Role of Charge Transport Layer in Toner Display by Electrical Particle Movement

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Abstract

The toner display by an electrical movement of conductive toner has been investigated. The display cell consists of two transparent electrodes coated with the charge transport layer (CTL) and a spacer. The conductive toner and white particle are placed in this cell. The toner movement is controlled by the external electric field applied between two transparent electrodes. The conductive toners on the anode electrode are charged positively by hole injection from the CTL and move to the cathode electrode. They are fixed on the CTL on the cathode by an electrostatic force across the CTL to display a black image. The toners can be put back to the counter electrode by applying a reverse electric field, and a white image is formed.

In toner display, the charge transport layer has the role of the hole injection from anode electrode to toner and blocking hole from a toner to the cathode electrode. It is necessary to do the existence of the Schottky barrier at the ITO/CTL/toner. In this paper, the charge injection is investigated by the measurement of I-V characteristic for ITO/CTL/toner sample. By using three kinds of charge transport material (CTM), an ionization potential of CTM is affected to the property of charge injection between electrode and toner. It is concluded that the contrast of display depends upon the ionization potential of CTM.

Introduction

Recently, an electronic document is distributed on the computer network and displayed on a monitor and printed out as a hard copy using an electronic printer. In order to read an electronic document, a development of a new paper like display, which has the convenience of the conventional hardcopy and a capability of access to digital information, is expected. The development a new display technology has been important. The thermal rewritable marking has been used practically as a rewritable card. A fatty acid-polymer composite type rewritable marking,[1,2] a leuco dye-polymer type rewritable marking, an electrophoresis display using micro-capsule,[3,4,5] a twisting ball display,[6] and dichromatic dye-liquid crystal composite type paper are reported as rewritable technology. We had reported the principle and characteristics of toner display using the conductive toner, which is a familiar to us as an image formation material for a hardcopy.[7]

In this paper, we discuss the role of charge transport layer for the toner display by the measurement of I-V characteristic for ITO/CTL/toner sample. And the dependence of reflection density for toner display on ionization potential of CTM is investigated.

Toner Display

The structure of toner display device using the conductive toner and white particle is shown in Figure 1. The display device is the sandwich type cell structure that is enclosed in two ITO transparent electrodes using an insulating spacer. The hole charge transport layer is coated on the each transparent electrode. The conductive toner and white particle are been built-in in this cell. The device displays white or black pattern by the change of applied voltage caused by the movement of toners between two transparent electrodes.

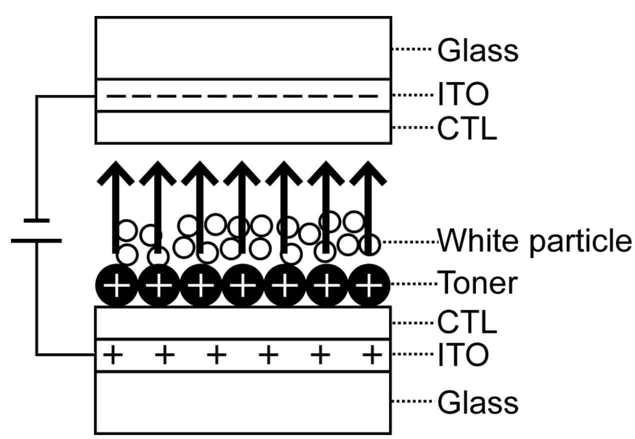

Figure 1. The structure of toner display device using the conductive toner and white particle.

The conductive toner and white particles are put in the cell. When the under electrode is applied by plus voltage, the conductive toners on the CTL are charged positively by the hole injection from CTL, and move to the top electrode due to the coulomb force between the toner charge and negative charge on the top electrode. The conductive toner is kept on the surface of CTL without applying voltage because the CTL acts on insulating layer due to the blocking contact between the toner and CTL. As the surface of the CTL on the top electrode is covered with the toners, the observer through the top electrode sees the black solid pattern. When the polarity of an applied voltage is reversed, the conductive toners are moved and covered on the opposite electrode and then the white pattern is seen through the top electrode by covering the toner layer with the white particles.

