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Low Voltage Organic Field Effect Light Emitting Transistors with Vertical Geometry

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Abstract **–**The devices developed in the field of organic electronics in recent years are on the technological applications and development of organic electronic devices using organic semiconductor films. The main applications of the organic electronic revolution are; Electrochromic Device, Organic Light Emitting Diodes (OLED), Organic Field Effect Transistors (OFET). Among these devices, OLED technology has taken its place in the commercial market in the last five years and has started to be used in our daily life in a short time. The efficiency of OFET devices is related to the operation of the devices at low voltage. This is only possible if the load carriers in the channel of the OFET have a low distance. A new field of research is the ability to implement two or more features on a single device, in the construction of integrated devices. Light emitting transistors (OLEFET), where light emission and current modulation are collected in a single device, are the most intensively studied devices. In this study, ITO substrate, source and drain electrodes were made from aluminum electrode structured organic field effect OLEFETs. In the study of instead of polymer dielectric PVA, PMMA polymer material which is mostly used in OFET construction was preferred.

Keywords – *Organic Electronics, Semiconductor, Organic Light Emitting Diode, Organic Transistor, Organic Light Emitting Transistor*

I. Introduction

Field effect transistors (FET) are three terminal devices based on metal and inorganic layers, consisting of source, drain and gate electrodes. FET devices, electrical amplification and switching functions, electrical behavior control is provided through the electric field. Organic field effect transistors (OFET), unlike traditional inorganic transistors, are composed of organic semiconductor layer of active layer. When the OFET device was first reported in 1987 Koezuka at al., it became one of the main working subjects of materials engineering, organic chemistry and device physics [1]. It consists of organic semiconductor pi-conjugated molecules and polymers used in Organic Field Effect Transistors [2-3]. It is possible to modify the structure of these molecules/polymers to adjust properties such as conductivity, thermal stability, light emission. Thus, they can be coated to very large surfaces with the desired thickness by preparing only their solutions. It has been possible to produce organic light emitting devices, organic transistors and organic photovoltaic devices with polymer and molecular structures that can exhibit multi-functional properties with small changes in their structures [4-7]. Organic semiconductor devices which can completely replace the world of silicon-based electronic devices have received great attention in electronic device studies since they have features such as light weight, easy fabrication, large area coating and low cost [8-9]. OFET devices produced today are comparable to the load mobility values of traditional polycristalline silicon transistors, approaching values above 10 cm^2/Vs and 50 cm^2/Vs [10-12].

With the studies in the field of organic optoelectronics, Organic Light Emitting Device (OLED) and Organic Field Effect Transistor (OFET) are collected in a single device. As a Organic Light Emitting Field Effect Transistor (OLEFET), both charge transport and light emitting are possible in OLEFETs [13-15]. With OLEFET, it is possible to change the position of the emitted light thanks to the current modulation feature in the transistor, as shown in Figure 1. Due to these interesting features, OLEFETs have become a great test device for theoretical studies and technological applications. Basically, traditional OFET / OLEFET devices are planar and consist of source (S) / drain (D) electrode, gate electrode (G), insulator layer and organic semiconductor layer. They can also be called planar capacitors, one layer of which is an organic semiconductor plate and the other layer is a gate plate.

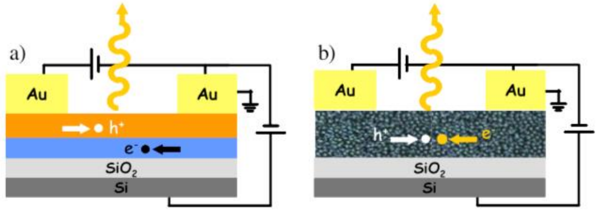

Fig. 1 Schematics of OLET devices based on the bi-layer heterojunction (a) and on the bulk heterojunction (b) [16].

In these planar transistors, the organic semiconductor layer is in contact with both the source and drain electrode and the gate is isolated from the dielectric layer and the gate electrode. The organic semiconductor consists of a Length (L) and Width (W) transistor channel, delimited by sorce and drain electrode. The current (I_{DS}) generated in this channel is modulated by gate bias (V_G). If the organic semiconductor light emitting polymer / molecule, the electron / holes injected from S and D electrons combine to form excitons in this layer. Excitons emit light radiatively by electroluminescence. In planar OFET / OLEFET devices, the current (I_{DS}) in the transistor channel always flows perpendicular to the electric field generated by the gate electrode in the dielectric layer. Many studies have been done on planar devices [17-20]. The large transistor channel, low current density and low operating voltage are a major disadvantage for planar devices. It is very difficult to reduce the channel size in these devices. For the first time, a vertical organic field effect transistor (VOFET) was reported in 2004 [21]. VOFET can be said to be one of the breakthrough developments in organic electronics. In vertical organic transistors, as shown in Figure 2, source electrode, active layer and drain electrode are stacked vertically. The organic semiconductor layers used in such a structure are generally anisotropic. For efficient current modulation with the gate electrode, the thickness of the active layer is also an important factor.

