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A low cost fiber optic refractive index sensor

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An intensity modulated extrinsic fiber optic Refractive index sensor is presented. A ‘Y’ shaped bundle fiber and mirror are used. Sensor principle is based on change in angle of reflected light caused by refractive index change of the medium surrounding the bundle fiber. The experimental results obtained for liquid of different refractive indices prove the sensor potential to act as sensitive refractometer.

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1. Introduction

Sensing and the need for more sensitive and reliable sensors to measure refractive index (RI) of liquid find many applications in chemical and biomedical industries. RI is an inherent characteristic of liquid and it is useful to find the physical parameters like concentration, pressure, density etc. of the liquid. Compared to conventional refractometer for measurement of RI of liquid, optical fiber RI sensor has several advantages like remote sensing, small in size, immune to EMI etc..[1,2]. Several fiber optic sensors for measuring the refractive index of liquid have been designed like, using etched cladding fiber [3], using frustrated total internal reflection technique in multimode fiber[4], using core diameter mismatch[5]. Iadicicco et al. used etched fiber Bragg grating [6], long period grating [7] for the measurement of RI. Measurement of refractive index of liquid using fiber optic displacement sensor was demonstrated by A.D.Shaligram et.al.[8]. Majority of the fiber optic RI sensors need elaborate and precision arrangements and hence there is a need to develop a simple, stable and easy arrangement to measure the RI of liquid.

In this paper a simple, rugged, low cost and very efficient fiber optic RI sensor with high repeatability and linearity is demonstrated using glycerol as test solution. Glycerol is a valuable component in the processing of Seeds, production of plastics, detergent and medicines etc.. The sensor consists of an IR source, fiber optic probe and a photo detector. The probe consists of bifurcated fiber optic bundle. Light from source is launched to one arm of the probe and directed to a region where light is interacted by the measurand. The interaction results in the modulation of light intensity and is collected by the other arm of the probe and is measured by a photo detector. Using the probe a successful verification of Refractive index sensing has been done by changing the concentration of glycerol.

2. Working principle and sensor structure

The proposed sensor consists of a transmitting bundle fiber, receiving bundle fiber and a reflector. The fiber bundles are parallel to each other and are placed in front of a reflector (mirror) at a distance ‘x’ as shown in Fig. 1.

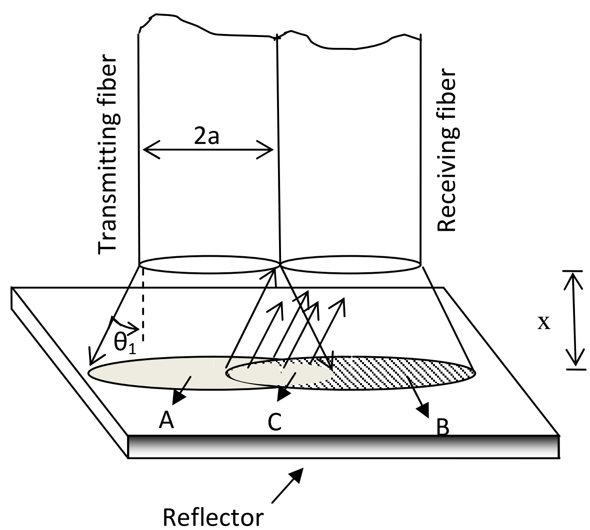

Fig. 1. Schematic arrangement for refractive index measurement using optical fiber.

The light is launched into the transmitting fiber and on emergence reflected by the reflector. Then it enters the receiving fiber and is sensed by the photo-detector to be displayed as output power. The incident light on the reflector forms a cone of emittance from transmitting fiber. It is reflected back in the form of expanding cone of light. The cone diameter depends on refractive index of the medium between the reflector and the probe. The space between the probe and the reflector is filled with a liquid of refractive index n_1 as shown in Fig. 1. Then cone angle

$$\theta_1 = \sin^{-1}(NA/n_1) \quad (1)$$

where NA is the numerical aperture of the transmitting fiber. If 'x' is the separation between the reflector and sensor tip then the radius of the reflected cone 'r_1' at 2x distance is given by [9]

$$r_1 = a + (2x) \tan \theta_1 \tag{2}$$

The areas of transmitting cone and receiving cone obtained on the reflector by the transmitting fiber and receiving fiber are 'A' and 'B' and 'a' is the radius of the transmitting fiber. Light collected by the receiving fiber is determined by the overlap region 'C' of the acceptance cone of receiving fiber and that of transmitting fiber. If the medium is filled with liquid of refractive index n_2, such that $n_2>n_1$ then $\theta_2 < \theta_1$ and $r_2 < r_1$ and hence the overlapping area decreases. The output power decreases with reduction in the spacing between the reflector and fiber tip. At higher values of x, entire region of the receiving fiber tip is covered by the reflected beam and there is no change in the overlap area, then the fall in output power follows the inverse square law. If the refractive index of the liquid increases the reflected beam becomes narrower and hence more light is concentrated in the beam. Thus the output power corresponding to a specific distance x increases with refractive index. Therefore maintaining the distance between the reflector and the probe at a certain value of x, the received power serves as a measure of refractive index of liquid.

