Study on Surface Fluorinating for Reducing Attenuation of Polymethyl Methacrylate Polymer Optic Fiber

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ABSTRACT: The effects of surface fluorinating on the F/C ratio of polymethyl methacrylate (PMMA) are investigated. The F/C ratio of PMMA increased when the fluorinating temperature was enhanced or the fluorinating time was prolonged and then was apt to be invariable. The attenuation of the polymer optical fiber (POF) was obviously reduced after PMMA POF was surface fluorinated. Finally, the mechanism of reducing attenuation of POF is discussed. J Appl Polym Sci 98: 2369–2372, 2005

Key words: optics; fibers; surfaces; fluoropolymers

INTRODUCTION

Recently, applications of polymer optical fiber (POF) are used more and more, for example, for light illumination, optical communication, and optical sensors[1,2]. However, the attenuation of POF is rather high. The attenuation of POF can be reduced by purifying materials, cleaning manufacture, or using more transparent fluorine- or deuterium-containing polymer.[3]

In this paper, we explore the surface fluorinating method of polymethyl methacrylate (PMMA). The effects of surface fluorinating on the F/C ratio of PMMA and on the attenuation of PMMA POF are investigated. Reducing the attenuation mechanism of the POF by surface fluorinating is also discussed.

SURFACE FLUORINATING PRINCIPLE

As a new surface process technology, surface fluorinating technology is recognized step by step. When hydrogen-containing polymer was surface fluorinated by XeF_2, a chemistry replacement reaction occurred between F_2 decomposed from XeF_2 and C-H groups of the surface polymer, and then new fluorine-containing polymer was formed as C-H groups were changed to C-F groups[4]. The chemistry reaction equation is

$$XeF_2 + —C—H \rightarrow —C—F + HF + Xe. \quad (1)$$

Similarly, when PMMA POF was surface fluorinated by XeF_2, clad polymer with more C-F groups on POF surface was formed. The mol refrangibility of F atom is less than one of H atom, the refractive index of the polymer with more C-F groups was reduced, and new clad of POF was formed. In other words, the new clad forming on POF has lower refractive index.

EXPERIMENTAL AND RESULTS

Effects of fluorinating temperature on F/C ratio

F/C ratio is the ratio of the F atom number and H atom number in polymer molecule chains. It can be used to express fluorine content or fluorinating degree of the polymer. There are five C atoms and eight H atoms in a PMMA molecule chain, so the F/C ratio maximum of fluorinated PMMA is 160%.

PMMA fibers with 1 mm diameter were put in a fluorinating furnace containing quantitative fluorine reagent and reacted with fluorine reagent for 2 h at different temperature. F and C atom contents on the fluorinated PMMA surface were measured by scanning electron microscope, and the F/C ratio was calculated. The relation of the F/C ratio to the fluorinating temperature is shown in Figure 1. A higher fluorinating temperature leads to a higher F/C ratio. According to the heat resistance of PMMA, the fluorinating temperature is better at less than 100°C.

Effects of fluorinating time on F/C ratio

Fluorinating experiments were carried for different times at 74 °C, and the results are shown in Figure 2.

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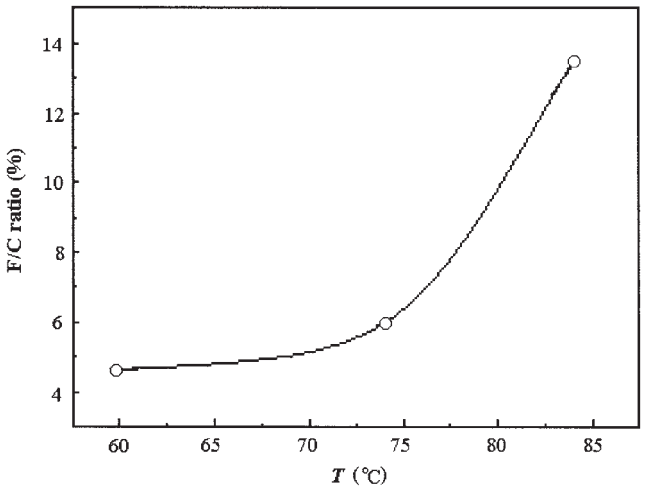

Figure 1 Relation of the F/C ratio to fluorinating temperature.

