Organic Integrated Circuits based on Pentacene TFTs

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Abstract
The integrated circuits such as inverters, ring oscillators, NAND and NOR gates, and rectifiers were fabricated on PEN substrate by using pentacene TFTs. The OTFTs used bottom contact structure and produced the average mobility of 0.26 $cm^2/V.sec$ and on/off current ratio of 10^5. All circuits worked successfully like the simulation results. Especially, the rectifier was able to operate up to 1 MHz input signals, and ring oscillator exhibited oscillation frequency of 1MHz at -40V.

1. Introduction

Organic thin film transistors (OTFT) and integrated circuits are attracting much attention because of their potential applications in flexible displays, smart cards and low cost RFID tags[1-3]. A key advantage of organic TFTs over transistors based on inorganic semiconductors is the reduced thermal budget during device processing, which often allows the use of light-weight, flexible polymeric substrates. Recently OTFT based circuits research focused in low cost RFID tags. And several groups have been demonstrated OTFT based circuits such as inverters, oscillators, and even full tags working at 13.56MHz[4-7].

Therefore, the most challenging application for OTFT is in integrated circuits. However, the goal, fast organic circuits needs more times to be achieved because the fast circuits operating speed requires more improvements in materials, device structure, fabrication process, and circuit design.

In this paper we fabricated the key integrated circuits based on pentacene TFTs such as inverters, ring oscillators, NAND and NOR gates, and rectifiers. All circuits worked by exhibiting fundamental characteristics but we figured out the limitations and also suggested the solutions.

2. Experimental

We developed a SPICE model of Pentacene Thin Film Transistor using HP a-TFT model of HSPICE level 40. The SPICE model of Pentacene TFT was made of parameter modulation, such as mobility modulation, conductance of TFT leakage current and drain voltage effect for leakage current. The model was verified by the measured I-V characteristics of Pentacene TFT. And then we design and simulated OTFT based inverter, NAND and NOR gate, ring oscillator, rectifier.

We fabricated OTFTs and circuits on 200μm thick 5 cm x 5 cm sized PEN substrate. The OTFTs employed bottom gate bottom contact structure(Fig. 1). First, we deposited 40nm thick aluminum (Al) film by thermal evaporation and patterned by photolithography and wet etching to define the gate electrodes. Subsequently, the cross-linked poly-4-vinylphenol (PVP) spin coated for gate dielectric layer. And the PVP layer is patterned by oxygen plasma etching for via hole. To define the source and drain contacts, 45nm gold are deposited by evaporation and patterned by photolithography and wet etching. Finally 40nm pentacene is deposited by thermal evaporation for active layer. Fig. 2 shows photograph of our organic integrated circuits.

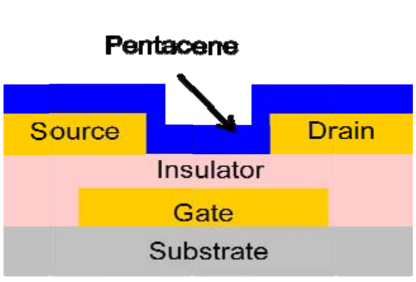

Fig. 1. Experimental OTFT structure.

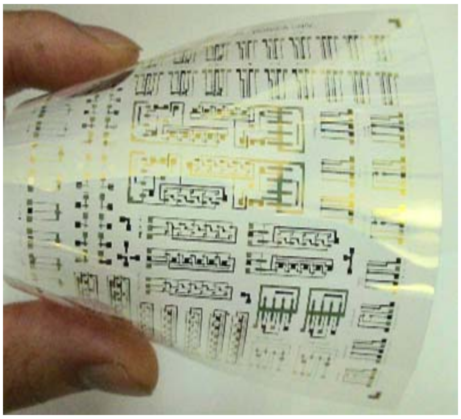

Fig. 2. Photograph of plastic organic circuits.

3. Results and discussion

All devices and circuits were characterized in ambient air. The OTFTs produced the average mobility of 0.26cm^2/V-sec, on/off current ratio of 10^5, subthreshold slope 0.8V/dec, off-state currnet of 0.1 pA/um.

According to simulation results the various inverters with the channel length of 5 um and 20 um and β of 1:1, 4:1, 8:1 were fabricated, and the gain of about 15 (Fig. 3).

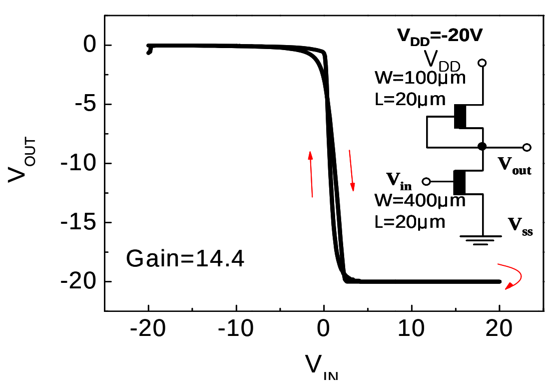

Fig. 3. Characteristics of inverter

We connected an OTFT to inverter with serial and parallel structure to made 2 input terminal NAND and NOR gate. And Fig. 4 shows the NAND and NOR gates also successfully worked at the operating voltage of 5V.

