

# High resolution long-period grating temperature sensor

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A simple etched and packaged LPG temperature sensor for biomedical application has been developed and resolution of 0.008 °C is achieved, in comparison with conventional thermometer, which only exhibits 0.01 °C. The temperature coefficient of the specially packaged LPG sensor is measured to be 3.776 nm/°C, which is 15 times higher than that of the bare LPG fiber inscribed in the same PS1250/1500 photosensitive optical fiber.

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## 1. Introduction

Temperature sensors made of long-period gratings (LPGs) are good alternatives to fiber Bragg grating (FBG) sensors in certain applications such as biomedical measurement (thermometer) where the temperature range of interest is moderately narrow around the normal body temperature of 37°C. LPG sensors are more cost effective as they are sensitive to temperature and economical to fabricate. However, most of the LPG-based sensor devices so far are still in their early development stage. Many practical device issues, such as packaging and parameter cross-sensitivities [10], need to be resolved before they can be used in real application. In this paper, a new packaging technique for LPGs to achieve high-resolution temperature sensors for biomedical applications is proposed. The principle of operation is based on the fact that the partial cladding removal is an enhancement on the sensitivity of the LPG to the ambient refractive index change. A small change in the ambient refractive index by about 1% would cause the resonant notch to shift by as much as 60nm [5]. Therefore, any temperature variation, which gives rise to the refractive index change, can lead to a considerable resonant wavelength shift of the LPG. In this paper, fabrication of packaged LPG temperature sensor is presented in Section 2. Experimental results are described in Section 3 and a conclusion is given in Section 4.

## 2. Fabrication of packaged LPG temperature sensor

A LPG was first inscribed in PS1250/1500 fiber by the continuous-wave (CW) laser method with output beam limited to a maximum 160 mW during fabrication as described in [1] with pitch period  $\Lambda = 350 \mu\text{m}$ . As the fiber's core is co-doped with boron which exhibits intrinsically photosensitive, the grating can be written and used directly after fabrication without going through the processes of hydrogenation and annealing.

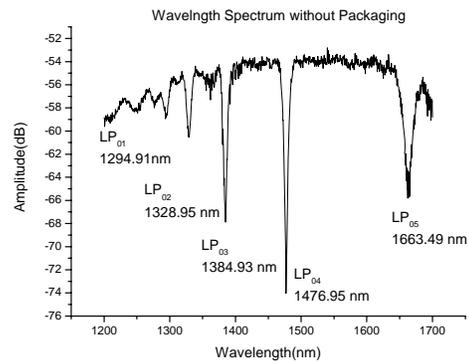


Fig. 1. Transmission spectrum of bare LPG in air.

The transmission spectrum of the LPG is illustrated as Fig. 1. The spectrum ranges from 1200nm to 1700nm. It has been demonstrated that LPG is most sensitive to ambient indices from 1.445 to 1.455 [5]. Hence, the resonant wavelengths could have considerable wavelength shifts, provided that the LPG is immersed into the fluid with a refractive index equal to 1.45.

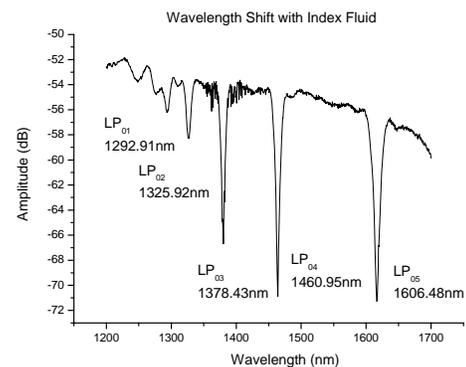


Fig. 2. Transmission spectrum of the bare LPG in 1.45 index fluid.

Fig. 2 shows the wavelength spectrum after submerging the bare LPG into 1.45 refractive index oil. Compared to Fig. 1, it is found that the resonant wavelength  $LP_{05}$  is most sensitive to the refractive index change, which shifts from 1663.49 nm to 1606.48nm. Therefore, the  $LP_{05}$  peak was selected for the experiments and the results of unpackaged LPG would be compared with the packaged one. The resonant wavelength had a blue shift which could be understood by considering the phase matching condition for LPG as described by the Eq (1).

$$\lambda_p = (n_{e0} - n_{em})\Lambda \quad (m=1,2,3,\dots) \quad (1)$$

where  $\lambda_p$  is m-th resonance wavelength.  $\Lambda$  is the period of LPG and  $n_{e0}$  is effective refractive index of core and  $n_{em}$  is effective refractive index of the m-th cladding mode.

