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High Sensitivity Temperature Sensor Based on Fresnel Reflection with Thermosensitive Polymer: Control Morphology and Coating Thicknesses

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Abstract

We report polycarbonate (PC) and polymethyl methacrylate (PMMA) coated on single mode fiber (SMF) based temperature sensor with high temperature sensitivity. The current study reveals that temperature sensitivity depends on coating thickness, coating morphology and thermosensitive polymer properties. It is thought that PC coated temperature sensor shows higher temperature sensitivity of ~245.4 pm oC^{-1} at a wide range of temperatures as compared to PMMA.

1. Introduction

Temperature is one of the significant parameters which has been used in the various field of science. More importantly, among different types of the temperature sensors, optic fiber temperature sensor has been successfully replaced to the traditional sensor due to its unique advantages such as, immunity to electromagnetic interference, stability, repeatability, durability against harsh environment. Apart from many advantages, these optic fibers having some shortcomings like cross sensitivity, poor repeatability, and complexity require the expensive demodulation of system for differentiating strain and temperature response. Therefore, it is urgent to develop the novel temperature sensor based on Fresnel reflection technique for temperature measurement because of its low price, suitable for real time, remote monitoring, good repeatability, easy to operate, high sensitivity, and stability [1]. Fresnel reflection based optic fiber sensor have demonstrated the phenomenon of optical fiber interferences which affect by surrounding material refractive index (RI). [2]

Polymer materials having high thermos-optic coefficient (TOC) plays a vital role in the determination of device performance, wavelength shift with change in the RI of the polymer as well as associated wavelength shift is very sensitive to small temperature change. Among polymer materials, we have chosen Polycarbonate (PC) and Polymethyl methacrylate (PMMA) because of their high TOC of -0.9×10^{-4} ^{o}C and -1.3×10^{-4} ^{o}C, respectively, while the coefficients of thermal expansion (CTE) of PC and PMMA are 2.2×10^{-4} ^{o}C and 1.3×10^{-4} ^{o}C, respectively. [3] In this paper, we report that Fresnel reflection based thermosensitive polymer coated single mode fiber (SMF) temperature sensors depending on coating thicknesses of polymers, controlled morphology, CTE, and TOC. It is also found that thin coated sensor shows higher sensitivity.

2. Sensing principle,

2.1 Fresnel reflection principle

Fresnel-reflection is basic optical phenomenon that occurs at interface between the medium of different RI. There are two reflection surface in the sensing head; one is fiber – polymer and other is polymer-air. The power reflection coefficients at two surfaces are defined as R_1 and R_2, respectively. The behavior of the cavity can be approximated using a two beam interferometric model,

$$\mathbf{R = R_1 + R_2 \pm 2\sqrt{R_1}R_2 Cos\,(\emptyset)} \qquad (1)$$

$\emptyset$ given by the equation, Denoted the optical phase of the interferometer, given by Eq. (2)

$$\emptyset = \frac{\mathbf{4\pi n_p L}}{\boldsymbol{\lambda}} \qquad (2)$$

The phase difference between both interference beams depends upon the optical path n_pL, where L is the thickness of polymer coating.

2.2 Polymer material characteristics

The change in RI (n_p) of a polymer with temperature is due to the temperature-caused density change and temperature change itself as

$$\frac{\mathbf{dn}}{\mathbf{dT}} = -\left(\frac{\rho\partial n_p}{\partial\rho}\right)\alpha + \left(\frac{\partial n_p}{\partial T}\right)\rho \qquad (3)$$

where n_p is RI, ρ is the density, α is the volume coefficient of thermal expansion of a polymer, dn /dT is the temperature-caused index change, i.e. thermo-optic coefficient, $(dn/dT)_\rho$ is the index change under constant density, while $(\rho dnp /d\rho)_T$ is a constant for a given polymer based on the Lorentz–Lorenz equation.

3. Sensor fabrication and characteristics

3.1 Sensor fabrication

The sensing schematic diagram is presented in Fig.1（A), PC and PMMA polymer were selected as the coating material since they could form viscous good solution at low wt.%, adhesive force between SMF-280 and polymer is strong, and is able to form uniform coating in the range of 10-20 wt.% polymer in chloroform. Adhesive characteristic is very important for forming high quality sensor. The sensing head with multilayer polymer were prepared by using the simple, low cost, fast, reproducible dip coating technique.

