Experimental Research on Polymer Optical Fiber Under Irradiation1 *

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Abstract The physical and chemical characteristics changes of polymer under irradiation environment were analyzed. The radiation damage and recovery property for Polystyrene (PS) optical fiber, polycarbonate (PC) optical fiber, and polymethylmethacrylate (PMMA) optical fiber under γ-ray irradiation were researched experimentally. Under different irradiation dose, the light transmission rate reduced by different ratio, and the irradiation damage of fibers could recover by different extent after stopping irradiating, moreover, the recovery happened mainly during the shorter time after irradiation. Under low dose irradiation 10^2 Gy, the transmission rate reduced a little, and the irradiation damage can recover during a short time. When the irradiation dose reached 10^3 Gy, the recovery process need longer time. When the irradiation dose exceeded 5×10^3 Gy, the transmission rate reduced obviously, and the recovery process is slow and the irradiation damage can't recover completely, that indicated fiber suffered lasting damage. By comparing experimental results of PS, PMMA, and PC opitcal fiber, It is discovered that the anti-irradiation performance of the PS optical fiber is better than that of both PMMA and PC optical fiber.

Keywords Polymer optical fiber; Anti-irradiation; Induced loss
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0 Introduction

With the rapid development of fiber technology, optical fiber transmission and fiber sensor are applied widely in many fields, including information engineering, optical instrument, medical apparatus, and automatic control and so on. In many cases, fiber may suffer from irradiation. For example, the fiber system applied in orbit space station will expose to the space and be influenced by γ rays, and some man-made radioactive environment, such as fission reactors, nuclear power plants, nuclear waste repositories[1], as well as optical fiber radiation detectors[2], all of these applications of fiber systems should be considered influence from irradiation and their hardness against optical attenuation induced by irradiation. The irradiation-induced attenuation deteriorates the performance of fiber system. Especially under high dose pulse radiation field, the momentary loss is very high, even if under long term lower lose irradiation, the fiber may suffer lasting irradiation damage.

Recently, Polymer optical fibers (POF) are paid numerous attention to apply it for short distance transmission networks because of its easy connecting consequently low cost of networks. More and more people believe POF will become main medium for short distance networks in the future. Because of its mechanical performance prior to glass optical fiber, POF was applied in military field and spaceflight very earlier. Our country succeeded in applying POF for meteorologic satellite few years ago[3]. Employing POF under space or other nuclear radiation environment, it is necessary to research the POF performance after irradiation. In this paper, we analyzed the physical and chemical change on characteristics of polymer under irradiation environment. The irradiation damage and recovery property for a kind of reformed polystyrene optical fiber under irradiation were researched experimentally.

1 Physical and chemical change of polymer after irradiation

After irradiation, there exist mainly effects in polymer, such as cross-link, irradiation degrade, the change of unsaturated links numbers and production of fallen free radical. All these changes can reflect the change of polymer material characteristics[4,5]. Because polymer molecule consists of millions of monomer units, so only little chemical change induced by irradiation may cause marked changes in the physical and mechanical performance. The cross-link and radiation degrade influence seriously the molecular mass and distribution, as a results the evident changes take place on the melting point, the solubility in solvent and mechanical strength. Irradiation cross-link is the phenomena of the polymer molecule linking together through bonds, the results are the polymer

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molecular mass increases with absorbed irradiation dose, until every polymer link has at least a bond linked another link and forms three dimension mesh structure. Irradiation degrade is the process of the polymer main link breaking off under high energy radiation, and the results are the polymer molecular mass decreases with absorbed irradiation dose, so much as some polymer molecule degrade into monomer molecule. The irradiation stability is dependent on the energy transferring inside polymer and the molecule spacial effect.

The main materials of POF have polymethylmethacrylate (PMMA), polystyrene (PS), and polycarbonate (PC). The primary change in PMMA and PC under radiation is radiation- degrade, and that in PS is radiation cross-link. After irradiation, the chemical structure of polymer changes, which leads to radiation induced loss, i, e irradiation damage effect. Irradiation damage causes the POF transmission loss increasing.

2 Experiments

We did irradiation experiments on a kind of reformed PS optical fiber, PMMA and PC optical fiber with 1 mm in diameter and 500 mm in length, and measured the light transmission rates of the fiber before and after different dose γ rays. Under Co^{60} γ rays irradiation, we radiated the fiber sample under different dose. After taking the fiber samples from radiation room, we measured the light transmission rate at once using He-Ne laser with 632. 8 nm as light source and HP81522A powermeter. In order to get the recovery characteristic, we measured the fiber five times. The results were shown in following tables. We choose several group samples, and the data shown in tables are the average normalized data. The transmission rate before radiation is set to Tab. 1.

