Printed polymer and a-Si TFT backplanes for flexible displays

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Abstract
The need for low cost flexible TFT display backplanes has focused attention on new processing techniques and materials. We have developed backplane technology based entirely on jet-printing, using a combination of additive and subtractive processing, and have applied this technique to both amorphous silicon and polymer TFT arrays.

1. Introduction
Jet-printing is an interesting patterning technique for electronic devices because it requires no physical mask, has digital control of ejection to provide drop-on-demand printing, and is also a non-contact process. The combination of additive and subtractive jet-printing provides flexibility in the choice of materials and structures as well as excellent layer-to-layer registration. We describe the fabrication of TFT arrays on glass and flexible substrates, measurements of device lifetime, and the performance of reflective displays.

2. Jet-printed TFT devices and arrays

2.1. Printing methods
The jet printing systems developed at PARC use piezo-jet print-heads based on commercial Xerox technology with about 600 independently addressable ejectors, as well as other commercial print-heads.

Two methods are used to fabricate devices by jet-printing. With *Digital Lithography*, an etch mask is jet-printed and used to pattering conventionally deposited thin films (metals, dielectrics and semiconductors) [1,2]. Our technique achieves precise features by printing a molten wax which freezes on contact with the substrate. The wax mask technique allows patterning of arbitrary films on various substrates. Figure 1 shows an example of a printed wax mask and the resulting etched film.

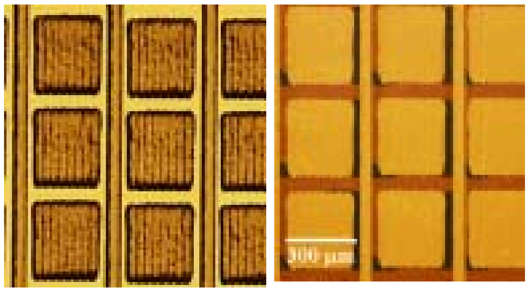

Figure 1 Photograph of the printed wax mask on a metal film (left), and the resulting etched layer (right).

Additive printing is the direct deposition and patterning of an active material. This technique has been used by several groups for printed OLEDs, color filter, metals and polymer semiconductors [3]. Our research has focused on the printing of polymer semiconductors, as described further below [4,5].

2.2 Digital lithography of amorphous silicon on glass and flexible substrates
Figure 2 shows part of an amorphous silicon (a-Si) TFT array fabricated using digital lithography in a 4 mask process. The 128x128 pixel array has 75 dpi resolution. Since conventional materials are used, the TFT characteristics are essentially identical as for conventional processing.

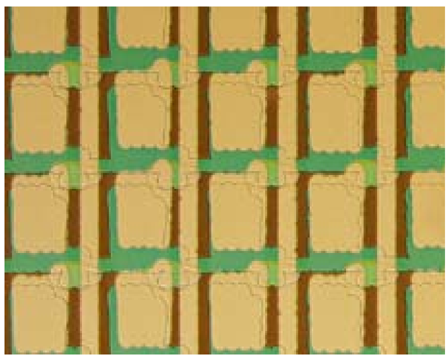

Figure 2. Part of a a-Si TFT array fabricated using digital lithography.

In order to fabricate a-Si TFTs on flexible PEN by digital lithography, it was first necessary to develop a low temperature process for a-Si and the gate dielectric. Devices deposited at 170C achieved a performance equivalent to the high temperature material. A TFT array on such a substrate is shown in Figure 3 and the TFT transfer characteristics are given in Figure 4, showing that the digital lithography process is successful for TFTs on plastic substrates.

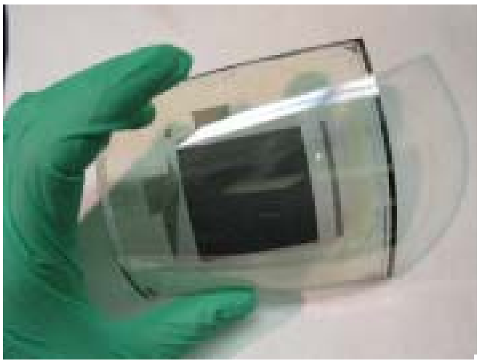

Figure 3. Photograph of a flexible printed amorphous silicon TFT array using a low temperature deposition process.

