Half-coated Tilted Fiber Bragg Gratings for Refractive Index Measurement

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Abstract

Tilted fiber Bragg gratings (TFBGs) are known to be accurate refractometers and they have been intensively used for biosensing purposes. In this report, we present an experimental analysis of the effects induced in their transmitted amplitude spectrum by depositing a gold thin film on half part of their cross-section. The transmission amplitude spectra of the obtained structures were collected as the surrounding refractive index (SRI) changed in the range 1.3351 - 1.3369. The half-coated gratings present the potential ability to sense both the volume and the surface refractive index changes, which is interesting in biosensing to enhance the signal-to-noise ratio. The transmission spectrum of half-coated TFBGs is analyzed and the resulting sensitivities are comparable to conventional bare TFBGs and full-coated TFBGs.

Introduction

Fiber Bragg gratings (FBGs) are narrow bandpass and rejection-band filters around the so-called Bragg wavelength that are usually fabricated in ordinary optical fibers. They correspond to a periodic and permanent refractive index modulation along the fiber axis and perpendicular to this. Tilted fiber Bragg gratings (TFBGs) are gratings for which the modulation of the core refractive index is angled with respect to the perpendicular to the fiber axis by a certain tilted angle [1]. In single-mode fibers, a small tilt angle induces a strong coupling from core mode to cladding modes at discrete wavelengths below the Bragg wavelength. TFBGs present multiple narrow-band dips in their transmitted amplitude. Since they propagate near the cladding-surrounding medium interface, the narrow attenuation bands produced by couplings are highly sensitive to environmental parameters, such as temperature, strain, bending and the external refractive index (RI) and thus can be used for demodulation purpose [2]. When the environment of the TFBGs slightly changes in refractive index, the resonance position of the corresponding cladding modes changes accordingly [3]. The largest resonance shift usually occurs around the cut-off wavelength, which corresponds to the mode whose effective refractive index is the closest to the surrounding refractive index. The cut-off mode of a bare grating can be used for refractometry purpose. This sensitivity can be improved thanks to a metal coating deposited around the fiber cross-section at the TFBG location. This gives birth to the excitation of surface plasmon resonance (SPR).

SPR is a prominent optical phenomenon that involves a resonant transfer of the pumping light energy to a surface-plasmon mode in the form of collective oscillations of electrons in the metal [4]. When the incident light is shined from the optically denser medium (silica) into optically thinner medium (water), total internal reflection will occur and the incident light produces the evanescent wave that penetrates into the thinner medium with the depth of approximately half of the wavelength. Since a thin metal film exists between the silica layer and water environment, the free electrons will be excited by the incident light to form surface plasmon which propagates parallel to the metal surface. As a result, the corresponding cladding mode's energy dramatically decreases due to the transfer of the incident energy to the surface plasmon [5]. Moreover, the polarization is essential to be used to refine the capabilities of the TFBGs. In order to allow this coupling (energy transfer), the incident light must be polarized in the plane of incidence (i.e., TM- or P-polarized) and the metal layer must be thin enough to let some light penetrate. The SPR -TFBG provides an analysis method that is label-free, real-time, rapid, and sensitive. Also, it consumes minimal samples.

In previous works [6,7], refractive index measurements have been obtained with bare TFBGs and gold-coated TFBGs. Both configurations show rapid and sensitive response to a change of aqueous sample's refractive index. But both configurations reveal the total refractive index change, corresponding to changes at the surface and changes in the volume (along the length of the evanescent field penetration). In environmental sensing or biomedical sensing, it is interesting to discriminate both effects as the sensor response is the surface refractive index change, which can be affected by unwanted fluctuations of the refractive index in the volume (that therefore can be considered as noise for the system). This discrimination would definitely increase the signal-to-noise ratio and hopefully avoid drifts that are present when the interrogation accounts for both modifications. Hence, the investigation on half-coated TFBGs is performed in this paper, together with the use of bare and gold-coated TFBGs. Furthermore, in order to find an optimized position of the sensitivity, spectra under multiple polarizations were analyzed.

Manufacturing of half-coated TFBGs

TFBGs were manufactured into hydrogen-loaded single mode fiber SMF28 by means of a pulsed excimer laser at 193 nm. A 1 cm long phase mask was mounted to apply an 8 degrees tilt angle in the plane perpendicular to the incident laser beam. A schematic of phase mask used for grating inscription is shown in the left of Fig. 1.

Fig. 1. Schematic of phase mask and the TFBGs fixed on V-groove for gold deposition.

