Design and development of compact sensing head based on single long period fiber grating for simultaneous temperature and strain measurements

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ABSTRACT

Long period gratings have been fabricated by using an indigenously developed set-up based on CO_2 laser and point by point grating writing method. In this paper, we are presenting a design of a compact single LPG based sensor head whose two neighboring resonant wavelengths show different sensitivities to strain and temperature. 1cm long LPG was written in SMF-28 corning fiber with a period of 650 micron with optimal energy and pulling tension. Once the desirable spectral features are achieved in the first step, the energy and pulling tension are increased and grating writing in second step is continued with the same period without physical separation in between to complete the process of compact device head of length 1.5 cm. One peak is highly sensitive to strain while the other is insensitive to strain.

Keywords: Long period grating, Optical sensors, temperature and strain measurements

1. INTRODUCTION

Optical fibre sensors have a number of advantages over conventional electrical counterparts such as immuninty to electromagnetic fields; ability to take many measurement points along a single fibre - greatly improving the ease at which sensors can be multiplexed; and can be embedded within or bonded to structures without the risk of de-bonding during operation. Optical fibres are advantageous as they offer remote operation.

There are two types of gratings inscribed in fibre viz., Bragg gratings whose periodicity is approximately 250- 500 nm and long period gratings having period of 100-1000 μm. Bragg Gratings have very high dynamic measurement capability but requires elaborate fabrication system. LPGs are based on the phase-matching condition between the guided and cladding modes in an optical fibre. Light launched in guided core modes interact with specific LPG cladding modes depending upon phase matching condition and exchange energy. The cladding modes propagate over short distances in the cladding before being attenuated by glass to air interface refraction in the fibre, we find attenuatation of broadband coupled light at specific wavelengths called as resonance peaks. The most significant property of these fiber gratings are their propagation characteristics, which are strong functions of the refractive index of the medium surrounding the cladding (environment effect). LPG based sensors have limited multiplexing capability but are easier to fabricate. A novel optical temperature and strain sensor based on in-fibre grating is developed as competitor to the traditional electrical gauge.

Phase matching between the mode propagating in the core of the fibre and a forward-propagating cladding mode is achieved at the wavelength, λ, which is given by [1]

$$\lambda = \left[\eta_{eff}(\lambda) - \eta^{i}_{clad}(\lambda)\right]\Lambda \qquad (1)$$

where $\eta_{eff}(\lambda)$ is the effective refractive index of the propagating core mode at wavelength λ, $\eta^{i}_{clad}(\lambda)$ is the refractive index of the i th cladding mode and Λ is the period of the LPG. The smallest transmission of the attenuation bands is governed by the expression[2]

$$T_i = 1 - Sin^2(k_i L) \qquad (2)$$

where L is the length of the grating and k_i is the coupling coefficient for the i th cladding mode, which is determined by the overlap integral of the core and cladding mode and by the amplitude of the periodic modulation of the mode propagation constants. The temperature sensitivity of the coupling wavelengths arises because of the difference between the thermo-optic coefficients of the cladding and core.

In this paper, we are presenting a design of a compact single LPG based sensor head whose two neighboring resonant wavelengths show different sensitivities to strain and temperature. This overcomes some of the drawbacks of the existing designs. Based on this idea, compact LPG based sensor heads have been designed, fabricated and analyzed for simultaneous measurement of temperature and strain.

