Ink-Jet Printed Oxide Semiconductor Transistors

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Abstract

We studied ink-jet printing for selective deposition of soluble oxide semiconductor to fabricate transistor. Sol-gel derived ZTO solution was synthesized for ink-jet printable solution. Transistors were produced by printing oxide layer between ITO electrodes. We demonstrated that ink-jet printed ZTO transistors work well and surface treatment significantly influences device performance.

1. Introduction

Traditionally, lithography technology has been widely used in the thin film transistors for patterning. However, there is currently significant interest in realizing high performance thin-film transistors (TFTs) based on solution processable semiconducting materials for applications requiring low-cost, low-temperature manufacturing for large area display devices.[1-3] Ink-jet printing technique of functional materials is one of the alternative technique of high-cost lithography due to its low temperature process, directing writing, solution processing, rapid prototyping and low cost.[4] Ink-jet printing requires low viscosity liquid phase materials, i.e, inks, to be printed through a nozzle, from which the semiconductive layer forms after drying. For such semiconducting inks, soluble processable organic semiconductors were used such as poly[5.5'-bis(3-dodecyl-2-thienyl)-2.2'-bithiophene] (PQT-12), poly(3-hexylthiophene) (P3HT) or α,ω-dihexyl-quaterthiophene (DH4T).[5-6] However, their electrical properties are unstable in ambient air. In this regard, inorganic inks such as silicon and zinc indium oxides have been reported recently.[7] Especially, several multi-cation oxides – zinc tin oxide, zinc indium oxide, and indium gallium zinc oxide – have been shown to provide improved performance, as compared to organic semiconductor and amorphous Si.[8-9] In this study, we developed a semiconductive ink which contains zinc tin oxide precursor. The ink was stable so that the printing can be performed in air. The printing conditions such as pulse frequency, pulse amplitude, and xy-stage moving velocity were optimized to achieve smooth semiconducting layer with high resolution. Thin film transistor were fabricated with this semiconducting layer and I-V measurement was performed.

2. Experimental

In this article, we synthesized a Sn-doped ZnO precursor solution using acetate salts and prepared a suitable ink for ink-jet printing technique by adding a various solvents. We analyzed the variation of electrical performance depending on morphology of printed pattern, based on thin-film transistors with amorphous ZTO layers printed onto substrates either pre-heated at various temperatures or with different surface energy. In addition, the influence of source/drain electrode on electrical performance was also investigated for obtaining the transistor with the best electrical performance. At first, we ink-jet printed a prepared ink onto a bare SiO2/n+-Si substrate, and the control of surface property of substrate is easier than the control of an ink composition for high contact angle, we controlled the wettability of substrate using a simple wet chemical method which is so called self-assembled monolayer molecules (SAMs)-treatment. in which it is observed that the regular patterns without any coffee-ring morphology are formed onto substrates pre-heated at both 50 and 80 oC.

3. Results and discussion

We have synthesized Sn-doped ZnO precursor solution for depositing oxide semiconductor layer by either spin-coating or ink-jet printing. The transistor based on spin-coated ZTO (30 mol% Sn addition) exhibits the mobility of 1.14 cm2/Vs and the on/off ratio of 5x106 when annealed at 500oC.

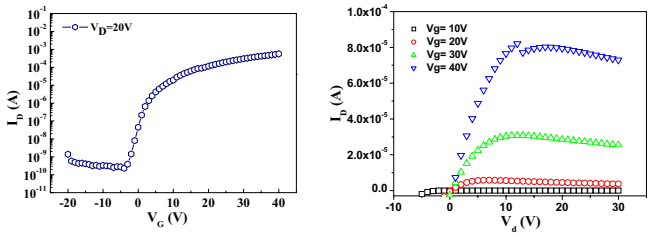

Fig.1. I-V Characteristic of ZTO transistor (Spin coating)]

We demonstrated the ink-jet printed ZTO transistor with a relatively highr mobility and on/off ratio based on ITO source/drain electrodes.

We studied a method of patterning of the semiconductor layer on SiO2 substrate by ink-jet printing of ZTO sol-gel ink. The ink was synthesized from zinc acetate and tin acetate in 2-methoxyethanol, and the viscosity of ink was 13.8 mPa-s. The ink was printed using a piezoelectric DOD ink-jet printing device and the nozzle orifice size was 50 μm diameters. The ejected droplet from nozzle has a diameter of about 59 μm and the velocity of 1.5 m/s. For high-performance ink-jet printed TFT, we controlled the substrate treatment type to obtain uniform oxide semiconductor layer. So, we controlled substrate treatment alcohol cleaning and HMDS treatment.

