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Encapsulation Process and Materials Evaluation for E-Textile Gas Sensor †

Ashwini Valavan *, Abiodun Komolafe, Nick Harris and Steve Beeby

Electronics and Computer Science, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton SO17 1BJ, UK; a.o.komolafe@soton.ac.uk (A.K.); nrh@ecs.soton.ac.uk (N.H.); spb@ecs.soton.ac.uk (S.B.)

* Correspondence: av1n15@soton.ac.uk; Tel.: +44-7769462929

† Presented at the International Conference on the Challenges, Opportunities, Innovations and Applications in Electronic Textiles (E-Textiles 2019), London, UK, 12 November 2019.

Published: 4 December 2019

Abstract: The degree of pollution in the environment increases because of the vehicular emissions such as carbon monoxide (CO) and nitrogen dioxide (NO_2) gases. To minimize the exposure levels, it is necessary for individuals to be able to determine for themselves the pollution levels of the environments they are in so that they can take the necessary precautions. Textile-based gas sensors are an emerging solution and this paper furthers the concept by investigating a novel method for encapsulating gas sensors in textiles. While encapsulation is required to improve the durability and lifetime of the sensors, it essential for their operation that the encapsulants do not reduce the sensitivity of the gas sensor. This paper investigates the selectivity of two different flexible and breathable thermoplastic encapsulants (Platilon®U and Zitex G-104) for sensing carbon monoxide by observing the sensor response with and without the encapsulants. Results show that while the encapsulants both enable the sensor to still function, Platilon®U reduces the sensor sensitivity, whereas Zitex G-104 has very little effect.

Keywords: encapsulation; flexible gas sensor; pollution; vacuum forming

1. Introduction

The World Health Organization (WHO) considers air pollution as the cause of 7 million deaths every year with toxic gases such as CO and NO_2 as primary causes [1]. Exposure to these air pollutants (depending on the concentration) could lead to devastating health issues endangering vital body organs such as the eye, skin, respiratory and nervous systems. E-textiles are a class of wearables that integrate sensors inside fabrics and these provide a platform for continuous monitoring of air quality at any location by the wearer [2]. E-textiles are helpful in areas like military and medical applications. One such example is a textile-based electrochemical sensor that continuously monitors and detects the glucose level of diabetic patients in real-time by using sweat samples [3]. MIT has built a toxic gas detector in the form of badges that can be attached to the apparel of the soldiers to sense sarin in the battlefield [4]. As the sensor is integrated with textile, it is important that the performance should be unaffected by humidity and other environmental factors making the sensor mechanically robust, waterproof and washable. This paper focuses on investigating flexible materials to protect the sensor. For this, first the fabrication of a flexible gas sensor is described and the unencapsulated performance is evaluated. This circuit is then encapsulated with a suitable material that is waterproof but gas permeable and the effect of the encapsulant on the sensor performance is determined.

2. Materials and Method

Electronic filaments with surface mount components can be easily woven into textile such that they appear invisible to the user [5]. A commercially available reducing gas sensor chip (MICS 5524 by SGX) was attached to a strip of Kapton to make a flexible gas sensing system. The tracks were fabricated by UV exposure lithography using the recommended measurement and supply circuit given in the datasheet. The chip is a reducing gas sensor that changes the sensor resistance in the presence of a reducing gas like carbon monoxide. The resistance of this sensor in the absence of any reducing gas varies from 100 kΩ to 1500 kΩ. The flexible filament contains the MICS 5524 chip, an 82 Ω resistor connected to the heater and an 820 Ω resistor to the sensor as shown in Figure 1a. The components were attached using solder paste and cured using the reflow oven.

