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Measurement of refractive index of liquids using fiber optic displacement sensors

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Abstract:
The paper describes a technique to determine the refractive index of liquids using reflective type fiber optic displacement sensor. The sensor consists of two multimode step index fibers and a mirror. The output light intensity from the receiving fiber is measured as a function of displacement of the fiber with respect to mirror in various solvents. The study shows that the light peak intensity position depends upon the refractive index of the medium. Different liquids such as water, carbon tetrachloride and chlorobenzene were used as a medium. [Journal of American Science 2009:5(2) 13-17] (ISSN: 1545-1003)

Key word: Refractive index measurement; fiber optic sensor; Liquids.

1. Introduction

The refractive index measurement sensors find numerous applications in industries for finding the physical parameters such as concentration, temperature, pressure, etc. Many people have proposed different optical fiber sensors for measuring the refractive index of liquids [M.Laguesse, 1988; Jan Turan et al., 2001; S. Kang et al., 1997; T.Suga et al., 1986; Brant C.Gibson et al., 2003]. Fiber optic sensors are more advantageous than conventional sensors. They exhibit high sensitivity and wide frequency response. They are non-contact and could be used in hostile environments.

Yu-Lung Lo et al., have proposed a fiber optic sensor based on Path-Matching Differential Interferometries (PMDI). It measures change of refractive index in the resolution of about 10^{-5}. Meriaudeau et al., presented a fiber optic chemical sensor based on surface plasmon excitation for refractive index sensing. It can be used to measure the refractive index in the range of 1 to 1.7. A.Suhadolnik et al., proposed an optical fiber reflection refractometer using three optical fibers in which one acts as an emitting fiber and others two as receiving fibers. The intensity ratio of two receiving fibers was found to be function of the refractive index of the medium. The study was carried out in the aqueous solutions of NaCl and LiBr. A.L.Chaudhari and A.D. Shaligram proposed two fiber model sensor (emitting and receiving fibers) based on reflective type fiber optic displacement sensor. The receiving fiber output intensity was measured as a function of a separation between the mirror and fiber for various liquids. It was found that the sensor distinguished the liquids of different refractive index for the separation greater than 6 mm. In these two techniques, the refractive index of liquids was measured in terms of the output intensity of the receiving fiber.

In this paper, we propose a simple and high sensitivity fiber optic sensor. In this technique, the sensor probe under goes linear displacement and the output corresponding to each displacement is measured. The intensity profile peak is related to the refractive index of the medium.

2. Sensor structure

The sensor was fabricated using two multimode step index optical fibers, which were cemented together with the small spacing between them. Among these, one act as an emitting fiber and other act as receiving fiber which are arranged side by side as shown in fig.1.

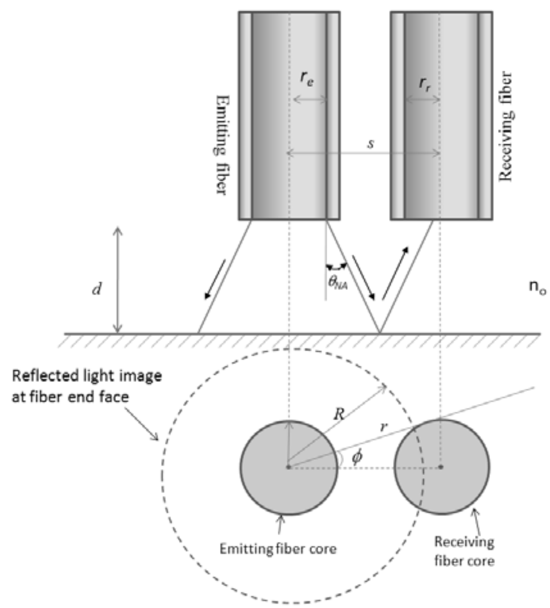

Fig. 1. Schematic structure of the proposed fiber optic sensor

The output of the emitting light spot overlaps the core of the receiving fiber and the output goes through a maximum, when distance between the mirror and optical fibers is changed. At particular position, the intensity peak gets maximum for a given liquid. The characteristics of the sensor depend on the fiber core diameter, numerical aperture, the spacing between the two fibers and refractive index of medium. In this study, fiber core diameter, numerical aperture and spacing between the two fibers are kept fixed.

