

Organic electronics and its applications in sensors

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Abstract

Strong, flexible, lightweight and cheap, plastics have acquired an additional attribute in recent years: the ability to function as semiconductors, forming diodes and transistors in plastic integrated circuits. Now, as the first plastic electronics products are hitting the market in displays that use organic light-emitting diodes, the stage is set for a new era of pervasive computing with polymers. Plastics may never match the sheer processing speed and miniaturization of silicon, but they will be able to go places that silicon cannot reach: ultracheap radio-frequency identification tags; low-end, high-volume data storage; displays that are inexpensive, even disposable, or that can be wrapped around a wall column; and wearable computing. Other uses for conductive plastics include photocells, chemical sensors and pressure-sensitive materials.

Nontraditional materials such as conjugated organic molecules, short-chain oligomers, longer-chain polymers, and organic–inorganic composites are being developed that emit light, conduct current, and act as semiconductors. The ability of these materials to transport charge (holes and electrons) due to the pi-orbital overlap of neighbouring molecules provides their semiconducting and conducting properties. The self-assembling or ordering of these organic and hybrid materials enhances this pi-orbital overlap and is key to improvements in carrier mobility.

The recombination of the charge carriers under an applied field can lead to the formation of an exciton that decays radiatively to produce light emission. (Schematics of organic transistors and light-emitting devices are provided in Figure 1). In addition to their electronic and optical properties, many of these thin-film materials possess good mechanical properties (flexibility and toughness) and can be processed at low temperatures using techniques familiar to the semiconducting and printing industries, such as vacuum evaporation, solution casting, ink-jet printing, and stamping. These properties could lead to new form factors in which roll-to-roll manufacturing could be used to create products such as lowcost information displays on flexible plastic, and logic for smart cards and radio-frequency identification (RFID) tags.

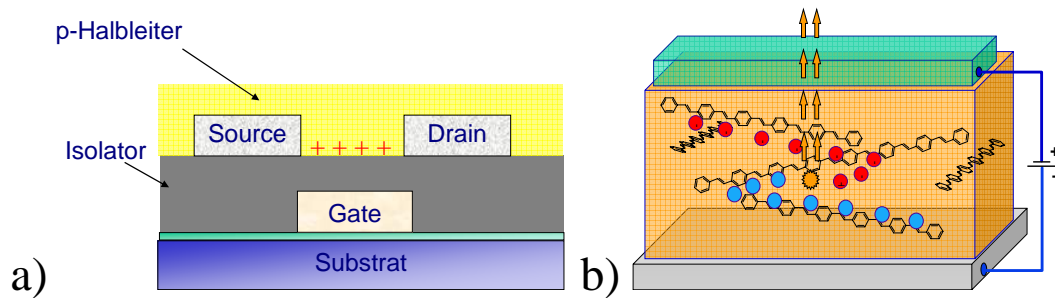


Figure 1: a) Schematic cross section of a p-type organic transistor. By applying a negative voltage at the gate a channel of positive carriers is formed at the insulator/organic interface. b) Schematic picture of an organic light emitting diode. Electrons and holes are injected from opposite electrodes into the organic layer, meet each other and form a neutral excited state (exciton). This state decays radiatively and emits a photon (light), which is coupled out through a transparent electrode.

Efforts on these “active” materials initiated in academia and in industrial research laboratories in the 1970s and 1980s have led to a dramatic improvement in performance due to innovative chemistry and processing, as well as the growing ability to understand and control the selfassembly and ordering of oligomers, polymers, and nanocrystals. Research efforts on semiconducting conjugated organic thiophene oligomers [1, 2], thiophene polymers [3–5], and the small pentacene molecule [6 –8] have led to improvements in the mobility of these materials by five orders of magnitude over the past 15 years.

