OPTICAL CHARACTERISTICS OF SILICON BASED ULTRA SENSITIVE REMOTE TEMPERATURE SENSOR

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***ABSTRACT**: Remote sensing is desirable for most of the situations where the use of ordinary traditional temperature sensors is not feasible. The reflectance and transmittance strongly depends on refractive index of optical materials which is a fundamental temperature dependent optical property, thus can be used for temperature sensing. An ultra sensitive temperature sensor is fabricated by creating a silicon based small Fabry-Perot cavity. Temperature measurements are carried out by measuring the change in transmitted light intensity. The sensor exhibits a linear behavior between room temperature up to 323.15 K. The transmitted intensity is observed decreasing linearly with increasing temperature.*

***KEY WORDS**: Fabry-Perot interferometer, temperature sensor, fiber optic, Silicon*

1. INTRODUCTION

Fiber optic based sensors are being of keen interest for the researchers from last few decades due to their remarkable advantages and applications in industrial, engineering and environmental monitoring sectors. The small size, passive nature, immunity to electromagnetic interference, resistant to harsh environment, compactness and low fabrication cost are the properties that have made it possible for an optical fiber based sensor to be used in rough conditions [1]. Fiber optic based sensors are being categorized in four categories on the basis of their characteristics, these include intensity modulated sensors, wavelength modulated sensors, polarization modulated sensors and phase modulated sensors (interferometers) [2]. Four types of fiber optic interferometers exist, namely Fabry-Perot interferometer, Michelson interferometer, Mach-Zehnder interferometer and Sagnac interferometer [3]. Among these sensors, Fabry-Perot interferometer (FPI) shows great potential for temperature sensing due to its small size, simple structure, high stability and low fabrication cost [4]. A FPI generally consists of two parallely opposed partially reflecting surfaces separated by a small distance called Fabry-Perot cavity or etalon. Two types of Fabry-Perot (FP) cavities can be created either intrinsic or extrinsic. The intrinsic FP cavity can be created by splicing a piece of multi mode fiber (MMF) between two single mode fibers (SMF) and the extrinsic FP cavity can be created by introducing a small gap between two cleaved fiber ends [5, 6]. The incident light partly reflected from first surface and partly transmitted that transmitted light travel through the cavity and partly reflected from second surface, the reflected light signal then re-coupled into the same fiber and guided to a detector. A phase difference is induced between the reflected light signals due to optical path length difference. Fringe pattern is produced in the light spectrum due to interference of light signals [4].

Refractive index is a fundamental optical property of any optical material that can be used for temperature sensing as it is a temperature dependent quantity. The refractive index of any glass is affected by temperature is ascertained through the temperature coefficient of refractive index, $\frac{dn}{dT}$, given as [7];

$$\frac{dn_{abs}(\lambda,T)}{dT} = \frac{n^2(\lambda,T_0)}{2n(\lambda,T_0)}\left(D_0 + 2D_1\Delta T + 3D_2\Delta T^2 + \frac{E_0 + 2E_1\Delta T}{\lambda^2 - \lambda_{TK}^2}\right)$$

Waxler and Cleek found the refractive index of different glasses linearly increasing with increasing temperature [8]. High refractive index of silicon makes it possible to use it as temperature sensing medium for ultra sensitive remote temperature sensor in conjunction with a light source that can be used for intense temperature monitoring in rough conditions [9, 10].

In this study a Silicon based extrinsic Fabry-Perot interferometer (EFPI) temperature is proposed and characterized for remote elevated temperature sensing. Refractive index of silicon has been utilized for temperature sensing.

2. SENSOR FABRICATION AND CHARACTERIZATION

The sensor has been fabricated by connecting a multimode fiber optic with 30 µm thick silicon wafer of size 2.5 mm × 2.5 mm through a glass capillary. The joints of the silicon wafer, fiber and the glass capillary were sealed with borosilicate glass powder [11]. The sensor fabrication process is illustrated in Figure 1; whereas the actual size of the sensor is demonstrated in Figure 2 by comparing the sensor with a 50 cent coin.

The sensing ability of the sensor was evaluated by using a calibrated standard high temperature thermometer in conjunction with a heating source, a spectrometer and Halogen light source. The newly developed sensor tip and the standard high temperature thermometer tip were coupled together and placed at an equal distance from the heating source. The distance between the heating source and the sensor tip was increased in steps in order to vary the temperature at the sensor tip. The light spectrum from Halogen light source was directed perpendicularly to the Silicon wafer surface. The transmitted spectra were measured by using JAZ COMBO-2 Spectrometer Module (200-1100nm), Ocean Optics; that has spectral sensitivity from 200 nm to 1100 nm. The Halogen light source was used in this study due to its broad wavelength range from 360 nm to 2000 nm.

3. RESULTS AND DISCUSSION

Transmission spectra of silicon FP cavity at different temperatures, from room temperature up to 323.15K, were measured and analyzed for sensor characterization. The reference Halogen light spectrum that was used for sensor behavior analysis is given in Figure 3. The transmitted intensities were found deceasing with increasing temperature shown in Figure 4. The transmitted intensities were observed decreasing linearly with increasing temperature, presented in Figure 5, having strong agreement with the fact that refractive index of the silicon linearly increases with increasing temperature [10]. Table 1 contains maximum transmitted intensities for each temperature. The transmitted spectrum intensity decreases with increasing temperature because of the destructive interference between the internally reflected spectra which correlate towards the phase change.

