Liquid level switch using Bragg grating

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A wavelength encoded liquid level switch and its fabrication is experimentally demonstrated using two inline fiber Bragg gratings (FBG). Cladding of one FBG is removed by etching and it makes the FBG to be refractive index sensitive. Thus FBG became an on-off switch sensor to control the liquid level. Another FBG is used for temperature compensation. The sensor has good repeatability.

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1. Introduction

A portable system for Maintaining the liquid level and temperature measurement finds applications in areas such as fuel storage and biochemical systems in modern industries. Over the years there has been many techniques developed for liquid level and temperature measurement [1]. Most conventional techniques are variable Resistive, capacitive electrical sensor, ultrasonic and mechanical float level sensor. Optical techniques are also adopted for the level control of highly inflammable liquids and chemicals [2]. Optical fiber sensing of level detection has many advantages like inherently nonconductive, low cost, longer life, remote sensing, multiplexing, and immune to EMI. Llko K. llev et al have measured the level with optical fiber using frustrated total internal reflection effect caused by the refractive index change of the surrounding medium[3]. An optical fiber refractometric liquid level sensor used for cryogenic liquid level measurement was described by Katya E Rormo-Medrano et al[4]. Liquid level also was sensed by side polished plastic optic fiber cable [5].

Wavelength modulation using FBG give good result for liquid level measurement. The principle of operation relies on the dependence of the Bragg resonance on effective refractive index (n_{eff}) and on the grating pitch (Λ) [6]. Temperature and level can be sensed by two FBG's proposed by Keisuke Fukuchi et al.[7]. Highly sensitive level sensing was proposed using etched FBG and side polished FBG [8, 9]. A FBG embedded in a cantilever for level measurement also was demonstrated [10]. Majority of the FBG based level sensors need elaborate mechanical arrangement and hence there is a need to develop a simple immovable arrangement for liquid level switch. In the present work, design of the sensor head and the sensor performance is demonstrated. The sensor is mainly designed to act as level switch for fuel tank.

The proposed model consists of a Broad band Source, two inline FBG's as sensors, circulator and optical spectrum analyser (OSA). Light from the source is launched into the fiber and directed to FBG's through circulator and the intensity and wavelength of the reflected light is measured using OSA. The cladding of one FBG is etched to a required thickness to enhance the refractive index(RI) sensing sensitivity. When the etched FBG is immersed into liquid a shift in wavelength is observed. This observation is exploited to make the sensor as a liquid level switch.

2. Principle

FBG is a periodic modulation of the refractive index in the core of a single mode fiber. The reflected Bragg wavelength (λ_B) is characterized by the grating periodicity (Λ) and the refractive index of the waveguide mode n_{eff}. The first-order Bragg condition is

$$\lambda_B=2n_{eff}\Lambda \tag{1}$$

The temperature sensitivity of the Bragg wavelength arises from the coefficient of thermal expansion (α) and the thermo-optic coefficient (ξ) of silica. The change in Bragg wavelength is given by

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

For silica, the values of α and ξ are 0.55×10^{-6} K^{-1} and 8.6×10^{-6} K^{-1}, respectively [11].

When the cladding part at FBG location is removed or sufficiently reduced n_{eff} is strongly affected by RI and a change in RI also causes a wavelength shift [12]

$$\Delta\lambda_B=2\,\Lambda\eta_{p0}\Delta n \tag{3}$$

η_{p0} is the fraction of the total power of the unperturbed mode that flows in the etched region when the etching process is complete, Δn is the difference between the cladding and the surrounding refractive indices. Changes in the surrounding refractive index also change the effective index of the core mode (n_{eff}) via the relation

$$\eta_{p0}\Delta n=neff \tag{4}$$

Most of the liquids have negative thermo optic coefficients and a temperature increase causes a decrease in the refractive index. As a result the contribution (eq.3) in this case is a negative wavelength shifts.

The RI changes with the temperature due to thermo optic effect. Therefore in etched FBG, the wavelength shift when the temperature changes is given by

$$\Delta\lambda_B = \Delta\lambda_T + \Delta\lambda_m \qquad (5)$$

where $\Delta\lambda_T$ is the contribution given by Eq.(2) and $\Delta\lambda_m$ accounts for the contribution given by Eq.(3).

