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Capacitance Studies on Organic-Inorganic Thin Film Transistors for Chemical Vapor Sensing Applications

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Abstract:

A dual channel, four terminal (4T) organic-inorganic hybrid thin film transistor is presented in which each channel gates the other. These devices are relatively inexpensive as they function in room temperatures and were fabricated using a combination of solution based processes and thermal evaporation. This metal insulator semiconducting field effect transistor (MISFET) functions as a chemical vapor sensor. Sensing response to isopropyl alcohol (IPA) gas was characterized by capacitance voltage (C-V) measurements and time dependent current measurements.

Introduction:

Inorganic transistors based on silicon and other inorganic semiconductors exhibit high charge carrier mobilities, high on-off current ratios, and environmental stability. Organic transistors, on the other hand, have attractive properties such as low temperature processing, mechanical flexibility, and compatibility with plastics [1]. Merging both inorganic and organic semiconductors in a dual channel thin film transistor combines the favorable characteristics of both types of semiconductors. We demonstrate such a device whose purpose is to function as a chemical vapor sensor. Organic semiconductors are especially known for their excellent chemical sensing properties and therefore a hybrid dual channel structure best serves our purposes.

The organic semiconductor functions as a gas sensor exposed to the ambient. Analyte delivery causes a decrease in the threshold of the organic layer which in turn induces a gating effect on the inorganic semiconductor, resulting in a net change in the current through the inorganic semiconductor, generating a stronger signal compared to the organic semiconductor.

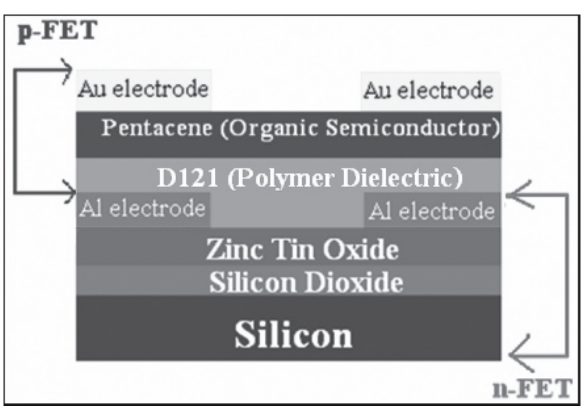

Figure 1: Schematic representation of 4T device.

Experimental Method:

The 4T device (Figure 1) was fabricated on an n-doped silicon substrate on which a 150 nm layer of silicon oxide was grown in a furnace. The substrate was cleaned using acetone, IPA, and deionized water in an ultrasonic bath for five minutes each. Next, we spin-coated 0.6 mM zinc chloride and 0.6 mM tin chloride in 5 mL of acetonitrile solution at 6000 rpm for 60 seconds after which post annealing was conducted at 500-600°C for 1 hour with oxygen exposure to create the zinc tin oxide (ZTO) semiconductor. We grew 50 nm layer of aluminum using 2 cm × 100 μm inter-digitated shadowmasks for bottom electrodes in a thermal evaporator. Next, we spin-coated D121, a polymer dielectric, at 5000 rpm for 90 seconds and annealed it at 140°C for 15 minutes, exposing it to a UV-ozone clean for 2 minutes. We coated 35 nm of pentacene, the organic semiconductor, using a thermal evaporator. Finally, we deposited 50 nm of gold electrodes by thermal evaporation with the same shadowmasks as before.

We also fabricated an organic field effect transistor (OTFT) control device to study the effects of the organic semiconductor. We use an indium tin oxide (ITO) coated glass substrate on which we deposit D121 followed by pentacene and gold electrodes with the exact specifications as that in the 4T device.

Electrical testing was conducted in ambient conditions. For analyte measurements, we squirted IPA on a filter paper which was loaded on a peristaltic pump and positioned on top of a device.

Results and Discussion:

Both the 4T device and the OTFT yield good transistor characteristics in current-voltage measurements, exhibiting good gate modulation. In the 4T device, the top layered (Au-

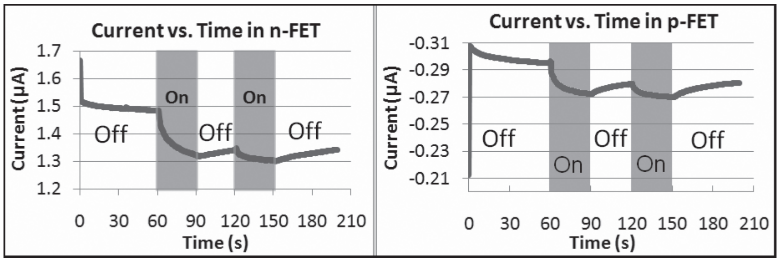

Figure 2: Transient current response in p-FET and n-FET in 4T device to analytes.

