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Macro-Bend Intensity Modulated Multipurpose Extrinsic Fiber Optic Glass Sensor for Measurement of Refractive Index, Temperature and Density

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Abstract: *The determination of refractive index, temperature and density involves three different setups using conventional measuring methods and sets the limitation on the cost and time consumption. The measurement of these parameters, play a crucial role in petrochemical, fragrant, oil, chemical, beverage, and pharmaceutical etc. industries. In this paper a novel method is proposed to determine the above parameters using a single design architecture using a U- shaped solid glass rod as a sensing probe with very great accuracy and tremendous high degree of sensitivity. In order to sense all the three parameters, the intensity modulation schemes are made use in the present setup. In fact, intensity modulated sensors offer the widest range of optical fibers sensors for accurate sensing and measurement of physical parameters and fields. The advantage of intensity modulated sensors lies in their simplicity of construction and their being compatible to the multimode fiber technology. The present setup is cost effective, simple and multipurpose for the measurement of above parameters online. Comparing with conventional measuring methods, it offers greater sensitivities due to the macro-bend introduced in the sensing region which causes the light to undergo frustrated total internal reflection leading to a larger power loss resulting a consequential loss of light from the transmitted light into the surrounding medium, and becomes much pronounced with absorptive nature of the medium around the glass rod. Such sensors can be used to determine various environmental parameters, and finds many applications spanning from everyday consumer, commercial and industrial engineering to medical and military applications and so forth.*

Keywords: U-shaped solid glass rod, Multi-purpose, Design architecture, Frustrated total internal reflection, Intensity modulation schemes.

INTRODUCTION

Use of visible light for communication purpose is the most primitive method known to the mankind since beginning. Smoke signals direction of sunlight in the day time and fire beacons at night were used for communication by ancestors. In early seventies when the fiber optic technology for telecommunication was developing, it was observed that transmission characters of light is, highly sensitive to certain internal perturbations such as refractive index (R. I.) of the fiber material, voids present in the fiber, impurities present in the fiber material, dopants added purposefully or otherwise, pH value, Hydroxyl ions present, and evolution of hydrogen from the material used to fabricate the cable etc. and certain external perturbations such as macro-bends, microbends, joints, splices, pressure, density, temperature and so forth. A great deal of effort was spent at that time to reduce the sensitivity of signal carrying optical fibers to such an external perturbations, through suitable fiber and cable designs and by perfecting the suitable fiber jointing techniques [1 – 5]. At about the same time, on this observation of sensitivity of optical fibers to external perturbations, an alternate thought began in the scientific world to exploit this sensitivity of optical fibers, to construct a large variety of sensors and instruments. The optical fiber telecommunication soon saw, intensive R & D activity around the world, which led to the emergence of the field of Fiber Optic sensors and devices.

The key features of this technology, which offers substantial benefits as compared to conventional electric sensors are: low volume and weight, high voltage insulation, highly reliable and secure with no risk of fire/sparks, high voltage insulation, safe in explosive environments, potentially resistant to nuclear or ionizing radiations, affords remote sensing, offers distributed sensing, used to sense parameters in inaccessible regions, readily employed in chemical process etc. The above advantages made them to attract intensive R and D activity around the world to develop a novel class of sensors based on optical fibers. This has led to the emergence of a variety of fiber optic sensors for accurate measurement and sensing of various parameters and fields, such as pressure, temperature, liquid level, liquid pH, liquid refractive index, antibodies, rotation, electric current, acceleration, displacement, acoustic pressure, acoustic, electric and magnetic fields and so on. The initial developmental work had concentrated predominantly on military applications like fiber optic hydrophones for submarine and undersea applications, and gyroscopes for applications in ships, missiles and aircrafts. Gradually, a large number of civilian applications have also picked up. Fiber optic sensors are expected to play a major role in future industrial, medical, aerospace, and consumer applications [6 – 9].

Broadly, a fiber optic sensor may be classified as either intrinsic or extrinsic. In the intrinsic sensors, the physical parameter to be sensed modulates the physical properties of light inside the fiber whereas in an extrinsic sensor, the modulation takes place outside the fiber. in the former, one of the physical properties of the guided light, e.g., intensity, phase, polarization and wavelength is modulated by the measurand, whereas in the latter case, the fiber merely acts as a conduit to transport the light signal to and from the sensor head. In this case, light modulation takes place outside the fiber. Four of the most common fiber optic sensing techniques based on the modulated light parameter in the sensing process are shown in table 1.