After the inscription process, the gratings were annealed at 100 °C for 12h to remove the residual hydrogen and to stabilize the grating. They were connected to a red laser source to identify the position and orientation of the gratings. The fiber was rotated until the strongest emitting position at which the gratings were perpendicular to the module's plane. TFBGs were fixed on the V-groove module (schematic shown in right graph of Fig. 1) and then put into the sputtering machine for a ~50 nm gold deposition.

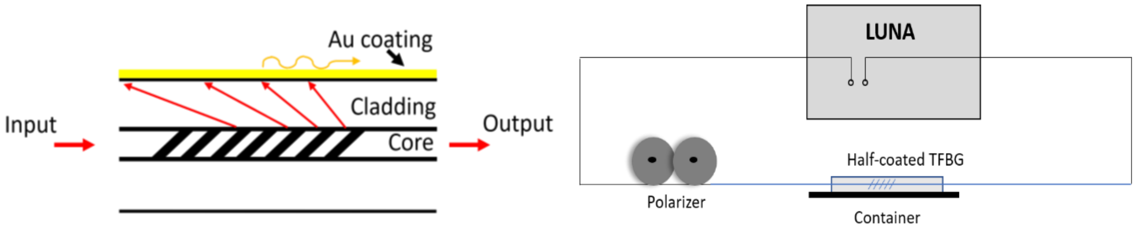
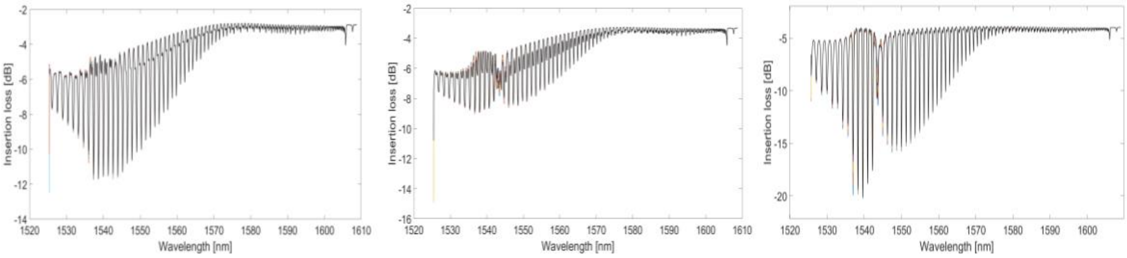


Fig. 2. Schematic of half-coated TFBGs and the experimental set-up

Half-coated TFBGs were connected to a polarizer and an optical vector analyzer LUNA OVA CTe that can provide a broadband light in the range 1525 – 1610 nm and measure the transmission spectrum simultaneously. Gratings were put into a container for aqueous solution measurement and the fiber was well fixed in order to eliminate any unwanted mechanical perturbation. A set of LiCl solutions with a refractive index ranged 1.3351 – 1.3369 was used for measurements. The experimental set-up is shown in Fig. 2. Before starting the measurement, the polarizer was adjusted to reach the maximum transmission amplitude spectrum. It was then rotated by steps of 45° to get 3 relevant polarized spectra.

Experimental results

In this section, we present the experimental results obtained with half-coated TFBGs, as a function of the input polarization state (for some selected values) and as a function of the surrounding refractive index values. In the experiments of RI measurements, we analyzed the transmission spectra for 3 input polarization angles to find the optimized one that has the most sensitive modes. These spectra are shown in Fig. 3.

