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Intensity Modulated Tapered Glass Rod Plastic Fiber Optic Intrinsic Refractive index Sensor

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Abstract: *Fiber optic sensors may be broadly classified as either intrinsic or extrinsic. In the intrinsic sensor, the physical parameter to be sensed modulates the physical properties of light inside the fiber whereas in an extrinsic sensor, light modulation takes place outside the fiber. In the former, one of the physical properties of the guided light, e.g. intensity, wavelength, polarization and phase is modulated by the measurand. In the later case, the fiber merely acts as conduit to transport the light signal to and from the sensor probe. However, out of these four, the intensity modulated ones offer the most wide range of optical fiber sensors. The advantage of intensity modulated sensors lies in their simplicity of construction and their being compatible to the multimode fiber technology. In the present experiment a borosilicate glass rod made into a taper is used as sensing zone is connected in between two 200/ 230 μm diameter plastic clad silica (PCS) fibers. The tapered portion is then immersed into a jar containing the liquid and the light from a source operating at a wavelength of 633 nm is launched and the output power is noted using a bench mark power meter. A relationship is formed between the light reaching the output end to the refractive index of the liquid surrounding the tapered zone. By using liquids with different r. i. values, the sensor is calibrated, which can be used for the determination of refractive index of unknown liquid either dark or transparent in the dynamic range of 1.3_{nD} and 1.5_{nD}.*

Keywords: Intrinsic Sensor, Glass rod made into a Taper, Plastic Clad Silica Fibers, Multimode Fiber Technology, Dynamic Range of 1.3_{nD} and 1.5_{nD}.

1. INTRODUCTION

Many attempts to develop fiber optic refractive index sensors using optical fiber itself, and U – shaped glass rod as a sensing element reported in the literature. Refractive index sensors using other designs are also proposed employing intensity modulation techniques. Although the phase modulated fiber optic sensors offer higher sensitivity as compared to intensity modulated sensors, the greatness of intensity modulated sensors lies in their simplicity of construction and they are being compatible to the multimode fiber technology and are being used widely. The need for low loss, low dispersion, ultra-wide bandwidth, and high dynamic range, durability, upgradability, and low cost networks have shifted the focus from traditional electrical sensors to optical fiber sensors [1 – 6].

The general configuration of an intensity modulated sensor is shown in figure 1. The baseband signal, the measurand in the form of a sinusoidal varying quantity is seen to modulate intensity of the transmitted light through the sensor. The modulation is reflected in the voltage of power output of the detector, which upon calibration can be used to retrieve measure of the measurand.

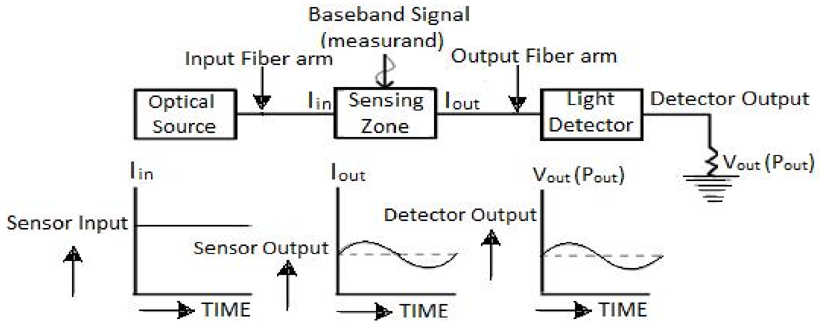

Fig.: General Design of Fiber Optic Sensor

It is clear from the above figure when a light of having some intensity, travels through multimode silica glass plastic fiber, when it interacts with a particular measurand at the sensing region, the intensity changes according to the magnitude of the measurand and the change will reflects in the output power. Thus the by measuring the change in the output power, the magnitude of the measurand can be determined. Several numbers of mechanisms with various sensor geometries were reported in the literature, to sense numerous parameters. The changes in geometries of the sensor depend on the parameter to be sensed. For the interaction of light with the medium, the medium can be characterized by a single parameter i. e. refractive index of the medium 7- 11]..

