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Optimization of a Long Period Grating distal probe for temperature and refractive index measurement

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Abstract

Long Period Gratings (LPG)-based sensors are widely used due to their higher sensitivity to various measurands. However, a single grating based LPG sensor system has the disadvantage of the probe being used in transmission mode due to the broad bandwidth of the attenuation bands formed by propagation mode coupling between core-cladding modes and hence a difficulty in use when acting as a typical sensor probe. To overcome these limitations, a Michelson Interferometer type sensor configuration is considered using a LPG grating pair formed by coating a mirror at the distal end of the LPG. This sensor configuration is more convenient and able to overcome the limitations of the single LPG sensor with the shifts in the attenuation bands thus easily detectable. To configure the probe in the most suitable way, a series of tests has been carried out to determine the optimum distance between the LPG and the mirror coating for a typical grating of period 250µm. The sensor is then used for temperature and refractive index calibration and the results presented show the detection scheme of the sensor probe thus optimized.

Keywords: Long Period Grating (LPG), Self Interfering Long Period Grating (SILPG), Michelson Interferometer

1. Introduction

A long-period grating (LPG) is a periodic perturbation, typically in the order of several hundreds of micrometers, of the refractive index along the core of a length of a photosensitive fiber, created by irradiating the fiber using UV light which is a useful alternative to the Fiber Bragg Grating (FBG) as the active element of a sensor probe. It is well known that when the LPG is connected to a broadband light source, the LPG enables coupling of light from the propagating core mode to the co-propagating cladding

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modes at discrete wavelengths, therefore producing several attenuation bands in the transmission spectrum. The resonance wavelength, λ_{res}, for the loss band can be obtained as[1],

$$\lambda_{res} = (n^{eff}_{core} - n^{eff}_{clad,m})\Lambda \tag{1}$$

where n^{eff}_{core} and $n^{eff}_{clad,m}$ are the effective refractive indices of the fundamental core mode and the mth cladding mode respectively and Λ is the grating period of the LPG.

This sensitivity can be employed in the development of sensor probes for several important parameters. The refractive index (RI) sensitivity of the LPG arises from the dependence of the resonance band on the effective RI of the medium in which the cladding modes propagate. This effective RI results from a contribution from both refractive indices of the cladding and its surrounding medium. The influence of the variation in the RI of a medium surrounding the cladding of a LPG can thus be expressed as[2],

$$\frac{d\lambda}{dn_{sur}} = \frac{d\lambda}{dn^{eff}_{clad,m}} \frac{dn^{eff}_{clad,m}}{dn_{sur}} \tag{2}$$

where λ is the wavelength of the attenuation band and n_{sur} is the RI of the surrounding material. If the grating is dipped in a liquid for example, a change in the concentration of the liquid would lead to a RI change in the solution which means a RI change in the surrounding medium of the coated LPG. As can be seen from equation 2, such a change in the RI of the surrounding medium would induce a wavelength shift in the attenuation bands of the modes in a LPG placed in the medium.

These effects can be seen when the LPG is used in a fiber in the normal transmission mode but this is inconvenient for a probe where the active element is usually placed at the distal end of the fiber. To overcome this, a simple configuration is shown where the LPG-based Michelson interferometer that formed the basis of the sensor itself was created by coating the end surface of the fiber containing the LPG with a Silver mirror in a "folded" interferometer configuration. To create this, the fiber was cleaved and coated with a layer of silver and a schematic diagram of the probe is shown in Figure 1.

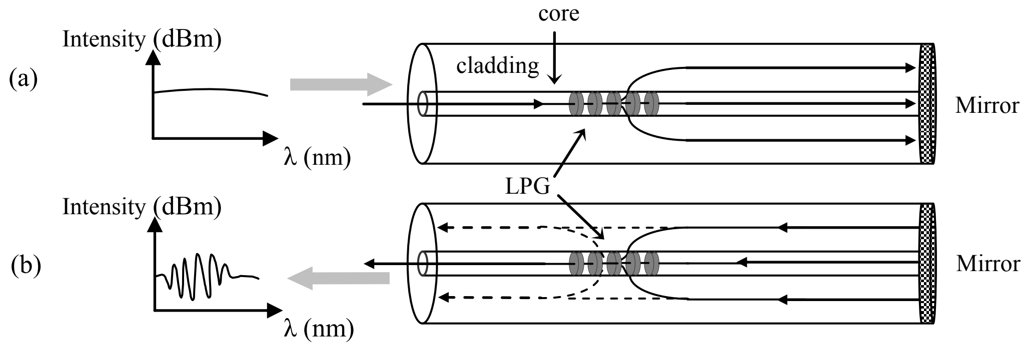


Figure 1 - Light propagation in the SILPG (a) forward propagation path (b) propagation path of the reflection

This type of arrangement is analogous to a Michelson interferometer and this is termed a self-interfering long-period grating (SILPG)[3]. Light propagating through the fiber encounters the LPG and part of the optical power couples into the cladding mode, while the residue remains in the core and propagates as the fundamental core mode. Reflection occurs when the two portions of light encounter the silver mirror coated at the end of the LPG. This result in both light waves retracing their path back and they are combined at the LPG from opposite directions, where once again coupling takes place. This second-time coupling creates complex modal interactions [4]. The differences in the optical path lengths in the SILPG produce a phase shift in the reflected spectrum which creates a fringe pattern. Therefore, a refractive index variation in the medium surrounding the SILPG would incur a defined shift in the interference fringes. This summarizes the optical technique which is employed in the sensor design presented here. It is important to be able to optimize such a sensor – to ensure that for convenience of use the active element of the probe is as near the end of the fiber as possible and to maximize the response of the device. The sensitivity of SILPG sensor can be tailored by optimizing the length of the cavity between the LPG and the mirror, since the nature of the interference pattern created depends on this optical path difference.

