Sensitivity Analysis of a Dispersed Clad Mode to Surrounding Refractive Index

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Abstract— **The sensitivity of a specific dispersed clad mode and a normal clad mode of a Long Period Grating (LPG) near Turn Around Point (TAP) to surrounding refractive index in the range of 1.3332 – 1.3348 has been studied experimentally. We could attain a sensitivity of ~2413 nm/RIU using $LP_{0,11}$ dispersed clad mode of a TAP-LPG with ~3dB attenuation at resonance.**

I. INTRODUCTION

In recent years Long Period Grating (LPG) sensors attain great interest among the researchers in bio-sensing applications [1]. The key merit function has found to be its sensitivity to surrounding refractive Index (SRI). Throughout last decade different techniques have been adopted to enhance the sensitivity of the conventional LPGs. Reduction of the fiber diameter [2], deposition of the overlay of high refractive index material on the fiber surface and working near the mode transition region [3], using the higher order clad modes of the sensor and working near the Turn Around Point (TAP) [4] are the well accepted methodologies to enhance the sensitivity of the LPG. The combination of these methodologies has also been studied, where the sensors have been designed using LPG with reduced clad diameter and with a high RI polymeric coating to operate near mode transition region [5], with a reduced clad diameter and working near TAP [6] and most recently on LPG with reduced clad diameter working near mode transition region and turn around point [7]. For the bio-sensing applications RI of the surrounding usually remains to be that of water. A TAP-LPG with a single attenuation band in air split up into two in either side of TAP when immersed in the water environment. In this situation the resonant wavelengths are far from the TAP. A solution to overcome this problem was suggested in [6].

In this work, for the first time to the best of our knowledge, we had shown experimentally the sensitivity characteristics of a dispersed mode [8] taken at the TAP. The sensitivity of $LP_{0,11}$ dispersed mode to surrounding refractive index ranging from 1.3332 to 1.3348 was found to have a sensitivity of ~2413 nm /RIU (refractive index unit).

II. BACKGROUND THEORY

The basic working principle of LPG for SRI measurement is well understood yet some points are reiterated for an easy understanding of our representation. LPG couples light from fundamental core mode to different co-propagating clad modes. The wavelengths (λ_{res}) at which core mode resonates with different clad modes can be obtain from the phase matching equation is represented as,

$$\lambda_{res} = (n_{eff}^{co} - n_{eff}^{cl0,m})\Lambda \qquad (1)$$

Where n_{eff}^{co} is the effective refractive index of the core mode and $n_{eff}^{cl0,m}$ is the effective refractive index of the guided mth order clad mode [4]. It is described in [8] that the resonant wavelength shift with respect to surrounding refractive index can be expressed as,

$$\frac{d\lambda_{res}}{dn_{sur}} = \lambda_{res}.\gamma.\Gamma_{sur} \qquad (2)$$

Where γ is "general sensitivity factor" and |γ|>5 for the higher order modes and the value theoretically tends to infinite at TAP. Γ_{sur} is the surrounding RI dependences of the waveguide dispersion and expressed as,

$$\Gamma_{sur} = -\frac{u_m^2 \lambda_{res}^3 n_{sur}}{8\pi r_{cl}^3 n_{cl} (n_{eff}^{co} - n_{eff}^{cl0,m})(n_{cl}^2 - n_{sur}^2)^{\frac{3}{2}}} \qquad (3)$$

Where u_m is the mth root of the zero order Bessel function of first kind and r_{cl} and n_{cl} are the radius and the refractive index of the clad of the fiber [4].

III. EXPERIMENTAL RESULTS

A. *Sensor Fabrication*

Two LPGs considered for the experiment were fabricated in standard single mode fiber SMF-28e of Corning Inc. using point-by-point inscription technique by a pulsed KrF excimer laser (BraggStar-500 from TUI Laser). Before inscription the fiber was hydrogen loaded at 1500 psi for 24 hours. Period of one was ~ 163 micron to get dual peaks of the $LP_{0,12}$ (LPG1) and that of the other was ~181 micron to get $LP_{0,11}$ resonant mode (LPG2). After inscription the LPGs were annealed at 150^0C for 6 hours to diffuse-out the non reactive hydrogen molecule from fiber core and also from fiber cladding. All the measurements were done by using white light source and wide

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band SLED source and Optical Spectrum Analyzer.

