

Optical fibre gratings with response to 2µm and their sensing capabilities

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ABSTRACT

Recently, we have extended fibre grating devices in to mid-IR range. Fibre Bragg gratings (FBGs) and long-period gratings (LPGs) with spectral responses from near-IR (800nm) to mid-IR (~ 2µm) have been demonstrated with transmission loss as strong as 10-20dB. 2µm FBG and LPG showed temperature and refractive index (RI) sensitivities of ~ 91pm/°C and 357nm/RIU respectively. Finally, we have performed a bio sensing experiment by monitoring the degradation of foetal bovine serum at room temperature. The results encouragingly show that the mid-IR LPGs can be an ideal biosensor platform as they have high RI sensitivity and can be used to detect concentration change of bio- samples.

Keywords: fibre Bragg grating, long period grating, refractive index sensing, foetal bovine serum

1. INTRODUCTION

So far FBG devices have been used in many applications, including telecommunication, fibre lasers and smart optical sensors. Basically, fibre-grating structure is a periodic form of modulation of the refractive index (RI) of the fibre core. This usually occurs by exposing a given length of silica glass fibre to an Ultraviolet (UV) laser, with a typical wavelength in the range of 244nm-248nm [1]. LPG devices have periods in the range of 100µm to 1mm compared to FBGs with shorter periods of few hundred nm.

2. GRATING FABRICATION

2.1 FBG fabrication and coupling mechanism

FBG devices have been inscribed in a hydrogenated standard SMF28 fibre using the two-beam interference technique. The UV induced index perturbation in the fibre core makes it possible for the coupling of the bound-wave to the counter-propagating modes. Bragg wavelength is expressed as:

$$\lambda_B = 2n_{eff} \Lambda \quad (1)$$

where n_{eff} is the core effective refractive index and Λ is the grating period.

2.2 LPG fabrication and coupling mechanism

LPGs were fabricated also in hydrogenated standard SMF28 fibre using the point-by-point inscription technique. In an LPG case, the UV induced index perturbation in the fibre core makes it possible for the coupling of the bound-wave to the co-propagating cladding modes. The LPG resonance is expressed as:

$$\lambda_m = (n_{co} - n_{cl,m}) \Lambda \quad (2)$$

where n_{co} and $n_{cl,m}$ are the effective indexes of the fundamental core mode and the m^{th} cladding mode and Λ is the grating period. It can be clearly seen that as the grating period increases, the resonant wavelength of coupled m^{th} cladding mode increases.

2.3 Spectral responses

During the fabrication, the growth of the grating resonance was monitored using a broadband light source and an optical spectrum analyser (OSA).

