Multiple Mode Polymeric-Silicon Dual Channel Gas Sensors

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Abstract

An organic-inorganic dual-channel sensor makes a strong chemical gas sensor because this device design combines the high chemical sensitivities and selectivity of organic semiconductors [1-4] with the superior electrical performance and convenient integration of silicon semiconductors. As shown in the device schematic in Figure 1, the organic channel is the chemically-active material and is exposed to interact with gas analytes in the ambient, and the silicon channel is lightly n-type doped in the channel allowing it to operate in accumulation-mode (also known as an "always on" device). A thin silicon dioxide dielectric layer separates the two semiconductor channels and blocks current flow while allowing strong electric field coupling between the two channels. Each channel is directly and independently controlled by separated sets of source-drain contacts. This device design allows four different modes of of sensing operation, where the sensing mode is determined by the relative applied voltage biases of the four terminals. In addition to the sensor operating in two traditional sensing modes--in organic field-effect transistor (OFET) sensing and chemical field-effect transistor (ChemFET) sensing, this dual-channel sensor can also operate in Both-On mode and as a chemical memory (ChemMem) cell, a mode of the device which can electronically read, write, and refresh instances of chemical detection. Using diketopyrrolopyrole-naphthalene (PDPP-TNT) as the sensing polymer, we fabricated and tested this sensor's detection of dipolar analytes. Figure 2 shows the sensing current measurements in ChemMem, ChemFET, and OFET mode of the experimental device. [5]

Using the Semiconductor Module in the COMSOL Multiphysics® software along with experimental data, we simulated the key physics of sensor operation in the ChemFET mode and the ChemMem mode. First we analyzed how the sensor response was impacted by different concentrations and distributions of fixed dipolar analytes on the surface of the organic channel. From this simulation model, we verified the model with the experimentally measured data, we proposed an optimized sensor design that increases the sensitivity of the devices for the electrically refreshable chemical sensor. To further optimize sensor design, we propose extending the simulation into a multiphysics model by using the Microfluidics Module to simulate free analyte flow around the active surface. With the Microfluidics Module, we can expand our sensor analysis beyond chemical gas sensing and into biosensing applications in liquid.

Reference

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Figures used in the abstract

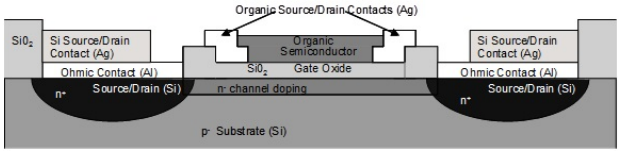

Figure 1: Schematic of the four-terminal device. Gate oxide (SiO2) serves as common gate dielectric for both the silicon n-FET and organic p-FET. Device dimensions not shown to scale.

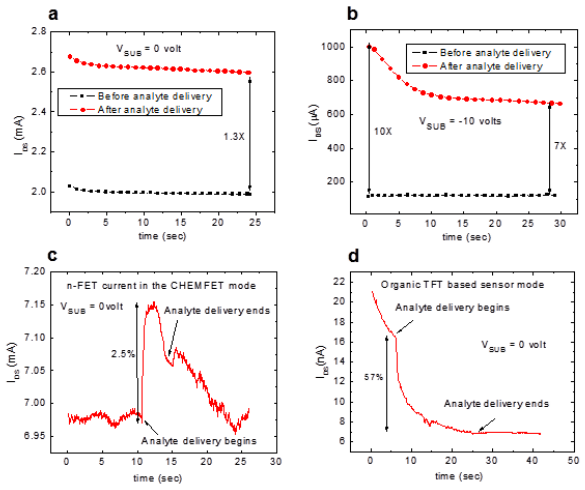

Figure 2: Measurements in different sensing modes. a, chemical memory mode sensing without any substrate bias shows a factor of 1.3 increase in the n-channel current; b, chemical memory mode measurement with -10 volts as substrate bias shows a factor of 7-10 increase in n-channel current; c, CHEMFET mode measurement showing 2.5% increase in n-channel current before it gets back to initial level once analyte delivery ends; d, p-channel current in the organic TFT based sensing mode decreases by 57% upon analyte delivery.