The impact of relative humidity on transmission properties of CYTOP polymer optical fiber

I. Chapalo,[1] A. Gusarov,[2] Y.-G. Nan,[1] K. Chah,[1] D. Kinet,[1] and P. Mégret[1]

[1] University of Mons, Electromagnetism and Telecom Department, Boulevard Dolez 31, 7000 Mons, Belgium

[2] SCK-CEN, Boeretang 200, 2400 Mol, Belgium

We report on an experimental research of transmission properties of perfluorinated (CYTOP) polymer optical fiber (POF) under different values of relative humidity (RH) in the range from 30 % to 90 %. We compare the case of pristine POF and POF irradiated by gamma radiation with ^{60}Co source up to a dose of 17.5 kGy at a dose rate of 7.5 kGy/h. The latter demonstrated significantly stronger RH sensitivity (≈5 times higher at 1387 nm) and more complex humidity induced attenuation behavior. Additionally, we found that keeping the irradiated POF in an increased RH environment provides partial transmission recovery in the visible range (radiation induced attenuation drop from 17.5 dB/m to 7 dB/m at 600 nm). The experiments were performed using a climatic chamber, and the optical scheme was based on a supercontinuum light source and an optical spectrum analyzer. The results of the work can be useful for development of RH sensors and for understanding the gamma radiation influence on CYTOP fiber.

Introduction

Fiber-optic sensors have been of growing interest for several decades. A wide variety of working principles and applications have been investigated and realized [1]. Recently, particular interest has been shown in polymer optical fibers (POFs) due to such their unique properties as high flexibility, low Young's modulus, simple handling and biomedical compatibility and safety [2-4]. Among POFs, perfluorinated (CYTOP) fibers demonstrate radically low attenuation in telecom transparency windows that made them especially attractive for both telecommunication and sensing [2-3]. Various sensing principles based on CYTOP fiber were proposed and investigated: Fiber Bragg gratings [5-6], Brillouin scattering [7], intermodal interference [8] are examples of them. The impact of ionizing radiation on CYTOP fiber properties is a relevant research topic considering potential data transmission in radiation environment and radiation dosimetry [9-11]. CYTOP fibers properties were investigated after being irradiated by gamma rays and during irradiation [9]. In particular, the influence of relative humidity (RH) was examined in [9] as well; higher sensitivity to RH was reported for irradiated fiber comparing to pristine one that is attractive for the RH sensing.

In this work, we investigate the influence of relative humidity on CYTOP fiber attenuation spectrum in detail. We compare the cases of a pristine fiber sample and a sample irradiated by gamma radiation up to 17.5 kGy at 7.5 kGy/h dose rate. In particular, we show two spectral zones sensitive to RH for pristine fiber. We demonstrate the humidity induced attenuation spectrum changes after irradiation, and we show partial recovery of transmission properties of irradiated fibers under exposition by increased RH.

Experimental setup

To measure fiber transmission in a wide range, we utilized a supercontinuum broadband source (BS) NKT SuperK Compact 450-2400 nm and an optical spectrum analyzer (OSA) Yokogawa AQ6374 350-1750 nm (Fig. 1). The BS was equipped with a "U-bench" with collimating optics and FC/APC connectors to avoid mechanical contact and possible damage of delicate PCF-fiber patchcord serving as a BS output. The POF (Chromis GigaPOF-50SR with 50 µm core and 490 µm overclad diameters) was connectorized using FC/PC bare fiber terminators with a ferrule diameter of 500 µm (Thorlabs) and connected to silica MMF patchcords at the input and the output sides. POF ends were prepared using a razor POF cutter (FiberFin) and cleaned by alcohol. Light from the BS was introduced to the POF using FC/APC to FC/PC 50/125 graded-index (GI) 1-m silica patchcord followed by 70-m 50/125 GI silica MMF. The long MMF section was used to reduce the influence of intermodal interference on the quality of the transmission spectrum measured by the OSA.

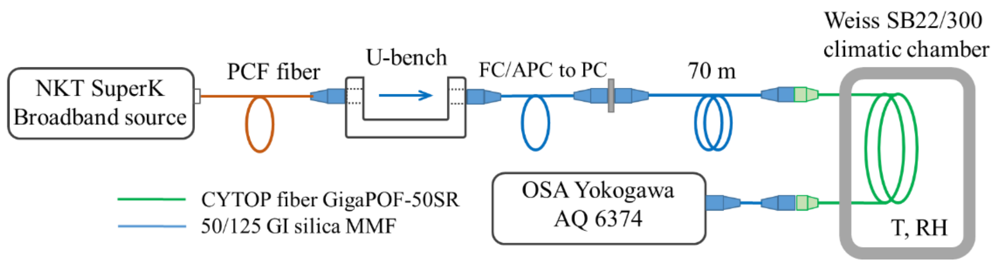

Fig. 1 Schematic of the experimental setup.

