# Refractive index and temperature dependent displacements of resonant peaks of long period grating inscribed in hydrogen loaded SMF-28 fiber

**T. M. Libish[1,2*], M. C. Bobby[1], J. Linesh[1], S. Mathew[1], C. Pradeep[1], V. P. N Nampoori [1], and P. Radhakrishnan[1]**
*1. International School of Photonics, Cochin University of Science and Technology, Cochin 682022, India*
*2. S.C.T. College of Engineering, Trivandrum 695018, India*

(Received 30 September 2011)


In this paper, the effects of refractive index (RI) of surrounding medium and ambient temperature on the transmission characteristics of a long period grating (LPG) are experimentally analyzed. The spectral behavior of LPG is investigated when the ambient index is higher or lower than that of the cladding material. The results show that the refractive index sensitivity of lower order attenuation bands is very low compared with that of the highest order attenuation band. But in the case of temperature, the lower order attenuation bands of the LPG can also exhibit good sensitivity like the higher-order bands.
**Document code:** A **Article ID:** 1673-1905(2012)02-0101-4
**DOI** 10.1007/s11801-012-1137-9

Optical fiber long period grating (LPG) technology has attracted much attention in recent years due to its various applications in fiber optic sensor[1] and communication systems[2-5]. An LPG couples light from the fundamental core mode to the forward-propagating cladding modes, and results in a transmission spectrum consisting of distinct resonant loss peaks[6]. The resonance wavelength of LPGs is a strong function of external perturbations, like strain, bending, surrounding refractive index (SRI)[7-9] and temperature[10-12]. The external perturbations affect the coupling strength between the core and cladding modes, which could lead to both amplitude and wavelength shifts of the attenuation bands in the LPG transmission spectrum. Measurement of the spectral parameters in response to environment surrounding the grating region is the basis of sensing with LPGs. LPG can be used as an ambient index sensor or a temperature sensor with high stability and reliability. The refractive index (RI) sensing is very important for biological, chemical and biochemical applications, as a number of substances can be detected through the measurement of RI.

LPGs can be produced in various types of fibers. The LPG with grating period of 415 μm, written into the cores of standard telecommunication fibers (SMF-28e, Corning) has been utilized for our studies. In this paper, we discuss the spectral variation due to the changes of SRI and then the impact of temperature variations on the attenuation bands of LPG.

The LPG is operated by coupling the fundamental core mode (i.e., the $LP_{01}$ mode) to co-propagating cladding modes (i.e., $LP_{0m}$ mode with $m$ =2, 3, 4···) in the fiber. The coupling yields rejection bands around specific wavelengths (resonant wavelengths) in the transmission spectrum of the LPG. The wavelength, at which the guided mode couples to the cladding modes, can be obtained through the phase-matching equation[13]:

$$\lambda_m = [n_{\mathrm{eff}}^{\mathrm{co}} - n_{\mathrm{eff}\,m}^{\mathrm{cl}}]\Lambda \,, \tag{1}$$

where $\lambda_m$ is the resonance wavelength corresponding to the one coupling to the $m$th cladding mode, $\Lambda$ is the grating period, $n_{\mathrm{eff}}^{\mathrm{co}}$ is the effective index of the fundamental core mode ($LP_{01}$), and $n_{\mathrm{eff}\,m}^{\mathrm{cl}}$ is the effective index of the $m$th order cladding mode ($LP_{0m}$). The resonance wavelength of LPGs is a function of strain, SRI bending and temperature. The external perturbations affect the coupling strength between the core and cladding modes, which could cause the resonant wavelength shift and amplitude changes of the LPG attenuation bands[14-17]. The shift of the central wavelength of the peaks can occur towards shorter or longer wavelengths[18].

