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Fully Printed Flexible Humidity Sensor

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Abstract

A humidity sensor that employs interdigitated capacitors (IDC) printed with silver (Ag) nanoparticle based ink on a flexible poly ethylene terephthalate (PET) substrate was successfully fabricated using gravure printing process. Thicknesses of 1 µm and 500 µm of a humidity sensitive polymer poly (2-hydroxyethyl methacrylate) (pHEMA) was deposited on the IDCs by means of gravure printing. The capacitive response of the sensor towards relative humidity (RH) was measured in the range of 30% RH to 80% RH; the maximum percentage change in capacitance was 172 % at 80% RH when compared to base capacitance at 30% RH. The humidity response of the printed sensor revealed a very high stability with a maximum error of 0.6 % and 0.8 % from the average value at 40% RH and 60% RH, respectively.

Keywords: capacitive humidity sensor; gravure printing; polymer printing; printed electronics; printed sensor;

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1. Introduction

Printed electronics, a rapidly emerging and relatively new technology within the electronics industry, is set to revolutionize the fabrication of electronic devices on flexible substrate materials such as plastic, paper, and textiles using electrically functional inks. Many studies have reported on the use of traditional printing methods (inkjet, screen and gravure printing techniques) for applications in printing electronic devices such as sensors, strain gauges, displays and radio frequency identification (RFID) tags [1-4]. However, there have been no reports on fully printed humidity sensors using traditional printing techniques like gravure printing.

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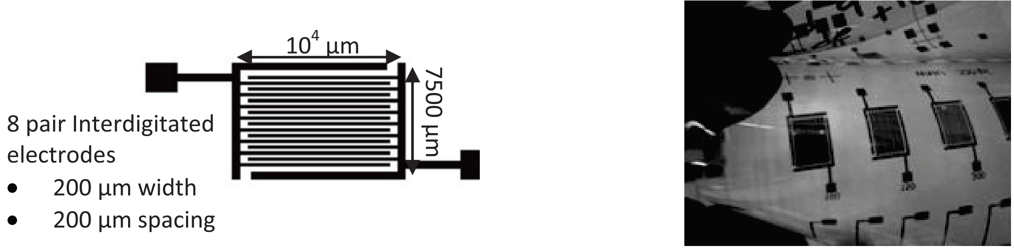
The development of sensors for cost effective and accurate humidity measurements is essential for applications in the environmental, agriculture, medical and semiconductor industries [5-6]. Humidity sensors can be of different types such as capacitive type, resistive, colorimetric, or surface acoustic wave (SAW), based on the sensing principle [7-10]. Capacitive type sensors are linear, require less complex circuitry and can operate for a wide range of humidity [11]. A typical capacitive type humidity sensor uses hydrophilic films as sensing layers which are stable at higher humidity levels. Polymers that are used as sensing layers include but are not limited to polymer poly (2-hydroxyethyl methacrylate) (pHEMA), polyimide, cellulose acetate butyrate (CAB) and polymethyl methacrylate (PMMA) [12]. Hydrophilic polymer pHEMA has been proven to have the highest response among known polymers due to the formation of hydrogen bonds between the -OH group of pHEMA and water molecules [13].

In this work, we have used a laboratory scale gravure press for printing a capacitive type humidity sensor. The sensor was fabricated on a flexible poly (ethylene terephthalate) (PET) substrate. Conductive silver (Ag) nanoparticle based ink was used for metallization of humidity sensors. pHEMA, a hydrophilic polymer, was used as the humidity sensing layer. The feasibility of the polymer coated printed device to be used as a humidity sensor will be demonstrated through the change in capacitance over a relative humidity range (RH) of 30% RH to 80% RH.

2. Experimental

pHEMA in crystalline form and ethanol in liquid form were purchased from Sigma Aldrich. pHEMA was dissolved in ethanol to form a 15 % solution by wt. A flexible PET (175 µm thick) from DuPont Teijin Films (Melinex ST 506) was used as the substrate. Interdigitated capacitors (IDCs) were gravure printed using Ag nanoparticle based ink (TEC-PR-20) from Inktec Inc., with an average particle size of 20 to 30 nm. A fully printed flexible humidity sensor was fabricated using a laboratory gravure press K-Printing Proofer (Testing Machines Inc.) at the Center for Advancement of Printed Electronics (CAPE), Western Michigan University. The schematic of a gravure printed device with 8 pairs of electrodes, each electrode having the dimensions of 8600 µm length, 200 µm width and 200 µm electrode spacing, is shown in Fig. 1(a). The pHEMA sensing layer was deposited on top of the IDCs in two different thickness using 120 and 280 lpi engraved plates by means of a K-Printing Proofer. The average measured polymer thicknesses were 1 µm and 500 µm for the 120 and 280 lpi plates, respectively. Fig. 1 (b) shows the photograph of an array of printed sensors.

The pHEMA coated IDCs were then placed in a humidity controlled Caron 6010 environmental chamber for investigating the humidity response of the printed devices. The sensor was connected to an Agilent E4980A precision LCR meter via alligator clips to perform the capacitive measurements, at an operating frequency of 1 kHz and applied voltage of 1 V. The experiment setup is shown in Fig. 2 (a). A custom built LabVIEW program on PC connected to the LCR meter via USB was used to record and analyze the response of the printed device.



