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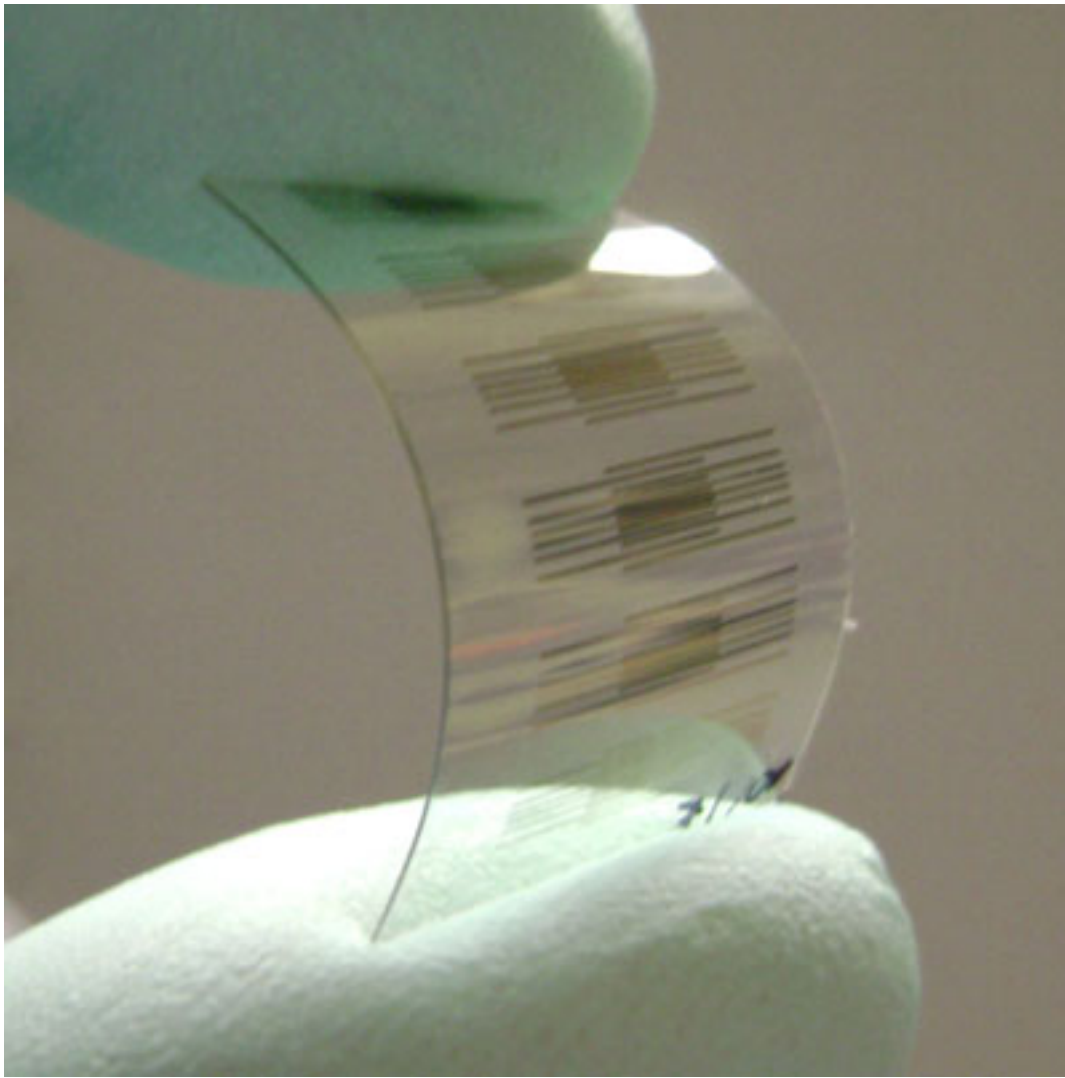
## Online News

October 9, 2008

# Organic thin-film transistors make a splash

## Operation of low-voltage organic transistors in aqueous solution is demonstrated for sensing applications.

Sensors based on organic thin-film transistors (OTFTs) hold great promise for applications in environmental monitoring, health care, and national defense. OTFTs have been used for the detection of a variety of vapor-phase analytes, but up to now, high operating voltages and problems with degradation, delamination, ionic currents, and electrochemical reactions have made OTFTs unusable in aqueous solutions or humid environments. Zhenan Bao, Mark Roberts, and colleagues of Stanford University and the Max Planck Institute for Polymer Research (Germany) have taken a step toward overcoming these hurdles by developing low-voltage OTFTs that can be used in aqueous media (*Proc. Natl. Acad. Sci. U.S.A.* **2008**, DOI [10.1073/pnas.0802105105](https://doi.org/10.1073/pnas.0802105105)).



