11P-21

The refractive index sensing of different types of long-period gratings

Jaw-Luen Tang[1], Jian-Neng Wang[2], and Ping-Chang Jui[3]

[1]*Department of Physics, National Chung Cheng University, 168 University road, Chia-Yi 621, Taiwan*
TEL: +886-5-272-0586, FAX +886-5-272-0587, Email: phyjlt@.ccu.edu.tw
[2]*Department of Construction Engineering, National Yunlin University of Science and Technology, Yun-Lin 640, Taiwan*
TEL: +886-5-534-2601-4723, FAX +886-5-531-2049, Email: wangjn@yuntech.edu.tw
[3] *IR Section, Materials and Electro-Optics Research Division, Chung Shan Institute of Science and Technology, Lung-Tan, Taiwan*

Abstract:

We report a comparative study of sensing characteristics (temperature, strain, refractive index, and chemical solution) for three different configurations of long-period gratings (LPGs), which include normal LPGs, phase-shifted LPGs, and LPGs inscribed in tapered fibers.

Introduction

Long-period fiber gratings (LPGs) are widely used for many applications in telecommunication and sensor systems such as band-rejection filters [1], and temperature/strain/refractive index (RI) sensors [2, 3]. The sensing applications are of particular interest partly due to their relatively simple of fabrication, low back-reflection, and particularly high temperature, bend, and load sensitivity. An LPG is a periodic axial RI variation in the core of a singlemode optical fiber that couples light from the fundamental guided mode to some co-propagating cladding modes, resulting in several attenuation bands at discrete wavelengths that are highly sensitive to RI of surroundings. Recently, several highly sensitive LPG-based RI sensors have been demonstrated for chemical and biological applications [4-6]. In this work, we investigate on analyses and sensitivity to surrounding medium's RI (SRI) of three types of LPG-based devices for RI and chemical sensing, which include a normal LPG, a phase-shifted LPG (PS-LPG), and a LPG written in biconical tapered fiber (BT-LPG).

Experimental

The LPGs were fabricated on singlemode standard communication fibers using a pulsed 193nm ArF excimer laser (laser energy of ~135 mJ/cm^2 and total exposure time of ~3 minutes) with an amplitude mask technique, as shown in Fig. 1. The fiber was hydrogen loaded at a pressure of 120 bar over a period of two weeks at room temperature. The length of three types of LPG-based sensors was about 2.7 cm and the grating period was set to 380 μm. The phase we used in PS-LPG is π. The technique to fabricate a BT-LPG was similar to that used in Ref. 7. The total length of tapered fiber is 1 cm with an approximate minimum fiber radius of 34 μm. After the laser exposure, all the LPGs were annealed at 150 °C for 24 h to stabilize their optical properties. With suitable fabrication parameters such as laser power, exposure time, and grating period, the resulting resonance wavelengths ranging from 1200 nm to 1600 nm with a greater than 20 dB peak depth were obtained. In this work, a number of these three types of LPG-based sensors associated with various attenuation bands (corresponding to various cladding modes) were measured and analyzed.

Results and Discussion

The characteristics of LPGs such as temperature and strain were first investigated. The thermal responses of the LPG were measured by heating the grating from 30°C to 150°C in incremental steps of 15°C, using a temperature-controllable chamber. When temperature is increased the resonance wavelength of LPGs is shifted to the longer or the shorter wavelength, showing that temperature sensitivity ($d\lambda/dT$) of LPGs exhibited either positive or negative sensitivity. The found temperature sensitivities for the investigated LPG, PS-LPG, and BT-LPG was 0.06-0.09 nm/°C, 0.04-0.09 nm/°C, and 0.07-0.08 nm/°C, respectively, which are several times larger than those of FBG (~0.01 nm/ °C). It can be seen that all three LPG-based sensors possess almost similar responses in magnitude to temperature changes. The spectral responses to the strain of the LPG were performed by mounting the grating on a translation stage that was moved outward to induce a strain in the optical fiber. For all LPGs used in this work the strain sensitivities of various resonance wavelengths were found to be very small (~0.09 ± 0.01 pm/ με) and exhibited nearly insensitive to strain variations.

In order to characterize the LPG as a RI sensor or a chemical concentration sensor, measurements with sucrose and sodium chloride aqueous solutions were performed. The surrounding RI was controlled through the use of sucrose solutions with various concentrations [6]. The ability of three LPG-based sensors to detect changes in the SRI or chemical solution concentrations was then studied For precise RI measurement, experimental setup and sample solution were maintained at the same temperature (within ~0.1°C fluctuation). Therefore, the results reported here were not influenced by temperature and strain effects. The experiment used to measure refractive index sensitivity was followed by Ref. 7. When the concentration and, hence, the refractive index of a sucrose solution increased in the range of 1.34-1.41, the transmission spectrum of the LPG sensor exhibited either a linear decrease (LPG and PS-LPG) or a linear increase (BT-LPG) in the insertion loss and a shift in the peak wavelength. Fig. 2 shows wavelength shifts of a typical PS-LPG against sucrose concentration and, hence, the corresponding changes in SRI. A linear regression approach [6] was employed to calculate the RI sensitivity of each type of LPG sensor. Our results show that RI sensitivities of LPG, PS-LPG, and BT-LPF are $d\lambda/dn$ = -45.3nm/RI,-(74.4-87.5)nm/RI, +271.7nm/RI, respectively, which leads to a limit of detection in index, 1.3×10^{-3}, $(6.9\text{-}8.1)\times10^{-4}$, $\sim2\times10^{-4}$, respectively. The investigation shows that BT-LPG exhibited the highest sensitivity to SRI among three LPG types of sensors.

