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Megahertz Operation of Rectifier Circuits using Pentacene Thin-Film Transistors

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1. Introduction

Organic thin-film transistors (TFTs) have attracted considerable attention because of their potentials to provide large area, flexible, lightweight, and low cost devices [1]. Improving operational frequency of the TFT is an important issue for those devices. We have demonstrated a high current-gain cutoff frequency above 10 MHz in *n*-channel C_{60} TFTs [2], which have a channel length of 2 μm and a field-effect mobility of 1 cm^2/Vs. The short channel and high mobility C_{60} TFTs were realized using AuNi adhesion layers and modified drain/source electrodes [3]. The adhesion layers and electrode modification are applicable for *p*-channel organic TFTs. In actual, we have fabricated high conductance pentacene TFTs and demonstrated a high cutoff frequency above 10 MHz in the pentacene TFTs [4,5]. An application of such high conductance TFTs is rectification circuits for RFID-tags [6,7]. In this paper, we report on rectification properties of pentacene transistor diodes operating at a frequency above 1 MHz.

2. Experimental

The cross section of the fabricated pentacene TFT is shown in Fig. 1. The substrate is a glass substrate. The gate electrode is an AlSi layer and the gate insulator is a 200-nm-thick SiO_2 layer. The SiO_2 layer has a unit area capacitance of 20 nF/cm^2. The drain/source electrodes were patterned by conventional photolithography and lift off. The electrodes consist of a 3-nm-thick $Au_{0.9}Ni_{0.1}$ adhesion layer and 25-nm-thick Au layer. The surfaces of the gate insulator and the drain/source electrodes were treated using hexamethyldisilazane and pentafluorobenzenethiol [8], respectively. Finally, pentacene was deposited at a room temperature on the channel region through a shadow mask. The channel width is 1 mm and the channel lengths (L) are 2, 4 and 10 μm.

The rectification properties were examined for a circuit shown in fig. 2. The drain and gate electrodes were connected in an external circuit; the input voltage $v_{in}(t)$ was applied to the connection. The amplitude of $v_{in}(t)$ was set to 20 V and the frequency f was in the range of 10k to 1.3 MHz. The output voltage $v_{out}(t)$ was measured with a digital oscilloscope. All measurements were performed in a dry-nitrogen glovebox.

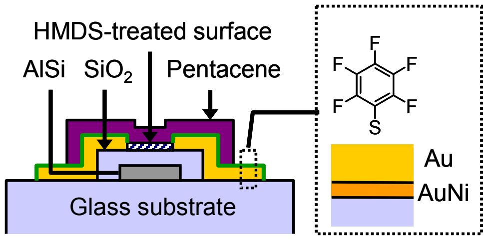

Fig. 1 Schematic of a pentacene TFT used as a rectification diode.

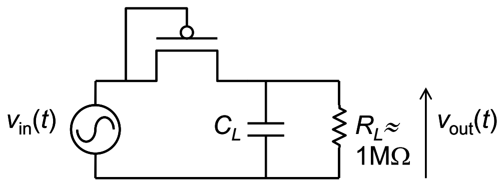

Fig. 2 Electric circuit for measurement of rectification properties.

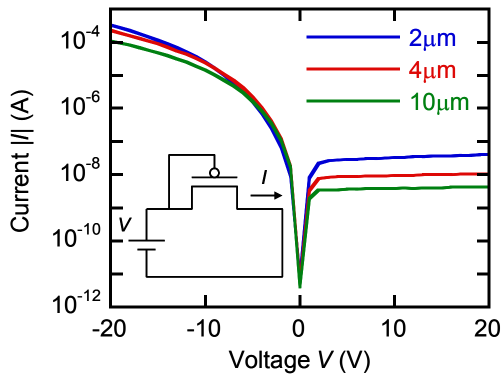

Fig. 3 Current-voltage characteristics of pentacene transistor diodes with L = 2, 4, and 10 μm.

3. Results

The fabricated pentacene TFTs with L = 2, 4, and 10 μm had saturation mobilities of 0.36-0.43 cm^2/Vs and threshold voltages of -4.3 to -5.5 V, which were calculated from transfer curves.

Figure 3 shows absolute value of current ($|I|$) versus voltage (V) characteristics for the pentacene transistor diodes, which were measured for a circuit shown in the inset in Fig. 3. Rectification properties are clearly obtained. The $|I|$ values at negative voltages are larger than those at positive voltages. This is because the pentacene TFTs normally operate as *p*-channel transistors.

