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Performance of the reflected concentration sensor using plastic fibers

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In this work the effects of fiber diameter, intensity fluctuation and reflector on the sensitivity of Plastic optical fiber sensor to measure the concentration of a solution is reported. This sensor works on fiber optic proximity sensor principle. The intensity of reflected light is modulated with the change in concentration of the liquid surrounded. The experimental results reveal that fibers with large diameter offer substantially a greater sensitivity and the position of the reflected peak corresponds to a particular concentration and is independent of reflectors.

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1. Introduction

Measuring and controlling the concentration of solutions is required for guaranteeing and improving product quality in chemical industries, sugar-manufacturing, food, paper-making and pharmaceutics etc.. For example, in the process of making soap, concentration of glycerol plays an important role in maintaining the quality of the product because it is a powerful cleanser and skin moisturizers. Concentration has direct relation with refractive index. Therefore, it is also required to monitor refractive index of various solutions.

Over the years there has been many techniques developed to monitor refractive index of solutions [1]. Most conventional one is Abbe refractometer to measure refractive index [2]. Marc Hennemeyer et al proposed micromechanical cantilever similar to the one used in an atomic force microscopy can measure concentration of solutions [3]. Kirti Soni et al proposed acousto-optic grating for the measurement [4]. Compared to many other techniques fiber optic sensor has a number of advantages like low cost, remote sensing, small in size, immune to EMI. It also offers multiplexing facility for simultaneous monitoring of refractive index of several liquids with a single setup with slight modification. Several fiber optic sensors for measuring the refractive index of liquid have been designed like, using etched cladding fiber [5], using frustrated total internal reflection technique in multimode fiber [6], using core diameter mismatch [7], using Relative Fresnel reflective intensity for concentration measurement [8], Iadicicco et al. used etched fiber Bragg grating [9], long period grating [10] for the measurement of refractive index. Measurement of refractive index of liquid using fiber optic displacement sensor was demonstrated by A.D.Shaligram et.al. and others [11,12,13]. Majority of the fiber optic concentration sensors need elaborate and precision arrangements and hence there is a need to develop a simple, stable and easy arrangement to measure the concentration of liquid. In the present work a simple, rugged, low cost and very efficient fiber optic concentration sensor with high repeatability and linearity is reported. To improve the sensitivity of the measurement the effect of fiber diameter and use of reflector is studied. Plastic optical fiber (POF) is used to fabricate the sensor heads and glycerol with different concentration is used as test solution. Glycerol has three hydrophilic hydroxyl groups that are responsible for its solubility in water and its hygroscopic nature. Glycerol has a special chemical property that allows it to be useful where oil fail. A wide refractive index of solution range can be achieved with the different concentration of glycerol solution.

The sensor arrangement consists of a LED as source, two POF's as probes and a photo detector. Light from the source is launched into a fiber and directed to a region where light gets interacted with the measurand. The interaction results in the modulation of light intensity and is collected by the other fiber and is sensed by a photo detector. The result obtained is useful for the enhancement of sensitivity of the concentration sensor.

2. Working principle and sensor structure

The sensor head consists of a transmitting fiber end, receiving fiber end and a reflector. The POFs are arranged parallel to each other and their tips are placed in front of a reflector (mirror) at a distance 'x' (Fig.1). The light is launched into the transmitting fiber and on emergence reflected by the reflector and is received by the receiving fiber. The light intensity is sensed by a photo-detector to be displayed as output power in micro amperes. 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 'n' of the medium (liquid) and the separation between the reflector and the probe at any fixed position between probe and the reflector. If the space between the probe and the reflector is filled with a liquid of refractive index 'n' Fig. 1, then cone angle

$$\theta_\alpha = \sin^{-1}(NA/n) \qquad (1)$$

where NA is the numerical aperture of the fiber. If 'a' is the radius of the POF then the radius of the reflected cone 'r_α' at 2x distance is given by

$$r_\alpha = a + (2x)\tan\theta_\alpha \qquad (2)$$

$k_\alpha = r_\alpha/a$ is a dimensionless coordinate on the image plane gives the boundary of the illuminated area.

3. Experimental setup

The setup consist of a super bright LED (λ_{peak} = 630 nm, 0.5W), reflector, photo detector, a digital multimeter and two plastic optical fibers. Two different probes A and B of 0.5 NA were used and their cross sectional view is shown in Fig. 3.

The core cladding diameter of transmitting and receiving fiber of Probe A are same and is 980/1000 µm. and that of Probe B are 980/1000 and 735/750 µm respectively. Transmitting and receiving fibers were glued to form a single probe. The tip of the probe was polished using suitable grit. The other ends of the fibers are cleaved and polished for better coupling of the fibers to source and to detector. The bending losses are minimized by putting both transmitting and receiving fibers in close contact and avoiding sharp bends.

