Northeast Journal of Contemporary Research, December 2014. Vol. 1 No. 2, pp 43-47
ISSN 2349-3089 ©NeJCR, 2014

An evanescent field waves based fiber-optic temperature sensor

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ABSTRACT

An evanescent field wave absorption based fiber optic temperature sensor being presented in this work has the potential to detect temperature changes in a liquid to a good degree of precision as when compared to traditional temperature sensing devices. The amount of rays guided along the fiber probe is a result of the absorption of evanescent waves being produced at the core-cladding interface. Some of the important characteristics of the proposed sensor are that it utilizes inexpensive analyte, uses multimode optical fiber and exhibits a small response time. A millivolt range multimeter displays voltage output which is an indicator of the temperature of the liquid bath. An effort has also been carried out for the search of a suitable liquid which exhibits optimum sensitivity and better response regarding the proposed set-up. Moreover, it has also been studied regarding the suitable wavelength which gives a better response to the proposed sensor.

Key words: Evanescent wave, Optical fiber, temperature sensor

INTRODUCTION

Some traditional temperature sensors namely, thermometers, thermocouples, RTDs, PRTs do not meet recent demands for sensing temperature to a required degree of precision. Some laboratories and industries need a different kind of temperature sensor which fulfils the precision considerations as well as maintains a lower expenditure. These requirements are also followed by performance, size and reliability. Moreover, non expertise in temperature measurement in industries is also preferred. The proposed sensor based on evanescent wave absorption phenomena provides a way to measure temperature that meets the aforementioned requirements. The temperature sensor designed using this phenomenon is susceptible to electromagnetic disturbances and is suitable at hazardous environments also (Gupta, 2006).

This paper illustrates an inexpensive temperature sensor designed using a step index multimode optical fiber in which a length of 3.3 cm about its middle portion has been stripped off the cladding, and is being substituted by a suitable liquid of known physical properties (Lee *et al*., 2010). The absorption of evanescent waves depends upon the refractive index of the liquid. On the other hand, refractive index of a liquid also bears a relationship with temperature

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of the liquid bath. The probe being immersed in the liquid gives a way to measure the temperature of the liquid by knowing the output power at the receiving end of the fiber. The following section illustrates the probe characteristics and the measurement procedures.

DESIGN AND EXPERIMENT

If the field phase is real in an optical fiber, the propagating rays are real, whereas unreal part is the evanescent field which is the exponentially decaying part of the light. The real field are the guided rays that exist in the core while the rays outside the core are leaky rays (Betta and Pietrosanto, 2000; Gupta,2006)

When a ray is incident at an angle (θ) greater than the critical angle for the interface separating the two media, then light is total internally reflected into the core, but has an evanescent wave in the surrounding medium. The penetration depth which is given by

$$d_p = \frac{\lambda}{2\pi(n_1^2 sin^2\ \theta - n_2^2)^{1/2}}$$

is associated with the electric field amplitude at the core-cladding interface given by $E=E_o exp\ (-zd_p)$ (Jianqing *et al*., 2000; Messia *et al*., 1996; Gupta, 2006)

This expression is dependent upon the length of the unclad portion 'z' and 'd_p' is a function of the refractive indices of the core, n_1 and that of the liquid, n_2 serving as the cladding. Considering that n_1 does not change owing to external parameters, but n_2 gives proportional change, it leads to change in the number of guided rays through the length of the fiber. One of the common external parameters bringing a change in refractive index of the liquid is temperature. Thus, the liquid when substituted for the plastic cladding at the probe length, an increase in temperature would bring about more output power at the receiving end. The minimum output will occur when the refractive indices of the core equals to that of the liquid at the temperature T_{min}. For rises in temperatures a gradual increase in the power output can be found, but is maximum upto a temperature, T_{max} (Betta and Pietrosanto, 2000). Thus, a very suitable liquid will enhance the difference (T_{max} - T_{min}). In this work, three test liquids, viz. kerosene, distilled water, and glycerol are being investigated as the cladding substance separately to get a conclusion about their sensitivities and responses.

