# Chirped mPOF Bragg grating for strain sensing

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**Abstract:** We demonstrate a chirped microstructured polymer fiber Bragg grating based on taper technology for strain sensing application. The effective bandwidth of the grating is dependent on strain and remains practically constant irrespective of humidity changes. Besides wavelength shift measurement in temperature and humidity stable conditions with 9.02 pm/με sensitivity, faster measurements under humidity fluctuations condition can be done by measuring the effective bandwidth of the grating. © 2018 The Author(s)

**OCIS codes:** (060.3738) Fiber Bragg grating, photosensitivity; (060.2370) Fiber optics sensors.

## 1. Introduction

Polymer optical fiber Bragg gratings (POFBG) are receiving greater attention during the last years due to their main benefits including their low Young's modulus, higher thermo-optic coefficient and large elastic strain limit. Previously demonstrated POFBGs can be used as sensors to detect strain [1], humidity [2], temperature [1], ultrasound [3] and fuel level [4]. POFBGs have been reported for strain measurement [1] by monitoring the shift of the resonant wavelength with a good response. Actually, not only strain but also temperature and humidity cause a central wavelength shift. This is a serious problem for poly (methyl methacrylate) (PMMA) POFBGs sensing applications which might be overcome by using other polymer materials such as TOPAS [5]. This material has a humidity sensitivity of less than 0.59±0.02 pm/% at 1568 nm, which is more than 50 times less than PMMA POFBGs. However, PMMA is the most widely used polymer and still the preferred material for POFs. At the same time, the center wavelength of the TOPAS and PMMA POFBGs are sensitive to temperature with similar sensitivities, this is a major problem for static strain sensing, in particular when temperature varies [6].

POFBGs can be used as humidity sensors. *W. Zhang* et al [2] investigated the time response of PMMA POF grating based humidity sensors with different diameters and demonstrated that the response was about 53 min with 150 μm diameter POF whereas the shortest response time is 12 minutes when a reduced diameter of 135 μm is employed. This response time limits the applications of POFBG for humidity sensing also for strain and temperature sensing in variable humidity condition environments due to the slow water absorption of PMMA material.

A dual FBG structure has been also proposed to avoid the effect of temperature and humidity fluctuation [6]. A second closely spaced and strain free FBG with a different resonance wavelength for an independent control of the temperature was required. Actually, the humidity furcation effect on the central wavelength shift of the grating under strain is different when compared with strain free FBG [2] - also here an additional grating is needed for compensation.

Tapered chirped fiber Bragg gratings (CFBGs) in silica fibers were already demonstrated for strain sensing [7]. In these gratings, the bandwidth of the grating changes with strain due to the tapered structure, but remains insensitive to humidity and temperature changes.

In this paper, we present a strain sensing method based on mPOF tapered CFBG, which combines the benefit of tapered chirped Bragg grating and POF material. A high wavelength shift sensitivity with strain is obtained compared with uniform FBG and quick measurements can be obtained by means of the bandwidth measurement with low humidity sensitivity, which makes such gratings suitable for use in variable humidity environment.

## 2. Experimental Setup

Endlessly single-mode BDK-doped PMMA mPOF [8] was produced by using the selected center hole doping technique. In order to remove any residual stress incurred during the drawing process, the fiber was pre-annealed at 70 ℃ for 12 hours. Then, a 20 cm long fiber sample was cleaved with a portable cleaver [9] and polished with sand paper to enhance the quality of the end face. Prior to inscription, the fiber section was immersed in acetone while the fiber was moved by the proper control of a programmable moving stage to obtain the desired taper profile shown in Fig. 1 a).

A chirped POFBG (CPOFBG) was inscribed in this fiber by using the phase mask method and a single 15 ns pulse from a 2.5mJ pulsed Coherent Bragg Star Industrial-LN krypton fluoride (KrF) excimer laser operating at 248 nm. The reflected amplitude spectrum of the fabricated grating is shown in Fig. 1 b).

