Advanced Research in Electrical and Electronic Engineering
p-ISSN: 2349-5804; e-ISSN: 2349-5812 Volume 4, Issue 3 April-June, 2017, pp. 150-153

http://www.krishisanskriti.org/Publication.html

Liquid Refractometer Based on DECL Added Parallel Multi Mode Fiber Couples

Dipankar Chetia[1] and Tulshi Bezboruah[2]

[1,2]Dept. of Electronics and Communication Technology, Gauhati University
E-mail: [1]deep.jeet333@hotmail.com, [2]zbt@gauhati.ac.in

Abstract—*An optical fiber couple based refractometer is reported for transparent liquids. Two 'multimode fiber-couples' are used. In each couple, the two fibers are kept parallel to each other, while both the fibers are decladded up to a certain length from one end of the fiber. When the separation between the fibers are kept constant, the light coupled between the two fibers varies, as refractive index of the separating medium changes. The proposed sensor can measure change of refractive index up to* 10^{-4}.

Keywords*: Refractometer, liquid, fiber, optics, sensor, laser.*

1. INTRODUCTION

Measurement of refractive index has got utmost importance in pharmaceuticals, beverage industries and in different chemical applications. Several models have been reported to measure refractive indices of liquids. Some involves classical techniques, using Brewster angle and critical angle calculation as in [1-3].

Due to the advantages like flexibility, cost efficiency, durability, EM wave immunity several optical-fiber based sensors have being developed. Modern techniques like Surface Plasmon Resonance based [4-6], photonic crystal based [7-9], Bragg grating based [10] and total internal reflection based refractometers [11-12] have also been developed and reported. The refractometers based on these techniques are highly sensitive. Several more techniques and probe designs to attain even higher sensitive and rugged sensors are being reported continuously.

A U-shaped optical fiber refractometer was reported by Bergman *et. al.* [13]. Some other reported models involve more than one of the above mentioned, in some models long period FBG and tapered fibers are used to measure the RI [14-15].

Most of the refractometers based on SPR, FBG and Photonic crystal are very highly sensitive, but involve very complex design and costly optical components. Also, there are some reported models [16] which have very basic optical components involved but have a comparable sensitivity value to the above-mentioned techniques. In this paper, we report a refractometer based on laterally spaced decladded multimode fibers. The proposed refractometer is simple, rugged, and highly sensitive.

2. REFRACTOMETER DETAILS

2.1 Sensor Principle

When the end of a multimode fiber is decladded and is inserted in a transparent liquid medium, the light coupled from the fiber core to the surrounding liquid depends on the refractive index of the medium. If we derive the loss of optical power between two parallel decladded fibers separated by a lateral spacing mathematically, it shows that, with the increase in the refractive index of the separating medium the power coupled from the first fiber to the liquid decreases. Because of this the power coupled to the second fiber from the liquid medium also decreases. Hence, the coupling efficiency η, between the two fibers decreases with the increase in liquid refractive index.

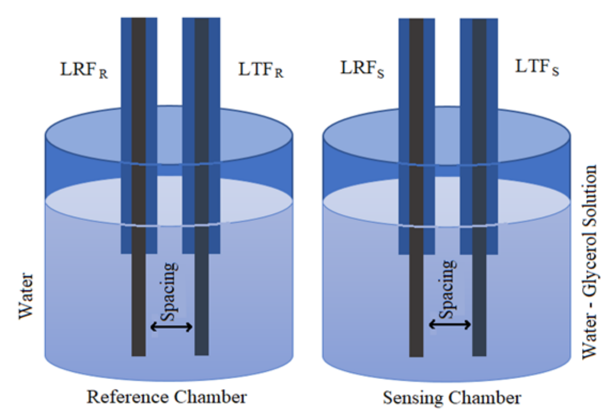

Fig. 1: The two fiber couples, inserted in two chambers filled with different liquids.

2.2 Sensor Fabrication

The proposed refractometer is designed using two multimode fiber couples termed as reference couple and sensing couple, all the four fibers used in these two couples are decladded at the one end. In each fiber couple, the decladded region is kept parallelly separated by a variable lateral spacing. For, each couple one fiber act as light transmitting fiber (LTF_R and LTF_S for reference and sensing couple respectively) while the other acts as light receiving fibers (LRF_R and LRF_S for reference and sensing couple respectively). Light is coupled to LTF_R or LTF_S from a diode, this light is then coupled to the surrounding liquid medium on the other end of the LTF_R or LTF_S, through the decladded region. Further the light gets coupled to the LRF_R or LRF_S after travelling through the liquid medium. The two fiber couples can be seen in Fig. 1.

