# Thermal Tuning of Polymer Optical Fibre Bragg Gratings

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# Thermal Tuning of Polymer Optical Fiber Bragg Gratings

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***Abstract*—Bragg gratings in polymethyl methacrylate (PMMA)-based polymer fibers were created and were tuned thermally. It is found that the tuning range is more than 18 nm over a temperature variation of 50 °C. More importantly, no hysteresis effect was observed as the gratings were heated up and cooled down.**

***Index Terms*—Bragg gratings, polymer fiber, thermal stability, tuning.**

## I. Introduction

BRAGG gratings in silica optical fibers have found a wide range of applications such as dispersion compensation, add-drop wavelength-division multiplexing (WDM), and optical sensing, etc. One disadvantage of these gratings is their low tunability. Bragg gratings in polymer optical fibers (POFs), however, overcome this problem. It has been shown that these gratings can be tuned over 74 nm by stretching [1]. This is significant when it is compared with the 2-nm tuning range in silica fiber gratings. For these POF gratings to be used in practical engineering applications, they have to be subjected to further investigations, one being its performance under temperature variation. The purpose of this letter is to report the tuning properties of these POF gratings by thermal means.

## II. POF Grating Fabrication

The preform that was used to draw into polymer optical fiber was fabricated following the procedure described in [2]. In order to increase the thermal stability and strength, however, higher temperature was used for core polymerization. A hollow polymer preform filled with core monomer mixture (MMA + EMA + BzMA) was thermally polymerized in an oven. The temperature of the oven was increased gradually from 65 °C to 85 °C for three days. It is noted that these temperatures are still well below the cladding's glass transition temperature that is usually around 100 °C. Polymer optical fibers were drawn at 270 °C from the preform. The diameter of the fibers is 133 $\mu$m with a core diameter of 6 $\mu$m. The difference in the refractive index between the core and the cladding is 0.0086, which was measured using the transverse interference method with a microscope after the fibers were drawn. Thus, the fiber is single-moded in the 1550-nm window. The fiber Bragg grating was prepared using the technique described in [3], which is an adaptation of the transverse method developed by Meltz *et al.* [4] with the introduction of a static ring interferometer based on the patent invented by Ouellettee [5]. The period of the phase mask is 1.06 $\mu$m, which was designed for use at 248 $\mu$m. The UV writing beam was obtained from the Nd : YAG laser with wavelength of 355 nm. The length of the grating thus fabricated is about 3 mm and the measured reflectivity is 75% at the Bragg wavelength with a linewidth of 0.5 nm [full-width at half-maximum (FWHM)].

In order to increase the intensity of the 355-nm UV laser beams, we added to the setup a pair of cylindrical lenses with focal lengths of 150 and 50 mm, respectively, in front of a phase mask used for the grating writing. The beams on the phase mask were reduced from 6 mm to about 2 mm in the perpendicular direction to the fiber. This effectively shortened the grating preparation time. For example, the time for saturation of grating reflection decreased from 85 to 15 min. The grating with a length of 3 mm created in the higher temperature-prepared POF has reflection of 75%, which is compatible with that of our previously reported value. This shows that the higher temperature used here did not degrade the photosensitivity of the POF to UV light.

## III. Thermal Tuning of POF Gratings

To test the thermal tuning of the POF grating, a setup shown in Fig. 1 was adopted. A Peltier cell was used as a heat source whose temperature is controlled by an electric current. This cell sat on top of an aluminum block with the POF grating and temperature sensor inserted between the block and the cell. The POF was quite short and both of its ends were connected to a piece of silica fiber to enable light to be launched into the grating and the transmitted light from the grating was directed to the optical spectrum analyzer (OSA). The accuracy of the temperature measurement was 0.1 °C, but it took about 10 min for the system to reach the desired temperature. When the temperature reached the desired value, the transmission spectrum of the grating was measured using the OSA. A tungsten lamp was used as the light source.

Fig. 2 shows the transmission spectrum of the grating obtained from the measurement. It has been estimated the reflectivity at the Bragg wavelength (1578.5 nm) is 75% and the spectral width is about 0.5 nm (FWHM). This reflectivity can be improved by: 1) increasing the grating length from 3 mm to several centimeters because the reflectivity of a grating is proportional to the square of the hyperbolic tangent of grating length and 2)

