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# Optic Fiber Sensor Based on Etching Long Period Gratings of Photonic Crystal Fibers

Wen-Fung Liu[1], Sheng-Zeng Peng[1], Hsin-Wen Peng[1], Ming-Yue Fu[2], Lung Ai[3], Hao-Jan Sheng[4] and Chuen-Lin Tien[1]

[1]*Department of Electrical Engineering, Feng-Chia University, Taichung, Taiwan 407, R.O.C.*
*Tel: 886-4-24517250 ext. 3807 Fax: 886-4-24516842 Email: wfliu@fcu.edu.tw*

[2]*Department of Avionics Engineering, Air Force Academy, Kangshan, Kaohsiung, 820, Taiwan, R.O.C.*
*Tel: 886-7-6268806 ext. 109 Fax: 886-7-6268806 ex.113t Email: fumy@cc. cafa.edu.tw*

[3] *Department of Electrical Engineering, Chung-Cheng Institute of Technology, National Defense University, Tahsi, Taoyuan, Taiwan 335, R.O.C.*
*Tel: 886-3-3895526 ext. 354 Fax: 886-3-3801407 Email: lung.ai@msa.hinet.net*

[4] *The Graduate Institute of Electrical and Communications Engineering, Ph.D. Program, Feng-Chia University, Taichung, Taiwan 407, R.O.C.*
*Tel: 886-4-24517250 ext. 3807 Fax: 886-4-24516842 Email: sheng@msa.hinet.net*

**Abstract:** A new fiber sensor based on an etched long period grating in photonic crystal fibers is used for sensing temperature and various refractive index solutions.

## 1. Introduction

The device applications based on photonic crystal fibers (PCF) include silica/polymer hybrid tunable fiber waveguides, fiber couplers, grating based tunable filters, etc [1-4]. A long period grating (LPG) fabricated in a PCF has potential applications in a fiber sensing head. For a conventional LPG, in the transmission spectrum there exist several different mode loss peaks at different resonant wavelengths, which should satisfy the phase matching condition. In this study, the temperature effect of the etched an LPG in a PCF is investigated by using etching fiber technology to reduce the diameter of fiber cladding for improving the temperature sensitivity. Moreover, when the surrounding solution index of the etched LPG in a PCF is increased, the resonant wavelength shifts toward the shorter wavelength side. Thus, from the experimental results, this technique maybe provide a novel sensing head for discriminating different chemical solutions or distinguishing various constituents in a chemical solution by combining the thin-film coating technique on the surface of the etched LPG.

## 2. Basic principles

According to the reference of [2], the cladding effective index $n_{cl(n)}^{eff}$ of an LPG in a PCF can be simplified as

$$n_{cl(n)}^{neff} = \left[n_{co}{}^2 - (\pi / 2\sqrt{3})(d / \Lambda_{LPG})^2 (n_{co}{}^2 - n_a{}^2)\right]^{1/2} \quad (1)$$

where $d$ is the average hole diameter, $n_{co}$ is the core index and $n_a$ is the refractive index of inside holes. By the combination of equation (1) and grating phase-matching condition, the resonant wavelength $\lambda$ of an LPG in a PCF can written as

$$\lambda = \left(n_{co} - n_{cl(n)}^{neff}\right)\Lambda_{LPG} = n_{LPG(n)}\Lambda_{LPG} \quad (2)$$

where $n_{LPG(n)} = (n_{co} - n_{cl(n)}^{neff})$.

The resonant wavelength shift $\Delta\lambda$ induced by the temperature perturbation $\Delta T$ can be expressed as

$$\frac{\Delta\lambda}{\lambda} = [\alpha + \zeta]\Delta T \quad (3)$$

where $\alpha = \frac{1}{\Lambda}\frac{\Delta\Lambda}{\Delta T}$ is the fiber thermal-expansion coefficient and $\zeta = \frac{1}{n_{LPG(n)}}\frac{\Delta n_{LPG(n)}}{\Delta T}$ is the fiber thermal-optic coefficient. Refer to Eq. (3), while a part of the cladding layer is removed by means of etching fiber technique to keep the original symmetrical structure, the fiber thermal-optic coefficient will be increased due to the $n_{LPG(n)}$ to be decreased and thus to cause the temperature sensitivity to be further improved. Besides, from Eq. (1), when the index of surrounding air-holes solution of LPG is changed, it will result in a variation of the cladding effective index $n_{cl(n)}^{eff}$. Thus, from Eq. (3), the resonant wavelength should be shifted owing to the index change of surrounding solution. This phenomenon can be verified by the following experimental results.

