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Realization of Enhanced Evanescent Field Long Period Fiber Grating Near Turn around Point for Label-Free Immunosensing †

Tanoy Kumar Dey [1], Sara Tombelli [2], Palas Biswas [1], Ambra Giannetti [2], Nandini Basumallick [1], Francesco Baldini [2], Somnath Bandyopadhyay [1,*] and Cosimo Trono [2,*]

[1] Fiber Optics & Photonics Division, CSIR—Central Glass & Ceramic Research Institute, 196 Raja S. C. Mullick Road, Kolkata 700032, India; tanoykumardey@gmail.com (T.K.D.); palas@cgcri.res.in (P.B.); nandini_b@cgcri.res.in (N.B.)

[2] Institute of Applied Physics "Nello Carrar", CNR-IFAC, Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy; s.tombelli@ifac.cnr.it (S.T.); a.giannetti@ifac.cnr.it (A.G.); f.baldini@ifac.cnr.it (F.B.)

* Correspondence: somnath@cgcri.res.in (S.B.); c.trono@ifac.cnr.it (C.T.)

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Abstract: A Long period Fiber Grating (LPFG) with maximum enhancement of evanescent field has been designed and fabricated, along with theoretical modeling, by working near the turn-around point (TAP) of lowest order symmetric cladding mode ($LP_{0,2}$ cladding mode). The LPFG was fabricated using a point by point inscription technique and it was characterized in term of surrounding refractive index (SRI) within the range of 1.333 to 1.3335 using a thermostated flow-cell. This closed cell, made of poly(methyl methacrylate) (PMMA), was designed for better handling of the sensor, because during the fabrication process the diameter of the LPFG was reduced up to ~20 μm by chemical etching, for the maximum enhancement of the evanescent field. The sensitivity of dual peak resonance of the $LP_{0,2}$ cladding mode near TAP was measured and resulted to be ~8751 nm/SRIU with a resolution of the order of 10^{-5} RIU. The sensor was further used for the label-free immunosensing application by the implementation of Immunoglobulin G (IgG)/ anti-Immunoglobulin G (anti-IgG) bioassay in human serum on the grating region inside the thermostated closed flow cell.

Keywords: long period fiber grating; evanescent field; biosensor

1. Introduction

LPFGs are turning out to be promising bio-chemical sensors for their ability to sense surrounding refractive index (SRI) changes [1–4]. In most of the bio-chemical applications, SRI is ~1.333 [5–7], being the bioanalytes dissolved in aqueous solutions. However, the sensitivity of the sensor in this RI range is not very high [8]. Different methodologies have been developed by the researchers throughout the years to enhance the sensitivity of the sensor, such as operating around mode transition [5,9–12], operating near cladding modes (CMs) TAP [13,14], enhancement of evanescent field of CMs [13,15,16]. Combination of these methodologies has also been developed [17–22]. Recently, it has been shown that by reducing the cladding diameter of a LPFG, a lower order CM (dispersed CM) can be obtained near TAP [18,23]. The dispersed lower order CM becomes more sensitive than the normal higher order CM near TAP due to the enhancement of the evanescent field [18,23]. In this work, enhancement of sensitivity of the LPFG is achieved by the combination of two methodologies: (1) maximum enhancement of the evanescent field and (2) working near the TAP of

a CM. A LPFG is fabricated in 125 μm single mode fiber and the cladding diameter is reduced up to ~21 μm to obtain the lowest order dispersed CM ($LP_{0,2}$) so as to attain the maximum enhancement of the evanescent field and of the TAP of the $LP_{0,2}$ CM. By theoretical modelling, grating period and refractive index modulation is optimised. A closed flow cell is fabricated to analyse the sensitivity of the sensor in order to avoid the problems associated to both fragility and difficult handling. The sensitivity is found out to be 8751 nm/SRIU within the RI range 1.333–1.3335 for the dual peak resonance of $LP_{0,2}$ CM. Moreover, a label free immunoassay using IgG/ anti-IgG interaction was performed using the sensor and the specificity of the sensor was confirmed by a negative control test using human serum.

