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Publication details:
Proceedings of Second Asia-Pacific Polymer Fibre Optics Workshop, Hong Kong, China
pp. 37-42

Event details:
Second Asia-Pacific Polymer Fibre Optics Workshop
Hong Kong, China

Publication Date:
2003

DOI:
https://doi.org/10.26190/unsworks/648

Thermal Characterization of Type I and Type II Polymer Optical Fiber Bragg Gratings

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Abstract: Two different types of POF gratings, named as Type I and Type I POF gratings, have been distinctively identified in our previous report. Thermal characterization for Type I and Type II POF gratings is carried out in this paper. Our investigation shows that the thermal sensitivity for Type I and Type II POF gratings are the same, while Type II are more thermally stable than Type I POF gratings. Furthermore, it is also demonstrated that POF gratings have much better thermal tunability and higher thermal sensitivity than that of silica fiber gratings.

1. Introduction

As we all know, thermal property of fiber gratings is one of the most important characteristics for fiber grating description. Lots of work on thermal characterization has been carried out in silica fiber gratings. It is found out that the thermal sensitivity for silica fiber gratings are grating type dependent [1]. In addition, the thermal stability for the different types of silica fiber gratings is also different [2-4]

Our group has been investigating for the POF gratings for couple of years and making some achievements. In our recent work on the dynamic growth of POF gratings, two kinds of POF gratings, named Type I and Type II following the same nomenclatures for silica fibre gratings, have been distinctively identified [5]. Furthermore, the formation mechanism and optical spectra for Type I and Type II POF gratings are different. Therefore, the thermal characterization of Type I and Type II POF gratings are examined in this paper. It includes, the thermal tuning, thermal sensitivity and thermal stability of POF gratings.

2. Thermal characterization measurement

The experimental set-up for POF grating thermal tuning and decay measurement is shown in Fig.1. A small furnace was used as a heat source whose temperature is controlled by the PID method. The furnace is an aluminum block with the heating element and temperature sensor inserted in it. The two ends of the POF grating for thermal characterization were first pigtailed by silica fiber for the convenience of measurement. Then the silica-fiber-pigtailed POF grating sample was put into the furnace for thermal test. The transmission and reflection spectra of the POF gratings were recorded by an Optical Spectrum Analyzer (OSA). An ASE was adopted as the grating characterization source. The accuracy of the temperature measurement was ±0.5°C but it took about 3 minutes for the system to reach the desired temperature.

For the thermal sensitivity characterization, the POF grating was heated from ambient temperature to 75ºC with heating step of 5ºC. When the grating was heated to the desired temperature, the transmission and reflection spectra of the grating were recorded. In order to test tuning reversibility, the POF grating was also characterized when it was cooled down from 75ºC to ambient temperature. The cooling down step is also 5ºC. For the thermal decay measurement, the set-up is the same as Fig.1. The furnace was set at a fixed temperature and the optical spectra of the POF grating were monitored with time. Thus the degradation of the POF grating curve is obtained.

