

Tipped Fiber Bragg Grating sensor for concentration measurements

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Abstract— An optical fiber sensing system for concentration measurement, based on Tipped Fiber Bragg Grating is presented. Laser Diode (LD) with wavelength of 1550 nm has been used. The Fiber Bragg Grating is cleaved by using optical cleaver. The FBG tip is immersed in different concentrations of Sodium Chloride (NaCl) solutions range from 5% to 25% and Sucrose solutions range from 10% to 50%. As the concentration of solution increases the shift in Bragg wavelength toward red region increases. The sensitivities of this sensor for different concentrations of NaCl solutions and Sucrose solutions are $8.3 \times 10^{-8} \mu\text{m}/(\% \text{w/v})$ and $3.085 \times 10^{-6} \mu\text{m}/(\% \text{w/v})$, respectively..

Index Terms— optical fiber sensor, concentration, Tipped Fiber Bragg Grating, sensitivity, wavelength shift.

I. INTRODUCTION

A fiber optic is a plastic or glass fiber which is fabricated to transmit light along the length of it by confining it as much as possible within the fiber. In 1840s, the principle of light guiding was suggested. In 1950s, the fiber optic technology was significantly developed for medical application. In 1966, the British company Standard Telephones and Cables was primarily predestined that the fiber might be used in practical medium for the application of telecommunication if the attenuation could be minimized to below 20 dB/km [1]. Optical fiber sensors have been fabricated after the development of the practical fiber by corning glass 1970, the first low loss fiber was produced by coring incorporated with losses below 20 dB/km. In the beginning of optical fibers era, the optical components such as lasers and photodetectors were only used by telecommunication companies because they are expensive. With the expansion of optical fiber during 1980s the optical devices which were used in optical fiber sensors became less expensive so that optical fiber sensors were used instead of traditional sensors [2]. Electrical power industry has two facts which can cause fall in electronic sensor: existence of high electromagnetic interference and presence of high voltage. Therefore, relying on the place of measurement of the parameter it may be very hard or impossible to use electronic sensor. The best solution to avoid this is via the use of an optical fiber sensor, because the optical fiber is fabricated from dielectric material sand, so it is possible to use them everywhere. Another problem with the using of conventional sensors is that they need electrical

energy. Optical fiber sensors don't need electrical energy because they are passive sensors [2]. Optical fiber sensor is designed to collect data by an optical fiber; the measured quantity alters a specific physical property and causes a change in the characteristics of transmitted light along the optical fiber [3-4]. They are used in various applications such as biological, environmental industries, and chemical, for the measurements of temperature, strain, Refractive index, and liquid level [5-7]. Optical fiber sensor provides various advantages contrasts the electronic sensor because of their properties such as small size, immune to electromagnetic interference (EMI) and radio frequency interference (RFI), robust to environment, allow to access into inaccessible areas, dynamic range, high sensitivity, non-electrical devices, light weight, allow remote sensing, high resolution[8-10]. The refractive index (RI) is a quite important parameter in these applications , especially in food industries or chemical in order to control the quality or in bio-sensing for biochemical reactions or controlling molecular bindings [11]. In the past years , several refractive indices sensors like Rayleigh and Abbe refractometers were used for the measurement of refractive index, but they have disadvantages of big size and weight [12]. Nowadays optical fiber refractive index sensors have widely used for these applications [13] . Fiber Bragg Grating is a periodic variation in the index of refraction in optical fiber , it can be accomplished by insinuation the core of fiber to high intensity optical interference pattern [14]. In recent years FBG sensors are widely used in several sensing application such as strain, pressure, temperature, humidity, vibration and refractive index measurements [14-17]. FBG may be used as a sensor by launching the fiber with a source of light with a wide spectrum, and the reflected wavelength is measured and associated to the measurand [18]. The idea of Fiber bragg sensors is that the environmental variations cause a change in properties of the FBG. The period, the amplitude of the index modulation, and strain are changed which affect the bragg condition [19]. This results in a change in the spectrum of reflected waves. With suitable equipment the spectrum changes may be analyzed and measured to determine the value of strain, temperature, and other parameters [19]. FBGs are very attractive for application of sensing for different reasons [20-22]:

- The center wavelength λ_B shifts in a linearly with strain and temperature and other parameters.
- The changes in the light intensity are not important.