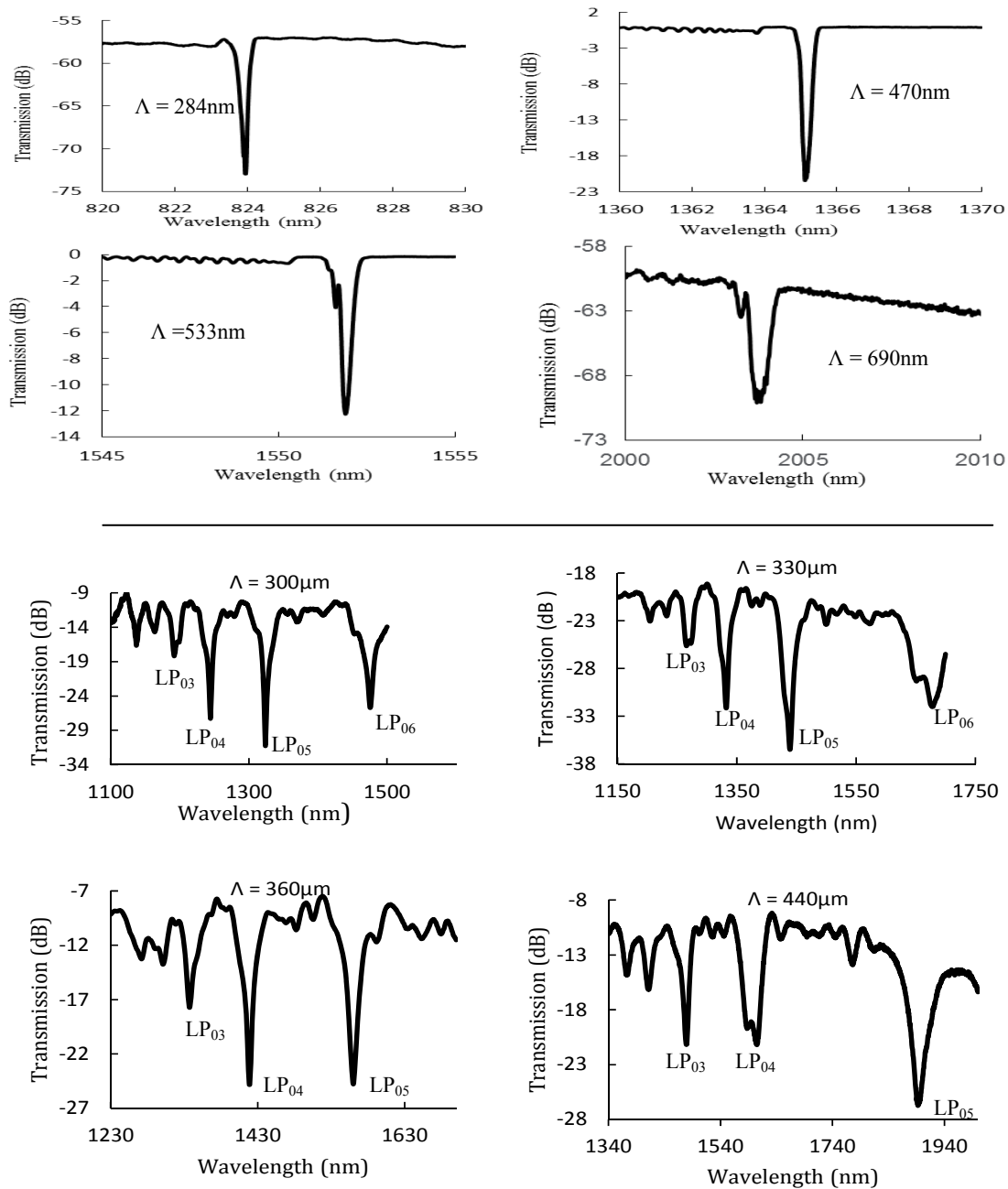


Figure 1. Transmission spectra of inscribed FBGs and LPGs with different periods in SMF-28 fibre.

Fig. 1 shows the typical transmission spectra of four FBGs (top four) and LPGs (bottom four) with spectral response from $\sim 800\text{nm}$ to $\sim 2\mu\text{m}$. The spectra also show that as the LPG period increases, the coupled cladding modes red shifts to the longer wavelength side, also the Bragg wavelength increases as the grating period increases.

3. TEMPERATURE AND RI SENSING CHARACTERISTICS

3.1 Temperature sensing

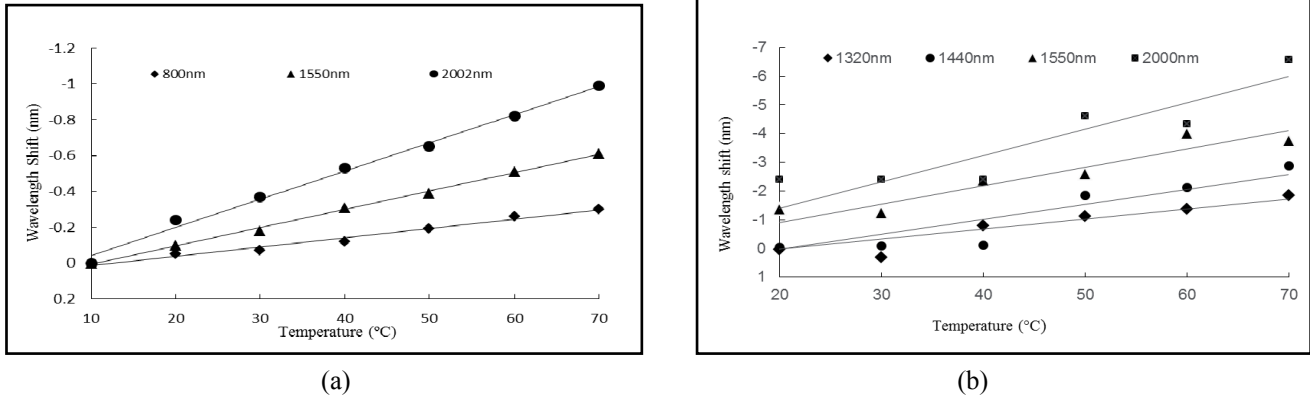


Figure 2. Comparison of (a) FBG and (b) LPG thermal responses.

The FBG sensing capability may be evaluated by monitoring the shift of the spectral response as the grating condition changes. As shown in Fig.2a, the temperature sensitivities for the three fabricated FBGs are $\sim 5.3 \text{ pm}/^\circ\text{C}$, $\sim 11.6 \text{ pm}/^\circ\text{C}$ and $\sim 14.8 \text{ pm}/^\circ\text{C}$ for 800nm, 1550nm and 2000nm regions respectively, and Fig.2b shows LP_{05} modes of the four LPGs exhibited higher sensitivity at longer wavelengths (2000nm) than shorter wavelengths (1320nm).