The majority of these semiconducting organic materials are p-type, transporting holes rather than electrons. Beside of p-type materials, n-type systems are also of interest because they enable the fabrication of p–n junctions, and complementary logic. Some examples have recently been reported in the literature [9 - 11]. Further research is needed to improve the mobility and environmental stability of n-type and p-type materials, as well as a fundamental understanding of electron injection, metal contact issues, electron transport, surface modification, and self-assembly.

The basic components in organic electronics are light emitting diodes (basic element for displays and lighting), transistors (basic element for logic circuits) and photovoltaic cells. A clever combination of the properties of these devices leads for example to sensors for pressure, chemicals and light.

Enormous enhancements in performance have been seen in the development of organic light-emitting diodes (OLEDs). With a dramatic increase in luminous efficiency of light-emitting molecular solids over a 15- year time scale. Pioneering work was done at Eastman Kodak in 1987 on evaporated small molecules [12] and at Cambridge University in 1990 on solution-processed semiconducting polymers [13]. Currently, the highest observed

luminous efficiencies of derivatives of these materials exceed that of incandescent light bulbs, thus eliminating the need for the backlight that is used in AMLCDs.

Displays made of OLEDs have a low power consumption compared to LCDs, exhibit an excellent viewing angle like paper, are extremely thin, can be made flexible and need only a simple fabrication processes, which gives the possibility to reduced production costs.

The basic element for logic circuits are transistors. A key advantage of organic transistors over silicon is their ease of fabrication. Building a state-of-the-art silicon chip takes weeks of work using complex and expensive processes such as photolithography and vacuum deposition, carried out under high temperatures in ultraclean rooms. In comparison, organic transistors can be made using faster, cheaper processes under less carefully controlled conditions. Finally, there is the promise of "roll-to-roll" fabrication similar to the continuous printing presses that revolutionized publishing.

The enormous progress in the field of organic electronics was demonstrated by presentation of an organic RFID tag (Radio Frequency Identification Device, sometimes called an electronic bar code) by Philips Research on the ISSCC conference in 2006 operating at the industrial standard of 13.56MHz. This demonstrated that a large complex organic circuit (nearly 2000 transistors) can work reliable even at high frequencies.



Figure 2: Organic electronic circuits on a flexible plastic foil. (Photo by Dago de Leeuw, Philips Research). In future electronic circuits can simply be printed e.g. modified inkjet printers.

An interesting combination of organic transistors and displays is followed by companies like Polymer Vision. They fabricate flexible displays that can be rolled up and are thin as paper. Instead of carrying a big display with you it is

now possible to transport it in a small roll with a diameter of only a few centimeter and to unroll to a large area if it is needed. This is possible as organic materials are flexible and the active layers are very thin namely several hundreds of nm or a few microns.

Organic electronics is also used for a variety of sensor applications. In principle the device concepts discussed above are used, sometimes added by using chemical modification of the organic materials. Examples are light sensors [14,15], vapour sensors [16,17] and nanoscale chemical sensors [18]. As organic electronics can be processed on thin flexible substrates it can be included in clothing, or even more, be used as an artificial skin, as done by researchers at the University of Tokyo [19]. The artificial skin consists of an array of organic pressure sensors that were fitted over a hand of a robot like a hand glove.

Especially organic transistors have been demonstrated as effective sensors in both gaseous and aqueous environments. They can be used as either field effect transistors or electrochemical transistors and they show superior performance compared to resistor-type, amperometric and potentiometric sensors. The amplification inherent to transistors enhances their sensitivity, and they offer several opportunities for achieving selectivity, including multiparameter measurements and direct integration with specific recognition elements. In fact, the ability to covalently integrate recognition elements directly with the active layer of the device is one of the most promising features of organic transistor sensors.

In summary, organic electronics has demonstrated an enormous progress in the last decade and is a rapidly growing field. There are intense activities in research and a large variety of applications were demonstrated. Organic devices find their way in commercial applications. But still, this is just the beginning of the use of this promising technology in displays, electronic circuits, sensors and further applications. Organic electronics will soon be part of our daily life.

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