Polishing Process Analysis for Surface Plasmon Resonance Sensors in D-Shaped Plastic Optical Fibers

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Abstract In this work we want to compare performances of different plasmonic sensors, obtained by different polishing processes of D-shaped Plastic optical fibers (POFs). Three D-shaped POF plasmonic sensor configurations, obtained by three different polishing processes, have been created and experimentally tested. The proposed devices are based on the excitation of surface plasmons at the interface between the under test medium and a thin gold layer directly deposited on plastic fiber core (D-shaped area). The experimental results have shown that the performances are influenced by surface roughness variations in the D-shaped POF region.

Keywords Plasmonic sensors · Plastic optical fiber (POF) · D-shaped POF

1 Introduction

Optical fiber sensors based on surface plasmon resonance (SPR) are today widely proposed for applications in different areas of bio-chemical and chemical sensing [1–4]. Among them, SPR sensors based on plastic optical fibers (POFs) can offer advantages due to their low cost, flexibility, robustness and simplicity of fabrication. Authors reported several bio-chemical applications [5–7] based on an SPR sensor platform in D-shaped POF [8].

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In this work, we compare the optical performances of different hand polished D-shaped POF platforms SPR sensors, in order to establish a mechanical polishing procedure. In particular, three D-shaped POF-SPR sensor configurations, obtained by three different polishing processes, have been created and experimentally tested. In the first case we used only 1 μm polishing paper to obtain the sensor, in the second one only 5 μm polishing paper and, finally, in the last case, we used both 5 μm and 1 μm polishing papers (first 5 μm, then 1 μm).

2 Optical Sensor Configurations

The adopted D-shaped fabrication procedure is based on the insertion of a portion of the POF fiber (about 10 mm long) in a resin support and on a successive hand grinding of the fiber surface. This procedure guarantees an easy and low-cost effective strategy for the removal of the cladding layer in the POF sensing region and for the reduction of the exposed core. In the end, a thin gold film (60 nm thick) can be deposited on the flat hand ground D-shaped POF core, by sputtering process, for exciting SPR resonance at the metal/external medium interface. Figure 1 shows the outline of the D-shaped SPR sensor.

For all three considered platforms, mentioned above, the total depth of the D-shaped POF region and the thickness of the gold film are the same. This analysis is interesting because the performances are influenced by small variations in the morphology of the D-shaped region (i.e. roughness and total depth) resulting from the manual process used for the preparation of the sensor [9, 10].

The proposed devices are characterized by exploiting a halogen lamp (HL–2000–LL, Ocean Optics) to illuminate the optical fiber sensor, observing the transmitted spectra by a spectrometer (FLAME-S-VIS-NIR-ES, Ocean Optics) and normalized to the spectrum transmitted when the outer medium is air [8].

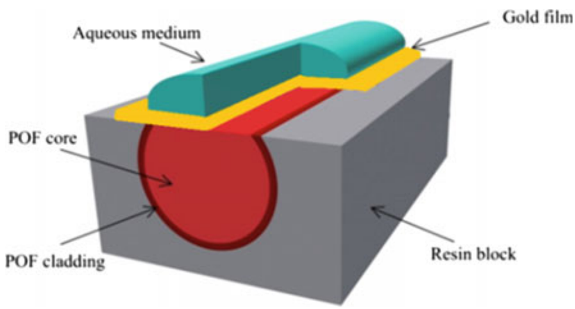

Fig. 1 Outline of the SPR sensor based on a D-shaped POF

3 Experimental Results

Figures 2, 3 and 4 report, for the three different D-shaped sensors, the experimental SPR transmission spectra (normalized to the spectrum recorded with air as the surrounding medium) referring to five different water-glycerine solutions, with refractive index ranging from 1.332 to 1.380.

In the first case (Fig. 2) we used only 1 µm polishing paper to obtain the sensor, in the second one (Fig. 3) only 5 µm polishing paper and, finally, in the last case (Fig. 4), we used both 5 µm and 1 µm polishing papers.

