

# 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  $\mu$ l (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 unit and are simply not cost-feasible to the average consumer. Employing polymer absorption as the means of ethanol detection presents a simple, reliable, and cost-effective method which can be packaged with little complexity. The result is a device which can be commercialized as an inexpensive and user-friendly field breath-alcohol screening measurement tool ideally, to reduce the likelihood of driving while illegally intoxicated.

The design, fabrication, and testing of a suitable micro-sized chemical gas sensor which can be used for ethanol detection in either liquid or vapor phase has been

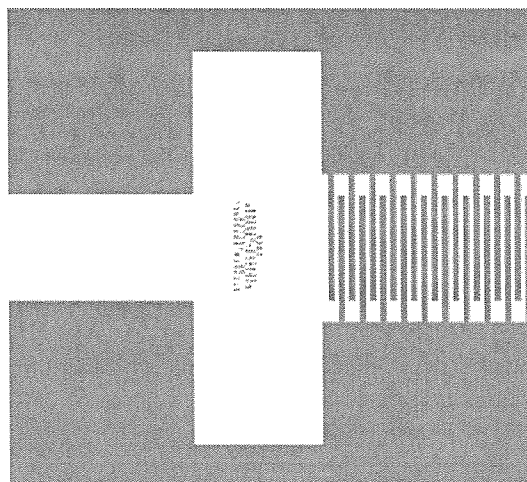
completed. The sensor, which consists of metal electrodes, is coated with a conductive polymer to adsorb the ethanol vapors. In the presence of ethanol vapors, the polymer “swells,” resulting in a measurable change in resistance across the electrodes.

## II. DESIGN AND FABRICATION

The sensor was designed on a 150 mm platform to allow for maximum real estate use resulting in a lower cost 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  $\mu$ m shown in Figure 1.

Following the 1<sup>st</sup> 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.



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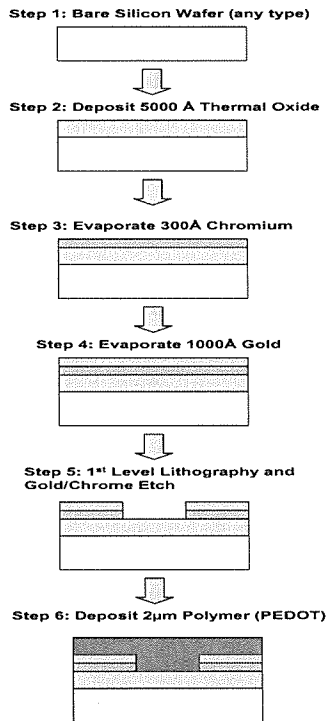
Figure 1: Sensor mask design defining a 25  $\mu\text{m}$  electrode spacing

Figure 2: Processing steps

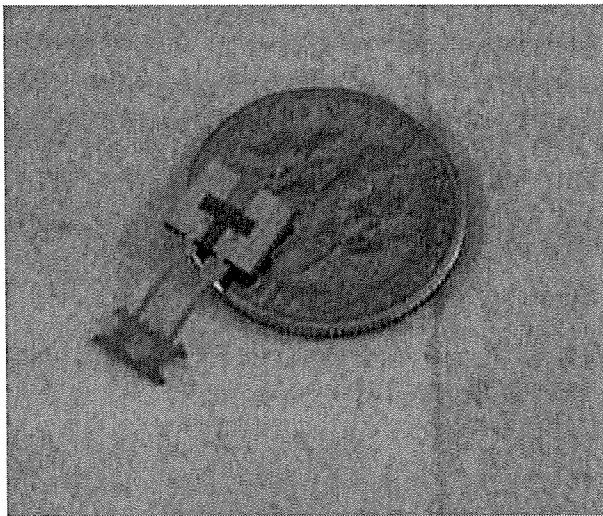


Figure 3: Finished device with chip-pins attached

### III. RESULTS

Baseline testing of the device involved coating the electrodes with 2  $\mu\text{m}$  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.