- The large ability for sensor networking and multiplexing.
- small size
- immune to EMI
- highly sensitive
- electrically passive operation
- easy of integration

I. FIBER BRAGG GRATING SENSOR MATHEMATICAL MODEL

The condition of FBG is a demonstration of the momentum conservation and energy. Energy conservation demands that the incident and the reflected radiation are the same, as defined in the following Equation [23]:

$$\hbar\omega_f = \hbar\omega_i \quad (1)$$

Where ω_i and ω_f and are the angular frequency of incident and scattered radiation; respectively. Momentum conservation requests that the wave vector of the scattered radiation k_f is equal to the incident wave vector k_i plus the grating wave vector K .

$$k_i + K = k_f \quad (2)$$

K has a direction vertical to the grating plane with a magnitude equal to [23]:

$$K = \frac{2\pi}{\Lambda} \quad (3)$$

Where Λ is the grating spacing (or pitch).

The reflected and the incident wave vector is opposite in the direction but they have the same magnitude. The magnitude of the incident wave vector and the scattered wave vector are given by the following equations [24]:

$$k_i = \frac{2\pi n_{ieff}}{\lambda_B} \quad (4)$$

$$k_f = \frac{2\pi n_{feff}}{\lambda_B} \quad (5)$$

Where λ_B is the Bragg wavelength, n_{ieff} and n_{feff} are the refractive indices of the medium of the incident and the reflected light, respectively [25-26].

Equation (7) is obtained by substituting (4), (5), and (3) into (2) [24]:

$$-\frac{2\pi n_{ieff}}{\lambda_B} = \frac{2\pi n_{feff}}{\lambda_B} - \frac{2\pi}{\Lambda} \quad (6)$$

Then

$$\lambda_B = 2n_{ieff} \Lambda \quad (7)$$

Figure (1) shows the internal structure and the principle work of Fiber Bragg grating [27].

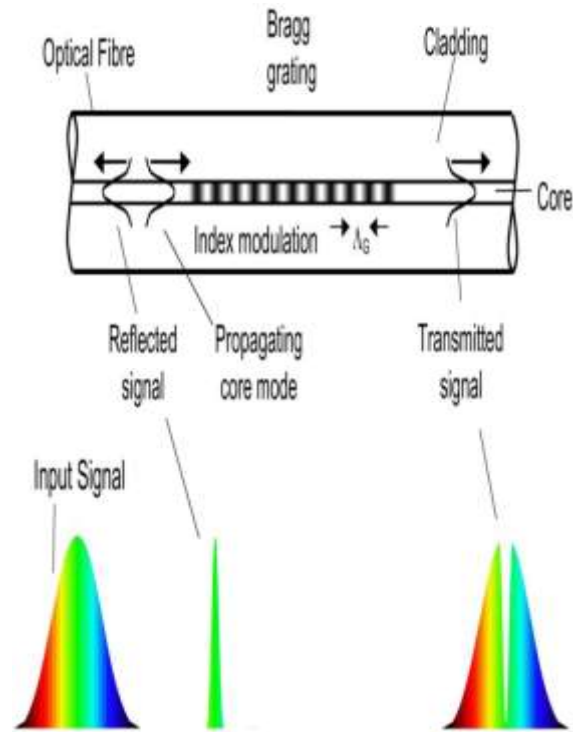


Fig. 1: The internal structure and working principle of fiber Bragg grating [27].

II. EXPERIMENTAL METHOD

Sodium Chloride (NaCl) and Sucrose are used as guiding liquids with different concentrations. The concentrations of Sucrose solutions range from 10% to 50% and for NaCl solutions range from 5% to 25%. The refractive index for NaCl and Sucrose solutions at each concentration is measured by using an Abbe

refractometer. The Fiber Bragg Grating is cleaved by using optical cleaver (CT-30), and etched by Hydrofluoric Acid (HF). After preparation of a Tipped FBG sensor, it is placed in a setup to measure its reflection spectrum. The system consists of laser diode with wavelength of 1550nm, the light source is coupled to FBG using 3-dB single mode fiber coupler (splitting ratio 50:50, operating wavelength 1550nm). The reflected light is measured by using Optical Spectrum Analyzer (Thorlab 203) which record the reflected spectrum pattern. The experimental setup schematic diagram and experimental arrangement of the FBG concentration sensor are shown in Figures (2) and (3), respectively.

