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-borm 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 600 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).

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, conventional UV curable optical fiber coating, the low density and low friction surface film can be achieved from UV curing 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/cm³. 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.

### References

1. Philip A. Barker; Davis J. Stockton; Christopher Fisk; Peter D. Jenkins, US 5,555,335
2. William C. Fisher, Cuyahoga Falls; Paul C, Menmur, Richfield, US 3,354,331 B1
charged into the reactor (as shown in Fig. 1), the polymerization reaction was induced at a reaction temperature of 60°C 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 100°C. When the viscosity of the material reached about 200,000cps with further reaction, the reactor temperature was then lowered to 60°C.

-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) was 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 60°C while rotating the reactor at a rate of 1,000-2,000rpm. As in the previous steps, the reaction temperature was set at 60°C initially and raised to 100°C and then decreased back to 60°C for achieving the condition under the similar viscosity criterion. Finally, the polymer rod was heat-treated at 60°C under 0.2mmHg for 8hr to complete the polymerization. The transparent solution with DMF (N,N-dimethyl formamide) on the rod. Approximated index exponent g of the rod. The refractive index profile investigated in this work was approximated as shown in Fig. 4. The approximated refractive-index profile was modeled by power-law equation following convex lens characteristic:

\[
(1) \quad n(r) = n_0 \left(1 - \frac{2 \Delta n_1}{R_p} \right) \left(\frac{r}{R_p}\right)^g
\]

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 \(\Delta n_1 = n_0 - n_1\) 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 \((n_0, n_1)\) was approximately 0.25. This profile can be flexibly changed by controlling each composition in Table 1.

Fibers of the bulk polymer (P(MMA-co-BzMA)) for graded-index fiber 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. 1](image1.png)

(a) The scheme of reactor for manufacturing polymer tube

![Fig. 2](image2.png)

(b) The scheme of reactor for polymer rod

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

<table>
<thead>
<tr>
<th>Comment</th>
<th>Composition of MMA-BMA</th>
<th>Monomer Copolymer Index</th>
</tr>
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<tbody>
<tr>
<td>C1 Monomer mixture</td>
<td>90-10</td>
<td>1.4226</td>
</tr>
<tr>
<td>C2 Polymer tube 1</td>
<td>80-20</td>
<td>1.4312</td>
</tr>
<tr>
<td>C3 Monomer mixture 2</td>
<td>78-22</td>
<td>1.4329</td>
</tr>
<tr>
<td>C4 Polymer tube 2</td>
<td>72.7-27.3</td>
<td>1.4375</td>
</tr>
<tr>
<td>C5 Monomer mixture 3</td>
<td>65-35</td>
<td>1.4441</td>
</tr>
</tbody>
</table>

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 25°C. 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 (eq. 1).

\[
L = -10 \log \left( \frac{2 \omega_1 \omega_2}{\omega_1^2 + \omega_2^2} \right)^2 (dB)
\]

where \(L\) is the splice loss caused by the MDF mismatch, \(\omega_1\) and \(\omega_2\) are the MDFs of the spliced fibers. This formula shows that both MDFs are necessary to calculate the MDF mismatch loss. 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.

References