MARK ROBERTS/ZHENAN BAO

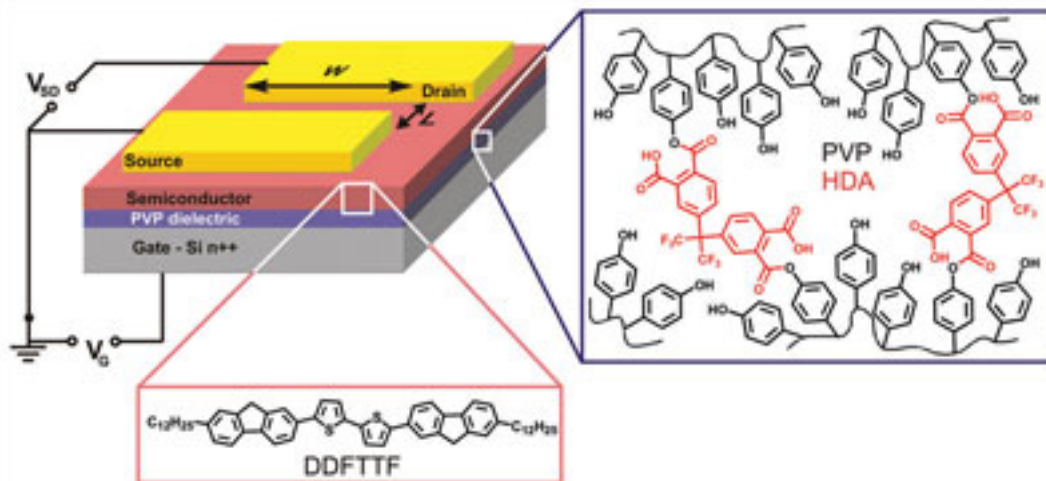
A plastic organic transistor has been developed by Bao, Roberts, and colleagues for aqueous sensing applications.

The organic transistor consists of two electrodes on top of the organic semiconductor layer, which in turn lies on top of a dielectric layer and a “gate” electrode. The current in the semiconductor can be amplified by as much as 6 orders of magnitude by applying a voltage through the gate electrode; this voltage induces charges into the semiconducting material and changes its conductivity. Amplifying the current yields a stronger signal, and therefore the semiconductor device becomes potentially more sensitive than resistor-based devices. Organic semiconductor and dielectric materials also may be used with flexible, large-area substrates and modified with selective layers as well as combined in arrays to yield slim, flexible, low-cost devices and single-use test strips.

New organic semiconductor and ultrathin dielectric materials developed by Bao, Roberts, and colleagues have made it possible to operate the OTFTs at  $<1$  V, a threshold that minimizes electrolytic hydrolysis of water and high ionic conduction through the analyte; the researchers note that this low voltage is critical to stable performance in aqueous media.

The new cross-linkable polymer dielectric layers, which have high stability as well as low-temperature

cross-linking ability, are made of poly(4-vinylphenol) cross-linked with 4,4'-(hexafluoroisopropylidene) diphthalic anhydride. To detect the analytes, devices incorporating the p-channel semiconductor 5,5'-bis-(7-dodecyl-9H-fluoren-2-yl)-2,2'-bithiophene were used. In addition, the researchers report that they used the devices to detect changes in pH as well as aqueous concentrations in the parts-per-million to parts-per-billion range of trinitrobenzene, cysteine, methylphosphonic acid, and glucose.



Schematic of OTFT showing gate, dielectric, and semiconductor layers and electrodes. Analytes are thought to diffuse to the boundary between the semiconductor and dielectric layers, affecting the transistor current by doping or trapping charges. (Adapted with permission. Copyright 2008 National Academy of Sciences U.S.A.)

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“This is very interesting work,” says George Malliaras of Cornell University. “This will help not only the use of organic semiconductors in sensors but also might help improve the stability of organic semiconductors in general, such as light-emitting diodes, transistors, and solar cells.”

Jiri Janata of the Georgia Institute of Technology is more cautious. “They have not eliminated the possibility of an artifact,” says Janata. “There is no mechanism that I know that would elicit this kind of response other than experimental artifact arising from inadvertent electrolysis. Operation of their devices below 1 V is no guarantee of artifact-free operation, because it depends on the absence of electroactive species in the solution.”

However, Bao notes, “We have not observed visible electrochemical reactions. If there is an electrochemical reaction going on in the organic semiconductor, then we would have observed a significant change in the electrical behavior over time. But in our case, we operated the device underwater repeatedly for 8 hours—that is, 10,000 cycles—and we [did] not see a change in the on current or the off current.”

The investigators also found no significant changes in the electronic characteristics of the device before and after it was exposed to water. “From this testing, we do not think there is any significant degradation of the semiconductor due to electrochemical reaction,” Bao says. Furthermore, she notes that the

solution characteristics were carefully controlled to ensure that they had the same ionic strength and could not give rise to experimental artifact.

The researchers present evidence consistent with a sensing mechanism that involves analyte diffusion to the semiconductor/dielectric interface. They recorded the OTFT sensor response to 1 ppt solutions of methanol, ethanol, and propanol. Because diffusion rate is limited by molecular size, the magnitude of the response for methanol should be greater than that for propanol. And in fact, the responses corresponded exactly to those expected if the diffusion mechanism were operating.

Bao agrees that more work is needed to elucidate the mechanistic details and to develop OTFTs as practical sensors. “To prove the mechanism, we will have to do many more studies than just this initial paper,” she notes. “And in the future, what we want to do is to make the sensor more selective.”

The new strategy will be to use several devices, each one incorporating different semiconductors and/or selective layers in a sensor array. This device in combination with pattern recognition algorithms will create a kind of “electronic nose”—or perhaps more aptly for aqueous media, “electronic tongue”—that can provide chemical specificity.

According to the experts, biomaterials offer many possibilities in this regard. “Biology gives us an arsenal of biorecognition elements that need to be interfaced with organic semiconductors to make very powerful and very specific sensors,” affirms Malliaras. “The application of organics in sensors and bioelectronics is the next wave. We’re going to be seeing a lot of groups aligning with that objective.” —  
DEBORAH L. ILLMAN

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