The light outside the medium (in free space) can be characterized as pure transverse electromagnetic (TEM) wave, both the electric and magnetic fields vibrate perpendicular to one another and perpendicular to the direction of light propagation. The general sinusoidal waveform of the electric (magnetic) field vector is expressed as:

$$E(x,t) = E_0 \sin(\text{µ} t - kx + \text{¤}_0) \quad (1)$$

Where, $\text{µ} = 2\text{®} f$

And $k = \dfrac{2\text{®}}{\text{a}_0}$

Equation (1), represents the complete phase of the propagating wave. During the interaction of light with solid materials, more specifically with optoelectronic materials, the light exhibits several phenomena like, reflection, refraction/transmission, absorption, interference, diffraction, polarization. In all the above optical processes, the light velocity v in any specific medium deviates from its value in free space given by

$$v = \frac{c}{n} = f\left(\frac{\text{a}_0}{n}\right) = f\text{a} \quad (2)$$

Where, $\text{a} = (\text{a}_0/n)$ is the modified wavelength of light in the medium with refractive index $n = (\text{«£})^{1/2}$. Here, μ and ε are the magnetic permeability and dielectric permittivity of the medium respectively. Besides light velocity, its amplitude (or intensity) and phase are also changed by above mentioned optical phenomena. The careful utilization of these elementary properties of light is the backbone of all sorts of optoelectronic devices and optical fiber based sensor systems [12, 13. Besides refraction and the refraction properties of light, another common phenomenon known as absorption occurs, when light passes through any medium. Due to the absorption process, the intensity of the incoming light will varies in most of the optoelectronic devices such as in optical fibers and fiber sensors. It is this absorption of light by the outside medium of the tapered glass rod results in the decrease in the output power.

Optical fiber sensors based on the evanescent absorption have become popular in the last few years for the applications of distributed and remote sensing [14 – 15]. The advantages of these sensors is many parameters and be sensed simultaneously having different sensors for different parameters connected in a single distributed sensing network and the parameter can be sensed from remote keeping the transmitter and the receiver at a single point. When light travels from core to cladding, some portion of the light escapes into the cladding as evanescent wave, if the cladding is an absorbing medium, the evanescent wave intensity is attenuated, giving rise to a decrease in the power propagating in the denser (core) medium. The attenuation also increase with number of reflection at the core and cladding interface. Thus the unclad tapered glass rod is more useful as an attenuated total reflectance (ATR) spectroscopic element.

2. EXPERIMETAL DETALIS

Two plastic clad silica (PCS) fibers, one is connected with light source operating at a wavelength of 633 nm using a SMA connector, and other one connected to a benchmark power meter using another SMA connector are used in the experiment. The other end of the input fiber is connected to the large end of the tapered glass rod, and the smaller end of the tapered glass rod is connected to the other end of the output fiber (Fig. 2).