3. Sensor fabrication and experimental setup

Two FBG's of 3mm length (FBG1 and FBG2) were written in a Fibercore SM1500 (4.2/80) fiber using two phase masks of 1058nm and 1069nm by LN KrF200 excimer laser (248nm) at the FBG fabrication Centre, IISc, Bangalore, India. The centre wavelength of FBG1 and FBG2 are 1544.04 nm and 1559.40 nm respectively. Prior to etching a thin coating of teflon was given to FBG2 to make the FBG2 region inactive to acid. The sensor head is made up of a Teflon tube of 10mm diameter.

The tube has an inlet and outlet provision and the dimensions are chosen to facilitate the process of etching and sensor operation (Fib. 1). The fiber is fixed at the two ends of the tube using an epoxy based resin. The hydrofluoric acid (HF 40%) is used for etching.

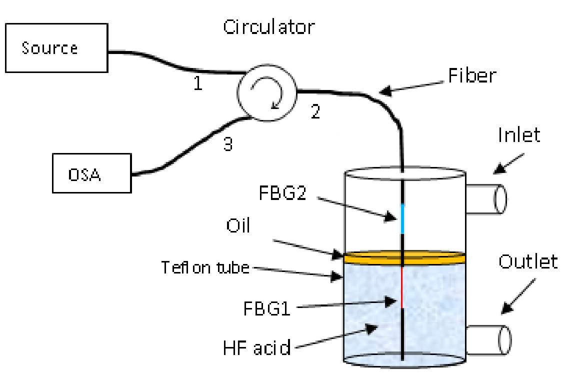

Fig. 1. Schematic of sensor packaging and etching process.

The chemical reaction is exothermic.

$$SiO_2 + 4HF \rightarrow SiF_4 + 2H_2O \qquad (6)$$

Silicon oil is added to the acid to reduce the tapering of fiber at the etching region and evaporation of HF solution. To stop the etching process at the desired depth, the HF solution is removed and the test tube is filled with solution of calcium oxide.

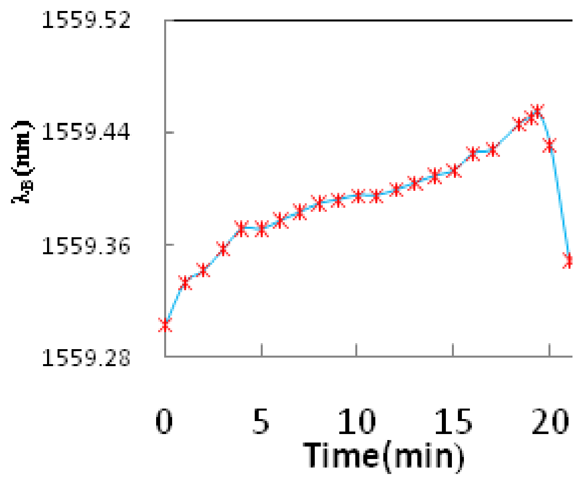

Fig. 2. Variation of λ_B and time during etching.

Etching process is monitored using OSA and a graph is plotted between change in Bragg wavelength and time (Fig. 2). It is observed that the centre wavelength is blue shifted by 0.12nm after etching the FBG1. The entire arrangement (sensor head) is suspended with a support in the Liquid tank (Fig.3). A thermometer is kept to measure the temperature of the liquid. Light from a broad band source (operating at 1550 nm with 40 nm FWHM) is directed to the two inline FBGs through a circulator and the reflected spectrum is sensed by the OSA (Agilent 86142B) through the circulator.

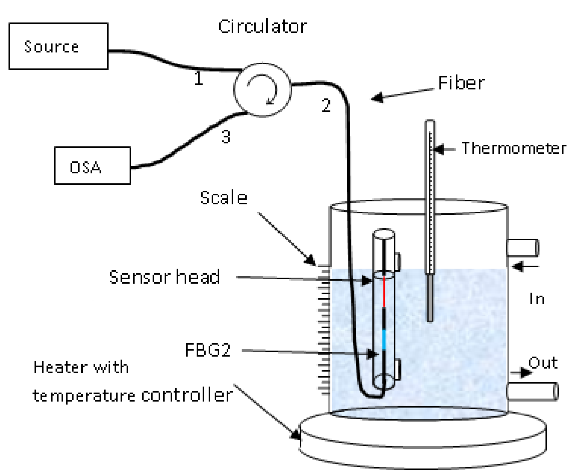

Fig. 3. Schematic experimental setup.

