2.0 wt%, are coated on fibers in the coating system and checked the blowing efficiency and physical properties.

The coated fibers were made on what is essentially a standard multi-fiber packaging line of the type used for the manufacture of ribbon cable or color coated line. Four other coating materials are applied to fiber coating system. Materials are cured with one UV lamps (600 W/inch D bulb, Model No. VPS 600I made by FUSION) at the line speed 100 m/min. One single mode fiber passed through 500 micro coating dice and UV zone.

Test results are illustrated in Fig 2. It is easy to know the fact densities of the cured film decrease proportionally with increasing fiber-coating thickness. Increasing rate of the coating thickness after curing shows the efficiency of blowing agent contents. As higher the contents of blowing agent, the thickness of the coated fibers are increased. Fig 3. (a) and (b) are the microscope pictures of the coated fiber surfaces, contents of blowing agent are 1.0 wt% and 1.5 wt%. We can find about twice number of foams in Fig .3. (a) than Fig.3.(b).

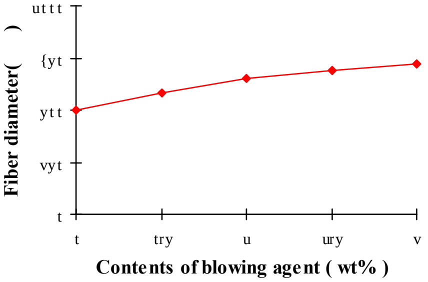
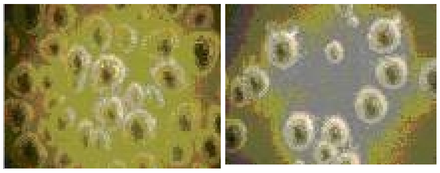


Fig 2. The change of coated fiber diameter vs. contents of blowing reagent



(a) 1.5wt% blowing agent (b) 1.0 wt% blowing agent

Fig. 3. Surface of coated fiber

In air blown fiber bundle materials, high elongations and strengths are very important point to have a bigger bend radius than unit fiber coating and to protect fibers from mechanical damages. To confirm the fitness of these materials, all physical properties vs. test materials are shown in Table 1. compared with the normal fiber coating materials (normal material).

Table 1. Physical properties of materials

	Normal material	*0.5% CBA*	*1.0% CBA*	*1.5% CBA*	*2.0% CBA*
Secant modulus (Mpa)	610	678	624	583	529
Strength (Mpa)	34	38	34	28	26
Elongation (%)	35	52	45	38	34
Density (g/cm^3)	1.1	0.89	0.78	0.61	0.59

The film density is inverse proportion to the coating modulus and the elongation. Low-density films by foaming for air blown fiber bundle have week mechanical properties. Using the toughness material, which has the polycarbonate group, makes up for weak properties in foaming coating. According to the table 1, properties of 1.0% CBA and 1.5% CBA are almost same as normal materials, although lower densities than it.

3. Conclusion

In this experiment, with implementation of UV induced blowing agent system into conventional UV curable optical fiber coating, the low density and low friction surface film can be achieved from UV cure process. The density-decreasing rate of foam film is proportional to blowing reagent content and ultra violet energy with limitation of saturation point. Materials including 1.0 % CBA and 1.5 % CBA show suitable properties for air blown fiber bundle, higher modulus and better elongation than normal fiber coating materials. And under optical fiber cable or bundle making lines, the density of foam film can be reached easily down to 0.50 g/cm^3. Therefore, low-density polymer sheath for air blown fiber bundle can be made in conventional UV curing system of optical fiber coating or cabling industries using this new formulation. This new UV curable coating material makes it possible to produce ABF optical bundle faster and cheaper than conventional thermal process.

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MF9 **5:30 PM**

The Method for Manufacturing Graded-Index Polymer Rod

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A useful method to prepare the polymer rods to be used for the preform to make the graded index polymer optical fiber (GI-POF) or for the optical rod lens is proposed.