The LPG used in our experimental study was fabricated using a 248 nm KrF excimer laser source and employing point-by-point writing method. The duty cycle of grating period is about 50%. The used standard single-mode fiber

* E-mail: libishtm@gmail.com

(SMF-28e, Corning) has a core diameter of 8.2 μm and cladding diameter of 125 μm. The core and cladding refractive indices are 1.461 and 1.456, respectively. To enhance the photosensitivity, the fibers were hydrogen loaded at 100 °C and with pressure of 1500 psi for 24 h before the LPG fabrication. The residual molecular hydrogen, which was not used in the photochemical reaction at the time of grating writing, had been removed by annealing process.

We use the experimental arrangement as shown in Fig.1 for measuring the LPG's RI response. A white light source (Yokogawa AQ 4305) was used as the signal source, and the transmission spectra of the LPGs were interrogated with an optical spectrum analyzer (OSA) (Yokogawa AQ 6319). LPG sensor head was fixed in specially designed glass cells with provision for filling the sample and draining it out. Drastic changes in performance of the LPGs are noted when there are fluctuations of external characteristics, like strain, temperature and bending. To avoid the effects of strain and bending, a special glass cell holder was designed, and the fiber was placed, stretched and bonded with epoxy at both end points of the cell, so that the grating section was fixed at the center of the cell. For precise measurement, the experimental setup and sample solution temperatures were maintained at 24.0 ± 0.5 °C. There was no protective coating at the grating section, so that the external RI could easily affect the effective RI of the cladding modes.

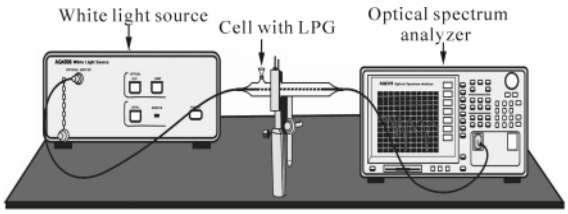


**Fig.1 Experimental setup**

The transmission spectra of LPG with air as the surrounding medium exhibit five resonance bands at 1254 nm ($LP_{02}$), 1284 nm ($LP_{03}$), 1333 nm ($LP_{04}$), 1423 nm ($LP_{05}$) and 1610 nm ($LP_{06}$), respectively. The changes of the LPG transmission spectra with the changes of the RI of the external medium are shown in Fig.2. We used the standard RI liquid samples supplied by Cargille laboratories Inc. The sensor responds to RI changes as soon as the samples are introduced in the glass cell. But to get a stable output, all readings took one minute after the LPGs immersed in the solution. The initial spectrum of the LPGs in air was used as the reference spectrum for all the sample analyses. At the end of each sample measurement, the sensor element was cleaned with isopropyl alcohol repeatedly, and dried properly, so that the original transmission spectrum of LPGs was obtained.

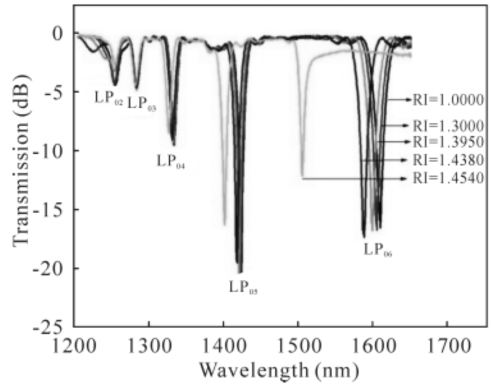


**Fig.2 Transmission spectra of LPG with a period of 415 μm for different refractive indices of ambient lower than that of fiber cladding**

When the SRI is changed from 1.0000 to 1.4540, a shift of the resonance bands towards the shorter wavelength side (blue shift) can be seen. We find that the highest order attenuation bands exhibit longer displacements compared with the lower order cladding modes. The wavelength shift occurs because the increasing SRI enhances $n_{\mathrm{eff}\,m}^{\mathrm{cl}}$, particularly for the higher order cladding modes which extend further into the external medium. The highest order cladding mode $LP_{06}$ exhibits a total blue shift of approximately 105.30 nm as shown in Fig.3, when the SRI is gradually changed from 1.0000 to 1.4540. The $LP_{03}$, $LP_{04}$ and $LP_{05}$ cladding modes show total red shifts of 1.59 nm, 7.16 nm and 22.66 nm, respectively in the same refractive index range. The highest RI sensitivity of LPG is observed when the index of external medium is close to that of the cladding.