The POF samples were placed into the climatic chamber Weiss SB22/300. Only small parts of the fiber near connectors were outside the chamber (~5cm from each side). We measured temperature and RH by internal chamber's sensors and by additional external temperature and RH sensor unit Thorlabs TSP01 for greater reliability.

We investigated pristine POF sample (23 m length) and a sample that received 17.5 kGy gamma radiation dose (2-m length). The fiber was irradiated at the Brigitte facility (SCK-CEN, Belgium) based on ^{60}Co irradiation sources at a 7.5 kGy/h dose-rate. Irradiated POF was stored at uncontrolled laboratory conditions during several months for the radiation induced attenuation (RIA) stabilization.

Experimental results

Firstly, we performed an RH cycle with the pristine POF sample. The cycle contained four RH levels from 30 % to 90 % with a step of 20 % at 25 ^{0}C temperature. We experimentally found that the time required for the transmission spectrum stabilization after changing the RH level by 20 % must be at least 2 hours, therefore we chose the stabilization duration of 4.5 hours for each RH level for greater reliability.

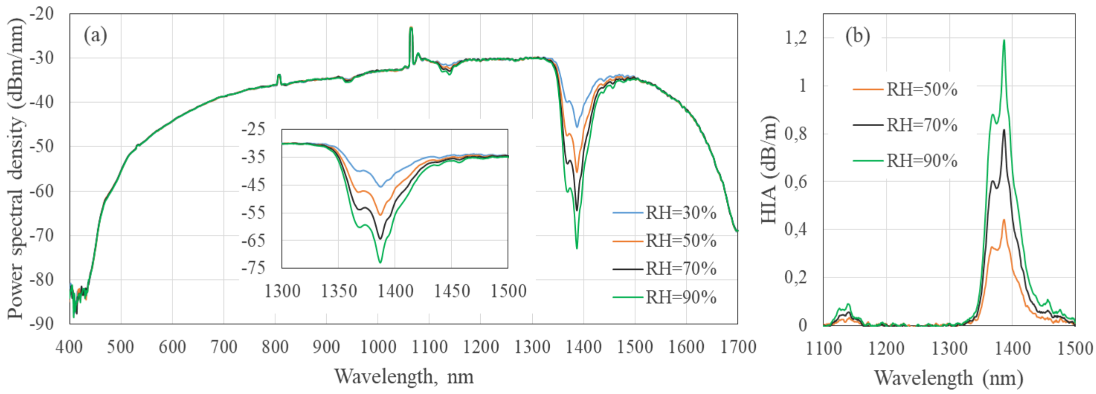

Fig. 2 Transmission spectra of 23-m CYTOP fiber sample at different RH levels (a); HIA calculated relatively 30 %RH level (b).

Fig. 2 (a) demonstrates transmission spectra recorded at different RH levels after each stabilization step. It is seen that the fiber transmission is sensitive to RH in the vicinity of 1380 nm that corresponds to (OH) absorption spectrum in optical fibers. The maximum sensitivity was observed at 1387 nm (0.0187 (dB/m)/%RH). We also observed very weak RH sensitivity zone with a peak of 1139 nm (≈0.0014 (dB/m)/%RH that is approximately 13 times less than 1387 nm case). The rest of the transmission spectral range showed no sensitivity to RH. In Fig. 2(b), we plot the graph of a humidity induced attenuation (HIA) according to the formula HIA [dB/m] = (S_{ref} [dBm] – S [dBm]) / L, where S_{ref} is the reference spectrum recorded at RH=30% (this value was chosen as the minimum RH in experiments), S is the spectrum recorded at given RH level, L is the POF length. Two zones of RH sensitivity are clearly seen.

It is common to characterize transmission changes of irradiated fibers in terms of radiation induced attenuation (RIA) [12]. CYTOP fibers have two spectral ranges of strong RIA: visible with the beginning of infrared, inherent for various fiber types, and the range around 1400 nm containing three sharp attenuation peaks [9]. For easier comparison of the RIA and the HIA, we plot the RIA graphs at different RH levels (Fig. 3(a)) and then the HIA graphs (Fig. 3(b)).