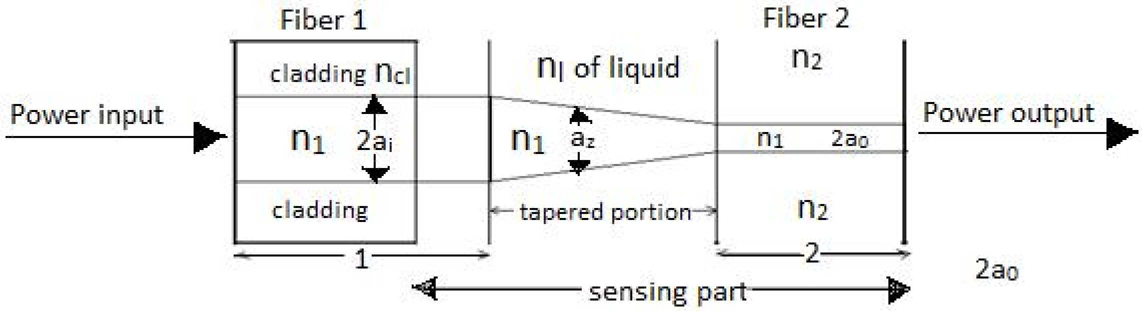

Fig. 2: Geometry of a tapered multimode fiber refractometer**.**

The tapered glass rod of taper ratio of 0.5 between the two ends of the taper is used in the present experiment. The bare portion of the tapered glass rod is then immersed in the in a liquid of refractive index, $n_l < n_1$. Immersing the taper subsequently in a number of other liquids with different r.i., and monitoring the corresponding power reaching the output fiber, a calibrated curve is generated. Thus by measuring the power exiting from output fiber when the taper is immersed in a liquid of unknown refractive index, one can use this calibration curve to determine the refractive index of the unknown liquid.

The tapered portion can be thought of as interconnection between two fibers, one fiber of core dia $2a_i$, and other of core dia $2a_0$ ($a_0 < a_i$). Fibers 1, 2 and tapered interconnecting zone all having the same core and cladding refractive indices n_1 and n_2, respectively except for the initial section of fiber 1 in which the cladding index is n_{cl}.

Consider the transmission of a mode from fiber 1 to fiber 2 when the taper is immersed in a liquid of $r.i. = n_l$. The Z component of propagation constant of a guided mode in fiber 1 is

$$_{1z} = n_1(k=1)\cos\bar{\ }_1 \tag{3}$$

$\bar{\ }_1$, being the mode propagation angle in fiber 1. And it gets transformed in the taper as

$$_{z,taper} = a(z)\sin\bar{\ }(z) = a_i\sin\bar{\ }_1 \tag{4}$$

Where, $\bar{\ }(Z)$ is the corresponding propagation angle at a distance z

And $a_i\sin\bar{\ }_1$ is the escaping component in fiber 1, and $\bar{\ }(z) = \bar{\ }_2$, in medium 2. Therefore, from equation 4,

$$\sin\bar{\ }_2 = (a_i/a_0)\sin\bar{\ }_1 \tag{5}$$

Where, $a(z)$, represents radius of the taper at a distance Z from its thick end. Accordingly, a mode having the propagation constant in the Z direction β_{1z} in fiber 1 will get transformed through the taper, into a mode of $\beta = \beta_{2z}$ in fiber 2, as

$$_{2z} = n_1\cos\bar{\ }_2 = n_1\left[1 - R^2\frac{(n_1^2 - \ _1^2)}{n_1^2}\right]^{1/2} \tag{6}$$

or
$$_{2z} = \left[n_1^2 - R^2(n_1^2 - \ _1^2\right]^{1/2} \tag{7}$$

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Where, $R(= a_i / a_0)$ represents taper ratio. For a mode to be guided in fiber 2, one must have

$$ {}_1 \geq \left[n_1^2 - \frac{n_1^2 - n_l^2}{R^2} \right]^{1/2} \equiv {}_{\min} \qquad (8)$$

This means only certain modes whose ${}_1 \geq {}_{\min}$, launched in fiber 1, will be transformed into the modes of ${}_2$ in fiber 2 and can reach the detector.

If P_0 Represents the total power injected into the guided modes of fiber 1, then the power in the modes with ${}_1 \geq {}_{\min}$ will be

$$ P_b = P_0 \left[\frac{n_1^2 - {}^2_{\min}}{n_1^2 - n_{cl}^2} \right] \qquad (9)$$

On substitution of ${}^2_{\min}$ from equation (8) into (9), it becomes

$$ P_b = P_0 \frac{n_1^2 - n_l^2}{R^2 (n_l^2 - n_{cl}^2)} \qquad (10)$$

It is evident from the equation (10), that power coupled to fiber 2 through the taper increases linearly with proportional decrease in n_l^2.

