Properties of Fiber Bragg Grating in CYTOP Fiber Response to Temperature and Humidity

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Cyclic transparent fluoropolymer (CYTOP) optical fibers have attracted more and more attention among fiber sensing applications in recent years. In this work, using 400 nm fs laser and phase mask technique, two uniform fiber Bragg gratings (FBGs) are inscribed in CYTOP fiber with and without over-clad, respectively. The properties of two FBGs response to temperature and humidity are investigated using a climate chamber. The results show that the gratings without over-clad are humidity insensitive leading to humidity independent temperature sensors, whereas gratings with over-clad are humidity sensitive that translates to temperature sensitivities that are also humidity dependent.

Introduction

Polymer optical fibers (POFs) play a more and more important role in the field of communications and sensing devices due to their significant advantages such as low Young's modulus, biocompatibility and high flexibility [1–4]. Among POFs, CYTOP fiber is a good candidate for such applications due to its low attenuation in telecom transparency windows and specific material properties [5–8]. For sensing purposes, fiber Bragg gratings (FBGs) are one of the most efficient and convenient technology [1, 9]. Therefore, the properties of FBG sensors in CYTOP deserve to further investigation.

For any CYTOP-FBG application, it is necessary to perform FBGs characterization, and, in particular, to determine their sensitivities to physical quantities such as temperature and relative humidity. To date, a series of works reporting on CYTOP-FBGs characterization are published [2, 10–13]. These articles can be classified into two categories: papers dealing with fibers with an over-clad [10, 11] and those dealing with fibers without an over-clad [2, 12, 13]. However, there is no study comparing properties of CYTOP-FBG inscribed with and without an over-clad by the same inscription method and characterized under the same experimental conditions. For FBGs in CYTOP with over-clad, the reported sensitivities to temperature and humidity are 17.62 pm/°C and 14.7 pm/%RH in [11], and 37.3 pm/°C and 22.3 pm/%RH in [10], whereas without over-clad, the sensitivities to temperature and humidity are approximately 27.5 pm/°C and 10.3 pm/%RH, respectively [2, 13].

In this work, to investigate the properties of CYTOP-FBG, the same inscription setup was used to produce FBGs in CYTOP fibers with and without over-clad, respectively. We characterize both CYTOP-FBG types versus temperature in the range from 20 °C to 50 °C with steps of 10 °C (heating up) and −10 °C (cooling down), and versus humidity in the range 20 %RH to 60 %RH with steps of 20 %RH. We demonstrate that similar temperature sensitivities are found for CYTOP fibers with and without over-clad, whereas humidity sensitivities strongly depends on the presence or absence of the over-clad.

Experimental setup

Figure 1 represent the CYTOP-FBG inscription setup in this work. A femtosecond pulsed laser (a Mai Tai and Spitfire Pro. amplifier from Spectra Physics) producing 120 fs light pulses at 800 nm with a repetition rate of 1 kHz and energy of 4 mJ is used as the inscription laser. Gratings in CYTOP fibers are inscribed with the second harmonic generated

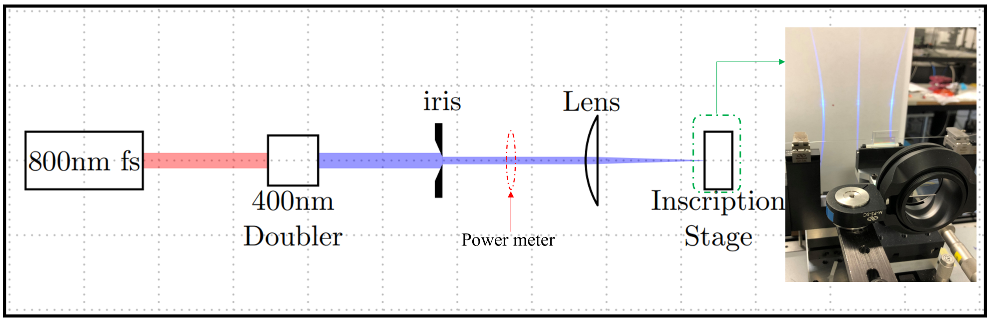

Figure 1: The inscription schematic of FBG in CYTOP polymer optical fibers.

pulses at 400 nm built in a nonlinear crystal starting from the 800 nm original pulses. The pulses then pass through a phase mask with a period of 1158 nm before reaching the CYTOP fiber with and without over-clad. The combination of the fs pulsed laser and the phase mask technique provides an efficient inscription method, producing FBGs with high reflectivity and good repeatability. For CYTOP-FBG without over-clad, the polycarbonate-based over-clad was removed on a length of 2 cm by dichloromethane CH_2Cl_2 in 10 min [2, 14, 15]. On the other hand, for the CYTOP fiber with the over-clad, a cover glass (from Corning) is inserted between the phase mask and the CYTOP fiber to protect the phase mask. The commercially available graded-index CYTOP fibers (GigaPOF-50SR and GigaPOF-62SR from Chromis) are used in this fabrication, with core diameter, over-clad diameter, and numerical aperture of 50 µm, 490 µm, and 0.185, and 62.5 µm, 490 µm, and 0.185, respectively. We inscribe FBG through the over-clad in the 62.5 µm core diameter fiber, and we remove the over-clad for the for 50 µm core diameter fiber. Indeed, for the 50 µm core diameter fiber, it is difficult to get good quality FBGs by writing through the over-clad. As the thickness of the over-clad is larger, the optical intensity needed to inscribe FBGs is too high and creates damage to the structure. A climate chamber (Weiss SB 22) with temperature and relative humidity ranges are –40 °C to 180 °C and 10 %RH to 98 %RH respectively is used to accurately set and control the temperature and humidity during the experiment.

