Organic electronic biological sensing

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Transduction of molecular recognition by closely packed organic electronics and membrane proteins may enable accurate, label-free diagnostic testing.

Biological assays are largely performed by methods such as polymerase chain reaction (PCR) or enzyme-linked immunosorbent assays (ELISA). These techniques, although high-throughput and reliable, require extensive sample treatment involving incubation, sample cleanup, or amplification. The analysis also requires labeling the bio-analyte—for instance, a pathogen such as the human immunodeficiency virus (HIV)—to enable transduction of molecular-recognition events, adding further sample handling. Moreover, optical detection relies on expensive, dedicated systems whose miniaturization is technologically demanding. These approaches are therefore mainly suitable for obtaining time- and resource-intensive laboratory-based diagnostics.

There is increasing interest in point-of-care (POC) analysis to perform low-cost, rapid, and reliable diagnostic procedures where they are needed: the doctor’s office or the patient’s house. Direct electronic bio-recognition transduction using a label-free process is a compelling alternative, offering true miniaturization and easy data handling and processing. Low costs and versatility add up if tests use organic thin-film transistors (OTFTs) as transducer. Recently, OTFT biosensors have shown potential to achieve very high performance. Organic electronics allow for fabrication of sensing circuits (also in an array configuration) on flexible, plastic or paper substrates using low-cost, printing-compatible procedures. This opens up the possibility of developing inexpensive paper test strips that combine reliability with label-free electronic detection and data processing.

Figure 1 shows a schematic of an OTFT sensing device, with a membrane protein as bioreceptor. An organic semiconductor is capacitively coupled to a gate dielectric, which induces a field at the interface between the organic thin film and the gate dielectric. High-dielectric-constant layers allow us to operate the OTFT at low voltage and power, even in a liquid environment. The device-channel material is composed of an organic-semiconductor thin film and a phospholipid bilayer. The latter contains receptors used for target-analyte recognition. Exposing the OTFT to the analyte solution changes the device output characteristics. We immobilize the biological recognition element by incorporating it into liposomes (artificial lipid bilayers organized in vesicles). This provides a nearly native environment for biomolecules. Spreading small lipid vesicles on solid support allows them to self-assemble into fluid planar bilayers hosting the selected protein.

The device, which is still under development, stems from our recent results on OTFT sensors containing a chiral organic semiconductor (see Figure 2). These sensors have amplified sensitivity, allowing differential detection of citronellol enantiomers in the part-per-million concentration range with highly repeatable

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responses. This is three orders of magnitude lower than previously reported, an achievement made possible thanks to field-enhanced sensitivity when the sensor is operated in the OTFT regime.

Reducing OTFT dimensions to the nanoscale further improves sensitivity. Single-molecule detection can be performed at this scale, but requires very demanding technological solutions. OTFTs offer enhanced sensitivity, but using micrometer-size devices realized with low-cost technology. Cost is a key driver, particularly for consumer-oriented sensor systems. Our technology can take full advantage of the rapid developments in the field of organic electronics, where OTFTs have already been implemented in complementary-metal-oxide-semiconductor circuits and in flexible plastic displays. In the future, we will focus on implementation of supramolecular architectures employed in microscale devices on plastic flexible substrates.

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Luisa Torsi has been a full professor of analytical chemistry since 2005. She is at the forefront of research in the analytical sciences, pioneering the use of OTFTs as high-performance sensors.

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