Available online at www.sciencedirect.com
ScienceDirect
Sensors and Actuators B 123 (2007) 1071–1076
SENSORS AND ACTUATORS B CHEMICAL
www.elsevier.com/locate/snb

Novel flexible resistive-type humidity sensor

Pi-Guey Su *, Chao-Shen Wang

Department of Chemistry, Chinese Culture University, Taipei 111, Taiwan

Received 2 August 2006; received in revised form 10 November 2006; accepted 13 November 2006
Available online 8 December 2006

Abstract

A novel flexible resistive-type humidity sensor was fabricated through in situ co-polymerization of methyl methacrylate (MMA) and [3-(methacrylamino)propyl] trimethyl ammonium chloride (MAPTAC) copolymer on a polyester (PET) substrate. The activation energy for conduction and the copolymer/substrate interface were used to explain the differences of humidity sensing characteristics of the sensors fabricated on a PET substrate, in comparison with those fabricated on an alumina substrate.

The humidity sensing characteristics of the flexible humidity sensor could be comparable with the sensor fabricated on an alumina substrate. The flexible humidity sensor showed acceptable linearity ($Y = -0.0327X + 5.9345$; $R^2 = 0.9351$) between logarithmic impedance ($\log Z$) and RH in the range of 10–90%RH, low hysteresis (within 6.1%RH), good response (45 s) and recovery time (150 s), and long-term stability (120 days at least), measured at 1 V, 1 kHz and 25 °C.

Keywords: Flexible humidity sensor; In situ co-polymerization; Substrate effect; Interface; Sensing properties

1. Introduction

Humidity sensors are widely used in measurement and control of humidity in human comfort and a myriad of industrial processes. The construction of a good humidity sensor is a complex matter because the requirements for a humidity sensing material essentially include linear response, high sensitivity, fast response time, chemical and physical stability, wide operating humidity range and low cost. Materials that have been studied for this purpose include polymers, composites and ceramics, which have their own merits and specific conditions of application [1–3]. Polymeric sensors can lower the cost than the ceramic counterparts because high-temperature processing and heat cleaning are not required.

Two main types of polymeric sensors, resistive and capacitive-type, are fabricated with polymer electrolytes and hydrophobic polymers, respectively. The conductivity of a polymer electrolyte usually increases with an increase in humidity, because the polymer electrolyte ionizes and produces conductive ions, which can migrate inside the material, upon adsorption of water molecules [4].

Most of the resistive-type polymer humidity sensors are fabricated by synthesizing the polymer films and then coating them on a ceramic substrate [5–10]. Ceramic alumina has good thermal and chemical stabilities, so it is suitable as a substrate material for humidity sensors. However, it is very difficult to integrate many sensors and control systems on a ceramic substrate. Recently, some papers have been reported the results of humidity sensors fabricated on Si or SiO_2/Si substrates [11–17]. The silicon substrates have good electrical and mechanical properties and are good materials for integrated circuits. However, their fabrication processes are complicated and high cost.

Today, organic electronic transistors, such as light emitting diodes, photodiodes, solar cells, and lasers, can be realized entirely from organic materials since they could be producible onto a low cost flexible carrier, and the production process could be a high volume technique such as reel-to-reel manufacturing. Another feature of organic materials, particularly of importance for chemical sensors application, is that both ions and electrons can be used as charge carriers [18,19]. Nilsson et al. [19] reported a humidity sensor made of an organic electrochemical transistor (OECT) combined with Nafion as sensing material. It is important to note that even many research groups used different substrates to fabricate humidity sensors but there were no investigation of the substrate effect on the humidity sensing characteristics.

* Corresponding author. Tel.: +886 2 28610511x25332; fax: +886 2 28614212.
E-mail address: spg@faculty.pccu.edu.tw (P.-G. Su).

0925-4005/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.snb.2006.11.015

Polyester film (PET) is one of the most widely used plastic organic films in the world. It is highly diversified in its applications, such as pressure sensitive labels and tapes, cable wrappings, and insulation laminates. In our previous study [10], we successfully prepared a humidity sensor made of PMMA/PMAPTAC copolymer material by in situ co-polymerization on a ceramic substrate, which showed good reproducibility and repeatability during the process of manufacture of the sensor device. In the present study, we tried to in situ co-polymerize MMA and MAPTAC on a flexible substrate (PET film) as a flexible resistive-type humidity sensor. The applied frequency and voltage and ambient temperature affected the humidity sensing characteristics of the sensors fabricated on PET and alumina substrate. The activation energy for conduction and copolymer/substrate interface were examined to elucidate the different humidity sensing characteristics between the sensors fabricated on PET and alumina substrates.