Table 1 PS optical fiber transmission rate after irradiation

Dose \ Time	Before irradiatio	After irradiatio	5 hours later	5 days later	15 days later
10^2 Gy	1	0.96	0.98	1	1
10^3 Gy	1	0.94	0.95	0.96	0.99
5×10^3 Gy	1	0.86	0.89	0.90	0.90
10^4 Gy	1	0.72	0.83	0.85	0.87

Table 2 PMMA optical fiber transmission rate after irradiation

Dose \ Time	Before irradiatio	After irradiatio	5 hours later	5 days later	15 days later
10^2 Gy	1	0.94	0.96	0.99	1
10^3 Gy	1	0.91	0.92	0.93	0.93
5×10^3 Gy	1	0.83	0.84	0.87	0.87
10^4 Gy	1	0.70	0.74	0.75	0.77

Table 3 PC optical fiber transmission rate after irradiation

Dose \ Time	Before irradiatio	After irradiatio	5 hours later	5 days later	15 days later
10^2 Gy	1	0.95	0.97	0.99	1
10^3 Gy	1	0.92	0.93	0.94	0.94
5×10^3 Gy	1	0.85	0.86	0.88	0.88
10^4 Gy	1	0.72	0.76	0.78	0.80

Comparing above three tables, we found that the transmission rate of PS is higher 1% ~3% than that of PMMA and PC after different dose irradiation, and this difference increases with the irradiation dose. For the 500 mm long fiber, this transmission rate difference is enough big, so it is deduced that the anti-irradiation performance of PS is the best, and that of PC is better than that of PMMA . When the irradiation dose is 100 Gy, the transmission rate of all three kind of fibers decreased a little, furthermore the irradiation damage recovered during five days. When the irradiation dose increased to above 5000 Gy, the transmission rate decreased markedly, moreover, the transmission rate measured even 15 days later after irradiation did not reach the original value. The results demonstrated that the fiber gets everlasting irradiation damage.

In addition, we observed the fiber after irradiation , and found that those fibers irradiated by 5×10^3 Gy and 10^4 Gy irradiation dose are light yellow color even after 15 days, this fact demonstrated that the induced loss at different wavelength is different.

After irradiation, fiber transmission rate decreased, and caused irradiation induce loss, which is defined as

$$\alpha = -10\log\frac{T_r}{T_o}(\text{dB}) \tag{1}$$

where T_r is the transmission rate after irradiation, and T_o is the transmission rate before irradiation. The recovery characteristics of PS, PMMA, and PC optical fiber are quite similar, and just the induced Loss has differences, so just only irradiation induced loss and recovery characteristic of PS was given in Fig. 1. a, b, c and d are corresponding to the irradiation dose 10^2 Gy, 10^3 Gy, 5×10^3 Gy, 10^4 Gy, respectively.

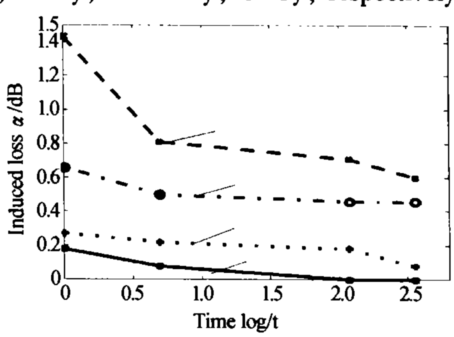

Fig. 1 Recovery property for radiated PS optical fiber under different irradiation dose

From Fig. 1, we can see that the transmission rate reduced a little, produced lower induced loss just only 0.18 dB under 10^2 Gy low dose irradiation, moreover, the irradiation damage can recover during a short time. When the irradiation dose reaches 10^3 Gy, the irradiation damage is 0.22 dB, the recovery process needs longer time. While the irradiation dose reaches 5×10^3 Gy, the transmission rate reduced obviously, and the recovery process is slow and can't recover completely, whick indicates fiber suffered lasting damage. Under the 10^4 Gy irradiation dose, the irradiation induces damage reached 1.43 dB, although the damage can recover partly, the irradiation damage is very serious, and the eventual loss reached as high 0.6 dB.

3 Discussion

From above experimental results for PS optical fiber, we discovered that the anti-irradiation performance of the PS optical fiber is better than that of PMMA and PC optical fiber. This is because the PS molecule contains a benzene ring (C_6H_6) with a macro-π link which is hard to be broken when the fiber is radiated, the materials containing benzene ring have perfect ant-irradiation performance. Our experimental results is good reference to applying POF for nuclear radiation environment. The further research is to investigate the induced loss at several wavelength and the irradiation damage relative to different dose rate.

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聚合物光纤辐照特性的实验研究

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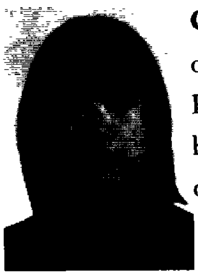
摘 要 分析了聚合物受辐照后发生物理化学变化的机理,实验研究了聚苯乙烯(PS)、聚碳酸脂(PC)、聚甲级丙烯酸甲脂(PMMA)三种聚合物光纤在不同辐照剂量下光传输性能的变化以及其恢复特性. 在各种辐照剂量下,光透过率有不同程度的下降,经过一段时间后也有不同程度的回复,并且恢复主要发生在停止辐照后的较短时间内. 在 10^2 Gy 以下,辐照造成的光损伤经过一段时间基本可以恢复,在更高剂量的辐照下(超过 $5*10^3$ Gy),辐照对光纤造成了永久损伤,经过很长时间也只能恢复一部分. 实验结果表明,PS 光纤的抗辐照特性最好,PC 光纤优于 PMMA 光纤.

关键词 塑料光纤;抗辐照;感生损耗



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