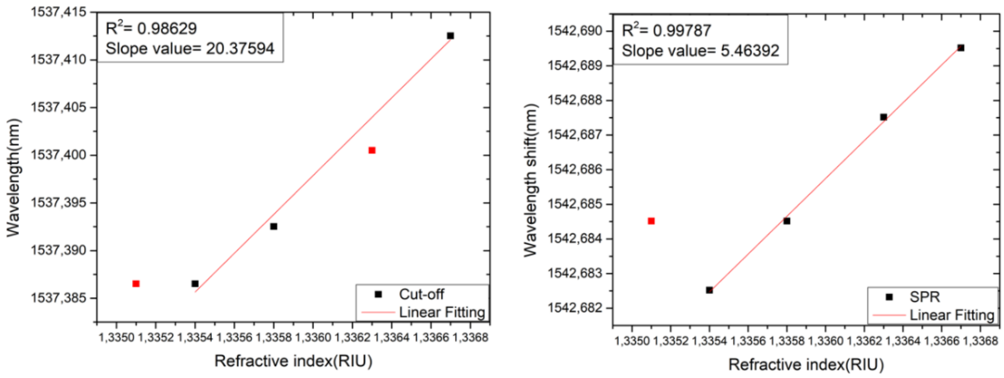


a. s-polarization b. intermediate-polarization c. p-polarization

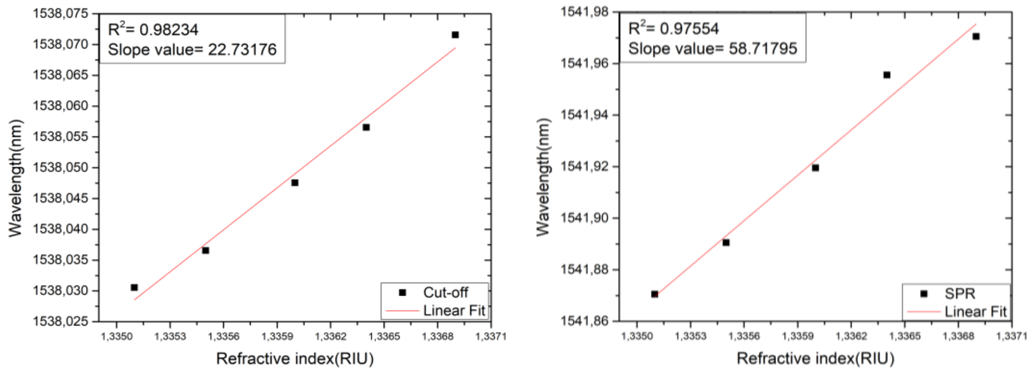
Fig. 3. Spectra in terms of insertion loss at three polarization angles

The graph a in Fig. 3 shows the spectrum of half-coated TFBGs at s-polarization. In the wavelength ranged from 1530nm to 1538nm the peak-to-peak amplitude decrease. But in the wavelength ranged from 1540nm to 1550nm which corresponds to SPR region, there is no peak-to-peak amplitude decrease. For the intermediated-polarization, all the modes in the spectrum decrease dramatically in amplitude and the spectrum appears groups of hybrid modes. When the TFBGs under the p-polarization, the spectrum presents the shrinkage both at wavelength range 1530nm – 1535nm (which corresponds to cut-off region) and 1540nm – 1545 nm (which corresponds to SPR region).

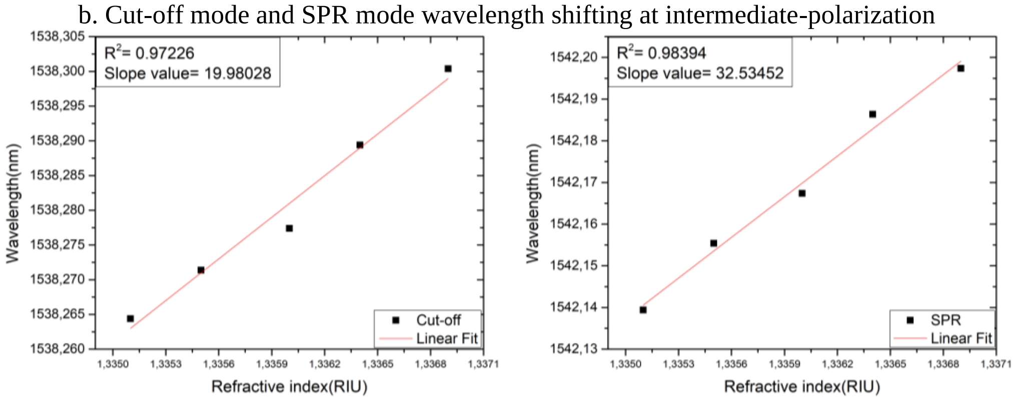
Besides that, we did the linear fitting of the wavelength shift. The obtained results are shown in Fig. 4. The analysis of half-coated TFBGs evolution of RI ranged from 1.3351 to 1.3369 shows high linearity over 97%. The sensitivity of the cut-off mode is around 20 nm/RIU while the sensitivity of the SPR mode reaches in maximum over 50 nm/RIU.



a. Cut-off mode and SPR mode wavelength shifting at s-polarization



b. Cut-off mode and SPR mode wavelength shifting at intermediate-polarization



c. Cut-off mode and SPR mode wavelength shifting at p-polarization

Fig. 4. Linear fitting results of wavelength shifts in corresponds to RI of three polarization angles

Conclusion

The spectral characteristics of half-coated TFBGs have been investigated to verify the interesting perspectives for refractive index sensing. The results showed that the Cut-off mode and SPR mode are visible in their transmission spectrum. This dual sensing mechanism promotes a possibility to measure the bulk refractive index and the surrounding refractive index simultaneously. The sensitivities of the Cut-off and SPR mode are comparable to those of conventional bare and full coated TFBGs, around 20 nm/RIU and 50 nm/RIU, respectively.

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