3.2 LPG RI sensing

In contrast to FBGs, LPG devices are sensitive to the external change in RI due the coupling to the cladding modes. High order modes are expected to be more sensitive to changes in the environment. Fig.3 shows that the LPG response in the $2\mu\text{m}$ region has a sensitivity of $357\text{nm}/\text{RIU}$ and higher than the other three modes at shorter wavelengths (e.g. at 1500nm, RI sensitivity is about $70\text{nm}/\text{RIU}$).

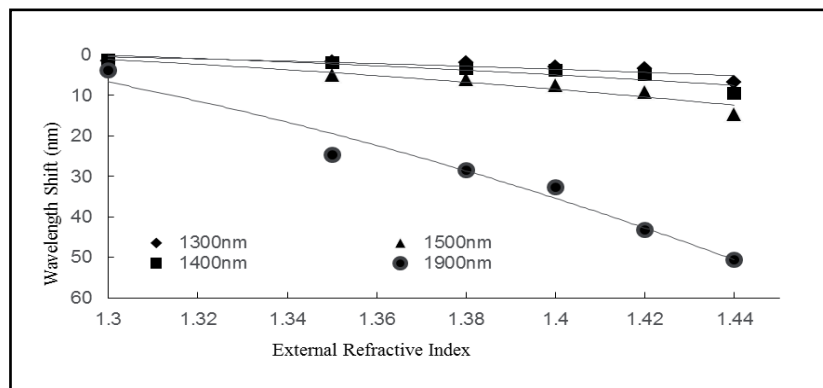


Figure 3. LPG refractive index sensing result for different wavelength regions and the mode at 1900nm shows a much higher sensitivity.

4. BIO-SENSING APPLICATION

4.1 Foetal bovine serum degradation monitoring

Foetal bovine serum (FBS) is a part of the plasma that remains after blood coagulation. FBS is made up of numerous components, some of which are growth factors (cytokines, fibroblast and hormones) and protein used in cell culture media. In 1934, William Sunderman concluded that as the concentration of protein increases in serum, the RI also increases [2]. The method proposed in this paper to measure protein degradation at room temperature is by sensing these changes with an LPG device with LP_{05} at around 1550nm. The results can be seen below:

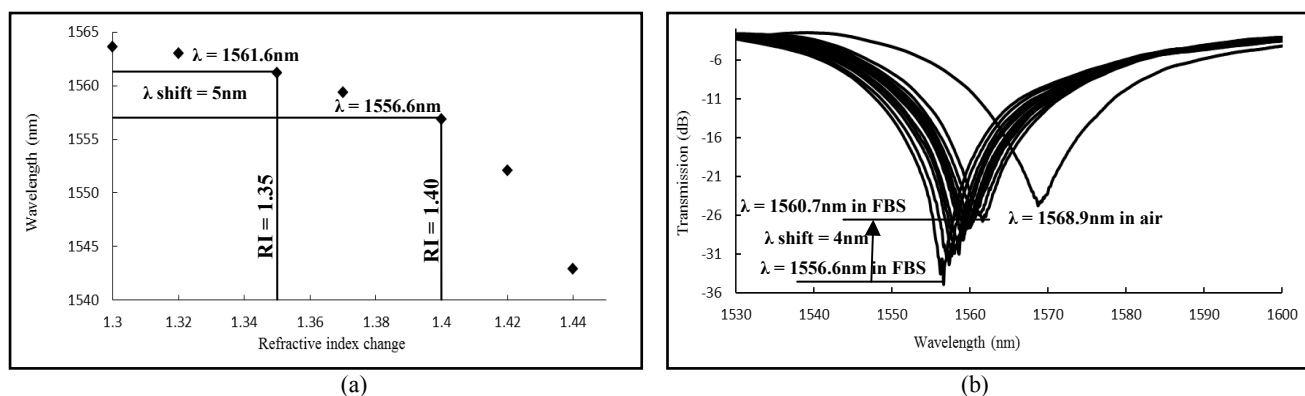


Figure 4. (a) RI calibration; (b) LPG wavelength shift with immersion in FBS.

About 0.5ml of FBS was transferred onto the LPG device, the wavelength shifts were then monitored over a period of time, which are then compared to a set of LPG refractive index calibrations as shown in Fig.4a. In air, the initial wavelength of the LPG was about 1568nm, with transmission intensity of about 24dB. Few seconds after the LPG device was immersed in FBS, the transmission peak experienced a blue-shift in wavelength to 1556.6nm (which corresponds to an RI of 1.40 from the calibration in Fig.4a). The spectral change was captured for about 15 minutes using auto-capture LabView software. It was observed that after few seconds at room temperature, the wavelength began to show a red-shift (to about 1560.7nm corresponding to an RI of 1.35) with a gradual reduction in the transmission intensity, as shown in Fig.4b. The result clearly shows that as the temperature of the FBS changes (from 4 °C to room temperature), its RI also changes. The shift and strength change of the LPG response when immersed in FBS is caused by the degradation of the component (proteins) of the FBS due to temperature change.

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