Temperature stabilized electrically tunable long period gratings coated with nanosized liquid crystal layer

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Abstract: Electrical spectral tuning of long-period gratings (LPGs) coated with high refractive index liquid crystal (LC) layer is presented. Temperature is stabilized at 60℃ to obtain a high sensitivity operating point. The tuning range is ～10nm.

OCIS codes: (060.2330) Fiber optics communications; (230.2090) Electro-optical devices; (050.2770) Gratings.

1. Introduction

In-fiber Long Period Gratings (LPGs) have been widely investigated for both sensing and communications applications [1]. They have the ability to couple energy from the core mode to different cladding modes with the same propagation direction. Various kinds of LPGs based optical devices have been reported [2, 3]. Recently, a detailed study was presented by Wang et al. [4] to investigate the LPGs sensitivity when they are coated with nm-thick films of refractive index higher than silica. The results showed that resonant wavelength of long period fiber can be shifted by a large magnitude by coated with only a nm-thick thin-film that has a refractive index higher than that of the glass cladding. More recently, a comprehensive theoretical and experimental investigation of the cladding modes re-organization in HRI coated LPGs is reported by Giordano [5]. Their analysis showed that by increasing the Surrounding medium refractive index, the transition from cladding to overlay modes occurred for a fixed overlay thickness and refractive index.

The effective refractive index of nematic liquid crystals can be controlled by thermal or electrical method. LCs exhibit both fluid and crystalline characters. The crystalline reorientation of LCs can be achieved by external applied fields. A nematic LC has uniaxial birefringent properties, and the optic axis can be realigned by means of an electric field. The optic axis is dependent on the average alignment of the molecules (director). When light polarization direction has an angle θ with respect to the director, the effective refractive index is then given by [6, 7]

$$n_{eff} = \left(\frac{\cos^2\theta}{n_{//}^2} + \frac{\sin^2\theta}{n_{\perp}^2} \right)^{-\frac{1}{2}}.$$

In this paper, we describe a simple scheme, illustrated schematically in Fig.1, for active electrical control and thermal stabilization tunable fiber gratings. Section 2 illustrates thermal spectral tuning of LC coated long-period gratings to obtain a high sensitivity operating point. Section 3 introduces electrical control when temperature is stabilized at a certain operating point.

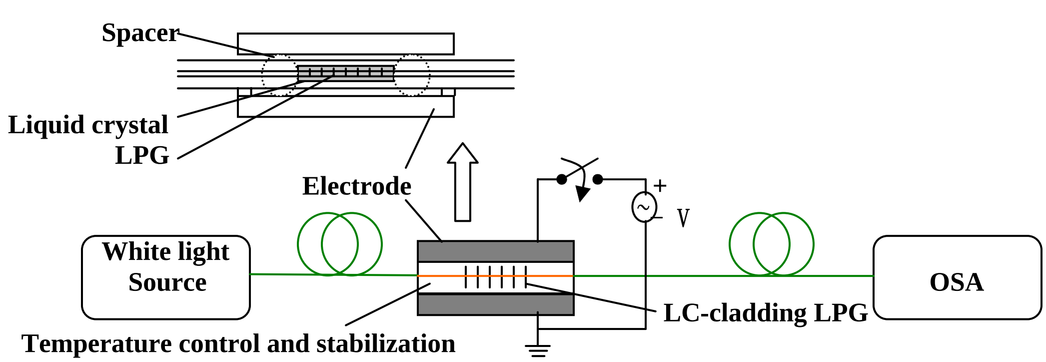


Fig.1. Experimental setup and schematic of the LC-cladding LPG.

2. Thermal spectral tuning of LC coated long-period gratings and the high sensitivity operating point

The LPG is fabricated using CO2 laser irradiation on Corning SMF28 fibers, with the grating period of 620μm, the grating region of 50mm. Attention bands have been investigated in the range of 1400-1700nm by using a white source in 400-1800nm wavelength range and an optical spectrum analyzer to record the spectral response of the device. The analysis is focus on the LP02 and LP03 cladding modes.

