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Vertical Type Organic Transistors for Flexible Opto-electric Devices

Kazuhiro Kudo

Department of Electrical and Electronic Engineering, Graduate School of Engineering, Chiba University
1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan
Phone: +81-043-290-3322 E-mail: kudo@faculty.chiba-u.jp

1. Introduction

Recently, field effect transistors (FETs) using organic materials [1-5] are promising in the future development for low-cost and large-area organic devices such as flexible displays, RF-ID tags, bio-sensors, etc. However, conventional organic FETs have a channel formed in the lateral direction and their performances are not sufficient for electronic devices. For practical applications of organic FETs, it is necessary to improve not only the electrical parameters of organic material itself but also the device structure.

In the application field, optoelectronic elements using organic materials show promise for low-cost, large-area and flexible devices. In particular, liquid crystal and OLED are expected to be used as display components of mobile electronic devices and excellent stability and high efficiency of OLEDs have been developed. On the other hand, organic transistors have seen great improvements in recent years and all-organic display devices are expected by combining the OLED with organic transistors. To be practical, however, it is necessary to operate with a drive voltage as low as a few volts and have sufficient reliability. Conventional FETs using organic materials have low-speed, low-power, and relatively high operational voltage. These low device performances are mainly due to their low-mobility and high-resistivity. The vertical type transistors, particularly SITs, are suitable for flexible displays and the basic SIT characteristics as a driving element for organic display devices were already reported [5,6]. From this point of view, organic light emitting transistors (OLET) combined with the organic SIT and OLED were proposed [6].

In this report, the basic characteristics of vertical type organic transistor and OLED are described.

2. Device Structures of Organic Transistors

Typical FET structures proposed in literature are shown schematically in Fig. 1. The lateral type FET (Fig. 1(a)) is proposed as a prototype of thin film transistor (TFT) and the current flows along the channel formed in the lateral direction. The lateral type FET using highly doped Si substrate which works as a gate electrode has a similar structure of metal-oxide-semiconductor (MOSFET) and the well established Si process is applicable. To fabricate a flexible FET, the substrate is replaced to plastic films (Fig. 1(b)). On the other hand, the current of the vertical type FET flows in the vertical direction. The device structure of vertical type FET is shown in Fig. 1 (c). In the vertical type FET, the channel length corresponds to the thickness of the organic semiconductor film and the excellent performances are reported [5]. The vertical type FET (Fig. 1(c)) proposed by Nishizawa is called as a static induction transistor (SIT) [7]. High-speed and high-power SITs have already been reported and some inorganic power switching devices with similar structures have been realized. It is known that SIT is a promising device because of the high-speed and high-power operation [5, 7]. Metal-insulator-semiconductor (MIS) type vertical FET as shown in Fig. 1(d) has also excellent characteristics similar to SIT [8]. Figure 1 (e) shows a layered structure FET. In particular, the FET consists of a charge-transfer-complex layer shows an ambipolar or metal-insulator transition characteristics [9]. Nano-transistors using single molecule or molecular wire (Fig. 1 (f)) are also reported [10].

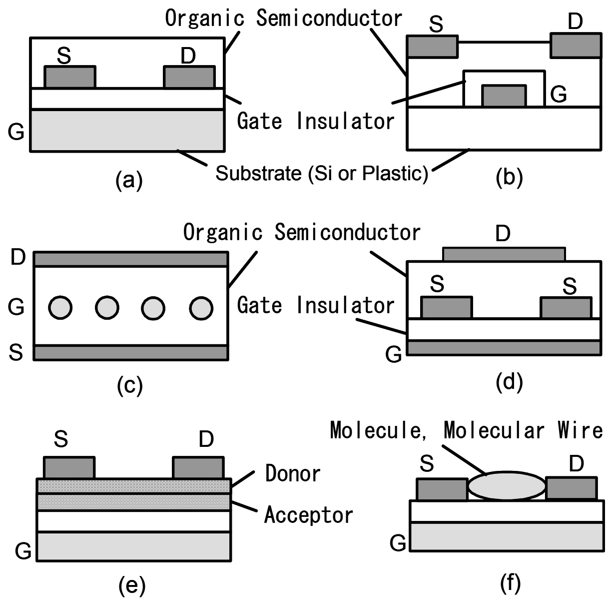

Fig. 1 Typical device structures of organic transistors.