Introduction

With increasing demand of high-speed data transmission, polymer optical fiber (POF) is expected to act as one of the important high data transmission media[1-2]. Graded Index (GI) POF has recently attracted extensive attention in light of their highly promising potential in optical fiber communication. The refractive index varies continuously within the graded index polymeric materials. This variety allows them to have unique optical properties that conventional optical materials with constant refractive index cannot achieve. Several synthetic approaches have been used to prepare the GI-POF, e.g. two-stage copolymerization[3], photocopolymerization[4-5], interfacial gel copolymerization[6], centrifugal polymerization[7], vapor phase diffusion copolymerization[8], etc. The differences among the monomer concentration, monomer reactivity, and monomer size were driving forces behind producing index gradient inside the polymer. In the case of interfacial-gel copolymerization, two monomers with different indices ($n_1<n_2$) should satisfy the following conditions: (a) $r_1>1$ and $r_2<1$ such as methyl methacrylate (MMA) with vinyl benzoate (VB) or (b) $r_1=r_2=1$ and the size of monomer 1 is less than that of 2 such as MMA with benzyl methacrylate (BzMA), where. r_i and n_i are the reactivity and refractive index of monomer i, respectively.

In present paper the rod type polymer preform with radially varying properties has been prepared. We have proposed convenient technique for the preparation of GI-POF that uses copolymerization in centrifugal field, and utilizes the swelling of the polymer and the diffusion of the monomers in the mixture. The bandwidth characteristic of the GI POF was theoretically calculated by considering not only modal but also the other factors affecting the refractive index profile. The preform made from this method may be able to be applied to produce high-bandwidth GI POF for transmitting a high-speed optical signal in a short-range network, which would not be possible if step-index type of POF would be used.

Experimental - Purification

The monomers were purified as follows: inhibitors in the monomers were removed by rinsing with a 10% NaOH aqueous solution, followed by several times washing out any remaining NaOH with distilled water. The monomers were dried over anhydrous sodium sulfate, distilled under reduced pressure, and filtered through a 0.2µm membrane filter. Benzoyl peroxide (BPO) from Aldrich Co. and n-dodecylmercaptan (nDM) from Wako Chemical Co. were used as the initiator and the chain transfer agent, respectively, without further purification.

-Preparation of polymer tube (diameters of 30mm and 50mm)

Glass tubes with inner diameters of 30mm and 50mm and with a length of 500mm were first prepared. Monomer mixtures consisting of 80wt% of MMA and 20wt% of BzMA, and 72.7wt% MMA and 27.3wt% BzMA (refer to C2 and C4 in Table 1, respectively) were charged into the glass tube to produce polymer tubes with about 5mm thickness after compensating for the volume shrinkage of about 20% which normally occurs during the polymerization reaction. After the mixture was charged into the reactor (as shown in Fig. 1), the polymerization reaction was induced at a reaction temperature of 60ºC while rotating the reactor at a rate of 5,000rpm. When the viscosity of the mixture in the reactor increased to about 100,000cps as the polymerization reaction proceeded, the reaction temperature was raised gradually to 100ºC. When the viscosity of the material reached about 200,000cps with further reaction, the reactor temperature was then lowered to 60ºC.

-Preparation of Graded-Index Rod

The materials for the second step were monomer mixtures C1, C3 and C5 of MMA and BzMA in Table 1. To reduce the shrinkage of the monomer mixture after polymerization, the mixture with 30-50% of P(MMA-co-BzMA) were added into a P(MMA-co-BzMA) tube. After putting polymer tube 2(outer radius 20mm and thickness 5mm) over polymer tube 1(outer radius 10mm and thickness 5mm) in glass tube (inner radius 25mm and length 500mm), the materials were charged into the reactor (as shown in Fig. 2). The polymerization reaction was induced at a reaction temperature of 60ºC while rotating the reactor at a rate of 1,000-2,000rpm. As in the previous steps, the reaction temperature was set at 60ºC initially and raised to 100ºC and then decreased back to 60ºC for achieving the condition under the similar viscosity criterion. Finally, the polymer rod was heat-treated at 60ºC under 0.2mmHg for 8hr to complete the polymerization. The transparent polymer rod thus prepared had a length of 500mm with the outside diameter of 50mm. Appropriate mixtures were continuously charged into a series of cylindrical polymer tubes

