Air Pressure Sensing by Monitoring Lateral Charge Carrier Transport in Pt Tetra(Carboxylphenyl) Porphyrins

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Abstract:

In this project, we constructed a pressure sensor based on a lateral charge carrier transport channel made of Pt-5,10,15,20-tetra(carboxylphenyl)porphy rin-(Pt-TCPP) thin film deposited on a SiO_2/Si chip. We directly converted pressure change into changed current flowing across this organic thin film.

To fabricate the device, we fabricated two interdigited electrodes separated by a 5 μm gap using photolithography followed by thermal evaporation of Cr/Au metal layers and consequent liftoff process. We formed the film on the SiO_2 surface between the electrodes by drop-casting 1% Pt-TCPP aqueous solution for 1 hour. Measurements were made on the device in a hermetic chamber with varied air pressure.

Compared to other conventional air pressure sensors, this new sensor can be easily made and directly converts the pressure change into electrical signal. More importantly, this device can be integrated with current CMOS circuits by a one-step dropcasting post-process. Furthermore, we can engineer the sensing molecule to improve its stability and sensitivity by exploiting the versatility of organic synthesis. By simply replacing the conjugated metal ion in the porphyrin ring, we can also alter the sensitivity spectrum of this device to sense other gases.

Introduction:

It has been well known that the phosphorescence lifetime of Pt-porphyrin molecules can be a sensitive function of oxygen concentration and hence these molecules have been used as an active sensing component in the pressure sensitive paint which has found application in pressure sensing in wind tunnels [1]. However, monitoring the light emission of these molecules for pressure sensing needs complicated optical instruments and is difficult to be directly integrated with following signal processing circuits. Since the concentration of the excited Pt-porphyrin molecule is strongly affected by the oxygen concentration, the conduction through films made of this molecule may be also affected by the oxygen concentration. In this paper, we found that the conduction through a thin film made of Pt-TCPP is indeed a strong function of the air pressure. Because this device measures the conduction through an organic thin film, it has the potential to be scaled down to nanometer range. Furthermore, both the performance and sensitivity spectra of this device can be easily altered through chemical modification, and this device can be easily interfaced with CMOS integrated circuits by only one additional process.

Experimental Procedure:

The platform for this device was made with a series of standard microfabrication steps. First we took an Si wafer and thermally oxidized it to create a 100 nm thick SiO_2 insulation layer. Then we used photolithography to expose AZ1512 photoresist according to a design pattern for a pair of interdigitated electrodes. Then we evaporated a 5 nm thick Cr adhesion layer followed by a 50 nm thick gold layer. Using a liftoff process in an acetone bath assisted by sonication, we fabricated the microelectrode pair which is shown in Figure 1.

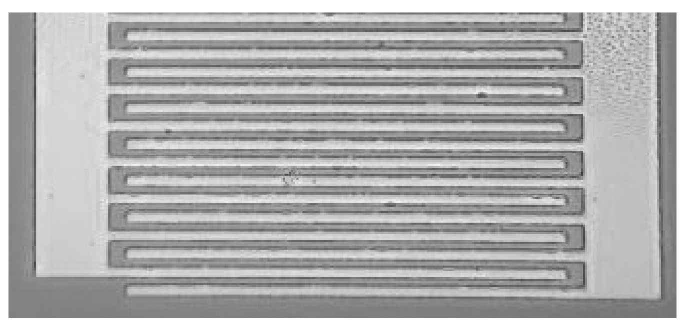

Figure 1: Interdigited Cr/Au contacts.