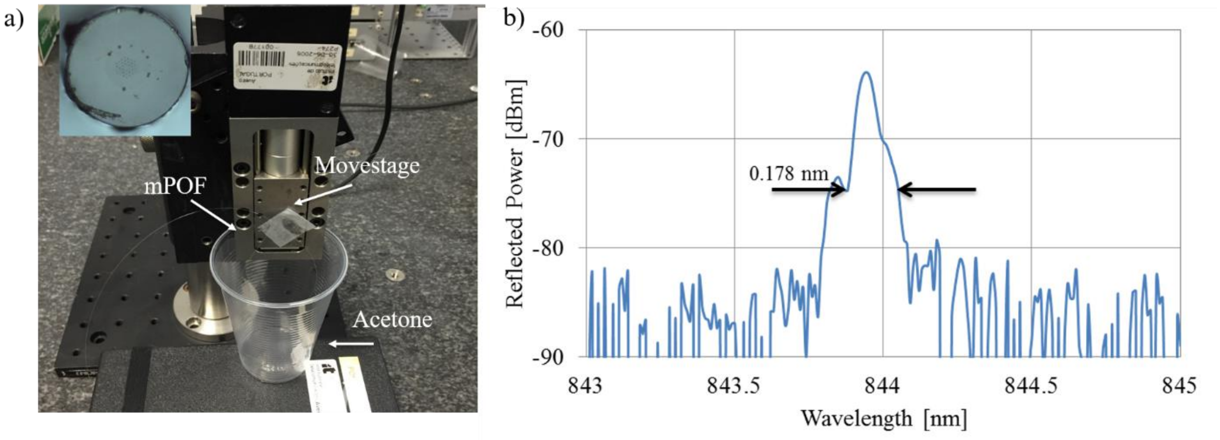

Fig.1. a) Taper setup for mPOF; Inset: end face of mPOF; b) Grating obtained with one pulse KrF laser.

The strain sensitivity of this FBG was then tested using the setup depicted in Fig. 2. The fiber was fixed with epoxy on the flexure stage accessories avoiding sliding. Axial strain was applied to the fiber through longitudinal displacement controlled by a 3D translation stage. The FBG reflected spectrum was monitored using a super luminescent diode (Superlum SLD-371-HP1) and an optical spectrum analyzer (Yokogawa AQ6373B) with 0.02 nm spectral resolution.

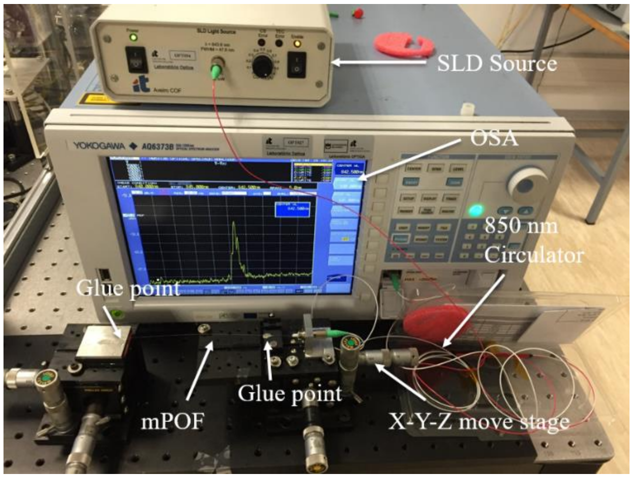

Fig. 2. Strain measurement setup.

## 3. Results Analysis

Experiments were conducted in room environment (almost stable temperature 22 ℃ and humidity 60 %). Fig. 3 a) shows the reflected power spectrum by the grating under strain. A 12.62 cm long POF section was stretched so that strain was applied on the grating with 20 μm step, which made the central bandwidth of the grating shift to longer wavelength, as shown in Fig. 3 a). Fig. 3 b) indicates that the central wavelength of the grating increases with strain, the strain sensitivity of grating is obtained as 9.02 pm/με, which is higher than the corresponding value of uniform POFBG due to the high taper etch of the fiber, as explained by *A. Pospori et al* [10]. Fig. 3 c) shows the bandwidth of the grating increase with strain, this can be used to measure strain instead of measuring the central wavelength of the grating, with the added value to avoid any humidity sensitivity.