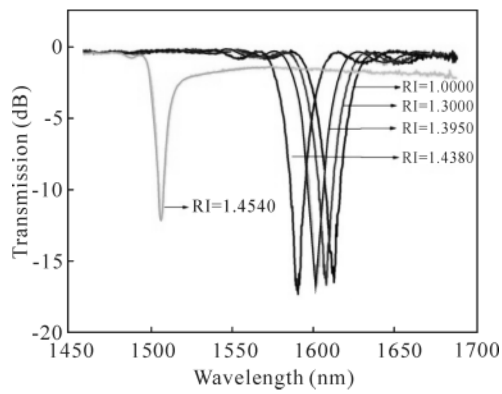


**Fig.3 Transmission spectra of the highest order cladding mode ($LP_{06}$) of LPG for different refractive indices of ambient lower than that of fiber cladding**

When the ambient index is higher than that of the cladding (1.456), the resonance peaks of the LPG can reappear at a wavelength slightly longer than that measured in air, and the strength of the attenuation peaks increases with increasing SRI as shown in Fig.4. The transmission changes of the highest order cladding mode of LPG corresponding to the changes of external refractive index are shown in Figs.5 and 6. An intensity change of 7.81 dB is obtained for the $LP_{06}$ mode of LPG in the refractive index range from 1.4580 to 1.6380, which corresponds to an average resolution of $2.30 \times 10^{-2}$ $dB^{-1}$.

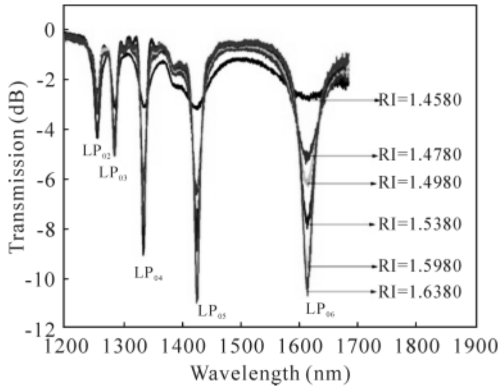


**Fig.4 Transmission spectra of LPG with a period of 415 μm for different refractive indices of ambient higher than that of fiber cladding**

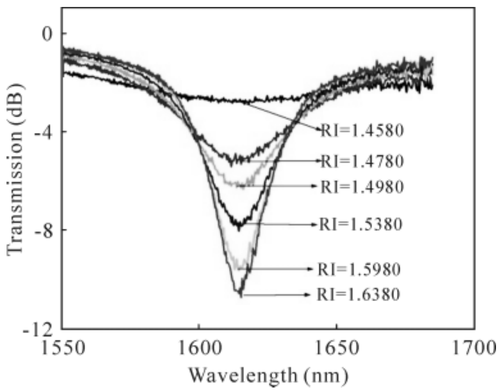


**Fig.5 Transmission spectra of the $LP_{06}$ mode of LPG for different external refractive indices higher than that of fiber cladding**

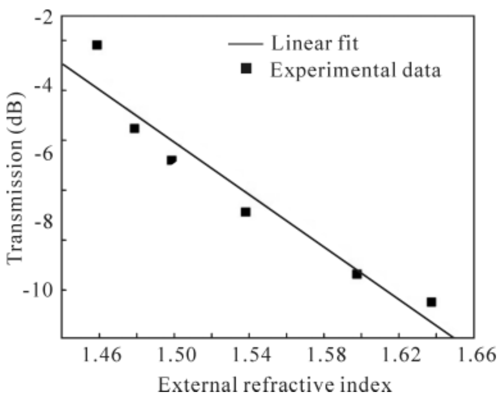


**Fig.6 Transmission changes of the highest order cladding mode ($LP_{06}$) of LPG in response to external refractive index change**