Table 1: Optical Modulation Schemes by the Measurand

Sensing Technique	Type of Information	Physical Mechanism	Detection Method	Typical Examples of measurands
Intensity Modulation	Intensity	Modulation of transmitted light intensity by emission, absorption or r.i. change of the measurand	By reading the intensity level of the signal	Pressure, displacement, r. i., temperature, liquid level, density
Phase Modulation	Phase	Interference between signal and reference signal in an interferometer	Fringe Counting	Hydrophone for pressure, Gyroscope for rotation, , Magnetometer magnetic file
Polarisation Modulation	Polarisation	Change in the rotation of electric field vector	Using polarization analyser, to read (amplitude comparison) of electric field vector	Magnetic field, current measurement of high voltage transmission lines
Wavelength Modulation	Wavelength	Spectral (wavelength) variation by absorption or emission of light by the measurand	Amplitude comparison at two fixed wavelengths	Temperature measurement

However, out of these four, the intensity and phase modulated ones offer the most wide range of optical fiber sensors.

The general configuration of an intensity modulated sensor is shown in figure 1. The baseband signal (the measurand) in the form of a sinusoidal signal is seen to modulate the intensity of the light transmitted through the sensor. The modulation is reflected in the voltage output of the detector, which upon calibration, can be used to retrieve measure of the measurand. Intensity modulation can be achieved through a variety of schemes [10 – 14].

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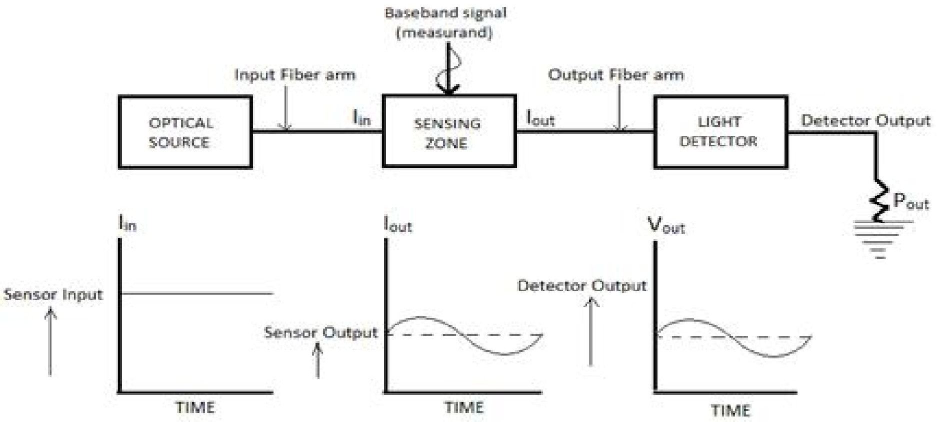

Fig. 1: General configuration of an intensity modulated sensor

1. EXPERIMENTAL ARRANGEMENT

In the present experiment a U – Shaped borosilicate solid glass rod is connected between two plastic (PCS) fibers (of 200/230 µm diameter and of length 0.5 meter) by using a index matching liquid which acts as sensing element and forms the sensing zone to sense density, refractive index and temperature (Fig. 2). The other end of the input fiber is connected to a light source operating at a wavelength of 633 nm using a suitable SMA connector. And the other end of the output fiber is connected to a benchmark power meter by using another SMA connector. The U-shaped glass rod acts as a core of the fiber in the sensing region. The sensing lengths of the U- shaped glass rod with curvature length as 1.5 cm is variously taken as 2 cm prong height, 3 cm prong height, and 4 cm prong height. Any liquid that surrounds the glass rod acts as cladding of the fiber in the sensing region. When light launched from the source transmits through the input fiber via the glass rod and couples into the output fiber and emerges as output signal and appears in the power meter as output signal.