The experimental results indicate that the configuration created by both polishing papers (Fig. 4) shows better performances.

Table 1 reports the sensors' sensitivity and the detectable refractive index range, obtained by the slopes of the linear fittings of the data (resonance wavelength shift versus refractive index) obtained by the three different polishing processes. Only in the last case (5 µm and 1 µm polishing papers) the linear fitting is a representative fitting of the data ($R^2 = 0.99$) in all the refractive index range.

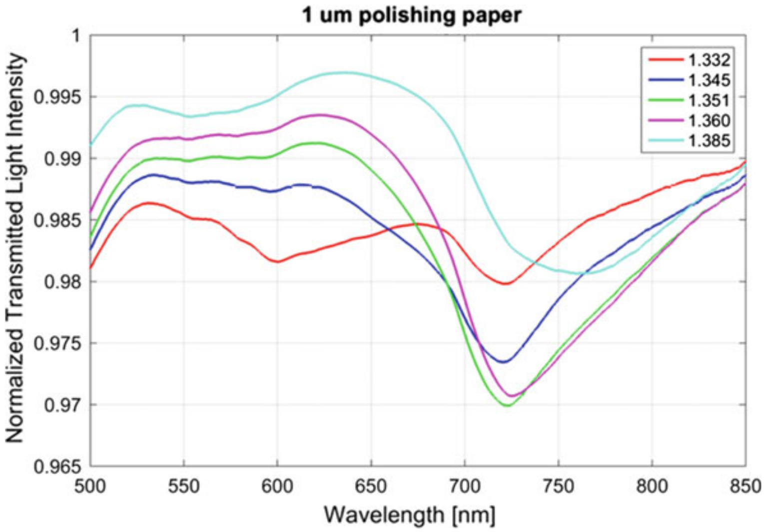

Fig. 2 SPR spectra of the sensor created by 1 µm polishing paper

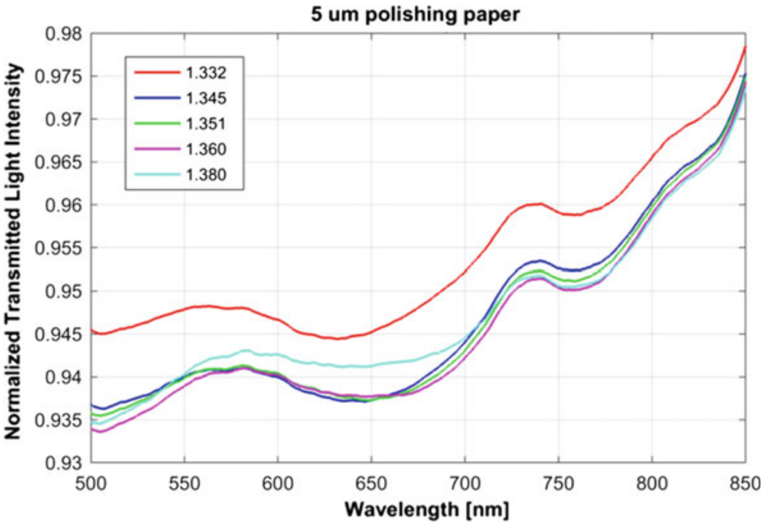

Fig. 3 SPR spectra of the sensor created by 5 μm polishing paper

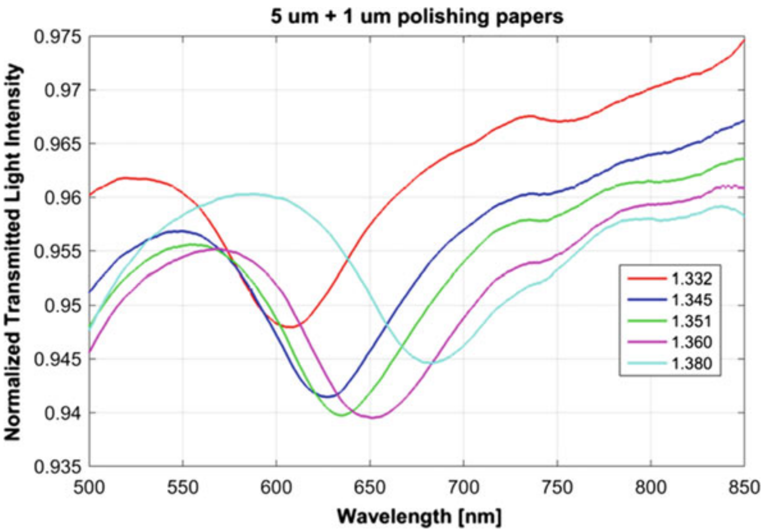

Fig. 4 SPR spectra of the sensor created by 5 μm and 1 μm polishing papers

Table 1 Parameters of the linear fittings of data

Polishing paper	(Slope of linear fitting) $S = \delta\lambda/\delta n_s$ (R^2)	Detectable refractive index range
1 μm	822 [nm/RIU], ($R^2 = 0.78$)	1.35–1.38
5 μm	205 [nm/RIU], ($R^2 = 0.55$)	1.33–1.35
1 μm + 5 μm	1437 [nm/RIU], ($R^2 = 0.99$)	1.33–1.38

4 Conclusions

The experimental results indicate that the configuration created by exploiting both the polishing papers shows better performances. In the future, a mechanical polishing procedure will be set-up starting from these experimental results.

References

1. Homola, J.: Present and future of surface plasmon resonance biosensors. Anal. Bioanal. Chem. **377**, 528–539 (2003)
2. Sharma, K.A., Jha, R., Gupta, B.D.: Fiber-optic sensors based on surface plasmon resonance: a comprehensive review. IEEE Sens. J. **7**, 1118–1129 (2007)