## 3. Experimental set-up and results

In this experiment, the LPG is fabricated by utilizing the electric arc of a fiber splicer to heat the PCF and to cause the fiber index change. The PCF used is the holey fiber with the type of ESM_12_1 from Blaze Photonics Company. By controlling discharging time of the fiber splicer (Fujikura FSM-40S-B) and adjusting the translation-stage to periodically move the PCF to be heated, the fabrication of an LPG in a PCF can be achieved by the point-by-point writing technique.

In order to investigate the temperature effect for an etched LPG in a PCF, a non-etching LPG is firstly measured for observing the resonant wavelength shift by using an OSA. The experimental results show the wavelength shift of the LPG loss peak from 1552.25 nm to 1553.8 nm with the total wavelength shift of 1.550 nm in the temperature range from $200^0$C to $30^0$C. The shift direction is toward the shorter wavelength side while the temperature is reduced. The temperature sensitivity of about 9.1 pm /$^0$C is obtained with a nice linear property as shown in Fig.1. An LPG in a PCF is etched down from 125 to 63 μm by using HF solution. By using this etched LPG in temperature measurements, the experimental results are shown in Fig. 2. The wavelength shift is from 1500.45 to 1504.45 nm in the temperature range from $200^0$C to $30^0$C with the temperature sensitivity of 23.5 pm /$^0$C. Comparing the temperature sensitivity of the etched LPG with that of the non-etched LPG, it is improved to be 2.6 times. Thus, from experimental results we can predict that the temperature sensitivity of the etched LPG in PCFs should be further enhanced by reducing the cladding diameter.

For sensing different index solutions, the etched LPG of 63 μm in a PCF is inserted in four different index oils of 1.333, 1.358, 1.365, and 1.47. The experimental results are shown in Fig. 3. From these curves, we can clearly observe that the resonant wavelength is shifted toward shorter wavelength side when the oil index is increased. This phenomenon can be explained from Eq. (2). The resonant wavelength shift is proportional to the increment of cladding effective index surrounding the cladding air-holes of PCF as shown in Fig. 4. Thus, from above experimental results, we see that this new sensing head has the ability to discriminate different index solutions in the index resolution of 0.001 by using an OSA with the resolution of 0.01 nm. In the future, the sensitivity in discriminating index will be further improved by designing different types of gratings and combining the thin-film materials to be coated on the surface of the etched LPG.

## 4. Conclusions

We have experimentally demonstrated that the temperature sensitivity of an LPG in a PCF is improved to be 2.6 times while the cladding diameter is etched down from 125 to 63 μm. Additionally, the etched LPG of 63 μm in a PCF is used for discriminating different index oils with the sensitivity of 12.4 nm per unit index.

## Reference


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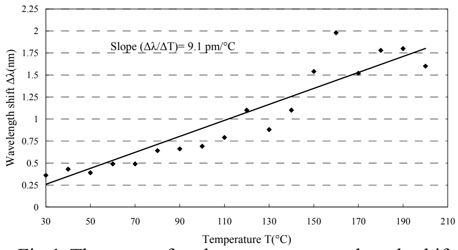


Fig.1 The curve for the resonant wavelength shift of non-etched LPG versus temperature variations.

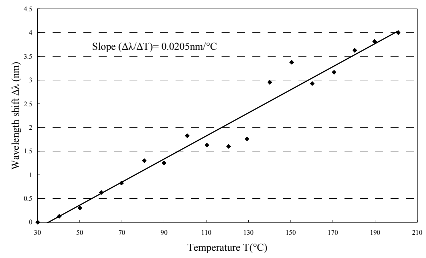


Fig. 2 The curve of the resonant wavelength shift versus temperature variations for etching the fiber to be 63 μm in diameter.

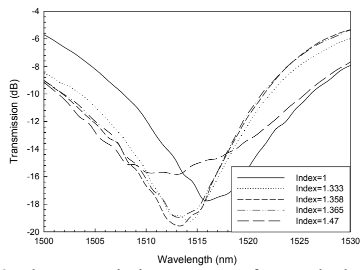


Fig. 3 The transmission spectra of an etched LPG of 63 micro-meters for measuring four different index oils

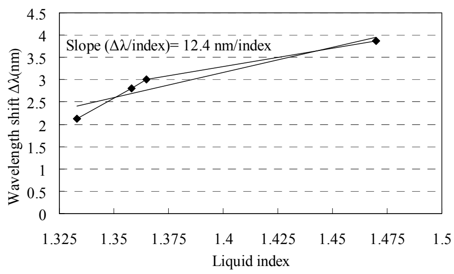


Fig.4 The wavelength shift of grating loss-dip versus different index oils.