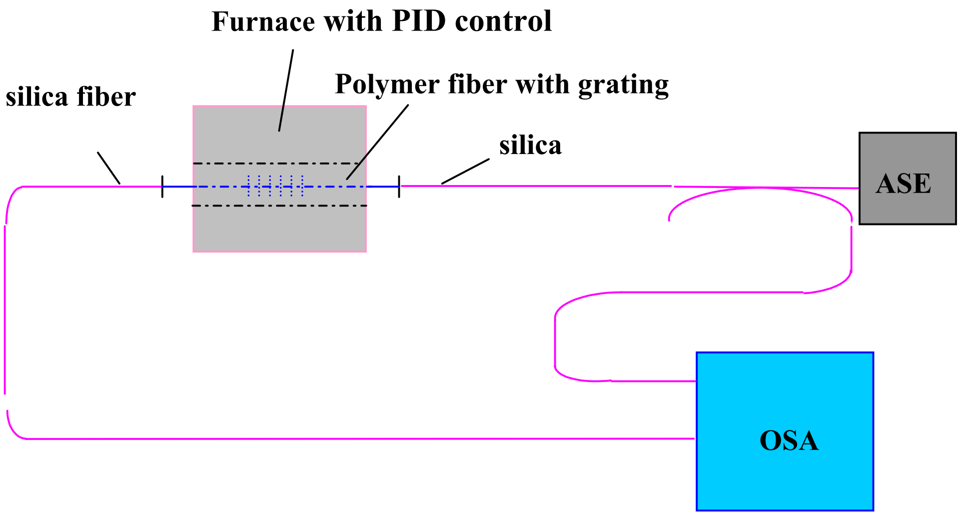


Figure 1 Thermal characterization set-up for POF gratings

3. Thermal tuning and sensitivity of Type I & II polymer fiber gratings

Type I POF grating for thermal sensitivity test has a transmission dip of about 4.3 dB. The maximum transmission dip for Type II gratings for thermal sensitivity test is about 13 dB. Fig.2 shows the transmission output of the POF gratings tuned between the ambient temperature and 75ºC, while Fig.3 demonstrates the thermal tuning output for Type II POF gratings. The reason for 75ºC as the highest test temperature is that the appropriate operating temperature for PMMA POF is below 80ºC. From Fig.2 we can found out that the grating strength for Type I POF grating doesn't change much at the low temperature, say less than 40ºC. While noticeable decrease in the grating strength can be observed at high temperature, and the grating becomes weaker as the temperature increase. Different from Type I POF grating, no obvious reduction in the grating strength is observed in Fig.3 even when it is heated to high temperature.

Fig.4 shows the Bragg wavelength of Type I and Type II POF gratings as the function of temperature. For each kind of grating there are two sets of data in the figure. One is the measured Bragg wavelength when the grating was heated up from room temperature to 75°C while the other is obtained when the grating was cooled down. For both kinds of grating the heating-up curve seems to be coincident with the cooling-down curve quite well, which reveals that there is no obvious hysteresis effect for the thermal tuning. The linear regression line in the figure indicates the high linearity of the Bragg wavelength tuned with the temperature, indicating that the control for this tuning will be very simple. It can be seen that almost 10nm tuning range can be achieved only with the temperature variation of 55°C, which is much larger than the several nanometers achieved in silica fiber grating by the several hundred degree temperature variation [6]. In addition, for silica fiber gratings the temperature response will become slightly nonlinear when the temperature is higher than 150°C [7, 8]. Therefore, POF grating shows much better thermal tunability than silica fiber grating.

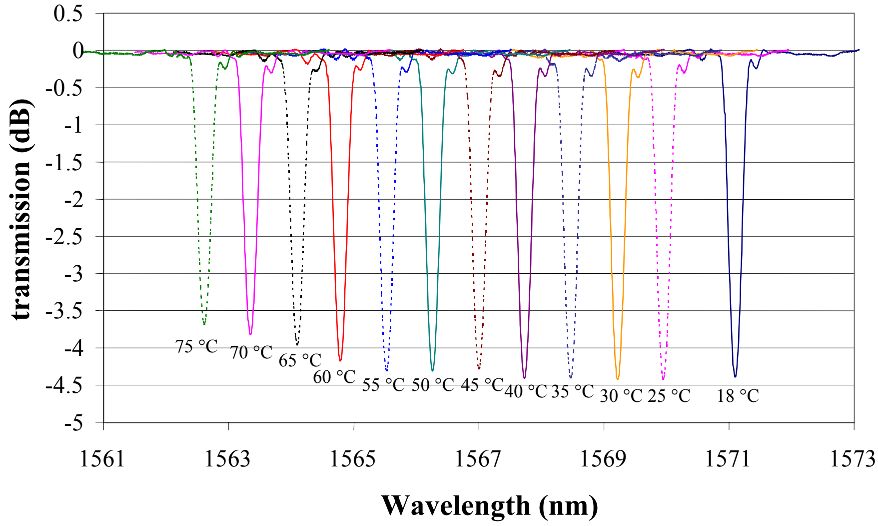


Figure 2 Transmission spectra of Type I POF gratings thermally tuned at different temperatures

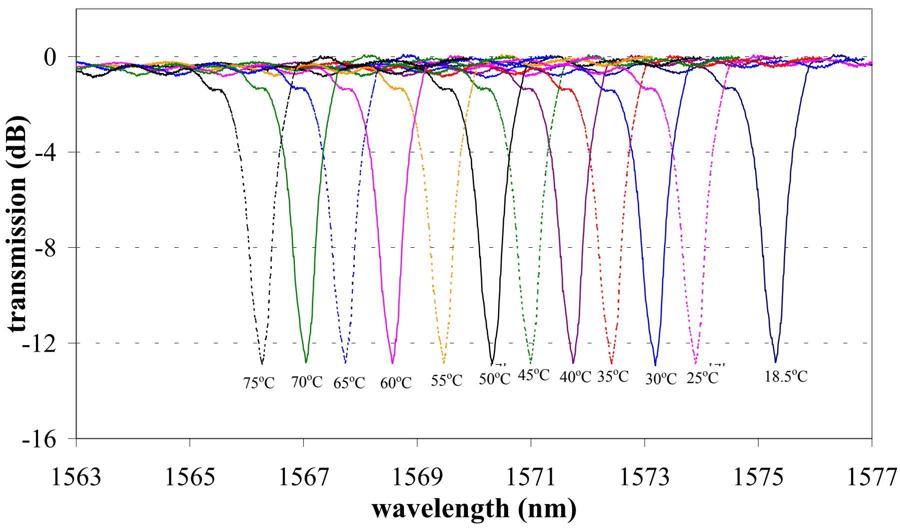


Figure 3 Transmission spectra of Type II POF gratings thermally tuned at different temperature