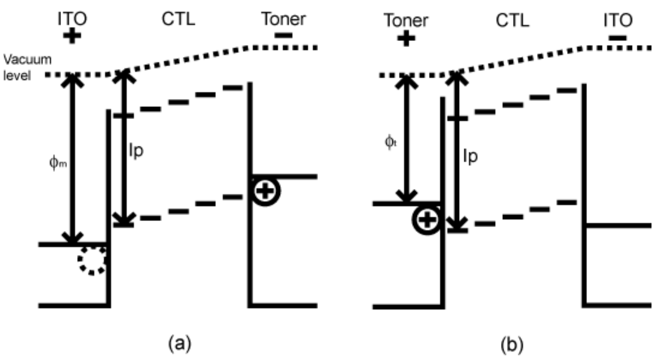

Figure 2.Energy band diagrams for the hole (a) injected from ITO to toner and (b) insulated from toner to ITO.

The CTL in toner display may exhibit diode characteristic that a hole can be injected from electrode to toner and cannot one from toner to electrode. It is necessary to do the existence of Schottky barrier at the electrode/CTL and CTL/toner interfaces. Figure 2 is an ideal energy band diagrams for toner display. If the work function of ITO electrode (ϕ_m) is larger than the ionization potential of CTL (Ip), a hole can be injected from electrode to CTL when electrode is applied by plus voltage. After toners move to opposite electrode, a hole in the toner is blocked to CTL due to Schottky barrier at the CTL/toner interface if the work function of toner (ϕ_t) is smaller than Ip of CTM. The relative relationship of ionization potentials between the ITO, CTL and toner is desired to obtain the good display properties in toner display.

Experimental

Charge Transport Material

The molecular structures and values of ionization potential for CTM used in this study are shown in Figure 3. The height of Schottky barrier at the ITO/CTL and CTL/toner interfaces should depend on the ionization potential of CTM. CTMs having different ionization potential will exhibit the different I-V characteristic.

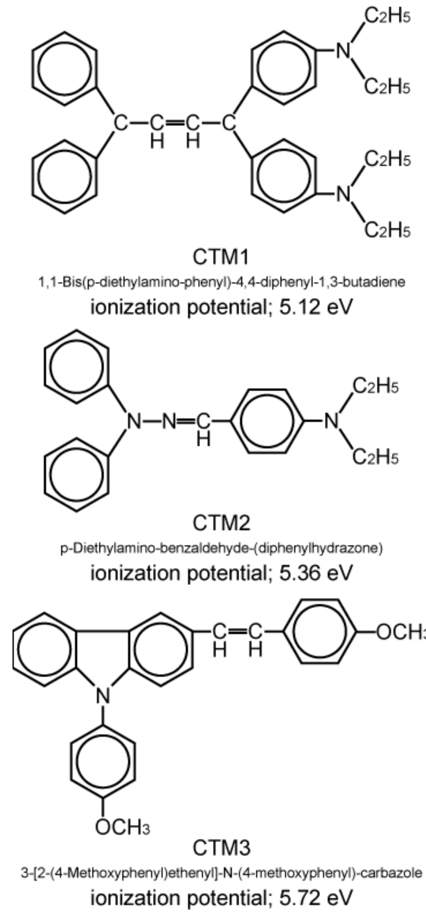

Figure 3. Charge transport materials used in this study.

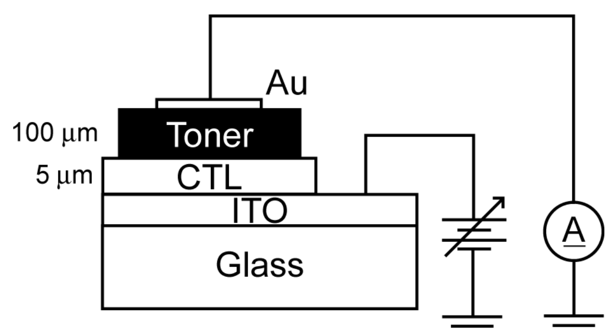

Figure 4. Schematic diagram of current-voltage (I-V) measurement system.