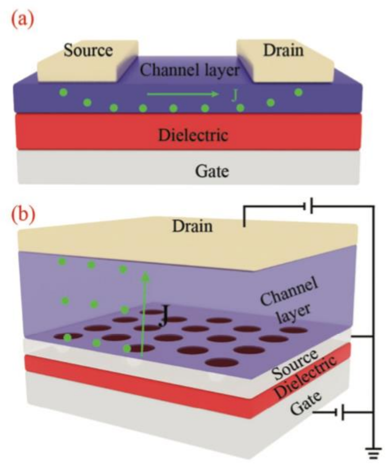

Fig. 2 Schematic illustrations of a) planar OFET structure and b) vertical OFET (VOFET) structure [22].

Nowadays, active matrix screen technology based on organic light emitting device, which replaces liquid crystal displays, is a good solution method for backplane problem and VFETs are used for low power consumption and high operating voltage. VOLEFET devices are the technology of the future, with integrated structure, multifunctional properties, where light modulation can be adjusted by current modulation, where exiton quencing is not seen near metallic electrodes (occurring in OLED pixels). In this study, an organic field effect transistor with low voltage vertical geometry was made by using PMMA insulating dielectric polymer and MDMO-PPV polymer which is a light emitting polymer.

II. Materials and Method

In this study, vertical organic light-emitting field effect transistors are constructed with source and drain electrodes metal; (Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene]), polymer and light emitting Poly[2-methoxy-5-(3′,7′-dimethyloctyloxy)-1,4 phenylenevinylene polymer were used for the light emitting layer. First, (Poly (3,4- Ethylenedioxythiophene): Poly (styrenesulphonate) which facilitates electron transfer by providing smooth interface of light emitting polymer with Indium-tin-oxide (ITO) layer having rough areas is coated on the ITO gate electrode. The (Polymethyl methacrylate) polymer coated as a dielectric layer is 200 nm thick. Source (100 nm) - drain (20 nm + 100 nm) electrodes were coated with aluminum vapor by thermal evaporation. The ratio of transistor channel width to length is the ratio W / L = 5000/200. In Figure 3, it is seen that the OLEFET device prepared with MDMO-PPV is produced in vertical geometry.

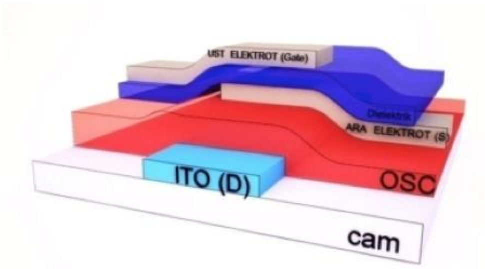

Fig. 3. Vertical Organic Field Effect Light Emitting Transistor prepared with ITO substrate and light emitting polymer [23].

A. Materials

Indium-tin-oxide (ITO) substrate is used as the gate electrode for the production of vertical OLEFET, aluminum (Al) metal is used for source and electrodes. Dielectric polymer PMMA (Polymethyl methacrylate), light emitting polymer MEH-PPV (Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene]), MDMO-PPV (Poly[2-methoxy-5-(3′,7′-dimethyloctyloxy)-1,4-phenylenevinylene]), hole injection PEDOT:PSS (Poly (3,4- Ethylenedioxythiophene): Poly (styrenesulphonate)). In the preparation of the solution, 1,2-dichlorobenzene (DCB) solvent and aqua regia solution were prepared for the cleaning step.

B. Preparation of ITO Gate Electrode

Firstly, the ITO coated glass is cut to the appropriate dimensions so that it can be placed in the areas of the masks used in the evaporation process. The surface is left to stand for 5 minutes in King Water solution for some etching purposes. The surfaces of the ITO parts are then etched to form a contact area. To do this, certain areas are painted with acid-free paint (nail polish) and allowed to dry. Drying substrates are left for 5-10 minutes in HCl for etching. After the etching process is completed, the ITO parts are washed with distilled water, free of acid. Samples are ultrasonic vibrated in an acetone-filled glass beaker to remove nail polish from ITO parts. Finally, a chemical cleaning method is used for the complete removal of impurities from the ITO surface using acetone, ethanol, methanol and isopraponol.