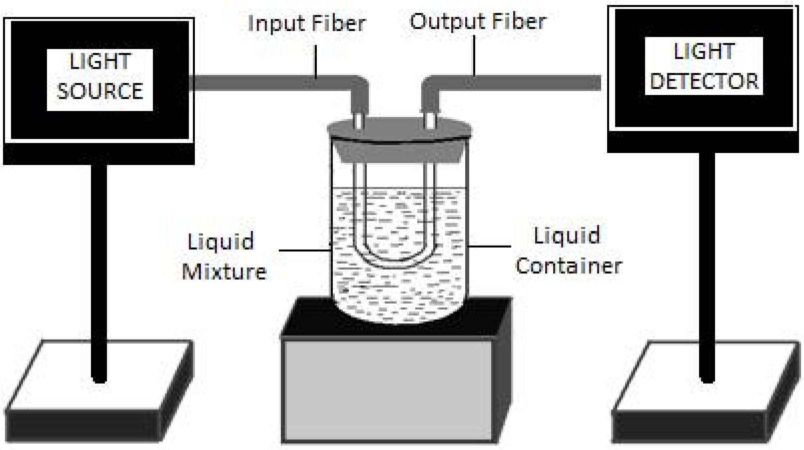

Fig. 2: Experimental arrangement of sensor

The light reaching the output end depends on the concentration of the liquid surrounding the glass rod, whose refractive index is less than the refractive index of the glass core. The light reaching the output end not only depends on the concentration of liquid but also on the radius of curvature of the solid glass rod and also on the diameter of the glass rod. Smaller is the radius of the glass rod greater is the power loss into the surrounding liquid in the form of an evanescent wave. And smaller is the radius of curvature of the glass rod greater is the loss of light into the liquid cladding. Similarly, more is the concentration of the liquid surrounding glad rod, more is the power loss into the liquid cladding and hence the less amount power couples to the power meter.

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2. RESULTS AND DISCUSSION

The sensor so designed is immersed in a 25 ml of oil and the light is launched from the source, will travel through the U- shaped glass rod and enters the power meter at the output end. The reading in the power meter is noted at room temperature. The liquid in the container is slowly heated and the power output through the sensing system is recorded at each interval of 5°C rise. The density of the liquid at each interval also measured simultaneously using a density meter and the values are noted. The results are plotted graphically in figure 3. The variations of power with respect to density as density of the guiding liquid increases, the power coupled to the output end decreases as is evident from the figure 3. This happens due to the increase in depth of absorption with concentration of the guiding liquid as the concentration increases, the density also increases becoming the liquid more absorptive than emissive. Due to which most of the light will be absorbed by the liquid with only a fraction of power will enter the power meter.

The magnitudes of powers are more with 4 cm length prong U- shaped element comparing with 2 cm prong length glass rod. This happens due to the increase in liquid column exposed to the guiding medium through which the light is travelling. More is the length of the liquid column, more is the absorption and hence more loss to the signal in the sensing region.

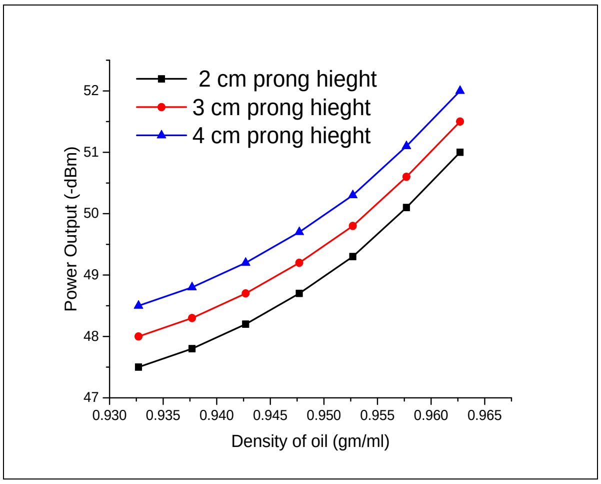

Fig. 3: Density versus Output Power when 2 cm/ 3 cm/ 4 cm prong height with 1.5 cm curvature glass rod exposed in oil

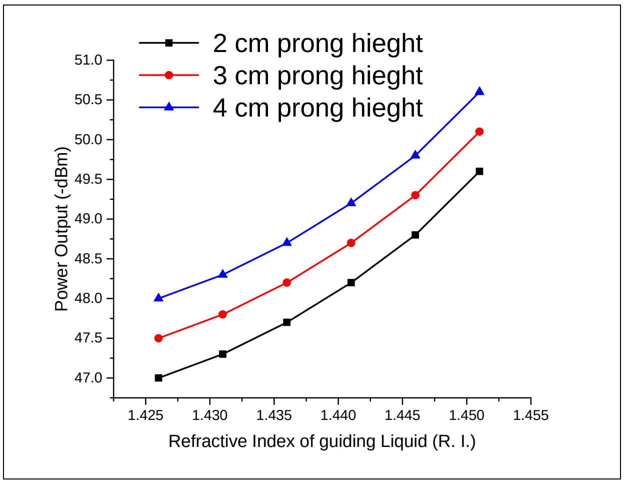

Fig. 4: Refractive index of guiding liquid versus Output power when 2 cm/ 3 cm/ 4 cm prong heights exposed to 25 ml oil.