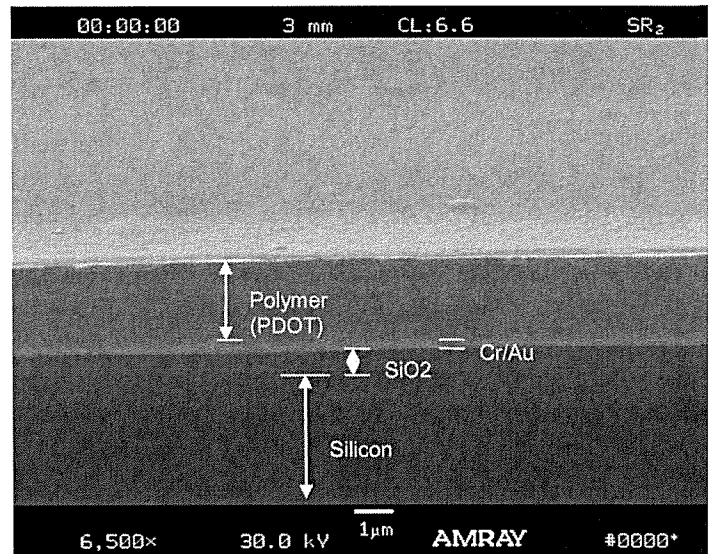


Fig.4. Device cross-section

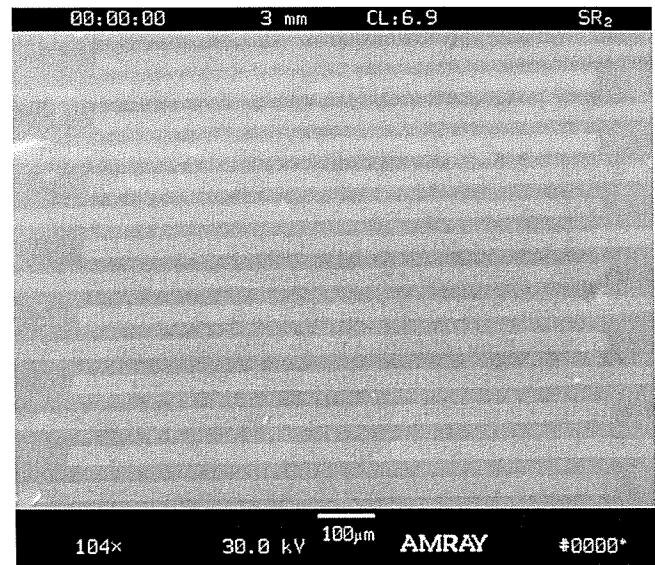


Figure 5: Aerial view of polymer-coated electrodes

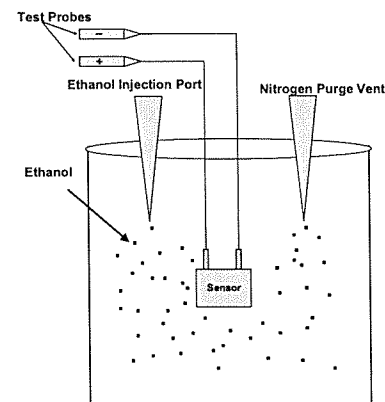


Figure 6: Experimental setup

The baseline response of the device was tested using an ethanol concentration of 50  $\mu\text{l}$  at room temperature 27  $^{\circ}\text{C}$ . 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  $\mu\text{l}$  to 200  $\mu\text{l}$ . 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.