3.2 Characteristics of polymer coated sensor

The PC and PMMA coated temperature sensor is more suitable temperature sensor because RI of the polymer is much higher than those of the Silica fiber and air, had led to polymer produce higher Fresnel-reflection. This controlled thick-

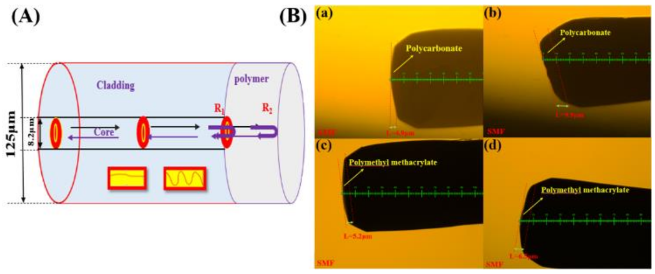

Fig.1, (A) Schematic of the sensor, (B) Optical microscopic images of the sensor,

ness of the coating was confirmed by the optical microscopic images (Nikon Eclipse 80i Upright Fluorescent Microscope-6980). It is clearly seen from the images in Fig.1. (B) that the coating is uniform, thin, bubble free and durable. Moreover, the spectral response of the bare SMF and polymer coated on SMF with different coating thickness are measured. The spectral response reveal that a longer thickness has a denser interference range of wave-lengths pattern and shorter thickness has longer interference range of wave-lengths pattern.

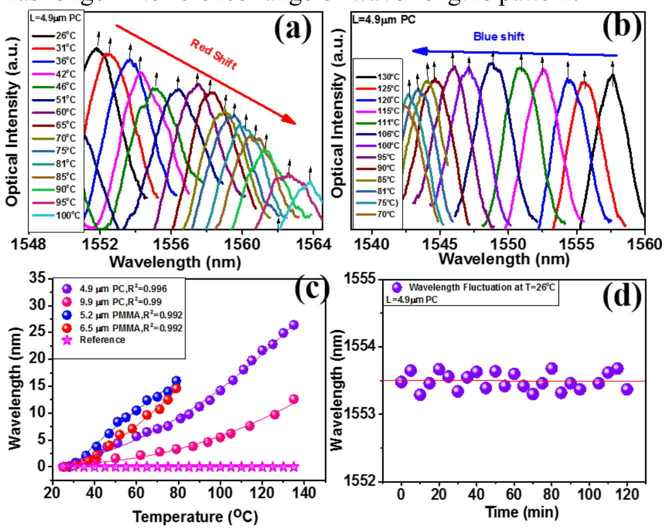

Fig.2 Spectral response of sensor having different thickness, (a) Red shift, (b) Blue shift of PC. (c) Experimental temperature sensitivity of proposed sensor with varying thicknesses, and (d) Wavelength of the spectral dip for various temperature.

4. Results and Discussion:

Sensor head is placed inside the temperature chamber, where the temperature was gradually increased from the 25 °C-135 °C at constant humidity. Proposed sensor is highly sensitive to the temperature variation because utilized polymers have high CTE. The spectral response of proposed 4.9 μm sensor with temperature variations are shown in Fig.2. (a) and (b). When increasing temperature, the temperature wavelength shifted to longer wavelength as a result of (1) increases volume, (2) lowering the refractive index of the polymer. Among all the sensor 4.9μm PC coated sensor shows highest temperature sensitivity 245.4pm °C^{-1} at long range of temperature.

Temperature response of the four sensors are shown in Fig.2. (c). The corresponding temperature sensitivity is summarized in the Table I. According to the results, PC shows higher sensitivity at long temperature range. The sensitivity difference is due to the thickness, TOC, CTE, and roughness of the polymer. The sensitivity at different temperature ranges were analyzed and corresponding fitting results were obtained. PC showed good second order polynomial fitting than PMMA. In case of PC at high temperature region between 100 °C-135 °C, sensitivity was 348.2pm °C^{-1} (L=4.6 μm). As expected, shorter the length of effective cavity higher is the sensitivity. PC coated sensor showed feasibility of high sensitivity with wide temperature range.

Table I. sensitivity data of the polymer with different thicknesses

Polymer	Coating thickness (μm)	Temperature Sensitivity (pm/°C)	R^2 Second order polynomial fitting	Temperature range (°C)
C	4.9	245.4	0.996	25-135
PC	9.9	103.6	0.99	25-135
PMMA	5.2	312.5	0.992	25-80
PMMA	6.5	257.0	0.992	25-80

To evaluate the stability of the sensor, wavelength at 1552 nm was investigated as a function of time with constant temperature 26 °C for 2h. Fig. 2(d) reveals that the wavelength variation. Deviation in the wavelength is about ±0. 19nm. Therefore, it is concluded that the PC is the potential sensing material than PMMA.

5. Conclusions

Optic fiber PC coated sensor with 4.6 μm thickness showed higher sensitivity of 245.4pm °C^{-1} at a wide range of temperature (25-135 °C) with second order polynomial fitting. In specific, PC at high temperature region of 100 °C – 135 °C, the sensitivity was 348.2pm °C^{-1}. This experiment shows the feasibility in durability of sensor, and sensitivity is improved by controlling thickness of polymer coating. We believe that the present temperature sensor has successfully removed the limitations due to the fluctuation of light, cross sensitivity, and influence of the environment.

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