

Chemically Responsive Organic Field-Effect Transistors

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Organic field-effect transistors (OFETs) have been studied recently in applications such as radio-frequency identification tags, display drivers, pressure-mapping elements, and sensors. OFETs are sensitive to the

environment through multiple mechanisms, making them ideal candidates for gaseous sensing. Analytes can bind to the receptor and influence the current flowing across the transistor channel. The response will be a change in the source–drain current for a given drain and gate voltage (see Fig. 1).

Dimethyl methylphosphonate (DMMP) is a simulant for the nerve agent sarin, while the explosive dinitrotoluene (DNT) is commonly used as a simulant for trinitrotoluene (TNT). The electrical properties of both *n*-channel (electron-carrying) and *p*-channel (hole-carrying) transistor sensors were measured upon exposure to either DMMP or DNT vapors. Electron-deficient analytes will try to dope *p*-type organic semiconductors (OSCs) but will quench *n*-type OSCs. The reverse happens for electron-donating analytes. This doping or quenching competes with the dipole effect of the analyte, which will always decrease the current.

The devices were all top-contact organic transistors made on Si/SiO₂ substrates. The film thickness was minimized for optimum response. The thinner device gave faster response times and had greater sensitivity because the conduction channel comprised most of the film. However, the reduced thickness would make the device unstable.

Small molecules and polymers were both used as OSCs. The small *n*-channel molecules used were bis-CF₃ NTCDI (naphthalenetetracarboxylic diimide)

and C₂PhF₅ NTCDI. 5,5'-Bis(4-*n*-hexylphenyl)-2,2'-bithiophene (6PTTP6), 5,5'-bis(4-(6-hydroxyhexyloxy)phenyl)-2,2'-bithiophene (HO6OPT), α -sexithiophene, and 1,4-bis(5-phenyl-2-thienyl)benzene (PTPTP) were *p*-channel small molecules, and poly(3,3''-dialkylquaterthiophene) (PQT-12) was a *p*-type polymer. Each compound gave a clear response to DNT or DMMP (Figs. 2 and 3). Electron-conducting OSCs showed decreased current in response to both DNT and DMMP; however, the mechanisms were different. DMMP decreased the threshold voltage (V_t), whereas

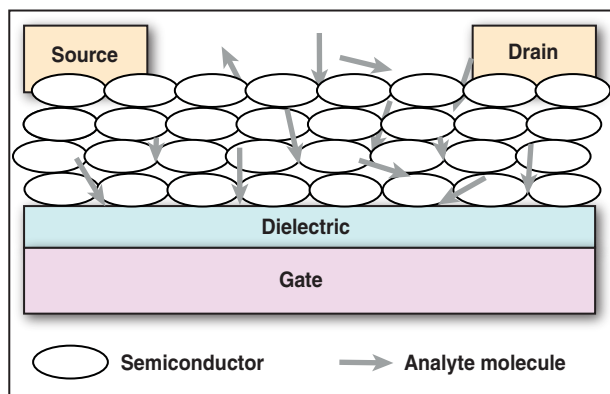


Figure 1. Schematic diagram of an OFET-based sensor illustrating analyte diffusion into the film.