B. Spectral evolution of LPGs

LPG1 with clad mode $LP_{0,12}$ was immeresed in the 10% HF for 2 hrs. The dual peaks of $LP_{0,12}$ clad mode, depending upon the reducing clad radius due to etching, moved toward each other and got coalesced and subsequently annihilated. With further etching a new pair of dual peakes of $LP_{0,11}$ mode was generated at the locations where previously $LP_{0,12}$ mode was observable as shown in Fig.1. After that the LPG1 was again immersed in 1% HF for 1 hr so that the dual peak of LP_{011} mode come sufficiently close to each other in the solution and when measured in air the attenuation become ~3 dB single peak which is shown in Fig. 2.

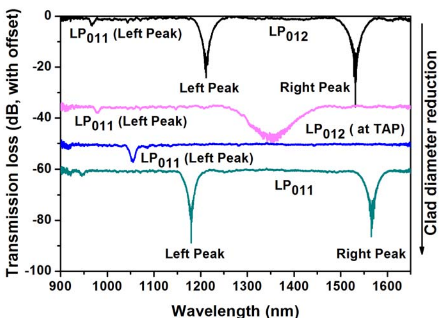

Fig.1. Spectral evolution of dual peaks of LPG1

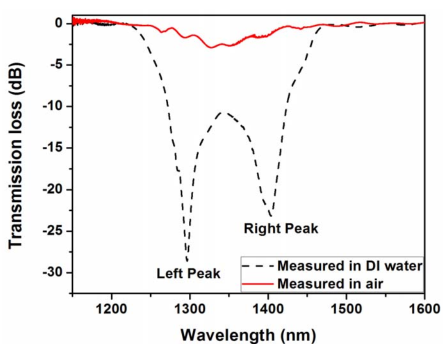

Fig.2. Spectrum $LP_{0,\ 11}$ of LPG1 after etching

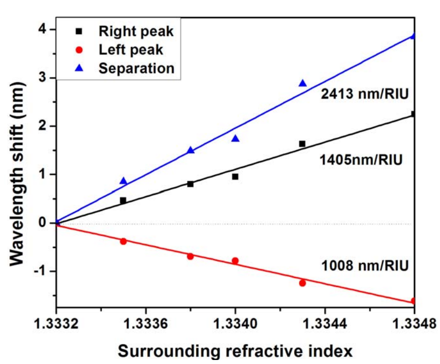

Fig.3. Variation of resonant wavelength of LPG1 as a function of SRI

Now LPG2 with LP_{011} clad mode was also etched using 1% HF for 1 hr. Here also the dual peak of that specified mode was allowed to come close to each other so that in air it has a single peak at the TAP with ~ 3 dB attenuation.

C. Sensitivity measurement to SRI

Both LPG1 and LPG2 were immersed in different RI solution ranging from 1.3332 to 1.3348 and corresponding wavelength shifts were observed in Fig. 3 and Fig. 4. It is clear from the experimental result that LPG1 is more sensitive (~2413 nm/RIU) than the LPG2 (~1770 nm/RIU).

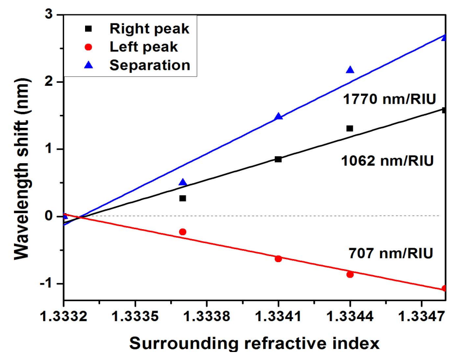

Fig.4. Variation of resonant wavelength of LPG2 as a function of SRI

IV. CONCLUSION

It has been shown experimentally that in LPG sensors the dispersed cladding mode ($LP_{0,\ 11}$) is more sensitive (~2413 nm/RIU) to a change in SRI (1.3332–1.3348) than the original cladding mode of the same order (~1770nm/RIU).

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