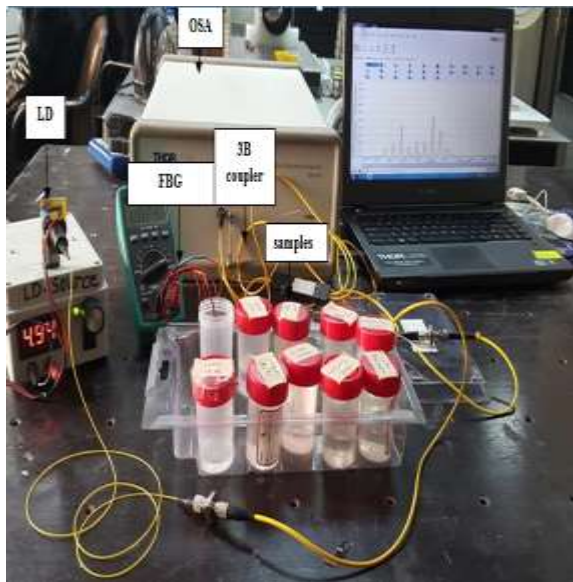


Fig. 2: The experimental setup schematic diagram of a Tipped FBG concentration sensor.

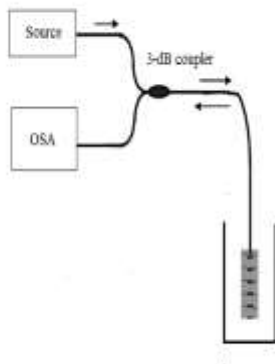


Fig. 3: The experimental setup arrangement of the FBG concentration sensor.

The end of fiber is immersed in distilled water and different concentrations of Sucrose and NaCl solutions. The concentration of solutions ranges from (10 % to 50 %) for sucrose, and from (5% to 25 %) for Sodium Chloride. The reflected spectrum is

measured by using Optical Spectrum Analyzer (OSA); it contains information from the external medium in the interaction zone. Analyzing this spectrum makes it possible to monitor the concentration variation of the analyte.

III. RESULTS AND DISCUSSION

Figures (4) and (5) show the relationship between refractive index and concentration of NaCl and Sucrose solutions, respectively.

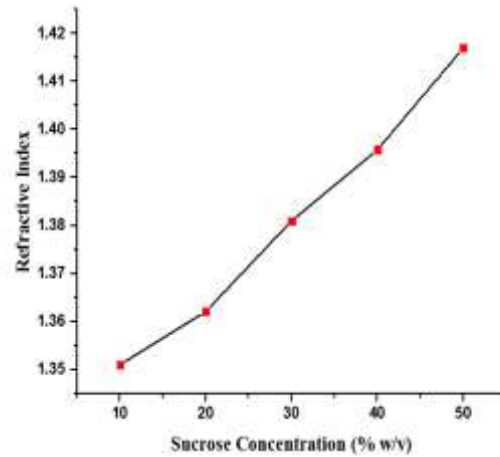


Fig. 4: The relationship between concentration and refractive index of Sucrose solutions.

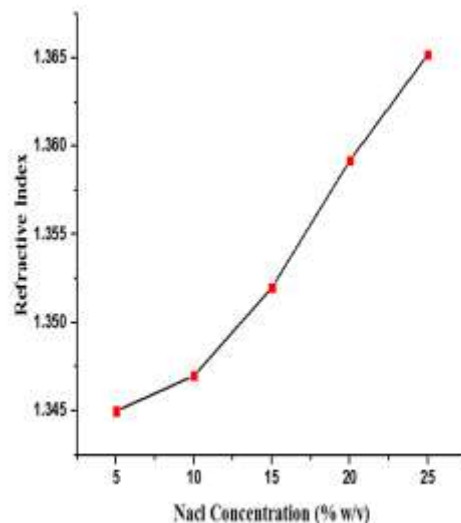


Fig. 5: The relationship between concentration and refractive index of NaCl solutions.

From the Figures the refractive index is directly proportional to the concentration, as the concentration of guiding liquid increases refractive index increases.

The FBG tip is immersed in various concentrations of NaCl solutions range from 5% to 25%, and Sucrose solutions range from 10% to 50%. Figures (6) and (7) show the reflection pattern of different concentration of Sucrose and NaCl solutions, respectively.

