A-6-1(Invited)

Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp938-939

# Inkjet Printing of Organic Thin-Film Transistors

Takeo Kawase, Soichi Moriya, Kiyoshi Nakamura, Keiichi Inoue,
Kazuya Nakamura and Takashi Aoki

Seiko Epson Corporation
Fujimi Plant, 281 Fujimi, Fujimi-machi, Suwa-gun,
Nagano-ken 399-0293, Japan
Phone: +81-266-61-1211 E-mail: kawase.takeo@exc.epson.co.jp

## 1. Introduction

Recently, the market of e-book is showing a remarkable growth. Current reader devices are equipped with a rigid display panel, and customers will expect much lighter weight and flexible devices in the next stage. There have been many flexible backplane demonstrations which are based on a-Si[1], LTPS[2] or oxide thin-film transistor (TFT)[3] technology. Compared to these inorganic TFTs, organic TFTs (OTFTs) have advantages in low temperature processability and stress-crack resistance. It is difficult to obtain good TFT performance with inorganic semiconductors deposited at low temperature at which plastic substrates are stable. Moreover, inorganic TFTs contain inorganic dielectrics, in which cracks are easily generated due to internal or external stress. It is true that many reports show that they withstand cyclic bending tests, but the stress patterns applied in such tests are simpler and milder than the stress experienced during assembling processes and actual use. One will find many cracks in a flexible backplane after a steel ball hits its surface. Organic films, especially polymer films, are more robust to such stress than inorganic layers. From these points of view, organic TFTs will become competitive technology over inorganic TFTs in the field of flexible devices, and it can be reinforced by introducing the efficient productivity of printing technology.

## 2. Hybrid Printing Approach

It has been 10 years since we reported inkjet printing of polymer TFTs[4]. In this period, there have been a number of reports on the fabrication of OTFT backplanes and circuits by inkjet printing. Some of them achieved all-inkjet-printed devices[5,6], and the others showed OTFTs fabricated by hybridizing inkjet printing and conventional deposition / patterning processes[7-10]. This approach could be the first step to the manufacturing of printable OTFTs, and the most efficient combination of inkjet printing and other matured process should be pursued. Fig.1 proposes that the combination ratio of printing approaches and photolithography should be varied depending on the resolution and the size of display panels. In the region of high resolution, photolithography, which has higher resolution than inkjet printing, is needed in the patterning of electrodes, signal lines or via holes. Inkjet printing, which does not cause any functional degradations in patterned materials, is indispensable in a semiconductor formation process. As resolution becomes lower, photolithography can be replaced by inkjet, which has sufficient resolution in such a region. Moreover, when patterning on a large plastic substrate is required, the instability of substrates makes patterning by photolithography more difficult. All inkjet-printing fabrication will become a realistic approach in the manufacturing of very large flexible panels, which are expected to be used for digital signages. We have been developing a hybrid printing approach, in which complex patterns of source and drain electrodes, interconnections, pads are formed at the same time by photolithography, and then other parts are added by inkjet printing. The patterns of the inkjet-printed parts are limited to simple arrays of dots or straight lines, which are printable in the minimum process time. The hybrid approach of photolithography and inkjet printing considered to be beneficial in terms of not only resolution but also process time.

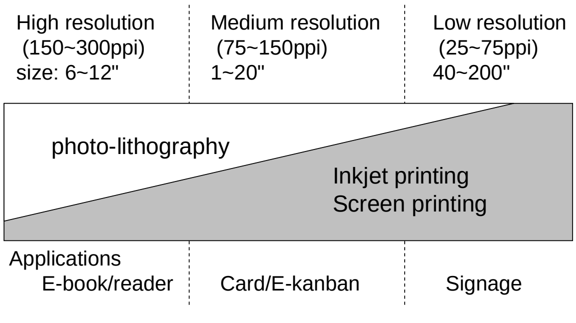


Fig.1 Combination ratio of photolithography and printing approach..

## 3. Inkjet Printing of Semiconductor

The process of inkjet printing semiconductor involves several steps of from ink formulation to drying or solidification. There are technical issues in each step as shown in Fig. 2, and related properties are needed to be

Table.1 Technical issues in the step of inkjet printing.