(a) (b)

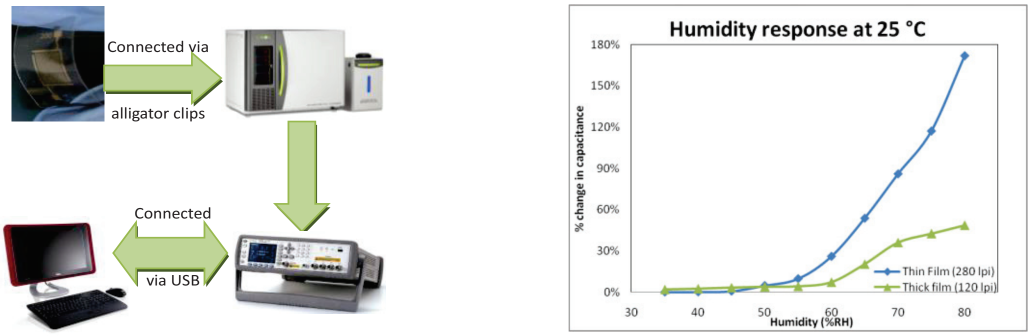
Fig. 1. (a) Schematic of humidity sensor; (b) Array of printed humidity sensors.

3. Results and Discussion

The response of the printed device towards humidity with humidity sensing polymer thickness of 1 μm and 500 μm at 25 °C is shown in Fig. 2(b). Initially, the polymer coated humidity sensors were placed inside the environmental chamber at 30% RH and 25 °C and allowed to stabilize. The percentage change in the capacitance for the 1 μm and 500 μm polymer coated humidity sensors was 172 % and 49 %, respectively at 80% RH when compared to the base capacitance at 30% RH.

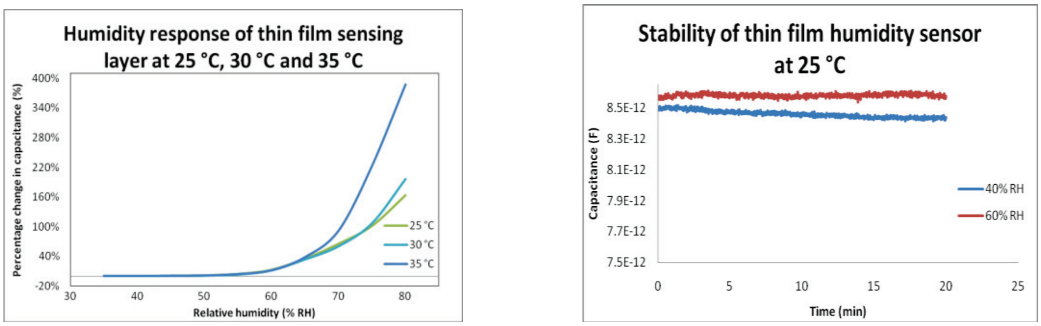
Capacitive response of the thin film printed device towards relative humidity at varying temperatures of 25 °C, 30 °C and 35 °C is shown in Fig 3(a). The response of the device towards increasing humidity was recorded from 30% RH to 80% RH with increasing steps of 5% RH while the temperature of the chamber was maintained at constant temperatures of 25 °C, 30 °C and 35 °C. The percentage change in the capacitance of sensor at 80% RH was observed to be 172 % at 25 °C, 200 % at 30 °C and 390 % at 35 °C when compared to base capacitances at 25 °C, 30 °C and 35 °C, respectively. The increase in capacitance was linear up to 60% RH and then increased rapidly for higher humidity levels. This can be attributed to the fact that polymers absorb more water molecules at higher humidity levels [14].

Figure 3 (b) demonstrates the stability of the fully printed thin film device at 40% RH and 60% RH at constant temperature of 25 °C. The sensor was placed inside the humidity chamber and subjected to 40% RH and 60% RH at 25 °C. The stability of the sensor was recorded for 20 minutes. The thin film sensor showed a variation of ± 0.6 % and ± 0.8 % from the average value of 8.3 pF and 8.5 pF at 40% RH and 60% RH, respectively at 25 °C.



(a) (b)

Fig. 2. (a) Experiment setup; (b) Capacitive response of fully printed humidity sensor.



(a) (b)

Fig. 3. (a) Thin film humidity response to different temperatures; (b) Stability of printed humidity sensor

4. Conclusion

A flexible fully printed capacitive humidity sensor was successfully fabricated using a laboratory gravure press. Ag nano particle ink was used as metallization and pHEMA, a moisture sensitive polymer was used as a sensing layer. The percentage change in the capacitance for two different thicknesses, 1 µm and 500 µm, of the humidity sensitive polymer coated sensors were 172 % and 49 %, respectively at 80% RH when compared to the base capacitance at 30% RH. The results from the stability test showed a variation of 0.6 % and 0.8 % change in capacitance from the average value at 40% RH and 60% RH, respectively at 25 °C. These results showed the capability of a gravure printed capacitive sensor to be used for humidity sensing applications. Our future research includes better understanding of the sensing mechanism, and improved sensitivity and operation of these devices over a wider range of humidity.

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