When the LPG is submerged in the fluid with an index higher than air, effective refractive index  $n_{em}$  of the LPG cladding modes increases and the coupled-wavelengths shift to the short wavelength side [3]. To further increase LPG sensitivity, the chemical etching was carried out to reduce the cladding layer. It is based on the fact that, if the cladding radius is reduced significantly, the change in refractive index of the core can be assumed to be zero as it is almost not influenced by the refractive index of the surrounding medium; but for the cladding, the effective refractive indices of the cladding modes are strongly dependant on the ambient refractive index. Therefore, by reducing cladding layer, a small change in the ambient refractive index can result in a large wavelength shift [3]. In the fabrication process, the cladding layer was reduced by immersing the LPG fiber in 10% HF acid for 30 minutes. As a result, the diameter of the cladding mode was reduced from a standard 125  $\mu\text{m}$  to 70  $\mu\text{m}$ , totally a 56% reduction in diameter shown in Fig. 3.

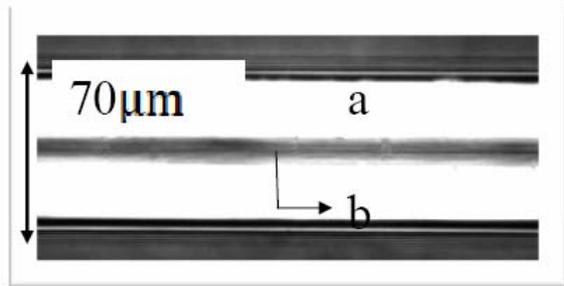


Fig.3. Cladding layer (a) and fiber core (b), the cladding layer has been reduced from 125  $\mu\text{m}$  to 70  $\mu\text{m}$ .

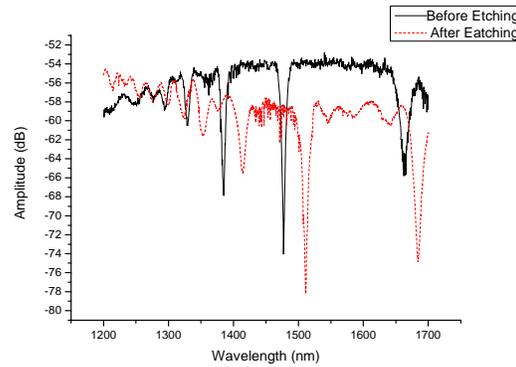


Fig. 4. Transmission spectral comparison between bare LPG and etched LPG.

Fig. 4 shows the transmission spectra of the LPG before and after etching. It is observed that the wavelength separations between two successive resonance bands increases as the cladding diameter are reduced [1]. The resonant wavelengths have red shifts after etching process. The magnitude of the shift is a function of the fiber parameters, the etching depth and the order of the resonance bands.

After chemical etching process, the LPG was ready for packaging. The etched LPG with 4cm long was first spliced with two segments of single mode fibers, so that the LPG fiber could be fixed within the core of the aluminum tube with 4mm in diameter. Two stoppers were placed at each end of the aluminum tube, providing further fixation to hold the fiber in shape to eliminate bend effect. As the LPG is most sensitive with ambient indices from 1.445 to 1.455, an index fluid with  $n=1.45$  (temperature coefficient  $dn/dT=-3.92 \times 10^{-4}/^{\circ}\text{C}$ ) was injected into the aluminum tube. Two stoppers were sealed by the adhesive to prevent leakage of the index fluid and the index fluid would distribute evenly within the tube.

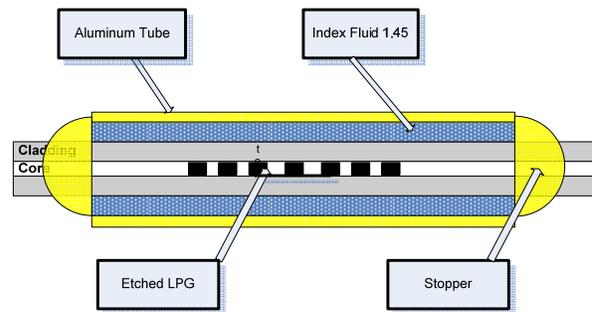


Fig. 5. Transverse diagram of the specially packaged LPG thermometer.