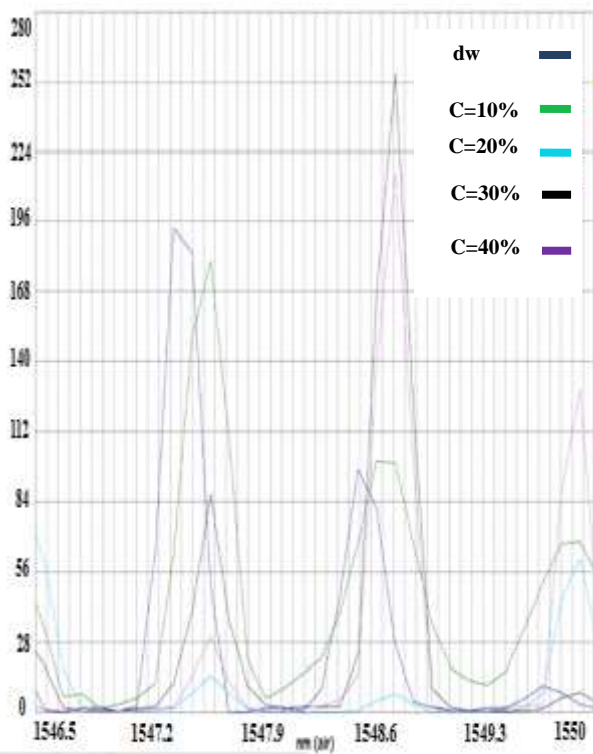


Fig. 6: Reflection spectra of Tipped FBG sensor for different concentrations of Sucrose solutions.

As the concentration of the solution increases, the effective index increases and according to Equation (7), the Bragg wavelength increases nonlinearly toward a red shift wavelength. The sensitivity of this sensor for sucrose solutions is $3.085 \times 10^{-6} \mu\text{m}/(\% \text{ w/v})$ and for NaCl solutions is $8.3 \times 10^{-8} \mu\text{m}/(\% \text{ w/v})$ as shown in Figures (8) and (9), respectively.

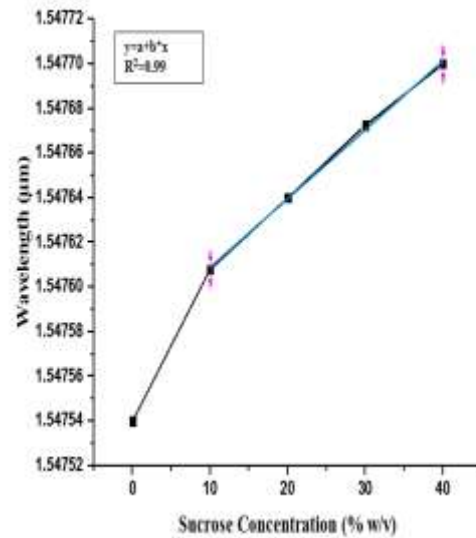


Fig. 8: The relationship between wavelength and different concentrations of sucrose solutions.

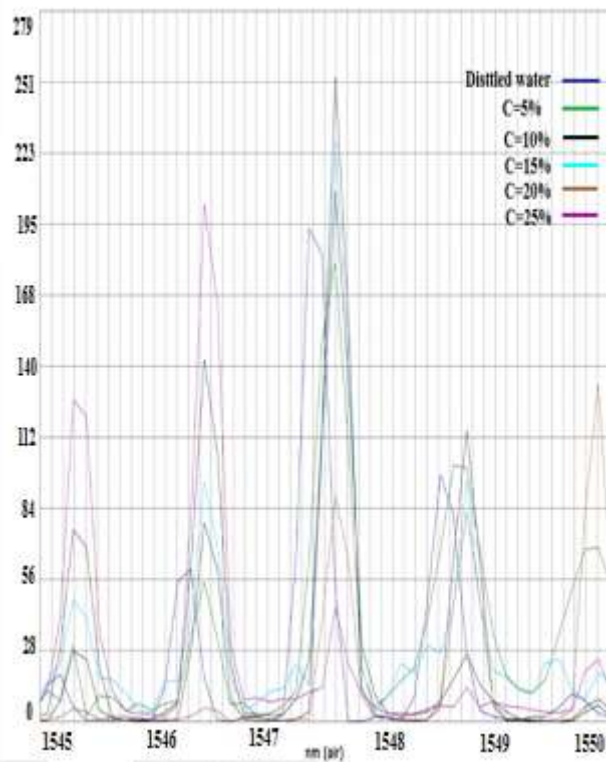


Fig. 7: Reflection spectra of Tipped FBG sensor for different concentrations of NaCl solutions.