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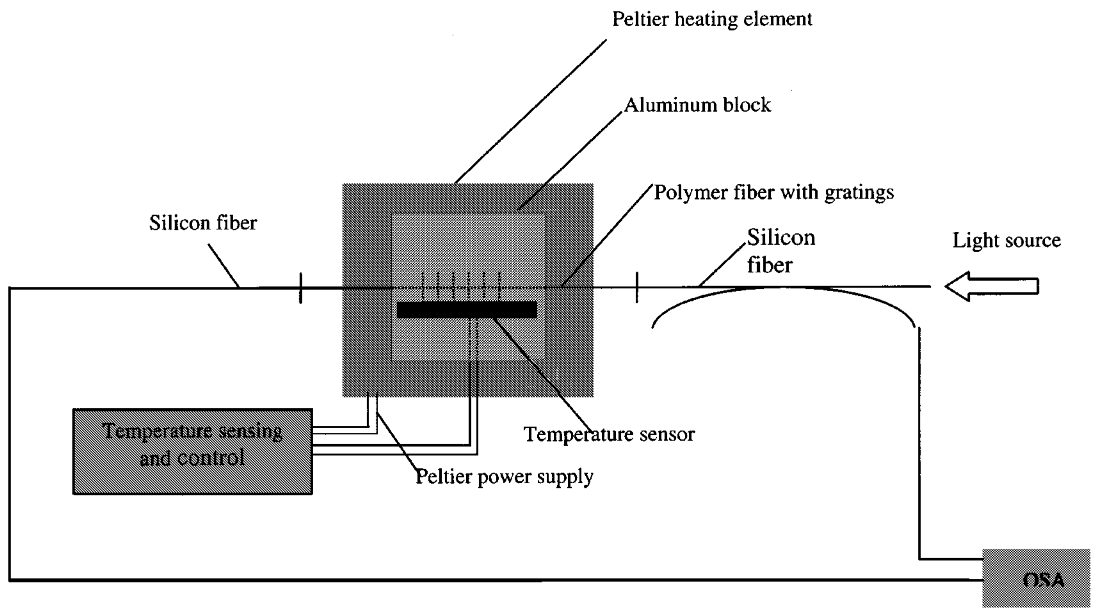


Fig. 1. Thermal testing of POF grating.

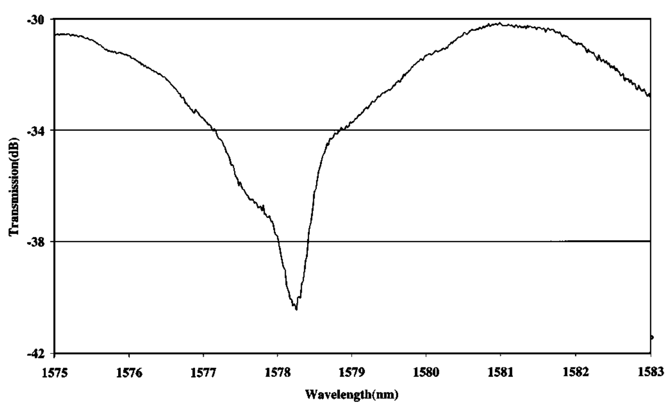


Fig. 2. Transmission spectrum of POF grating.

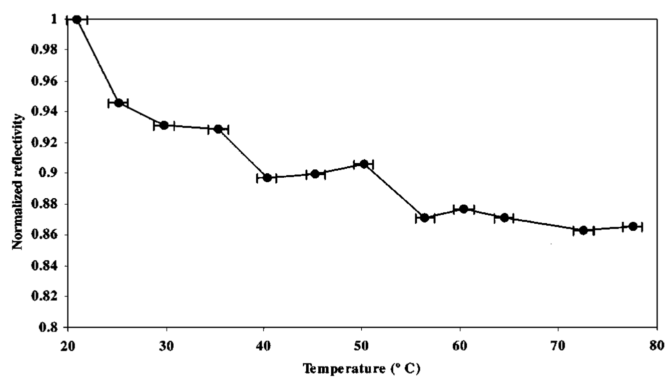


Fig. 3. Temperature dependence of normalized reflectivity of Bragg grating.

the illumination wavelength changed from 355 to 325 nm. This is because the photosensitivity effect in polymer is more pronounced at the shorter wavelength.

Fig. 3 shows the change of the reflectivity of the grating as a function of the temperature with a step time of 10 min. It can be seen that the change is less than 10%. Included in this figure are the error bars of the measurements due to the inaccuracy in determining the temperatures.