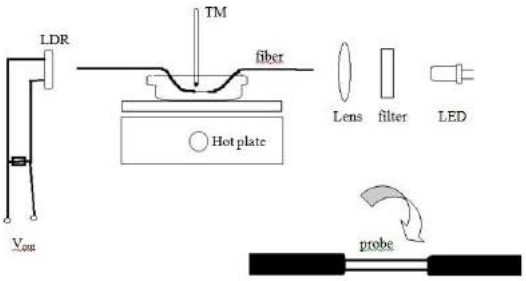

Figure 1. Experimental set-up

The multimode fiber is a PCS (plastic clad-silica) FT-600UMT (n_1 = 1.457, n_2 = 1.368, NA = 0.37) of dimensions 200/220 μm has been stripped to 3.3 cm of its cladding exposing the core[1]. A suitably shaped frame fixes the fiber to let the probe immersed into the liquid kept in a bowl that can be heated by the hot-plate. The hot plate is equipped with a temperature controller that has temperature calibrations to supply a suitable value. A laboratory thermometer is dipped into the same liquid at a vertical position to check the stability of the temperature of the bath.

The light source is a white LED (EVERGREEN ELECTRONICS) wherein the

final wavelength is determined using wavelength filters which have 20 nm spectral width bandpass characteristics. The rays are focussed into the fiber using a convex lens of short focal length. The filters being used in the experiment have wavelength specifications of 460nm, 540nm, 570nm, and 635nm.

The attenuated light at the output end of this fiber is fed to the surface of a light dependent resistor (LDR), CdSe coated having peak spectral response at 550nm; model NORP12 (RS components).

The output across the LDR using a megaohm resistor is displayed by a mV range digital multimeter whose voltage values are indicative of the temperature of the liquid bath for that particular instant. Having fixed the temperature at a particular value, the wavelengths are varied. Thus, the search for the suitable wavelength has also been made throughout the experiment.

It has been considered that white light of comparable brightness can significantly excite the fiber at the interface between the two media, and the related transducer gives the proportionate temperature relative to the output power.

In order to account the variation of output intensity with temperature changes, equal intervals of temperature are tuned by the controller, and at particular moment, the thermometer is held to show a stable value. Then, wavelength is varied (Kyuma *et al.,* 1982).

RESULTS

The output voltages across the LDR are tabulated for both temperatures as well as wavelength variations. Separate graphs are being plotted for all the three test liquids having normalised voltage output along ordinate and temperature along abscissa (figures 2,3,4). To study the sensitivity of the sensor from the point of view of wavelength dependence, two extreme temperatures are considered, i.e. 30C and 80C for plotting normalised output vs wavelength graph [5] for all the three liquids (figures 5 and 6).

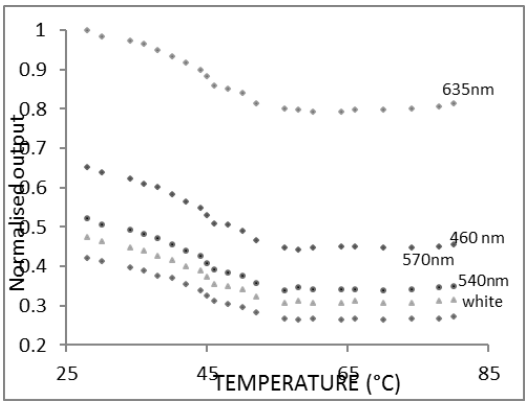

Figure 2. Normalised output vs. temperature for kerosene as the liquid medium for different wavelengths

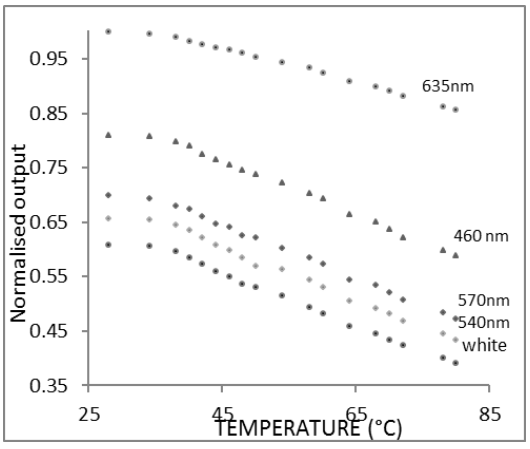

Figure 3. Normalised output vs. temperature for water as the liquid medium for different wavelengths