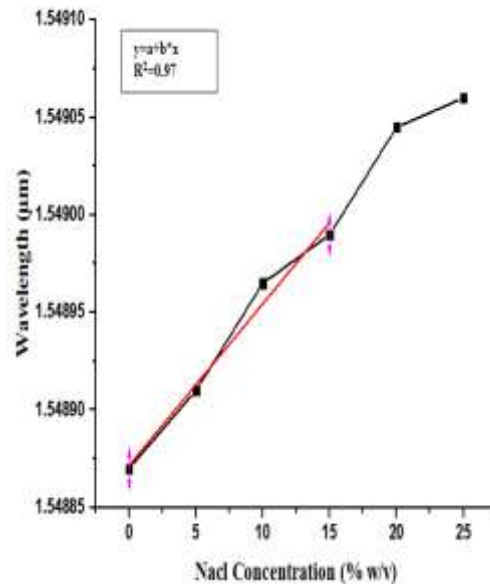


Fig. 9: The relationship between wavelength and different concentrations of NaCl solutions.

IV. CONCLUSION

A tipped Fiber Bragg Grating sensor has been demonstrated where the variation of surrounding concentration is obtained by detecting the shift in Bragg wavelength. A red shift in the output spectrum is observed with increasing of concentration. The

sensitivity of this sensor for sucrose solutions in the range of 10% to 50% is $3.085 \times 10^{-6} \mu\text{m}/(\% \text{ w/v})$ and for NaCl solutions in the range of 5% to 25% is $8.3 \times 10^{-8} \mu\text{m}/(\% \text{ w/v})$. This sensor can be used for measuring concentration in various applications such as medical, food industry, pharmaceutical, environmental controlling systems, and monitoring the quality of drinking water.

