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Study of Long Period Grating as Strain Sensor

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ABSTRACT

In civil engineering , strain sensors have a very important role for monitoring of the civil infrastructure and buildings. The traditional electronic strain transducers suffer from large size, mediocre accuracy.. Long period grating based sensors provide good alternative and they cover all the shortcomings which affect the performance of traditional strain sensors. This paper will demonstrate the use of LPG as a single parameter strain sensor in which the applied strain can be estimated in relation to the shift in resonant wavelength.

Keywords: Fibre optics, long period grating, strain sensor, strain sensitivity

I. INTRODUCTION

Different type of strain sensors are used in civil engineering for estimating the strain and for monitoring purposes. Various techniques like acoustic, ultrasonic, radiography have been developed but they are not immune to electromagnetic interferences. Electrical strain gauges are also not suitable because they suffer from long term signal drift so they are not very stable

Now days Fibre optic sensors are the new alternatives and have provided an excellent choice to civil engineers because of their small dimensions, good[1] resolution and accuracy, and excellent ability to transmit signal over long distances They are immune to electromagnetic and radio frequency interference and may incorporate a series of interrogated sensors multiplexed along a single fiber. They are also suitable for internal strain measurements because they do not significantly affect the stress and strain states of the material in which they are embedded due to their small dimensions

There are basically two types of fibre optic sensors widely used Fibre bragg grating based sensor and long period grating based sensor. The fibre Bragg grating relies on detection of the shift in a reflected wavelength and relating it to the applied input. So Bragg grating based sensor has been proposed as tool for measuring strain. But its disadvantage is the limited strain induced wavelength shifts. So they require expensive spectrum analyzers or unbalanced inferometers for demodulation.

On the other hand Long period grating based sensors are more sensitive to the applied axial strain and hence can overcome the limitations related to the fibre bragg grating based sensors. Long-period gratings are easily multiplexed and implemented with simple demodulation techniques. Long-period gratings are based on the phase-matching condition between the guided and cladding modes in an optical fibre. Light launched in a guided core mode interacts with the long-period grating and is converted into a number of cladding modes. These modes propagate over short distances in the cladding before being attenuated by the lossy jacket and bends in the fibre. Due to these advantages it is more favourable to use Long period grating based strain sensors.

2. THEORY OF LPG

A long-period fibre grating (LPG) is a periodic modulation of the optical characteristics of an optical fibre, obtained by either inducing a physical deformation in the fibre material or by modifying the refractive index of the fibre's core. Compared to other optical devices,[3] LPGs have a number of unique advantages such as the fact that simple techniques are required to fabricate them, their compact construction(they are intrinsic fibre devices) and non-conducting (dielectric) structure that is immune to electromagnetic interference (EMI) .The basic principle of the LPG is to couple light from the fundamental guided mode (i.e. the LP_{01} mode present in the core) to other forward-propagating cladding modes (LP_{0m} mode with m =1, 2, 3, 4 ...) in the fiber with periodical variation of the RI is shown in Fig. 1.

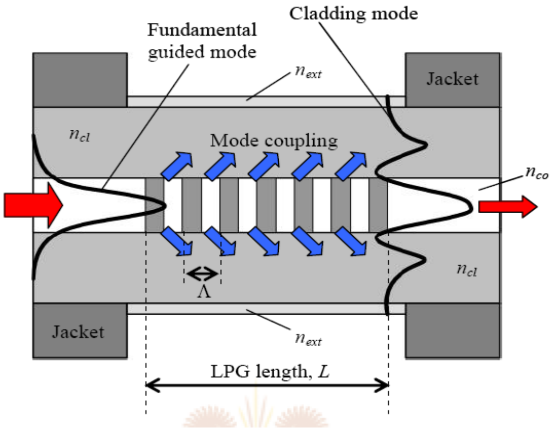

Fig 1: Coupling of a fundamental guided mode to a cladding mode in a long-period grating

The phase matching condition between the fundamental[2] mode and the forward propagating cladding mode for the long-period grating (LPG), is given by

$$\lambda_{res} = (n_{co}(\lambda) - n_{cl}^{m}(\lambda))\Lambda \qquad (1)$$

Where λ_{res} is the resonance wavelength, n_{co} is the effective refractive index of the core mode and n_{cl}^{m} is the effective index of the mth cladding mode. Λ is the grating period. This is the transmission spectrum for LPG in which there are different resonant peaks whose centre wavelength is decided by the phase matching condition which is different for different cladding modes. In this paper only lower order cladding modes are coupled to principle core mode .