2. METHODOLOGY

For present work, standard telecommunication grade fibre (CORNING SMF28) is used. Polymer jacket of the fibre is removed chemically. Home built CO_2 laser (Max power 20 Watt) is focused onto the unjacketed fibre held between a 10 μm resolution translation stage and a fibre holder as shown in figure 1. The fibre is exposed to CO_2 laser for predetermined period and then translated by the required grating period, in present experiment 650 μm for next exposure. Long period gratings have been fabricated by using an indigenously developed set-up based on CO_2 laser and point by point grating writing method. Physical properties of LPGs that can be altered during the fabrication process are the amplitude of index modulation, length and period of the grating. In the corresponding transmission spectrum, these parameters directly affect the resonance wavelengths, the intensities of each grating peaks and bandwidths[3] .
To implement the sensor head, a 1cm long LPG was written in SMF-28 corning fiber with a period of 650 micron with optimal energy and pulling tension. The evaluation of LPG spectrum was observed on-line using optical spectrum analyzer (Agilant OSA 8612). Once the desirable spectral features are achieved in the first step, the energy and pulling tension are increased and grating writing in second step is continued with the same period without physical separation in between to complete the process of compact device head of length 1.5 cm. The fibre is mounted on heating plate as shown in figure 2. And signal is monitored on OSA at various temperatures ranging from 25 ^{0}C to 85 ^{0}C and 0 to 1500 με.

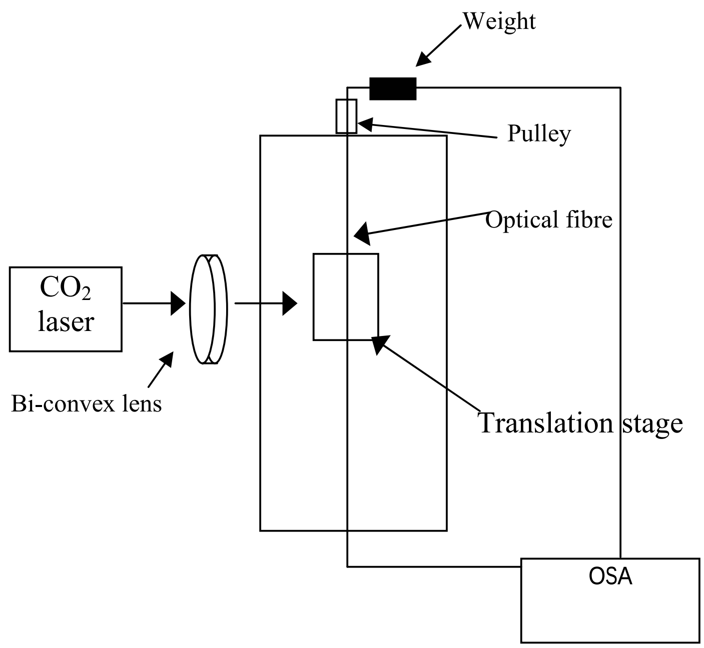

Fig 1: Experimental set up for the writing long period gratings (LPGs)