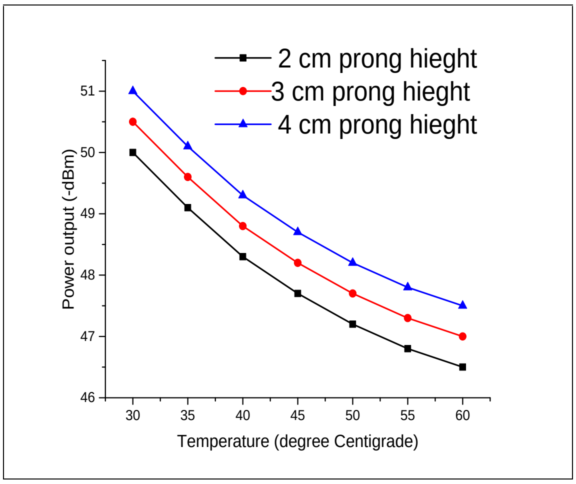

Fig. 5: Temperature versus power output when 2 cm/ 3 cm/ 4 cm prong height glass rod is exposed in 25 ml oil.

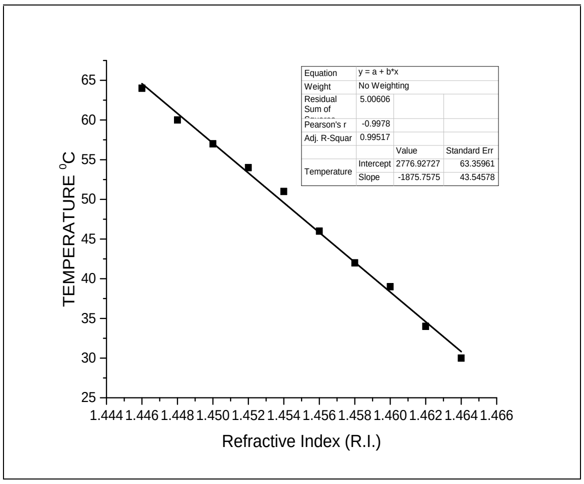

Fig. 6: Refractive index of guiding liquid versus Temperature when the 2 cm prong glass rod exposed in 25 ml oil

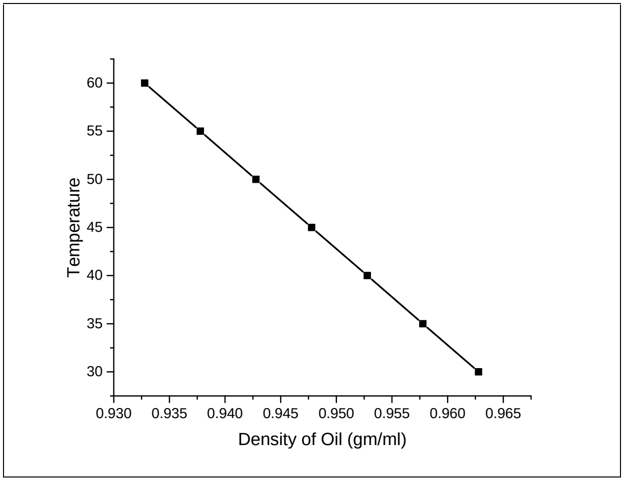

Fig. 7: Density of guiding liquid versus Temperature when 2 cm prong glass rod exposed in 25 ml

A similar argument can be made with reference to figure 4 as the density and refractive index are directly related to one another. As the r.i. is more, then concentration becomes more hence the absorption light by the surrounding liquid increases and light reaching the output end decreases. In figure 5 a different variation of power output is observed comparing with the first two graphs (figures 3 & 4). This is because, as the temperature of the guiding liquid increases, then the liquid becomes a rarer and rarer medium, the concentration decreases, the density and hence the refractive index also decreases, thereby the liquid becomes a weaker absorbing medium due which most of the light that is transmitting through the U-shaped glass rod and couples to the power meter. it is also shown in figures 6 & 7 that the behavior of the temperature is almost same with density and refractive index.

3. CONCLUSIONS

From figure 3, by selecting a proper sensing length, the sensor can be calibrated and can be put into use for measuring densities with high degree of accuracy and with greater sensitivity. And from figure 4 a similar argument can be made to develop a fiber optic macro-bend glass rod sensor measurement of refractive indices of many liquids. And from figure 5, it is clear that the sensor works as temperature sensor for the measurement of various liquids at different temperatures. Thus the sensor developed operates as versatile sensor for the measurement of various parameters even at various temperatures by calibrating properly. The fiber optic sensors find many advantages in comparison with other conventional sensors. They basically cheap in cost, rugged in nature, immune to EMI, offers very large bandwidth which make them to be used in the multiplexing of various sensors in a single line for the simultaneous measurement of various parameters at a time even from remote.

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