Figure 4 shows waveforms of $i_{in}(t)$ and $i_{out}(t)$ obtained at frequencies of 10 kHz and of 1.3 MHz for a pentacene TFT with L = 2 μm. The waveforms of output voltages for C_L = 1 pF and 10 nF are denoted with red and green lines, respectively. For f = 10 kHz and C_L = 1 pF, the waveform of $i_{out}(t)$ is similar to a half sine wave and rectification property is clearly seen in Fig. 4(a). The amplitude of the measured half wave is about 12.2V, and less than that of $i_{in}(t)$. The amplitude mainly depends on relation between the load resistance and the conductance of the transistor diode. Direct-current voltage is obtained by use of a large capacitance. For f = 10 kHz and C_L = 10 nF, $i_{out}(t)$ is almost constant and the DC output voltage V_{OUT} is about -10.5 V.

In the case of C_L = 1 pF, the waveform of $i_{out}(t)$ for f = 1.3 MHz is very different from that for f = 10 kHz. Positive voltages clearly appear in the waveform of $i_{out}(t)$. The waveform consists of sine and half-sine waves with different phases, which are provided by currents passing through the capacitance between gate and source electrodes and the transistor channel. The current for capacitance increases with frequency. Thus, the positive voltage is attributed to the capacitance between the gate and source electrodes. On the other hand, the waveform of $v_{out}(t)$ for C_L = 10 nF and the V_{OUT} value at f = 1.3 MHz are almost the same as those at f = 10 kHz, respectively. Since the capacitance provides AC current without offset, the current passing though the capacitance does not affect the DC output voltage. Thus, the V_{OUT} is provided by the channel current of the pentacene TFT. In addition, no dependence of V_{OUT} on f indicates that the conductance of the pentacene TFT does not depend on f in the range of 10 kHz to 1.3 MHz. The maximum frequency in this study is limited by the measurement setup. Therefore, we expect that the pentacene TFT rectifies AC voltages at frequencies of higher than 1.3 MHz because of the high cutoff frequency of about 10 MHz [4].

Figure 5 shows V_{OUT}-L characteristics at f = 1.3 MHz. The V_{OUT} values increases with reducing L according to the conductance. The short channel transistor is useful to obtain high output voltage. Further improvement in output voltage will be achieved by use of the transistor with higher conductance.

4. Conclusions

We investigated properties of rectification circuits having pentacene TFTs. The transistor diodes successfully rectify an AC supply voltage at a frequency above 1 MHz into a DC voltage without decrease in the output voltage at high frequency. The achievement will progress to applications that require high speed operation of organic TFTs.

Acknowledgements

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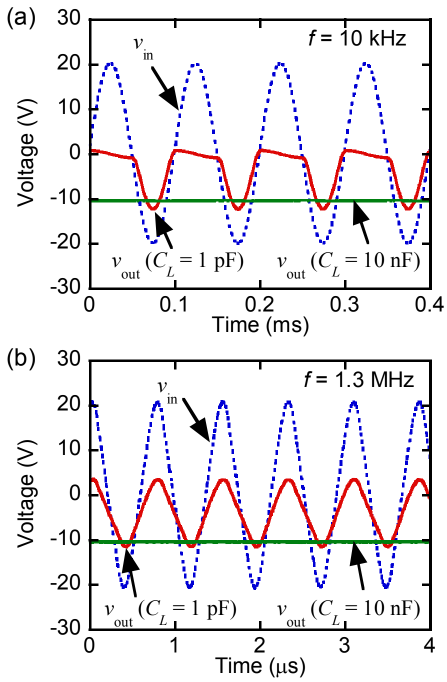

Fig. 4 Waveforms of $v_{in}(t)$ and $v_{out}(t)$ at f = 10 kHz and 1.3 MHz. The waveforms of $v_{out}(t)$ for C_L = 1 pF and 10 nF are shown.

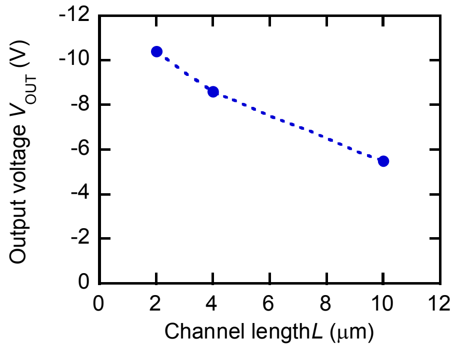

Fig. 5 Output voltage for pentacene transistor diodes with L = 2, 4, and 10 μm.

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