Study of etched polymer optical fiber Bragg gratings for ethanol vapor sensing

X. Hu[1] C. Zhang,[2] D. Kinet,[1] M. Debliquy,[2] P. Mégret,[1] and C. Caucheteur,[1]

[1] Electromagnetism and Telecommunication Department, University of Mons, Bld Dolez 31, 7000 Mons, Belgium

[2] Material Science Department, University of Mons, Rue de l'Epargne 56, 7000 Mons, Belgium

For the first time to the best of our knowledge, we report an ethanol vapor sensor based on etched fiber Bragg gratings (FBGs) written into step-index polymer optical fibers (POFs). The end of POF with grating was etched by immersion in a mixture of acetone and methanol (ratio 2:1). The etching rate was computed equal to 3.44 µm/minute. Then, the etched FBG was exposed to ethanol vapors mixed with dry air in different concentrations at room temperature. The sensitivity of this sensor was tested with different grating lengths and diameters.

Introduction

Fiber Bragg gratings (FBGs) written in polymer optical fibers (POFs) present several attractive features, especially for sensing purposes. In comparison to FBGs written in silica fibers, they are more sensitive to temperature and pressure, because of the larger thermo-optic coefficient and smaller Young's modulus of polymer materials [1-3]. Although different polymer materials can be used to manufacture POF, the most often encountered one is poly (methyl methacrylate) (PMMA). Unlike silica, PMMA demonstrates absorption of moisture up to 2 w.t. %, so that PMMA FBGs can be used as humidity sensor [4], biochemical concentration sensor [5] and water detection sensor [6]. Besides water, PMMA can swell and vary its refractive index with low molecular weight alcohols [7]. Ethanol sensing has been tested in silica fiber Bragg grating coated with PMMA [8].

In this paper we demonstrate etched PMMA fiber Bragg gratings ethanol vapor sensor in the telecommunication window around 1550 nm. The fiber contains trans-4-stilbenemethanol in the core, as a photosensitive material, which makes inscription available with laser wavelength ranging around 310 nm [9,10]. FBGs were produced through the use of a phase mask and a Helium-Cadmium laser emitting at 325 nm. Using cylindrical lenses, the beam width was adjusted to the core of the desired grating in a single exposition. POF with grating was etched in a mixture solution then, it was exposed to ethanol vapors mixed with dry air in different concentrations.

Experimental setup for FBGs fabrication

Figure 1 depicts a sketch of the experimental set-up that was used to manufacture FBGs in POFs. Figure 2 shows the real devices in the experiment. The fiber was supplied by *The Hong Kong Polytechnic University*. It has a core diameter of 8.2 µm and a cladding diameter of 150 µm. The core is made of PMMA doped with Diphenyl sulfide (5 mol%) and Trans-4-stilbenemethanol (1 w.t. %) while the cladding is in pure PMMA. The refractive indices are computed equal to 1.5086 and 1.4904 for the core and the cladding, respectively, at the wavelength of 589 nm. The laser used in this work is a He-

Cd laser (Kimmon IK5751I-G) with an output power of 30 mW at 325 nm. The output beam diameter of the laser is 1.2 mm. The inscription was made from the top, and a uniform phase mask (Coherent) with a period of 1044 nm was placed above the fiber as closely as possible. Two plano-convex cylindrical lenses were incorporated in the inscription setup. One of the cylindrical lenses with 10 cm focus length was just in front of the phase mask, which was used to increase the power density on the core. The other lens was used to expand the laser beam diameter in the cross direction. Here, 10 mm long FBGs were photo-inscribed in the set-up. The inscription time was 45 minutes.

The grating was located at the end of a short section of POF (typically 5 cm) that was glued (using Norland optical adhesive 78) to a standard silica optical fiber pigtail.

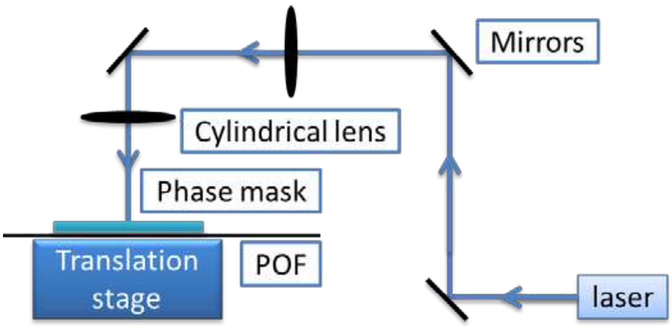

Figure 1: Sketch of the experimental set-up used for grating inscription in POF.

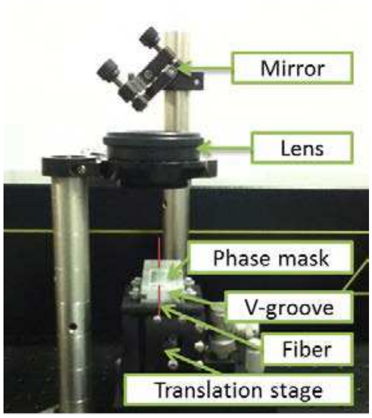

Figure 2: Real opto-mechanical devices in the experiment.

Etching process

The POF was etched by immersion in a mixture of acetone and methanol (ratio 2:1). Figure 3 shows the evolution of POF diameter when being etched. The etching rate was computed equal to 3.44 µm/minute, so that, after 30 minutes, the remaining fiber diameter was estimated to 47 µm. Figure 4 shows the evolution of the FBG reflected spectrum. A blue shift occurs during the etching process, which is attributed to the release of water molecules. At the end of etching process, the fiber was broken in the center of FBG. So the remaining length of FBG is estimated around 1 mm. Figure 5 shows the final FBG spectrum, which was used after drying in air during 2.5 hours.

