A novel probe for a fiber optic humidity sensor

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Abstract

A fiber optic humidity sensor based on the moisture dependence absorption of light by the phenol red doped polymethylmethacrylate (PMMA) film over a small portion of the lower refractive index core of the plastic clad silica (PCS) fiber is reported. The high refractive index of the film increases the interaction between the light guided in the fiber and the dye in the film and hence increases the sensitivity of the sensor. To increase the sensitivity, a second dye is added in the film. The U-shaped probe decreases the angle of incidence of the ray at the core-film interface in the bent region and hence increases the transmission of light from core to the film. The increase in the transmitted light increases its interaction with the dye present in the film and hence increases the sensitivity of the sensor. It has been shown that as the bending radius of the probe decreases the sensitivity of the sensor increases. The sensor operates in the humidity range 20 to 80% RH and its response time is about 5 s. Further a good degree of reproducibility of the results is obtained.

Keywords: Optical fiber; Sensors; Humidity; U-shaped probe; PMMA film; Sensitivity

1. Introduction

With the development of fiber optic technologies, various fiber optic sensors have been proposed for physical and chemical measurements. This is because of numerous advantages of fiber optic sensors over the conventional sensors. Some of the advantages are their small size, immunity to electromagnetic interference and radio frequency interference, explosion proof, remote sensing, possibility of multiplexing information from a large number of sensors in a single fiber and in some cases the low cost of these sensors.

In recent years the need of humidity sensor has greatly increased because of its applications in control of air-conditioning, quality control of food products in a wide range of industries, paper and textile industries, optimal functioning of modern solid state electronic equipment, civil engineering etc. The operating conditions and requirement of humidity sensors depend on the field of application. For example, a humidity range of 40 to 60% RH is needed for health and comfort of human beings and therefore there is a need for humidity control mechanism in air conditioners. Due to its wide spread applications, the development of a simple, inexpensive, highly sensitive and quick to respond fiber optic humidity sensor is required. There are a number of fiber optic humidity sensors employing different concepts that have been reported in the literature [1–8]. These sensors use either expensive method of probe fabrication or fragile probe. In the case of some sensors the probe is less sensitive or the response is slow.

Muto et al. [5] have observed that when a polymethylmethacrylate (PMMA) film containing phenol-red dye is exposed to moisture environments, its absorption coefficient at around 530 nm changes remarkably. Based on this, they developed a phenol-red dye doped plastic fiber as the sensor head for detection of moisture in air and in soil. The propagation loss of this fiber at around 530 nm was detected and it was found to increase with increasing water vapour in air. On the basis of Muto et al.'s findings, we, in the present paper, propose a novel fiber optic probe for the humidity detection. A polymethylmethacrylate (PMMA) film containing phenol red dye is deposited over the unclad core of a highly multimode plastic clad silica (PCS) fiber. The refractive index of the PMMA film is greater than that of the fiber core. Thus when the light launched in the fiber reaches the coated portion of the fiber (called sensing region) a fraction of light guided transmits to the film after each reflection at the core-film interface as it propagates along the fiber axis. If the wavelength of the light launched in the fiber is close to the peak absorption wavelength of the
phenol red dye present in the film, the absorption of the transmitted light in the film occurs. The absorption depends on the moisture present in the air around the phenol red doped PMMA film. After traversing the film (i.e., the sensing region) the light couples back to the fiber core and is detected by a power meter at the other end of the fiber. For a given length of the coated probe, the amount of absorption depends on the angle of incidence of the ray at the core-film interface. This is because the angle of incidence at the interface controls the amount of light transmission in the film. Smaller is the angle of incidence larger will be the transmission. Thus if the angle of incidence of a ray is decreased by some mechanism the transmission and hence the absorption can be increased which may result in the increase in the sensitivity of the sensor. Recently U-shaped probe has been used to decrease the angle of incidence for fabricating a highly sensitive evanescent field absorption sensor [9–11]. Therefore, in the present study, we have used a U-shaped probe to decrease the angle of incidence at the interface and hence to increase the sensitivity of the humidity sensor. To fabricate the probe cladding was removed from a small portion of the central region of the fiber. The unclad region was heated and bent to give it the shape of the letter 'U'. The unclad U-shaped probe was then coated with phenol red doped PMMA film. The probe operates in the humidity range 20 to 80% RH and its response time is about 5 s. We have also studied the effect of bending radius of the U-shaped probe on the sensitivity of the sensor. It has been shown that as the bending radius decreases the sensitivity of the sensor increases. This is because as the bending radius decreases the angle of incidence at the interface decreases and hence the transmission of light in the film increases which results in the increase in the absorption. The U-shaped probe used, in the present study, is less fragile as compared to tapered probe and is easy to fabricate. Further, its size is small and therefore can be used as a point sensor. The present fiber sensor is different from Muto et al.'s sensor in that a part of the light guided is transferred to the film where it is absorbed by the dye in the presence of moisture. Secondly, to increase the interaction of light with the dye, the transmission of the light from the fiber core to the film is increased by fabricating U-shaped probe. This increases the sensitivity of the sensor.