Then we made 1% and 2% Pt-TCPP aqueous solutions. To increase the solubility of the molecule, we added NH_4OH to a 0.5% final concentration. We tried two methods, spincoating or dropcasting to form the thin Pt-TCPP thin film. In dropcasting, we put Pt-TCPP solution on the chip patterned with the microelectrode and covered the chip with a PDMS stamp. We waited for 9 hrs to allow the water to be

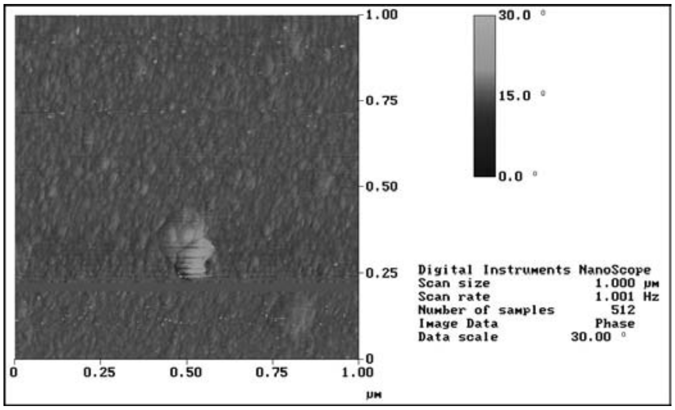

Figure 2: Crystallization of dropcast film.

completely evaporated and to allow crystals to form. In spincoating, a drop of the Pt-TCPP solution was placed on a chip and spun at 2,000 rpm for 180 seconds.

The morphologies of the thin films formed by these two methods were examined using both an optical microscope and AFM. Figure 2 shows an AFM of the crystals of the surface of the dropcast film.

To make the chip electrically connected, we used a wirebonder to ballbond the contacting pad of the microelectrodes to the pad in a standard 16 pin dual inline package. Testing of the finally fabricated chip was performed in a custom-made hermetically sealed chamber. By carefully controlling two valves leading to a house vacuum and the atmosphere respectively, we could alter the air pressure inside the chamber. We then measured the current through the fabricated devices under different pressure and plotted the current-pressure curve which is shown in Figure 3.

Results and Conclusions:

Measurements of the Pt-TCPP show a linear dependence of current through the Pt-TCPP thin film on the air pressure. In this experiment, the device is biased at 5V constantly.

However, when we changed the partial oxygen pressure inside the chamber, we found little change in the electrical conduction through the thin film. This observation implies that though the excited Pt-porphyrin molecules respond to the oxygen concentration, conduction through the Pt-TCPP thin film is not affected by the oxygen concentration. It is likely the changed conduction through this film according to the varied air pressure is caused by water.

Future Work:

The future work remaining on this project will be to decouple the observed affects due to oxygen from the affects due to water and other molecules in the air. For this reason some thought has been put into hydrophobic porphrins such as fluorinated porphrins.

With modifications in the molecule we will hopefully be able to isolate oxygen as the only substantial contributor to the variations in current through the film.

Once the proper molecule can be engineered, then scalability issues may be addressed. We can test how the lateral charge carrier transport is affected by a nano scale gap between contacts. Theoretically, a binary sensor could be developed to determine whether oxygen has bound to a given molecule or not.

Acknowledgments:

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References:

[1] Oxygen pressure measurement using singlet oxygen emission, Khalil et. al. University of Washington, Review of Scientific Instruments; May2005, Vol. 76 Issue 5, pN.PAG, 8p.

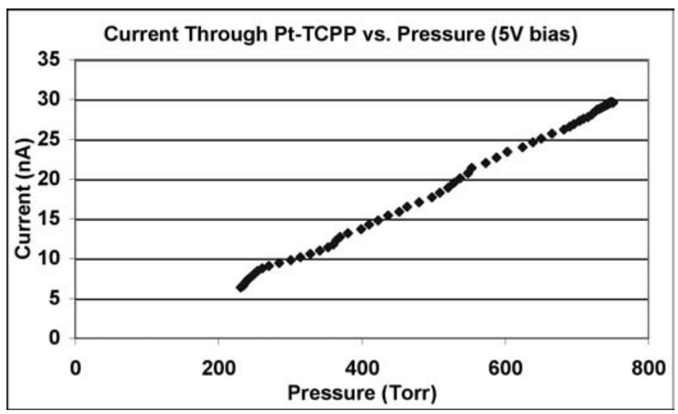

Figure 3: Variations in current through a dropcast Pt-TCPP film as a function of air pressure in a standard mixture of gases.