Self-Alignment Technologies of Organic Electronic Devices and Its Integrated Panels

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Self-alignment (SA) technologies and multiple integration of organic electronic devices are introduced. For obtaining higher device performance, self-alignment technology is effective. For example, SA organic field effect transistor (OFET) can be realized using back surface exposure for gate electrode as a mask and lift-off technique for formation of source/drain regions. Another self-alignment technology under study is formation of emission region in organic light emitting diode (OLED) using ink-jet printing (UP) technique, where ink jet printed dot becomes emission region. In the case of multiple integration technology, face-to-face emission panel named “Dual Drive & Emission Panel (DDE)” with stacked two set OLED with common scan line and two set of data lines and combination of emission and photo detection named “Bi-Function Matrix Panel (Bi-Matrix)” with stacked OLED and organic photodiode (OPD) can be realized. These approaches will be expected for novel application.

Keywords: self-alignment, organic transistor, organic light emitting diode, organic photodiode

1. Introduction

Many research studies on organic electronic devices have merits of potentiality of large area device panel, ultra-light weight and flexible have been actively carried out. These merits are advantageous for next-generation flat-panel displays. For crystal semiconductor devices, self-alignment technology has been widely used to improve the device performance. Definition of the self-alignment technology is the technology that position of the second pattern is automatically determined by the first pattern. Well-known example of the SA technology is diffusion process of source/drain for metal-oxide semiconductor (MOS) transistor, where gate electrode is used as the first pattern. Multi layered organic devices with high performance have been also reported, such as multi photon emission devices,1) tandem organic solar cells,2) and stacked two terminal device with OLED and OPD.3,4) Above mentioned backgrounds, we have investigated self-alignment technologies of OFET and OLED and multiple integration of organic electronic devices.

2. Variety of Device Technologies

2-1 Self-aligned Organic Field Effect Transistor

From the practical standpoint, there are many research subjects, such as the improvement of the short-channel effect, mobility, mutual conductance and long-term stability, as well as the establishment of a patterning technique. For reducing parasitic capacitance, SA technique is one of the most essential technologies. In this
gate Ta (500 Å)
Pentacene (1000 Å)
Glass substrate
Insulator Al2O3 (2000 Å)
Ohmic metal Cr(100 Å) Au (500 Å)

Fig. 1 Cross-sectional view of organic self-aligned FET.
time, we have fabricated a self-aligned OFET using the back surface exposure method and have evaluated its operational characteristics.

Figure 1 shows a cross-sectional view of the self-aligned organic FET. Fabrication process is as follows. First, gate electrode was sputtered on the glass substrate and was patterned by dry etching. Next, the gate insulator was formed and contact holes were made. Back surface exposure was then carried out, where the gate electrode was used as the photomask. The ohmic electrode was evaporated and the lift-off process was carried out. Furthermore, the ohmic electrode was etched off. Finally, the pentacene was evaporated.

Figure 2 shows drain current (I_D) versus drain voltage (V_D) characteristics. Excellent field-effect operation was obtained. Inset view shows an upper view of an optical micrograph for the obtained self-aligned transistor. The

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self-aligned source and drain electrodes to the gate electrode were observed, where the overlapping length of the gate–source and gate–drain electrodes was 0.8 μm. The evaluated series resistance per channel width was 1.68 MΩ/mm. The maximum field-effect mobility obtained was 0.12 cm²/Vs, and mutual conductance $g_m$ was 1.8 mS. The on-off ratio was $10^5$, threshold voltage $V_T$ was -1.0 V, and subthreshold slope $S$ was 0.5 V/decade. To estimate high-frequency characteristics, gate capacitance ($C_G$) characteristics were measured. The cutoff frequency $f_T$ is expressed as $g_m/2\pi C_G$. From a capacitance measurement at accumulation condition, the maximum gate capacitance was 1.58 pF. By using this value and the mutual conductance $g_m$, the cutoff frequency was estimated to be 0.18 MHz.

2-2 Self-aligned Bank Formation of OLED Using IJP Method

For fabricating OLEDs using the IJP method, bank formation is commonly used to prevent shorting of the device. The IJP method requires bank formation and entails a high cost and difficulty in precise alignment control. Therefore, a new fabrication process not beset by these problems is desired. In this time, we investigate the self-aligned bank formation of organic electroluminescent devices using the ink-jet printing method, in which an insulating material is formed and a mixture of organic materials mixed with host and emission materials is ink-jet-printed on a substrate, where these ink-jet-printed regions become emission regions.

Figure 3 shows process steps of self-aligned OLED. An insulating film was formed on an anode of an indium-tin oxide (ITO)-coated glass substrate. It was necessary for this insulating material to be soluble in an organic solvent and to exhibit good insulating characteristics. Then, the solution dissolved with organic host and emission materials was ink-jet-printed. Here, the insulating layer was dissolved in the solvent and an emission layer was formed alternately, that is, self-aligned OLED fabrication was carried out. Finally, a cathode layer was evaporated onto the organic layer. The merits of the self-aligned fabrication process are as follows: First, the fabrication process is simple. Using this self-aligned process, the lithographic process of bank formation becomes unnecessary. Second, an arbitrary pattern formation without constraint is possible. This may be advantageous for high-resolution and large-area emission poster displays.

Poly(methyl methacrylate) (PMMA) was used as an insulating material. For ink-jet printed materials, small molecules of the host material 4,4′-bis(N-carbazolyl)biphenyl (CBP) with bipolar carrier transport characteristics and the green emission phosphorescent material fac tris(2-phenylpyridine)iridium [Ir(ppy)$_3$] were used. The mixing ratio of organic materials was CBP:Ir(ppy)$_3$ = 100:5. The description of the ink-jet printing apparatus (Brother Industries Ltd.) is as follows: ink-jet head ceramics; piezodriving; and resolution, 150 dots per inch. Finally, a hole-blocking layer of bathocuprine (20 nm) and a stacking layer of cathode Cs (1 nm)/Al (100 nm) were evaporated.

