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Investigation on Characteristic of PMMA Optical Fiber Under Irradiation

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Abstract The physical and chemical characteristics change of polymer under irradiation environment was analyzed. The irradiation damage and recovery property for polymethylmethacrylate (PMMA) optical fiber under γ-ray irradiation were researched experimentally. The visible light transmission spectrum and recovery property of the POF under different irradiation dose were measured. Under different irradiation dose the light transmission rate was reduced by different ratio. The measured spectrum indicated that the POF irradiation damage and recovery were dependent on wavelength, and the visible light transmission rate of the POF at the range of 400 nm to 550 nm comparing 600 nm to 800 nm, decreased seriously under the irradiation dose exceeded 5 kGy. But under lower dose below 1 kGy, the transmission rate decreased identical at the whole visible light range.

Keywords Polymer optical fiber; Irradiation damage; Transmission spectrum

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0 Introduction

In many fields, including information engineering, optical instrument, medical apparatus and automatic control and so on, optical fiber transmission and fiber sensor are applied widely. Even in environments with extremely high radiation exposure such as nuclear reactors, nuclear fuel reprocessing facilities, high energy physics acceleraors, or space satellites the use of optical fibers can be advantageous because of their low weight, high bandwidth, electrical isolation, and heat resistance. In many cases, optical fiber may suffer from all kinds of irradiations. For example, the fiber system applied in orbit space station will be exposed to the space and be influenced by γ rays, and some man-made radioactive environment, such as 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. In recent years, the behavior of optical fibers under γ rays irradiation has been actively investigated[3~5]. The radiation-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 radiation, 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[6~8]. 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, the physical and chemical change on characteristics of polymer under irradiation environment was analyzed. The irradiation induced attenuation and recovery property for polymethyl methacrylate (PMMA) optical fiber under irradiation, as well as the change of transmission was researched experimentally.

1 The irradiation damage effect and recovery characteristics under single wavelength

One main material of polymer optical fiber is PMMA. The primary change in PMMA under radiation is radiation degrade[9,10]. After irradiation, the chemical structure of polymer changes, so lead to radiation induced attenuation, i. e irradiation damage effect. Irradiation damage causes the POF transmission loss increasing. Some chemical and physical change induced by irradiation would recover, which is called irradiation reversible

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reaction, and physical change is easy to be reversible, chemical change isn' t easy to be reversible. The reversible reaction happens during or after irradiation.

Irradiation experiments were done on PMMA optical fiber with 1mm 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 that is different distance from radiation source. After taking the fiber sample 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 also measured the fiber five times. The results are shown in Table 1. Choosing several group samples, the data shown in Table 1 is the average normalized data. The transmission rate before radiation is set to 1.

Table. 1 Transmission rate of PMMA optical fiber after irradiation

Time / Dose	Before irradiation	After irradiation	5 hours later	5days later	15days later
0. 1 kGy	1	0. 94	0. 96	0. 99	1
1 kGy	1	0. 91	0. 92	0. 93	0. 93
5 kGy	1	0. 83	0. 84	0. 87	0. 87
10 kGy	1	0. 70	0. 74	0. 75	0. 77

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

$$\alpha = -10\log \frac{T_r}{T_o} \qquad (1)$$

where T_r is the transmission rate after irradiation, and T_o is the transmission rate before irradiation. The irradiation induced loss and recovery characteristic are shown 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. From the experiment results above it is known that the transmission rate reduced a little, and produced lower induced loss just only 0. 27 dB under low dose irradiation 10^2 Gy, moreover, the irradiation damage can recover during a short time. When the irradiation dose reaches 10^3 Gy, the irradiation damage is 0. 43 dB, the irradiation damage can almost recover, but the recovery process need longer time (more than 15days). 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, which indicates fiber suffers lasting damage. Under the irradiation dose 10^4 Gy, the irradiation induces damage reached 1. 55 dB, although the damage can recover partly, the irradiation damage is very serious, and the eventual loss reached as high 1. 13 dB.