For the experimental confirmation, the experiment is carried out by selecting methanol (CH_3OH) refractive index of which is 1.325n_D and Benzene (C_6H_6) the refractive index of which is 1.5n_D as initial liquids. The liquids are taken in different proportions and mixed up to have a range of mixtures having the refractive indices ranging from 1.325 to 1.488. The sensor arrangement is placed into the glass jar and the starting liquid methanol with zero ml of benzene is slowly poured into the jar and by launching the light from the source the power out is noted and tabulated. This procedure is repeated by taking the mixtures of rest of the combinations of methanol and benzene and the output power is recorded and tabulated. This scheme helps to have a range of values which in turn helps to calibrate the sensor thereby to define the dynamic range of the sensor. Thus the dynamic range of the present sensor ranges nearly from 1.3nD to 1.5nD. And also the sensor was calibrated at room temperature, and hence, this sensor is used to measure the refractive indices at room temperature as the ambient temperature.

3. RESULTS AND DISCUSSION

Graphs are plotted between various parameters that are recorded in the experimentation. From figure 3 it can be noticed that the normalized power is varied in accordance with variation of the refractive index values. As the refractive index of the mixture around the tapered glass rod increases, the output power decreases. This is because with increase in concentration, the absorbing power of the liquid increases and as result most of the evanescent waves that escape into the liquid cladding will be attenuated there leading to a loss of light power in the cladding and as a result the of this, the intensity of the transmitted light decreases as it enters the output end. The loss of light in the fiber takes place due to three factors.

1. The absorbing nature of the liquid acting as cladding in the sensing zone.
2. The length of exposure of the light with the liquid cladding,
3. Mainly on the tapering the glass rod

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As a result less amount of light will reach the output end of the fiber. Thus the evanescent field attenuated in the cladding. The amount of loss of light in the liquid medium is the measure of the magnitude of the measurand. The different proportions of the methanol benzene mixtures, r.i. values, power output, Mole Fraction and n_l^2 values are tabulated in the tabular form 1. Figures 3, 4, 5, and 6 shows variations of different parameters involved in the mechanism. The variation of normalized power output with refractive index (n_l^2) of the liquid surrounding the taper is shown to be linear. This indicates the decrease in power output with increase in refractive index surrounding the taper. This graph can be used as a calibrated standard graph to measure refractive index of unknown liquids either they can be dark of transparent in the range between 1.325 and 1.488. a dynamic range of the sensor can be varied by selecting a lower ranged r.i. and higher ranged refractive index. By mixing them proportionally, a range of liquids can be prepared which range spans from 1.325 n_D to 1.488 n_D.

Table 1: Change in power with refractive index and mole fraction of benzene and methanol Mixtures

SL. No.	C_6H_6 (ml)	CH_3OH (ml)	R. I. of Mixture	Power output (dBm)	Mole fraction of CH_3OH	n_l^2
1	0	10	1.325	-47.4	1.0000	1.756
2	1	9	1.339	-48.0	0.8039	1.793
3	2	8	1.353	-48.4	0.6457	1.831
4	3	7	1.370	-48.8	0.5153	1.877
5	4	6	1.389	-49.2	0.4060	1.929
6	5	5	1.405	-49.7	0.3130	1.974
7	6	4	1.421	-50.0	0.2330	2.019
8	7	3	1.437	-50.4	0.1634	2.065
9	8	2	1.453	-50.7	0.1026	2.111
10	9	1	1.471	-51.2	0.0482	2.164
11	10	0	1.488	-51.5	0.0000	2.214

Now, immersing the sensor arrangement into a liquid of unknown R. I., value and launching the light into the input fiber the output power can be noted. Using standard graph (Fig.3), the refractive index on the x- axis corresponding this power value, can be obtained. Thus with the help of this experiment the refractive indices of innumerable number of liquids can be determined either they can be transparent and dark liquid at room temperature. The relation between mole fraction and power output is shown. As the mole fraction of methanol in benzene increases, the concentration of liquid mixture decreases and hence the absorption of evanescence decrease thereby transmitted light increase.