Sample

Figure 4 shows the sample structure for the measurement of I-V characteristic. The mixture of the charge transport material and polycarbonate (PC) polymer (Teijin chemicals Ltd., Panlite k-1300) was coated on transparent ITO electrode. The dopant concentrations were 30 wt% by weight in the charge transport layer (CTL). The layer thickness of CTL was 5µm. The conductive toner layer with thickness of 100µm was put over the CTL. In order to adhere toner to the CTL, the toners were melted at 140 °C on hotplate. Furthermore, Au is evaporated on the toner layer as an electrode. The DC current was measured by applying voltage between ITO and Au electrode.

Results and Discussion

Figure 5 is I-V characteristic for the ITO/CTL/toner samples. Figure 5 (a) is the result for the sample using CTM1. When ITO electrode was applied positive voltage, a hole could be injected from electrode to toner through the CTL. The other side, when negative voltage was applied ITO electrodes, the amount of hole could not be transported from toner to electrode. It showed that there was Schottky barrier to block the hole from toner to electrode. It shows an ideal characteristic for toner display such as the hole injected to toner was kept after the toner moved to opposite electrode.

Figure 5 (b) shows the result for the sample using CTM2. The dc current for the sample using CTM2 was smaller than the sample using CTM1. It showed that Schottky barrier was formed at the ITO/CTL or CTL/toner interfaces to block the hole from electrode to toner.

Figure 5 (c) is the result for the sample using CTM3. When ITO electrode was positive, the reverse dc current was shown. The larger barrier was formed at the ITO/CTL interface than the sample using CTM2. It was unknown reason that the current was increased when ITO electrode was negative.

The work functions of ITO and ionization potential of CTL1 are 5.28 eV and 5.12 eV, respectively. It will be expected that the hole will be injected from ITO to CTM1 based on the these values. The experimental result exhibited good agreement with prediction. Although the work function of toner was unknown, it seemed to be smaller than ionization potential of CTM1. The samples using CTM2 and CTM3 with larger ionization potential than CTM1 exhibited the decrease of hole injection from electrode to toner. There seemed to be higher barrier at the ITO/CTL interface to block the hole injection from electrode.

As the experimental results, The sample using CTM1 exhibits the best I-V characteristic for toner display such as large number of holes can be transported from electrode to toner and cannot be transported from toner to electrode. Furthermore when CTM3 was used, an electrostatic force between toner and negative electrode is small due to the small amount of toner charge.