C. Preparation and Spin Coating Steps of Polymer Electrodes

PEDOT:PSS conductive polymer is covered with spin-coating at 3000 rpm in a glove box for 40 s. The solvent is evaporated at 120^0C for 40 minutes by heat treatment. A solution of MDMO-PPV and MEH-PPV polymers is prepared in 10 mg / ml DCB solvent. These solutions are mixed for 6 hours with the magnetic stirrer until they become homogenous, not to exceed 50°C. When the mixtures are ready, the glove box is removed and covered by rotating the coating for 40 s, annealing is performed at 120^0C for 15 minutes.

III. Results

ITO / PEDOT: PSS / MDMO-PPV / Al / PMMA / Al, the electrical characterization of the built-in device is shown in the Figure 4. The device polarity is as follows; the upper is the aluminium (Al) gate electrode, the common aluminum electrode in the middle is the source electrode and the bottom is PEDOT: PSS coated ITO drain electrode.

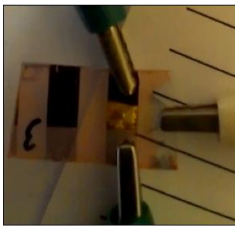

Fig. 4. It is seen that yellow-orange light emitting is emitted from VOLEFET.

ITO:PEDOT:PSS Al with the top gate electrode is negative bias with respect to the source contact in the middle. Gate current I_G and drain current I_D are negative biased. Gate negative bias. At the same time I_G is lower than I_D (FIGURE Y) and V_G can modulate the I_D. In such device polarization, the electric field generated by the gate electrode is parallel to the electric field generated by the drain. As shown in the Fig. 5, negative gate potential and I_D increase are observed. This structure increases the electron conduction in the MDMO:PPV semiconductor polymer with increasing electric field strength in the source-drain region.

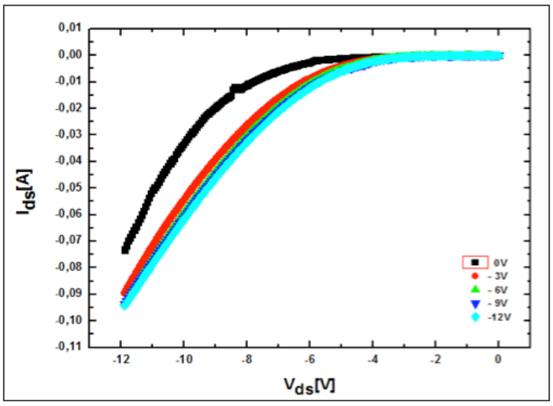

Fig. 5. Electrical output characteristic of the device in the common electrode structure, where the intermediate electrode is the source contact, in the range 0 <VG <-12 V.

The drain current, depending on the gate voltage values, is different from the planar structured FETs as shown in Fig.6. Because the increased V_G and the transconductance due to the gate voltage increase. Therefore, the charge transport within the MDMO-PPV leads to a space-charge limited current (I αV_2) linear dependence of the V_D ($\sqrt{I_D}$) at V_G = 0 for large V_D

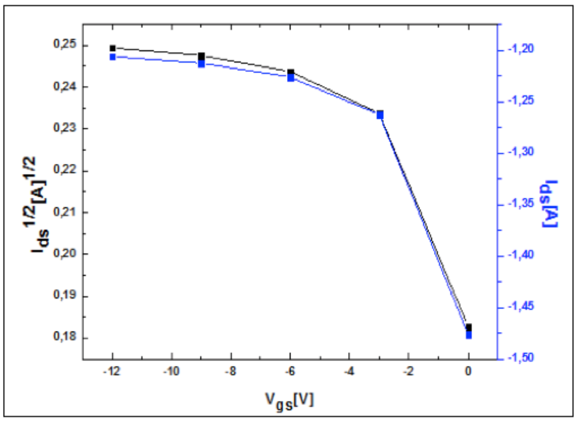

Fig. 6. Transfer graph of MDMO-PPV vertical organic field effect transistor. Plot of the $I_D(V_D)$ dependence, evidencing the space- charge limited current characterized by I α V^2.

In this device, the electric field generated by the gate increases the electric field generated by the drain, so that the source acts as a grid with effective electric field permeability. As described above, the current modulation of the device connected to the gate electrode is also seen in the characteristic electrical output graph. In addition, the vertical structure of the drain and gate electrodes and the electrons in the transistor channel parallel to the electric field formed by the electron-hole combination of excitons, radiative radiation and yellow-orange light emission was observed.

IV. CONCLUSION

Take this study as an inspiration Rossi at al study was used. Rossi et al. applied two types of polarization in the VOFET device and examined their electrical characteristics but did not use light emitting polymers [24]. .

In this study, a low-voltage organic light emitting field effect transistor is constructed using a similar polarizing structure but transparent ITO substrate for light emission with different insulator and semiconductor material. In this perpendicular geometry, the common aluminum electrode acts as a grid, allowing the electric field to pass. Thus, the IDS current modulated by the gate and the light emission from the device is provided.

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