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Polymer Optical Fibre Bragg Grating Humidity Sensor at 100ºC

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Abstract: We have demonstrated a polymer optical fibre Bragg grating humidity sensor that can be operated up to 100ºC. The sensor has been fabricated from a polycarbonate (PC) microstructured polymer optical fibre Bragg grating (mPOFBG). PC mPOFBG gave a relative humidity (RH) sensitivity of 6.95±0.83 pm/% RH in the range 10-90% RH at 100ºC and a temperature sensitivity of 25.94±0.47 pm/ºC in the range 20 - 100 ºC at 90% RH. Despite PC mPOFBGs shows smaller humidity sensitivity compared to PMMA mPOFBGs, they can be used to sense humidity beyond the operating temperature limit of PMMA mPOFBGs.

Key Words: Polymer optical fibre, Fibre Bragg grating, Fibre optic sensor, Humidity sensor, Annealing.

1. Introduction

The interest in polymer optical fibres (POFs) in sensing is steadily increasing because of their low processing temperature, high flexibility in bending, high fracture toughness, ease of handling, and non-brittle nature, which are properties that glass fibres do not have [1-2]. In addition, POFs are biocompatible and have a high elastic strain limit and low Young’s modulus, which makes them advantageous for fibre Bragg grating (FBG) based strain and bio-sensing applications [3-5]. Some polymers, such as PMMA, are humidity sensitive and strongly absorb water [6], while other polymers, such as TOPAS 5013, were shown to be insensitive to humidity and high operating temperature [7]. Nevertheless, it is polycarbonate microstructured polymer optical fibre (mPOF) that has the highest operating temperature among currently exiting POFs [8]. Due to the moisture absorbing capability of PMMA based POFs, which leads to a change in the refractive index and size of the fibre, both of which contribute to a change in Bragg wavelength [9], they are used for developing humidity sensors [10]. PC has also moisture absorbing capability although it is smaller than that of PMMA. The water absorption (saturation value) at 23ºC of PC is 0.3% [11], and PMMA is 2.1% [12]. This means that the water absorption capability of PC is 7 times smaller than that of PMMA but about 40ºC larger glass transition temperature (T_g) as compared to PMMA.

For PMMA POFBGs the temperature operational limit is strongly dependent on the surrounding relative humidity (RH) level at which they are being operated, in addition to its T_g. If they are operated at ambient or less RH level, this limit is 15-20ºC below their T_g. For instance, at ambient RH PMMA POFBGs has been operated up to 90 ºC [13]. But, when the surrounding RH is high, the temperature operational limit significantly decreases. For instance, at 90% RH they can be operated only up to 75 ºC [14]. This is due to the fact that for such polymers the glass transition temperature decreases with increasing humidity. Similarly, when PMMA POFBGs are used as humidity sensor the RH range of operation highly dependent on the temperature of the environment in which the sensors are being operated. PMMA POFBG has been operated from 10-90% RH up to 75ºC. However, beyond this temperature the grating could not handle it. If the temperature in which PMMA POFBGs humidity sensors are being operated is higher than 75ºC, the maximum RH should be less than 90%. For instance, if we want to operate PMMA POFBGs at 85 ºC, the range of RH operation will be limited to only 60% RH for stable operation. Likewise, at 90°C the range of possible RH becomes even narrower. Thus, it is important to develop POFBG humidity sensors which can operate at high temperature and also with wide range of RH for some applications. Here we demonstrated a stable and highly linear mPOFBGs humidity sensor that can be operated beyond 100ºC and with RH range of up to 90%. This sensor is developed with PC mPOFBGs.

2. Experiment

The fibre used in this experiment is a PC mPOF. The diameter of the fiber is 130µm, and the hole and the pitch size are 1.5 µm and 4.2µm, respectively. The hole to pitch ratio is 0.38, ensuring that the fiber is endlessly single mode [15]. First FBG was inscribed by using phase mask technique. The setup used was the same as described in ref. 16. The Bragg wavelength of the grating was 892.67nm and the full width half maximum was 0.8nm. The PC mPOFBG was first connectorized [17] and coupled with a single mode silica fibre and then placed in the CLIMACELL environmental chamber. A Supercontinuum source (NKT Photonics A/S) has been used as a light source and Compact CCD Spectrometer (THORLABS) has been used to continuously track the grating in the chamber during the experiment. The FBG has been first annealed at 100ºC and 90% relative humidity (RH). The annealing process was stopped when the rate of blue shift was less than 0.1nm/hour. This process took 26 hours. The amount of blue shit was 8nm.

After annealing the humidity response of the mPOFBG sensor has been measured at 100ºC in the interval of 10-90% RH. At this temperature and RH range the environmental chamber has a precision of 0.5ºC and 1% RH. The humidity measurement has been done first by increasing the RH from 10% to 90%, with step of 10% and then decreasing it from 90% to 10% with step of 10%. The stabilization period after incrementing or decrementing the RH was 60 minutes. .