The RIA peaks in the infrared are observed at 1395 nm, 1417 nm and 1440 nm wavelengths. According to Fig. 3(a), the attenuation increases with RH in the range above 1300 nm. Besides, the amplitude of the strongest RIA peak (1440 nm) almost does not change under the RH variations. From Fig. 3(b), we found the wavelength of maximum sensitivity to RH (1393 nm), which is slightly red shifted (by 6 nm) comparing to the pristine POF, and almost matched to the left RIA peak of 1395 nm. The sharp dip of the HIA corresponds to the stable RIA peak of 1440 nm. We calculated the RH sensitivity at 1387 nm to be 0.0984 (dB/m)/%RH that is 5.3 times stronger comparing to pristine POF; the maximum RH sensitivity is calculated to be 0.1125 (dB/m)/%RH at 1393 nm. Unlike it is presented in the work [9], we did not observe two HIA dips: only the 1440 nm dip is present in Fig. 3(b). It is interesting to note, that the 1440 nm dip takes even negative values, i.e. attenuation slightly decreases with an increase of RH.

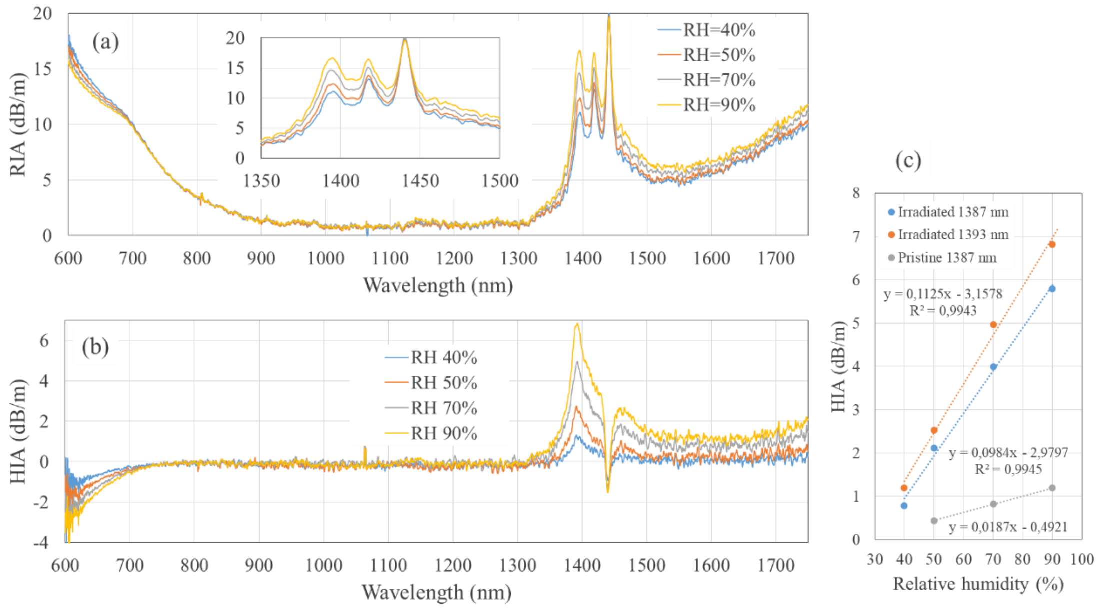

Fig. 3 Radiation induced attenuation of CYTOP fiber received 17.5 kGy dose of gamma radiation for different levels of relative humidity (a); humidity induced attenuation (b); Peak HIA versus relative humidity for pristine and irradiated POF (c).

In Fig. 3(c), we plot HIA vs. RH for irradiated and pristine POFs for easier comparison of sensitivities and forms of dependencies.

It is also seen in Fig. 3 (a,b) that the RIA decreases with RH increase in the visible spectral range, and this process did not demonstrate reversibility. We kept the POF sample under increased RH (≈70% average value) during 100 hours and obtained more than 10 dB/m RIA reduction at 600 nm. This effect can be prospective for CYTOP fiber transmission recovery after being irradiated by gamma rays. We note that unlike RH, keeping the fiber under increased temperature did not show changes in RIA in the visible range.

Conclusion

We experimentally investigated the influence of relative humidity on transmission properties of CYTOP fiber. Pristine POF demonstrated humidity induced attenuation in the vicinity of 1380 nm with maximum sensitivity at 1387 nm, and a zone around 1139 nm, however, with very weak RH sensitivity. The POF sample received a gamma radiation dose of 17.5 kGy is 5.3-times more sensitive to RH and has more complex HIA spectrum in 1400 nm range having an almost not sensitive to RH zone. Continuous fiber exposure under increased RH demonstrated significant RIA reduction in the visible that can be used for the transmission recovery of POFs irradiated by gamma radiation. Obtained results clarify CYTOP fiber behavior under various RH conditions and seem prospective for RH sensing applications.

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