Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 600-601

P-10-1

The current gain improvement of organic base modulation triodes

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1. Introduction

The organic thin-film transistors (OTFTs), with low cost, simple process, mechanical flexibility and large area coverage, have attracted a great deal of attention from academic and industrial researchers.[1-4] The most research groups are interested in the planar-type OTFTs. The architecture of the planar-type OTFTs has adopted inorganic metal-oxide-semiconductor filed-effect transistors, where the carriers transport from source to drain on the lateral direction. However, the low carrier mobility and the structure limited of planar-type OTFTs, resulting in high operation voltage and slow operation speed. In order to improve the device performance, the vertical-type transistor has to be adopted because of its superior short channel length, which depends on the thickness of the active layer. Although the vertical-type OTFTs have the advantages of the lower operation voltage and higher output current, they lock of apparent saturation region and low current gain, which still limits the development of them in low-power and high-frequency electronic applications.

In this letter, we have demonstrated the organic base modulation triodes (OBMTs) which are operated under apparent saturation region by using two back-to-back Schottky diodes.[5-7] With the optimization of the collector-base (CB) diode thickness, it can decrease off current and further enhance current gain. Therefore, the current gain can reach up to 10 while the base-emitter current density (J_{BE}) is applied for -0.5 mA/cm^2 at V_{CE} = -7 V.

2. Experimental

The figure 1 shows the schematic structure of OBMT. Prior to device fabrication, the substrates were pre-cleaned by using detergent, acetone, isopropylalcohol and treated with an ultraviolet (UV) ozone cleaner for 15 min. The 30 nm Au layer as the collector electrode was deposited on the glass substrate. The CB diode is composed of the copper phthalocyanine (CuPc) layer and the pentacene layer. The CB diode thickness of 320 nm maintains constant value as varying the CuPc thickness and the pentacene thickness. The pentacene layer was thermally evaporated at rate of 0.1 nm/sec and the 30 nm thick Al layer as the base electrode was thermally evaporated on the pentacene layer. The thin Al layer of 2.5 nm was deposited as the base layer and the LiF layer of 0.4 nm was thermally evaporated as the carrier injection enhancement layer. Then, the 20 nm thick NPB layer and the 140 nm thick pentance layer was thermally evaporated at the rate of 0.1 nm/sec as the emitter layer. Finally, the 30 nm thick Au layer was thermally evaporated on the pentacene layer as the emitter electrode. All organic materials and metal electrodes were deposited in a thermal evaporation chamber at a base pressure of 10^{-6} torr and pattern by the metal mask. The active area is 4.0×10^{-3} cm^2, which is defined as the intersection of top and bottom electrodes. The current-voltage (I-V) characteristics of the devices were measured by HP 4145B semiconductor parameter analyzer. All the electrical characteristic of these devices are measured in darkness under atmospheric environments.

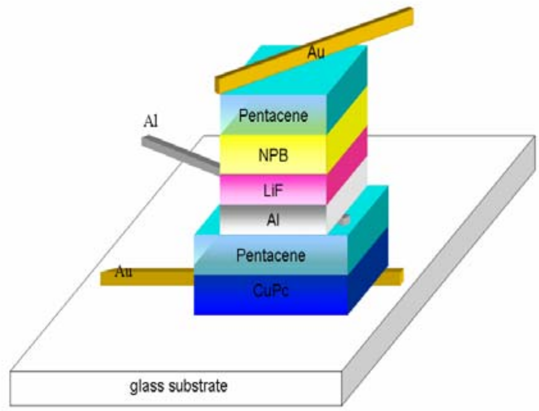

Fig. 1 the structure of the OBMT fabricated on the glass substrate.

3. Result and Discussion

The figure 2(a) shows the collector-emitter current density (J_{CE}) v.s collector-base voltage (V_{CE}) at the base-emitter current density (J_{BE}) from 0 to -2.5 mA/cm^2 while the CuPc thickness / CB diode thickness ratio is 0.5 and the figure 2(b) shows the current gains (β) of the devices with different CuPc thickness / CB diode thickness ratio. The current gain β is defined as the following equation:

