Thin Film Electronics – Electronics Anywhere

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Introduction

Microelectronics has been spectacularly successful at providing increasingly complex digital processing and memory, but thus far less successful at providing simple functions at very low cost. Thin film electronics offers an attractive alternative to conventional Ics for low-cost or large-area applications because device materials can be deposited and processed at low temperature and low cost. Amorphous silicon thin film transistors (a-Si:H TFTs) fabricated on glass substrates are widely used for active matrix displays, but a-Si:H TFTs can also be fabricated on flexible polymeric substrates with potential advantages in manufacturing cost and device applications. Organic thin film transistors (OTFTs) can be fabricated at much lower temperatures than a-Si:H devices and OTFT device performance now rivals or exceeds that of amorphous silicon devices. Low OTFT processing temperatures allow fabrication on a range of surfaces including cloth, paper, or polymeric substrates. Potential applications for organic TFTs include pixel access devices in active matrix displays, and low cost electronics for smart cards or merchandise tags.[1-4]

OTFTs have been demonstrated using a variety of organic semiconductors, including both polymers and small molecule materials. OTFTs fabricated on rigid substrates using pentacene as the active layer material have shown the best performance[5-6] with carrier field-effect mobility greater than 3 cm^2/V-s, subthreshold slope less than 0.4 V / decade, near-zero threshold voltage, and on/off current ratio larger than 10^8. These characteristics are similar to or better than those typically obtained for a-Si:H TFTs and are sufficient for a range of low-cost or large-area electronics applications.

Flexible Substrate Devices

We have fabricated OTFTs using pentacene as the active layer material on polyethylene naphthalate (PEN) substrates with performance similar to that obtained on silicon or glass substrates. Best measured mobility is greater than 2 cm^2/V-s with typical mobility near 1 cm^2/V-s and mobility uniformity near 5% (1 σ) over a 1 cm^2 area. Fig. 1 shows a PEN substrate with pentacene OTFT devices and both digital and analog circuits. The substrate also includes some simple polymer dispersed liquid crystal (PDLC) displays (the PDLC material is the milky material in the figure). Although the test displays were quite small (16 x 16 pixels) the displays were driven with standard ¼ VGA video timing signals (roughly what might be needed for a video capable PDA or cell phone) and demonstrated that OTFTs have the performance required for practical applications.[7]

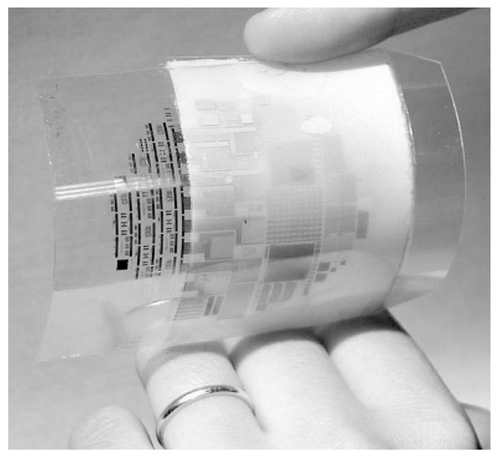

Figure 1. PEN OTFT substrate with devices, circuits and PDLC test displays.

a-Si:H TFT fabrication currently requires higher temperatures than OTFTs. It is possible to deposit high-quality a-Si:H at temperatures as low as 130°C or possibly even lower,[8] but the silicon nitride gate dielectric most often used for a-Si:H TFTs typically requires higher temperatures (usually >200°C) to obtain good characteristics. Figure 2 shows a-Si:H TFT devices and circuits fabricated on high-temperature polyimide substrates. A maximum process temperature of 250°C was used and the devices have characteristics similar to those fabricated on glass substrates.

Because a-Si:H TFTs are usually n-channel devices and most OTFTs are p-channel, organic and inorganic devices can be combined as a simple route to complementary circuits.[9] It is also relatively simple to combine TFTs of either or both types with polymer based microelectromechanical system processing or other processing to build complex light-weight or flexible devices. Figure 3 shows a gas microwell detector built using a-Si:H TFTs fabricated on a Kapton® substrate with a thick film photopolymer laminated and patterned on top of the TFT substrate.

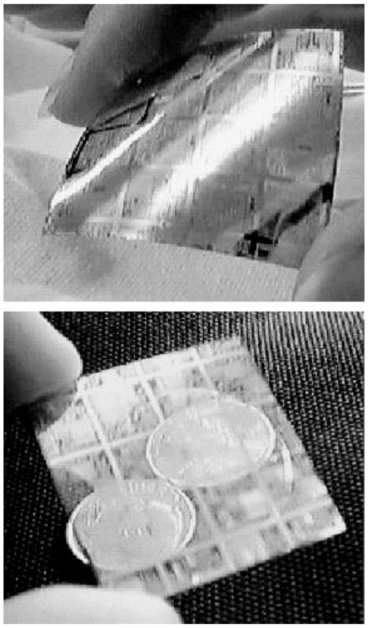

Figure 2. a-Si:H devices and circuits fabricated on Kapton® (top) and colorless polyimide (bottom) substrates.

