Enhancement of sensitivity of the refractive index using ITO coating on LPG

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In this paper, an Indium Tin Oxide (ITO) coated LPG (Long Period Grating) refractive index (RI) sensor is experimentally demonstrated. The metal oxide coating is analyzedand optimized with respect to surface morphology and spectroscopic properties.The RI characterization for coated and uncoated LPG using aqueous solutions of glycerol with different concentrations is carried out.Field emission scanning electron microscope (FESEM), Raman spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR) have provided detailed evidence and analysis of attachment of the amalgamation on LPG surface using adapted dip coating methodology. The RI sensitivity of coated LPG is enhanced by a factor 2-3 for the glycerol solution ranging RI from 1.3490 to 1.4198.

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1. Introduction

Refractive index is a fundamental physical property of any substance and its measurement has promising potential in the field of chemistry, biochemistry, process control, pharmaceuticals and biology. The potential of FBG (Fiber Bragg grating) and LPG as refractive index sensor have been explored by various research groups world wide [1-7]. The modification in RI response of LPG occurs when a thin film overlay with higher RI than cladding is deposited on it is due to cladding mode reorganization [8-12]. In this paper, we have experimentally demonstrated the effect of ITO coating on LPG for RI sensitivity enhancement.

2. Working principle

LPG couples the fundamental guided mode to discrete cladding modes resulting in distinct resonance bands in the transmission spectrum.Any change in external RI directly influence the effective index of cladding modes which in turn attenuates phase matching condition. The presence of ITO coating introduced strong changes in the cladding mode distribution. Due to presence of coating, the transition from cladding to overlay modes occurs, the lowest order cladding modes becomes guided into overlay. The higher modes move to recover the original field configuration leading to improvement in SRI sensitivity. This concept is also investigated theoretically. The transverse electrical field component, with azimuthal order ν, propagating along the z axis, is given by [13]:

$$R_\nu(r) = A_0\, Z_{V,1}\left\{u_1 \frac{r}{r_1}\right\} \qquad for\ r \le r_1 \qquad (1)$$

$$= A_1 Z_{V,2}\left\{u_2 \frac{r}{r_2}\right\} + A_2 T_{V,2}\left\{u_2 \frac{r}{r_2}\right\} for\ r_1 < r \le r_2 \qquad (2)$$

$$= A_3 Z_{V,3}\left\{u_3 \frac{r}{r_3}\right\} + A_4 T_{V,3}\left\{u_3 \frac{r}{r_3}\right\} for\ \ r_2 < r \le r_3 \qquad (3)$$

$$= A_5 K_V\left\{v \frac{r}{r_3}\right\} for \qquad r > r_3 \qquad (4)$$

Where $Z_{V,i}(x) = J_V(x) if n_{eff} < n_i$

$= I_V(x) if n_{eff} > n_i$

$T_{V,i}(x) = Y_V(x) if n_{eff} < n_i$

$= K_V(x) if n_{eff} < n_i$

$$u_i = r_i k_0 \sqrt{\left|n_i^2 - n_{eff}^2\right|} for i = 1,2,3$$

$$v = r_3 k_0 \sqrt{\left(n_{eff}^2 - n_{out}^2\right)}$$

where r is the radius, J_V and I_V are the ordinary Bessel functions of first and second kind of order ν and Y_V and K_V are the modified Bessel functions of first and second kind of order ν, respectively. n_1, n_2 and n_3 are the core, cladding and overlay refractive indices, respectively, while n_{out} is the surrounding refractive index and n_{eff} is the effective refractive index. r_1 and $r_2$are the core and cladding radius and r_3-r_2 is the overlay thickness. The set of equations from (1) to (4) represent the approximation required for obtaining transmission, if the ambient refractive index is higher than that of cladding. On applying the boundary condition, field must be continuous along the interface between the each two cylindrical layer as well as the continuity of derivatives of filed should be satisfied at radius r = r_i (i=1, 2, 3). In addition, A_1, A_2, A_3, $A_4$and A_5 can be obtained, as function of A_0, by imposing the continuity of the fields at the interface between core and cladding, cladding and overlay and overlay and surrounding medium while A_0 is related to the optical power of the mode.