The regression lines in Fig.4 for both kinds of gratings are expressed as,

Type I POF gratings: $\lambda_B = 1573.6 - 0.1464 * T$

Type II POF gratings: $\lambda_B = 1578 - 0.1503 * T$

Therefore, the temperature coefficient for Type I and Type II POF gratings are calculated to be -9.35×10^{-5} and -9.52×10^{-5}, which are roughly the same. This value is about ten times larger than that of silica fiber gratings. As a result, Type I and Type II are equably thermal sensitive and their thermal sensitivity is about 10 times of silica fiber gratings.

The other noteworthy phenomenon is that Bragg wavelength for POF gratings blue shifts when the temperature of the POF increases and its temperature coefficient is negative. For pure bulk PMMA material, the thermal coefficient α is about 5×10^{-5}/°C, while thermal index change rate dn/dT is -1.1×10^{-4}/°C [9]. Hence, the thermo-optic effect is also the dominant effect for POF gratings.

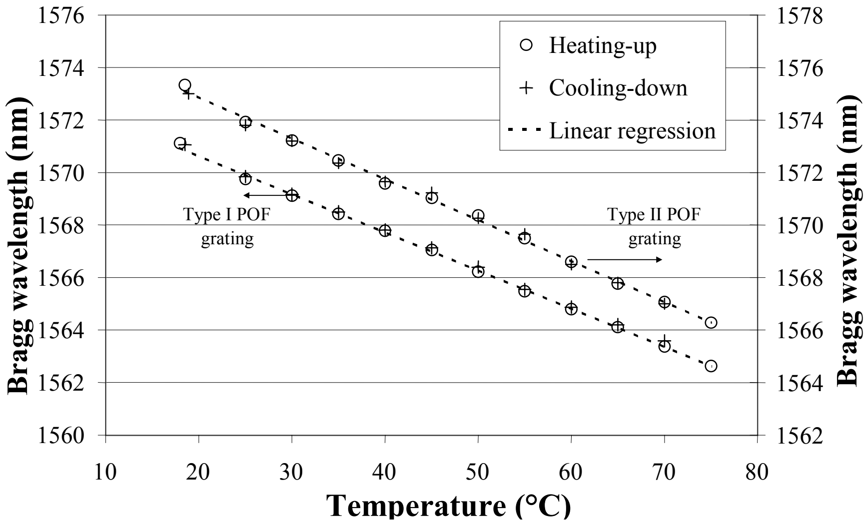
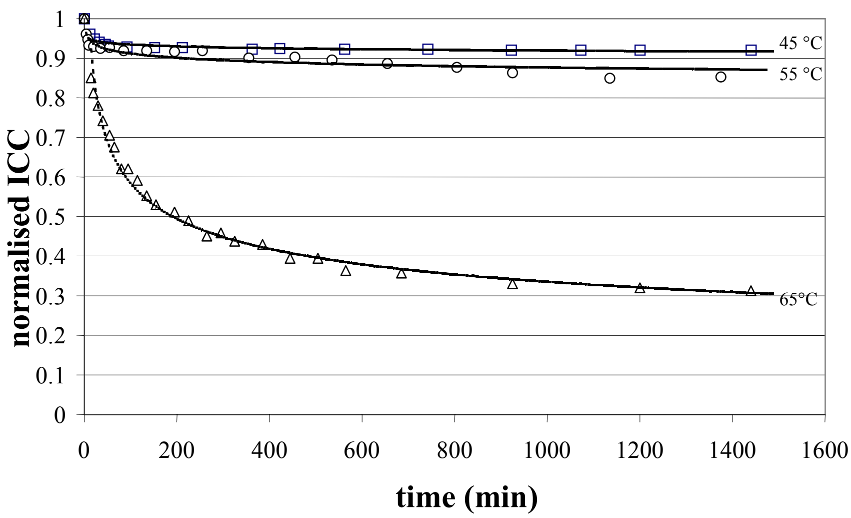


Figure 4 Bragg wavelength of Type I and Type II POF gratings as function of temperature

4. Thermal decay of Type I & II polymer fiber gratings

The thermal degradation of POF gratings was monitored at 45°C, 55°C and 65°C. In the experiment, when the spectrum analyser swept through the point of minimum transmission, the time and the minimum transmission T_{min} were recorded. The starting time t=0 was taken as the instant when the grating was placed into the furnace. Type I POF gratings for thermal decay examination has a maximum transmission dip of about 4 dB. The transmission depth for Type II POF grating for the test is about 15 dB.