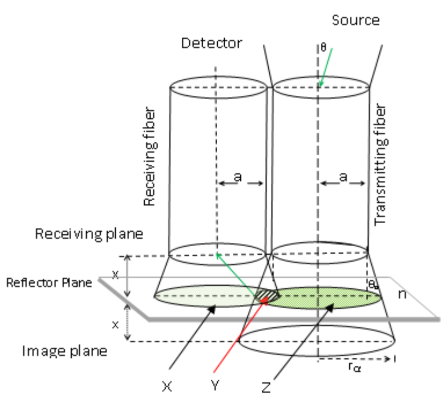

Fig.1. Schematic arrangement for refractive index measurement using optical fiber.

The areas of transmitting cone 'Z' and receiving cone 'X' obtained on the reflector by the transmitting fiber and receiving fiber depends on the radius 'a', the acceptance angle 'θ_α', Numerical Aperture of the fibers and refractive index 'n' of the liquid. Light collected by the receiving fiber is determined by the overlap region 'Y' between 'X' and 'Z', Fig. 1. If the space is filled with liquid of refractive index n_l, such that n_l>n then $\theta_{\alpha l} < \theta_\alpha$ and $r_{\alpha l} < r_\alpha$ and hence the decrease in output power. The output power decreases with reduction in the spacing between the reflector and fiber tip. At higher values of 'x' and beyond, 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 concentration of the liquid increases the reflected beam becomes narrower. Thus the output power corresponding to a specific distance 'x' increases with concentration. Therefore maintaining the distance between the reflector and the probe at a certain value of x, the power received is a measure of concentration of the liquid

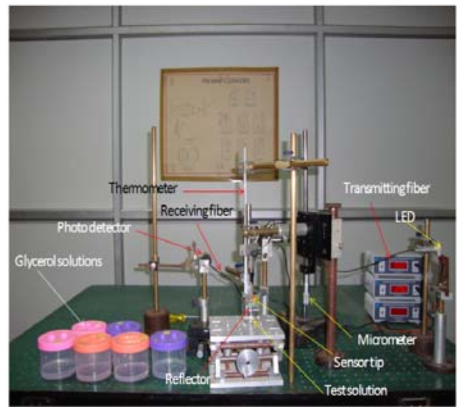

Fig.2. Experimental setup.

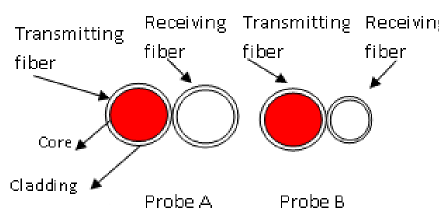

Fig. 3. Cross section view of probes.

A 630 nm LED source is used since POF has minimum absorption near 647nm and the absorption coefficient is 153dB/Km. Since the fiber diameter is large the Light from LED is directly coupled to the transmitting fiber. The light from the receiving fiber is coupled to a Si photo diode (λ_{range} = 400 nm to 1100 nm) and the output current is measured with the help of digital multimeter. Polished metal surfaces are used as reflectors Fig. 4.

Fig. 4. Surface of reflectors.

The spacing between the tip of the probe and reflector is 11.5mm and the readings are taken in successive steps of 1mm using a micrometer arrangement. The intensity of reflected light is measured in micro amperes against the corresponding translation.

With distilled water as medium the intensity is measured at first for a particular value of ‘x’. Then water is replaced by glycerol of 20, 40, 60, 80 and 100% (v/V) concentrations, where ‘v’ is the volume of glycerol and ‘V’ is the total volume of the solution. Experiment is conducted at 26.5 ^{0}C temperature (±0.5^{0}C).

4. Results and discussion

Using Probe A the variation of the reflected light intensity in terms of photo detector current (μA) with the separation (mm) in the receiving fiber at different concentration of glycerol from 20% to 100% is noted and it is shown in Fig. 5 .

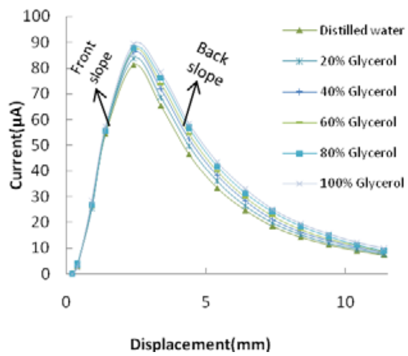

Fig. 5. Variation of detector current Vs. displacement using probe ‘A’.

A minimum output current is observed when the probe is at close proximity of the reflector. Increase in separation increases the light launched into the receiving fiber resulting in rapid increase of output current and reaches to a maximum with steep front slope Fig. 5. It is observed that at any separation, light reaching the receiving fiber is dependent on the concentration of solution. The light intensity after reaching maximum starts decreasing for larger separation resulting in moderate back slope. The decrease in power density is due to the increase in the area of transmitting fiber cone with increasing separation and inverse square law [14].

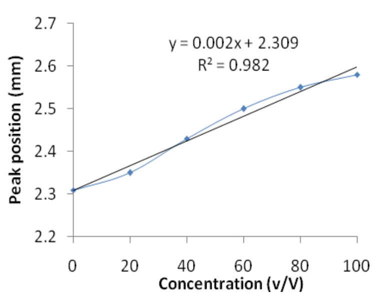

Fig.6. Variation of peak position with glycerol concentration.