The lights from the source diode are coupled to LTF_R or LTF_S, through a 50:50 optical beam splitter. The two fiber couples are inserted in different chambers termed as reference chamber and sensing chamber respectively. The optical power output of LRF_R or LRF_S inserted in the reference chamber and the sensing chamber respectively, are measured using two photodiodes namely reference photodiode (PD_R) and sensing photo diode (PD_S) respectively. The reference chamber is filled with water all the time while different liquids having different refractive index values, are introduced in the sensing chamber to measure the sensing response of the refractometer. Let, the optical power received by PD_R and PD_S are P_R and P_S respectively. If we term, the refractive indices of the liquid in the reference chamber and the sensing chamber as RI_R and RI_S respectively then, according to the sensor principle, P_S will decrease with the increase in RI_S. And as RI_R is kept constant, the value of P_R will also remain constant. P_R and P_S are finally processed in a digital acquisition system (DAQ) and final sensor response are acquired in a personal computer or a handheld mobile device connected to the DAQ circuit.

2.3 Processing circuits

Further we feed the voltage responses V_R and V_S of PD_R and PD_S respectively, into an amplifier circuit comprise of an AD620 chip. A simple schematic diagram of the DAQ circuit can be seen in Fig. 2. The circuit amplifies the difference between V_R and V_S and gives us an amplified voltage response 'V_A'. The amplification factor can be controlled by changing the value of the resistor R_G.

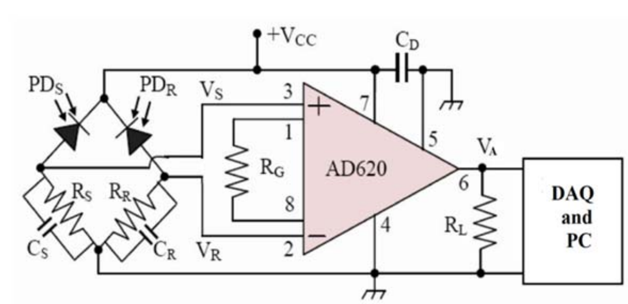

Fig. 2: Schematic diagram of the differential amplifier circuit.

3. EXPERIMENTAL DETAILS

3.1 Experimental Setup and Liquid Samples

The schematic of the main setup can be seen in Fig. 3. The liquid samples used in the experiments are prepared by mixing glycerol with plain water in different proportions. Glycerol is used, because it is completely mixable with water, and different ratio of the mixed liquids give different refractive index values. We prepared six samples of different glycol-water proportions. The refractive indices of the samples are measured with a standard Abbes Refractometer. The measured refractive index vs glycerol concentration graph is shown in Fig. 4.

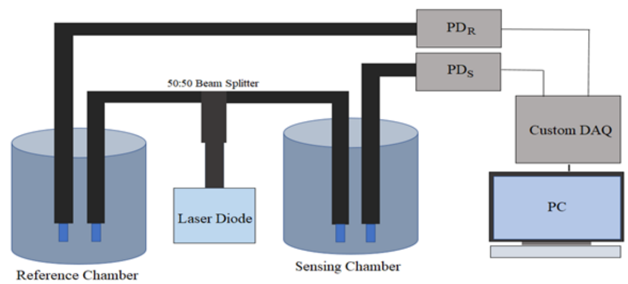

Fig. 3: Schematic diagram of the experimental setup.

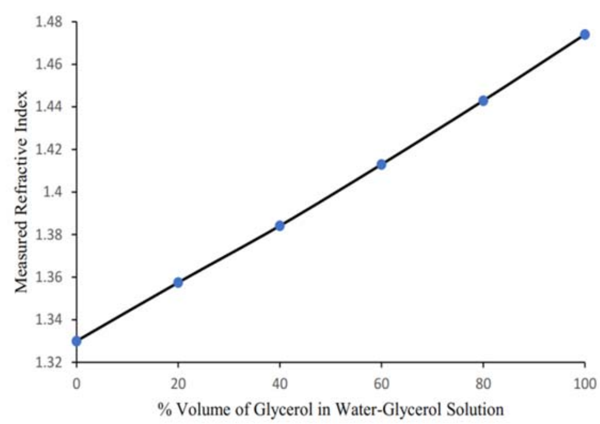

Fig. 4 Scattered plot of %volume of Glycerol concentration in the liquid solution vs RI

3.2 Measuring Sensor Response

Different glycerol-water samples are introduced in the reference chamber in the experimental process one by one. While water in kept in the reference chamber for all the time. Every time a new liquid is inserted into the reference chamber V_R and V_S and amplified voltage output V_A is recorded. for a specific set of readings, same lateral spacings are introduced in both the chambers between the two fibers of each couple.

