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Temperature Dependence Analysis of Printed Organic MOSFET

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Abstract

Device characteristics of printed organic MOSFETs have been investigated experimentally and theoretically. Our focus is given on the temperature dependence, where an anomalous improved I_{ds}-V_{gs} characteristic at high temperature has been observed for devices fabricated with the printing technology. It was found that the origin is the temperature dependence of trap density and carrier transport mechanism. This is confirmed with the compact model HiSIM-Organic developed based on the physics of carrier dynamics in organic materials. It is demonstrated that circuit applications with improving stable characteristics at higher temperature are achievable.

1. Introduction

Organic devices have important applications due to low cost and mechanical substrate flexibility. Most investigations of the organic materials and devices are rather focused directly on practical applications, while basic device physics are less intensively investigated, partially due to the many possible material variations [1]. However, different from the silicon MOSFET, the organic device characteristics are very much dependent on these basic material features. In this work, our focus is given on the temperature stability of organic devices, aiming at the organic solar system applications. Organic p-MOSFET characteristics and their impact on circuit performances at different temperatures and bias conditions are investigated.

2. Fabrication of Printed Organic MOSFETs

Organic MOSFETs were fabricated with a printing technology [2]. In Fig. 1 the fabricated MOSFET devices are shown together with inverter circuits. Since fabricated p-MOSFETs have much better *I-V* characteristics than n-MOSFETs, our present focus is given on the p-MOSFET. Fig. 2 shows the measured temperature dependence of drain current *vs*. gate voltage (I_{ds}-V_{gs}). An increase of I_{ds} at higher temperature is verified, which is different from crystalline p-MOSFETs [3]. It is also observed that the subthreshold leakage current reduces drastically at the higher temperature, however, only at large drain voltages V_{ds}. These detected anomalous features are observed for all fabricated devices.

2. Analysis of Measured Anomalous Features

Device analysis is done using the compact model HiSIM-Organic [4], which has been developed on the basis of bandgap theory, namely carriers are controlled by the gate-voltage-induced electric field. This means the basic relevant equation is the Poisson equation, which is solved iteratively. All charges induced within the MOSFET are considered together with trap densities in the Poisson equation. The HiSIM-Organic model includes also the specific mechanisms of carrier scattering and transport in organic devices. Namely, the mobility is governed by three mechanisms, Coulomb scattering, Pool-Frenckel hopping transport, and band-like carrier transport [5].

Parameter extraction for HiSIM-Organic has been performed to analyze the measured characteristics. Extraction results are depicted together with measurements in Fig. 3, verifying good reproducibility of the anomalous feature. The temperature dependences of flat-band voltage, mobility, and trap density had to be considered for these good extraction results. Fig. 4 depicts the influence of the trap density. Without trapped carriers the subthreshold swing is improved. At high temperature carriers obtain enough energy from their environment to repeat the trap/detrap process, which results in reduction of the trap time constant. This phenomenon is enhanced by increasing V_{ds} (see Fig. 2). Even though the gate oxide is relatively thick (200nm), V_{gs} controls the carrier density as shown in Fig. 6. The reason for the current increase under strong inversion condition is attributed to the Pool-Frenckel hopping transport, which dominates the carrier transport within the organic device [5].

3. Application of Organic MOSFETs in Circuits

Circuit application is investigated by using the p-MOSFET based resistive load inverter test circuit, depicted in Fig.7. Fig. 8 shows the simulated waveforms at the different temperatures and bias conditions. Different from the silicon devices, no switching performance degradation is seen at high temperature. An 11-stage ring-oscillator is also investigated, with the basic inverter circuit element (see Fig. 7) used in each stage. The results are summarized in Table I. The ring-oscillator shows stable temperature characteristics with no circuit performance degradation, but rather a frequency increase at high temperature. This promises a good applicability of the organic p-MOSFET for the solar power systems, which often have to operate at high temperature and which are known to degrade when Silicon devices are used.

4. Conclusions

Temperature dependent organic MOSFET characteristics and their circuit performances are investigated. Anomalous I_{ds}-V_{gs} characteristics are predicted with the developed HiSIM-Organic and verified by measurements. It is demonstrated that the organic devices with such anomalous characteristics could be useful for an organic solar power system, where the basic environment variable is often a high operating temperature.

References

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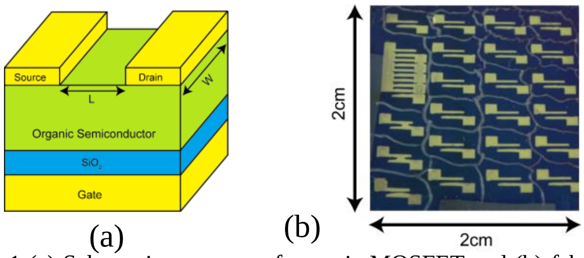

Fig. 1 (a) Schematic structure of organic MOSFET and (b) fabricated devices together with inverters and ring oscillator.