2. Materials and Methods

2.1. Materials

Hydrofluoric acid (HF), sodium chloride (NaCl), ethanol (EtOH), goat anti-mouse IgG, bovine serum albumin (BSA) and the reagents for phosphate buffer saline (PBS, 0.01 M pH 7.4) preparation, were purchased from Merck Life Science (Milan, Italy). Mouse IgG was from Thermo Fisher Scientific (Milan, Italy). Pooled normal human serum was from HyTest Ltd. (Turku, Finland).

2.2. Methods

The LPFG was fabricated within a Fibercore PS1250/1500 B/Ge co-doped photosensitive fiber with a KrF excimer laser (Lambda Physics Compex 110) by using the point-by-point inscription technique. The period of the LPFG was Λ = 246 μm and the number of grating planes was 123, with a resulting calculated grating length of 30.012 mm. The period was optimized using theoretical modeling in such a way that the left peak of the dual resonance of the $LP_{0,2}$ can be obtained in C band in water medium after cladding diameter reduction. Detailed calculation is shown in our previous work [24]. The LPFG characterization setup was composed of a SLED source (FiberLabs Inc. SLD-1310/1430/1550/1690-10) and an optical spectrum analyzer (OSA; Anritsu MS9030A/9701C). The minimum wavelengths were calculated by fitting the resonant band with a Lorentzian function. The bandwidth was considered from 1300 nm to 1700 nm depending on the SLED source band and on the cut-off wavelength of the used fiber (1209 nm).

After inscription, chemical etching of the fiber was done by dipping it in 20% HF solution; the fiber was kept straight during this process in order to avoid bending induced perturbations caused by the reduced fiber diameter.

For a better handling of the sensor and to eliminate the effect of surrounding temperature fluctuation during the SRI sensitivity measurement and also during immunoassay, the LPFG was inserted inside a thermostated closed flow cell made of poly(methyl methacrylate) (PMMA). Detail of the flow cell and the insertion procedure was described in [24].

SRI sensitivity analysis was performed using NaCl solutions in water (0.0–0.5% *w*/*v*) (RI in the range 1.333 to 1.3335 [25]) and the immunoassay was carried out using mouse IgG/Anti mouse IgG interaction [10]. BSA was used to block the nonspecific adsorption. The specificity of the sensor was confirmed using human serum as negative control. Both the SRI sensitivity analysis and the immunoassay were performed inside the flow cell.

3. Results and Discussion

The LPFG was fabricated by using the procedure described in Section 2.2. The diameter of the etched LPFG was measured to be ~21 μm. The spectra of the LPFG after inscription and after cladding diameter reduction is shown in Figure 1. It was clearly observed that after cladding diameter reduction the left peak of $LP_{0,2}$ CM was generated within C band.

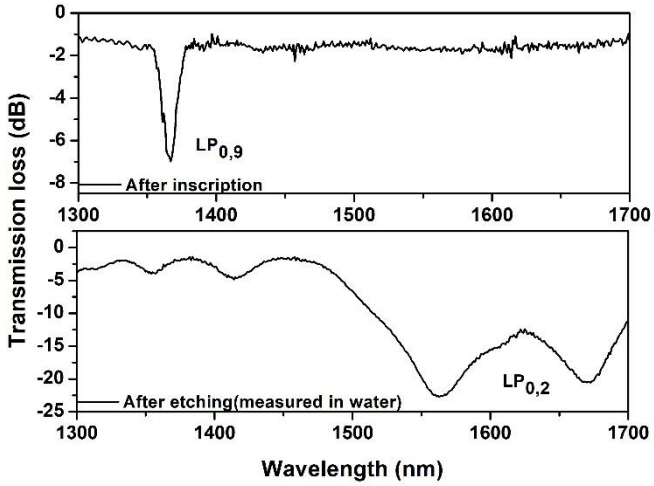

Figure 1. Spectral measurement of LPFG after inscription and after cladding diameter reduction.