3. Working model

The working model of the sensor is based on two-fiber model, one act as an emitting fiber and other as receiving fiber. The emitting light angle and receiving fiber capturing light angle are depended on the refractive index of medium (n_0) and numerical aperture (NA) of the fiber. When the fibers have same numerical aperture, the maximum emitting angle θ_{NA} is given by,

$$\theta_{NA} = \sin^{-1}\left(\frac{NA}{n_0}\right)$$

The efficiency factor $\eta(2d,n_0)$ is given as the ratio between the light power captured in the receiving fiber $P_0(2d,n_0)$and the total power P_t launched into the incoming fiber [A.Suhadolnik et al., 1995].

$$\eta(2d,n_0) = \frac{P_0(2d,n_0)}{P_t} = 2\int_{R_1}^{R_2}\int_0^{\phi_c} R_m T_i(n_0) T_0(r,2d,n_0) \frac{2}{\pi R^2(d)}\left(1-\frac{r^2}{R^2(d)}\right) r\,d\phi\,dr$$

Where, P_t is the total optical power transmitted through the input fiber, $P_0(2d,n_0)$ the light power captured by the receiving fiber and 'R_m' is the mirror reflectivity. The $Ti(n_0)$ and $T_0(r,2d,n_0)$ are Fresnel transmittance coefficients of the emitting fiber and receiving fiber, respectively. The 'r' is the distance from the emitting fiber axis, ϕ is the azimuth angle, 'r_e' and 'r_r' are input and receiving fiber radius respectively. The 's' is spacing between the fiber cores, 'd' is distance between the mirror and fiber tip and 'R' is the radius of the light cone at the distance 2d, and R is given by

$R = r_e + 2d \tan(\theta_{NA})$.

The fig. 2. gives the theoretical curve for s = 1.2mm, NA =0.47 and nc = 1.495 (refractive index of fiber core) for a air medium [A.Suhadolnik et al., 1995].

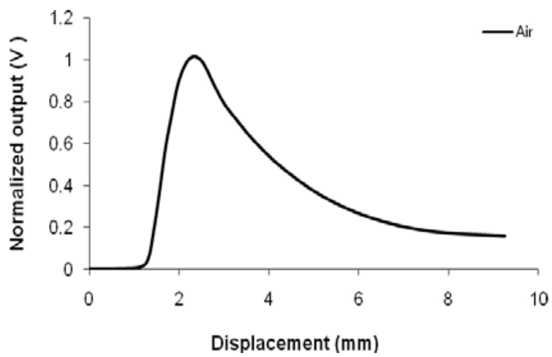

Fig. 2. Theoretical curve for air medium

4. Experiment

The optical fibers were attached to a movable micrometer stage, as shown in fig.3. The core and cladding diameters of input fiber and output fibers were 200 & 225 μm and 400 & 425μm, respectively. The core separation of input fiber and receiving fiber was 500 μm. Displacement measurements were carried out by mounting the sensor in front of aluminium coated mirror. The LED (λ=625nm) was used as a light source.

The output intensity of the receiving fiber is measured by the photodectector. Various solvents such as water, carbon tetrachloride and chlorobenzene were used.

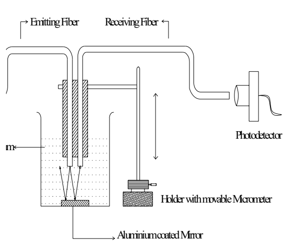

Fig. 3. Block diagram of the experimental set-up.

5. Results & Discussion

Fig. 4. shows the variation of the output of the receiving fiber for various displacements. It is seen initially that the output is almost zero for small displacements (about 1.2mm). When the displacement is increased, the output starts increasing rapidly and reaches a maximum. Further increase in the displacement leads to decrease in the output as shown in figure. These behaviors are similar to that observed by theoretical model (eg. air medium) [A.Suhadolnik et al., 1995] (Fig.2).