| printing steps | technical issues | related factors |
|---|---|---|
| ink preparation | ink stability | polymer solubility<br>molecular weight |
| ejection of ink droplet | nozzle blocking<br>ejection stability | boiling point<br>viscoelasticity<br>driving waveform |
| ink landing and spreading | ink confining | surface tension<br>surface free energy<br>viscosity |
| dying / solidification | uniformity control<br>coffee-stain effect<br>crystallization | viscosity<br>drying conditions<br>molecular weight |

optimized. However, they are often incompatible with each other or semiconductor performances. High mobility, for example, comes from strong molecular cohesion, but it prevents material from dissolving in organic solvents and this makes it difficult to formulate a stable ink. Viscosity acts as resistance in inkjet ejection and hinders jetting droplets especially at a high rate, but stabilizes droplets deposited on a substrate, which leads to the formation of uniform films. In this sense, inkjet printing is not as great in universality as photolithography. Depending on devices or processes, basic maters such as material, ink formulation, ejection and drying conditions should be developed by overcoming the contradicting properties. We optimized these properties for fabricating the backplanes of electrophoretic displays, and have achieved both stable inkjet printing and acceptable TFT performance. Stable ink ejections from all 180 nozzles in an inkjet head, sufficient accuracy of registration in the middle resolution region, and constant morphology among printed semiconductors are obtained. The TFT characteristics in ambient condition shown in Fig. 2 are found to be stable after a bias test.

In order to accelerate such a development, we need to understand "printing physics" including the behavior of conjugated molecules in solution, micron-scale fluid dynamics of solutions, or liquid-solid interfacial phenomena. Industry-academia collaborations are expected in this effort, and will promote the emergence of printable electronics.

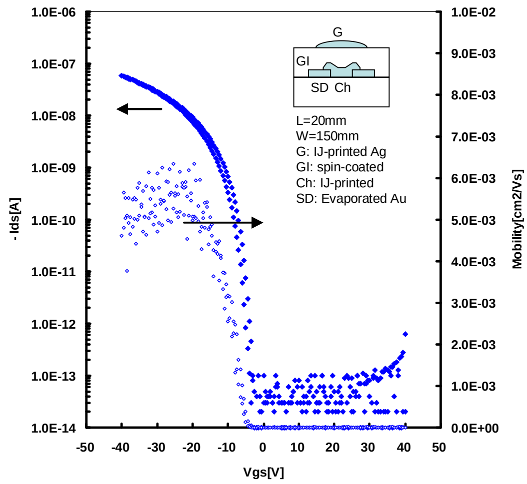


Fig.2 Transfer characteristics of inkjet printed OTFT.


### Acknowledgements
We would like to thank Mr. T. Miyamoto, Mr. T. Saeki and Mr. T. Katakabe for their technical support in the evaluation and preparation of samples.


### References


[1] Y. Okada, A. Ban, M. Okamoto, W. Oka, Y. Matsuda, S. Shibahara, SID'02 DIGEST (2002)1204

[2] H. Kawai 1, M. Miyasaka, A. Miyazaki, T. Kodaira, S. Inoue, T. Shimoda, K. Amundson, R. J. Paolini Jr., M. McCreary, T. Whitesides, SID'05 DIGEST (2005) 1638

[3] D. Jin, J. Lee, T. Kim, S. An, D. Straykhilev, Y. Pyo, H. Kim, D. Lee, Y. Mo, H. Kim, H. Chung, SID'09 DIGEST (2009) 983

[4] H. Sirringhaus, T. Kawase, R. H. Friend, T. Shimoda, M. Inbasekaran, W. Wu and E. P. Woo, Science, 290 (2000) 2123

[5] J. H. Daniel, A. C. Arias, W. S. Wong, R. Lujan, B. S. Krusor, R. B. Apte, M. L. Chabinyc, A. Salleo, R. A. Street, N. Chopra, G. Iftime, P. M. Kazmaier, SID’05 DIGEST (2005) 1630

[6] K. Suzuki, K. Yutani, A. Onodera, T. Tano, H. Tomono, A. Murakami, M. Yanagisawa, K. Kameyama, I. Kawashima, Proc. IDW'08 (2008) 1477

[7] S. Moriya, T. Miyamoto, T. Saeki, T. Kawase, S. Inoue, T. Shimoda, SID’06 DIGEST (2006) 277

[8] S. Kim, J. Bae, T. Ahn, M. C. Suh, S. W. Chang, Y. Mo, H. Chung, S. Lee, IMID’07 DIGEST (2007) 151

[9] N. Kawashima, N. Kobayashi, N. Yoneya, H. Ono, T. Fukuda, T. Ohe, Y. Ishii, A. Nomoto, M. Sasaki, K. Nomoto, SID’09 DIGEST (2009) 25

[10] J. Kim, B. Song, D. H. Kim, B. W. Yoo, J. Lee, Y. Yi, H. Kwon, M. H. Jung, J. Jang, J. Jung, B. Lee, J. Park, B. Koo, Y. W. Jin, S. Lee, J. Kim, SID’10 DIGEST (2010) 572