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Performance Evaluation of Metal-Coated Fiber Bragg Grating Sensors for Sensing Cryogenic Temperature

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I Introduction

The ability to provide real-time information for superconducting (SC) magnets is an important diagnostic process for their effective design, construction and protection. Knowledge of the temperature and stress distribution inside the SC magnets could help the magnet designer to identify the exact location of the hotspot generated and the direction of its propagation. Electrical strain gauge (ESG), diodes and many other conventional electro-mechanical sensor systems have been reportedly used[1].

II Motivation and Objective

The use of Fiber Brgg Grating (FBG) sensors has advantages of miniature size and the possibility of accommodating many sensors in single fiber.

III Methodology

The Bragg reflection wavelength λ_B of an FBG is given as

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

where the Bragg grating wavelength, λ_B, is the free space centre wavelength of the input light which will be reflected by the Bragg grating, η_{eff} is the effective refractive index of the fiber core at the free space centre wavelength, and Λ is the grating spacing. The FBG is sensitive to strain due to linear expansion affecting the grating period and change in refractive index that results from the photo-elastic effect. Similarly, it is also sensitive to temperature due to thermal expansion and the thermo-optic effect of the fiber material[2].

IV Experimental Set-up

A Low Temperature Measurement

The testing facility was built to measure the temperature and strain response of the FBG sensors at low temperature of around 15 K. This paper deals only with the temperature characteristic of the sensors and hence care has been taken to ensure that the FBG sensor is mechanical strain free. The testing facility consists of an upper pneumatic control part and the lower test chamber. The test chamber is inserted into the cryostat which can be cooled down to 77 K using liquid nitrogen supply and to 4.2 K using liquid helium. The FBG sensor is installed through the feed-through. The FBG sensor for temperature measurement is left to hang freely inside the chamber to avoid any stress effect other than temperature.

B Magnetic Field Measurement

The magnet inside the cryostat is made of NbTi material. The magnet is cooled down to 4 K using liquid nitrogen and liquid helium. By applying 12.4 mA current, the magnetic field of 1 T was generated inside the cryostat. The magnetic field can be varied up to 8 T by varying the applied current up to 99.4 mA. The sensor sample is introduced in to the cryostat.

V Results

The FBG sensors were coated with different metals like Al (ARCFBG), Cu (CRCFBG), Pb (LRCFBG) and In (IRCFBG). These were then installed in the testing facility and the cryostat was cooled down to 4 K from room temperature. Fig. 1 shows the calculated sensitivities of the above sensors.

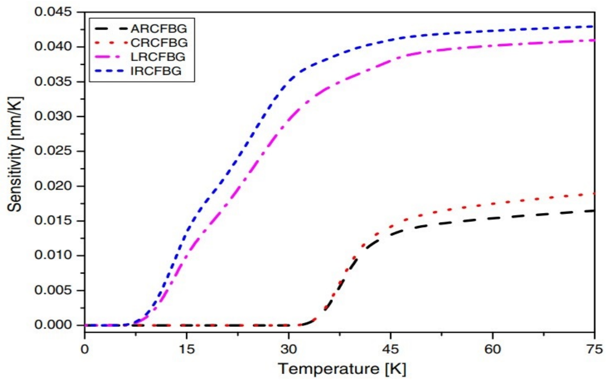

Fig. 1. Sensitivity of different metal-coated FBG sensors

It is clear that the IRCFBG sensor reaches a higher sensitivity at lower temperature of about 15 pm shift/Kelvin at 15 K. The IRCFBG sensor was then subjected to a varying magnetic field from 1 to 8 T. Fig. 2 shows that the sensor performance was not affected by the varying magnetic field.

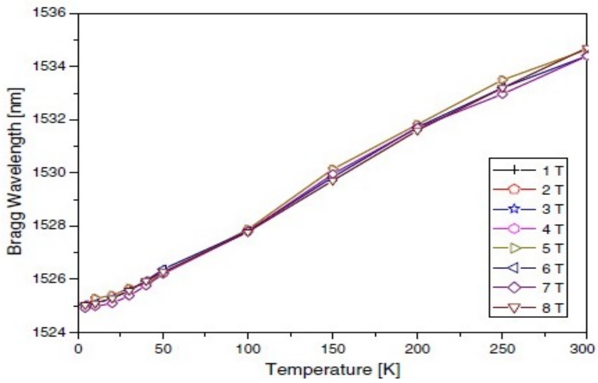

Fig. 2. IRCFBG sensor responses for varying magnetic fields

VI Conclusion

A metal recoated FBG has been designed, fabricated and tested to study its temperature response at 15 K. Metals like aluminium, copper, lead and indium are considered for recoating the sensors. IRCFBG sensor showed a higher sensitivity at around 15 K compared to Al, Cu and Pb coated FBG sensors. Also, it is not affected by the magnetic field of up to 8 T.

References

[1] V. J. Johnson, Properties of materials at low temperature(phase 1), Pergamon Press, (1961).

[2] A. A. Tracton, Coatings technology handbook, Marcel Decker, (2005).