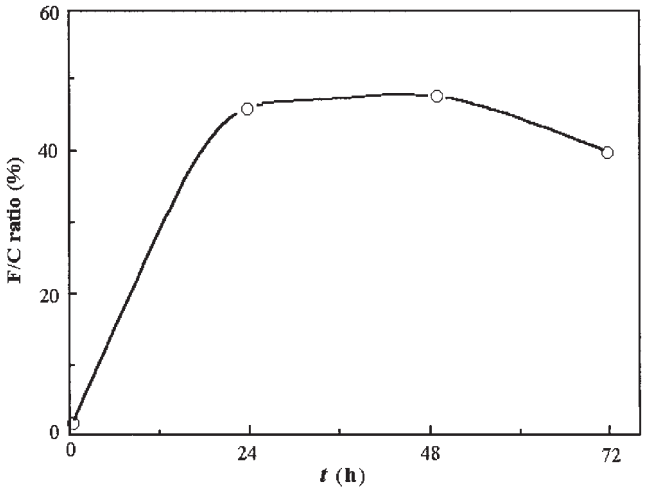

Figure 3 Relation of the F/C ratio to fluorinating time at 30 °C.

The longer the fluorinating time, the higher the F/C ratio.

When fluorinating time is prolonged and fluorinating temperature is reduced to 30°C, the F/C ratio is close to 50% (as shown in Fig. 3) When the fluorinating time was longer than 24 h, it was invariable; but when the fluorinating time was longer than 48 h, it was reduced because the corrupting effect of fluorine gas leads to the decomposition of PMMA. The detailed mechanism of the PMMA polymer's decomposition must be investigated further.

PMMA polymer can be fluorinated by XeF_2. The fluorinating rule is that when fluorinating time is prolonged or fluorinating temperature is increased, the F/C ratio is increased.

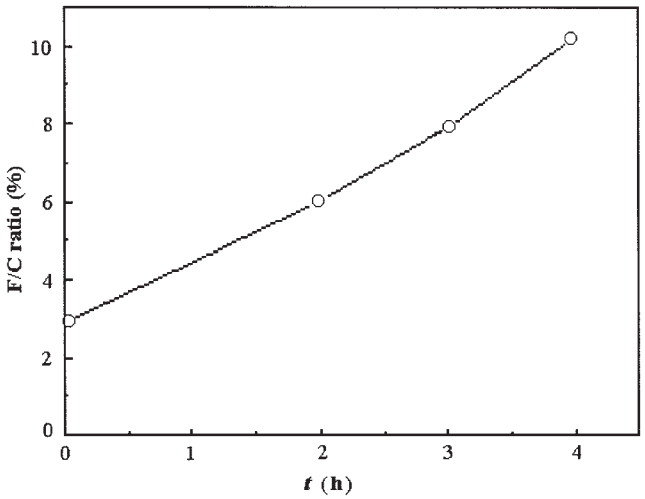

Figure 2 Relation of the F/C ratio to fluorinating time at 74 °C.

Surface fluorinating effects on the attenuation of PMMA POF

Samples 1, 2, and 3 are PMMA fibers, and the other samples are step-index PMMA POF. All samples were surface fluorinated, and then attenuations were measured (Table I). Figure 4 shows the attenuation spectrums of sample 7 POF before and after surface fluorinating.

Table I shows that attenuations (650 nm) of PMMA fibers and POF after surface fluorinating are obviously reduced. The attenuation spectra of POF before and after surface fluorinating (as shown in Fig. 4) are alike.

DISCUSSION

Light transmission in multimode optical fiber has many modes[5]. Lower mode light is severely restricted to transmit around the fiber axis, and little can come

TABLE I
Attenuations of POFs before and after Surface Fluorinating (650 nm)

Sample	Attenuation before surface fluorinating (dB/m)	Attenuation after surface fluorinating (dB/m)
1		1.64
2	>3.00	1.29
3		1.90
4	0.95	0.71
5	0.94	0.77
6	0.91	0.58
7	0.19	0.17
8		0.16

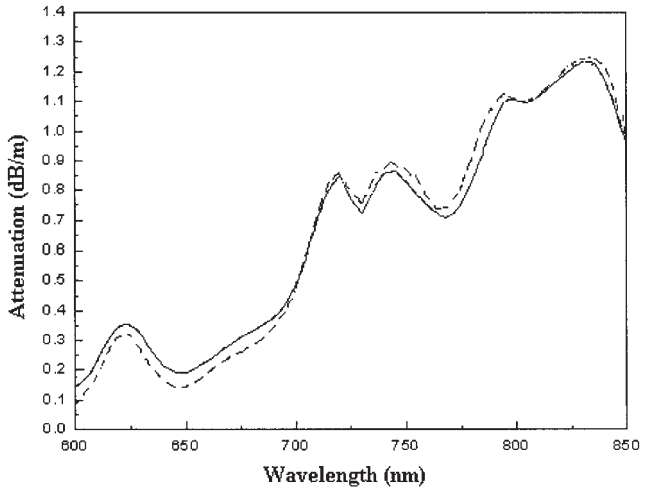

Figure 4 Attenuation spectrums of sample 7 POF (—) before surface fluorinating and (. . .) after surface fluorinating.

into clad. But higher mode light is apt to transmit around the fringe of the fiber core, so a large amount can come into clad. Otherwise, some leak mode light that doesn't satisfy transmission conditions of the guided wave mode also will come into clad. It is said that light can transmit across the interface of core and clad or clad, so the attenuation of multimode optical fiber can be increased by disfigurements of the interface of core and clad or clad.