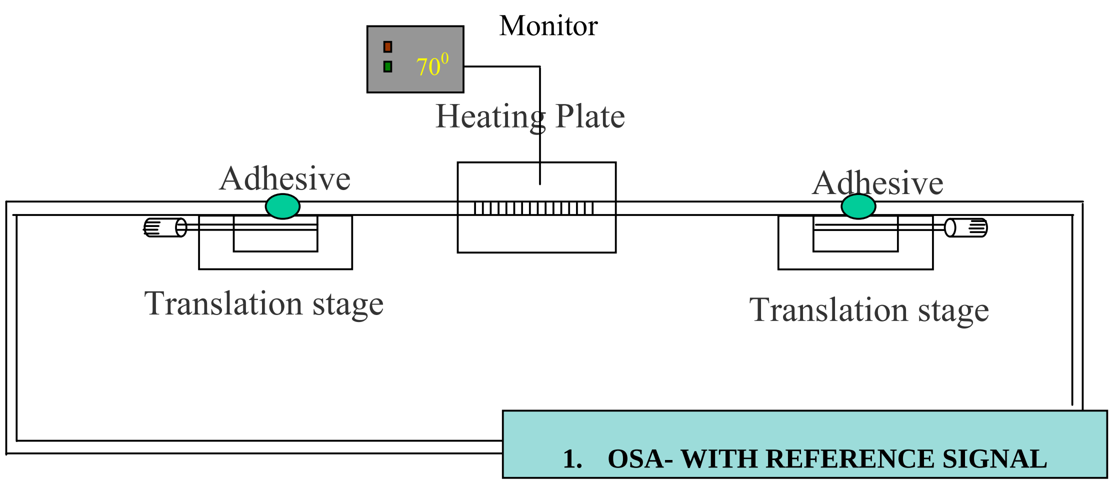

Figure 2: Experimental setup for testing thermal and strain sensitivity of LPGs

3. RESULTS

Figure 3 shows transmission spectrum of the fibre with and without grating. Here non-grating curve shows source signal as it is collected from a fibre without grating. Grating curve is the spectrum when signal is collected from fibre with 24 mm long grating of period 650 μm. Ratio curve is the ratio of the signal obtained from grating fibre divided by spectrum obtained for non-grating fibre. Figure 4 shows the transmission spectrum of two such sensor grating heads being evolved in two steps. By this process, we have selectively introduced sensitivities for strain and temperature between two resonance peaks. One peak is highly sensitive to strain while the other is insensitive to strain.

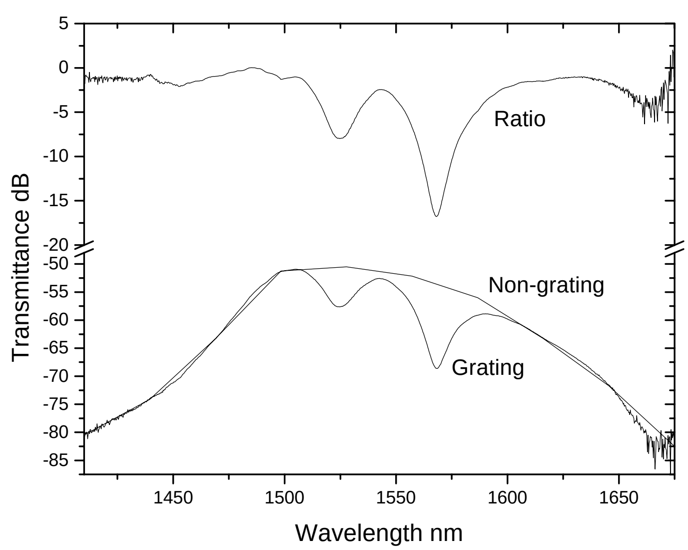

Figure3: Transmission spectrum of the fibre with and without grating

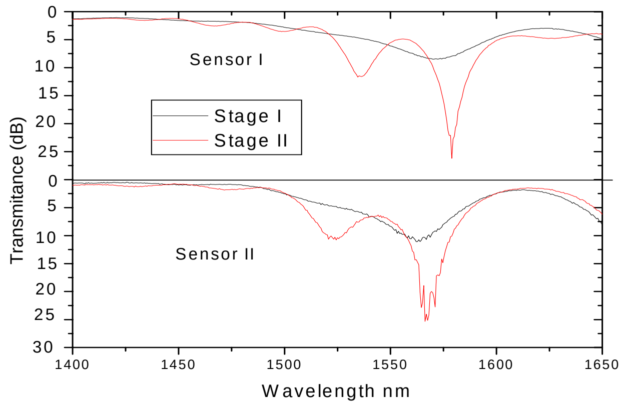

Figure 4: Evolving transmission spectrum of the LPG

The loss peak is shifted as temperature is changed or strain applied. Sensitivity is calculated as change in the position of loss peak for ^{0}C or με. Table 1 summarizes temperature and strain sensitivity of these fibres. Using this data, the matrix equation is evolved for simultaneous measurement of strain and temperature.

Grating Type	Grating Peak	Sensitivity	
		Temperature in nm /°C	Strain in pm/ με
Sensor I	1536	0.041	-1.02
	1578	0.067	-0.53
Sensor II	1525	0.067	0.2
	1568	0.051	-0.76

Table 1: Comparison of temperature and strain sensitivity of LPGs for resonant peaks.

4. CONCLUSIONS

Uniform long period gratings have been fabricated using CO_2 laser because of excellent beam quality. Novel two step grating method is used in producing two resonance peaks These peaks have different sensitivity to temperature and strain which may be used in simultaneous measurement of temperature using matrix method.

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