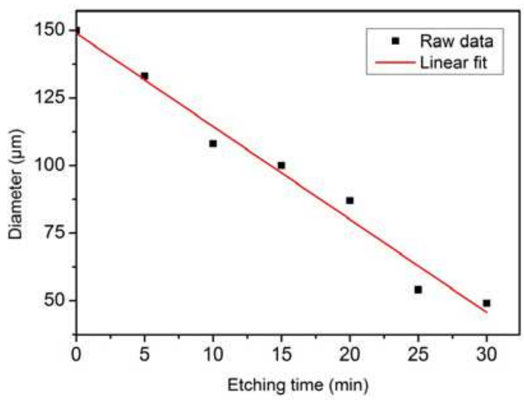

Figure 3: Evolution of the FBG reflected spectrum during etching process.

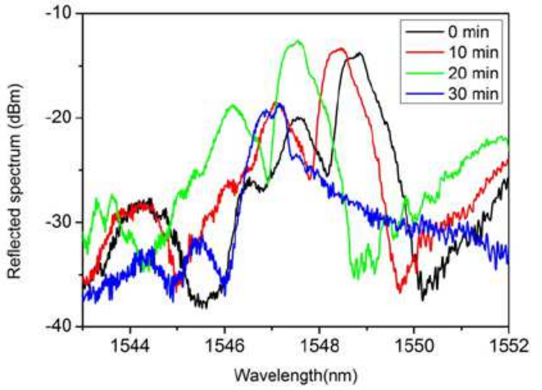

Figure 4: Evolution of the FBG reflected spectrum during etching process

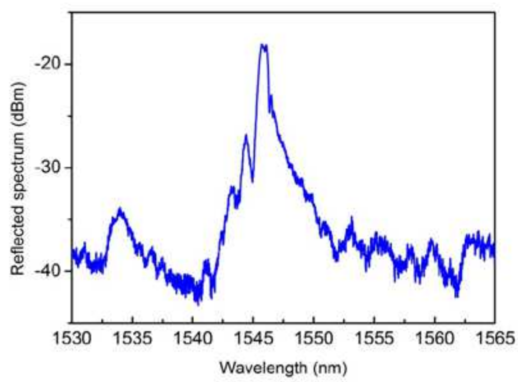

Figure 5: FBG reflected spectrum after 2.5h drying

Experimental setup for ethanol vapor test

The performances of the sensors were measured in a glass chamber which is connected with dry air and ethanol vapors at room temperature. The ethanol vapors were generated in bubbler when dry air was going through. The ethanol vapor concentration was controled by adjusting two volume flow rates. Figure 6 shows that the total Bragg wavelength shift for the peak around 1546 nm occurred within 2 minutes of exposure while the recovery in dry air lasts for ~15 minutes. Finally, Figure 7 shows that the sensitivity of this sensor is equal to 56 pm/% of ethanol vapor concentration. Similar experiments were conducted on non-etched FBG and no response was obtained.

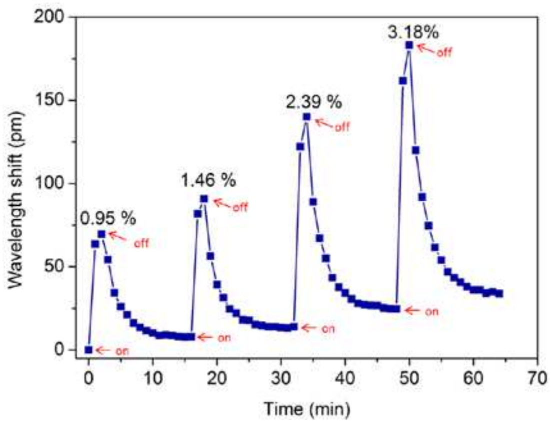

Figure 6: Wavelength shift of the etched FBG for different ethanol concentrations as a function of time.

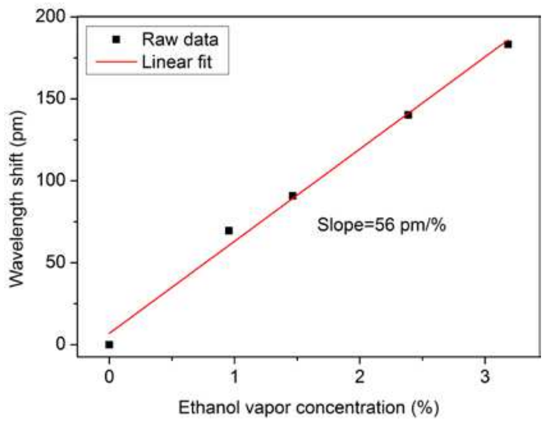

Figure 7: Sensitivity of ethanol vapor sensor.

Discussions

We have tested different fiber thicknesses ranging from 40 to 80 µm and different grating lengths varying between 1 mm and 4 mm. The results presented in Figure 6 are the best obtained until now. We are currently investigating the combined effect of fiber thickness and grating length on the sensitivity of the device. Although a full control is difficult to achieve, our observations are the following: in order to get a higher sensitivity and faster response, thinner fiber with FBG is needed. Short length of FBG can dramatically decrease the drift during sensing test.

Conclusions

In this paper, we have reported an ethanol vapor sensor based on etched fiber Bragg gratings (FBGs) written into step-index POFs. The end of POF with grating was etched by immersion in a mixture of acetone and methanol (ratio 2:1). The etching rate was computed equal to 3.44 µm/minute. Then, the etched FBG was exposed to ethanol vapors mixed with dry air in different concentrations at room temperature. The sensitivity of this sensor is equal to 56 pm/% of ethanol vapor concentration.

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