Pentacene-D121) p-type field effect transistor (p-FET) has a mobility of 10^{-3} $cm^2/V{\cdot}s$ whereas the bottom layered (Si-SiO_2-ZTO-Al) n-FET reports a mobility of 0.1 $cm^2/V{\cdot}s$.

In Figure 2, transient current curves show that the current decreases in both the p-FET and n-FET upon analyte delivery and increases when analytes are off. Upon analyte delivery, the IPA molecules align themselves such that their negative poles are trapped in the pentacene. Such trapped charges lower the charge carrier (hole) density of pentacene layer, thereby reducing the current. Decreasing carrier density in the pentacene is mirrored in the ZTO layer due to capacitive effects across the polymer dielectric. A decrease in ZTO carriers (electrons) causes current to decrease, as observed in Figure 2. It is important to note that the transient current in the n-FET is greater than the p-FET by a factor of 10, further proof of the n-FET's better amplifying characteristics. As shown in Figure 3, C-V measurements of the p-FET show a significant drop in capacitance upon analyte delivery which proves that there is a decrease in accumulated charges following simple Q = C-V relation.

C-V measurements on the control device (Figure 4) show that the capacitance drop due to analyte delivery is much smaller than that in the 4T device. The absence of the bottom n-FET results in smaller signal. Therefore, the majority of the capacitance decrease in the 4T device is actually due to a reduction of the ZTO-silicon coupling capacitance across the SiO_2. Hence it is evident that the role of the top layers in the 4T device is to modulate the accumulation of charges in the ZTO layer which transduces (with amplification) the response to the analytes of the top sensing layers.

Future Work:

In our 4T device, uniform deposition of pentacene over the entire chip spanning 50 devices causes spreading effects. Pentacene will be patterned between the electrodes of a single device using shadowmasks. Analytes other than IPA such as ketones and aldehydes will be used and the response will be studied.

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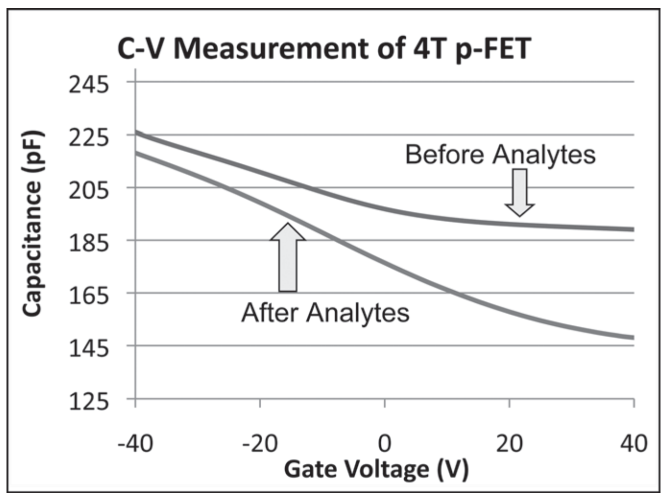

Figure 3: Effect of analytes on capacitance across p-FET in 4T device.

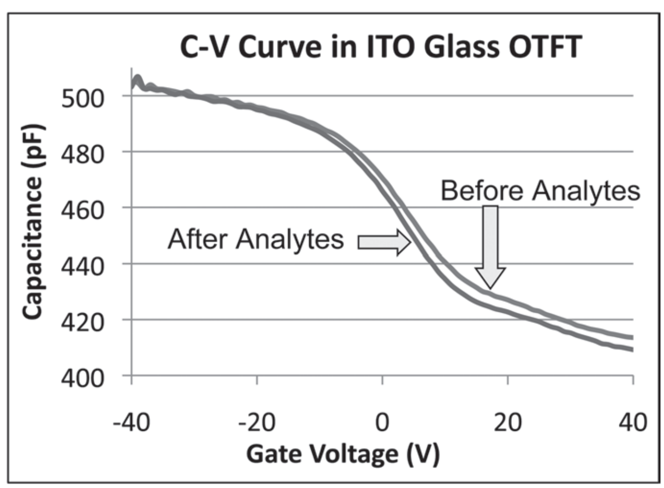

Figure 4: Effect of analytes on OTFT capacitance.