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Measurement of environmental parameter (i.e. Humidity) by using Bragg Grating Sensor for Structural Health Monitoring Application

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Abstract: ***Here in this paper we presented the modelling of FBG as humidity sensor for structural health monitoring application is geometrically designed in the wavelength window of 1.568-1.580µm. Simulation has been done by using optical software R-Soft (GratingMOD).***

Keywords: ***FBG, SHM, GratingMOD, Humidity.***

I. Introduction

Modelling and simulation are mathematical models that allow representing the dynamics of the system via simulation, allows exploring system behaviour in an articulated way which is often either not possible, or too risky in the real time. Fibre Bragg grating (FBG) sensors have been investigated intensively in the past few years due to its small size and robustness, ease of fabrication, suitability for use in multiplexed sensor networks and smart structures [2]. In this paper we represent the modelling of FBG for humidity sensor for structure health monitoring.

II. Fiber Bragg Grating

Consider a uniform Bragg grating formed within the core of an optical fibre with an average refractive index *n*0. The index of the refractive profile can be expressed as

$$n(z) = n_0 + \Delta n \cos\left(\frac{2\pi z}{\Lambda}\right) \ldots (1)$$

Where Δn is the amplitude of the induced refractive index perturbation (typically 10^{-5} to 10^{-2}) and z is the distance along the fibre longitudinal axis. Using coupled-mode theory [1] the reflectivity of a grating with constant modulation amplitude and period is given by the following expression

$$R(l,\lambda) = \frac{k^2 \sinh^2(sl)}{\Delta\beta^2 \sinh^2(sl) + s^2 \cosh^2(sl)} \ldots (2)$$

where $R(l,\lambda)$ is the reflectivity, which is a function of the grating length l and wavelength λ . k is the coupling coefficient, $\Delta\beta=\beta-\pi/\Lambda$ is the detuning wave vector, $\beta=2\pi n_0/\lambda$ is the propagation constant and finally $s^2 = k^2-\Delta\beta^2$. For sinusoidal variations of the index perturbation the coupling coefficient, k, is given by

$$k = \frac{\pi \Delta n}{\lambda} M_{Power} \ldots (3)$$

Where M_{power} is the fraction of the fibre mode power contained by the fibre core. In the case where the grating is uniformly written through the core, *Mpower* can be

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approximated by 1-V^{-2}, where V is the normalized frequency of the fibre, given by

$$V = (2\pi / \lambda) a \sqrt{n_{co}^2 - n_{cl}^2} \ldots(4)$$

Where a is the core radius, and nco and ncl are the core and cladding indices, respectively. At the centre wavelength of the Bragg grating the vector detuning is $\Delta\beta = 0$, therefore the expression for the reflectivity becomes

$$R(l,\lambda) = \tanh^2(kl) \ldots(5)$$

The reflectivity increases as the induced index of refraction change gets larger. Similarly, as the length of the grating increases, so does the resultant reflectivity.

III. Structural Health Monitoring

A typical health monitoring system is composed of a network of sensors that measure the parameters relevant to the state of the structure and its environment [2] Nowadays structural health monitoring is a fundamental tool to assess the behaviour of existing structures but also to control the performance of large new structures, foreseen to give information to monitor their lifetime. In this paper, the monitoring of humidity with optical fibre bragg grating sensors recorded in standard single mode optical fibers. Since FBG sensors are an all-in-fibre technology, they take advantage of the optical fibre properties, presenting also advantages over traditional electronic sensors due to the possibility to multiplex a large number of different sensors (temperature, displacement, pressure, pH value, humidity, high magnetic field and acceleration) into the same optical fibre, reducing the need for multiple and heavy cabling used in traditional electronic sensing.

IV. GratingMOD

R-Soft is an optical simulator in which one of the tools GratingMOD is used for design and simulation of grating [3]. Any type of waveguide structure that can be defined in the R-Soft CAD interface can be treated as perturbed or, unperturbed waveguide in GratingMOD. Perturbation can be applied to index, width, height and both in combination. GratingMOD can simulate multiple types of grating profile and also can include multiple apodization types. Analysis and Synthesis are the two tools for simulation which facilitate to complete information of light wave field inside core of the fiber with gratings. Analysis simulation gives the information of reflectivity and transmitivity, modes, B.W.

- GratingMOD derived *via* couple mode theory based on orthogonal modes.
- Report has been compiled to understand the CAD Tool for Fiber Bragg Grating Sensor.