2. Experimental

2.1. Sensor preparation

Fig. 1 displays a picture of the structure of humidity sensors fabricated on a PET substrate. The interdigited gold electrodes were fabricated on a PET film using low temperature sputtering technique. The same interdigited gold electrodes were also fabricated on an alumina substrate.

The preparation of the precursor solution of MMA/MAPTAC was as follows: MMA (1 ml, 99%, Merck) was mixed with MAPTAC (0.1 ml, 50% solution, Aldrich) and azobisisobutyronitrile (AIBN, 0.01 g), and then 0.6 ml ethanol was added to form a highly homogenized solution. The mixture solution was deposited by dip-coating on a PET substrate containing a pair of interdigited gold electrodes, followed by heating at 90 °C for 1 h in air for co-polymerization to undergo, and the film thickness obtained was about 3.5 μm, as described elsewhere [10]. Thus a flexible resistive-type humidity sensor was obtained (Fig. 2).

2.2. Instruments and analysis

The complex impedance of a sensor was measured as a function of relative humidity (RH) with an LCR meter (Philips PM6304) in a test box. The humidity of the text box was controlled by mixing dry and wet air with the aid of mass flow controllers (Hastings), as described elsewhere [20]. The setting humidity and temperature points were calibrated by using a standard hygrometer (Hygropalm 2 model, Rotronic Inc.) which was pre-calibrated in the National Measurement Laboratory (NML) humidity laboratory [21]. The frequency for impedance measurement ranged from 1 to 100 kHz, and the humidity varied from 10 to 90%RH at temperatures of 15, 25 and 35 °C.

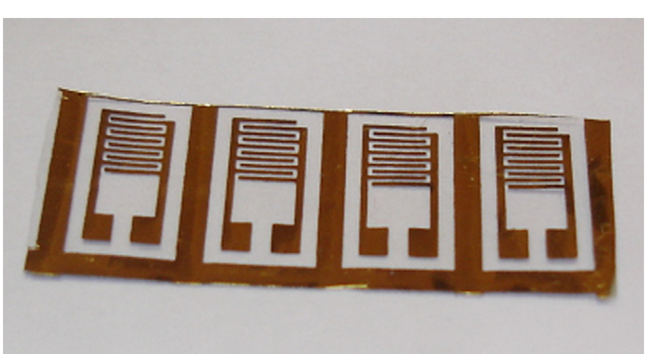

Fig. 1. The photo of the humidity sensors on a PET substrate.

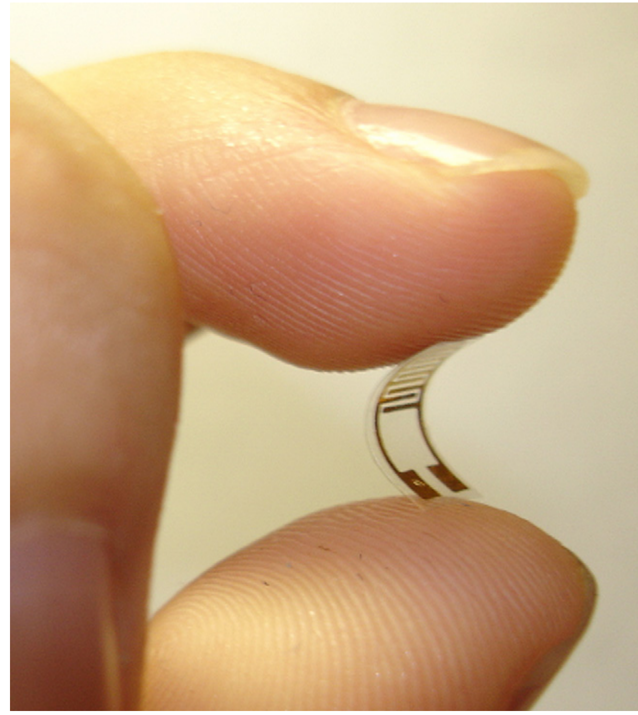

Fig. 2. The photo of a flexible humidity sensor.

3. Results and discussion

3.1. Structure of humidity sensor on PET film

Fig. 1 shows the photo of the humidity sensors fabricated on a PET substrate. The interdigited gold electrodes were made of firstly sputtering Cr (thickness 50 nm) and then Au (thickness 250 nm) in a temperature range of 120–160 °C. The electrode gap was 0.2 mm. The sensors were sufficiently flexible, as shown in Fig. 2, and good electrical performance was achieved while they were bent.

3.2. Humidity sensing properties

In this study, we investigated the humidity sensing characteristics of the sensors fabricated on the PET substrate, in comparison with those on an alumina substrate, based on the same fabrication technique and polymer electrolyte (PMMA/PMAPTAC).

Fig. 3 shows the plot of impedance versus RH of the sensors fabricated on PET and alumina (as shown as the inset) substrates as a function of measurement frequency at a voltage of 1 V. In the