Nanosized liquid crystal cladding material MDA-98-3699 (from Merck) has a n_0 larger than silicon. A heater is used to increase the temperature of the liquid crystal from 20ºC to 65ºC. The refractive index of the liquid crystal in the infrared light region at temperatures between 20ºC and 65ºC have been measured. The measured indices of refraction are shown in Fig.2.

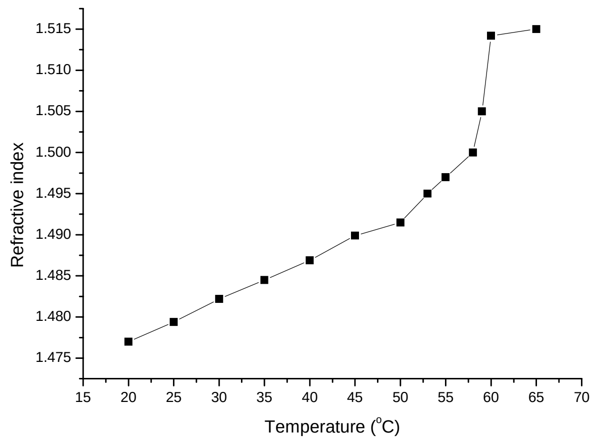
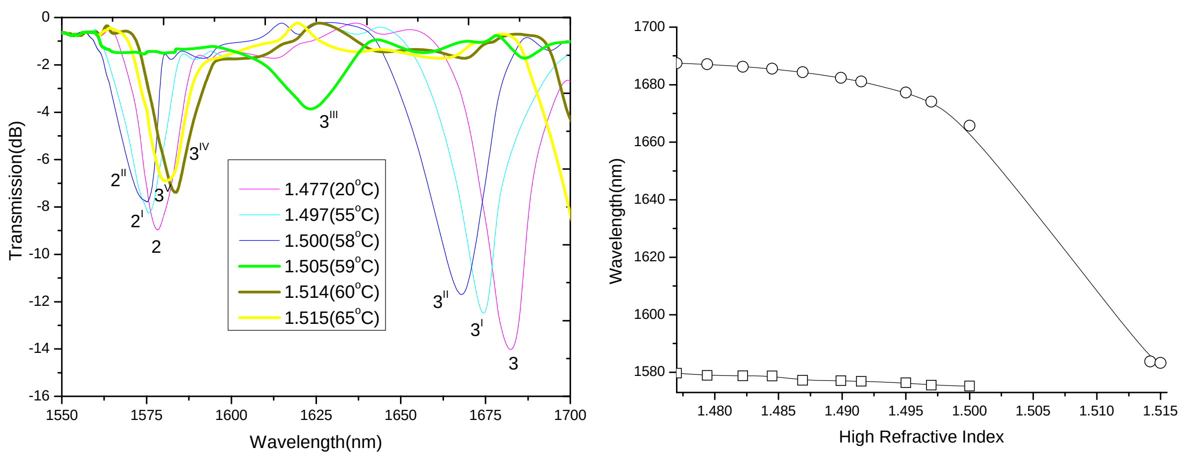


Fig.2. Refractive index versus Temperature (ºC) of LC MDA-98-3699 in the infrared light region.

Fig.3(a) reports the transmission spectrum of the ultra-thin LC coated LPG for different temperature. In the figure, the LP_{0i} mode has been marked with i, i', and so on for the different HRI. As observable, a slight wavelength blue shift is achieved due to the increases of HRI from 1.477 to 1.5, i.e., temperature from 20 ºC and 58ºC. When temperature exceeds 58 ºC, a large wavelength shift in the attenuation band of LP_{03} mode is observed. It is worth to note that the high sensitivity region appears when HRI is changed from 1.500 to 1.514. A more clear comprehension of attenuation bands behavior is provided in Fig.3(b), where the wavelength shifts are reported. Outside the sensitive region, the center wavelength is shift from 1579.7nm to 1575.2nm in the attenuation band of LP_{02} mode and from 1687.5nm to 1665.7nm in LP_{03} mode. Within the sensitive region, i.e., when temperature is changed from 58ºC to 60ºC, only LP_{03} mode can be observed in the investigation range of 1400-1700nm with its center wavelength shifting from 1665.7nm to 1583.7nm, which changed 82nm. The center wavelength shifts over a small LC layer refractive index range, which means we can choose a high sensitivity operating point in this sensitive region.