V. Simulation

The FBG sensors were designed with core diameter 8 µm with refractive index of 1.47, and cladding diameter 125 µm with refractive index 1.44.The gratings were inscribed over a length of about 3000 µm. The magnitude of the photo-induced periodic modulation of refractive index inside the core is generally of the order of $10^{-5} – 10^{-2}$. The grating periodicity produced with this phase mask was approximately Λ=0.5365µm and N_{eff}= 1.464926 giving a

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baseline Bragg wavelength around 1.57174 nm.

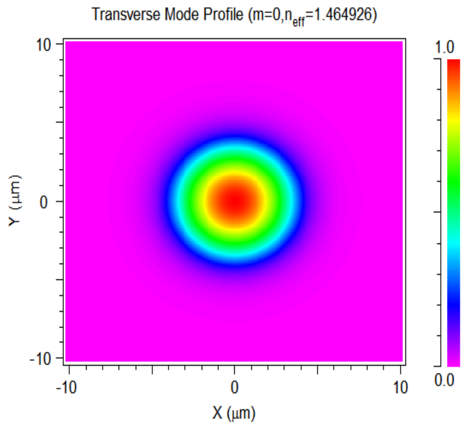

Fig1.Computed modes for the Bragg grating

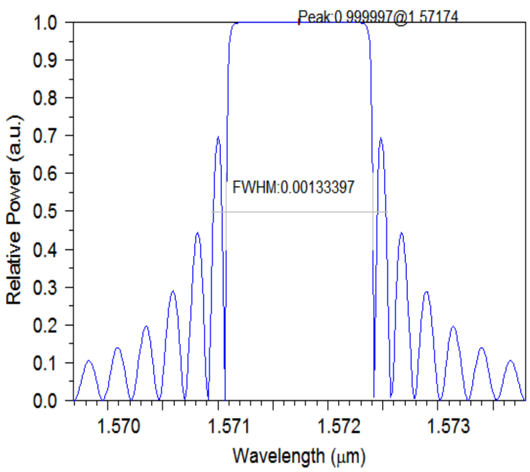

Fig2. Computed reflection spectra Bragg wavelength at 1.57174µm

Reflectivity increases as Grating length increases. For short period grating, concluded in paper [2], that for sensor application the reflectivity should be narrow spectral width.

The effect of elongating the optical fibre and thus the grating pitch has been simulated by taking the output graphs by varying the grating pitch from 0.5365µm to 0.540µm in regular intervals of 0.00035µm. Simulation results in the form of graphs of reflected power as a function of wavelength. From iterations it has been established that at a grating pitch of 0.5365µm, maximum reflected power is recorded at wavelength of 1.550µm.

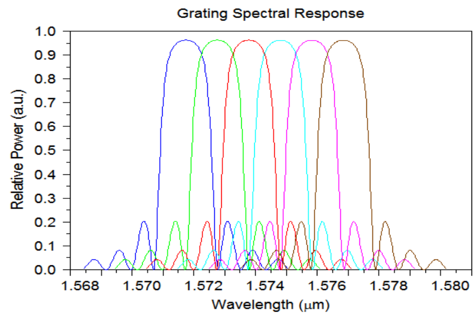

Fig3-Grating periodicity produced with this phase mask was approximately Λ=0.5365µm

Humidity Sensitivity

Humidity refers to the water vapour content in air or other gases and its measurements can be stated in a variety of terms and units. The three commonly used terms are absolute humidity, relative humidity (RH) and dew point. Absolute humidity is the ratio of the mass of water vapour to the volume of air or gas. It is commonly expressed in grams per cubic meter. Dew point, expressed in °C or °F, is the temperature and pressure at which a gas begins to condense into a liquid. The ratio of the percentage of water vapour present in air at a particular temperature and pressure to the maximum amount of water vapour the air can hold at that temperature and pressure is the relative humidity.

One of the most frequent causes of infrastructure deterioration is the corrosion of concrete, in which water causes damages to structures. The ingress of water acts as a transporting vehicle for aggressive agents, such as chloride and sulfate ions, that

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penetrate into the concrete by capillary force. Water is also a reaction medium in destructive chemical processes, causing the corrosion of the concrete steel rebar.

Relative humidity is the ratio of the partial pressure of water vapor in the air-water mixture to the saturated vapor pressure of water at those conditions. The relative humidity of air is a function of both its water content and temperature. Relative humidity is normally expressed as a percentage and is calculated by using the following formula. It is defined as the ratio of the partial pressure of water vapor (H_2O) in
the mixture to the saturated vapor pressure of water at a prescribed temperature.

$$RelativeHumidity(\%) = \frac{Actualvapordensity}{Saturatedvapordensity} \times 100$$

Low Temperature Levels

Now we consider the temperature range from 5°C -20°C. At these low temperature range, we obtain the relative humidity as shown in table below. The saturation vapor density is obtained from the database[4].