During temperature response study, the LPG was positioned in a temperature controlled fiber oven (ASP, 500C Fiber Oven). To avoid the effects of strain and bending, the LPG was stretched and then fixed in the fiber oven. All readings were taken with air as the surrounding medium. The initial spectrum was recorded at room temperature (25°C). The LPG was then heated from 50 °C to 100 °C in steps of 10 °C using the temperature controller of oven. During the process, the transmission spectra were recorded using the OSA. Figs.7 and 8 show the wavelength shifts for different cladding modes of LPG with temperature changing. We observe a spectral shift to longer wavelengths (red shift) with increasing temperature, and the wavelength shifts of the peaks are linear as shown in Fig.9. The $LP_{02}$, $LP_{03}$, $LP_{04}$, $LP_{05}$ and $LP_{06}$ cladding modes experience total red shifts of 3.58 nm, 2.39 nm, 3.58 nm, 2.78 nm and 4.37 nm, respectively. It can be

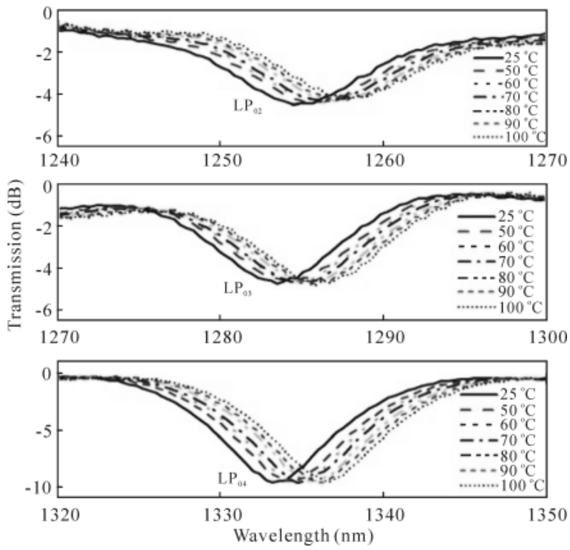


**Fig.7 Peak wavelengths of $LP_{02}$, $LP_{03}$ and $LP_{04}$ cladding modes of LPG at different temperatures**

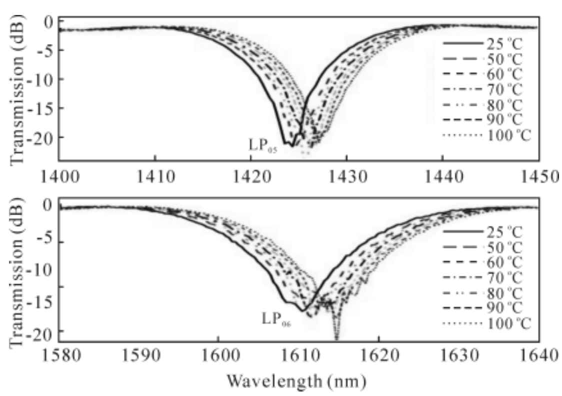


**Fig.8 Peak wavelengths of $LP_{05}$ and $LP_{06}$ cladding modes of LPG at different temperatures**

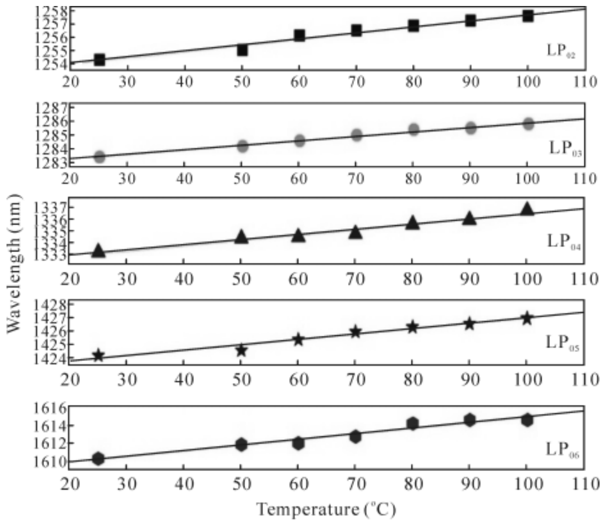


**Fig.9 Shifts in the central wavelengths of the five attenuation bands as a function of temperature**

seen that different resonant peaks have different temperature sensitivities, and the highest order cladding mode $LP_{06}$ is the most sensitive to external temperature with a good sensitivity of about 0.06 nm/°C. The lower order cladding mode $LP_{02}$ displays a sensitivity of about 0.05 nm/°C. The results show that the lower order bands can also be sensitive to temperature changes like higher order bands.

