Organic Light Emitting Transistors for Flexible Displays

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Abstract
Organic light emitting transistors (OLET) which are vertically combined with the organic static induction transistor (OSIT) and organic light emitting diode (OLED) are fabricated and the device characteristics are investigated. High luminance modulations by relatively low gate voltages are obtained. In order to realize the flexible electronic circuits and displays, we have fabricated OSIT on plastic substrates. The OSIT fabricated on plastic substrate show almost same characteristics comparing with those of non-flexible OSIT on glass substrate. The OLET described here is a suitable element for flexible sheet displays.

1. Introduction
Recently high performance electric and optoelectronic devices based on organic semiconductors have been demonstrated, such as OLED, thin-film transistors (TFT), and solar cells. These organic devices show promise for low-cost, large-area and flexible devices. In particular, display panels using OLED are expected for mobile electronic devices and excellent stability and high efficiency OLED have been reported. On the other hand, rapid progress of organic transistors has been made in recent years [1]. Furthermore, all-organic display devices are expected by combining the OLED with organic transistors [2-4], because organic transistors driving OLED are necessary to achieve flexible and large scale active-matrix-displays. To be practical, however, it is necessary to operate with a drive voltage as low as a few volts and have sufficient reliability. Conventional field-effect transistors (FETs) using organic materials have low-speed, low-power, and relatively high operational voltage mainly due to their low-mobility and high-resistivity. It is known that static induction transistor (SIT) is suitable for a driving element of displays because of the high-speed and high-power of operation.[5-7] The excellent characteristics of the SIT arise from the vertical structure with a very short distance between the source, drain, and gate electrodes. From this point of view, the vertical type OLET combined with the O SIT and OLED are promising for flexible sheet displays [4-7].

This paper describes the device performances of OLET on glass substrate and OSIT fabricated on plastic substrates.

2. Experimental Details
The device structures of OSIT and OLET are shown schematically in Fig. 1 (a), and (b). These devices were fabricated on indium-tin-oxide (ITO) coated glass substrate or polyethylene naphthalate (PEN) substrate. All layers are formed using vacuum evaporation technique at approximately $2x10^{-4}$ Torr. During the evaporation, the substrate temperature was maintained at room temperature. The slit-type gate electrode was formed using a shadow evaporation mask [].Device processing of OSIT is as follows. First, the pentacene thin film of 100 nm was deposited on the flexible ITO substrate. Second, a very thin Al film of 30 nm was formed on the pentacene. Third, the Al film as a gate electrode was covered with the pentacene film of 100 nm. Finally, the drain Au electrode was fabricated on the pentacene. The source temperature of pentacene and evaporation rate were 200 ℃ and 0.1 nm/s, respectively. The gate electrode of OLET was inserted in the hole transporting layers of 4,4'-bis[N-(1-napthyl)-N-phenyl- amino] biphenyl (α-NPD). In this case, tris-(8-hydroxyquinoline) aluminum (Alq3) and Al were employed as a emitting layer and top electrode, respectively. Typical thicknesses of α-NPD and Alq3 layers are 100 and 50 nm. The effective electrode area

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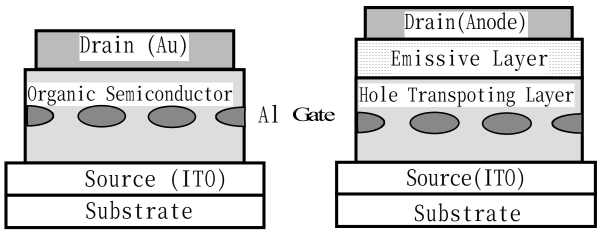
of OLET and OSIT is approximately 4 mm^2. The OLET can be fabricated by the same procedure as that of OLED in flexible displays by replacing the glass to plastic substrates. Device characteristics of pentacene SIT fabricated on glass and polyethylene naphthalate (PEN) were also examined. The electrical characteristics were measured using semiconductor parameter analyzer Agilent 4156C.



(a) OSIT (b) OLET

Fig.1 The device structures of (a) OSIT and (b) OLET.