Results

It was shown in [2] that the temperature sensitivities for the different mode groups and cross-mode groups are the same; therefore we only monitor the wavelength shift of the first mode group (fundamental mode) to compute the FBG response to temperature and humidity of grating with over-clad and without over-clad, respectively.
Figure 2 (a) and (b) show the temperature response of the CYTOP-FBG with and without over-clad for three humidity levels. According to the evolution of the wavelength peak of first mode group with different environmental conditions, the following conclusion are drawn:

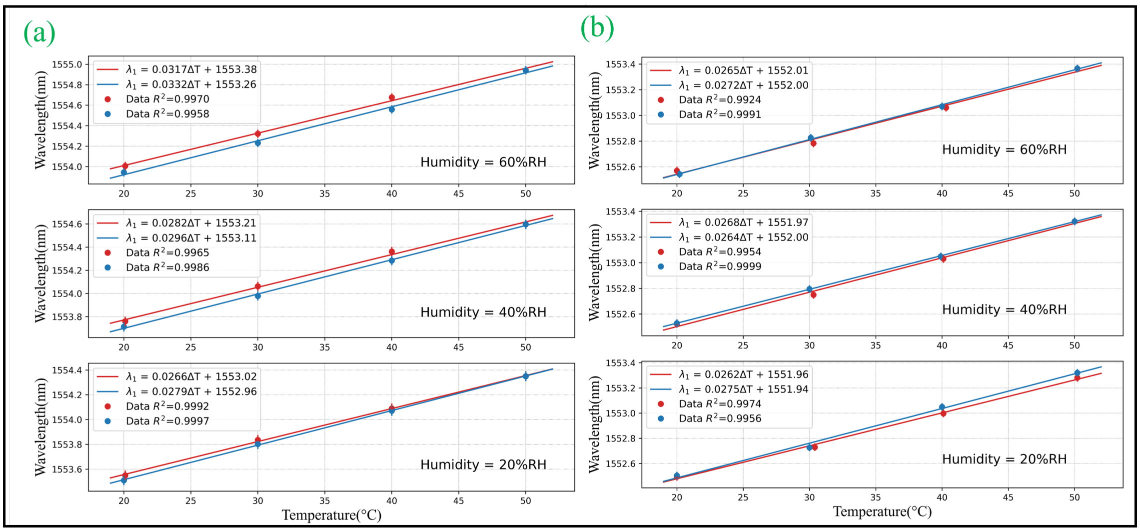

Figure 2: Temperature response of the first mode group of gratings for different humidity levels in CYTOP fibers: (a) with over-clad, and (b) without over-clad.

- It is clear that the first mode group evolves linearly with the change of temperature for different humidity levels with a coefficient of determination R^2 always better than 0.99 in both gratings with and without over-clad;
- For a given humidity level, in Fig. 2 (a), approximately the same temperature sensitivity is found in both heating and cooling processes;
- However, temperature sensitivities are humidity dependent, ranging from 33.2 pm/°C for 60 %RH to 27.9 pm/°C for 20 %RH in Fig. 2 (a).
- Decreasing the humidity level decreases the temperature sensitivity, for CYTOP fiber with over-clad;
- Contrary to CYTOP-FBG with over-clad, temperature sensitivities are not humidity dependent, with a value around 26.7 pm/°C for all humidity levels;
- There is negligible humidity sensitivity (<1 pm/%RH) for all temperature levels in CYTOP-FBG without over-clad;
- The main outcome of this experiment is that the temperature and the humidity sensitivities are correlated with the CYTOP-FBG's polycarbonate over-clad, due to its hydrophilicity.

Conclusions

Gratings in CYTOP fibers with and without over-clad were fabricated using the phase mask technique and a femtosecond pulsed laser operating at 400 nm. Then gratings were spectrally characterized to check the multi-peak-like spectra typical of gratings in multi-mode fibers response to environmental parameters.
The comparison of the temperature and humidity sensitivities for CYTOP-FBG with and without polycarbonate over-clad highlights the importance of the hydrophilic properties

of over-clad material. Indeed, without over-clad, gratings are nearly humidity insensitive leading to humidity independent temperature sensitivities, whereas gratings with over-clad are humidity sensitive that translates to temperature sensitivities that are also humidity dependent.

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