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Improvement in temperature sensitivity of FBG by coating of different materials

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ABSTRACT

This paper presents the simulation results of coated Fiber Bragg Grating (FBG) as temperature sensor. As we know that bare FBG cannot be used as temperature sensor because they are made of silica and the thermal expansion coefficient of silica is very less. Hence bare FBG is less sensitive to temperature variation. To enhance the temperature sensitivity of the FBG sensor different types of materials are coated on FBGs whose thermal expansion coefficients are greater than that of silica. In this simulation Lead, Indium, Copper, Aluminium, and PMMA are coated on FBG and the simulation results are compared with the previous experimental work for the temperature range 50 K – 300 K. PMMA coated FBG sensor showed best sensitivity value among above coating materials.

1. Introduction

In the field of optical fibers sensors there has been an extensive research on FBG sensors for the measurement of different physical quantities such as temperature, pressure, motion, bending, and strain [2]. Temperature is the most frequently measured parameters in the industries for controlling different processes [8]. Available electronic temperature sensors are not able to measure the temperature in presence of strong electromagnetic field [1]. The applications of Fiber Bragg Grating temperature sensors are increasing day by day due to their special advantage like immunity to electromagnetic interference and polarization, light weight, low cost, wavelength encoded nature, etc. [3–5]. In the outer space structural health monitoring of satellite and space vehicles are main concern and FBG sensors are become extreme interest due to strong electromagnetic field generated by natural sources [7,18]. Bare Fiber Bragg Grating sensors cannot be used in measurement of temperature because they are made of glass or silica and the thermal expansion coefficient of which is very less [11,16]. Hence bare FBG is less sensitive to temperature variation. There are number of techniques incorporated to increase the temperature sensitivity of FBG. To increase the thermal sensitivity of FBG different type of materials are used as a coating on FBG whose thermal expansion coefficient is greater than that of silica and these coating materials act as driving element [11,12,14]. The thermal expansion coefficients of the coating materials are listed in Table 1. Fiber Bragg Grating temperature sensor is to be protected and the material coating is the best method to protect it [13,15].

In this paper Indium, Aluminium, Copper, Lead, and PMMA are chosen as coating material with the thickness of 20 μm on FBG sensor to improve thermal sensitivity of optical sensor and it is shown that thermal performance of coated FBG sensor is better than that of bare FBG. Due to the mismatch of thermal expansion coefficient of coating material and silica, stress is produced and leads to increase in the length more than that of bare FBG [5,6,11]. As the length increases the grating period also increases and thus more wavelength shifts occur [11].

Several experiments on coated FBG have been reported in [6,10]. Different types of metallic coated FBGs like ARCFBG, CRCFBG, LRCFBG, and IRCFBG which refers to Aluminium Recoated FBG, Copper Recoated FBG, Lead Recoated FBG, and Indium Recoated FBG, respectively are used and temperature characteristics are demonstrated in [10]. The temperature characteristics of PMMA coated FBG are demonstrated in [6] for different thickness and the compared with that of bare FBG.

The simulation results are compared with the above demonstrated temperature sensitivities and we got better value of temperature sensitivity. However to the best of our knowledge such value of sensitivity has not demonstrated yet.

The paper is structured in the following format. Section 1 gives a brief description on introduction and literature review. Section 2 throws some light on the theory behind experiment. Section 3 describes the simulation parameters for various coating on the FBG.

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Table 1
Thermal expansion coefficient of materials.

Material	Thermal expansion coefficient (m/m °C)
PMMA	61×10^{-6}
Aluminium	23.03×10^{-6}
Lead	28×10^{-6}
Indium	33×10^{-6}
Copper	16.6×10^{-6}

Section 4 shows the result of the simulation and graphs. Finally Section 5 deduces some conclusion from the performed simulation. A brief comparison is also shown in the same section.

2. Theory

The Bragg reflection wavelength λ_B of an FBG is given by [6].

$$\lambda_B = 2\Lambda n_{eff} \quad (1)$$

where, Λ is the grating spacing of FBG and n_{eff} is the effective refractive index of the core of the FBG.

The normalized temperature sensitivity of FBG at room temperature is given by [6].

$$\frac{\Delta\lambda_B}{\lambda_B \Delta T} = (\alpha + \xi) \quad (2)$$

where, ΔT is the change in temperature, α is the thermal expansion coefficient of silica equal to 0.55×10^{-6} and ξ is the thermo-optic coefficient of fiber material equal to 8.3×10^{-6}.