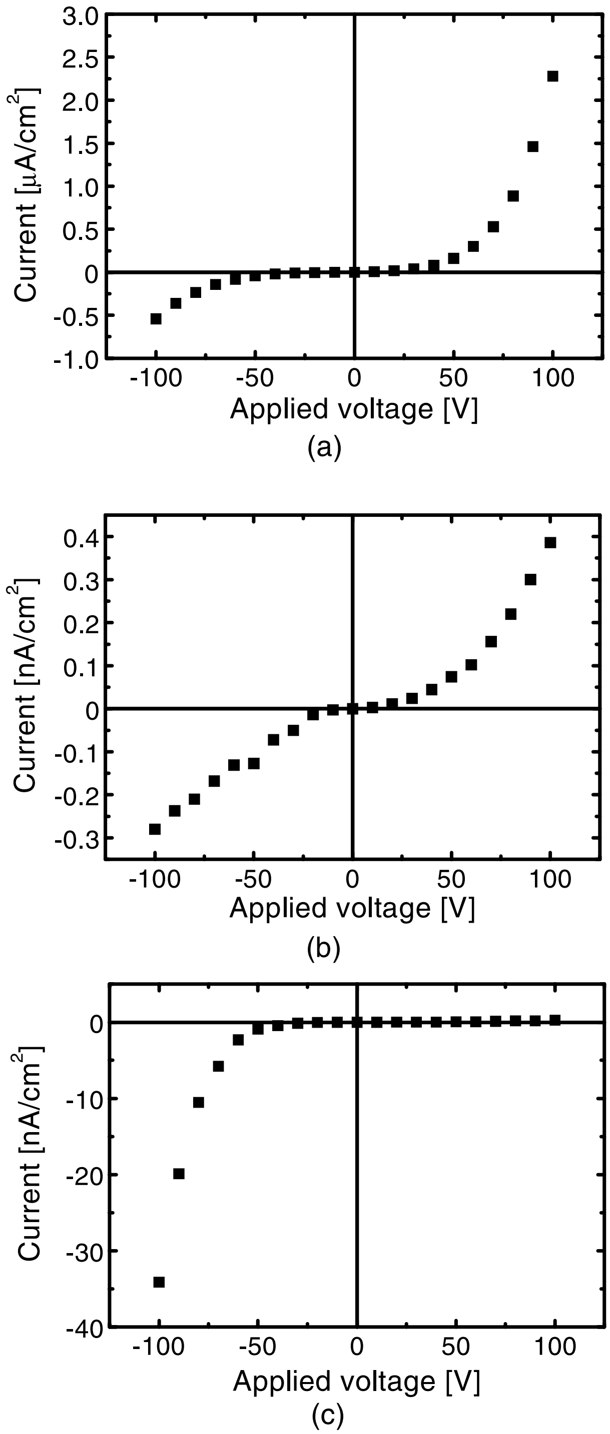

Figure 5. I-V characteristics for ITO/CTL/toner sample used CTM1 (a), CTM2 (b) and CTM3 (c).

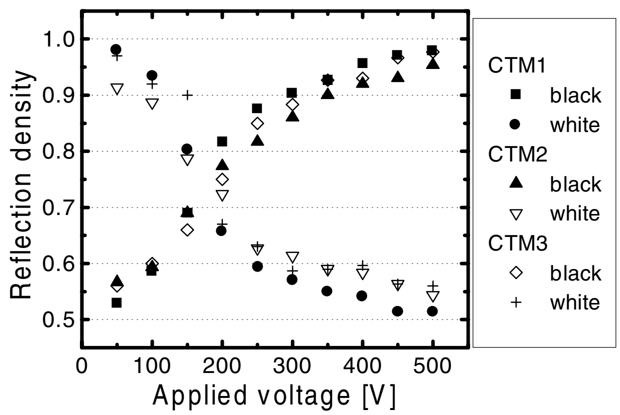

Figure 6. Relationship between reflection density and applied voltage

Table 1. Values of ionization potential of CTM and contrast ratio of toner display.

Molecule	Ionization potential [eV]	Contrast ratio
CTM1	5.12	2.93
CTM2	5.30	2.57
CTM3	5.72	2.61

It was confirmed that the amount of hole transported from electrode to toner depend on the ionization potential of CTM. The differences in the I-V characteristic should have an effect on the display characteristic for toner display. When the three kinds of CTM were used in the charge transport layers for toner display cells, the reflection density of black and white displays were measured. Figure 6 shows the reflection density of black and white displays for the sample using different CTMs. Table 1 shows the values of ionization potential of CTM and contrast ratio of toner display. In the case of using CTM1, the best density difference of 0.48 and contrast ratio of 2.93 were obtained. It was considered that the property of the charge injection and insulation of CTL influences the toner movement and causes a best contrast for toner display.

Conclusion

The I-V characteristic for ITO/CTL/toner was measured. The amount of charge injected from electrode to toner depends on the ionization potential of CTM. The sample using CTM having lower ionization potential exhibited good I-V characteristic and display contrast ratio for the toner display.

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Biography

Makoto Yasuda received his B.S. degree in image science from Chiba University in 2000. He is a student in a master course in Graduate School of Science and Technology, Chiba University. His research interest is in reversible recording system.