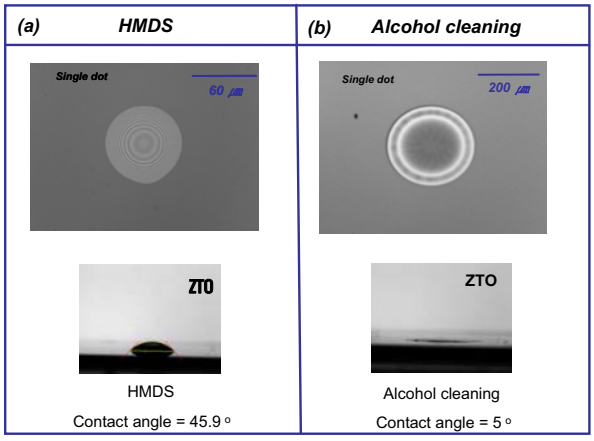

Fig. 2. Optical microscope image and contact angle of single droplet of the ink-jet printed ZTO on different substrates treated by either (a) HMDS or (b) alcohol cleaning.

Figure 2 is optical microscope image of ink-jet printed ZTO patterns with varying the substrate treatment type. As shown in the figure, a single droplet`s thickness of HMDS was too thick to applied to TFT. But, surface condition of single drop by alcohol cleaning was as uniform and thin as applied to TFT.

Moreover, the transistor I-V characteristic based on ink-jet printed ZTO (30 mol% Sn addition) with HMDS treatment had lower value compare with I-V characteristic with alcohol cleaning. the I-V characteristic based on ink-jet printed ZTO with HMDS treatment exhibits the mobility of 0.0162 cm^2/Vs and the on/off ratio of 10^4. and, the I-V characteristic based on ink-jet printed ZTO with alcohol cleaning exhibits the mobility of 0.58 cm^2/Vs and the on/off ratio of 10^7.

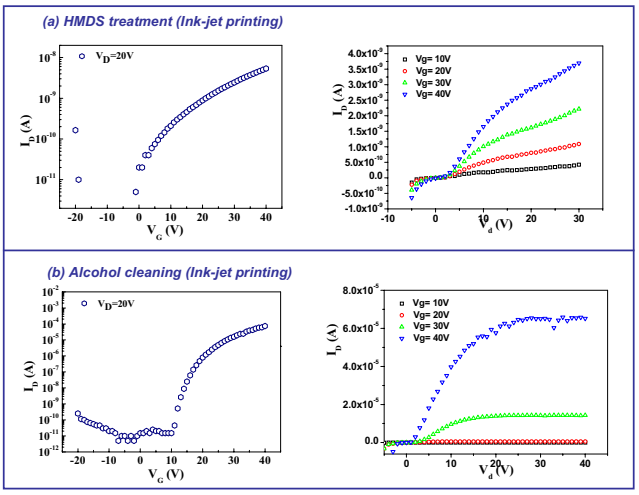

Fig. 3. I-V characteristic of the ink-jet printed ZTO transistors fabricated on different substrates treated by either (a) HMDS (b) alcohol cleaning.

We demonstrated the substrate treatment plays an important role in determining the transistor characteristics when the device is fabricated by ink-jet printing. and We inspect reliability of I-V Characteristic of ink-jet printed ZTO transistor.

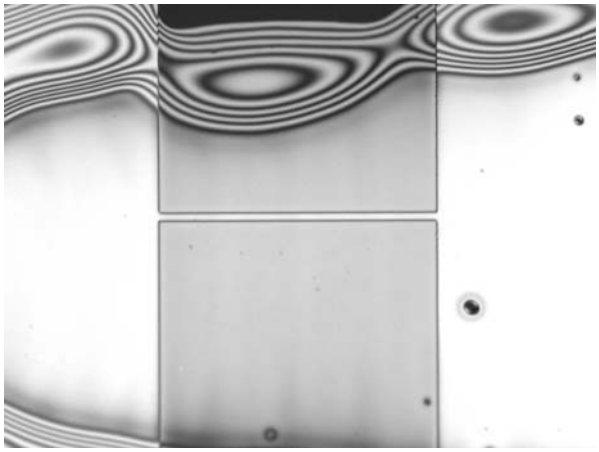

Fig. 4. ZTO semiconducting layer was patterned on ITO electrodes which patterned on the silicon oxide.

4. Summary

Recently, much research efforts have been directed to use ink-jet printing technology for a variety of the fields such as displays and electronics. We developed a semiconductive ZTO ink and achieved a technique by which the well-defined pattern is produced by ink-jet printing. This offers the potential of replacing photolithography which involves several complex processing steps.

5. References

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