High-Performance Flexible Organic Field-Effect Transistors with Biodegradable Components: An Effort Towards Green Electronics
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In the current fast-growing electronic world, computers are acting as the backbone for our efficient and comfortable work experience. On average, today a working person is surrounded by more than 1000 processors. Conventional silicon based inorganic electronics has solved many challenges related to our increased electronics use, but there are limitations to what silicon electronics can do. There is a growing need for alternative technologies that can be used for large-area flexible systems requiring low fabrication cost and processing temperatures. In addition, the methodologies and resources used in silicon electronics manufacturing concerns the negative environmental impact and there is a need for technology that can reduce the electronic waste at the end of the life span of the devices. Flexible electronics has promised to be the best possible alternative to conventional silicon technology. The use of organic materials provides a platform for the electronic world to be more environmentally friendly and reducing production costs. Along with low temperature processing capability, the soft nature of the organic semiconductors allows them to be processed on bendable and foldable plastic and other flexible substrates. The flexibility properties are used to make electronic skin with tactile sensing properties that can be used in robotics and other applications where flexible touch sensors are required that were impossible to be built by existing silicon technology. The flexible nature also favors the production of organic devices through the roll to roll processing, where the fabrication is almost similar to printing a newspaper with high speed. The roll to roll processing cuts down the processing cost to a large extent and allows the bulk production at a faster rate. Today using flexible organic electronic devices in a commercially available product is not more a dream, rather the industry has already left its footprints in the flexible electronics industry with cellphones using organic light-emitting displays is one of its examples. Printed electronics, flexible large-area electronics, polymer electronics, plastics electronics, etc. are some of the names today use for this technology, which uses a combination of low-cost materials, printing technology, and large-area processing capabilities with environmentally friendly processes to open up new fields of application. Some of the major applications are organic light-emitting diodes (OLEDs), flexible displays, radio frequency identification tags (RFIDs), intelligent packaging, solar cells, energy-efficient lighting, organic memory devices, printable batteries, flexible sensors, and printable circuits are examples of the advancement of this area. The technological achievements in the field in such a short span shows the interest of the research community in this fast-growing field and its development. Flexible electronics has travelled a long way and there is a huge scope for the industry to grow with an immense number of products to come in the future and is thus called the futuristic technology. In addition, flexible electronics offers advantages over conventional electronics with the possibility of fabrication on unconventional and biodegradable substrates, eventually leading towards green electronics. Organic field-effect transistors (OFETs) receive significant attention because of their potential use in flexible electronics, specifically for circuit and sensing applications.

Flexible OFETs have potential to be used as a building block for applications in electronic skin (E-skin), health monitoring, and Biomimetic applications due to flexibility or stretch ability. However, during the operation, these devices are encountered with various electrical, mechanical, and thermal stimulations. Thus, for reliable operation in practical applications, OFETs must be operationally stable. With various process optimization techniques high performance flexible p-channel OFETs with TIPS-Pentacene as organic semiconductor were demonstrated. These devices operated at low voltages (5 V) and exhibited mobility values exceeding 1 cm²/V.s, current on/off ratios higher than 10^5, and very high electromechanical stability [1].

High performing OFET devices fabricated on unconventional substrates such as paper can pave the way towards biodegradable electronics. Recently, we demonstrated high-performance high performance OFETs on a low cost paper substrate (PowerCoat™ HD 230) with TIPS-Pentacene-Polystyrene (PS) blend as active layer and Poly(4-vinylphenol)(PVP)/HfO2 as hybrid gate dielectric. Device structure and relevant aspects are summarized in Figure 1. Excellent p-channel transistor characteristics, high current on-off ratio, and excellent bias-stress stability were achieved from these devices. These OFETs displayed very stable electrical characteristics even after long exposure to humidity. In addition, the remarkable shelf life stability of more than 6 months in the ambient environment was observed. These devices were also demonstrated as novel paper-based phototransistors.

Flexible OFETs have potential to be used for real-time health monitoring applications, with use of suitable material components. However, there are various challenges that need to be addressed to use these devices in real-time health monitoring systems. Challenges include improving the electrical performance and operational stability to ensure prompt and accurate response towards a specific stimulus. In recent years various biocompatible, biodegradable materials like natural proteins have been used for high-performance OFETs. Along with biodegradable nature, natural proteins have unique properties that are difficult to achieve through conventional organic and inorganic insulating materials. The device formed with such biodegradable and highly sensitive material can be used to sense various stimuli related to human health along with the advantage of biodegradability. The nature-inspired materials not only serve as substrate or dielectric but their biodegradable nature also helps in reducing electronic waste. Gelatin is a low-cost natural protein most commonly used in capsules for oral drug ingestion, but is one such biocompatible and biodegradable potential material. High-performance flexible OFET with gelatin as dielectric and solution-processed TIPS-pentacene as semiconductor were fabricated on flexible poly(ethyleneterephthalate) (PET) substrate. Fig 2
summarizes the related results and applications. The fabricated devices exhibited high-performance and electromechanical stability, demonstrating high field-effect mobility with near-zero threshold voltage and Ion to Ioff ratio approaching $10^5$ with a low operating voltage of -5 V. Devices exhibited highly stable electrical characteristics under multiple transfer scan measurement. High electromechanical stability was observed under strain application.

These flexible devices shown excellent switching behavior in circuit applications. Moreover, upon exposure to humidity exposure cycles, the devices respond quickly acting as humidity sensor. This property is eventually being utilized for real time health monitoring applications such as breath rate analyzer. These devices will eventually be useful for low-cost self-health monitoring systems and lead towards environment friendly green electronics.


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