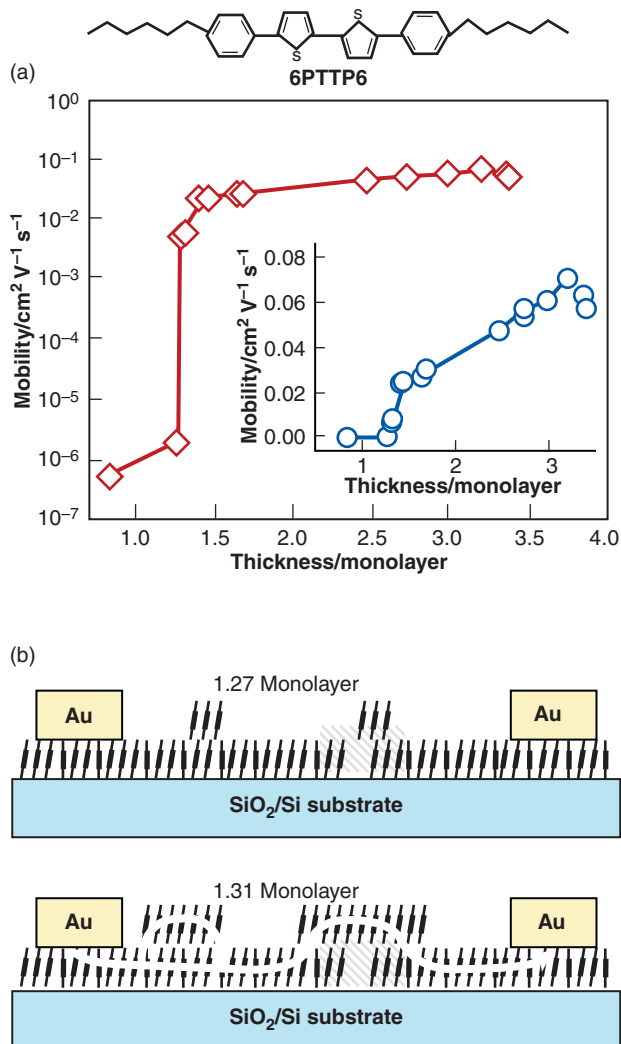


Figure 2. (a) Field-effect mobility of 6PTTP6 FETs at various film thicknesses, calculated with the linear region of the $I_d - V_g$ curves. The inner graph is also mobility but is not in log scale. (b) Schematic illustration of the conduction channel formation.

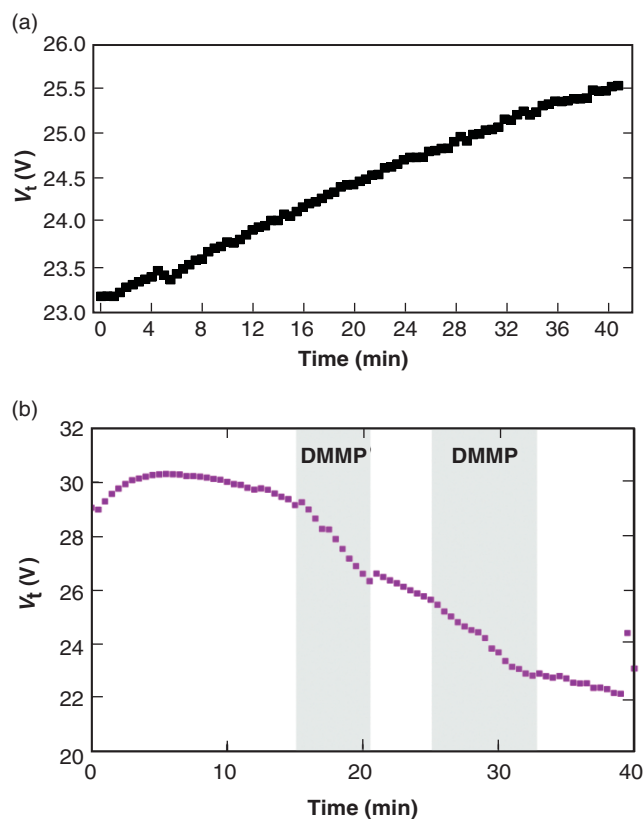


Figure 3. (a) DNT has little effect on threshold voltage. (b) DMMP decreases threshold voltage.

DNT decreased the mobility. Hole-transporting OSCs showed decreased current for devices without the incorporation of receptors and increased current for devices with receptors. These different responses show the feasibility of manufacturing an array that can sense multiple analytes with each analyte having a distinct fingerprint.

For further information on the work reported here, see the references below or contact andrew.mason@jhuapl.edu.

¹Katz, H. E., and Huang, J., "Thin-Film Organic Electronic Devices," *Annu. Rev. Mat. Res.* 39, 71–92 (2009).

²Huang, J., Sun, J., and Katz, H. E., "Monolayer-Dimensional 5,5'-Bis(4-hexylphenyl)-2,2'-bithiophene Transistors and Chemically Responsive Heterostructures," *Adv. Mat.* 20, 2567–2572 (2008).

³Huang, J., Miragliotta, J., Becknell, A., and Katz, H. E., "Hydroxy-Terminated Organic Semiconductor-Based Field-Effect Transistors for Phosphonate Vapor Detection," *J. Am. Chem. Soc.* 129, 9366–9376 (2007).