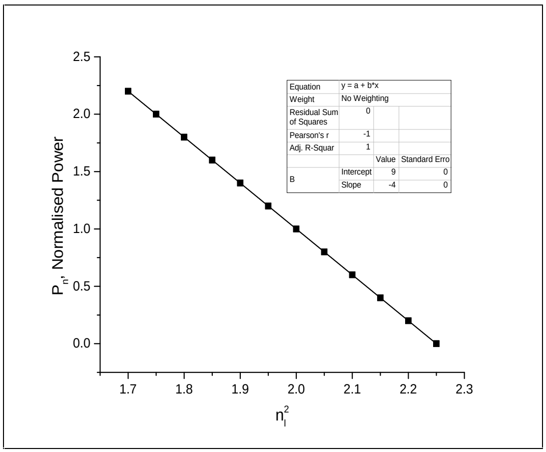


Fig. 3: The relation between n_l^2 and power

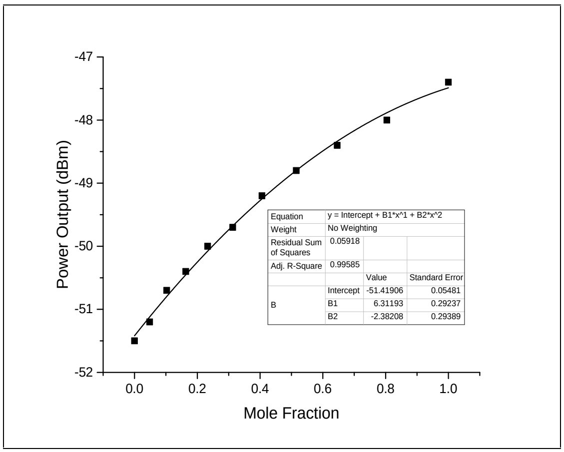
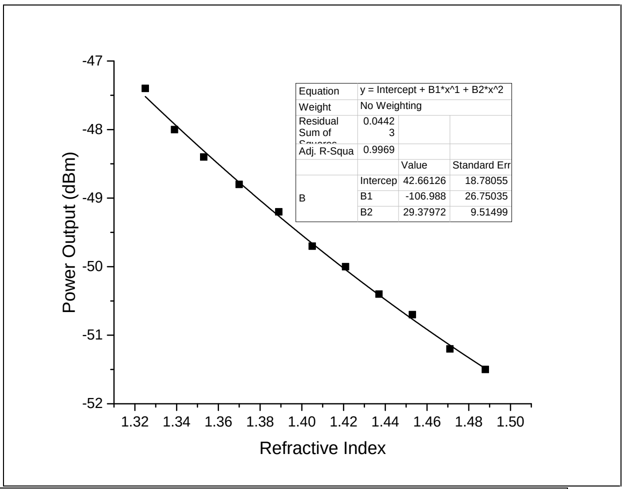


Fig. 4: The relation between mole fraction the normalized and output power



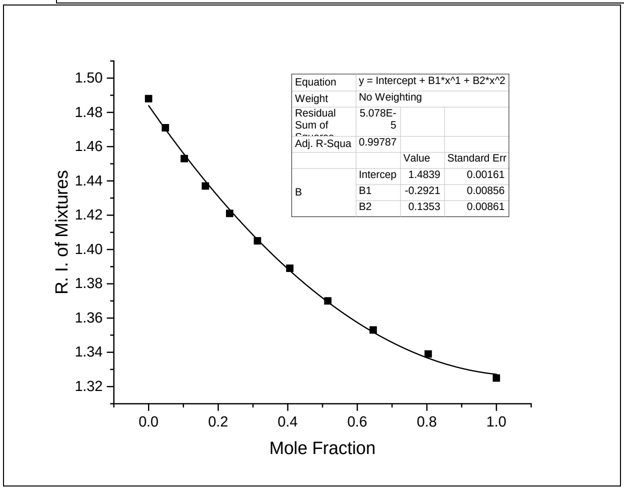


Fig. 5: The relation between refractive index and power output

Fig. 6: Relation between mole fraction and R. I. of mixtures

The relationship of refractive index and output power is represented in fugure 5. And in figure 6, the variation of r.i. with mole fraction is plotted.

