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Electrical bistability of organic thin-film devices using Ag electrode

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1. Introduction

Memory phenomenon, especially electrical transition from a high impedance state (OFF state) to a low impedance state (ON state) under electrical field using organic materials for active medium have been studied for more than four decades, but their behaviors were instable. Recently, Ma *et el.* (UCLA) reported on a high performance organic electrical bistable device which has a metal nanocluster layer inserted within the organic layers [1] [2] [3]. The ON and OFF state differ in their impedance by about 10^6 times and can be switched back to each other by applying a forward bias and a reverse bias, respectively. Bozano *et el.* (IBM) also reported electrical bistable devices, which are similar to the UCLA structure [4]. However, electrical behavior of the IBM device is different from the electric behavior of UCLA device. On the other hand, Kawakami *et al.* (Fuji Electric) reported organic bistable devices with a single organic layer inserted between two electrodes [5]. In this report, we demonstrate an organic bistable device with the structure of a single organic layer interposed between Al and Ag electrodes. Our bistable device behaved differently from both the UCLA and Fuji devices and was found to work similarly with the IBM device.

2. Experimentals

A precleaned glass substrate was treated with boiling ethanol followed by UV-ozone cleaning. After the treatment, poly-cholo-*p*-xylylene (PCPX, Daisankasei Co. Ltd.) was subsequently formed by thermal chemical vapor deposition at the thickness of 700nm. The PCPX film has been reported to grow as a flat continuous organic film and to have excellent electrical insulating property. Next, the substrate was coated with a 80nm Al layer, which was patterned into parallel columns electrode with 2 mm-width by use of a shadow mask. Then, 2-amino-4,5-imidazoledicarbonitrile (AIDCN) as active medium was deposited on top of the Al electrode. AIDCN was obtained from Nippon Soda Co. Ltd, and purified twice by train sublimation before use. Finally, an Ag layer was patterned into parallel row electrode with 2 mm-width. The deposition process of Al, AIDCN and Ag were carried out in a vacuum of about 3×10^{-6} Torr. Current-voltage (I-V) characteristics were measured using an Agilent semiconductor analyzer. In this report, the forward bias indicates the case when the top Al electrode is positively biased.

3. Results and Discussion

Figure 1 shows the typical I-V characteristic of an electrical bistable device. Staring from an OFF state, the transition from the OFF state to the ON state occurred at threshold voltage (V_{th}). When a voltage was ramped up from 0 V to +9 V and then immediately set back to the 0 V (single sweep), the device was left in its OFF state. However, when a voltage was ramped up from 0 V to +9 V and continuously ramped down from +9 V to 0 V (double sweep), the I-V curve at the scan when voltage was ramped down differed from the initial I-V curve at the scan when voltage was ramped up. During voltage was applied in the sequences of the double sweep, the high current ON state was kept.

To study the transition from the OFF state to the ON state in more detail, the device was initially set in the OFF state and the double sweep with 0 V to limited upper voltage was repeated, as shown in Figure 2. It should be noticed that the transition observed in both positive and negative bias directions. In the positive bias, the intermediate value of current was observed at the down sweep from +4 V to 0 V. After the +6 V ramps, the ON state was attained. In the negative bias, intermediate currents was found at the sequential sweep from -6 V to 0 V. In addition, we found that the bistable behavior of our device using the Ag the top electrode was much more stable than the one using the Al top electrode.

Our results were well corresponded with the reports of IBM [4]. Only the difference was the initial OFF state in our pristine device. Although our device structure is different from that of the IBM device, we assume that the origin of the bistable behavior is the same. Figure 3 shows the schematic illustrations of the possible bistable mechanism at several bias conditions. We suppose that the initial state is the OFF state. It means that trapping sites near the Ag/organic interfaces are charged. Possible reasons for

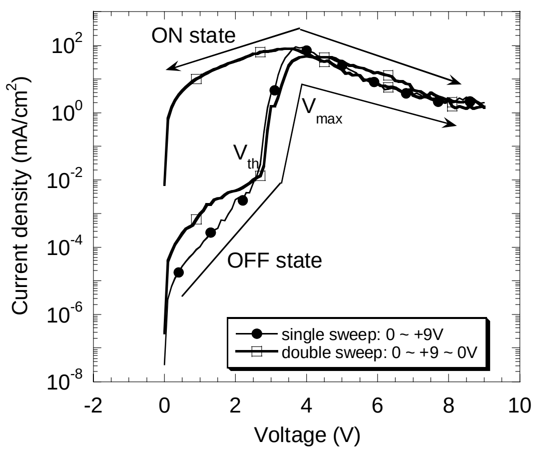

Fig. 1. Current-voltage characteristics organic electrical bistable device with the strcuture, glass / PCPX (700nm~) /Al (80nm) /AIDCN (150nm) /Ag (80nm).