Temperature (°C)	Saturation vapor density (gm/m^3)	Actual vapor density (gm/m^3)	RH (%)
5	6.8	1	14.7058
10	9.4	2	21.276
15	12.83	7	54.559625
20	17.3	10	57.80346

Table 1. Relative humidity obtained at low temperature level

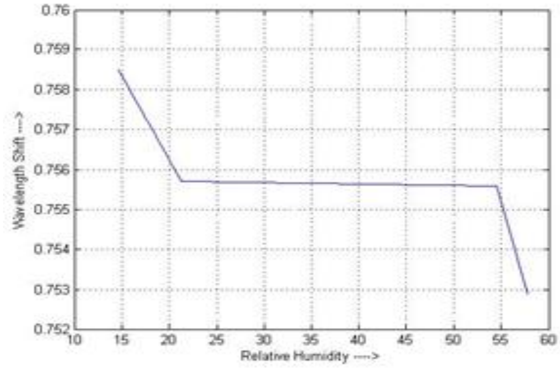

Fig 4. Plot of relative humidity vs wavelength shift at low temperature

As water relative humidity increases, the shift in wavelength decreases correspondingly as shown in fig 4 at the low temperature level.

Medium temperature level: Now we consider the temperature range from 25°C - 50°C. At these temperature range, we obtain the relative humidity as shown in table below.

Temperature (°C)	Saturation vapor density (gm/m^3)	Actual vapor density (gm/m^3)	RH (%)
25	23	15	65.2173913
30	30.4	20	65.7894
35	39.7520437	30	75.46781802
40	51.1	40	78.2778865
45	64.6066512	53	82.03489736
50	80.69	70	86.75176602

Table 2. Relative humidity obtained at medium temperature level

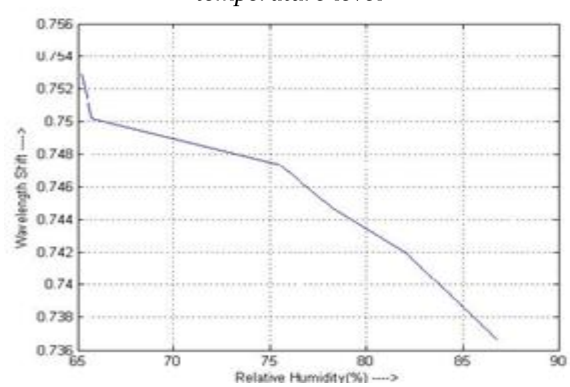

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Fig 5. Plot of relative humidity vs wavelength shift at medium temperature

As water relative humidity increases, the shift in wavelength decreases correspondingly as shown in fig 5 at the medium temperature level.

High temperature level

Now we consider the temperature range from 55°C -70°C. At these temperature range, we obtain the relative humidity as shown in table below.

Temperature (°C)	Saturation vapor density (gm/m^3)	Actual vapor density (gm/m^3)	RH (%)
55	99.5338087	90	90.42153734
60	130.5	120	91.95402299
65	146.408096	135	92.2080156
70	174.91	162	92.61906
80	293.8	280	95.30292716
90	328.16	310	95.98976
100	598	580	96.98996656

Table 3. Relative humidity obtained at high temperature level

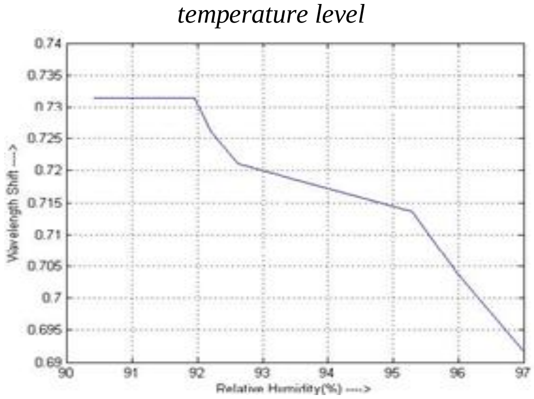

Fig 6. Plot of relative humidity vs wavelength shift at high temperature

As water relative humidity increases, the shift in wavelength decreases correspondingly as shown in figure 5.12 at the high temperature level.

VI. Conclusion

Simulation results show the design parameter at L=1500µm, reflectivity 97.26% and FWHM =1.04nm for optical sensor by using mod-grating toolbox to achieve narrow spectral response which is very much required for high sensitivity. The modelled simulated parameters implemented for temperature sensor in the range of 30-100°C for structural health monitoring.

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