3. Homola, J., Yee, S.S., Gauglitz, G.: Surface plasmon resonance sensors: review. Sens. and Actuators B Chem. **54**, 3–15 (1999)
4. Wang, X.D., Wolfbeis, O.S.: Fiber-optic chemical sensors and biosensors (2013–2015). Anal. Chem. **88**, 203–227 (2016)
5. Cennamo, N., Varriale, A., Pennacchio, A., Staiano, M., Massarotti, D., Zeni, L., D'Auria, S.: An innovative plastic optical fiber-based biosensor for new bio/applications. The case of celiac disease. Sens. Actuators B Chem. **176**, 1008–1014 (2013)
6. Aray, A., Chiavaioli, F., Arjmand, M., Trono, C., Tombelli, S., Giannetti, A., Cennamo, N., Soltanolkotabi, M., Zeni, L., Baldini, F.: SPR-based plastic optical fibre biosensor for the detection of C-reactive protein in serum. J. Biophotonics **9**(10), 1077–1084 (2016)
7. Cennamo, N., Alberti, G., Pesavento, M., D'Agostino, G., Quattrini, F., Biesuz, R., Zeni, L.: A simple small size and low cost sensor based on surface plasmon resonance for selective detection of Fe(III). Sensors **14**, 4657–4671 (2014)
8. Cennamo, N., Massarotti, D., Conte, L., Zeni, L.: Low cost sensors based on SPR in a plastic optical fiber for biosensor implementation. Sensors **11**(12), 11752–11760 (2011)
9. Gasior, K., Martynkien, T., Urbanczyk, W.: Effect of constructional parameters on the performance of a surface plasmon resonance sensor based on a multimode polymer optical fiber. Appl. Opt. **53**(35), 8167–8174 (2014)
10. Gasior, K., Martynkien, T., Wojcik, G., Mergo, P., Urbanczyk, W.: D-shape polymer optical fibres for surface plasmon resonance sensing. Opto-Electron. Rev. **25**, 1–5 (2017)