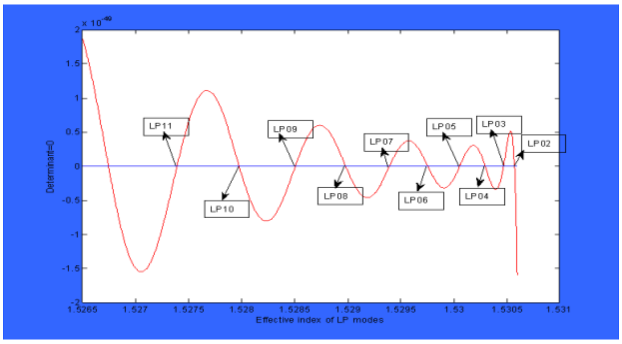


Fig. 1.(a) Cladding modes LP_{02} to LP_{11} without overlay.

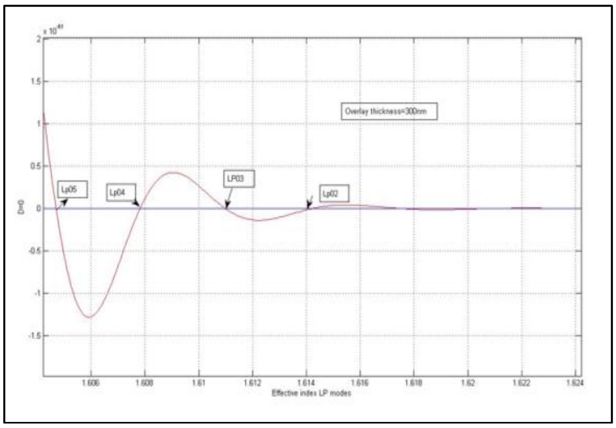


Fig. 1.(b) Cladding modes LP_{02} to LP_{11} with overlay of thickness 300nm and RI=1.67.

In the Fig. 1 (a), the cladding modes LP_{02} to LP_{11} are shown without any overlay. The core and cladding radii are 4.2µm and 62.5µm, refractive indices of 1.5362 &1.5306 respectively. The modes are calculated using couple mode theory. In Fig. 1(b), the shifted position of modes is shown because of the deposition of overlay with refractive index 1.67 and thickness 300 nm on LPG. The cladding mode LP_{02} is shifted to value near 1.618 and accordingly rest of the cladding modes. As if the overlay of higher refractive index is deposited on an LPG, the cladding modes shift their effective index to higher values. When the overlay is thick enough, one of the cladding mode is guided by the overlay. It is exactly the lowest order cladding mode (highest effective index cladding mode) that jumps to the overlay. This causes a reorganization of the effective index of rest of modes. Higher order cladding mode than that is guided by the overlay will shift their effective index value towards the effective index of the immediate lower order cladding mode. The immediate consequence of the shift in effective index is that it leads to a displacement in all attenuation bands.

3. Results and discussion

In our experiment, we fabricated a LPG with a resonant wavelength of 1591 nm and period of 670 µm over a 2.0 cm length of boron co-doped fiber by point-by-point writing method using an excimer KrF UV laser having a pulse repetition rate of 200 Hz, pulse duration of ~ 15 ns and peak pulse energy of ~ 3 mJ. The fabricated LPG was then annealed at 150^0C for 24 hours for thermal stabilization.

To develop a metal oxide coatinga combination of Indium chloride ($InCl_3$) and Tin chloride ($SnCl_{2}.2H_2O$) in the ratio 1:0.2was prepared in 25 ml of ethanol in ultrasonic cleaner and applied on LPG surface using dip coating method.Surface modification was investigated by FESEM (Hitachi S4300 SE/N). Fig. 2 showed the FESEM micrograph of ITO coated LPG.