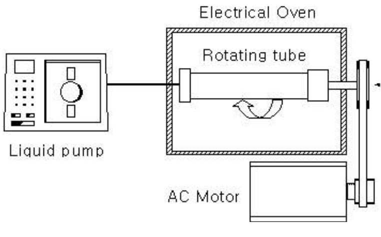

Fig. 1. The scheme of reactor for manufacturing polymer tube

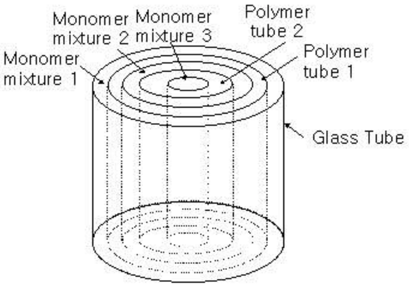

Fig. 2. The scheme of reactor for polymer rod

Table 1. Composition and refractive index of MMA and BMA for manufacturing polymer rod

Comment		Composition of MMA-BMA [wt%]	Monomer Refractive Index	Copolymer Refractive Index
C1	Monomer mixture 1	90-10	1.4226	1.4970
C2	Polymer tube 1	80-20	1.4312	1.5040
C3	Monomer mixture 2	78-22	1.4329	1.5054
C4	Polymer tube 2	72.7-27.3	1.4375	1.5091
C5	Monomer mixture 3	65-35	1.4441	1.5145

Results & Discussion

The radial distribution of the refractive index of the preform were measured by using prism coupler analyzer (Nettest P101). The samples were taken from the preform and this apparatus was shown to have ability to measure the refractive index with high enough accuracy. The refractive index of monomer was also measured by Abbe refractometer at 25ºC. Fig. 3. represents refractive index distribution of monomer mixture, polymer rod-monomer mixture and after polymerization. The refractive index profile of polymer rod completed is also shown in Fig. 4. The approximated refractive-index profile was modeled by power-law equation following convex lens characteristic:

(1)

$$n(r) = n_0(1 - 2\Delta(r/R_p)^g)^{1/2}$$

Where n_0 is the refractive index at the center axis, n(r) is the refractive index at a distance r from the center axis, R_p is the radius of the rod, and $\varphi = (n_0^2 - n_1^2)/2n_0^2$ is the fractional index difference between the center (n_0) and the periphery (n_1) of the rod. Approximated index exponent g of the index profile shown in Fig. 4. was 1.9. The numerical aperture (N.A) estimated from the index profile (n_0 and n_1) was approximately 0.25. This profile can be flexibly changed by controlling each composition in Table 1.

Films of the bulk polymer (P(MMA-co-BzMA)) for optical loss was prepared by spin coating the solution with DMF (N,N-dimethyl formamide) on a silicon wafer. In this film, refractive index of core and clad material were 1.42 and 1.41, respectively. Optical loss measurement was done in waveguides by cut-back method and optical loss was 400dB/km at 633nm. This result does not consider the concentration fluctuations and extrinsic loss caused during fiber manufacturing process. It could be calculated that P(MMA-co-BzMA) model system could produce the preform which can draw the GI-POF with the attenuation of approximately 350dB/km at 633nm.

Bandwidth characteristic of the polymer rod was calculated by Wentzel-Kramers-Brillouin(WKB) numerical computation method. If only modal dispersion was considered, the calculated bandwidth was 1.1GHz. If all dispersions were considered, the calculated bandwidth became about 2.2GHz.