Fig. 4 shows the shift of Bragg wavelength as a function of temperature of this POF grating. In this figure, two curves are shown. One is obtained when the grating was heated up from room temperature to 70 °C while the other is obtained from the grating was cooled down. Both curves are not very linear. The error bars due to the inaccuracy in determining the temperature are also shown. It is noted that the shift $\Delta\lambda_B$ of Bragg wavelength $\lambda_B$ in a grating due to thermal tuning $\Delta T$ can be expressed as [6]

$$\Delta\lambda_B = \lambda_B(\alpha + \varsigma)\Delta T \tag{1}$$

where $\alpha$ is the thermal expansion coefficient of the fiber. In silica fiber, $\alpha$ is approximately $0.55 \times 10^{-6}$ cm/cm/°C. However, for polymer fiber made of polymethyl methacrylate (PMMA), it is $8.0 \times 10^{-5}$ cm/cm/°C. $\zeta$ is the thermooptic coefficient and has a value of $8.6 \times 10^{-6}$ /°C for silica fiber and $10^{-4}$/°C for PMMA polymer fiber.

It is noted that from (1) the effect on the change of refractive index (due to $\zeta$) is much larger than the effect of change of the grating period (due to $\alpha$).

More significantly, however, is that the heat up curve and the cool down curve more or less coincide with each other. This indicates the absence of hysteresis and shows that thermal means can be used to tune the Bragg wavelength in practice. The tuning range is more than 18 nm over a temperature variation of 50 °C. This is much larger than the corresponding range of silica fiber grating, which is less than 1 nm. Error bars of temperature measurements have been included in Fig. 4 to show the accuracy of the experiment.

The thermal stability of the grating in polymer fiber is further investigated by maintaining the grating at an elevated temperature and monitoring its reflectivity as a function of time. Fig. 5 shows the change of the reflectivity as a function of time when the grating was maintained separately at 30 °C, 50 °C, and 65 °C. Although these plots bear a remarkable resemblance to

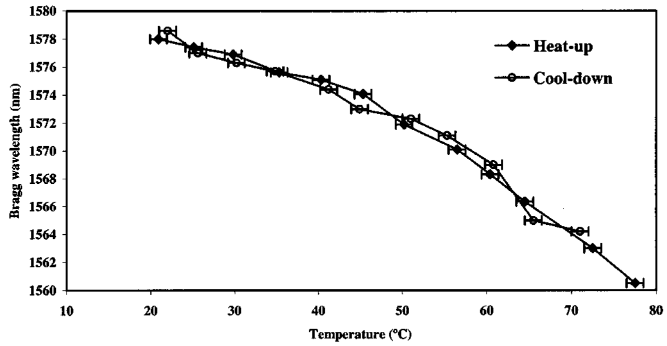


Fig. 4. Temperature dependence of Bragg wavelength.

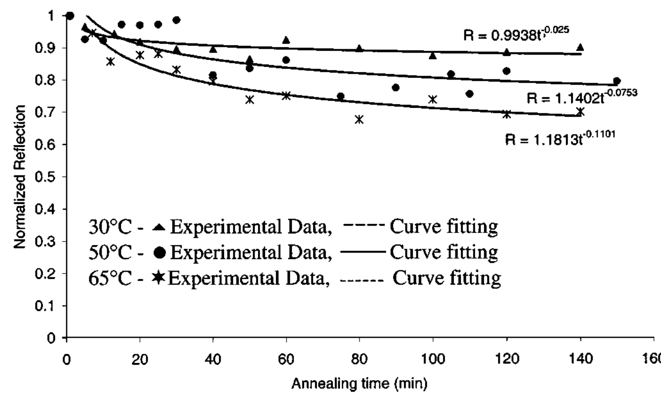


Fig. 5. Degradation of peak reflectivity of polymer fiber gratings with time.

those of silica fiber gratings [7], [8], we found they do not fit the Erdogan model [7] for nonhydrogen loaded gratings. Neither do they fit the Baker model [8] for hydrogen-loaded gratings. In the end, we resigned to the simple curve fitting

$$\text{Normalized Reflection } R = At^{-\alpha} \tag{2}$$

where $A$ and $\alpha$ are shown in Fig. 5. There is a notable difference in thermal stability between polymer fiber gratings and silica fiber gratings in that for the polymer case, there is no dramatic decrease of the reflectivity when $t$ is small whereas in the case of glass gratings, the decrease is very pronounced in by hydrogen-loaded and nonhydrogen-loaded gratings. The fact that these plots do not fit both Erdogan and Baker models may be due to the different photosensitivity mechanisms. For polymer, it is chiefly due to photopolymerization [9], whereas in the case of silica glass, it is due to the trapping of the UV-excited charge carriers [7]. Just as in the case of silica fiber gratings, the long-term stability of polymer fiber grating requires burning in at an elevated temperature for a short time.

## IV. Conclusion

The Bragg wavelength of POF grating can be tuned by means of thermal means. The tuning range is more than 18 nm over a temperature variation of 50 °C. This is much larger than that afforded by silica fiber gratings. More importantly, there is no thermal hysteresis effect when the grating heats up or cools down.

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