Microfabrication and Commercialization of a Polymer-absorption Chemical Gas Sensor

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Abstract – A polymer-absorption chemical gas sensor has been microfabricated and tested to discriminate varying concentrations of ethanol vapors. The polymer, PEDOT (3,4-polyethylenedioxythiophene-polystyrenesulfonate) was combined with carbon to function as the sensing device. The sensor demonstrated well-defined responses to the smallest tested ethanol concentrations of 0.1 μl (185 ppm) and is expected to be accurate to much smaller ppm levels.

When packed with the proposed external feedback network, the device may be suitable for field-breath alcohol level detection as an alternative to expensive fuel-cell and chromatography based devices. The proposed device will be portable, user friendly and inexpensive to operate.

Index Terms—chromatography, ethanol sensor, fuel-cell, microfabrication

I. INTRODUCTION

Microfabrication techniques are used to design and fabricate a polymer absorption chemical gas sensor. Using semiconductor technology to produce the chemical gas sensors creates an opportunity to offer a small, low-cost alternative to current chromatography and fuel-cell based portable breath-alcohol (ethanol) detection devices. Current means of field breath-alcohol detection involve the use of complicated devices averaging $100+ per device, and ultimately a time to break-even decrease. Starting with a non-specific silicon substrate, a thermal oxide layer of 5000 Å is grown. Next, an adhesive chromium layer of 300 Å is deposited using evaporation. Gold is then used as the electrode metal, deposited using a molybdenum boat and evaporation of a thickness of 1000 Å. The sensor design is accomplished by a single lithography level which defines the interdigitated electrodes spaced at 25 μm shown in Figure 1.

Following the 1st lithography step, the gold and chromium metals are etched via wet processing to define the metal electrodes. The photoresist is left on the substrate to serve as a protection layer during the wafer sawing step. Following the sawing step, the resist is removed using acetone and the device is ready for packaging and electrical testing. The cross-sectional processing sequence is shown in Figure 2.

In order to conduct remote testing of the sensor while it is isolated in a chamber, metal chip pins are attached to the sensor contacts using a back-side adhesive. The completed device with chip-pins attached is shown in Fig. 3 placed next to a dime to demonstrate the scale of the device.
III. RESULTS

Baseline testing of the device involved coating the electrodes with 2 μm of the conductive PEDOT polymer. An SEM micrograph of the device cross-section following polymer application is shown in Figure 4 and an aerial view is shown in Figure 5.

The experimental setup for device testing is shown in Figure 6. The sensor is isolated in a chamber volume of 250 ml connected by two test probes. A computer controlled ohmmeter is used to measure the change in resistance of the sensor under test. Two ports, an inlet injection for introduction of ethanol vapors and a nitrogen outlet purge vent, were used for testing of the device.
The baseline response of the device was tested using an ethanol concentration of 50 µl at room temperature 27 °C. Ethanol is injected into the chamber at time zero and the sensor is allowed to respond. Once the polymer reaches equilibrium with the ethanol and will no longer absorb any additional ethanol vapors, the chamber is purged with nitrogen to test the recovery time of the device as seen in Figure 7. The sensor is then tested for various concentrations of ethanol ranging from 50 µl to 200 µl. Ideally, the sensor would distinguish increasing levels of ethanol concentration by increasing the measured resistance; however, the distinction is not easily characterized as seen in Figure 8. In addition to the sensor's inability to recognize increasing levels of ethanol concentrations, the device exhibited response and recovery times of 5+ and 2 minutes, respectively. These times are simply not feasible as a commercial breath sensor device.

In order to improve the sensitivity of the device, 100 mg of carbon (As atomized) was added to 1 ml of PEDOT polymer. The carbon absorbs the ethanol vapors and allows the polymer to saturate and reach equilibrium much faster than the polymer alone, thus improving sensitivity.

Using the same experimental setup, the effect on the relative resistances for ethanol concentrations ranging from 0.1 µl to 400 µl were investigated with air as the carrier gas. To simulate the expected temperature associated with the human breath, the tests were performed at a temperature of 37 °C. As seen in Fig. 9, the sensor clearly distinguishes increasing levels of ethanol concentration. In addition, the response time of the device is improved to approximately 1 minute, which is feasible when compared to similar devices currently available. To characterize the sensitivity of the device, the change in resistance divided by the initial resistance versus time is shown in Figure 10. Ideally, the response would be linear in nature; however, further enhancements to the polymer would be needed to improve the sensitivity.

IV. COMMERCIAL APPLICATIONS

The device exhibited quantifiable sensitivity to ethanol concentrations of the smallest tested volume of 0.1 µl. This volume of ethanol in a 250 ml chamber is equivalent to a breath-alcohol level (BAC) of 0.07. With a response time of 60 seconds and a recovery time of approximately 90 seconds, the sensor may be suitable as a commercial breath-alcohol detection device.

Once the desired level of ethanol ppm response is obtained, the device can be tuned to respond at the corresponding breath-alcohol level as seen in Figure 12 i.e. 200 ppm of ethanol vapors sensed for a given volume corresponds to a
relative breath-alcohol level of 0.08 (NY State maximum vehicle operation BAC level). A proposed external circuit is shown in Figure 11 to provide the user feedback of the BAC level of the breath sample. The circuit is designed to operate on 9 V batteries and will provide a portable packaging option for the sensor. The packaged device will offer a low-cost, portable, and reusable means of detecting breath alcohol levels.

![Proposed external feedback network diagram]

Figure 11: Proposed external feedback network

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<tr>
<th>PPM</th>
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<tr>
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Figure 12: Ethanol ppm to BAC equivalency

ACKNOWLEDGMENT

The author would like to thank his advisor, Dr. Lynn Fuller of the Rochester Institute of Technology for his advice and guidance throughout the project. The author would also like to thank Dr. K.S.V. Sanatham of the Rochester Institute of Technology for his help with the polymer characterization as well as the SMFL staff for their support in the fabrication of the device.

REFERENCES