In summary, the effect of SRI changes on the transmission spectrum of LPG written in hydrogen loaded standard single mode fiber is experimentally studied. The analyses are made in terms of wavelength shift and transmission band intensity variations. We observe that the refractive index sensitivity of the lower order attenuation bands is lower than that of the highest order attenuation band. We also investigate the temperature sensitivity of the LPG fabricated with SMF-28 fiber. The obtained results show that different resonant peaks have different temperature sensitivities, and the lower order attenuation bands of the LPG can also exhibit good temperature sensitivity like higher order bands.

## References

[1] S. A. Vasil'ev, O. I. Medvedkov, I. G. Korolev, A. S. Bozhkov, A. S. Kurkov and E. M. Dianov, Quantum Electronics **35**, 1085 (2005).

[2] A. M. Vengsarkar, P. J. Lemaire, J. B. Judkins, V. Bhatia, T. Erdogan and J. E. Sipe, J. Lightwave Technol. **14**, 58 (1996).

[3] M. Das and K. Thyagarajan, Opt. Commun. **190**, 159 (2001).

[4] B. J. Eggleton, R. E. Slusher, J. B. Judkins, J. B. Stark and A. M. Vengsarkar, Opt. Lett. **22**, 883 (1997).

[5] Zhu Y, Lu C, B. M. Lacquet, P. L. Swart and S. J. Spammer, Opt. Commun. **208**, 337 (2002).

[6] A. M. Vengsarkar, J. R. Pedrazzani, J. B. Judkins, P. J. Lemaire, N. S. Bergano and C. B. Davidson, Opt. Lett. **21**, 336 (1996).

[7] S. W James and R. P Tatam, Meas. Sci. Technol. **14**, R49 (2003).

[8] B. H. Lee, Y. Liu, S. B. Lee, S. S. Choi and J. N. Jang, Opt. Lett. **22**, 1769 (1997).

[9] J. H. Chong, Ping Shum, H. Haryono, A. Yohana, M. K. Rao, Chao Lu and Yinian Zhu, Opt. Commun. **229**, 65 (2004).

[10] F. J. O. Flaherty, Z. Ghassemlooy, P. S. Mangat and K. P. Dowker, Microwave and Optical Technol. Lett. **42**, 402 (2004).

[11] S. Khaliq, S. W James and R. P Tatam, Meas. Sci. Technol. **13** (2002), 792.

[12] Ruan Ju-an, Zeng Qing-ke, Qin Zi-xiong, Liang Wei-yuan and Huang Ping, Optoelectronics Lett. **4**, 0114 (2008).

[13] V. Bhatia, Opt. Exp. **4**, 457 (1999).

[14] H. J. Patrick, A. D. Kersey and F. Bucholtz, J. Lightwave Technol. **16**, 1606 (1998).

[15] X. W. Shu, L. Zhang and I. Bennion, J. Lightwave Technol. **20**, 255 (2002).

[16] O. Duhem, J. Fraòois Henninot, M. Warenghem and M. Douay, Appl. Opt. **37**, 7223 (1998).

[17] H. Tsuda and K. Urabe, Sensors **9**, 4559 (2009).

[18] Y. Koyamada, IEEE Photon. Technol. Lett. **13**, 308 (2001).