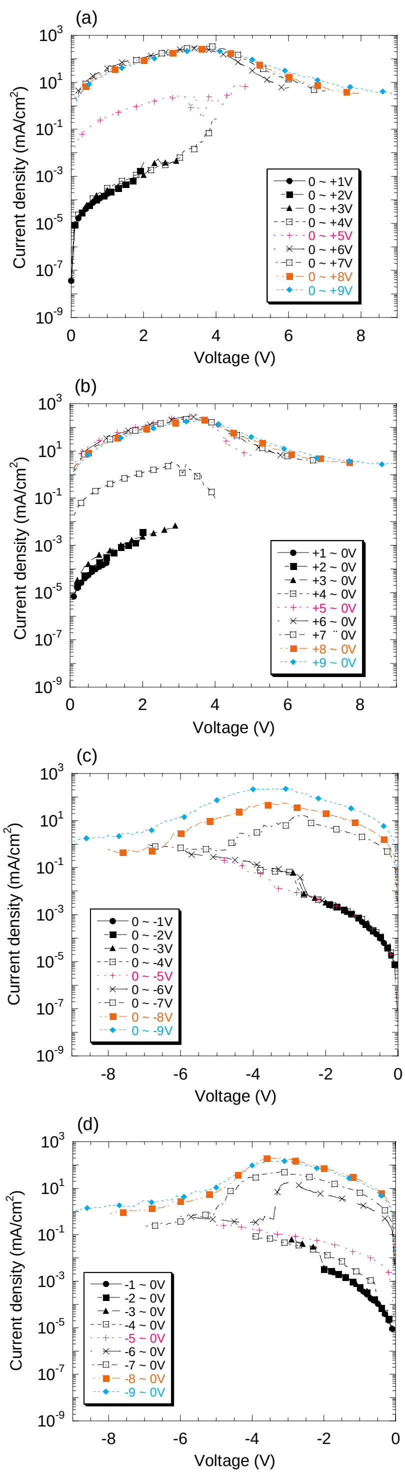

Fig. 2. Demonstration of multistability using a sequence of saw-tooth ramps on positive and negative bias. (a) and (b) show the same continuous experimental sequences (for example 0~+1~0 V). (c) and (d) also show the same continuous experimental sequences.

providing the trapping sites are assumed to be i) chemical reaction between metal and organic materials and ii) metal nanocluster which is made by metal migration. The latter may be the main reason, because the device using the Al top electrode showed no stable bistable behavior (not shown here). Above the threshold voltage, i.e., a region of

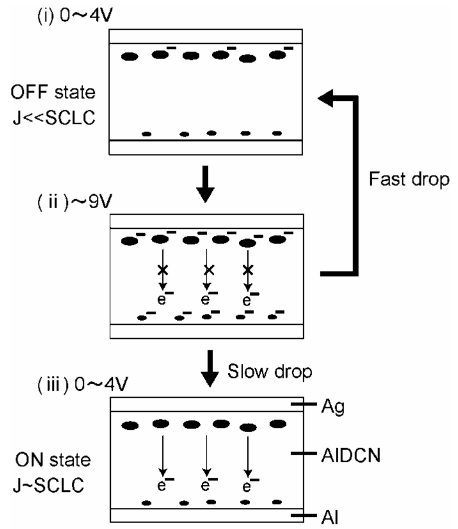

Fig. 3. Schematic representations of the bistable behavior. (i) small current flows due to trapping of injected charges and small barrier for injection from electrodes. (ii) above the threshold voltage, NDR reduces the current. When voltage is immediately set back to 0 V, the initial device condition is restored (i). On the other hand, when voltage is continuously ramped down, (iii) large current flows because trapped charges are swept out to the electrodes.

negative differential resistance (NDR), the currents are assumed to reduce due to the build up of a space-charge field, which opposes the field applied.

4. Conclusions

In this paper, we demonstrated electrical bistable device with a simple structure, i.e., an organic layer interposed between Al and Ag electrodes. The electrical bistability was assumed to occur as the result of inhibition of space-charge injection and transfer due to trapped charge on trapping sites. This report provides one of the most clear-cut experimental data on electrical bistability and helps our further understanding of electrical bistable behaviors in organic thin-film devices.

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