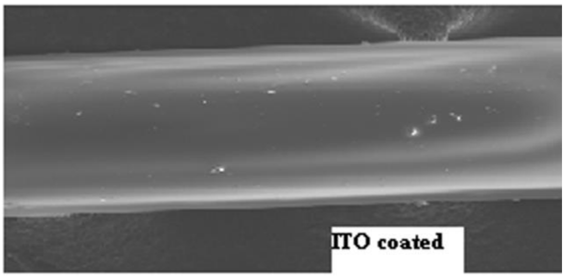


Fig. 2. FESEM micrograph of ITO coated fiber.

FTIR transmission spectrum was acquired from Nicolet iS10 and the results are shown in Fig 3. The spectrum revealed several peaks, which can be described to vibration modes of different bonds in the ITO film. The peaks situated at 419 cm^{-1} and 561 cm^{-1}confirms the existence of In-O-In bonding. Also, the Sn-O-Sn bonds are evidenced by the peak situated at 618 cm^{-1} and the large peak situated at 1118 cm^{-1} is given by the Si-O-Si vibration at the interface of fiber and film [14]. The Raman spectroscopy was analysed by using Invia Raman, (Renishaw). The Fig. 4 showed the peaks at 862.7 and 1261 cm^{-1}in accordance with the signature intensity pattern of ITO due to band gap of ITO and two-phonon process respectively [15].

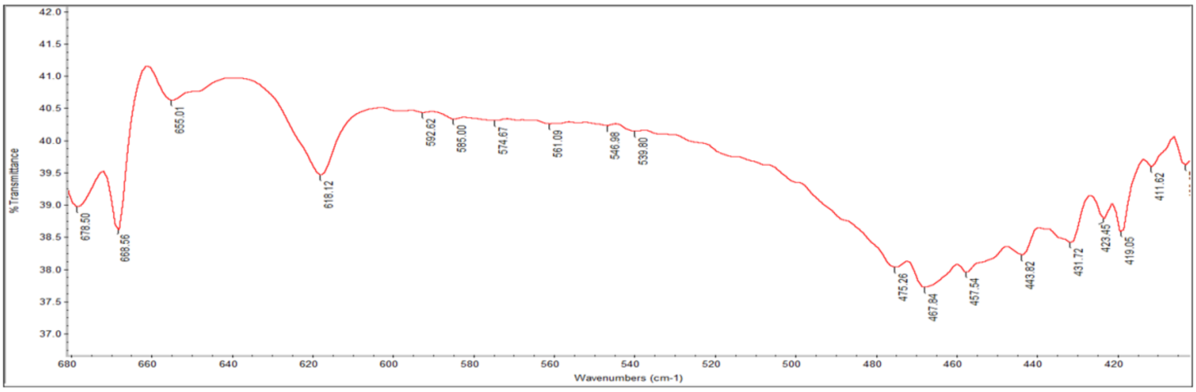


Fig. 3. FTIR spectrum of ITO coated LPG.