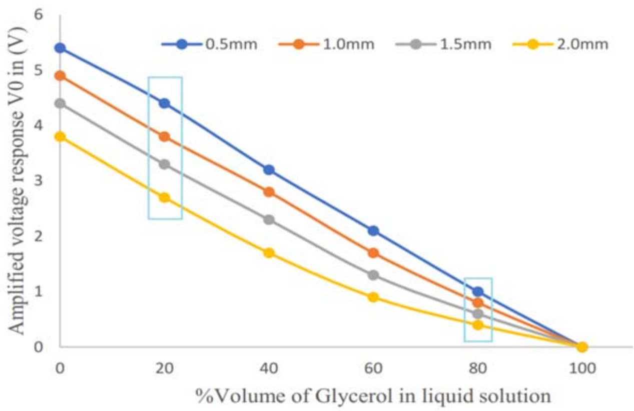

Fig. 5: Amplified output response (in Volt) vs %volume of Glycerol concentration in the liquid sample

Firstly, the fiber spacing is kept constant in both the chambers and the and liquids having different refractive indices are inserted into the reference chamber one by one. Secondly, after completion of the first set of readings we change the lateral spacings between the two fibers in both the fiber couples to a certain value, and then take the sensor response for all the liquid samples for this new spacing again. We repeat the same process for two more fiber spacings. Fig. 5 shows the amplified sensor response vs Glycerol concentration in the liquid samples for different lateral spacings between the two fibers.

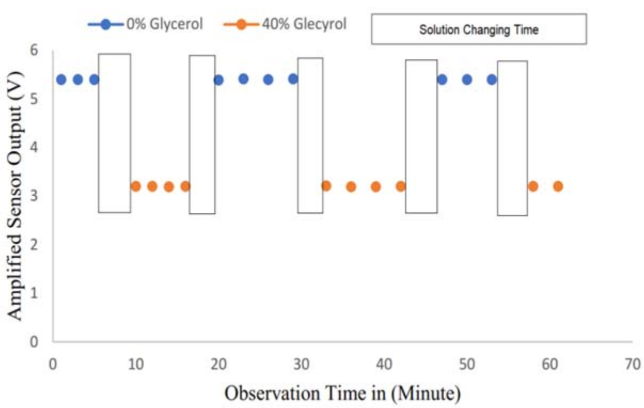

Fig. 6: Time response of the sensor output, the solid rectangular boxes denotes the cleaning time.

Thirdly, the sensitivity of the sensor is calculated. It is calculated by determining the ratio of the voltage change (ΔV_0) vs refractive index change (ΔRI) using the co-ordinates of Fig. 5. We assumed a 5% uncertainty for measurement. So ΔV_0 and ΔRI will have 10% uncertainty for each in the final sensitivity value. To get a sensitivity with RI change of 0.0001 we multiply the ratio by 10^{-4} and further the term is multiplied by 10^3 to get the sensitivity value in millivolt. Sensitivity values can be seen on table 1. While we use the following equation to determine the sensitivity values,

$$\textbf{Sensitivity, S} = \left\{\frac{\Delta V_0 \pm 10\%}{\Delta RI \pm 10\%}\right\} X10^3 X10^{-4} \qquad (1)$$

Table 1: Sensitivity of the proposed refractometer sensor (with an uncertainty level of 20%)

Lateral Gap	0.5mm	1mm	1.5mm	2mm
Sensitivity	3.98 ± 0.99 mV	3.51 ± 0.70 mV	3.16 ± 0.63 mV	2.69 ± 0.53 mV

Fourthly, we checked the time response of the sensor setup by, observing sensor output by continuously introducing different liquid samples for a long time. Sensor response can be seen in Fig. 6.

4. RESULTS AND DISCUSSIONS

From Fig. 5 it is confirmed that with increase in the RI value the sensor response decreases as the power coupling decreases. Fig. 5 also confirms that, with the increase in lateral spacing power coupling between the two fibers decreases. The response shown in Fig. 5 can be described by taking the coupling efficiency η_T between LTF_S (or LTF_R) to the liquid into consideration. As the glass core has a higher RI compared to the all the liquid samples and hence the light is refracting from a denser to rarer medium, η_T varies inversely with the refractive index change. Hence, it is justified that the final coupling efficiency η from the liquid to the LRF_S (or LRF_R) [effectively from LTF_S (or LTF_R) to LRF_S (or LRF_R)] also varies inversely with RI. While the coupling efficiency decreases as the lateral spacing increases, this is due to loss in the spacing medium and due to divergence of light with increasing distance.

We have also tested stability and repeatability of the proposed sensor. Resolution of the sensor is found to be, 10^{-4}, it is comparable to some other recently proposed sensors. Though sensors based on FBG, SPR and photonic crystal sensors have almost 10 times higher resolution. But the advantage of the proposed sensor is that it is very inexpensive and it involves very minimal optical and electronic components and simple setup process.