Liquid level in the tank is controlled by inlet and outlet. The level is measured using a scale attached to the tank (Fig. 3).

4. Results and discussion

The temperature response of the FBG1 before and after etching is plotted (Fig. 4).

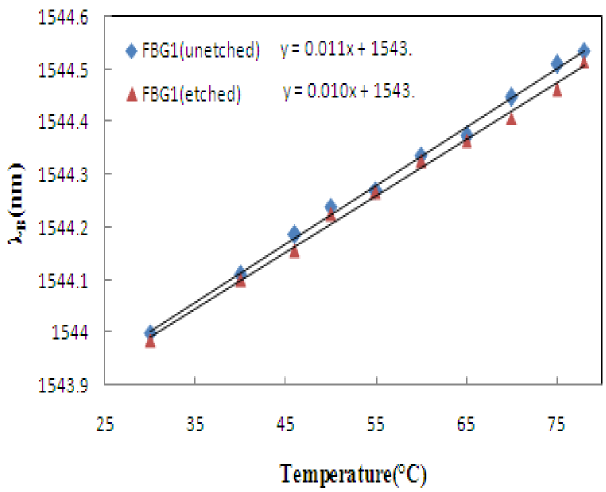

Fig. 4 .Temperature Response of FBG1.

The temperature sensitivity of the FBG1 after etching decreased to 10pm/^{0}C from 11pm/^{0} C. This effect is due to the negative thermo-optic coefficient of the surrounding medium in agreement with theoritical analysis[12,13]. Similarly the temperature sensitivity of FBG2 is 11pm/^{0}C (Fig. 5).

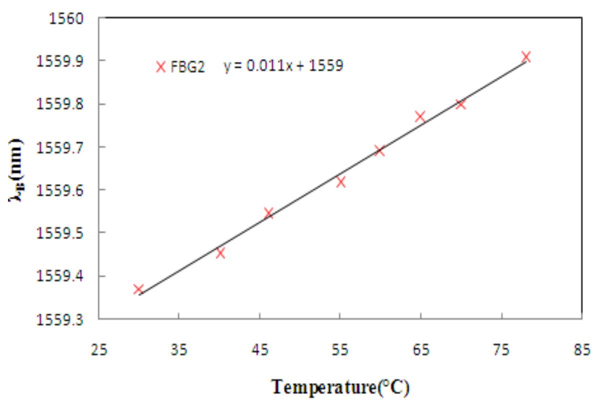

Fig.5. Temperature response of FBG2.

The temperature sensitivity of both the FBG's is nearly equal and is useful for temperature compensation. Experiment is conducted for level detection using water at room temperature. When the FBG1 is completely immersed in water,116pm shift of centre wavelength was observed. This shift is due to the effect of temperature, refractive index of the water (Fig. 6). The change in wavelength can be utilized as liquid level switch for controlling the level. When the water level rises (forward path) to the half of the 3mm of FBG1, wavelength shift is observed and it remained constant on further increasing the level (Fig. 6). However when the liquid level decreases (reverse path) then approx. 0.5mm level error was observed

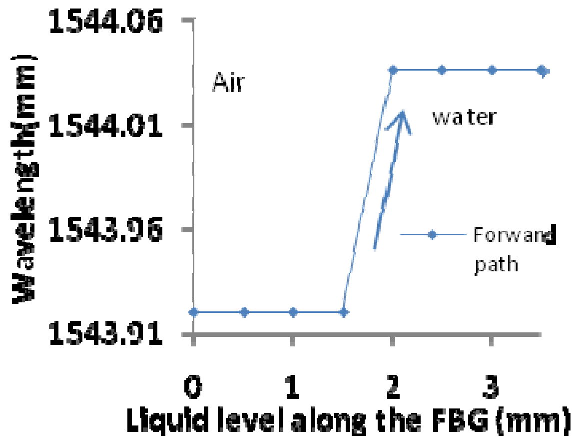

Fig.6. Wavelength response of FBG1 with liquid level rising.

And this change in wavelength is due to local strain (Fig. 7). The same experiment is also conducted with various liquids and the corresponding shift of centre wavelength (λ_B) of FBG1 with reference to the centre wavelength in air at constant temperature is shown in Table.1. $\Delta\lambda_B$ is the difference of centre wavelength of FBG1 in liquid from air.