Fig.5 illustrates the thermal decay for Type I POF by using normalized integrated coupling constant (ICC) at 45°C, 55°C and 65°C. It is clearly proved that ICC value is proportional to the grating induced refractive index change, even for the case of a nonuniform grating [10]. For convenience, the quantity η is defined to be equal to the ICC normalized to its initial value at t=0.



It is apparent from Fig.5 that Type I POF grating exhibits an initial rapid decrease in normalized index change followed by a progressively diminishing but nonzero rate of change, which is similar to the decay behavior of Type I unloaded silica fiber grating [2]. But the data in Fig. 5 doesn't fit the same function in the "power law " model [2] for Type I non-hydrogenated silica fiber gratings. In the end, the regression function for the decay data in Fig.5 is determined as,

$$\eta = \frac{1}{At^{\alpha}} \tag{4}$$

where the factor A and exponent α both depend on temperature as well. A and α are dimensionless, and t is the time value normalized to 1 min to keep dimensions consistent. The regression function is also plotted in Fig.5 to compare with the experimental data. The regression function fits well, apart from the several data points at the beginning of each decay curve. The regression function for the different temperature are expressed as $\eta = \frac{1}{1.035t^{0.0071}}$ at 45°C, $\eta = \frac{1}{1.013t^{0.0071}}$ at 55°C and $\eta = \frac{1}{0.565t^{0.2408}}$ at 65°C, respectively. The mean error of the fit to the data and the variance of the error are shown in Table 1.

Table 1 Mean error and error variance of the regression

	45°C	55°C	65°C
Mean error (%)	0.005	0.028	0.019
Error variance (%)	0.46	1.25	2.28

The attempt to regress the temperature dependence of A and α was made. It was found out that they don't follow the "power law" model for unloaded Type I silica fiber gratings [2]. Neither does the decay curve fit the "log time" model for hydrogenated fiber gratings [11]. More work has to be carried out in order to determine A and α temperature function.

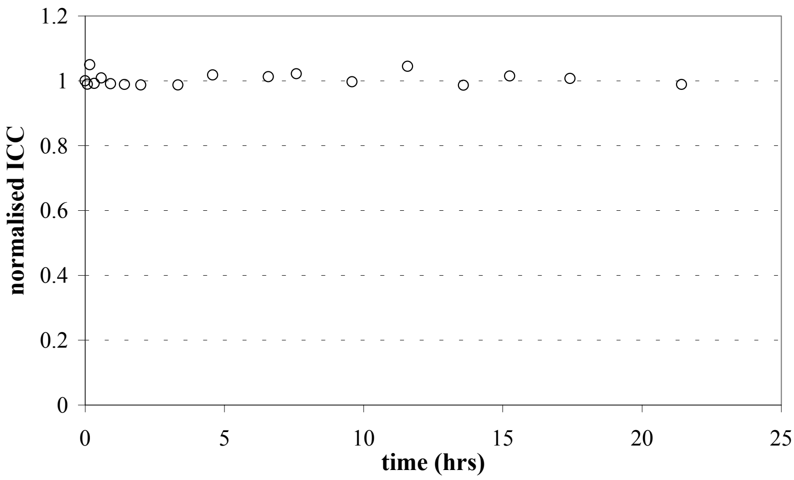


Figure 6 Decay curve for Type II POF gratings at 65ºC

The thermal decay behavior for Type II POF gratings was also studied, and it is found to be much more stable than Type I POF gratings. Fig.6 shows the decay curve of Type II POF gratings at 65ºC. It is striking to notice that no noticeable decay is observed for Type II POF gratings at 65ºC. The excellent stability for Type II POF gratings makes it attractive in some high temperature environment.

5. Conclusions

The thermal characterization of Type I and Type II POF gratings are carried out. It is shown that POF gratings have much better tunability than silica fiber gratings. Almost 10 nm tuning range has been achieved just with 55°C temperature variation. Furthermore, the high linearity and the absence of thermal hysteresis make the thermal tuning for POF grating easy to be implemented and controlled. In addition, Type I and Type II POF gratings are found to be equable thermal sensitive and the temperature sensitivity for POF gratings is about 10 times larger than that of silica fiber gratings. Thermal decay study for POF gratings indicate that Type II POF gratings is much more stable than Type I POF gratings. Type II POF gratings is very stable and no noticeable decay can be observed at 65ºC. While for Type I POF gratings, a rapid decay followed by a substantially decreasing rate of decay is found. However, the decay behavior doesn't follow the "power law" model for Type I non-hydrogenated silica fiber gratings or the "log time" model for hydrogenated silica fiber gratings.

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