The maximum luminance of the self-aligned device obtained was 8,800 cd/m² ($J=100$ mA/cm²). The maximum emission pattern of self-aligned TE-OLED with 300 ppi resolution.
power, EL, and external quantum efficiency of the self-aligned device were 3.4 lm/W (J=36 mA/cm²), 10.8 cd/A (J=54 mA/cm²), and 3.1 % (J=54 mA/cm²), respectively. Top emission device was also fabricated. Device structure was Glass/ AlNd (50 nm)/BAq (50 nm)/ emission layer/ α-NPD (50 nm)/MoO₃ (30 nm)/ IZO. Maximum luminance obtained was 1,000cd/m². Using this top emission device fabrication technique, we have demonstrated prototype display panel. The panel size was 30x30mm² and the panel resolution was 300 ppi. Figure 4 shows an example of pattern emission at luminance of 100 cd/m². Clear emission of pattern was achieved.

2.3 Dual-Drive and -Emission Panel

One of interesting topics is transparent OLED emitted double sided. Many matrix panels have been demonstrated. However, display image showed flip horizontal and is limited for few applications. In this time, we have demonstrated newly proposed device structure of “Dual-Drive & -Emission (DDE) panel”.

Figure 5 shows concept of the dual-drive & -emission (DDE) panel under study. In this device, two OLED structures are stacked on the both sides of intermediate electrode with reflective characteristics. This intermediate electrode acts as common scan line of the double-sided matrix panel. Independent image can be displayed by applying in dependent data signal to each transparent electrode.

In order to realize the DDE panel, device performance of upper OLED, i.e., top emitting device, have to be improved. Three points are considered as follows: (a) Improvement of surface morphology using AlNd (Kobe pelco Research Institute) as intermediate cathode, (b) Inverted structure of top emitting OLED is selected for upper OLED. (c) For satisfying low resistivity, small damage, and highly stable, we selected sputtered indium-zinc-oxide (IZO, Idemitsu Kosan). (d) For improving an electron injection characteristics, additional organic layer of 2,5-bis(6′-(2′-2′-bipyridyl))1,1-dimethyl-3,4-diphenylsilole (PyPySPyPy, Chisso) was evaporated on the intermediate electrode. (e) In order to reduce sputtering damage, we added buffer layer of an oxide semiconductor MoO₃. Device structure of the optimized DDE panel is as follows. Lower device structure was ITO/ α-NPD (50 nm)/ Alq₃ (50 nm)/ ErF₃ (0.5 nm)/ AlNd. Upper device structure was AlNd/ PyPyPyPy (20 nm)/ Alq₃+DCM (100:1) (30 nm)/ α-NPD (50 nm)/ MoO₃ (50 nm)/ IZO (200 nm). In both devices, the symmetric characteristics were obtained and the luminances exceeded over 4,000 cd/m².

Figure 6 shows emission pattern of the DDE panel. Applied voltages of upper and lower devices are 7.5 and 5.0 V, respectively. This photograph shows a dual emission image, where mirror was placed behind the DDE panel. It is obvious that clear image was observed at both sides of the DDE panel.

2.4 Bi-function Matrix Array

Research on an organic electroluminescent device (OLED) combined with an organic photo detector has been reported. We propose and demonstrate the “Bi-function matrix array (Bi-Matrix)” with a stacked layer of OLED and OPD matrix arrays, i.e., a matrix panel of the OLED display with the function of a scanner.

In order to demonstrate the operation of the Bi-Matrix, the following device structure was fabricated on a glass substrate: indium tin oxide (ITO)/copper phthalocyanine (CuPc) (5 nm)/ 4,4′-bis [N-(1-naphthyl)-N-phenyl-amino]biphenyl (α-NPD) (50 nm)/ tris-(8-hydroxyquinoline) aluminum (Alq₃) (50 nm)/CuPc (5 nm) / sputtered indium zinc oxide (IZO, 150 nm, Idemitsu Kosan)/ N,N′-bis(3-methylphenyl)-(1,1′-biphenyl) 4,4′-diamine (TPD) (50 nm)/ N,N′-ditridecylyl-3,4,9,10-perylene-tetracarboxylic diimide (td-PTC) (50 nm)/Al.
Fig. 7 Full (a) and check (b) emission patterns of the OLEDs.

Fig. 8 Measurement system of Bi-Matrix operation (a) and observed current values (b).

In order to demonstrate the device operation, the prototype device of a 4x4 Bi-Matrix was fabricated. Figures 7(a) and 7(b) show full and checked emission patterns of the OLEDs. It is obvious that clear emission is obtained. The basic OPD mode operation is similar to that described by Yu and Cao. Figure 8 shows (a) the measurement system of Bi-Matrix operation and (b) the observed current values. In Fig. 8(b), numeric values indicate the observed current at the selected point. A clear checked on and off currents was observed.

3. Future prospects

We have investigated self-alignment technologies and multiple integration of organic electronic devices. We have also been investigating vertical type FET, as shown in Fig. 9, direct patterning technique of organic layer using excimer laser, nano-imprinting technique and spray coating technique of organic layer. By integrating these technologies, application of novel organic electronic devices with new features will be developed.

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Fig. 9 Cross-sectional view of vertical type organic field-effect transistor feasible for device integration.

References