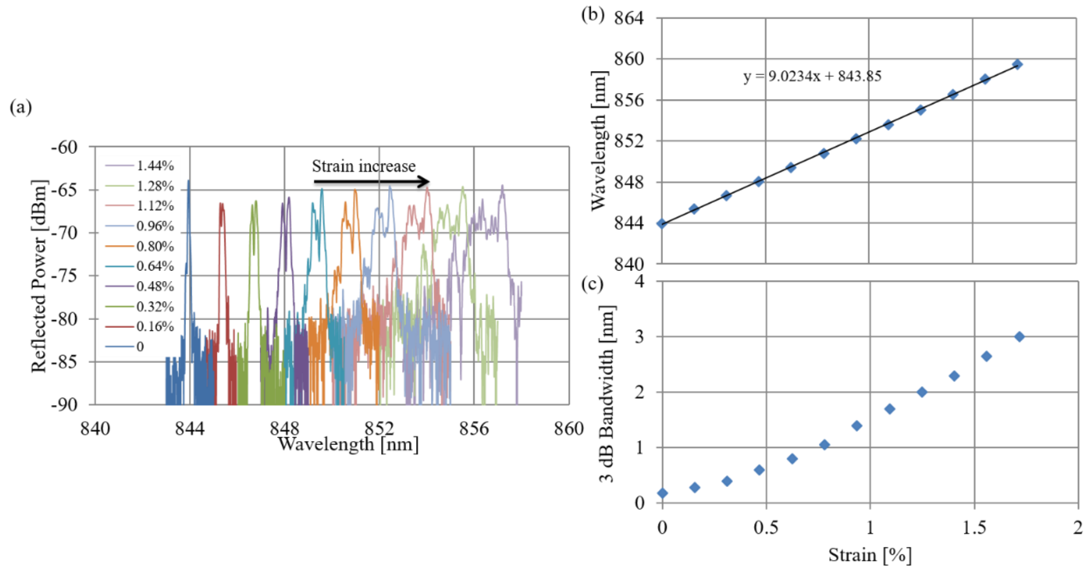

Fig. 3 a) Reflected spectrum vs strain; b) Wavelength shift vs strain; c) 3dB bandwidth vs strain.

Humidity is a major problem for POFBG strain sensing in practical applications. During the experiment described in the following, the grating was left at a constant temperature of 22 ℃ and no strain was applied. Fig. 4 a) shows the central wavelength stabilization curve when humidity was changed from 60% to 30% where the stability was achieved after 60 min. Fig. 4 b) indicates the resulting curve when humidity conditions of the grating have been changed from 30 % to 90 % and 100 min are required until observing stability. The humidity sensitivity of the grating is 34±0.4 pm/%, similar to the values obtained by *C. Zhang et al* [11] but indeed, the response time is slow for practical applications. Fig. 4 c) depicts the reflected spectral optical power of the grating under 30 % humidity, during humidity change and at 90 % humidity and we can notice that the 3 dB bandwidth is not dependent on humidity in fig. 4 d).

