

Organic electrochemical light emitting field effect transistors

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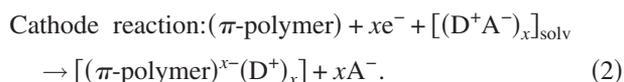
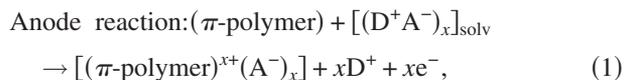
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We report on the demonstration of an organic electrochemical light emitting field effect transistor. The device fabricated in bottom gate/bottom contact geometry using a conjugated polymer poly[2-methoxy-5-(3',7'-dimethyloctyloxy)-1,4-phenylenevinylene] (MDMO-PPV) mixed with polymer electrolyte poly(ethylene oxide) including lithium trifluoromethanesulfonate (Li triflate) as active layer and poly(vinyl alcohol) as gate dielectric. Orange-yellow light emission is observed from the device. The output characteristics (source-drain current versus the source-drain voltage) and transfer characteristics (source-drain current versus the gate voltage) of the device are reported. © 2010 American Institute of Physics. [doi:10.1063/1.3464558]

Organic light emitting field effect transistors (OLEFETs) show great potential for technological applications such as active matrix full color electroluminescent displays. The display panels using the OLEFETs have the advantage of largely reducing both the number of devices and the circuit complexity. Combining optical and electrical functionality in an OLEFET device would increase the number of potential applications in integrated circuitry for signal processing that involves both optical and electrical signals. Furthermore, it is an ideal structure for life time studies of organic light emitting materials under different driving conditions and charge-carrier balance conditions. Since the demonstration of the OLEFET,¹ many advances have been reported.²⁻⁷

On the other hand, polymer light emitting electrochemical cells (LECs) are an interesting alternative approach to electroluminescence light emitting diodes (LEDs) using semiconducting polymers.⁸ Unlike LEDs, which are based on the intrinsic properties of undoped semiconducting polymers, the polymer LEC is a solid-state device in which both electrical and ionic charge carriers are present.

When a sufficiently large voltage bias is applied to an LEC, the conjugated polymer gets electrochemically doped in opposite redox states at the opposite electrodes as in Eqs. (1) and (2). In this process, the ions redistribute and intercalate, redox occurs near the electrodes, and a *p-i-n* junction is formed *in situ* by this process.



The low resistances of the doped regions facilitate injection of electrons and holes, respectively, into the *n*-type and *p*-type regions. Light is emitted from an LEC through the radiative recombination of positive and negative polarons in the undoped, intrinsic (*i*) region.⁹⁻¹³ The LEC is the semi-

conducting polymer device that is based on a doping-induced homojunction; an LEC is more like an inorganic *p-i-n* junction.

We report here the same ideology of an LEC in the field of organic light emitting transistors. The organic semiconductors employed as OLEFET active layers were already known in organic electronics.¹⁴ Whereas mixed ionic/electronic conduction in conjugated organic materials-conjugated polyelectrolyte composites-introduces additional functionality,¹⁷ the understanding of the fundamental processes that take place is still in its infancy. These materials combine the optical and electronic qualities of conjugated polymers with the properties of polyelectrolytes can be modified by electrostatic interactions.¹⁵⁻¹⁷

Conjugated polyelectrolyte composites have also recently attracted much attention as charge injection/transport layers in organic optoelectronic devices.¹⁸⁻²¹ One significant practical aspect is that they can be used to fabricate multilayer devices by spin coating techniques.²² Furthermore, the charges, dipoles, and counterions offer the opportunity to reduce electron injection barriers from high work function metals such as aluminum and gold. The exact mechanism of this process, however, remains under debate.

One of the known effects of the inclusion of an ionic species in a conjugated polymer is the increase in electrical conductivity associated with the electrochemical doping of the material. The conductivity increase in these materials arises from the introduction of charged polaronic species on the polymer backbone, which is charge-compensated by a counterion.²³

Benefits of using ionic effects have been demonstrated in LECs,⁸ polymer electrochromic devices,²⁴ artificial muscles,²⁵ and biosensors,²⁶ among others. In these kinds of devices, efficient polymer light emitting devices have been fabricated by blending the active layer with electrolytes,²³ or substituting it with single-component polymers that have ion pairs tethered to the side chains.²⁷ Applications such as these, which take advantage of ionic movement and/or electrochemical oxidation and reduction in an organic electronic film, are remarkably numerous, yet these processes and the benefits they provide have received little attention in the scientific literature.

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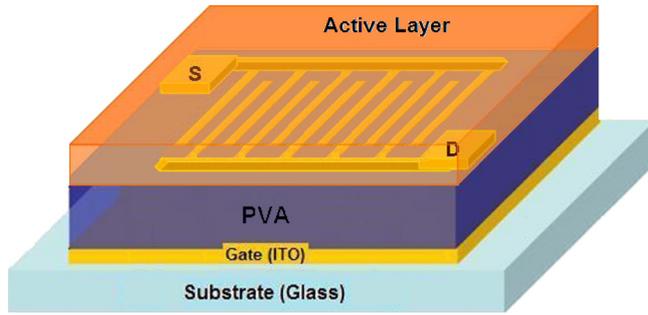


FIG. 1. (Color online) Scheme of the OELEFET device geometry.

Although electrolytes have been demonstrated as gate insulators in silicon-based transistors²⁸ and in organic field effect transistors²⁹⁻³¹ or as ion-transporting layer in polymer based electrochemical transistors;³² this work is an attempt to demonstrate that electrolytes can be mixed with organic luminescent polymers and they can be used as active layer to produce an organic electrochemical light emitting field effect transistor (OELEFET).

