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Full-swing pentacene organic inverter with long-channel driver and short-channel load

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1. Introduction

As the complex organic circuits have been demonstrated [1], the simplicity of the circuit and noise immunity becomes important. In a previous research, a full-swing pentacene organic inverter scheme (Fig. 1) that is composed of only two OTFTs (organic thin-film transistors), i.e. an enhancement-mode driver and a depletion-mode load, was proposed [2]. The proposed inverter shows high gain and large noise margin with a simple circuit structure. However, the integration of two different mode OTFTs in a same substrate is difficult in that study, because the selective deposition of the PMMA for the enhancement-mode devices is hard to be realized. In this paper, it is demonstrated that the full-swing organic inverter suitable for integration can be easily implemented by combining the two OTFTs with different channel length using the "short channel effect."

2. Device fabrication and electrical characteristic

Bottom-contact OTFTs with various device dimensions are fabricated on the same Si/SiO_2 substrate. The device structure is illustrated in Fig. 2. A Ti gate is patterned by the photolithography and wet etch process. The hybrid insulator structure with PECVD oxide and cross-linked poly-(vinyl alcohol) (PVA) is adopted to reduce the hysteresis problem. The insulator layer is defined using photolithography and dry etch. The Au source/drain layer is patterned by the conventional photolithography and lift-off process. Finally, the pentacene is thermally evaporated without further purification through an aligned shadow mask at the high vacuum ambient of about 10^{-8} Torr. The electrical characteristic is measured in the atmosphere without passivation using a HP4156C semiconductor parameter analyzer.

Fig. 3 depicts the typical transfer curves of the fabricated OTFTs with the channel length (L) of 5 and 30 μm. The curve of the 5 ㎛channel length is positively shifted comparing with that of the 30 ㎛device. Fig. 4 clearly shows the tendency, although there is a little hysteresis effect. As the channel length becomes shorter, the switch-on voltage [3] is increased to the positive direction and the drain current (I_{DS}) at the zero gate voltage (V_{GS}) is increased. This phenomenon is reproducible and the similar feature is observed in other works [4]. The trend is presumably related to the short channel effect that is similar to the threshold voltage roll-off of n-channel MOSFET [5]. Because the long channel OTFTs are close to the enhancement-mode and short channel OTFTs are close to the depletion-mode, a full-swing inverter in Fig. 1 can be implemented by using a long channel OTFT as an enhancement-mode driver and a short channel OTFT as a depletion-mode load.

3. Full-swing organic inverter

The OTFT with the channel length of 3 ㎛, which is the shortest channel length of the fabricated devices, is selected as a depletion-mode load and the long channel OTFTs are used as the enhancement-mode driver. The width (W) of the load OTFT is fixed to the largest one of 300 ㎛, to be the closest to the depletion-mode devices. The organic inverter is completed by wiring the two different OTFTs on the same substrate. At first, the long channel OTFTs with 30 ㎛ channel length (L_{driver}) and various channel width (W_{driver}) are selected as the driver OTFTs. The measured voltage transfer curves (VTCs) of the pentacene organic inverters are depicted in Fig. 5. Although there is a little hysteresis, the effect is negligible. As expected, the curves show the full-swing characteristic that the minimum output voltage (V_{OUT}) falls to about 0 V when the input voltage (V_{IN}) is high. Furthermore, it is clearly observed that the curves are shifted to the left side, and that the maximum inverting gain decreases, and that the maximum V_{OUT} decreases, as W_{driver} is decreased. This is because the pull-down ability of load OTFTs becomes comparatively stronger as the W_{driver} decreases, and it is easily understood by using the load line diagram [2], [6]. From the viewpoint of the noise margin, the optimized VTC will be obtained by using the load OTFT with the width of around 50 ㎛. When W_{driver} is equal to 50 ㎛, the maximum inverting gain is about 5.1~5.5. For the driver OTFTs with W_{driver} of 10 ㎛, the result is similar, as shown in Fig. 6. In Fig. 7, the shape of the VTC becomes worse as the L_{driver} gets shorter. Therefore, it will be necessary to make W_{driver} reduced or to make the load width increased for more optimized noise margin characteristic.