We have also measured the temperature sensitivity at 90% RH in the range 20 to 100ºC. The temperature measurement has been done first by increasing the temperature from 20 to 100ºC, with steps of 10ºC and then decreasing it back to 20ºC with same amount of step. The stabilization period after incrementing or decrementing the temperature was 60 minutes.

3. Results

The response of the PC mPOFBGs for both increasing and decreasing relative humidity at 100ºC for the stabilized period is shown in Fig. 1.

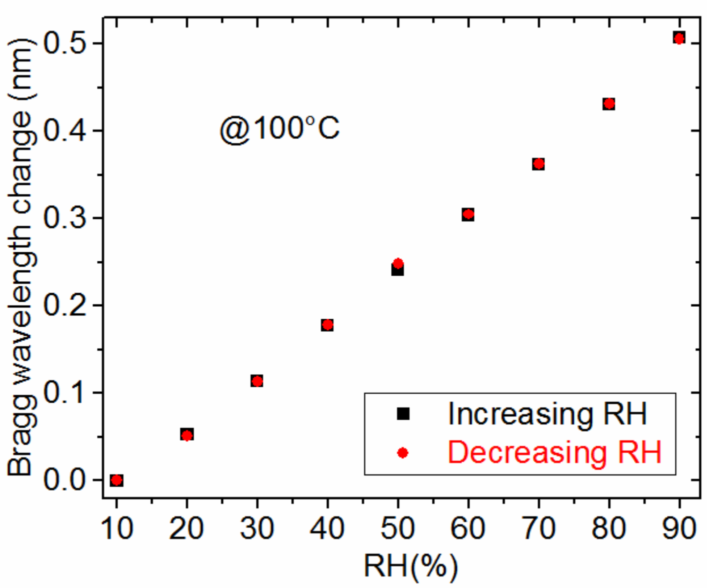

Figure 1. Measured humidity response at 100ºC of the PC mPOFBG.

The humidity sensitivity at 100ºC was 6.95±0.83 pm/%RH for both increasing and decreasing humidity. The R-squared for this fitted regression line is 0.998. The humidity sensitivity of a PMMA mPOFBG at 75 ºC, which is the maximum operating temperature at higher RH, in the 850nm region is typically around 45 pm/%RH in the range 10-90%. This shows that PC mPOFBG has wider operating temperature range but lower RH sensitivity as compared to PMMA mPOFBGs.

The response of the PC mPOFBGs for both increasing and decreasing temperature at 90% RH is shown in Fig. 2. The temperature sensitivity at 90 % RH was 25.94±0.47 pm/ºC for both increasing and decreasing temperature. The R-squared for this fitted regression line is 0.998. There were no hysteresis observed for both humidity and temperature measurement. This is due to the fact the FBG was annealed well enough.

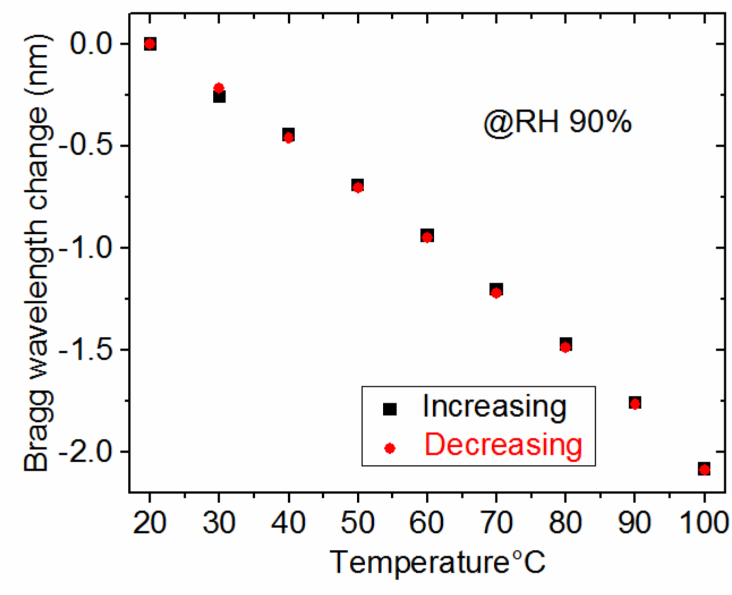

Figure 2. Measured temperature response at 90% RH of the PC mPOFBG.

4. Conclusion

We have developed a polymer optical fibre Bragg grating humidity sensor that can be operated up to 100ºC. The sensor has been fabricated from a PC mPOFBG. PC mPOFBG gave a RH sensitivity of 6.95±0.83 pm/% RH in the range 10-90% RH at 100ºC and a temperature sensitivity of 25.94±0.47 pm/ºC in the range 20-100 ºC at 90% RH. Thus, PC mPOFBGs humidity sensors can be used beyond the operating temperature limit of PMMA mPOFBGs.

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