REFERENCES

- [1] J. Yang, "NUMERICAL MODELING OF HOLLOW OPTICAL FIBER DRAWING PROCESS", Ph.D Thesis , Mechanical and Aerospace Engineering , University of New Jersey , 2008.
- [2] M.M. Werneck, R. C. S. B. Allil, B. Ribeiro and F. de Nazaré, " A Guide to Fiber Bragg Grating Sensors", in Current Trends in Short- and Long-period Fiber Gratings, edited by Christian Cuadrado-Laborde, Rijeka, Croatia, 2013, ch.1, sec.1 pp. 1-24. Available from: <https://www.intechopen.com/books/current-trends-in-short-and-long-period-fiber-gratings/a-guide-to-fiber-bragg-grating-sensors>.
- [3] S. Thakral, and P. Manhas, " Fiber Optic Sensors Technology & their applications", International Journal of Electronics & Communication Technology, Vol. 2, No. 2, pp.126-127, 2011.
- [4] H.H. Qazi, A.B.B. Mohammad, and M. Akram , "Recent Progress in Optical Chemical Sensors",Sensors,Vol.12,No.12, pp. 16522-16556, 29 November 2012.
- [5] L. Li, L. Xia, Z. Xie, and D. Liu," all-fiber Mach-Zehnder interferometers for sensing applications", Optics Express,Vol.20, No.10,pp. 11109-11120, 7 May 2012.
- [6] X. Chen, C. Zhang, D. J. Webb, K.Kalli, and G. D.Peng', "Highly Sensitive Bend Sensor Based on Bragg Grating in Eccentric Core Polymer Fiber", IEEE Photonics Technology Letters,Vol.22 ,No.11,pp. 1-3, 23 April 2010.
- [7] C.R.S. Dennison," Development and application of in-fibre Bragg grating based biomedical pressure sensors", M.S. thesis , Mechanical Engineering , University of Victoria, Canada, 2008.
- [8] R. B. Malla , A. Sen and N.W. Garrick , "A special fiber optic sensor for measuring wheel loads of vehicles on Highway",Sensors, Vol.8, No.4, pp. 2551-2568 ,2008.
- [9] B.P. Pal, "Fundamentals of fibre optics in telecommunication and sensor systems", New Delhi,1992,pp.15-25.
- [10] K.A. Fidanboyulu , and H. S. Efendioglu , "FIBER OPTIC SENSORS AND THEIR APPLICATIONS ", International Advanced Technologies Symposium (IATS'09), Vol. 6 ,No.2 pp.1-6 ,May 2009.
- [11] P. Lu, L. Men, K. Sooley, and Q. Chen," Tapered fiber Mach–Zehnder interferometer for simultaneous measurement of refractive index and temperature", Applied Physics Letters, Vol.94, No.13, pp. 131110, 30 Mar 2009.
- [12] J. Zhou, Y. Wang, C. Liao, B.Sun, J.He, G.Yin, S. Liu, Z.Li, G. Wang, X. Zhong, and J.ZhaoK," Intensity modulated refractive index sensor based on optical fiber Michelson interferometer", Sensors and Actuators B: Chemical ,Vol.208, pp. 315-319, 11 November 2014.
- [13] V. Rastogi, K. Kamakshi, R. K. Patra, A. Kumar and J. Rai," DESIGN AND FABRICATION OF SINGLE MODE FIBRE OPTIC REFRACTIVE INDEX SENSOR ",International conference on optics and photonics, CSIO, India, pp.1-4 , Nov 2009.
- [14] U.S. Raikar, V.K. Kulkarni, A.S. Lalasangi, K. Madhav,and S. Asokan," Etched fiber Bragg grating as ethanol solution concentration sensor",Optoelectronics and Advanced Material,Vol. 1, No. 4,pp. 149-151, 2007.
- [15] P. Boland, G. Sethuraman, A. Mendez, T.Graver, D. Pestov, and G.Tait , " Fiber Bragg grating multichemical sensor", Photonic Sensing Technologies conference, pp. 637109-637109, 2006.
- [16] H. A. Kazem , " Solar Radiation, Temperature and Humidity Measurements in Sohar-Oman", International Journal of Computation and Applied Sciences IJOCAAS,Vol . 1, No. 1, PP:15-20, AUGUST 2016.
- [17] A. H. A. Al-Waeli, K. Sopian, H. A. Kazem ,and M.T. Chaichan," Photovoltaic Thermal PV/T systems: A review", Vol. 2, No. 2, pp. 62-67,2017.
- [18] C. Doyle,"Fibre Bragg Grating Sensors An Introduction to Bragg gratings and interrogation techniques", Smart Fibres Ltd , <https://smartfibres.com/.../Smart%20Fibres%20Technology%20Introduction.pdf>, 2003.
- [19] I. Petermann, "Fibre Bragg Gratings Realization, Characterization and Simulation", Ph.D Thesis, Department of Microelectronics and Applied Physics, Royal Institute of Technology, 2007.
- [20] W. J. Bock, I .Gannot, and Stoyan Tanev," Optical Waveguide Sensing and Imaging", Springer, Netherlands ,October 2006.
- [21] Z.Meng, B.Yan, X. Sang, C. Yu, K. Wang, and D. Xu," The sensitivity of fiber Bragg grating based chemical sensor", Advanced Sensor Systems and Applications III conference, pp. 683011-683011, 2007.
- [22] Y. Cao, Y.Yang, X. Yang, and Z. Tong," Simultaneous temperature and refractive index measurement of liquid using a local micro-structured fiber Bragg grating", Chinese Optics Letters,Vol.10,No.3,pp.1-5, 2012.
- [23] T. Saktioto and J.Ali," Non Linear Optic in Fiber Bragg Grating, in Optical Fiber Technology", Dr Moh. Yasin (Ed.), Croatia ,2012, ch.22, sec.2 , PP. 588-606, Available from: <http://www.intechopen.com/books/selected-topics-on-optical-fiber-technology/non-linear-optic-in-fiber-bragggrating> , PP. 588-606, 2012.
- [24] C.K. MAN , "Advanced Fibre Bragg Grating And Microfiber Bragg Grating Fabrication Techniques", Ph.D Thesis, Hong Kong Polytechnic University, ,March 2012.
- [25] Q. Chen and P. Lu, " FIBER BRAGG GRATINGS AND THEIR APPLICATIONS AS TEMPERATURE AND HUMIDITY SENSORS", Atomic, Molecular and Optical Physics , pp.235-260, 2008.
- [26] S.A. Kadhim, S.A.A. Taha,and D.A. Resen," anemometer sensor by using Fiber Bragg Grating Based Bending Controlled by Wind Speed", Journal of Nanoscience and Technology,Vol.2,No.2,pp. 91-93.
- [27] R. Kashyap," Fibre Bragg Gratings", Academic press, USA, September 2006.