$$\beta = \frac{J_{CE} - J_{CE}(J_{BE} = 0)}{J_{BE}} \qquad (1)$$

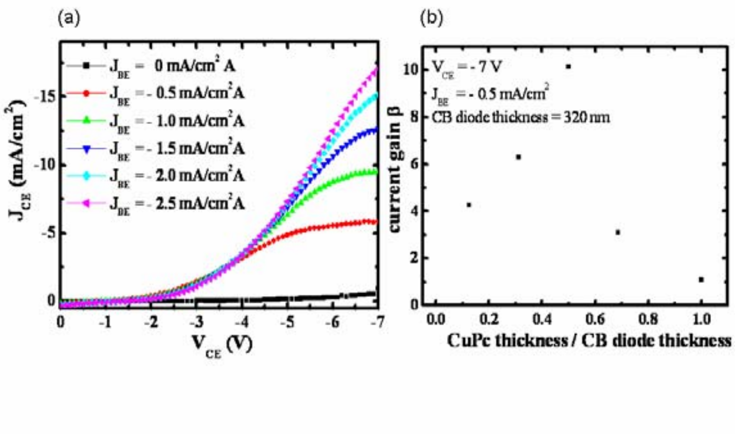

Fig. 2 (a) the collector-emitter current density ($J_{CE)}$ v.s collector-base voltage (V_{CE}) at the base-emitter current density from 0 to -2.5 mA/cm2 while the CuPc thickness / CB diode thickness ratio is 0.5 (b) the current gain as a function of CuPc thickness / CB diode thickness

The J_{CE} is the collector-emitter current density and the J_{BE} is the base-emitter current density. As the equation (1) and figure 2(a) shown, the current gain is 10 at J_{BE} = -0.5 mA/cm^2 while the V_{CE} is applied for -7 V. Base on the equation (1), it is known that the current gain will increase with the decrease of the collector-emitter current density at J_{BE}= 0. The collector-emitter current density at J_{BE} = 0 is the off current density. Compare to the mobility of the CuPc and pentacene, the materials of CuPc has lower mobility than pentacene. Therefore, while the CuPc thickness is thicker, the off current density can become lower. However, as the figure 2 shown, the maximum current gain is 10 while the CuPc thickness / CB diode thickness is 0.5 at V_{CE} = -7 V and JBE = -0.5 mA/cm^2. Although the off current density is lowest as the CuPc thickness / CB diode thickness is 1, the JCE also becomes lower. This could be explained by the atomic force microscopy (AFM) images of 2.5 nm Al films deposited on on the CuPc thickness / CB diode thickness of 0.125 and 1, as shown in figure 3(a) and 3(b). The root-mean-square (rms) of the figure 3(a) and 3(b) are 13.3 nm and 8.5 nm, respectively. While the CuPc thickness becomes thicker and thinner, the surface morphology of CB diode becomes more rough and more smooth, resulting in creating less opening voids. Due to the ON current is attributed to the part of induced current from the BE diode flows through the opening voids; therefore, the opening voids in the thin Al films played a considerable role for ON current. [7] With less opening voids to modulate current from emitter to collector, the most current will conduct through base electrode instead of diffusing into collector layer. The current which conducts through the base electrode is leakage current and it decreases output current density. Based on those, we believe that maximum opening voids with suitable dimension are happened in CuPc thickness/ CB didoe

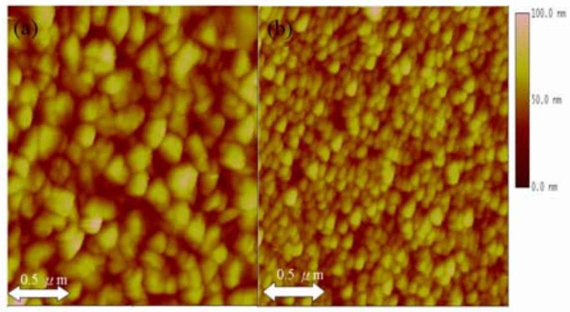

Fig. 3 the AFM images of 2.5 nm Al layer deposited on the CuPc thickness / CB diode thickness ratio of (a) 0.125 and (b) 1

thickness of 0.5 and therefore the ON current has a maximum value happened at same thickness ratio.

4. Conclusions

In summary, we improved the current gain of organic base modulation triodes by altering the CuPc and pentacene at CB diode. The output current density is depended on the number of the opening void. While the CuPc thickness / CB diode thickness is 0.5, the OBMT exhibited a high output current density of -5.82 mA/cm^2 at V_{CE} = -7 V and J_{BE} = -0.5 mA/cm^2 and a high current gain of 10 at low voltage.

Acknowledgements

The authors are grateful to the National Science Council (NSC), Taiwan (95-2218-E-001-003), (96-2628-E-007-030-MY2), and Academia Sinica for financial support.

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