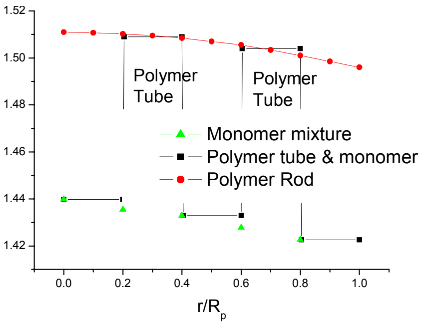

Fig. 3. Refractive-index distribution of before polymerization (polymer tube and monomer), and after polymerization (Polymer rod)

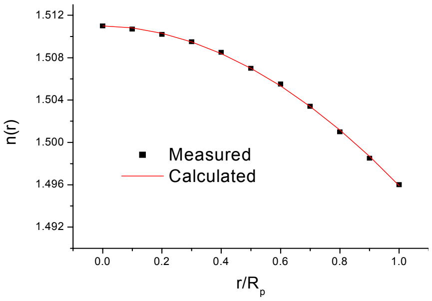

Fig. 4. Refractive-index distribution of the polymer rod. Dots are the measured values and the line is fitted values using power law equation (eq 1).

Conclusion

We successfully prepared the polymer rod by utilizing the swelling of the polymers and the diffusion of the monomers in the polymer-monomer mixtures. The refractive index of this polymer rod decreased from the center axis to the periphery

form for GI-POF could be made easily. Refractive index profile investigated in this work was appropriate for practical GI-POF and various profiles could be obtained by simply changing composition at each compartment. Excessive heat generation in local area during the reaction could also be avoided by this method. For the future work, the experiments are under progress: real GI-POF is going to be prepared by a conventional thermal drawing process from the GI polymer rod. The clad of GI-POF will be coated by a UV-cured fluoroacrylate resin (EFiRON® UVF PC Series). The diameter of the GI-POF will be controlled to 1.0mm(core 0.98mm and clad 0.02mm) in the experiment.

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MF10 **5:30 PM**

Improvement of Estimated Splice Loss Accuracy by Measuring MFD of Spliced Fiber

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Estimated splice loss accuracy has been improved. The splicer has been improved to measure the MFD of the spliced fiber, and estimate the MFD mismatch loss accurately. This improvement is useful for dissimilar fiber splicing.

1. Introduction

In order to highlight unacceptable splices, almost all fusion splicers have an estimating splice loss function. The main factors of the splice loss are core axis offset, core deformation, and MFD mismatch. The splicer observes these factors at the splice point and estimates the splice loss by using Profile Alignment System (PAS)[1].

Recently, due to the large variety of specialty fibers coming on the market, requirements for dissimilar specialty fiber splicing have increased. In case of dissimilar fiber splicing, each fiber has a different Mode Field Diameter (MFD) and the MFD mismatch at the splice point may be the dominant contributing factor for the splice loss. Therefore, in order to improve the estimated splice loss accuracy in dissimilar fiber splicing, the MFD mismatch has to be considered.

Generally, the MFD is thought to be unmeasurable by PAS. But we have developed a special algorithm to measure the MFDs by using PAS. Through this development, the splicer can measure the MFD mismatch accurately, and the estimated splice loss accuracy has been greatly improved.

2. MFD mismatch loss

In case of dissimilar fiber splicing, MFD mismatch occurs at the splice point. The MFD mismatch loss may have a profound influence on the splice loss for dissimilar fiber splicing.

Assuming that the intensity distribution of the light in the fiber is Gaussian, the MFD mismatch loss is calculated by the formula (1)

$$L = -10 \log \left(\frac{2\, w_1\, w_2}{w_1^2 + w_2^2} \right)^2 \quad \text{(dB)} \qquad (1)$$

where L is the splice loss caused by the MFD mismatch, w_1 and w_2 are the MFDs of the spliced fibers. This formula shows that both MFDs are necessary to calculate the MFD mismatch loss[2].