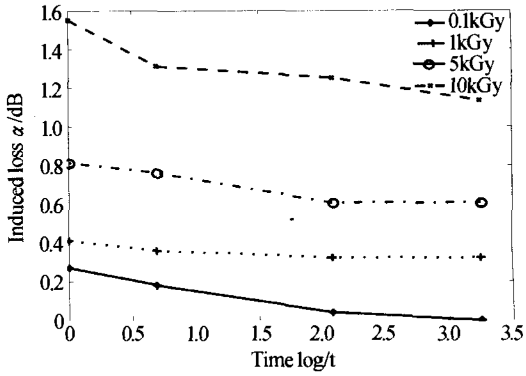

Fig. 1 Recovery property for radiated PMMA optical fiber under different irradiation dose

2 The irradiation characteristics at visible light range

In order to investigate the irradiation induced attenuation of PMMA optical fiber under different wavelength, the Cs lamp was used as light source, and the absorption spectrum of fiber was measured by using monochromator. The visible light range is 400～850 nm, and the fiber transmission spectrum is normalized (every fiber has its own normalized value). The transmission spectrum under four level irradiation dose is showed in Fig. 2.

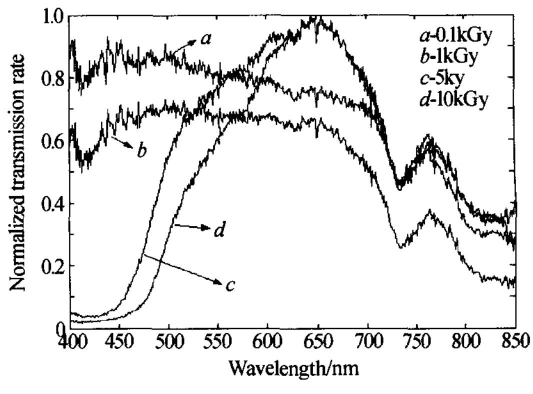

Fig. 2 Visible light spectrum of PMMA optical fiber after different irradiation dose

The spectrum was measured after four days later stopping irradiation. Under low dose of 0. 1 kGy and 1 kGy, the transmission rate descends a little. As shown in Fig. 2, under irradiation dose 5 kGy and 10 kGy, the transmission spectrum changed seriously. The measured spectrum indicated that the visible light transmission rate of the POF at the range of 400 nm to 550 nm comparing 600 nm to 800 nm, decreased seriously under the irradiation dose exceeded 5 kGy.

3 The recovery spectrum at the visible light range

The transmission spectrum of POF, after irradiation and four days later, were measured respectively. The results are shown in Fig. 3. For all figures, a is the result measured after irradiation, and b is the result four days later. Comparing the recovery curve, the spectrum in a is flatter than that in b, which indicates the low dose irradiation damage at all visible light range is very similar. But under high dose (above 5 kGy), the transmission rate at short wavelength decreased rapidly comparing that at long wavelength. After a period of time, the irradiation damage under low dose recovered mostly. Under either low or high dose recovered partly dependent on wavelength. Both the irradiation damage and recovery under high dose depends markedly on wavelength, and the recovery below 500 nm and above 700 nm is bad.

