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Electrostatic discharge robustness on organic ring oscillator.

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Abstract

We have improved robustness of organic thin-film transistors (TFTs) for electrostatic discharge (ESD) with polymer encapsulation layer. Finally, we obtained 5-V operation organic ring-oscillators (RO) withstanding over 300-V ESD stress. Encapsulated organic transistors in this ring-oscillator can also stand over100 V which is 5 times as large as transistors without encapsulation. In addition, it can release ESD stress as failure current up to 70 mA improved from 35 mA of bare transistors. In previous our work, it has been reported that source/drain electrode was damaged strongly and came off apart from bottom organic semiconductor layer after applying 14-V ESD stress into the organic circuits[a]. Therefore we make encapsulation layer on top of the pentacene transistors with poly chloro para xylylene(Parylene) by chemical vapor deposition (CVD) to suppress that ESD detach those electrodes away.

1. Introduction

Organic electronics is expected to realize novel devices such as flexible display [2], electrical skin [3] and large area sensor [4]. Several researchers, on the other hand, start to investigate application to biomedical devices [5,6], intensely. Organic thin-film transistors (OTFTs) are fundamental elements in these circuits. High electrical characteristics of OTFTs such as high mobility (~1 cm/Vs) or long atmospheric stability are required to be utilized into the devices. Robustness of electrostatic discharge of OTFTs is also important for bio electronics. It is because organic device on flexible substrate is easy to get charge, and to be broken by ESD when it is put on conductive human body.

In this study, we fabricate ESD robust OTFTs with polymer encapsulation structure that also brings good electric characteristics such as high thermal stability [7] and atmospheric stability[8].

2. Experiment

Organic transistors with SAM gate dielectrics were manufactured by vacuum evaporation and solution processes. First, we deposited 25-nm-thick aluminum as a gate electrode on polyimide film substrate by thermal evaporation through the shadow mask. An aluminum oxide layer was prepared on the gate electrode by oxygen plasma treatment. Plasma power was 150 W and the exposure time is 10 min. Next, we dipped the substrate into a solution of 5-mM n-octadecylphosphonic acid in isopropyl alcohol for 16 hours to form uniform 2-nm-thick SAMs [9]. The combination of SAMs on aluminum oxide functions as the gate dielectric layer. 30-nm thick pentacene was deposited by thermal evaporation to form the channel layer. Finally, we deposited 50-nm-thick Au by thermal evaporation onto the pentacene surface to make source/drain electrodes. After

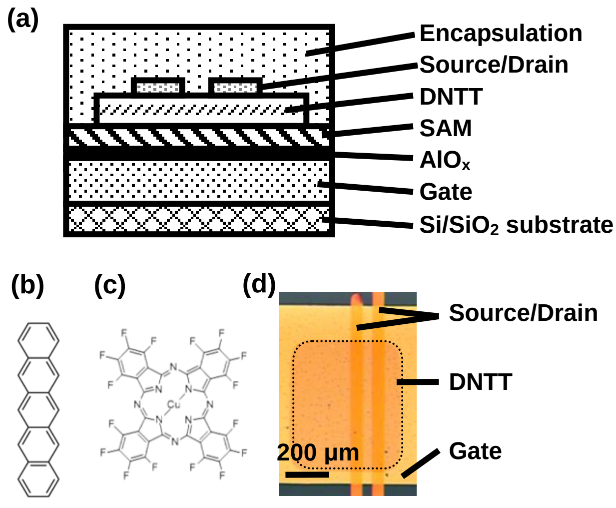

Fig.1. Device structure: (a) Cross section structure of OTFTs. (b), (c) Chemical structure of DNTT (b) and n-octadecyl phosphonic acid (c). (d) Optical image of OTFT without encapsulation from top view.

that, we deposited 1-μm-thick parylene by CVD. To contact underneath electrode, we made via hole using green lazer.