The POF used in this paper is a kind of multimode optical fiber. There are three possible reasons that attenuations (650 nm) of PMMA fiber and POF are obviously reduced after surface fluorinating.

First, the PMMA fiber before surface fluorinating had no fluorine-containing polymer clad (as shown in Fig. 5(a)), so the attenuation was large. After surface fluorinating, fluorine-containing polymer clad (fluorinated PMMA, FPMMA) with a low refractive index

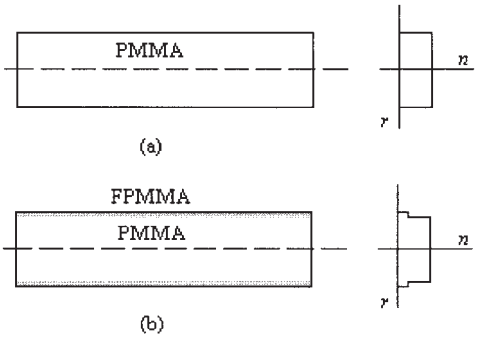

Figure 5 Structure and refractive index profile of PMMA fiber (a) before surface fluorinating and (b) after surface fluorinating.

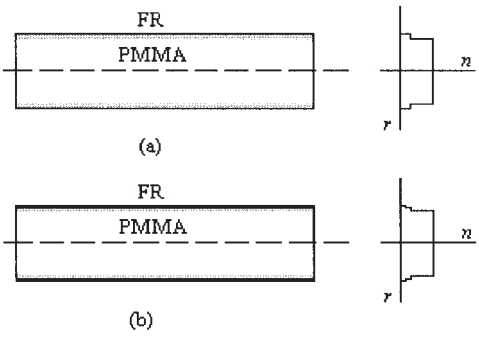

Figure 6 Structure and refractive index profile of PMMA POF (a) before surface fluorinating and (b) after surface fluorinating.

was formed on the surface of the PMMA fiber (as shown in Fig. 5(b)), and POF was formed accordingly, so the attenuation was reduced.

Second, after surface fluorinating, a new fluorine-containing polymer clad with lower refractive index was formed on the surface of the POF clad (as shown in Fig. 6(a)), and POF with double clads was formed accordingly (as shown in Fig. 6(b)). In this situation, some scatter light could be returned into the fiber core, so the POF attenuation was reduced.

Finally, there are some disfigurements in the clad of POF (as shown in Fig. 7(a)), and the disfigurements will increase the attenuation of the POF[6]. After surface fluorinating, new fluorine-containing polymer clad was formed to repair the disfigurements of the POF clad (as shown in Fig. 7(b)). This can reduce scatter attenuation led by the disfigurements.

CONCLUSIONS

PMMA polymer can be fluorinated by XeF_2. The fluorinating rule is that when fluorinating time is pro-

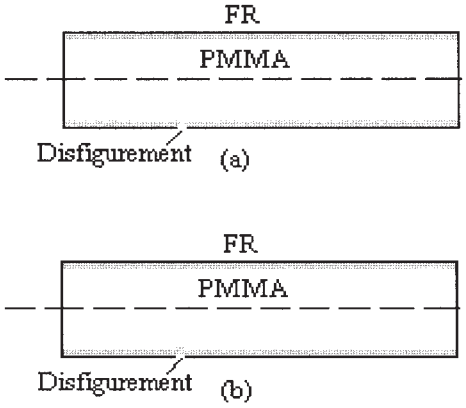

Figure 7 Disfigurement of POF clad (a) before surface fluorinating and (b) after surface fluorinating.

longed or fluorinating temperature is increased, the F/C ratio is increased.

Attenuations (650 nm) of PMMA fibers and POF after surface fluorinating are obviously reduced. There are three possible reasons for this: forming a new clad of PMMA fiber, forming a double clad of POF, and/or repairing the disfigurements of the POF clad. Surface fluorinating can reduce the attenuations of PMMA POF.

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