3. Experimental setup

The setup consists of an IR Source, fiber optic probe, reflector, thermometer, photo detector and a digital multimeter. A bifurcated fiber optic bundle from Oriel instruments (Model no 77533) is used as probe and its NA is 0.56. Its common end has half portion (a semi-circle) from transmitting fibers and the other half from receiving fibers. Diameters of transmitting and receiving fiber bundles are same. Light from IR LED (λ_{peak}=850nm) is coupled to the transmitting fiber. The light from the receiving fiber is coupled to detector (Si photo diode) and it is connected to a digital multimeter for the measurement. An aluminum coated mirror is used as reflector. A micro displacement meter is used for displacing the probe from the reflector over a span of 25 mm in successive steps of 1mm. The intensity of reflected light is measured in terms of milli volts against the corresponding translation.

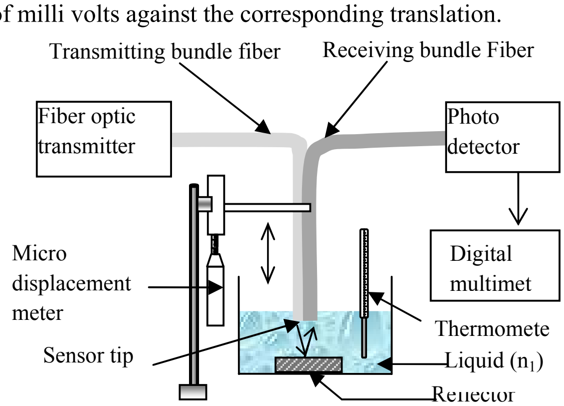

Fig. 2. Schematic experimental setup.

The reflected light intensity is measured using deionized water by changing the position of the fiber probe with respect to the reflector. Measurements were carried out for glycerol solution with concentrations of 20, 40, 60, 80 and 100 percent (v/V), where 'v' is the volume of pure glycerol and 'V' is the total volume of the solution. Experiment was conducted at 26.5^{0}C temperature.

4. Results and discussion

The variation of the reflected light intensity in terms of output voltage in the receiving fiber with the increase of glycerol concentration from 20 to 100% in volume is measured and is shown in the Fig. 3. The output voltage is minimum when the probe is at minimum separation from mirror because there is no overlapping region on the reflector (C = 0). As the separation increases, the area of the cone (A) due to the transmission fiber at the reflector increases and starts overlapping with the area of the receiving fiber cone (B). This increases the amount of light collected by the receiving fiber.

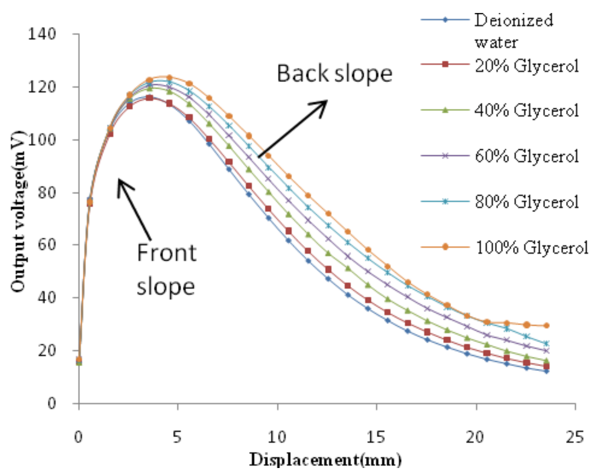

Fig. 3. Variation of output voltage with displacement.

Further increase of displacement increases the overlapping region resulting rapid increase in output voltage and reaches to a maximum resulting in steep front slope. As the concentration of the solution increases, refractive index also increases proportionately. The increase in refractive index of the solution results in the decrease of radius of acceptance cone on the reflector, eqn.2. For a given separation the increase in the glycerol concentration, decreases the overlapping region of acceptance cones on the reflector. The maximum overlapping region on the reflector is achieved by increasing the separation between the probe tip and reflector. At certain separation maximum light reaches to the receiving fiber and is dependent on concentration of liquid and is shown in Fig.3. The light intensity after reaching maximum starts decreasing for larger displacement.