Hence temperature sensitivity depends mainly on thermo-optic coefficient for bare FBG. For a polymer coated FBG, a variation in the temperature causes variation in the grating period due to the thermal expansion of the fiber and the effect of strain induced which is proportional to thermal expansion of the polymer coating material [6,17]. The normalized temperature sensitivity of a polymer coated FBG is given by [6].

$$\frac{\Delta\lambda_B}{\lambda_B \Delta T} = [(1 - P_e)\alpha_{\ coating} + \xi] \quad (3)$$

where, P_e is the photo elastic coefficient and $\alpha_{coating}$ is the thermal expansion coefficient of coating material.

Above equation shows that temperature sensitivity of a polymer coated FBG is much higher than that of bare FBG. The temperature sensitivity is due to thermal expansion effect of coated material and the thermo-optic effect of the fiber material. The normalized temperature and strain sensitivity of metal coated FBG is given by [10].

$$\Delta\lambda_B = 2n\Lambda(1 - n^2/2)[P_{12-\upsilon}(P_{11} + P_{12})]\varepsilon + [\alpha + (\frac{dn}{dt})/n]\Delta T \quad (4)$$

where, α is thermal expansion coefficient of metallic coating, P_{11} and P_{12} are Pockel's coefficients, υ is Poisson ratio, ε is induced strain, and ΔT is change in temperature.

3. Simulation

The simulation of coated FBG as temperature sensor is done on GratingMOD tool of optical software R-Soft Cad version 2013.12. The simulation parameters of the generated Fiber Bragg Gratings are listed in Table 2.

4. Results and discussion

In this simulation, five different types of materials have been coated on FBG with a thickness of 20 µm and then characterized in simulation. The shift in Bragg wavelength of bare FBG, Copper coated FBG, Aluminium coated FBG, Lead coated FBG, Indium coated FBG, and PMMA coated FBG are shown in Figs. 1–6. The total shift in the Bragg wavelength for bare FBG sensor is 0.4 nm, copper coated FBG sensor is found to be 6.4 nm, aluminium coated FBG sensor 8.9 nm, lead coated FBG sensor 10.8 nm, indium coated FBG sensor 12.7 nm, and PMMA coated FBG sensor 23.5 nm in the temperature range of 50 K – 300 K. The results clearly showed that the bare FBG cannot be used as temperature sensor in this temperature range.

Table 2
Simulation parameters of FBG.

Simulation tool	GratingMOD
Grating type	Volume index
Structure type	Fiber
Index profile	Step index
Length	4000 µm
Height	5 µm
Width	5 µm
Modulation depth	0.0044
Delta	0.008

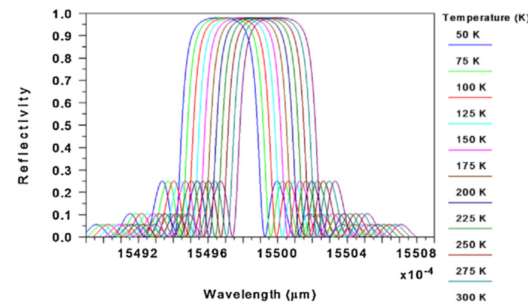

Fig. 1. Reflection spectra of bare FBG sensor at various temperatures.

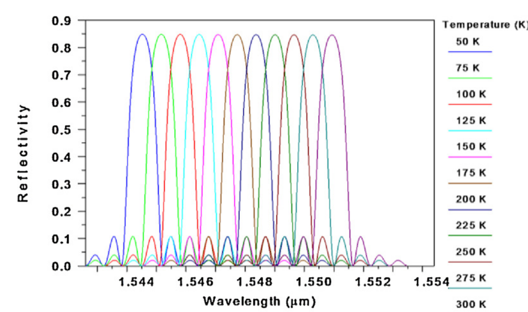

Fig. 2. Reflection spectra of copper coated FBG sensor at various temperatures.

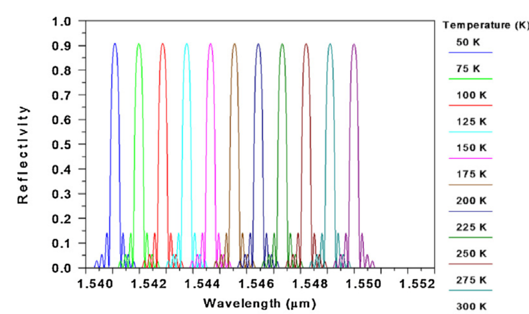

Fig. 3. Reflection spectra of aluminium coated FBG sensor at various temperatures.

Fig. 7 shows the comparison of temperature sensitivity of bare FBG and coated FBG that are obtained after simulation. The same is tabulated in Table 3. The obtained values of the sensitivities are compared with the literature. It is seen that the simulated results