2. Experimental

2.1. Probe fabrication

The optical fiber used for probe fabrication was plastic clad silica fiber of 600 μm core diameter and 0.17 numerical aperture. The refractive index of the core was 1.457. The U-shaped probe was fabricated according to the method described in [9–11]. The unclad U-shaped probes of different bending radii were coated with phenol red doped PMMA film. The composition of coating solution was phenol red-POMMA: 1:4 Di-o-xane as 20 mg:400 mg:100 ml. The solution was heated around 100°C on a temperature controlled hot plate with magnetic stirrer until a clear solution of yellow colour was obtained. To increase the stability of the film on fiber core 10 ml of chelating agent, 2-methoxy ethanol, was added in the coating solution. To coat, the U-shaped probe was dipped in the solution and was pulled at a constant speed by means of a pulley-thread arrangement connected to an electrical power driven motor. The pulling speed was 10 cm/min. The constant pulling speed gave a uniform thickness of the film. The coated U-shaped probes of different bending radii were dried at room temperature for 24 h. To increase the film thickness two coatings were done on the probe.

2.2. Experimental set up

The experimental set up for the characterization of the humidity sensor is shown in Fig. 1. Light from a He-Ne laser operating at 544 nm was focused using a microscope objective (NA = 0.4, 20X) on the input face of the fiber. The green laser was used because its wavelength is close to the peak absorption coefficient of the phenol red doped PMMA film which is at about 530 nm. The total length of the fiber was about 50 cm. One of the coated U-shaped probes was fixed inside a plastic cylindrical container (called humidity chamber) of about 10 l capacity. The output end of the fiber was connected to a power meter. The humidity inside the chamber was decreased on passing the hot air from a blower. To increase the humidity a beaker filled with hot water was placed inside the chamber. The temperature of the hot water decides the humidity inside the chamber. Increase in temperature increases the humidity. To measure the humidity and hence to calibrate the sensor, a hygrometer (German

![Image](image_url)

Fig. 1. Experimental set up of the fiber optic humidity sensor based on U-shaped probe.)
(make) was placed inside the chamber. The power meter and the hygrometer readings were noted down only when these become constant. The experiment was repeated with other U-shaped probes.

3. Results and discussion

To study the response characteristics of the sensor, measurements were carried out for different relative humidity in the chamber. To start the measurement, the humidity was reduced on passing the hot air inside the chamber. The hot air reduces the humidity level to 20% RH. The output power at this humidity level was measured from the power meter. The humidity in the chamber was then increased on placing a beaker filled with hot water. The hot water increases the moisture in the air inside the chamber and hence the humidity. The output power and the humidity were measured when these become constant. The fiber probe response was observed to be very fast (few seconds) while in comparison to it the hygrometer response was very slow. It took 15–20 min for the hygrometer to stabilize the reading. To increase the humidity, the temperature of the water was further increased and the readings were taken. The maximum humidity level we could achieve was 80% RH. The measurements were carried out for both increasing and decreasing humidity cycle. These experiments were carried out a number of times and a good repeatability in the results was observed. Fig. 2 shows the variation of normalized power with the change in the relative humidity for the coated U-shaped probe with bending radius 2.45 mm. The variation is approximately linear. It may be noted that as the humidity increases the output power decreases. The decrement occurs due to the absorption of light by the phenol red dye in the presence of moisture. As the moisture content increases the absorption increases. The sensor range 20 to 80% RH covers almost full range of the output power. It means that the slope of the response curve is approximately maximum for the full range of the relative humidity (0 to 100% RH). Thus the probe is highly sensitive and covers whole humidity range. The response time of the sensor was measured by sudden increase in the humidity level around the probe. To measure it, the humidity level was first decreased in the chamber by passing hot air inside it. The output power was then measured. After this a beaker containing hot water was placed quickly inside the chamber and it was closed with a cover. The time taken by the power meter to give constant output power after covering the chamber was then measured with a stop watch. This exercise was carried out 3 times and then the response time of the probe was concluded to be around 5 s.

Fig. 3 shows the variation of sensitivity with the change in the relative humidity for the above probe. The sensitivity has been defined as the fractional change in power per unit change in relative humidity $[-1/P(\partial P/\partial RH)]$. The variation is nearly linear. As the humidity increases the sensitivity of the probe increases. To see the effect of bending radius on the sensitivity of the sensor, two additional U-shaped probes with bending radii 2.8 mm and 3.8 mm were fabricated and coated with the same coating solution and on the same day. The experiments were carried out on these probes and the sensitivities were calculated for both the probes. The variation of sensitivity with the bending radius for 45% RH for the three probes is shown in Fig. 4. It may be noted that as the bending radius decreases the sensitivity increases. This occurs because the decrease in the bending radius decreases the angle of incidence of the ray at the core-film interface in the bent region and hence increases the transmitted power in the film which increases the absorption and the sensitivity of the sensor. In addition to high sensitivity, the U-shaped

![Fig. 2: Calibration curve of the fiber optic humidity sensor for the U-shaped probe of 2.45 mm bending radius.](image)

![Fig. 3: Variation of sensitivity with relative humidity for the U-shaped probe of 2.45 mm bending radius.](image)
Fig. 4. Variation of sensitivity with bending radius of the U-shaped probe for 45% RH.

probe has many advantages. It is small in size, easy to fabricate and is less fragile as compared to tapered probe. Further, it can be used as a point sensor.

4. Conclusion

To conclude, a fiber optic humidity sensor utilizing the effect of enlarged core i.e. the coating of unclad region of the fiber with a moisture sensitive film of refractive index higher than that of the fiber core is reported. By having the refractive index of the film higher than that of the core a fraction of the light guided in the fiber core comes directly in contact with the moisture sensitive material (phenol red) in the film. This increases the interaction of the light with the moisture sensitive material in the film. To increase this interaction the sensing region was given the shape of the letter 'U'. The U-shape decreases the angle of incidence of the ray at the film-core interface and hence increases the fraction of light in the film. It has been shown that as the bending radius of the probe decreases the sensitivity increases.

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References


Biographies

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