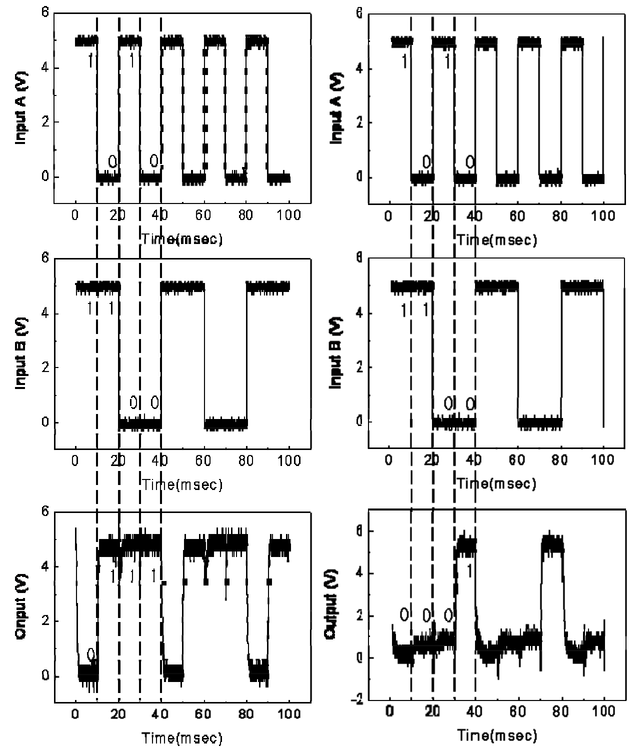

Fig. 4. Input and output signal of NAND and NOR gate

For easy integration in the same process steps as the logic circuit, we use an OTFT with shorted gate-drain as a diode. Fig. 5 shows the characteristics of diode connected OTFT. The rectifier consists of 4 diode-connected-OTFTs generated 4V DC output voltage while input 10V AC signal at 1MHz shown as fig. 6. However, there still have some problems such as large ripple element and low rectifying efficiency.

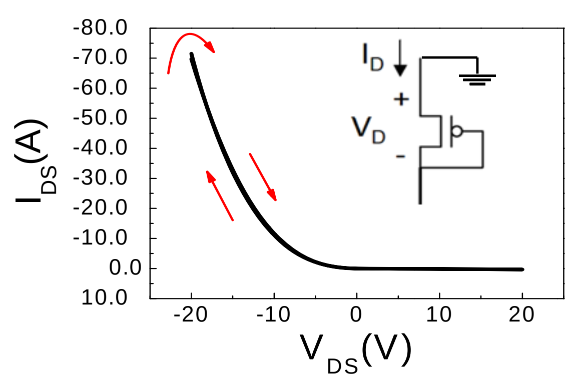

Fig. 5. Diode connected OTFT

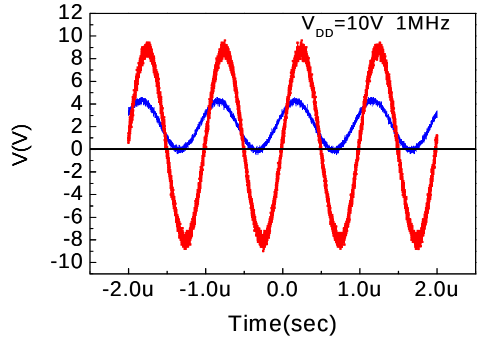

Fig. 6. Characteristics of rectifier

The 5-stage ring oscillator produced 1MHz oscillation frequency corresponding to the single stage propagation delay as low as 0.1μsec.

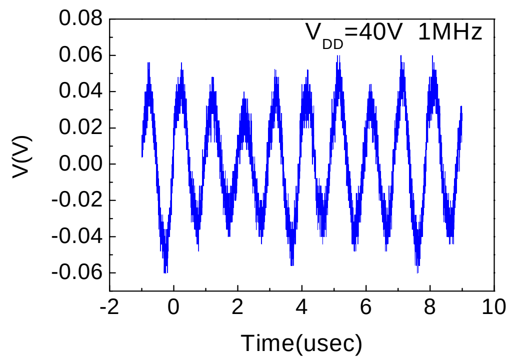

Fig. 7. Output signal of 5-stage ring oscillator

4. Summary

We demonstrated the working integrated circuits, which are key circuit units of organic electronics, based on pentacene TFTs. Based on the results of integrated circuits we decide that it is possible to implement the low cost RFID tags with OTFTs. In terms of response time and oscillation frequency there remains still problems to be solved. We need to improve performance of OTFTs together with threshold voltage control and reduction of interface states for low cost organic RFID tags.

5. Acknowledgment

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6. References

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