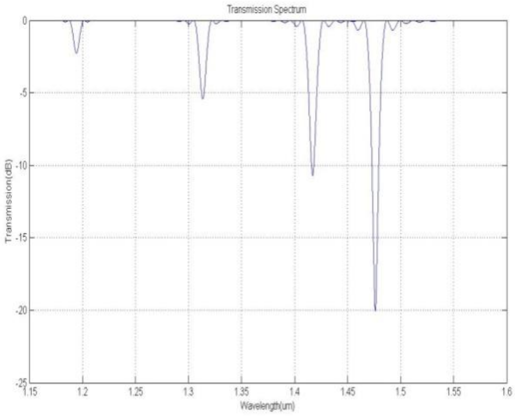

Fig 2: Transmission spectrum of a long–period grating

3. AXIAL STRAIN SENSOR

The axial strain sensitivity of LPGs may be assessed by differentiating phase matching condition with respect[3] to strain ε:

$$\frac{d\lambda_o}{d\varepsilon} = \frac{d\lambda_0}{d(\delta n_{eff})}\left(\frac{dn_{eff,co}}{d\varepsilon} - \frac{dn_{eff,cl^m}}{d\varepsilon}\right) + \Lambda\frac{d\lambda_o}{d\Lambda} \qquad (2)$$

Here the sensitivity comprises material effect and waveguide effects. Material effect. The material contribution to the strain-induced shift is a function of the change in the differential effective index with strain d(δneff)/dε, Axially straining a fibre changes the core and the cladding indices of refraction and the radii. The deviation in the value of these parameters from the unperturbed case serves to vary the differential effective index and results in the phase-matching condition being satisfied at a different wavelength[4]. strain-induced changes in core and cladding radii contribute significantly to the material effect.

The variation in the core and the cladding dimensions arises from Poisson's effect, which reduces the radii based on the following expression given by

$$\frac{dq}{d\varepsilon} = -\upsilon q \qquad (3)$$

where q = a, b for core and cladding radii respectively, and υ is Poisson's ratio for the corresponding material. For[5] the cladding of fused silica, υ = 0.17, and for the core of fused silica of fused silica with 3% GeO2, υ = 0.165.

The strain-induced change in the material refractive index is given by

$$\frac{dn}{d\varepsilon} = -n^3[p12 - (p11 + p12)]/2 \qquad (4)$$

where ,n_1 n_2 = for the refractive indices of the core and cladding respectively, and p_{ij} are the strain optic coefficients. For fused silica p11=0.12 and p12=0.27 and from the calculations, $dn_2/d\varepsilon$=-0.316 and $dn_1/d\varepsilon$=-0.3208. The material contribution is negative since the overall changes in the core and the cladding indices and radii produce an overall reduction in the differential effective index

The waveguide contribution increases with the period since gratings with large periods have higher slopes (d λd /Λ) of the corresponding characteristic curves. The effect is more pronounced for higher order modes and introduces a non-linearity in the wavelength shift. For[6] higher order cladding modes, waveguide effect dominates material effect but as the modelled LPG has lower order cladding modes coupled to principle core mode , therefore in our case material effect will dominate and hence we will get a negative strain sensor.

Now due to applied axial strain there will be change in the strain optic coefficients and also the dimensions of core cladding radii will change and hence a shifted spectrum with respect to strain is obtained

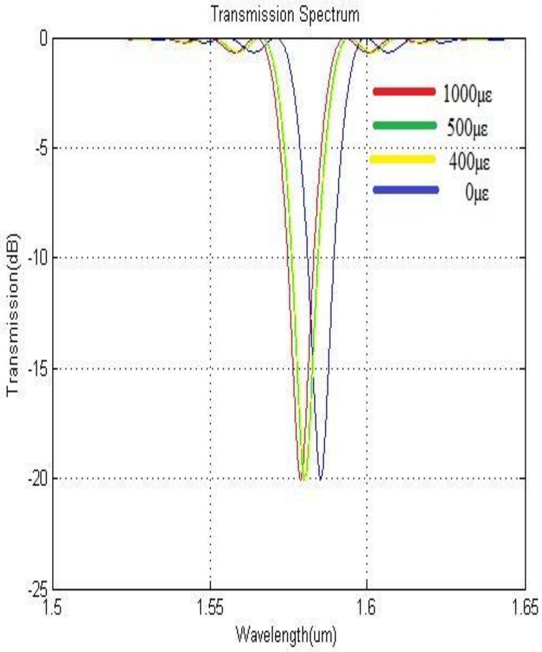

Fig3: Shift in transmission spectrum with strain

In fig 3 the resonant peaks are shifted to left with the application of strain, so the applied strain is directly proportional to the shift in resonant wavelength and hence a very effective strain transducer can be developed .

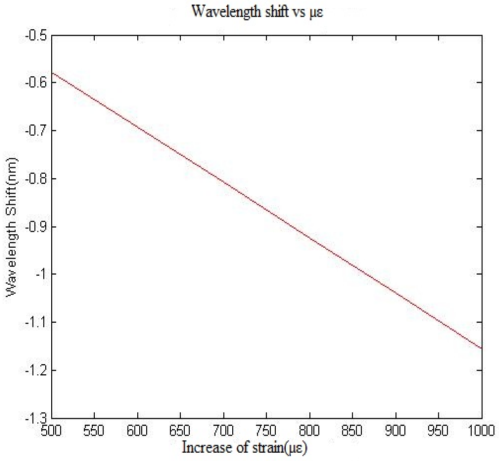

Fig4: wavelength vs strain

In fig 4 we can see the relation between the shift in wavelength with applied strain(500 to 1000με). The relation is a straight line but has negative slope, its sensitivity comes out to be 1.15×10^{-3}nm/ με .This sensitivity is better than strain gauge(0.56×10^{-3}/ με).

4. CONCLUSION

In this paper an axial strain sensor based on Long period grating is modelled which can be an effective alternative to the traditional strain sensors because of its high sensitivity and also it is has more advantage because of the non interference of electromagnetic and RF fields.

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