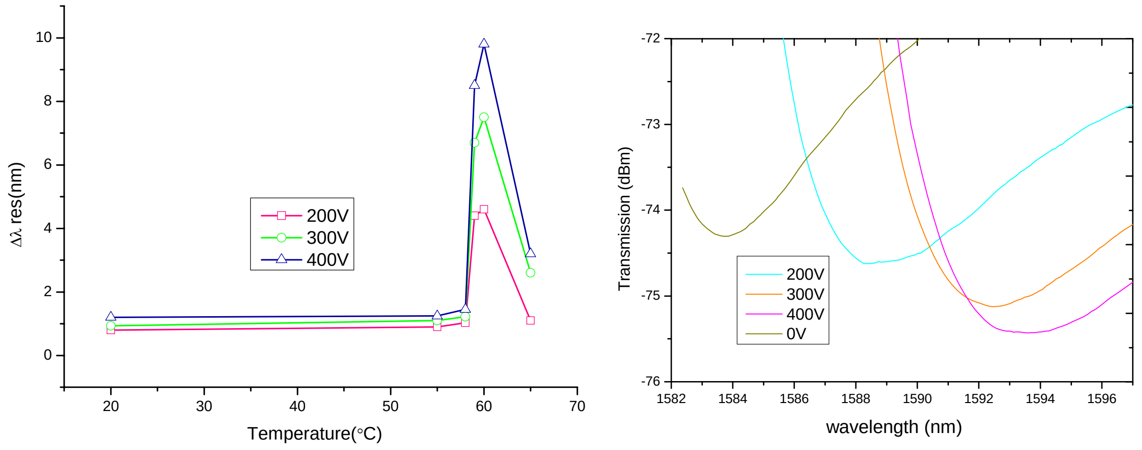


(a) (b)

Fig.3. (a) Transmission spectra of a ultra-thin HRI Liquid crystal coated LPG for different temperature in the range 20 ºC -65ºC. (b) Wavelength shift of LP_{02} and LP_{03} cladding modes for the LPG coated with high refractive index layer.

3. Electrical spectral tuning of LC coated long-period gratings at the high sensitivity operating point

The LC coated LPG is aligned between two substrates parallel to each other. The gap is maintained using 125-µm-thick spacers. The external electric fields are applied using two parallel electrodes. Temperature is stabilized at 20 ºC, 55 ºC, 58 ºC, 59 ºC, 60ºC and 65 ºC respectively. Attention bands have been investigated in the range of 1500-1600nm. Fig.4(a) shows the electrical spectra tunability of the LC-cladding LPG at different temperature. From the figure, we know that 60 ºC is the most sensitive operating point in the high sensitive region when temperature is changed from 58 ºC to 60 ºC. Fig.4(b) reports the transmission spectra of the LC coated LPG according to the applied voltage at 60 ºC. The center wavelength shifts from the initial 1583.7nm to 1588.3nm, 1591.2nm and 1593.5nm when the external voltage is applied up to 200V, 300V and 400V, respectively. The tuning range is about 10nm. The applied voltage is high and the tuning range is relatively small because of the thick gap. However, the problem can be solved by etching the fiber to reduce the diameter to a smaller value.



(a) (b)

Fig.4. (a) Electrical spectra tunability of the LC-cladding LPG at different temperature. (b)Transmission spectra of the LC coated LPG according to the external applied voltages at 60 ºC.

4. Conclusion

This paper presents a preliminary research focused on achieving electrical spectral tuning of long-period gratings (LPGs) coated with high refractive index (HRI) liquid crystal (LC) layer for potential applications in optical devices and optical communications. We propose an LPG structure based on a standard optical fiber with LC claddings. Experimentally, it was proved that the LPGs can have a high spectral sensitivity to the external voltages changes by choosing an appropriate operating temperature.

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