Table 1: Maximum transmitted intensities for different temperatures

Temperature [k]	Intensity [a.u]
300	1337
308	1308
313	1289
318	1273
323	1247

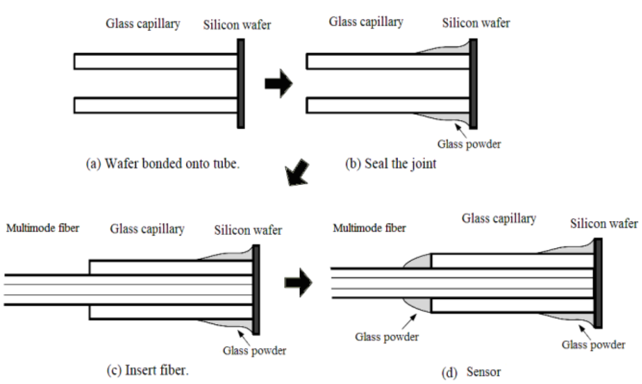

Figure 1: Schematic diagram of fabrication process

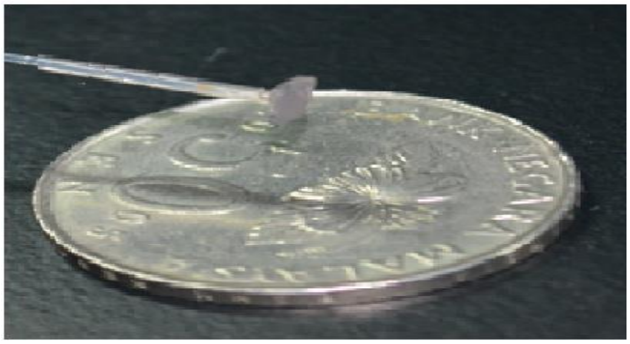

Figure 2: Size of the sensor tip compared with a coin

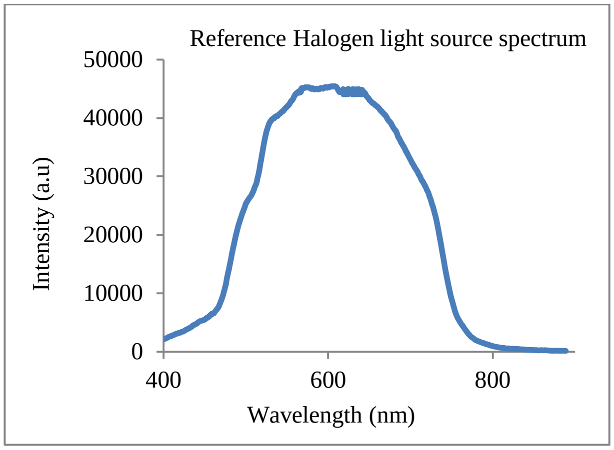

Figure 3: Reference Halogen light spectrum at room temperature

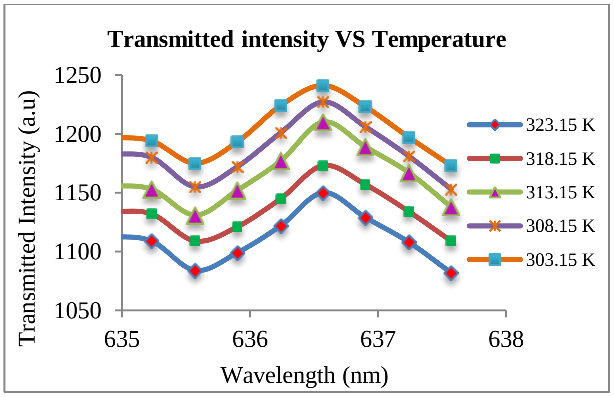

Figure 4: Effect of temperature variation on transmitted intensities

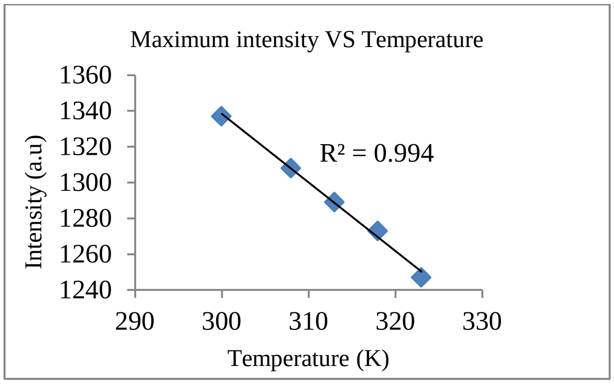

Figure 5: Relationship between transmitted intensities and temperature

4. CONCLUSION

The results obtained in this study indicate that a silicon based Fabry-Perot interferometer temperature sensor is a strong candidate for remote temperature sensing where intense temperature monitoring is essential but difficult due to unfavorable conditions for other temperature sensors i-e industries, environment, nuclear power plants and aerospace industry etc.

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