This work aims to explore this optimization of the mirror configuration to offer a better detection of the shifting attenuation band and thus probe response. The sensitivities of the SILPG to variations in temperature and external refractive index are demonstrated and compared to that achieved with the performance of a bare LPG.

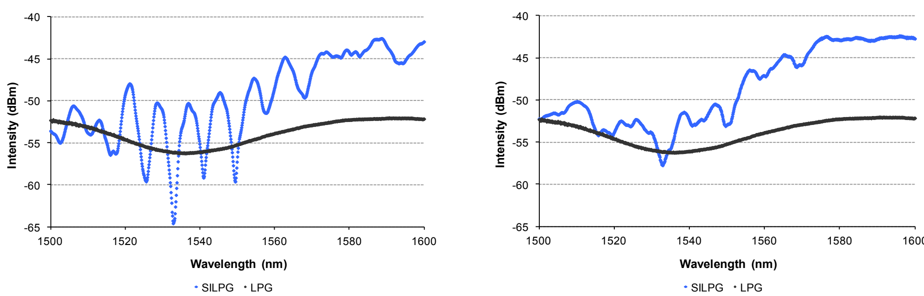
2. Experimental Procedure

The grating period of the LPGs used in this work was 250µm and upon fabrication, the LPGs were annealed at 100°C for 15 hrs. One end of the bare LPG was connected to a SLED (1550nm), and the other to an Optical Spectrum Analyzer. Sensitivity to both temperature and refractive index were investigated, although probes of this type can be configured for other parameters. For comparison, the bare LPG was first subjected to a temperature variation using an environmental chamber from 0°C to 100°C in steps of 5°C before the mirror was coated. Then it was subjected to a refractive index calibration for the range of 1.30 to 1.60 using oils (supplied by Cargille Laboratories) of known refractive indices.

After the tests were carried out on the bare LPG, a silver mirror was coated at the distal end of the fiber containing the LPG in order to create the Michelson interferometer arrangement. The end of the fiber containing the LPG was cleaved using a high precision cleaver and the mirror was coated at the tip of the fiber using a chemical technique with Tollen's reagent. This process was repeated for each length between the grating and the mirror, from 50mm to 100mm in steps of 10mm. The same temperature and refractive index calibration was performed on the SILPG to enable a close comparison of the results.

3. Results and Discussion

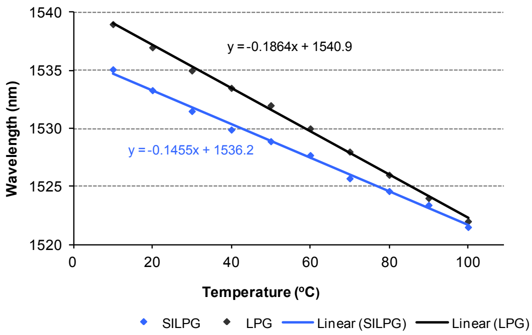
Fig. 3 shows results when the mirror coating was placed at fixed distances of 80mm and 70mm from the centre of the LPG. As can be seen from the figure and from spectrum produced, the reflection spectra obtained for 80mm offered the optimum interference for the SILPG. Figs. 4 show the performance of both the bare LPG and the SILPG configuration to variations in the two important parameters considered, the temperature and external refractive index.



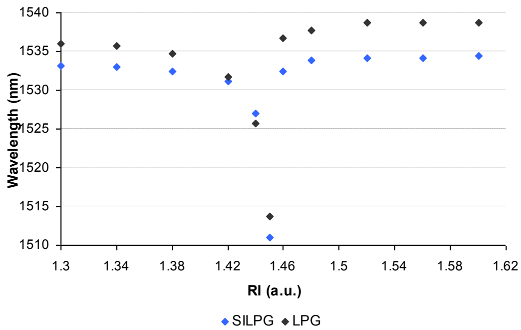
(a) (b)

Figure 3 – The reflection spectra of the SILPG for (a)80 mm and (b)70 mm between the grating and the coated mirror

It can be seen that while the SILPG configuration offers a considerable increase in convenience of detection as it can be used as a probe which can be 'dipped' into the medium under study, in the optimized configuration (at 80 mm separation) the sensitivity of the device does not differ greatly from that of the more inconvenient LPG used in transmission mode. It was also observed that the potential measurement resolution of the SILPG would be much higher than that of the LPG due to its narrower bandwidth, offering the potential for a higher resolution in the measurand.



(a)



(b)

Figure 4 – (a) Performance of the LPG and SILPG probe to variations in temperature and (b) Performance of the LPG and SILPG to variation in the external refractive index

4. Conclusion

In this work, an experimental evaluation was conducted for the two conditions of a bare LPG and a folded Michelson interferometric setup using a SILPG. It is observed that the SILPG setup could be used in reflection mode offering a greater advantage of being used as a sensor probe without any degradation of performance.

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