The sensitivity of LPG to concentration change in chemical solution was further investigated using sodium chloride (NaCl) solutions. The LPG under test was immersed in a container of deionized water (volume 100 cc) and increments of 5 cc of 4 molar NaCl solution were added. The temperature kept constant to 0.1^{o}C. Fig. 3 shows wavelength shifts of a typical PS-LPG against molar concentration of NaCl and the corresponding changes in SRI, showing that sensitivities of LPG, PS-LPG, and BT-LPF in terms of NaCl molar concentration are -0.3nm/Mol, -(0.33 − 0.68)nm/Mol, 0.57nm/Mol, respectively, leading to a limit of detection in molar concentration, 0.2, 0.08-0.18, 0.1, respectively. That small sensitivity of BT-LPG to NaCl molar concentration remains unknown and the investigation is under way. However, studies presented here demonstrate the feasibility of using the design of LPG-based sensor for RI or chemical sensing with high sensitivity.

Conclusion

We report a comparative study of sensing capabilities (temperature, strain, RI, and chemical solution) based on three different LPG configurations (LPG, PS-LPG, and BT-LPG) using a pulsed UV laser with an amplitude mask technique. Our results demonstrate that LPG fiber sensor can provide a resolution of $\sim10^{-3}$ to 10^{-4} for refractive indices in the range of 1.34 to 1.41, suggesting that these devices may be suitable for use with aqueous solutions for chemical sensing.

References

[1] A.M. Vengsarkar, P.J. Lemaire, J.B. Judkins, V. Bhatina, T. Erdogan, and J.E. Sipe, “Long-period fiber gratings as band-rejection filters,” *IEEE J. Lightwave Technol*. **14**, 58-65, 1996.

[2] V. Bhatia, D. Campell, R.O. Claus, and A.M. Vengsarkar, “Simultaneous strain and temperature measurement with long-period gratings,” *Opt. Lett.* **21**, 336-338, 1996.

[3] V. Bhatia and A.M. Vengsarkar, "Optical fiber long-period grating sensors", *Opt. Lett.* **21**, pp. 692-694, 1996.

[4] H. J. Patrick, A. D. Kersey and F. Bucholtz, "Analysis of the response of long period fiber gratings to external index of refraction", *J. Lightwave Technol.* **16**, pp. 1606-1612, 1998.

[5] T. Allsop, et al. "Detection of organic aromatic compounds in paraffin by a long period fiber grating optical sensor with optimized sensitivity", *Opt. Commum.* **191**, pp. 181-190, 2001.

[6] J.-L. Tang, S.-F. Cheng, W.-T. Hsu, T.-Y. Chiang, L.-K. Chau, “Fiber optic biochemical sensing with a colloidal gold-modified long period fiber grating,”, *Sensors & Actuators: B. Chemical*, **119**, 105-109, 2006.

[7] T. Allsop, F. Floreani, K. Jedrzejewski, P. Marques, R. Romero, D. Webb and I. Bennion, “Refrative index sensing with long-period grating fabricated in bionical tapered fibre,” *Electron. Lett.*, **41** (8), 2005.

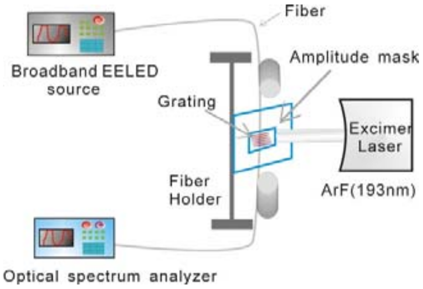

Fig. 1. Experimental set-up for LPFG fabrication with a UV excimer laser.

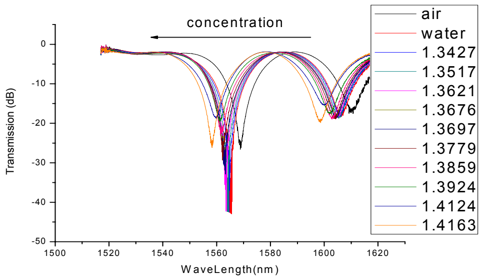

Fig. 2. Spectral responses of a typical PS-LPG sensor in aqueous solution containing increasing concentration of sucrose (from right to left).

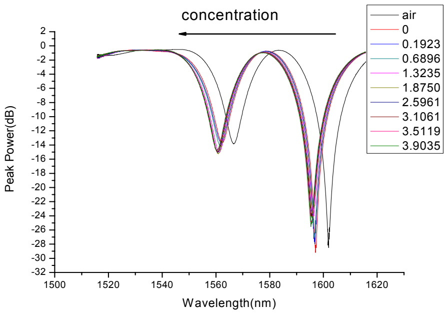

Fig. 3. Spectral responses of a typical PS-LPG sensor in aqueous solution containing increasing molar concentration of NaCl (from right to left).