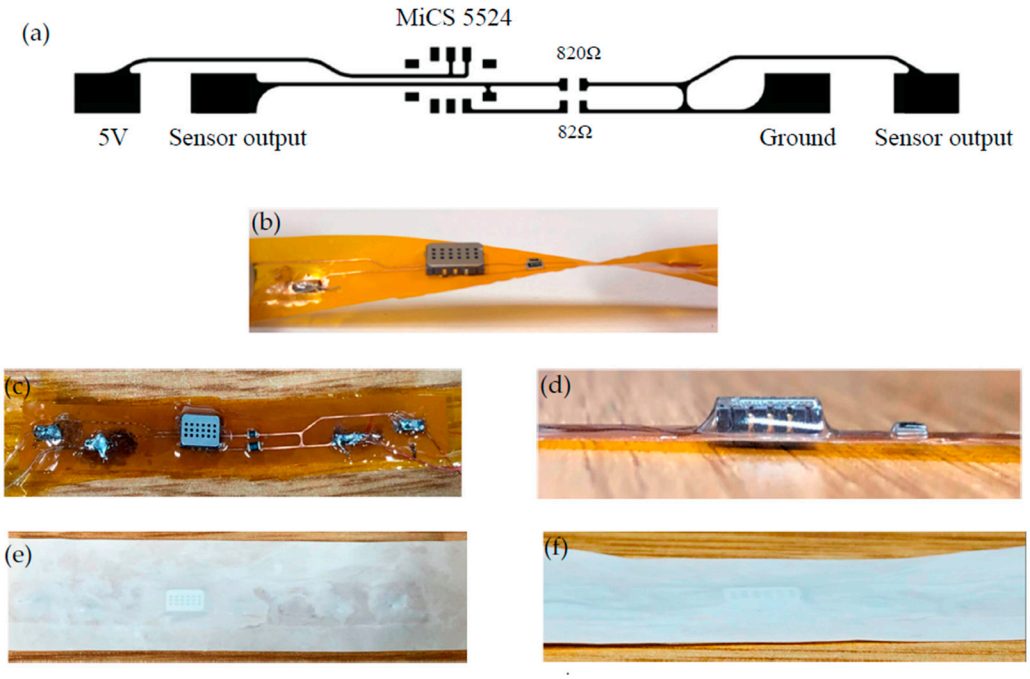

Figure 1. (**a**) The schematic illustration of flexible filament design; (**b**) flexible gas sensing system with MOS reducing gas sensor chip; (**c**) thermoplastic polyurethane encapsulated by vacuum forming method on the flexible gas sensor; (**d**) side view of TPU encapsulated system; (**e**) top view of Zitex encapsulated; (**f**) side view of Zitex encapsulated system.

The flexible gas sensing filament was encapsulated with a novel vacuum forming method using a Formech 450 DT machine. The thermoplastic films were heated at 70% power for different time duration. When the film softens, an applied vacuum draws the softened film over the circuit forming a conformal coating as shown in Figure 1c,d. The encapsulated strip is cooled for 30 s and removed from the machine. Two thermoplastic films were used; Platilon®U is a thermoplastic polyurethane film, (60 µm thickness) heated for 25 s. The TPU film contains a hot melt adhesive hence it directly glues to the filament sensor after vacuum forming. Zitex G-104 (100 µm thickness) is a PTFE film which cannot be softened by the temperatures achieved in the forming machine. As a result, the vacuum can be applied to force the material against the flexible circuit, but the film does not form a conformal coating as shown in Figure 1e,f. The filament was coated with a combination of Permabond POP Primer and cyanoacrylate adhesive to bond the Zitex G-104 to the gas sensing filament.

The flexible filaments were tested in a gas chamber made of plexiglass with dimensions of 150 mm (L) × 150 mm (W) × 160 mm (H). The chamber was made airtight by attaching rubber beading on the top lid. The advantage of having a smaller chamber is it requires less amount of carbon monoxide to reach higher concentration. The air in the gas chamber is not removed and this gives an ambient (indoor) environment to test the samples. A reference detector (UEI CO71) was used to determine the concentration of gas inside the chamber. A 5V DC axial fan was attached to the top lid

to uniformly distribute the carbon monoxide inside the chamber. Electrical connections pass through an airtight seal and provide the power supply and signal connections. The gas sensor was tested using carbon monoxide supplied from a gas cylinder with a concentration of 1000 ppm cylinder with a constant flow regulator (0.5 lpm from SGi) as shown in Figure 2. The gas enters the chamber by opening the cylinder valve for four different time durations to achieve different concentrations. The valve was opened for 10, 20, 30 and 40 s to obtain a concentration inside the chamber of around 19 ppm, 34 ppm, 45 ppm and 65 ppm respectively which was observed using the reference sensor. The reference sensor was observed to take around 12 min to get a settled reading of the concentration. Based on these concentrations, the flexible gas sensor was calibrated for four different concentrations and the response was observed with and without the encapsulation layer. The experiment was carried out under a fume hood to extract the gas from the outlet. The response was measured after 3 min for each sensor. A digital thermometer was placed inside the chamber to monitor the temperature in degree Celsius (°C).

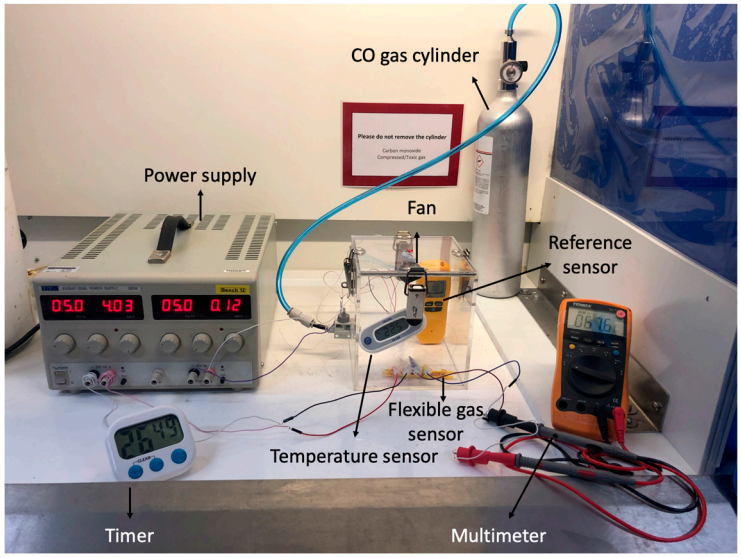

Figure 2. Experimental setup.

