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Bending test of organic TFTs with a soluble polycrystalline semiconductor

Takeyoshi Tokuhara[1], Tsuyoshi Sekitani[1], Tomoyuki Yokota[2], and Takao Someya[1,2,3]

[1]Department of Electrical and Electronic Engineering and Information Systems, University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Phone: +81-3-5841-6756 E-mail: tokuhara@ntech.t.u-tokyo.ac.jp
[2]Department of Applied Physics, University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[3]Institute for Nano Quantum Information Electronics (INQIE), University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

1. Introduction

Mechanical flexibility is one of the important features in organic thin-film transistors (TFTs). In flexible applications such as artificial skins [1], RFID tags [2], and displays [3], they presuppose bending during use. However if we bend them, we can easily estimate that their electrical properties change (often degrade) or they may be destroyed at a bending radius due to the damages to the electrodes, insulator and semiconductor layer. We can assume that in those applications, the bending radius during use is a few millimeters at the smallest. So it is important to know how the electrical properties change when the bending radius is around a few millimeters and the limit of bending.

Organic TFTs can be fabricated in solution process. Solution process like printing, spin-coating, and dipping enables to fabricate large-area devices with few process steps and is easy and cost-effective process. Therefore solution process is suitable for mass production. Recently, many solution-processed transistors with high mobility have been reported [4-5], and bending effects on the transistors with evaporated semiconductors has already been reported [6], however there are no reports of the bending test with the semiconductor layer being formed in solution process.

In this study, we report the bending experiments of organic TFTs with a semiconductor layer being formed by drop-casting a polycrystalline semiconductor solution, when they are continuously bent in the tensile or the compressive direction. When they were bent in the compressive direction, the drain current increased by 20~30% at the bending radius of about 1 mm.

2. Fabrication process

The structure of an organic TFT is shown in Fig 1. The transistors were fabricated by vacuum evaporation and solution processes. First, 50-nm-thick Au layer was thermally evaporated through a shadow mask as gate electrode on 75-nm-thick polyimide films. Second, about 500-nm-thick parylene layer was formed by chemical vapor deposition as gate dielectrics. Then the organic semiconductor layer (Lisicon OSC, Merck) was formed by drop-casting solution on a tilted substrate and annealing at ambient temperature in air atmosphere. This method of drop-casting organic solution on tilted substrate is reported as a method that improves the mobility [7] due to the ordered crystalline orientation [8].

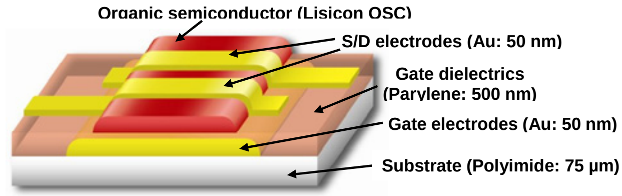

Fig 1. The structure of an organic TFT

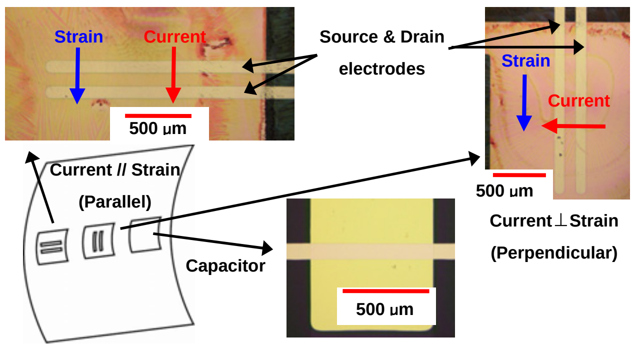

Fig 2. Optical microscope images of two transistors and a capacitor for bending test with an image of bending

Finally, 50-nm-thick Au layer was evaporated through a shadow mask to form the source and drain electrodes. The channel length, channel width and line width of the device for bending test was 100 μm, 1600 μm, and 100 μm, respectively. The photographs of the transistors fabricated in this process and the capacitor with a schematic of the devices for bending test are shown in Fig. 2.

3. Results

Fig. 3 shows the typical transfer characteristics and output characteristics of an organic TFT. All measurement was done in the air. This TFT showed low leakage current and no hysteresis. The mobility extracted from Fig 3 (a) was 1.5 cm^2/Vs in the air, the on/off ratio was 1.1×10^5, and the threshold voltage was -15 V.