4. CONCLUSIONS

Though the U- shaped glass fiber/ rod fiber optic method of measuring refractive index is more popular, the sensitivity offered by the tapered fiber optic refractometer offers highest possible extent. As the taper is prepared from the glass the sensor can be directly used in the chemical analysis of many chemical, the sensor can be used in the numerous chemical processes. This mechanism can be used to sense the refractive index of liquid from remote simply by placing both source and the detector on laptop or desk top which arises in case of measuring the refractive index of many acids and dangerous liquid, or the liquid in the radioactive field. The sensor is quite rugged and sturdy in measuring refractive index of many liquids. The operational range of the sensor also can be varies in the present method simply by selecting liquids with required r.i. values at room temperature.

5. REFERENCES

[1] A. Kumar, T.V.B. Subrahmanian, A. D. Sharma, K. Thyagarajan, B. P. Pal and I. C. Gopal, "A Novel Refractometer using optical fibers", Electron letters Vol. 20 (1984), pp. 534 -535.
[2] Hand book of Fiber Optics, Mc Grawhill Publishing Co. (1981)

[3] A. K. Ghatak, Thyagarajan, Optical Electronics, Cambridge University Press (1991)
[4] P. Radha Krishna, V. P. N. Nampoori, Vallabhan, “Fiber Optic Sensor Based on Evanescent wave absorption”, Opt. Eng., Vol. 32 No. 4, pp 692 – 694.
[5] B. D. Gupta, C. D. Singh and A. Sharma, “Fiber Optic Evanescent field Absorption Sensor – Effect of launching condition and Geometry of sensing region”, Opt. Eng., Vol. 33, No. 6, pp 1864
[6] G. Stewart, B. Culshaw, “Optical waveguide modeling and design for evanescent field chemical sensor” Optics and Quantum electron Vol. 26, pp S 249 -259 (1994).
[7] D. A. Krohn, Fiber optic sensor – fundamental and application, Instrument society of Indi (1989)
[8] B. P. Pal, Optical Fiber Sensors and Devices in fundamentals of Fiber Optics in Tele communication and Sensor system (1992), Wiley Eastern Ltd.
[9] T. G. Giallorenze, J. A. Bocara, A. Dandridge, G. H Siger, J. H. Cole, S. C. Rashleigh and R. G. Priest, “Optical Fiber sensor Technology”, IEEE J. Quantum Electon, Vol. QE -28, pp 625-665 (1982).
[10] T. H. Windhorn and C. A. Cain “Optically active binary liquid crystal thermometer”, IEEE Trans. Biomed Eng. Vol 26, pp 148 - 152 (1989)
[11] G. B. Hocker, “ Fiber optic sensitivity of pressure and temperature”, Appl. Optics, Vol. 18, No. 9 pp 148 1445 – 1449 (1979).
[12] K. Kyuma, S. Tai, T. Matsui, T. Sawada and M. Nunoshita, “Fiber optic measurement instrument for temperature”, IEEE Journal of quantum electronics, Vol. QE – 18 No. 4, April 1982.
[13] K. Kyuma, S. Tai, T. Matsui T. sawada and M. Nushita: “Fiber Optic measurement instrument for temperature”, Tech. Dig. C L E O 81.PP 102 – 103 (1981)
[14] B. Culshaw, G. W. Day, A. D. Kersey, and Yohtsuke, “Special issue on optical fiber sensore” IEEE / OAS. J. Lighwave Technol., Vol. 13, No. 7 (1995)
[15] T. G. Giallorenzti. J. A Bocara, A. Dandridge and J. H. Cole. “Optical fiber Sensors Challenges the Competition”, IEEE Spectrum pp 44-49. (1986).