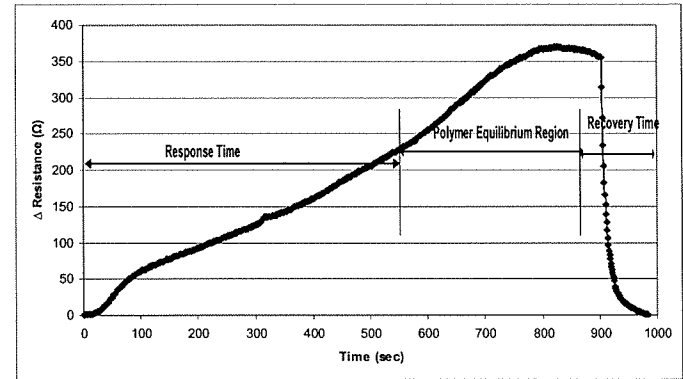


Figure 7: Sensor characterization

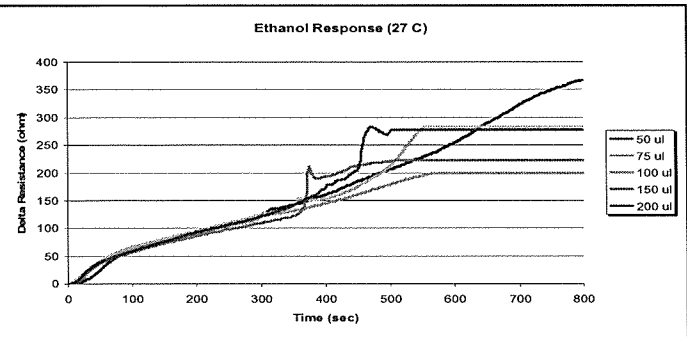


Figure 8: PEDOT response at room temperature

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  $\mu\text{l}$  to 400  $\mu\text{l}$  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  $^{\circ}\text{C}$ . 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.

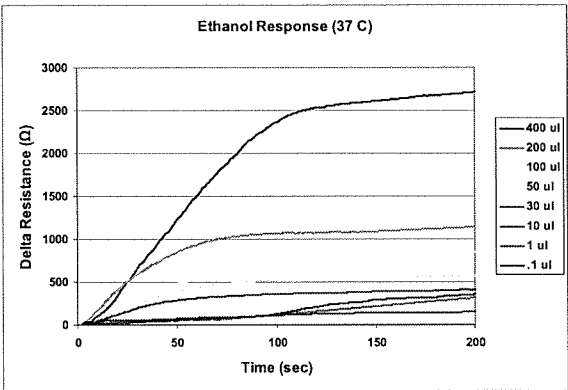


Figure 9: Relative resistance change at 37  $^{\circ}\text{C}$  for various concentrations of ethanol with carbon added to polymer

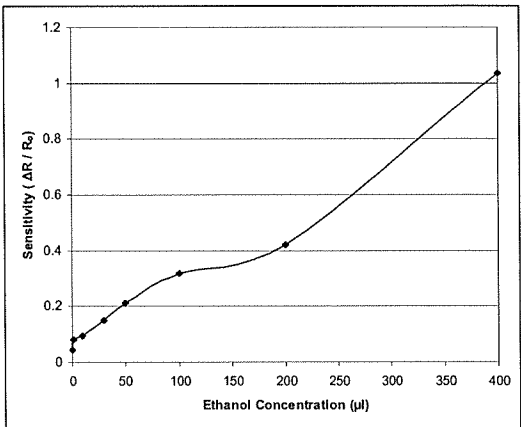


Figure 10: Sensitivity curve of the sensor for various concentrations of ethanol at 37  $^{\circ}\text{C}$

IV. COMMERCIAL APPLICATIONS

The device exhibited quantifiable sensitivity to ethanol concentrations of the smallest tested volume of 0.1  $\mu\text{l}$ . 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.

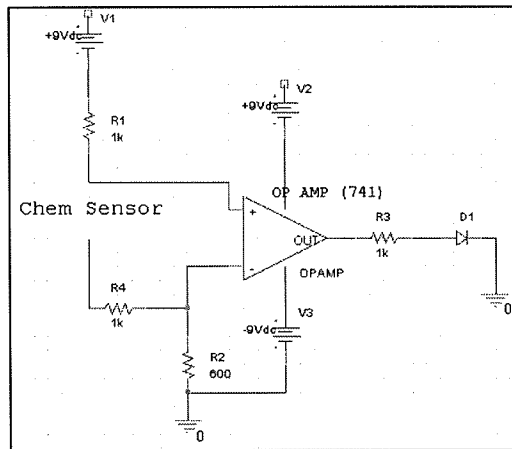


Figure 11: Proposed external feedback network

PPM	BAC
85	0.01
100	0.02
115	0.03
130	0.04
145	0.05
160	0.06
185	0.07
200	0.08
215	0.09
230	0.1

Figure 12: Ethanol ppm to BAC equivalency

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