3. Pentacene SIT

Figure 2 shows the photograph of OSIT fabricated on a flexible PEN substrate. It was found that the characteristics of the OSIT were greatly affected by a very thin Al film. The ideal Al gate electrode should be a mesh types [4-6]. In this experiment, the grid type gate electrode with line and space region was fabricated by using the evaporation mask. The thicker Al part of the grid gate blocks the current flow from the source to the drain electrode, due to the formation of double Schottky barriers, and the wider gap region of the gate electrode also does not control the current flow effectively [4-7]. In this case, the estimated the gap between gate electrodes was approximately 1 μm.

The static characteristic of the pentacene SIT consists of the structure with Au/pentacene/Al/ pentacene/ITO as shown in Fig.3. The drain-source current (I_{DS}) at constant drain-source voltage (V_{DS}) decreases with increasing the gate voltage (V_G). This phenomena show that the majority carriers of hole in the pentacene flow from the source to drain and are controlled by the gate voltage (V_G) applied to the Al Schottky gate electrode. In this case I_{DS} is restricted by spreading the depletion layer around the Al Schottky gate electrode under positive V_G.

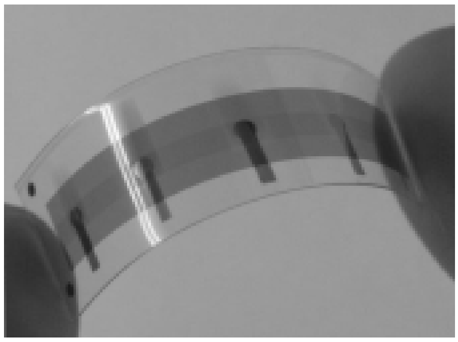


Fig. 2 Photograph of OSIT fabricated on a flexible PEN substrate.

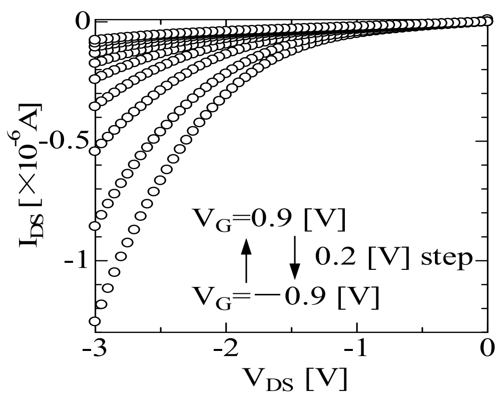


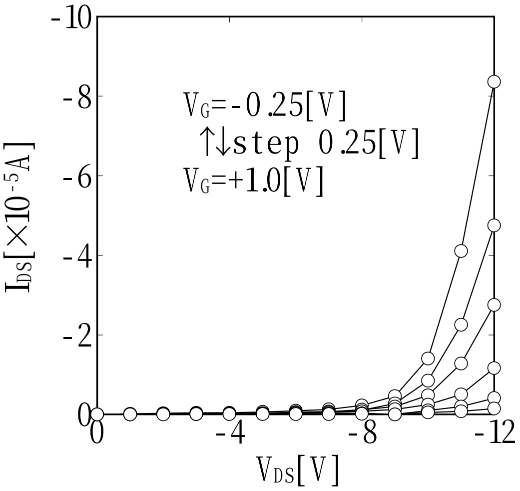
Fig. 3 Static characteristic of the pentacene SIT consists of the structure with Au/pentacene/Al/ pentacene/ITO.

The slope of the I_{DS}-V_{DS} curves increases with increasing V_{DS} without current saturation and of I_{DS} is a typical characteristic of an inorganic SIT [8]. The current unsaturation of the pentacene SIT is considered to be mainly due to the principal operating mechanism of the conventional SIT.