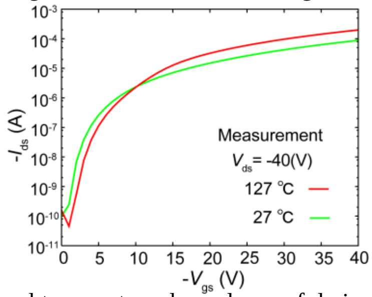

Fig. 2 Measured temperature dependence of drain current *vs.* gate voltage (I_{ds}-V_{gs}) characteristics, which are opposite to conventional silicon devices.

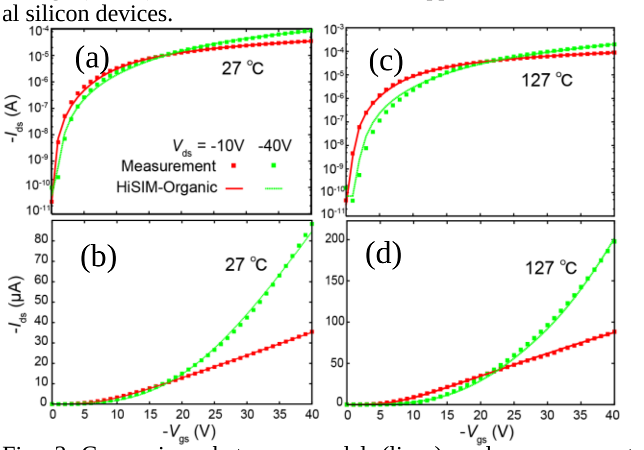

Fig. 3 Comparison between model (lines) and measurements (symbols). Model prediction and parameter extraction are done with HiSIM-Organic model. (a) and (c) logarithmic scale, (b) and (d) linear scale.

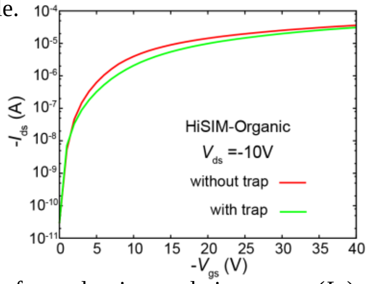

Fig. 4 Effect of trap density on drain current (I_{ds}), obtained using HiSIM-Organic model. I_{ds} decreases in presence of trap charges.

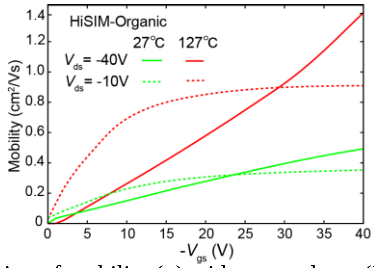

Fig. 5 Variation of mobility (μ) with gate voltage (V_{gs}) at different temperatures and drain voltages (V_{ds}).

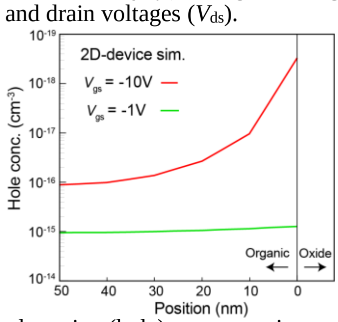

Fig. 6 Induced carrier (hole) concentration extracted across the depth of the organic MOSFET with 2D-device simulator ATLAS.

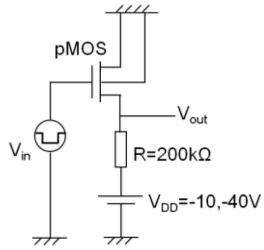

Fig. 7 Test circuit of p-MOS based resistive load inverter. The circuit is studied at V_{DD} = -10V and -40V with load resistance 200kΩ.

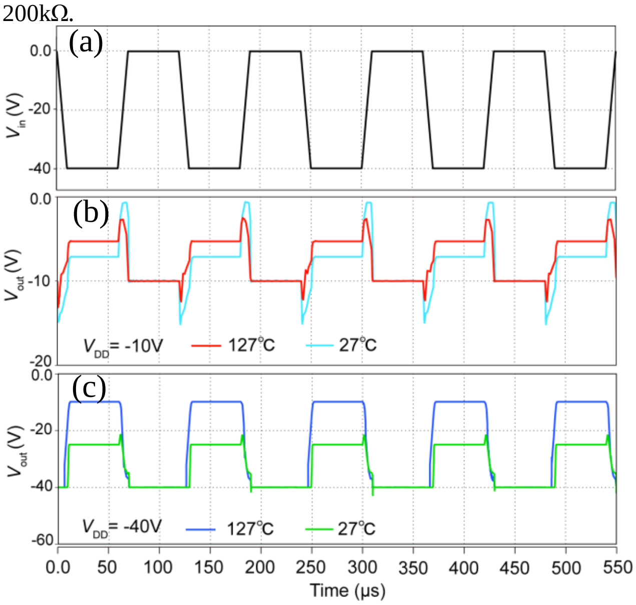

Fig. 8 Simulated waveforms of the inverter circuit at (b) V_{DD} = -10V and (c) -40V, and at temperature 27°C and 127°C.

Table I Oscillation-frequency summary for 11-stage ring oscillator

	T = 27 °C	T = 127 °C
V_{DD} = -10V	0.109 kHz	0.345 kHz
V_{DD} = - 40V	1.908 kHz	5.369 kHz