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Published in:
25th International Conference on Optical Fiber Sensors

Link to article, DOI:
10.1117/12.2265884

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Woyessa, G., Pedersen, J. K. M., Fasano, A., Nielsen, K., Markos, C., Rasmussen, H. K., & Bang, O. (2017). Simultaneous measurement of temperature and humidity with microstructured polymer optical fiber Bragg gratings. In Y. Chung, W. Jin, B. Lee, J. Canning, K. Nakamura, & L. Yuan (Eds.), 25th International Conference on Optical Fiber Sensors (Vol. 10323). [103234T] SPIE - International Society for Optical Engineering. DOI: 10.1117/12.2265884

Simultaneous measurement of temperature and humidity with microstructured polymer optical fiber Bragg gratings

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ABSTRACT

A microstructured polymer optical fiber (mPOF) Bragg grating sensor system for the simultaneous measurement of temperature and relative humidity (RH) has been developed and characterized. The sensing head is based on two in-line fiber Bragg gratings recorded in a mPOF. The sensor system has a root mean square deviation of 1.04 % RH and 0.8 °C in the range 10 to 90% RH and 20 to 80 ºC. The proposed sensor system is easy to fabricate, cheap and compact.

Keywords: Polymer waveguides, fiber Bragg gratings, fiber optics sensors, humidity, temperature

1. INTRODUCTION

The interest in polymer optical fiber (POF) sensors 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 fibers do not have [1,2]. In addition, POFs have a high elastic strain limit with low Young's modulus and are biocompatible, which makes them advantageous for fiber Bragg grating (FBG) based strain and bio-sensing applications [3-8]. Some polymers, such as PMMA, are humidity sensitive and strongly absorb water [9], while other polymers, for instance TOPAS and Zeonex, are insensitive to humidity [10-12]. Exploiting such unique and intrinsic properties of POFs, researchers in this area have developed different single parameter POFBG sensors such as strain, temperature, humidity, pressure and soon [13-17]. Only little work has been done in the development of multi-parameter POFBG sensors. For instance, Zhang,C. et al developed simultaneous measurement of temperature and humidity using cascaded silica and PMMA FBGs [18]. Despite this sensor system provided a well-conditioned response, there was a potential problem of limited mechanical stability due to the fact that the silica and PMMA fibers were glued together. In addition, the glue could not withstand relatively high temperature and humidity which limited the range of operation of the sensor. Bhowmik,K. et al demonstrated a sensing configuration for simultaneous measurement of strain and temperature with enhanced intrinsic sensitivity based on a fiber Bragg grating (FBG) pair with one grating being inscribed in the etched and the other in unetched polymer fiber region [19]. Here we demonstrate the first simultaneous measurement of temperature and humidity using microstructured polymer optical fiber Bragg gratings. The sensing device is purely made of polymer materials.

2. FIBER FABRICATION

The mPOF was fabricated in-house at DTU Fotonik. The polymeric materials used for fiber fabrication are ZEONEX 480R produced by ZEON CORPORATION [20] and commercial PMMA from NORDISK PLAST A/S [21]. First a ZEONEX 480R cane was fabricated as described in reference 12. The Zeonex cane was sleeved with a Zeonex tube which was then sleeved with a PMMA tube, forming an over cladding, and finally drawn to a fiber of an average diameter 150 µm. The diameter of the Zeonex portion is 100µm, whereas the over cladding PMMA thickness is 25 µm. The core diameter of the fiber is 8µm and the hole to pitch ratio is 0.42 ensuring that the fiber is endlessly single mode [22,23]. A microscope image of the Zeonex-PMMA mPOF end facet is shown in Fig. 1.

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25th International Conference on Optical Fiber Sensors, edited by Youngjoo Chung, Wei Jin, Byoungho Lee, John Canning, Kentaro Nakamura, Libo Yuan, Proc. of SPIE Vol. 10323, 103234T · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2265884

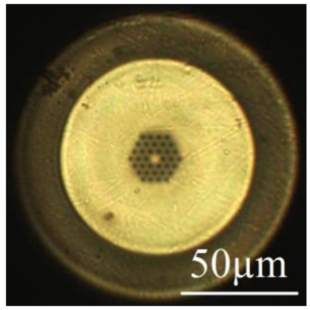

Figure 1. Optical microscope image of the fabricated Zeonex-PMMA mPOF

3. SENSOR FABRICATION

First, one end of a 50 cm long piece of the fabricated fiber was connectrorized [24]. From the other end, in the first five centimeters of the fiber the PMMA over cladding was etched out by using acetone, so that only Zeonex was left in this section. In the section composed only of Zeonex, four centimeters far from the end of the fiber an FBG (FBG1) was inscribed and the Bragg wavelength was at 865.62 nm. The FBG was then annealed at 90 ºC in a conventional oven for three hours and blue shifted to 847.79 nm. After annealing two centimeters far from FBG1 a second FBG (FBG2) was inscribed in the section where PMMA was not etched out and the Bragg wavelength of this grating was at 866.11 nm. The grating inscription technique and the configuration setup used in this work were described in reference 25. The two FBGs then annealed together in an environmental climate chamber (CLIMACELL, MMM group) for 24 hours at 85 ºC and 90 % RH for a stable operation of the sensor [15]. The new Bragg wavelengths for FBG1 and FBG2 after annealing were found to be 841.21 nm and 855.32 nm, respectively.