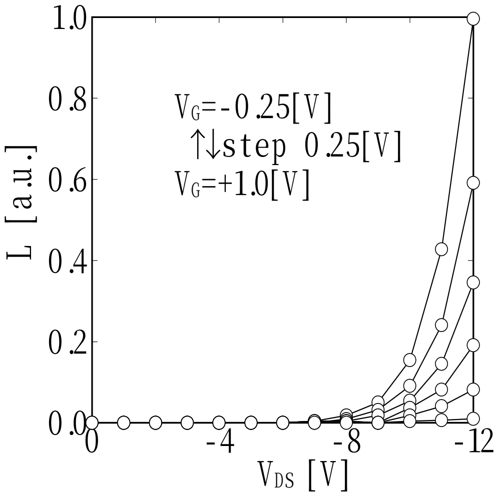
For comparison, pentacene SIT was fabricated on ITO / glass substrate. It was found that the characteristics of the flexible pentace SIT provided comparable results of that of the non-flexible pentacene SIT. From these results, we succeed in fabricating the flexible pentacene SIT. The variation of SIT characteristics is negligible less than 5 % in I_{DS} when a flexible SIT is bended to the radius of 10 mm.

4. OLET

The current – voltage (I-V) and luminance - voltage (L-V) characteristics of the OLET are shown in Fig. 4 (a) and (b). The I_{DS} is controlled by relatively low gate voltages and typical SIT characteristics are observed in the OLET. The luminance intensity L also varies corresponding the I-V characteristics. The luminance on-off ratio of approximately 100 with relatively small V_G (-0.25-+1V) was obtained.



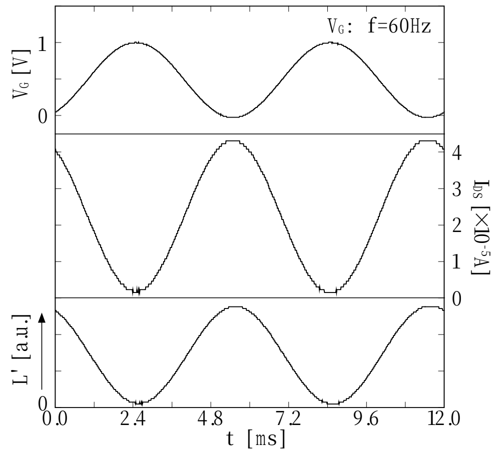
(a)



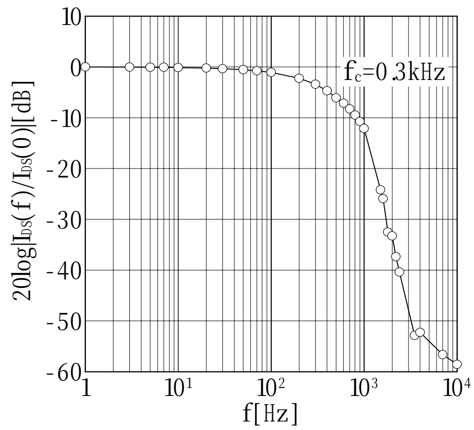
(b)

Dynamic operations of the OLET are shown in Fig. 5 (a), (b). Luminance intensity L' measured by silicon photodiode. The peak-peak value of V_G and V_{DS} were 0-1.0 V and –12 V, respectively. For the application to displays, 60 flames/s is necessary. No phase shift and same L value as the static state (f=0 Hz) were obtained at V_G modulation of 60 Hz (Fig. 5 (a)). Fig. 5 (b) shows dynamic characteristic of the OLET as a function of V_G. frequency. The cut-off frequency fc at 3 dB down from the static state was approximately 300 Hz. The maximum luminance value of approximately 10,000 cd/m^2 at 10 mA was obtained by optimizing the electrode structure and organic materials.

The results obtained here demonstrate that the OLET is a suitable element for flexible sheet displays.



(a)



(b)

Fig. 5 Dynamic operation of the OLET.

5. Conclusions

We have investigated the basic characteristics of OLET and discussed their device structures and device performances. Relatively high luminance modulation by low gate voltage was observed in the OLET by optimizing the gate electrode and layer thickness. These results demonstrate that the OLET described here is expected for application to all-organic display devices. It was found that the characteristics of the flexible pentacene SIT provided comparable results of that of the non-flexible pentacene SIT

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7. References

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