

## **Printed thin film transistors to be discussed in Tokyo**

A diverse toolkit of electronic components can today be printed. These include batteries, antennas, memories, sensors, etc. An important building block linking all these components is the printed thin film transistor. This vital device enables logic and therefore data processing. Despite years of development however, printed transistors are not yet a commercial reality.

Far Asia is the primary centre for the development and production of thin film transistors, which are used in display, X-ray detectors, large-area photosensors, etc. Global companies like Samsung and LG are leading the way. This has promoted us to dedicate a session to "Printed Logic" in our Printed Electronics Asia event, [www.PrintedElectronicsAsia.com](http://www.PrintedElectronicsAsia.com) [1], which takes place October 2-3, 2012 in Tokyo.

In this short article, we will give a brief overall assessment of printed electronics, outlining critical challenges facing printed transistors from both a market and technical prospective. This article will help set the parameters for the debate that we hope to promote in our event.

### **Where is the value in printing transistors?**

Today, we have a rapidly increasing range of material options available for fabricating TFTs, including oxides, organics, etc. In spite of this, amorphous and polycrystalline silicon remain the dominant technologies.

The current fabrication methods are all subtractive, regardless of the specifics of the deposition or annealing technique (e.g., plasma enhanced chemical vapour deposition, sputtering, excimer laser annealing, etc). This is because a photolithographic patterning technique can require more than six steps for depositing a single layer. In addition, much of the deposited material is etched away and thus wasted. This adds to both the bill of materials and the processing cost.

In contrast, printing techniques offer an additive fabrication technique. Here, a layer can be directly deposited with as little as three steps. More critically, material wastage will be minimised. These two factors indicate a potential cost saving. It is this strong rationale that underpins the drive towards printed thin film transistors.

Printing thin film transistors offer numerous other advantages too. Primary amongst them are the ability (a) to cover large areas and (b) to print on low-temperature flexible substrates such as paper. Both these attributes can enable a broad range of new markets including ultra large sensor arrays, smart packaging and point-of-sale posters, etc.

### **What are the challenges?**

The technology is at a state where we have a range of printable semiconductor (e.g., the active channel in the transistor) at our disposal. This toolkit includes organics, oxides, CdSe, crushed silicon, liquid silicon, carbon nanotubes, nanowires, etc. None of these semiconductors offer a one-size-fits-all solution and all suffer from significant limitations, including:

**Low mobility:** field-effect mobility is a key figure-of-merit which determines how fast transistors can switch. Printable semiconductors typically struggle to reach the 0.5-1 cm<sup>2</sup>/Vs mark. Even reaching this value will not be sufficient for many emerging applications, including OLEDs. Indeed, it may not be sufficient to displace the current incumbent technologies, such as amorphous and polycrystalline silicon, which offer 1 and >100 cm<sup>2</sup>/Vs, respectively.

**Low stability:** thin film transistors are interfacial devices. A poor interfacial quality (e.g., high density of defect states) will result in unstable devices whose characteristics change during operation. In addition to this, the absence of ultra-high-performance encapsulation can lead to device degradation, particularly when organic semiconductors are involved. This is a major handicap because circuits are designed to tolerate a range of characteristic variations and will cease to function once the device drifts out of the compliance range. Increasing the compliance range will significantly drive the costs up as it often requires incorporating more transistors.

**Low spatial uniformity:** device characteristics must remain uniform across the device surface in order to maintain a uniform brightness distribution. Therefore, the manufacturing technique must be able to reproduce the same conditions (geometry, contact, interface, etc) over large areas. This is proving to be a major challenge with printing equipment.

**Dielectrics:** research has been mainly focused on printed semiconductors. This, however, is only a part of the picture. We will also require reliable, pin-hole-free printable dielectrics. This is a challenge, particularly because the annealing and wetting properties of the ink must be compatible with both the under- and over-lying layers. In addition, the printed dielectric must withstand subsequent processing conditions. The outstanding questions over printed dielectrics are likely to mean that printed transistors will initially consist of hybrid structure in which only the semiconductor and the conductors are printed.

**Low temperature annealing:** flexible substrates tend to have a low annealing temperature. They will constrain the device processing conditions. In turn, this constraint will lead to poor device performance because often high-temperature annealing is a prerequisite for high-quality devices.

In addition to technical challenges, printed thin film transistors are actively searching for markets. In many application areas, the main go-to-market strategy is replacing an existing component/layer in a product. This is a challenge because the incumbent technology is often well-entrenched. Two primary high-volume target markets for printed transistors are:

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RFID tags: here the printed versions are envisioned to replace crystalline silicon chips. The challenges however are the HF and UHF communication protocol require the integration of thousands of transistors running at 13.56 MHz and 865-960 MHz, respectively. Given the lack of uniformity, reproducibility and mobility, we assess that displacing silicon will be very difficult. In addition, printed chips will occupy more space. Finally, the RFID business is a pure cost game in which margins are very small (<1 cent) and huge volumes are required for reasonable profits.

Displays: printed thin film transistors may lower the production cost for display backplanes. The challenge here will be lifetime (i.e., change of characteristics during operation) and uniformity. Mobility will also be critical when moving towards OLED and/or 3D display. It is not clear whether printed thin film transistors can meet the technical requirements.

Our assessment is that printed thin film transistors will have to find niche markets in the first instance. These markets are likely to be on low-end disposable products. The printed circuits would require few transistor counts and would only perform simple logic. This approach is likely to require producers to design ready-to-go printed logic platforms which can be incorporated into end products.

The main challenge with this business model is that transistors are complex devices, requiring a large investment and R&D effort to optimise them. Manufacturers may therefore be reluctant to invest in the absence of established large target markets.

We invite to attend our Printed Electronics Asia show, [www.PrintedElectronicsAsia.com](http://www.PrintedElectronicsAsia.com) [1], in Tokyo to join the debate and learn about the latest developments in printed logic.

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### Links:

[1] <http://www.PrintedElectronicsAsia.com>