The proposed sensor is an intrusive type sensor, which is a disadvantage of it. As it's an intrusive one it can't be used with highly acidic liquids. But as the core material is glass, this effect is still very less. By using standard refractometer, the proposed sensor is being calibrated. Further miniaturization of the same sensor setup will be done in the future.

5. CONCLUSION

A parallel multimode fiber based refractometer setup has been reported. It can measure refractive indices of transparent liquids up to a resolution of 10^{-4}. The sensitivity slightly increases with the increase in the lateral gap. The refractometer setup is low cost involves simple setup and highly rugged.

6. ACKNOWLEDGEMENT

The authors are thankful to USIC and Instrumentation center, Gauhati University for fabrication of the glass chambers required for the experimental setup. Authors are also thankful to UGC for providing research fellowship to one of the authors.

REFERENCES

[1] H. K. Singh, N. Chamuah, D. Sarkar, and T. Bezboruah, "Non-intrusive technique for measuring refractive index of clear and transparent liquids," IEEE Sensors J., vol. 14, no. 2, pp. 313–314, Feb. 2014.

[2] G. H. Meeteen, Refractive Index Measurement—The Instrumentation, Measurement and Sensors, J. G. Webster, Ed. Boca Raton, FL, USA: CRC Press, 1999

[3] *Pulfrich Refractometer*. accessed on Apr. 12, 2015. [Online]. Available: http://www.refractometer.pl/Pulfrich-refractometer

[4] A. K. Sharma, R. Jha, and B. D. Gupta, "Fiber-optic sensors based on surface plasmon resonance: A comprehensive review," IEEE Sensors J., vol. 7, no. 8, pp. 1118–1129, Aug. 2007

[5] J. Cao, E. K. Galbraith, T. Sun, and K. T. V. Grattan, "Comparison of surface plasmon resonance and localized surface plasmon resonance based optical fibre sensors," J. Phys., Conf. Ser., vol. 307, no. 1, p. 012050, 2011.

[6] Z. Q. Tou, C. C. Chan, W. C. Wong, and L. H. Chen, "Fiber optic refractometer based on cladding excitation of localized surface plasmon resonance," *IEEE Photon. Technol. Lett.*, vol. 25, no. 6, pp. 556–559, Mar. 15, 2013.

[7] A. Banerjee, "Enhanced refractometric optical sensing by using one-dimensional ternary photonic crystals," in *Proc. Prog. Electromagn. Res.*, vol. 89, 2009, pp. 11–22. [Online]. Available: http://jpier.org/PIER/pier89/02.08112105.pdf

[8] P. Wang *et al.*, "A photonic crystal fiber half taper probe based refractometer," in *Proc. Opt. Soc. Amer.*, 2013, pp. 1–4. [Online]. Available:http://www.orc.soton.ac.uk/publications/66xx/6694.pdf

[9] R. Jha, J. Villatoro, G. Badenes, and V. Pruneri, "Refractometry based on a photonic crystal fiber interferometer," *Opt. Lett.*, vol. 34, no. 5, pp. 617–619, 2009.

[10] A. Asseh, S. Sandgren, H. Ahlfeldt, B. Sahlgren, R. Stubbe, and G. Edwall, "Fiber optical Bragg grating refractometer," *J. Fiber Integrated. Opt.*, vol. 17, no. 1, pp. 51–62, 1998.

[11] M.-H. Chiu, S.-N. Hsu, and H. Yang, "D-type fiber optic sensor used as a refractometer based on total-internal reflection heterodyne interferometry," *Sens. Actuators B, Chem.*, vol. 101, no. 3, pp. 322–327, 2004

[12] P. Nath, H. K. Singh, P. Datta, and K. C. Sarma, "All-fiber optic sensor for measurement of liquid refractive index," *Sens. Actuators A, Phys.*, vol. 148, no. 1, pp. 16–18, 2008.

[13] T. L. Bergman, F. P. Incropera, and W. H. Stevenson, "Miniature fiber-optic refractometer for measurement of salinity in double-diffusive thermohaline systems," *Rev. Sci. Instrum.*, vol. 56, no. 2, pp. 291–296, 1985.

[14] T. Zhu, Y. Song, Y. Rao, and Y. Zhu, "Highly sensitive optical refractometer based on edge-written ultra-long-period fiber grating formed by periodic grooves," IEEE Sensors J., vol. 9, no. 6, pp. 678–681, Jun. 2009.

[15] P. Wang *et al.*, "Enhanced refractometer based on periodically tapered small core single mode fiber," *IEEE Sensors J.*, vol. 13, no. 1, pp. 180–185, Jan. 2013.

[16] D. Chetia, T. Basumatary, H. K. Singh and T. Bezboruah, Low-Cost Refractometer with Longitudinally Displaced Optical Fibers, IEEE Sensors Journal, Vol. 16, No. 15, pp. 5950-5957, August 2016.