


# Organic Field-Effect Transistors for the Detection of Airborne Explosives

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*Organic field-effect transistors (OFETs) are promising materials for sensor applications because organic semiconductor materials can be readily modified to bind target analytes. This binding process*

influences the electrical current flowing through the transistor channel, causing a noticeable response in the measured source–drain current.

There is currently a need for explosive sensors that provide sensitive, selective, real-time responses. This work describes the progress made toward developing OFET devices for the detection of airborne explosive compounds such as 2,4-dinitrotoluene (DNT) and 2,4,6-trinitrotoluene (TNT).

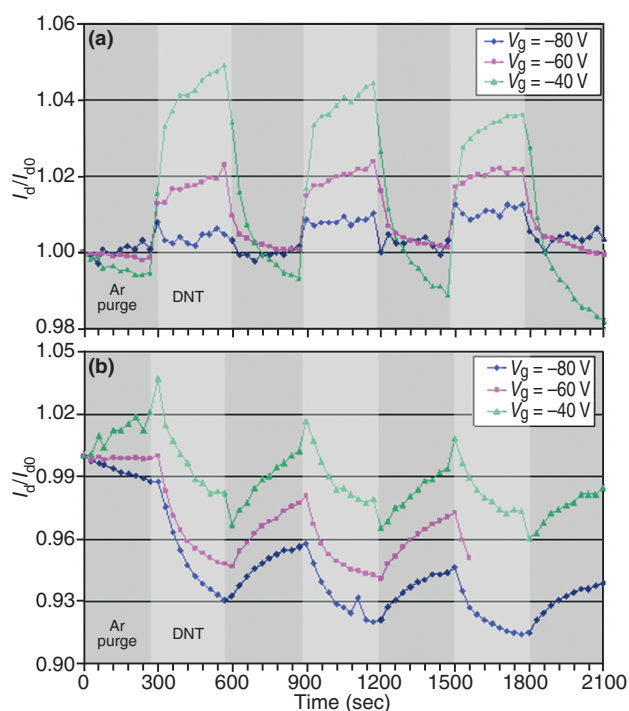
A variety of OFET devices were created by physical vapor deposition of organic semiconductors onto Si/SiO<sub>2</sub> substrates. Both *p*-channel devices [5,5'-bis(4-*n*-hexylphenyl)-2,2'-bithiophene (6PTTP6) and 5,5'-bis(4-(6-hydroxyhexyloxy)phenyl)-2,2'-bithiophene (HO6OPT) semiconductors] and *n*-channel devices [bis-CF<sub>3</sub> naphthalenetetracarboxylic diimide (NTDCI) semiconductor] devices were created by passing explosive vapor over the testing apparatus (Figs. 1 and 2).

All transistors gave significant responses when exposed to DNT vapor. For *p*-channel devices, the source–drain current decreased for alkylated thiophene semiconductor 6PTTP6 upon exposure to DNT,

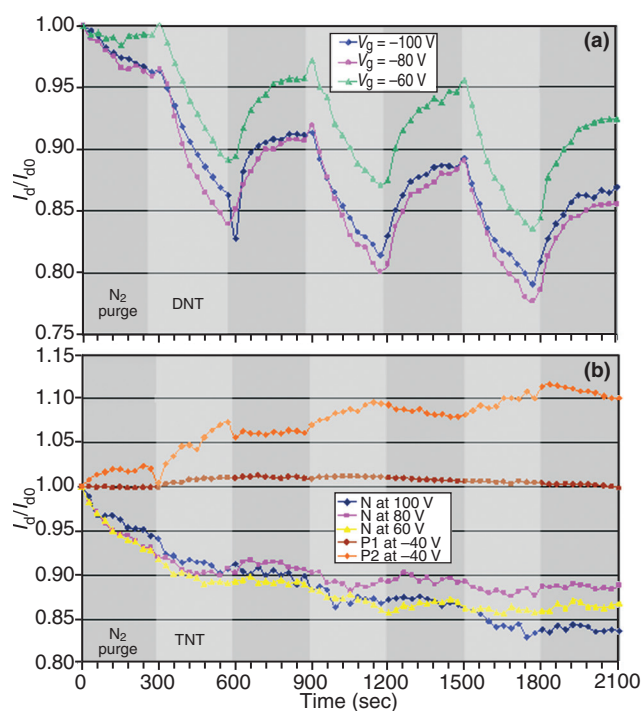
whereas a current increase was measured for hydroxyl-functionalized thiophene HO6OPT. A current decrease was observed for all *n*-channel devices in the presence of DNT. The variety of responses by different semiconductors to DNT suggests that explosive compounds can be selectively identified on the basis of the combined response of an OFET array consisting of multiple semiconductor materials.

Responses also were observed upon exposure to TNT, although it appears that the low vapor pressure of TNT prevents cycling of the OFET devices between bound and unbound states. To improve TNT responses, templated explosive binding sites will be synthesized and incorporated into new OFET devices.

Device response to TNT and DNT can be used to interpret possible mechanisms for current modulation in these systems. Analyte molecules with a strong dipole moment can disrupt charge conduction as a result of the gate-induced electric field. Alternatively, charge conduction can be affected by electron donors in the semiconductor matrix forming charge-transfer complexes with electron-poor analytes.



**Figure 1.** Transistors P1 (a) and P2 (b) tested under alternating DNT and argon flow at  $V_g = -40$ ,  $-60$ , and  $-80$  V. The DNT vapor decreases the drain current of transistor P1 but increases the drain current of transistor P2. Transistor P1 displays a larger response at higher gate voltages, whereas transistor P2 displays a larger response at lower gate voltages. Additionally, transistor P2 has a faster response time.



**Figure 2.** (a) Transistor N tested under alternating DNT and nitrogen flow at  $V_g = 60$ ,  $80$ , and  $100$  V. DNT vapor decreases the drain current of transistor N. Transistor N displays relatively consistent results at all gate voltages, with a linear decrease in current under DNT conditions. (b) Transistors P1, P2, and N tested under alternating TNT and argon (P1 and P2) and nitrogen (N). Exposure to TNT vapor increases the current for *p*-type transistors and decreases the current for *n*-type transistors. The argon/nitrogen purge is not effective at removing TNT from the transistors, probably because of the lower vapor pressure of TNT relative to that of DNT.

For further information on the work reported here, see the references below or contact [andrew.mason@jhuapl.edu](mailto:andrew.mason@jhuapl.edu).

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

<sup>2</sup>Huang, 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).

<sup>3</sup>Huang, 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).