OELEFETs are fabricated in bottom gate/bottom contact geometry, as shown in Fig. 1. The OELEFET fabrication starts with the etching of the indium tin oxide (ITO) on the glass substrate. ITO coated glass substrates ($15 \times 15 \text{ mm}^2$) were etched to leave an area of $1 \times 15 \text{ mm}^2$ serving as a gate electrode and cleaned with 2% Hellmanex solution in ultrasonic bath which was followed by further ultrasonic bath with H_2O and then in isopropanol. After cleaning steps poly(vinyl alcohol) (PVA) was spin cast as soluble dielectric insulator. PVA with an average molecular weight of 127 000 (Sigma-Aldrich Mowiol[®] 40-88) was used as received. The PVA was dissolved in distilled water and filtered using $0.2 \text{ }\mu\text{m}$ filters, lyophilized and redissolved again in distilled water. PVA films were cast from a 5 wt % aqueous solution by spin coating at 1500 rpm, yielding films with a thickness around 0.8 to $1 \text{ }\mu\text{m}$. The films were dried over night in an Argon atmosphere at $60 \text{ }^\circ\text{C}$. Following the PVA curing, bottom contact electrodes consisting of Cr/Au (0.6 nm and 60 nm , respectively) were evaporated under high vacuum ($\sim 10^{-6}$ Torr) through a shadow mask. The channel length

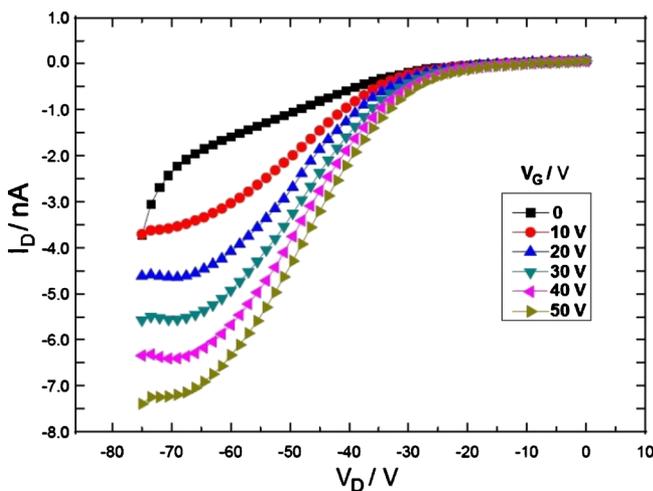


FIG. 2. (Color online) Output characteristics of OELEFET at various gate voltages.

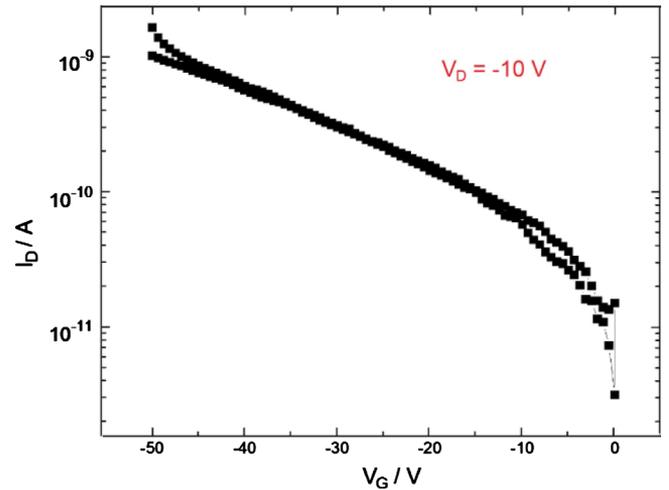


FIG. 3. (Color online) Transfer characteristics of OELEFET at $V_D = -10 \text{ V}$.

(L) and width (W) of the transistor was $100 \text{ }\mu\text{m}$ and 1 mm , respectively.

The luminescent polymer used in this study was MDMO-PPV (purchased from Sigma-Aldrich). The polymer electrolyte consisted of poly(ethylene oxide) (PEO) and lithium trifluoromethanesulfonate (Li triflate). The luminescent polymer, PEO, and Li triflate were blended 5:5:1 by weight and dissolved in cyclohexanone to create master solutions of concentrations of 2% (w/v). The polymer blend was then spin cast onto the PVA dielectric substrate at 1400 rpm to form a film of about $0.60 \text{ }\mu\text{m}$ in thickness, followed by drying at $50 \text{ }^\circ\text{C}$ for 3 h. All device fabrication procedures were carried out in a glovebox filled with dry nitrogen. Electrical measurements were performed at room temperature using an Agilent E5273A with two source-measure unit instruments.

Typical output characteristics of an OELEFET are displayed in Fig. 2. It exhibits the characteristics of a p -type field effect transistor with well observed saturation behavior. The electrical transfer characteristics are displayed in Fig. 3. We calculated the mobility from linear regime using the standard transistor equation³³ to be $2.2 \times 10^{-4} \text{ cm}^2/\text{V s}$. Ionic migration time scales are important, as the switching speed of the transistor depend on the response time of the ions in the polymer matrix to an applied gate voltage.³⁴ Therefore, a voltage sweep rate of 6.7 mV/s was used in the current-voltage measurements. Figure 4 is a photograph of an operating OELEFET taken through an optical microscope. We observed orange-yellow light emission from the device char-



FIG. 4. (Color online) Photograph of an operating OELEFET taken through an optical microscope.

acteristic for the MDMO-PPV light emitting devices.

This report on the existence of the OELEFETs is continued with detailed studies of the electrical capacity, optical emission/absorption and nanoscale space-resolved experiments of the *p-i-n* junction itself and these studies will be reported elsewhere.

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