3. Results

The output of the sensor is in the form of a change in resistance which is obtained by measuring the voltage across the load resistor using Equation (1).

$$R_s = \frac{R_L}{V_L} (V_s - V_L) \quad (1)$$

where R_s is the sensor resistance, R_L is the resistance across load resistor (820 Ω), V_L is the voltage across the load resistor and V_s is the supply voltage (5 V). The response of the filament sensor in the presence of carbon monoxide is shown in Figure 3 where the response decreases with increase in the concentration of the gas. The response is given by R_s/R_0 where R_s is the sensor resistance in the presence of carbon monoxide and R_0 is the sensor resistance in the absence of carbon monoxide (in ambient air).

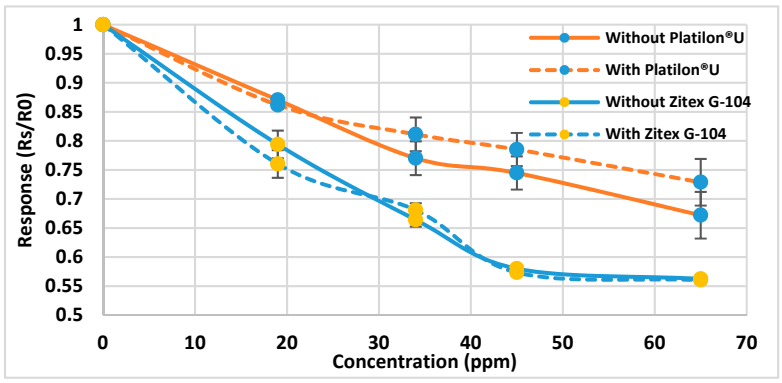

Figure 3. Response of the flexile gas sensing system without the encapsulation layers; Platilon®U and Zitex G-104.

It is observed that the sensitivity of the Platilon®U encapsulated filament is lower than the Zitex G-104 encapsulated filament.

It was also observed that the time taken for the sensor to show a change output was around 10 s for the unencapsulated filament. The Zitex G-104 matches this very closely but the Platilon®U encapsulation layer slows down the sensor response to around 30 s as shown in Figure 4.

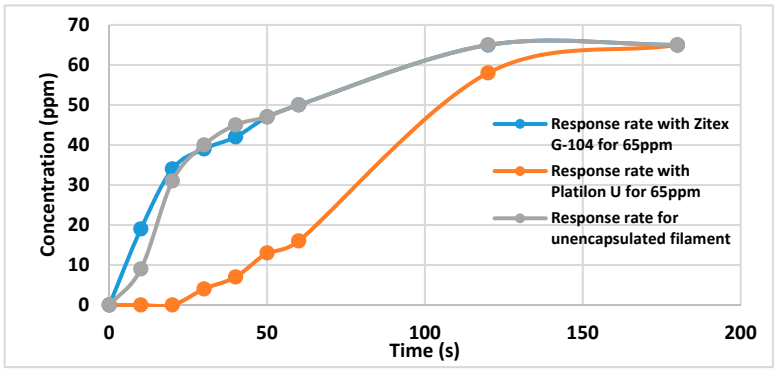

Figure 4. Response time for Platilon®U and Zitex G-104 for 65 ppm of carbon monoxide.

4. Discussion

The results demonstrate that the thermoplastic materials Platilon®U and Zitex can allow carbon monoxide to pass through and can be used as an encapsulating layer. The vacuum forming method gives more conformal coating with Platilon®U than Zitex G-104, but the Platilon®U increases the response time and reduces the sensitivity compared with the unencapsulated circuit. The Zitex G-104 has a very little negative effect on the sensor response. This is because of the Zitex G-104 is designed to be a highly porous material that allows CO molecules to pass through it more easily than the Platilon®U material.

5. Conclusions and Future Works

A flexible gas sensing system that can detect carbon monoxide was reported. The encapsulation of gas sensor was demonstrated using a novel method vacuum forming. It was shown that the Platilon®U polyurethane and Zitex G-104 can allow carbon monoxide to pass through it and can be used as an effective coating for encapsulating a flexible gas sensor. Future work will focus on evaluating the reliability of the encapsulated filaments during peeling, bending and washing.

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