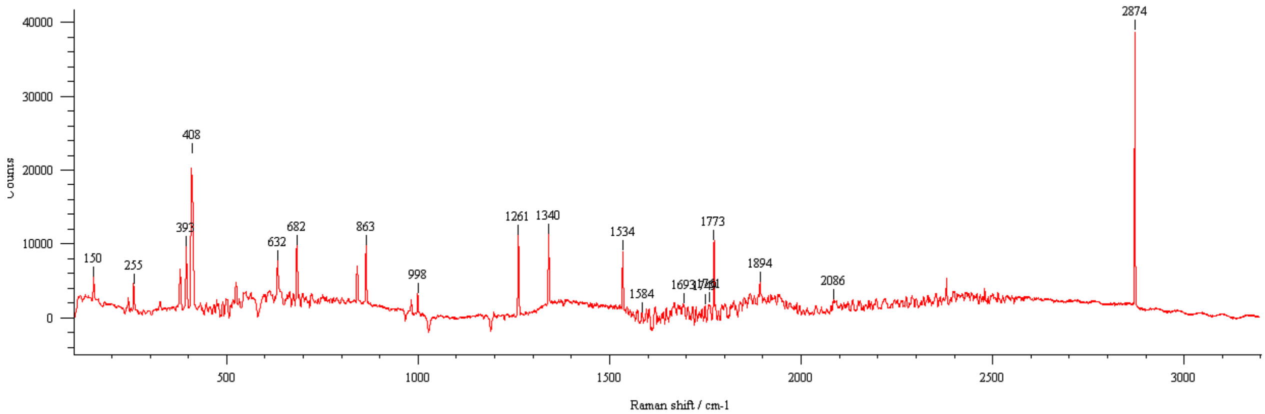
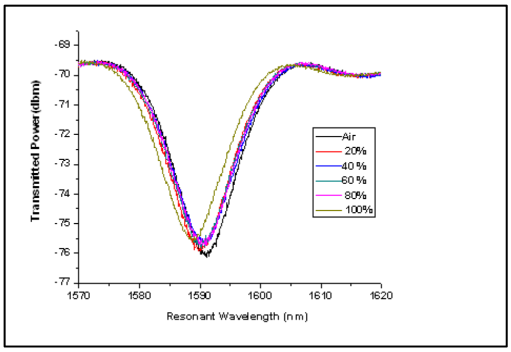
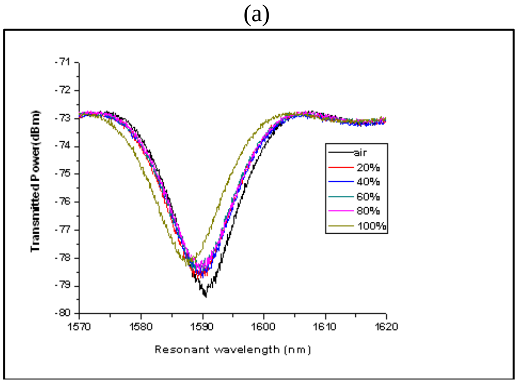


Fig. 4. Raman Spectroscopy results of ITO coated LPG.

For refractive index sensitivity analysis, transmission spectrum of both uncoated and coated LPG was monitored firstly with standard liquids(Cargille Labs) of different RI values (1, 1.45, 1.454 and 1.458). A broadband light source(AQ4305, Ando Electric Co. Ltd)connected to one end of the LPG and an optical spectrum analyser (OSA) to the otherwith level resolution 0.01dBm and wavelength resolution of 0.1nm (Yokogawa, AQ6319, Ando electric Co. Ltd) to monitor the transmission spectrum.Experiment with glycerol solution of different concentrations (20-80%) was performed. The RI values of different concentration of glycerol solution were measured by using BS-RFM 840 Refractometer giving sensing region with refractive indices from 1.3490 to 1.4198. We observed that the coated LPG is 2-3 times more sensitive than uncoated LPG in our case.This factor can be higher for lesser value of grating period. We have done the experiment for comparatively high value of grating period. The spectral response with different concentrations of glycerol was shown in the Fig. 5.(a) & 5(b).



(a)



(b)

Fig. 5.(a) Spectral response of (a) uncoated LPG (b) ITO coated LPG with different concentrations of glycerol.

The enhancement in the sensitivity is due to shifting and rearrangement of modes due to high RI i.e 1.8 of ITO.The sensitivity of LPG sensor to external index of refraction is governed by [16]

$$\frac{d\lambda_{res}}{dn_{sur}} = \lambda_{res}.\gamma.\Gamma_{sur} \quad (6)$$

Where γ is the waveguide dispersion and Γ_{sur} is the surrounding RI dependency of the waveguide dispersion. The value of γ for cladding modes m<8 remains positive [15]. This condition was satisfied for our fabricated LPG which was calculated by OptiGrating 4.2.2 software .The value ofΓ_{sur} is –ve and contains imaginary part for $n_{sur}>n_{cl}$. This is true in our case as the RI of the solution used to deposit the overlay found to be 1.8 using refractometry. This confirms the obtained blue shift.

4. Conclusion

This research illustrates the enhancement in the refractive index sensitivity of long period grating. A very simple, easyapproach has been used for RI sensitivity enhancement.The process like SEM, FTIR and Raman spectroscopy has given us a better understanding of coating structure and thickness. This approach has certainly gives a better understanding about the coated LPG behavior.

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