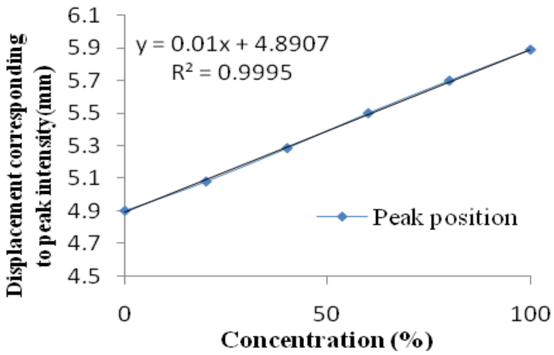

Fig.4. Variation of peak intensity with glycerol concentration.

This is due to the decrease in the power density of light with increase in the area of the light cone. A theoretical model supports these experimental results [9].

The change in peak position with the variation of concentration of glycerol is shown in Fig. 4. The peak intensity displacement in 20% to 100% concentration range is 760µm. The rate of displacement of peak position with respect to concentration is 0.01mm/concentration.

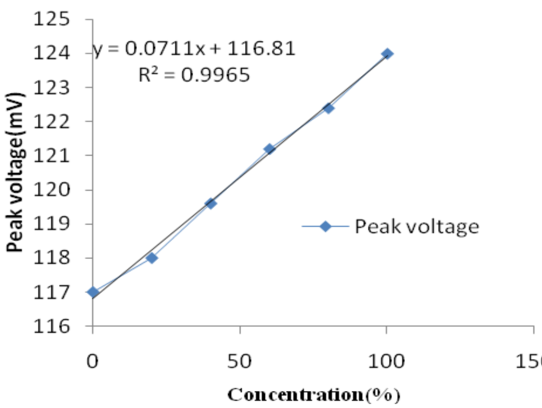

Fig. 5. Variation of peak voltage with increasing glycerol concentration.

The variation of reflected peak intensity (output voltage) with different concentrations of glycerol is shown in the Fig. 5. The increment in peak voltage with variation in concentration is linear and is 0.071mV/concentration

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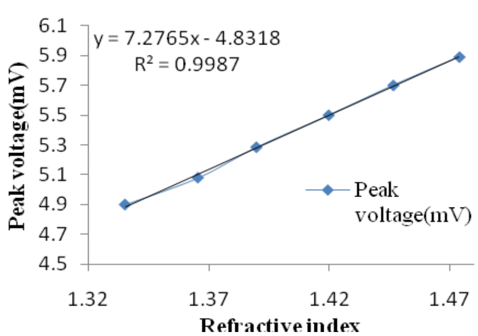

Fig. 6. Variation of peak voltage with Refractive index of glycerol.

The RI corresponding to the concentration is measured and a graph plotted between peak voltage and RI is shown in Fig. 6, and the change is linear.

This enables us to determine the unknown RI of given glycerol solution. In order to test the repeatability of the sensor the experiment was repeated and observed a negligible error in peak intensity with respect to concentration of glycerol.

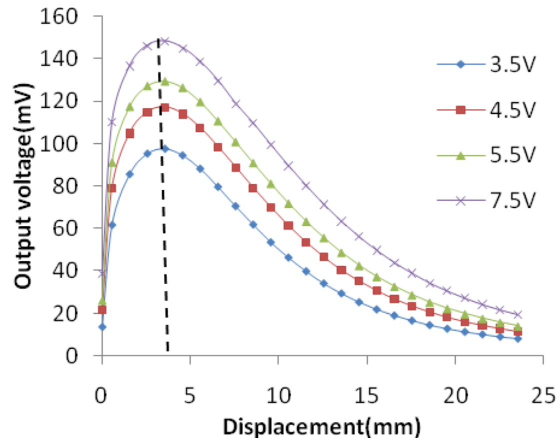

Fig. 7. Output characteristic of the sensor in deionized water.

The reflected light intensity is measured by changing the bias voltages applied to the LED and the plot is as shown in Fig. 7. It shows that the intensity of the peak increases with increase in bias voltage. But the peak position remains constant for different bias voltage. It also shows that peak position corresponding to a liquid concentration is independent of bias voltage. Measurement of refractive index of a liquid can be done with the help of characteristic curve drawn with known RI. The response of the sensor depends on characteristics of the fiber used, source and detector.

4. Conclusions

A simple, rugged and low cost fiber optic sensor is presented using bundle fiber to determine the refractive index and concentration of a liquid. The standard techniques are accurate but are costly and are not applicable in harsh environment. The results obtained can be useful for the development of an instrument for online measurement of refractive index of the liquid. This type of sensor also helps to find the purity of a liquid by comparing the refractive index of the liquid with that of its pure form. The simple design of the sensor has excellent repeatability.

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