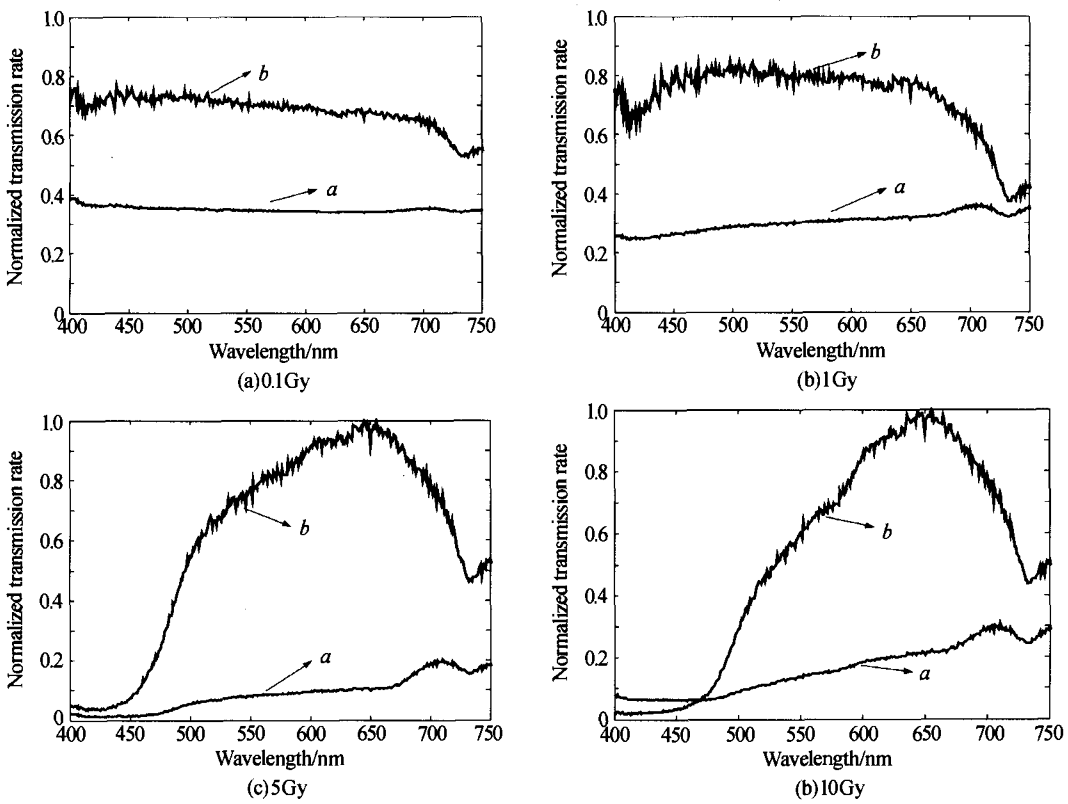

Fig. 3 Recovery property for radiated PMMA optical fiber under different irradiation dose

4 Discussion

From above experimental results for PMMA optical fiber, we comprehend the irradiation damage and recovery feature of PMMA optical fiber. The radiation-induced attenuation deteriorates the performance of fiber. Especially under high dose irradiation, the fiber may suffer lasting irradiation damage. Our experimental result is good reference to applying POF for nuclear radiation environment.

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PMMA光纤辐照特性研究

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摘 要 分析了聚合物光纤在辐照环境下的物理化学变化,实验研究了聚甲基丙烯酸甲脂(PMMA)光纤在不同剂量的γ射线辐照下的辐照损伤和恢复特性,测量了PMMA光纤在可见光波段的辐照光谱和恢复光谱以及在638 nm的辐照前后透过率及辐照损伤.测量结果表明,光纤的辐照损伤和恢复都有波长相关性,辐照剂量低于5 kGy,PMMA光纤在整个可见光波段的辐照损伤情况差别不大,辐照剂量超过5 kGy,PMMA光纤在400 nm～550 nm波段的辐照损伤比600 nm～800 nm的辐照损伤要严重.

关键词 聚合物光纤;辐照损伤;透射光谱

Ge Wenping was born in 1969. She received her B. S. degree from Physics Department of Sichuan University in 1989 and her M. S. degree in optical engineering from Xi'an Institute of Optics and Precision Mechanics, CAS in March 2000, and her Ph. D. in electromagnetic field and microwave technology from Shanghai Jiaotong University in July 2003. Now She is an associate professor in Xinjiang University and a Postdoc in Xi'an Institute of Optics and Precision Mechanics, CAS. Her research interests include optical fiber technology, optical fiber component and optical fiber sensor.