### 3. Experiment results

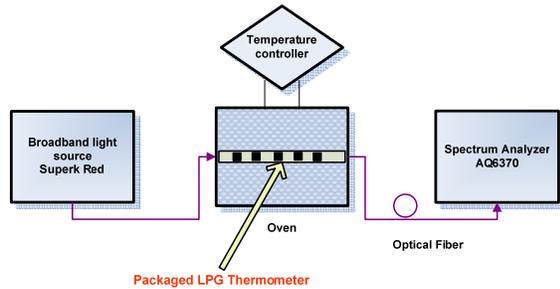


Fig. 6. Block diagram of the LPG temperature sensor.

As shown in Fig. 6, the packaged LPG temperature sensor was enclosed and secured inside the oven. One end of LPG was connected to the super continuum broadband light source (KOHERAS superk red) and the other end was connected with the optical spectrum analyzer (OSA) (AQ8370, 0.02nm resolution). Broadband light radiation from the source was guided into an end of the optical fiber, and transmission spectrum was detected by using OSA at the other end. Memmert oven provided constant temperature allowing specially packaged LPG to achieve thermal equilibrium at fixed interval, and the temperature stability of the oven was 0.02 °C. The temperature of oven was changed from 20 °C to 50 °C, the wavelength shift of the LP<sub>05</sub> resonance peak was measured for every 5 °C temperature changed inside the oven.

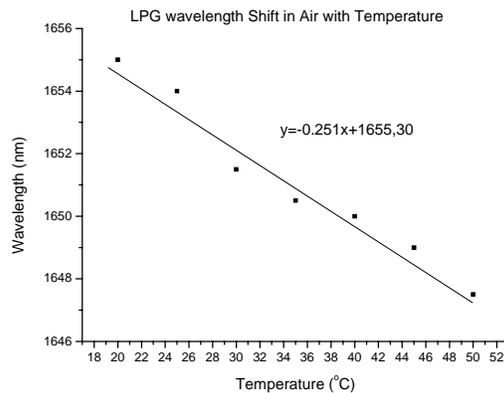


Fig. 7. Temperature sensitivity of bare LPG fiber without etching.

Fig.7 plots the wavelength shift of the LP<sub>05</sub> resonant peak of the LPG when the oven temperature was changed from 20°C to 50°C. A linear response of wavelength shift to temperature is observed and the temperature coefficient is about 0.251nm/°C. Fig. 8 shows the temperature coefficient of the etched and packaged LPG temperature sensor. Although the temperature response of the packaged LPG was non-linear, the experimental results were

repeatable and the temperature response curve could be fitted with a third order polynomial. The temperature coefficient of the etched and packaged LPG was 3.776 nm/°C from 35 °C to 40 °C (body temperature), which was about 15 times increased comparing to the LPG without etching and packaging. In addition, the resolution of the sensor had also been improved; the resolution of this specially packaged LPG was able to achieve 0.008 °C while for unpackaged LPG was about 0.08 °C.

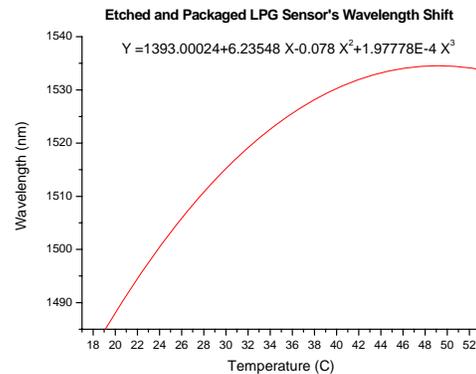


Fig. 8. Temperature sensitivity of packaged LPG thermometer.

The LPG temperature sensor then underwent human trial to find out accuracy and stability under real application. The sensor was first secured underneath armpit together with a reference digital thermometer. The readings of the LP<sub>05</sub> resonant peak were recorded and averaged for one reference temperature. Once averaged wavelength readings were obtained, the result curve Fig. 8 was used to trace corresponding temperature provided by the LPG temperature sensor. After numerical trials, the accuracy of the LPG thermometer was about 0.1°C deviation from the reference readings.

### 4. Conclusions

A high-sensitivity and high-resolution LPG temperature sensor is developed by subjecting the chemically etched LPG to refractive index fluid that changes in corresponding to ambient temperature. The temperature coefficient of the specially etched (cladding diameter from 125µm to 70µm) and packaged LPG sensor is 3.776nm/°C, which is about 5.3 times higher than the packaged LPG without etching, and 15 times higher than the bare LPG fiber inscribed in the same PS1250/1500 photosensitive optical fiber. In addition, the thermal resolution of the LPG has been optimized with packaging, which is about 0.008°C, much better than conventional thermometers in the market that only able to achieve 0.01°C.

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