4. Conclusions

It is shown that the full-swing pentacene organic inverter is possible by using the long channel OTFT as an enhancement-mode driver and the short channel OTFT as a depletion-mode load. The VTC characteristics of the pentacene inverter can be optimized by the suitable adjustment of the driver and load sizes. Therefore, the integrated full-swing pentacene organic logic circuits will be possible.

Acknowledgements

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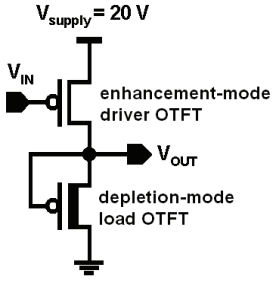

Fig. 1. Schematic diagram of the full-swing organic inverter

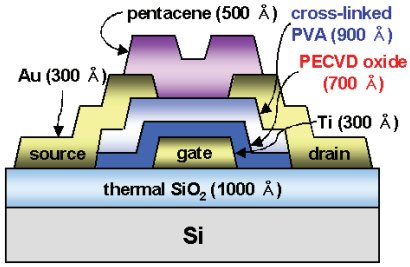

Fig. 2. Device structure of the fabricated bottom-contact OTFTs

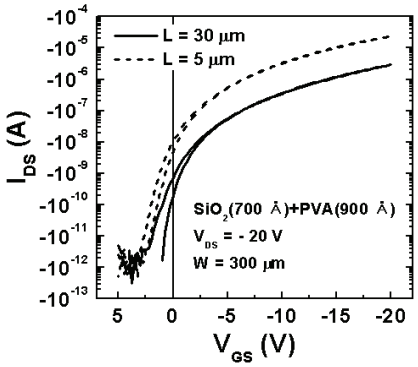

Fig. 3. Typical transfer curves of the fabricated OTFTs with the channel length of 5 and 30 ㎛

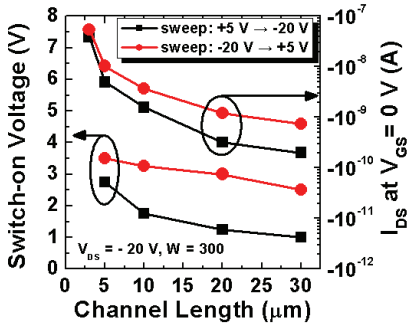

Fig. 4. Switch-on voltage and drain current at zero gate voltage with various channel length

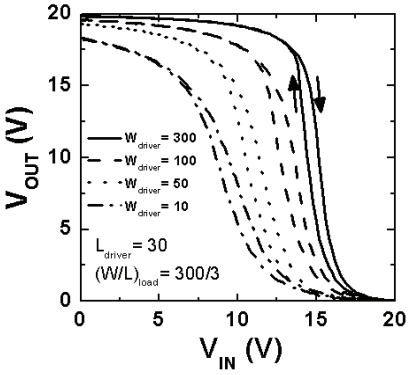

Fig. 5. Voltage transfer curves with the driver width when the channel length of the driver is fixed to 30 ㎛

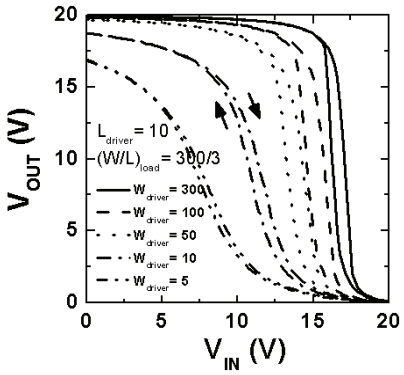

Fig. 6. Voltage transfer curves with various driver width when the driver length is fixed to 10 ㎛

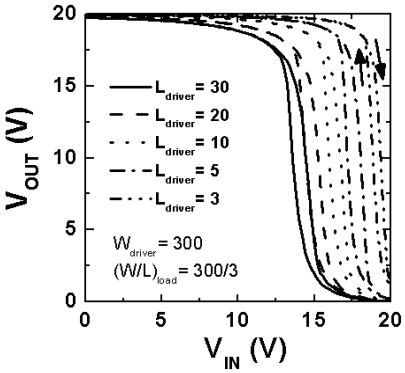

Fig. 7. Voltage transfer curves with various driver length when the driver width is fixed to 300 ㎛