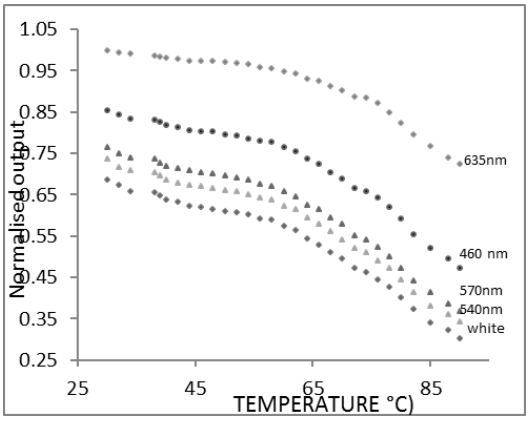

Figure 4. Normalised output vs. temperature for glycerol as the liquid medium for different wavelengths

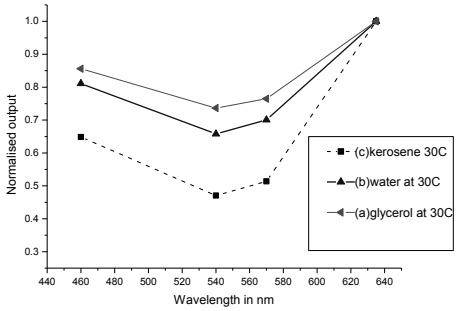

Figure 5. Normalised output vs. wavelength for all three liquids at 30°C

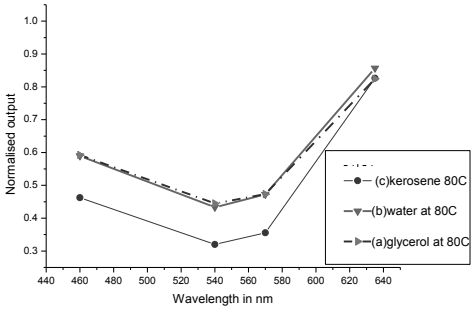

Figure 6. Normalised output vs. wavelength for all three liquids at 80°C

In this work, three different liquids have been tested, namely, kerosene, water and glycerol of their known refractive indices as well as temperature. The proposed set-up utilizing evanescent wave field absorption is found to exhibit good yield in terms of temperature change as well as wavelength change. The temperature change was incurred by heating element and monitored by a sensitive thermometer. Similarly, during the experiment, wavelength is tuned by deploying different filters of precise wavelengths.

So far, with different temperature variation with respect to testing liquid as kerosene, the highest transmittance is observed at the room temperature, i.e. at 28-30 degrees Celsius. After that, as the temperature rise, there is a sharp decline in the output until it reaches a value of 45°-50°C. After that, the output remains almost linear and saturated.

As of water, transmittance vs. temperature curve yields a consistently declining curve. Within the whole temperature range of 25°-80°C, a decreasing trend has been observed. However, compared to kerosene, water seems to be more responsive in the context of transmittance. The same yield has also been achieved in the case of glycerol. With temperature variation, a consistent decline in the transmittance has been seen. Comparing all the three liquids under observation, the maximum non-linearity in the output is contemplated in the case of kerosene whereas glycerol and water preferably exhibits less non-linearity.

Similarly, the plot of normalised output vs. wavelength exhibits a varying pattern. A large dependence of output with respect to wavelength can be observed. It is quite evident that the three different liquids

produce minimum output at the wavelength of 540nm whereas highest transmittance is achieved at 635 nm which is inclusive of all the experimental liquids. Noteworthy fact is that the output decreases with the increase in temperature. For example, glycerol shows higher contrast with respect to change in temperature.

Thus, with the current setup, the wavelength dependence of refractive index as well as temperature can be monitored. The key point in this set up is to select the optimal liquid which is more susceptible to changes in temperature as well as wavelength variation. In our current set up, exploiting the evanescent wave field, glycerol is found to reveal the highest sensitivity compared to water and kerosene. Although LDR is utilised as the receiver or detector, the set-up was also tested with photodiode and the same results were obtained. Apart from this, all the results have good degree of repeatability.

CONCLUSIONS

The experimental setup so designed for the purpose of sensing temperature utilizing evanescent field wave absorption phenomena has been investigated to an extent to provide a measure of the advantageous qualitative and quantitative parameters as compared to other types of temperature sensors available. The degree of accuracy, the utilisation of optical phenomena and using less expensive equipments are its noteworthy points. The repeatability and precision are found to agree every time from previous identical conditions. The liquids used here are very common and easily available, are non-volatile and harmless. The output voltages so obtained in each of the cases throughout the experiment have been monitored by the use of a good precision digital multimeter. When interfaced to a PC using Data Acquisition System, the data could be maintained and stored digitally for further references.

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