The SRI sensitivity analysis was done using the procedure described in Section 2.2 and it was found out to be 8751 nm/SRIU as shown in Figure 2.

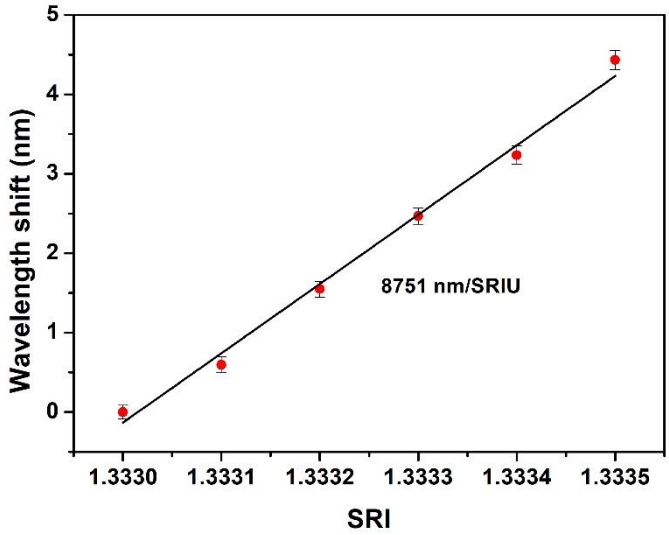

Figure 2. Wavelength shift of dual peak of $LP_{0,2}$ CM near TAP as a function of surrounding refractive index.

To perform the immunoassay, mouse IgG (1000 μg/mL in PBS) was covalently bound on the sensor surface by following the procedure described in [10]. After blocking the non-specific sites on the sensor surface using BSA, a negative control measurement was performed using human serum and then two concentrations of anti-mouse IgG (0.0001 μg/mL and 0.001 μg/mL) were used to carry out the assay. After each step, rinsing with PBS was performed and also every measurement was done in PBS solution. The dual peak resonant wavelength shift due to the exposure of the sensor to different concentrations of anti-mouse IgG is shown in Figure 3.

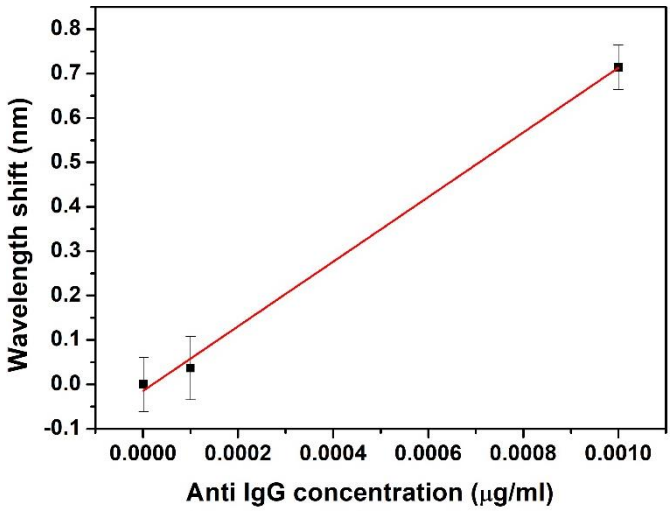

Figure 3. Wavelength shift of dual peak of $LP_{0,2}$ CM at different concentration of anti-IgG.

4. Conclusions

A reduced cladding diameter LPFG sensor was fabricated with maximum enhancement of evanescent field along with the combine effect of the TAP by working with lowest order of symmetric CM ($LP_{0,2}$ CM) near TAP. The sensor was characterized by SRI sensitivity and a label free immunoassay was performed using IgG/ Anti IgG interaction in a closed thermostated flow cell.

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