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Solution-Processed Hybrid Organic–Inorganic Complementary Thin-Film Transistor Inverter

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Abstract

Hybrid organic–inorganic complementary inverters composed of Dinaphtho [2,3-b:2',3'-f] thieno [3,2-b] thiophene (DNTT) and indium–gallium–zinc–oxide (IGZO) as p- and n- semiconductors, respectively, were fabricated. An IGZO film, used as an n-type semiconductor, was fabricated by a solution process. It showed a field-effect mobility of 0.3 cm^2·V^{-1}·s^{-1}. The time and temperature required for the preparation of the IGZO were 5 min and 200 °C, respectively. A hybrid complementary inverter was fabricated by combining the IGZO with a DNTT thin-film transistor.

1. Introduction

Recently, oxide semiconductor materials such as amorphous indium–gallium–zinc oxide (a-IGZO) have attracted interest as an active layer of thin-film transistors (TFTs) owing to their high performance and low-temperature processing capability [1]. In particular, because a solution-processed IGZO can be prepared at low temperature, it can be applied to a printed circuit on a flexible plastic substrate. We have already carried out the development of an IGZO precursor ink for application in various printing processes [2,3]. However, the solution process requires a high annealing temperature and a long annealing time to completely eliminate the organic components in the precursor film [4]. In a previous study, we reported the fabrication of an a-IGZO TFT with a short annealing time using microwave. The a-IGZO TFT showed higher performance in spite of an annealing time of 5 min than annealing in an electric oven for 120 min [5]. Recently, some researchers have reported fabrication of IGZO TFTs prepared with a precursor at low temperature using both photo irradiation and conventional thermal annealing method [6,7]. In this case, the total process time was reduced compared with that using only the thermal annealing process. However, these processes requires pre- and/or post-thermal annealing processes of at least 1 h. Recently, we have reported that the annealing temperature and its processing time can be reduced by combining microwave annealing and photo irradiation using Xenon flash and Excimer lamps [8,9].

Organic TFTs have also been extensively studied as a semiconductor for high-performance TFTs because of the low process temperature and large area processability. Recently, in a p-type organic semiconductor, the hole mobility has exceeded that of an amorphous silicon. Various electronic components such as inverters and logic circuits require both p- and n- type semiconductors. However, an n-type semiconductor a high electron mobility capable of being formed by a low-temperature process has not yet been reported. In the present study, we fabricated a hybrid organic–inorganic TFT complementary inverter.

2. Experimental

An IGZO precursor solution was prepared by dissolving Indium, Gallium, and Zinc nitrates in an alcohol. The resulting precursor was filtrated using a membrane filter. The inverter was fabricated in a top-contact and bottom-gate configuration. Dinaphtho [2,3-b:2',3'-f] thieno [3,2-b] thiophene (DNTT) and IGZO films were used as a p- and n-type semiconductors, respectively. The IGZO precursor film was fabricated on the surface of a thermally grown 300-nm-thick silicon dioxide layer on a silicon wafer by spin coating at 2000 rpm for 30 s. The precursor films were annealed in a single-mode microwave cavity at 200 °C for 5 min at a frequency of 2.45 GHz. The temperature was measured using a radiation thermometer (FTK9, Japan Sensor). A 30-nm layer of DNTT was deposited through a shadow mask using thermal evaporation. Source and drain electrodes made of Au for the p-channel and Al for the n-channel were deposited onto each sample.

2. Results

The transfer characteristics of both n- and p-channel transistors are shown in Figs. 1 and 2. The IGZO TFT shows a field effect mobility of 0.3 cm^2·V^{-1}·s^{-1}. Although the IGZO TFT was fabricated by a solution process at 200 °C for 5 min, the mobility shows a relatively high performance compared with the other n-type TFTs prepared by the solution process at low temperature [10]. The transfer characteristics of the DNTT TFT exhibits field effect mobility of 1 cm^2·V^{-1}·s^{-1}.

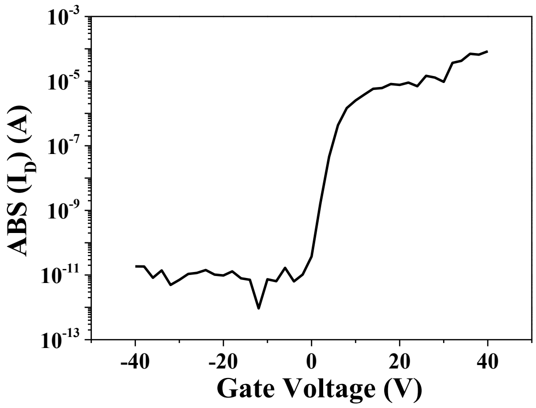

Fig. 1 Transfer characteristics of TFTs fabricated with solution-processed IGZO by annealing an IGZO precursor solution using microwave at 200 °C for 5 min.