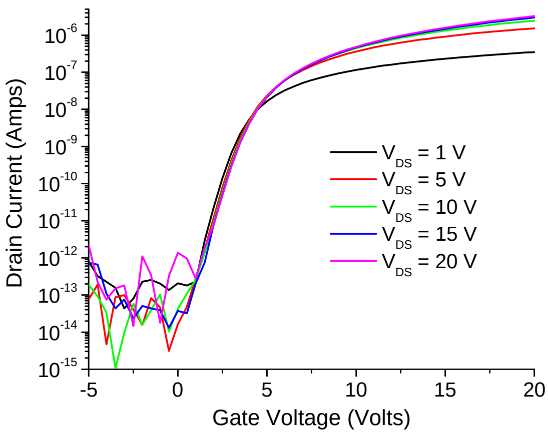

Figure 4. TFT characteristics for a-Si deposited onto flexible substrate at 170C

2.3 Additive printed polymer TFTs

Additive jet-printing requires solution-based materials and suitable metal, insulator and dielectric materials are available. Our research has focused on additive jet-printing of polymer semiconductors. Specifically, we use a polythiophene polymer which results in TFTs with mobility of about 0.1 cm^2/Vs, and on/off ratios of ~10^7, giving them a suitable performance for flat panel displays [5].

The printing process fabricates bottom gate TFTs with coplanar source and drain contacts. This structure is similar to conventional a-Si TFTs. It is also convenient because the metal and dielectric layers are completed before the semiconducting polymer is deposited, thus minimizing the possible degradation of the polymer from subsequent processing. Our process uses subtractive printing to pattern the metal and dielectric layers, but additive printing of these materials can be expected in the future. Figure 5 shows part of a polymer TFT array made by this process. Alternatively the metals and dielectric layers could be patterned by conventional photolithography and only the polymer jet-printed.

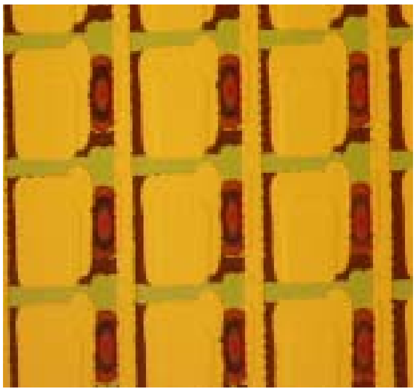

Figure 5 Photograph of part of a 128x128 pixel printed polymer TFT array.

3. Prototype displays

TFT backplanes have been integrated with reflective display media to make small prototype displays. The intention is to demonstrate that digital lithography and additive printing are a practical means to fabricate both a-Si and polymer active matrix arrays, and that polymer semiconductors can operate displays.

We have tested both gyricon and electrophoretic display media with a-Si and polymer TFTs. Either 1- or 2-particle electrophoretic media were encapsulated in an SU8 cell structure and laminated onto the backplane. An example of a display with a print-patterned a-Si TFT backplane is shown in Figure 6, and operates at a gate voltage of 15-40V.

The gyricon media comprises rotating bichromal spheres, and has the characteristics of excellent bistability, with a high operating voltage of 60-100V. Operation of this display with printed polymer TFTs was successfully demonstrated, with brightness and contrast that are consistent with the known properties of the media, and an image is shown in Figure 7.

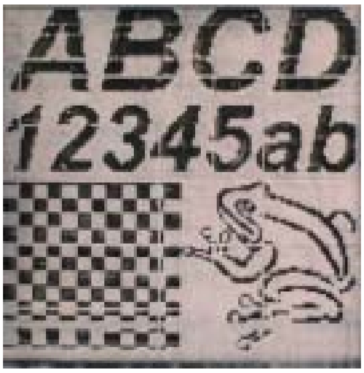

Figure 6. Reflective electrophoretic display made using the printed TFT backplane.

One of the printed polymer TFT gyricon displays has been tested intermittently for about a year with no obvious degradation, despite being stored in room light ambient. This shows that the media provides sufficient protection so that transistors degradation is not a significant problem. However, the polymer TFTs show significant bias-stress effects, particularly at high gate bias, and extended lifetime studies are needed to evaluate the effects.

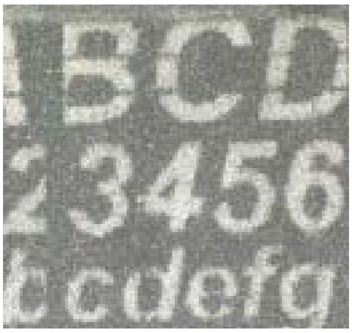

Figure 7. Reflective display fabricated from a 128x128 printed polymer TFT array with gyricon media.

4. Summary

Jet-printing is a versatile method of patterning electronic devices and particularly flat panel displays. The combination of printed etch masks and additive printed active materials allows almost any combination of materials to be patterned. Although the feature sizes are still large, due to the existing print-heads, significant reduction in size can be expected as the printing technology develops.

5. Acknowledgements

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6. References

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