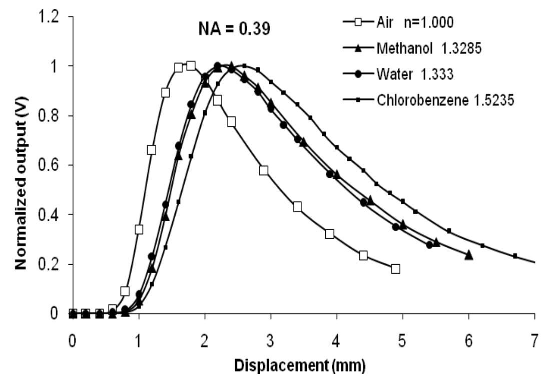

Fig. 4. Normalized output Vs Displacement (NA:0.39)

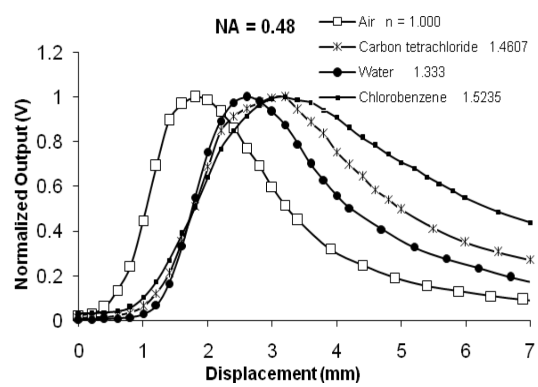

Fig. 5. Normalized output Vs Displacement (NA:0.48)

The variation of output intensity with displacement may be understood as follows. For smaller displacements, the size of the cone of light from the emitting fiber is very small and doesn't reach the receiving fiber after reflection.

This results in almost zero output. When the displacement is increased, the size of reflected cone of light increases and starts overlapping with the core of the receiving fiber leading to presence of small output. Further increase in the displacement leads to large overlapping resulting in rapid increase in the output and reaches a maximum. The output after reaching the maximum starts decreasing for larger displacements due to increase in the size of the light cone as the power density decreases.

It is seen in the fig. 4. that the maximum intensity varies for different solvents. It may be related to the change in the size of the cone of the emitting light due to change in the refractive index of the medium. Fig.5. shows the plot observed for the optical fibers with numerical aperture of 0.48.

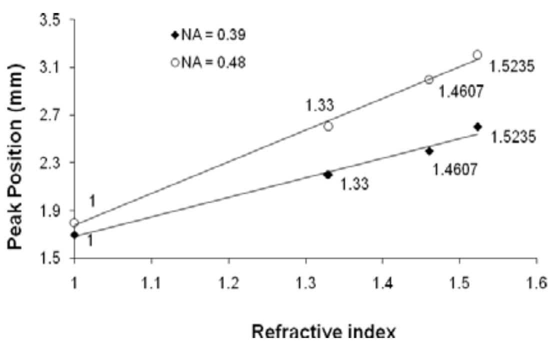

Fig. 6. Variation of peak position for different refractive index of medium

Fig.6. shows a plot between the refractive index of the medium and peak position. It is seen that when the refractive index increases, the peak position occurs at larger displacements. There is a linear relation ship between the peak position and the refractive index of the medium. The results suggest that the sensitivity increases when the numerical aperture is large.

Different light powers were used (1.5 to 3.5 μW) to understand the effect of light power on the output characteristics of the sensor. Fig.7. shows the output characteristics of the sensor for various powers for a water medium.

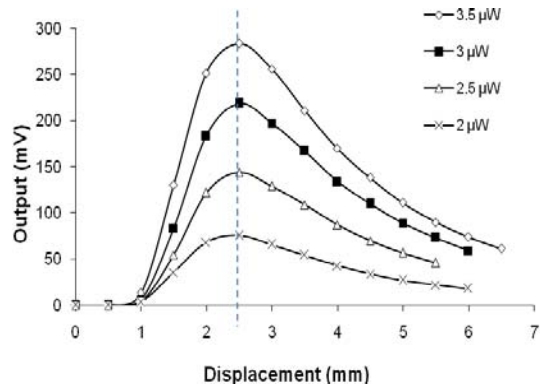

Fig. 7. The output characteristics of the sensor

It is seen that the intensity peak remains constant though the intensity profile varies for various powers. It shows that the output intensity peak position in a given liquid is independent of the power change or absorption of light by the medium.

6. Conclusions

A simple fiber optic sensor is presented to determine the refractive index of liquids. The study shows that the output light intensity peak observed in various liquids is function of the refractive index of the medium and there is a linear relationship between them. The paper presents the results obtained for the liquids over the refractive index range of 1 to 1.52. The light intensity peak in a given medium is independent of the change in the light power or any light absorption by the medium.

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