Then we applied bending strain to these transistors using a precision mechanical stage. The bending radius was evaluated by precisely fitting the bending curvature of the base plastic film at each gap in side-view photographs taken by a digital camera in advance. And we bent the devices continuously from the bending radius of about 18 mm to around 0.1 mm, which was almost equal to the limit in this measurement system.

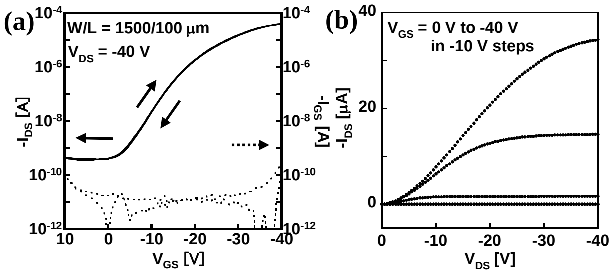

Fig 3. (a) Transfer characteristics and (b) output characteristics of a fabricated organic TFT before bending, and measured in air atmosphere

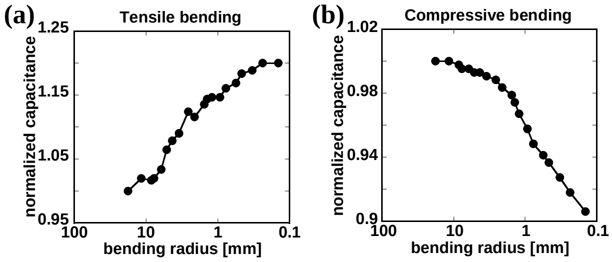

Fig 4. The capacitance as a function of bending radius, bending in (a) tensile and (b) compressive direction

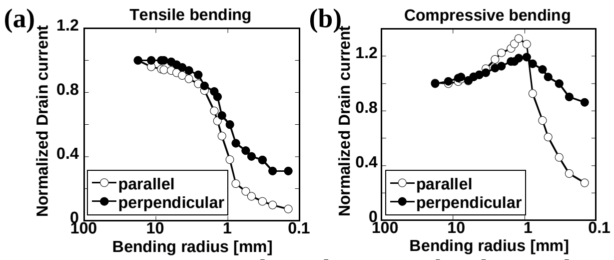

Fig 5. Drain current dependence on bending radius during bending in (a) tensile and (b) compressive direction, and the current flows perpendicular or parallel to the bending-induced strain in each TFT

Fig 4 shows the normalized capacitance change of the capacitor during bending the device illustrated in Fig 2. In Fig 4, the change in the capacitance when the capacitor was bent in the tensile direction was about two times as large as the change when it was bent in the compressive direction. This indicates the parylene dielectrics are so sensitive to the tensile bending that the electrical properties such as the drain or the leakage current are possibly degraded by bending in the tensile direction.

Fig 5 (a) shows the change of the normalized drain current during bending the device in the tensile direction, and (b) shows the change of the normalized drain current during bending in the compressive direction. In each figure, two kinds of transistors, in which the drain current flows either parallel or perpendicular to the bending-induced strain, were plotted. From these figures, it can be seen that when the transistors were bent in the compressive direction, the drain current increased till the bending radius was decreased about 1 mm and then decreased when the bending radius was smaller than 1 mm. While when they were bent in the tensile direction, the drain current decreased monotonically. In this measurement, all transistors worked not being destroyed at the bending radius of around 0.1 mm, which is quite small value compare to the previous works [6] [9].

4. Conclusions

In this work, we have fabricated flexible organic TFTs using a polycrystalline organic semiconductor solution on polyimide films. The TFTs showed no hysteresis and low leakage current, and the mobility was 1.5 cm^2/Vs. Then we tested its flexibility applying bending stress to them without an encapsulation layer. As the bending radius became smaller than 1 mm, the drain current decreased, but the all transistors were not destroyed when the bending radius was around 0.1 mm, which is enough small value compare to previous works [6] [9]. In future, we can improve these degradations in the drain current and the mobility by reducing the bending stress with the encapsulation layer of the same thickness as the base films [9] or thinner base plastic films.

5. Acknowledgements

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6. References

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