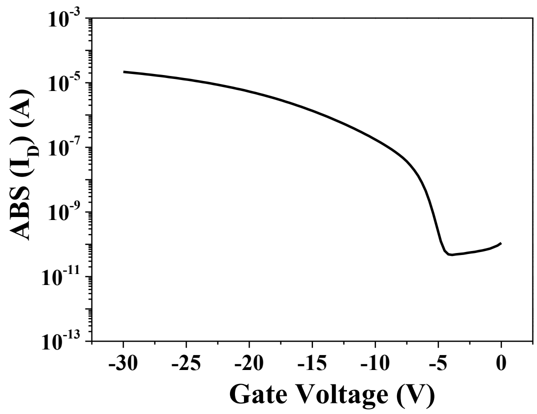

Fig. 2. Transfer characteristics of the TFTs fabricated with DNTT as a p-type organic semiconductor.

Then, hybrid complementary inverters were developed using these organic (i.e., p-type) and inorganic (i.e., n-type), TFTs to confirm the inverter operation when the IZGO prepared by the solution process at low temperature was used as an n-type channel. The voltage transfer characteristics and maximum dc voltage gain at supply voltage of V_{DD} = 5, 10, 20, and 30 V are shown in Fig. 3. The inverter operation of the device was observed, and the maximum gain values at V_{DD} = 20 and 30 V were 55 V/V and 58 V/V, respectively. These results revealed that the IGZO prepared by the solution process at low temperature can be used as an n-type channel of an inverter circuit.

3. Conclusions

We have fabricated a hybrid organic–inorganic complementary TFT inverter using a solution-processed IGZO TFT as an n-channel. Although the TFT was fabricated at low temperature (200 °C) and in a short time (5 min), it showed good mobility, and the CMOS that used the IGZO as an n-channel exhibited an inverter operation.

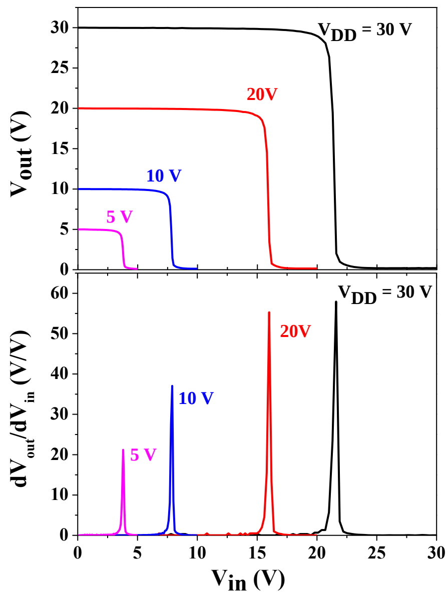

Fig. 3 Voltage transfer characteristics and the corresponding dc gain value of the inverter.

References

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, Nature **432** (2004) 488.

[2] N. Fukuda, S. Ogura, K. Nomura, and H. Ushijima, MRS Proc. **1547** (2013) 123.

[3] H. J. Cheong, N. Fukuda, S. Ogura, H. Sakai, Y. Manabu, T. Kodzasa, H. Tokuhisa, K. Tokoro, K. Takeuchi, R. Nagahata, T. Nakamura, and S. Uemura, J. Photopolym. Sci. Technol. **27** (2014) 339.

[4] M.-K. Ryu, K.-B. Park, J.-B. Seon, and S.-Y. Lee, J. Soc. Inf. Disp. **18**, 734 (2010).

[5] H. J. Cheong, N. Fukuda, H. Sakai, S. Ogura, K. Takeuchi, R. Nagahata, and S. Uemura, Jpn. J. Appl. Phys. **53** (2014) 05HA12-1.

[6] P. K. Nayak, M. N. Hedhili, D. Cha, and H. N. Alshareef, Appl. Phys. Lett. **100** (2012) 202106.

[7] B. Y. Su, S. Y. Chu, Y. D. Juang, and H. C. Chen, Appl. Phys. Lett. **102** (2013) 192101.

[8] H. J. Cheong, S. Ogura, M. Yoshida, Hirobumi Ushijima, N. Fukuda, and S. Uemura, J. Photopolym. Sci. Technol. Accepted.

[9] H. J. Cheong, S. Ogura, Hirobumi Ushijima, M. Yoshida, N. Fukuda, and S. Uemura, AIP Adv. Submitted.

[10] J. H. Lim, J. H. Shim, J. H. Choi, J. Joo, K. Park, H. Jeon, M. R. Moon, D. Jung, H. Kim, and H. J. Lee, Appl. Phys. Lett. **95** (2009) 012108.