3. Characteristics of OSIT

The vertical FETs operate as an SIT and the short length between the source, drain, and gate electrodes in the device structure improve the device characteristics. The high on/off ratio and high current value of the OSITs was achieved by inserting an ultra-thin CuPc layer between pentacene layer and ITO electrode. Figure 2 shows the static characteristics of OSITs with an ultra-thin CuPc layer. The experimental results demonstrate that the inserting ultra-thin CuPc layer works to improve the characteristics of OSITs by controlling the hole injection barrier at the interface between pentacene and ITO [11].

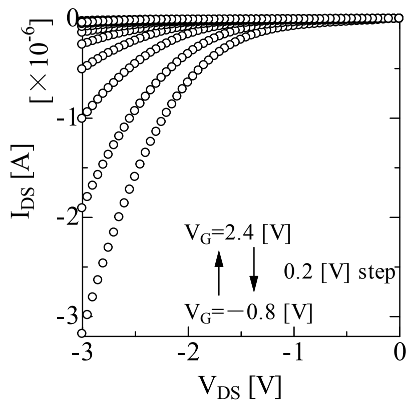

Fig. 2 SIT characteristics of with an ultra-thin CuPc layer.

4. Organic Light Emitting Transistors

Example devices of OLED and OLET combined with the SIT and OLED are shown schematically in Figs. 3 (a) and (b). The OLET has a simple structure similar to the OLED. All layers were fabricated on ITO coated glass substrate using vacuum evaporation technique at approximately 10^{-4} Pa. The OLET has a grid- type Al gate electrode in the hole transporting layers of α-NPD. The grid-type gate electrode was formed using a shadow evaporation mask. Line and space of the shadow mask are 24 and 18 µm. Typical thicknesses of the first and second α-NPD layers are 50 nm and 30 nm. In this case, Alq3 and Al were employed as an emitting layer and top electrode, respectively. The effective electrode area of OLED and OLET is approximately 4 mm^2.

Figure 4 shows the luminance - voltage (L-V) characteristics of the OLET. The drain - source current (I_{DS}) at a

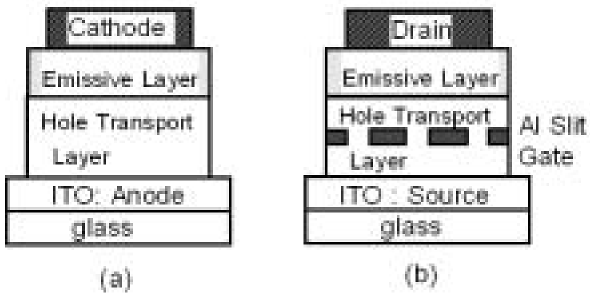

Fig. 3 Device strucutes of (a) OLED and (b) OLET.

constant drain - source voltage (V_{DS}) decreases with increasing the gate voltage (V_G). The current is controlled by relatively small V_G (1 V) and the luminance also varies corresponding to the I-V characteristics.

The luminance of OLET is controlled by gate voltages as low as 1 V and excellent dynamic operation is obtained at 60 Hz. Future developments of OLET operating with high power and high speed are expected by optimizing the device structure.

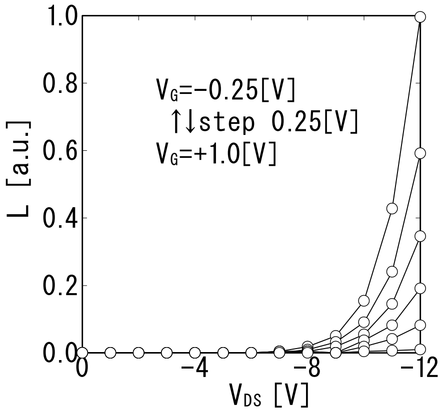

Figure 4 L-V_{DS} characteristics of OLET.

5. Conclusion

The basic characteristics of OSIT and OLET are investigated. Relatively high luminance modulation by low gate voltage was observed in the OLET by optimizing the gate electrode and layer thicknesses. These results demonstrate that the OLET described here is expected for application in all-organic display devices.

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