4. SENSOR CALIBRATION

The calibration of the sensor was made in a climate chamber. A supercontinuum source (SuperK Compact, NKT Photonics) was used as the broadband light source and spectrometer (CCS175-Compact Spectrometer, Thorlabs) was used to continuously track and record the grating during the experiment in the climate chamber. First, relative humidity measurement was made in the range 10-90 % RH at 50 ºC. Figure 2(a) shows that the humidity responses of both FBG1 and FBG2 at 50 ºC. Temperature measurement was done following the RH measurement in the range 20-80 ºC at 50 % RH. Figure 2(b) shows that the temperature responses of both FBG1 and FBG2 at 50 % RH.

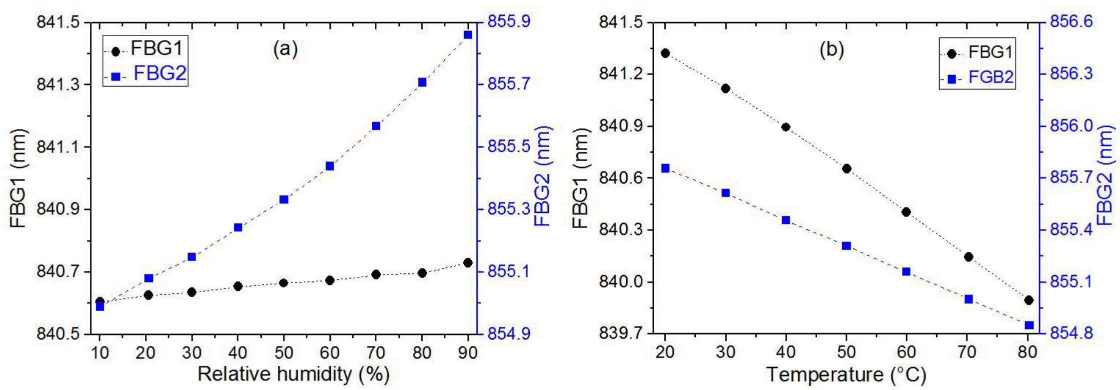

Figure 2. (a) Measured humidity response of FBG1 and FBG2 at 50 ºC. (b) Measured temperature response of FBG1 and FBG2 at 50 %RH.

5. ERROR ANALYSIS

A suitable model for the responses of the two FBGs, including the nonlinear RH-response of FBG2, is

$$\Delta\lambda_1 = \alpha_1 \Delta T + \beta_1 \Delta H \quad (1)$$
$$\Delta\lambda_2 = \alpha_2 \Delta T + \beta_2 \Delta H + \gamma_2 \Delta H^2 \quad (2)$$

where $\Delta\lambda_1$ and $\Delta\lambda_2$ are the net wavelength changes of FBG1 and FBG2, respectively. By combining (1) and (2) we arrive at the following expression for the change in relative humidity

$$\Delta H = \frac{-b+\sqrt{b^2-4ac}}{2a} \tag{3}$$

where,

$$a = \frac{\alpha_1}{\alpha_2}\gamma_2,\;\; b = \frac{\alpha_1}{\alpha_2}\beta_2 - \beta_1,\;\; c = \Delta\lambda_1 - \frac{\alpha_1}{\alpha_2}\Delta\lambda_2$$

Thus, once the coefficients $\alpha_{1,2}, \beta_{1,2}$ and γ_2 were determined by fitting polynomials to the calibration data, we were able to determine the relative humidity using (3) and subsequently the temperature from (1) by simultaneously measuring the Bragg wavelength shifts of the two FBGs. By fitting the data in Fig. 2 we found the following parameters, where ΔT = 0 at T = 50 °C and ΔH = 0 at H = 50% RH and the stated uncertainties are the standard errors of the fitting parameters.

i	α_i	β_i	γ_i
1	-23.9 ± 0.4 pm/°C	1.4 ± 0.1 pm/%RH	-
2	-15.1 ± 0.1 pm/°C	6.4 ± 0.5 pm/%RH	0.090 ± 0.005 pm/(%RH)^2

Using these coefficients we reconstructed the calibration points shown in the Fig.2 from the corresponding measured values of λ_1 and λ_2, see Fig.3. The root mean square deviations in the reconstructed values are 1.04 %RH and 0.8 °C for the relative humidity and temperature, respectively, which demonstrates that the proposed sensor system is a viable way of effectively separating the responses of temperature and relative humidity.

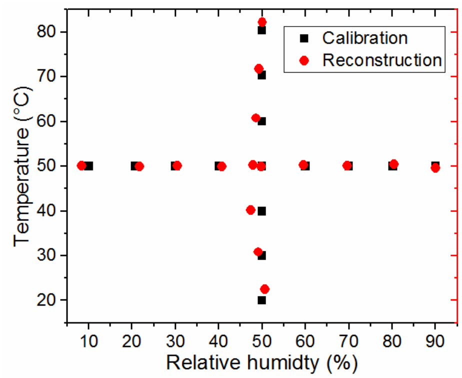

Figure 3. Reconstruction of temperature (vertical) and relative humidity (horizontal) from the measured values of λ_1 and λ_2.

6. CONCLUSION

In this work, we have demonstrated a sensing system for simultaneous measurement of temperature and humidity using microstructured polymer optical fiber Bragg gratings. The fiber was fabricated from two types of polymers: Zeonex, which is humidity insensitive and PMMA, which is highly humidity sensitive. An rms deviation of 1.04 % RH and 0.8 °C were observed in our experimental results. The developed sensor system offers a number of advantages such as ease of fabrication, compactness and low cost and it can be used in many applications where simultaneous measurements temperature and humidity are required.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA grant agreement n° 608382. The authors also acknowledge financial support from Innovation Fund Denmark for the project BIOFORS (contract no. 1382-00058B) and ShapeOCT (J. No. 4107-00011A) and Danish Council for Independent Research (FTP Case No. 4184-00359B).

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