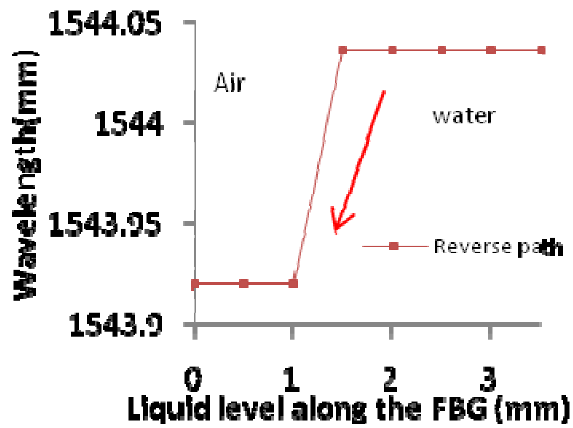

Fig.7. Wavelength response of FBG1 with liquid level falling.

Table 1. Wavelength response of FBG1 in different liquids at room temperature.

Medium	λ_B(nm)	$\Delta\lambda_B$(nm)
Air	1543.92	0
Water	1544.036	0.116
Petrol	1.41	0.224
Kerosene	1544.26	0.34
Diesel	1544.322	0.402

It is also found that when water is replaced by petrol (RI 1.40) the amplitude of reflected spectrum decreased along with the shift in centre wavelength. The reflection spectra when both FBG1 and FBG2 are in air is shown in Fig 8. A power loss of 123nW occurred along with a shift of wavelength 0.224nm when the FBG1 is totally immersed in petrol (Fig. 9). When both FBG1 and FBG2 are in air and petrol, their recorded reflection spectra shows that surrounding RI sensitivity of FBG2 is zero, where as FBG1 is sensitive to RI change, at constant temperature and suitable for level switch (Fig. 8 and 9). This study offers an efficient, fast, safe and inexpensive technique for applications involving remote monitoring of level in fuel storage tanks and can be utilized as an alarm system for the same.

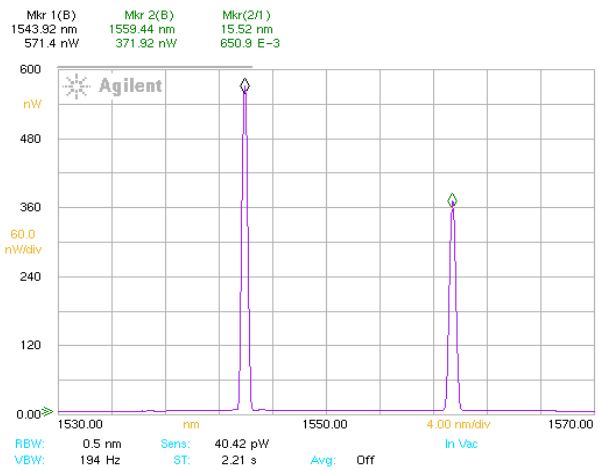

Fig. 8 .Spectrum of FBG1 and FBG2 in air.

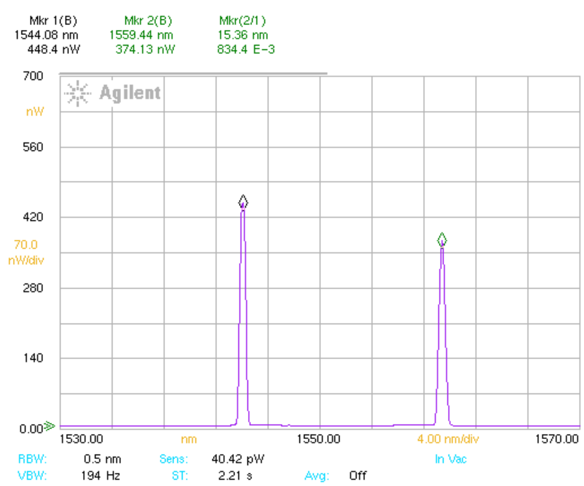

Fig. 9. Spectrum of FBG1 and FBG2 in petrol.

5. Conclusions

A low cost prototype sensor head is realized to sense the level of the liquid. It can be used as level switch and is independent of source fluctuation and fiber losses since the sensed information is wavelength encoded. This configuration has potential to be integrated in systems directed to remotely monitor the level of liquids. A low cost interrogator system is high enough to convert optical signal to electrical signal for the discrimination and control. This sensor has an advantage that it has no movable mechanism for the level sensing.

Acknowledgements

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