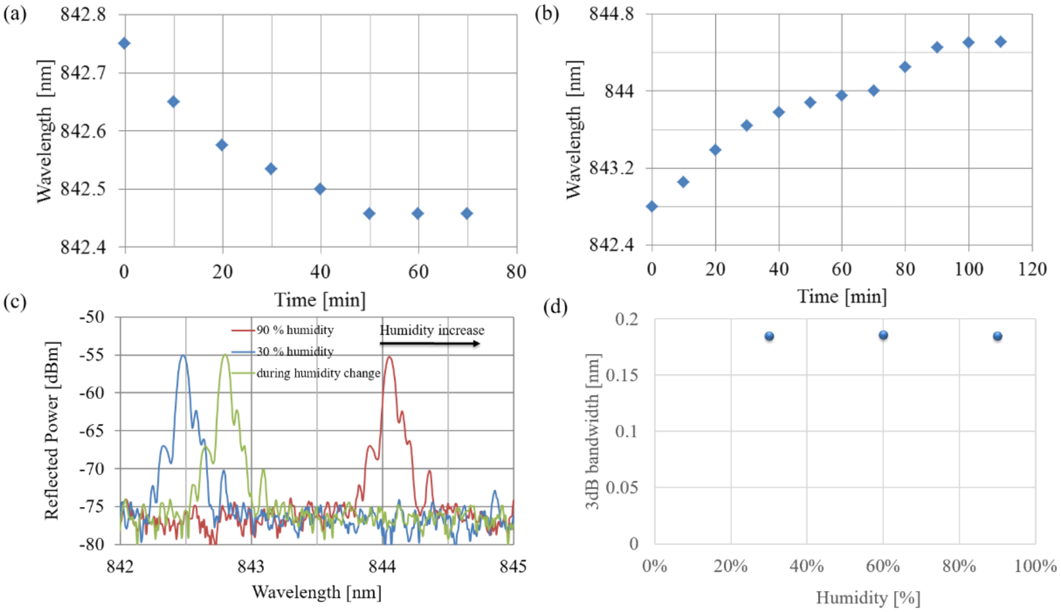

Fig. 4 a) Wavelength vs time under humidity change from 60% to 30%; b) Wavelength vs time under humidity change from 30% to 90%; c) Reflection spectrum vs wavelength under humidity change; d) 3 dB bandwidth vs humidity change from 30% to 90%.

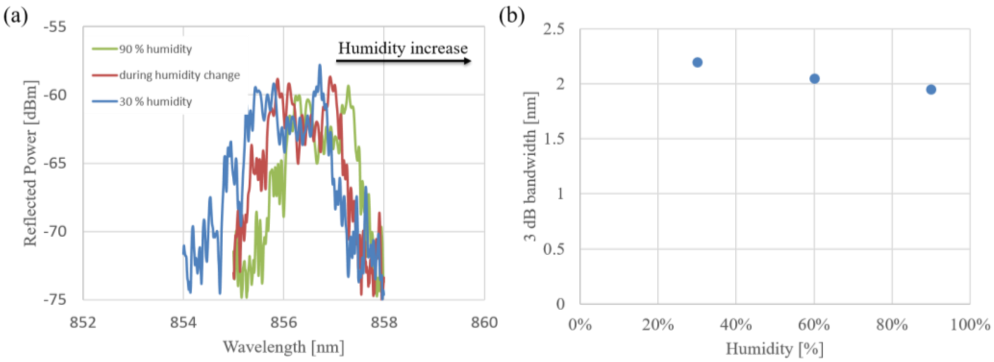

Fig. 5 a) Reflection spectrum vs wavelength under humidity change, b) 3 dB bandwidth vs humidity change from 30% to 90%.

Fig. 5 a) displays the reflected amplitude spectrum of the grating under 30 % humidity, during humidity change and 90 % humidity for a grating subject to an axial strain of 1.25 %. The humidity sensitivity of the grating is 11.7 ±0.4 pm/% under 1.25% strain condition, hence a bit lower when compared with no strain condition. A similar performance is explained as a reduced swelling coefficient in the fiber under strain when compared with the fiber under no strain condition [12]. We found under high strain condition, with 60 % humidity fluctuation, that the 3 dB bandwidth decreases with humidity increases and a sensitivity about -4.2 ±0.4 pm/% is obtained from fig. 5 b), where this sensitivity is lower than measuring the central wavelength shift. As known from [8], tapered CFBGs in silica fiber for strain sensing are completely insensitive to humidity. Our results showed a similar performance where CPOFBG is strain free. However, under high stain condition, the performance of CPOFBGs is different. It means that the bandwidth decreases with humidity increases and we attribute this different performance in CPOFBG to the absorption of water in the material.

## 4. Conclusion

We demonstrated that CPOFBGs could be used for strain sensing, where a high sensitivity 9.02 pm/με could be obtained with wavelength shift measurement due to the taper technology. At the same time, a fast measurement could be obtained by the benefit of the effective bandwidth change with strain, which is almost insensitive to humidity when the fiber is under no strain and a low humidity sensitivity performance around -4.2 ±0.4 pm/% was achieved at high strain condition. The grating response time is significantly improved by measuring the effective bandwidth, which we consider to be a significant improvement for future commercial strain sensing applications of POFBGs under different humidity conditions.

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