Fig. 6 is a plot between peak position corresponding to maximum current and concentrations of glycerol using a micrometer of 10μm resolution. For a 0 to 100% variation of glycerol concentration the maximum current peak position shifted by 270 μm. The rate of displacement of peak position with respect to concentration is 0.002 mm/concentration with linearity 98.2%.

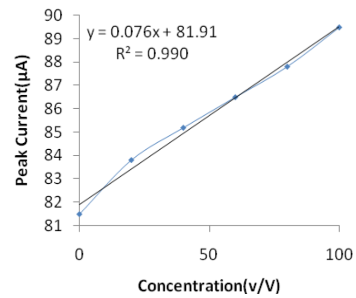

Fig.7. Variation of peak position with glycerol concentration.

The variation of reflected peak intensity (output current) with different concentrations of glycerol is shown Fig. 7. The increment in peak current with variation in concentration is 0.076μA/concentration and is of 99% linear.

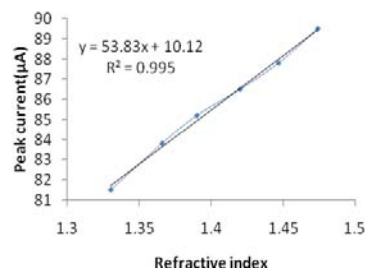

Fig. 8.Variation of peak current with glycerol refractive indices.

The refractive index corresponding to the concentration of the solution is plotted with peak current Fig. 8 The sensitivity is 53.83μA/Refractive index with linearity 99.5%. In order to test the repeatability of the sensor the experiment is repeated and the deviation is negligible.

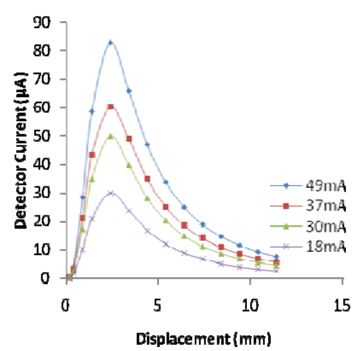

Fig. 9. Output characteristic of the sensor in distilled water.

When the sensor is in distilled water the change in reflected light intensity is measured by changing the current passing through the LED and is shown in Fig. 9. Plot shows that the intensity of the detector peak current increases with increase in applied current at a rate 1.703. But the peak position remains constant for different applied currents.

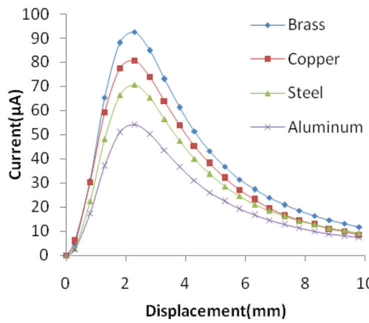

Fig. 10. Response of the sensor using different reflectors in distilled water.

Fig. 10 shows the effect of reflectivity of light from reflector in terms of detector current. All the curves follow the same basic shape but with varying currents at a specific displacement. The increase in peak current is directly proportional to reflectivity of the reflector.

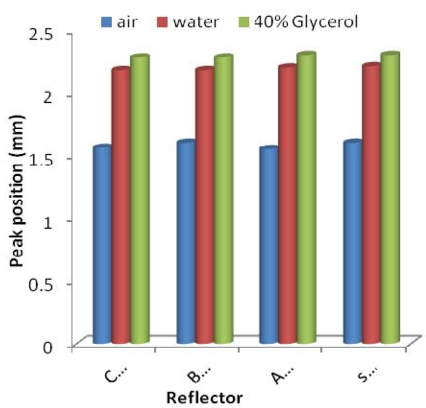

Fig.11. Response of reflector corresponds topeak position in mediums.

However the peak position of a particular concentration of liquid does not change with the change of reflector. Fig. 11. This is being verified in comparison with air, water and 40% glycerol solution. This proves that concentration of any solution can be measured with any kind of reflector profile.

The experiment is also being conducted with probe ‘B’. It shows a total 210 µm of displacement and peak position sensitivity of 0.002 mm/concentration for the concentration change 20% to 100% of glycerol solution. It has 0.043 µA/concentration peak current sensitivity. The reflectivity of the Brass reflector is maximum followed by copper, steel and aluminum. Reducing the receiving fiber diameter decreases the intensity of the light received from the reflector satisfies the theoretical model [15]. Measurement of concentration of a liquid can be done with the help of characteristic curves. Thus response of the sensor depends on characteristics of the fiber used.

5. Conclusions

Based on the reported result, we conclude that enhancement of sensitivity depends on sensor probe configuration only. The experimental data is the realization of the theoretical model and will help to improve the sensor sensitivity. It is observed that the increase in diameter of receiving fiber (Type A) with good reflector (Brass) enhanced the sensitivity. The cost required for this enhancement is low. This approach can be efficiently used if sensitivity enhancement is required especially in the case when the change in concentration is very small.

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