We have used the taransmission line pulsing method with human body model equivalent pulses. These pulses have a 100-nscec. pulsewidth and a 10-nsec. rise time. We elevated an amplitude of those pulse from 0 V, gradually.

3. Results

As shown in Fig. 2, encapsulated p-OTFT stands ESD stress up to 109 V. On the other hands, bare transistor was broken by ESD stress of 17 V. Then failure current through encapsulated organic TFT becomes up to 73 mA, and that of bare organic TFTs becomes 59 mA. Effect of channel width is consistent. When we change channel width from 500 to 3.8×10^4 μm, failure current of ESD increases up to 468 mA, linearly, while, channel length doesn't affect ESD characteristics in change from 55 to 124μm. It implies that channel resistance/conductivity of organic semiconductor is inconsequential for ESD robustness, but contact resistance or parasitic capacitance between electrodes can affect ESD characteristics.

ESD characteristics of encapsulated organic RO are shown in Fig. 3. We apply ESD stress in two ways: one is a path from electrode for higher voltage in circuit named V_{DD} to grand (GND), and the other is a path from GND to V_{DD}. In both way, organic RO shows 5 times higher ESD robustness on failure current than invertor circuit which is used in RO. This is quite consistent because our RO can be considered as 5 parallel invertors. Finally, encapsulated organic RO stands ESD stress up to over 300V. Then failure current is 486mA. This is equivalent to ESD stress of 730 V in human body model (HBM). Device is more stable against ESD from GND to V_{DD} in both circuit, RO and invertor.

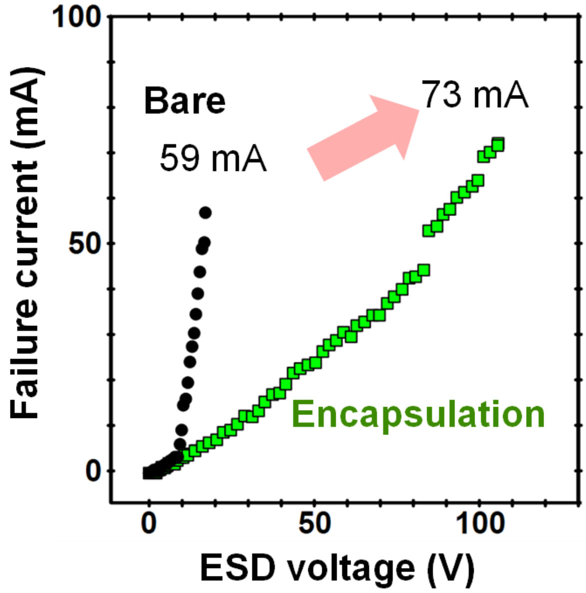

Fig.2 ESD failure current as a function of ESD voltage: Black dots shows organic TFTs without polymer encapsulation and organic TFTs with encapsulation is shown by light green dots.

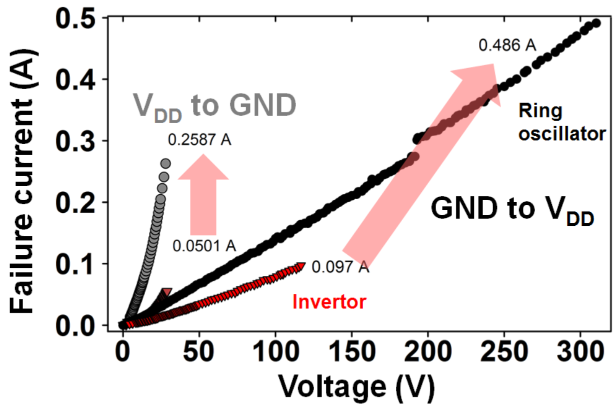

Fig.3 Failure current on organics RO and organic invertors as a function of ESD voltage: Black and red dots shows data with a ESD path from GND to V_{DD}, and gray and light red dots shows data with the path from V_{DD} to GND. In each ESD direction, RO flows 5 times lager failure current than invertor. Invertors are prepared in isolation from ROs

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