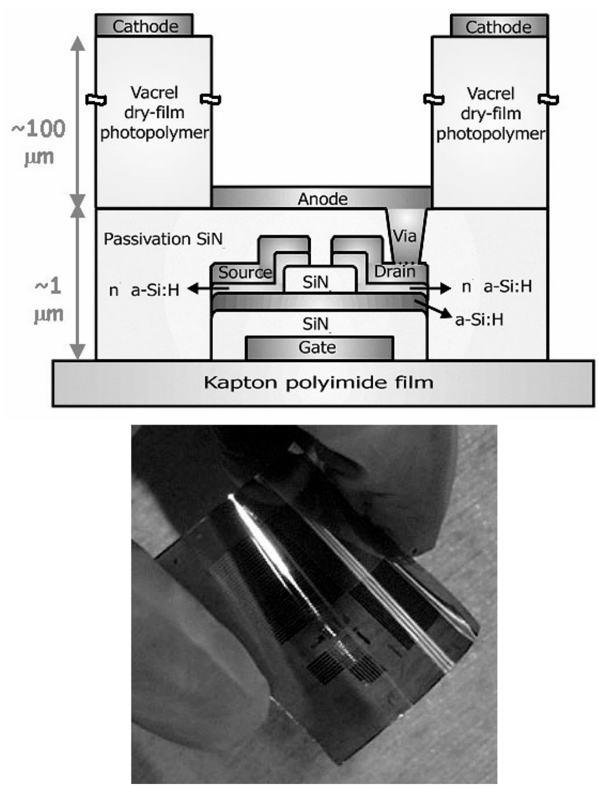

Figure 3. Gas microwell detector with thick photopolymer laminated on a-Si:H devices on fabricated on polyimide.

Organic or a-Si:H TFTs are also attractive devices for use in fabricating active backplanes for organic light emitting device (OLED) display backplanes. The current required for typical OLED pixels is low (µA) and can easily be provided by small TFTs.[10] Figure 4 shows a simple a-Si:H active OLED pixel fabricated on a glass substrate. A maximum pixel brightness of several hundred cd/m2 can be obtained with device voltage sufficiently low that it may be possible to correct for device instability using an external correction approach. The low processing temperatures required for a-Si:H or organic TFTs may also allow compatibility with barrier-coated or other flexible substrate approaches required for good OLED stability and lifetime.

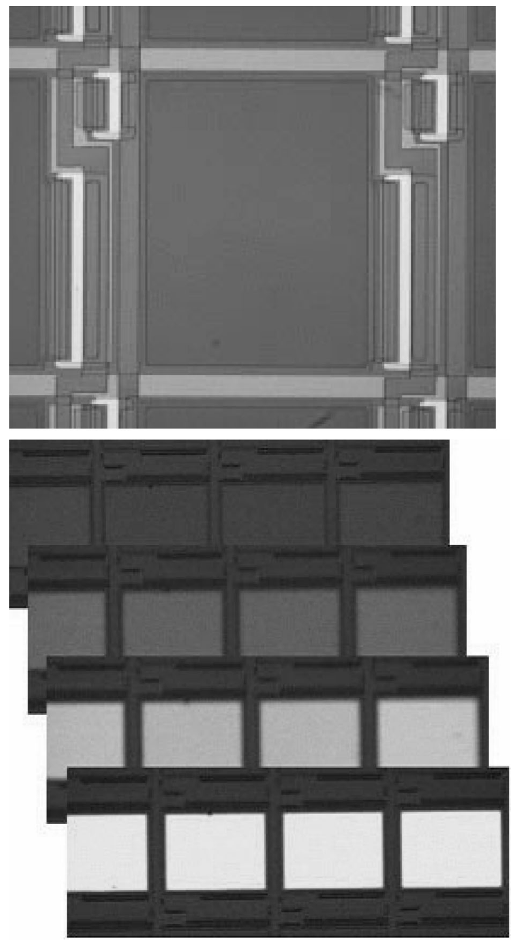

Figure 4. a-Si:H active OLED pixel (top) and pixel operation (bottom).

Future Directions

The low temperatures and simple processing required for a-Si:H and organic TFT devices and circuits allows fabrication on arbitrary substrates including flexible polymers and, for organic devices, even cloth or paper. This will allow a wide range of future large-area or low-cost electronic applications.

Acknowledgements

Collaborations with the Sarnoff Corporation, the Kent State Liquid Crystal Institute, Rensselaer Polytechnic Institute, Universal Display Corporation, NASA, and the support of DARPA, Wright Laboratory (Air Force), the Naval Surface Warfare Center (Navy), and NASA are gratefully acknowledged.

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Biography

Thomas N. Jackson, holder of the Robert E. Kirby Chair in Electrical Engineering at Penn State University, received his Ph.D. in Electrical Engineering from the University of Michigan in 1980. He joined Penn State in 1992 after twelve years with the IBM T. J. Watson Research Center. Dr. Jackson's research focuses on exploratory electronic devices and microfabrication techniques. His current areas of interest include organic and molecular electronics, thin film electronics, micro-electromechanical systems (MEMS), III-V and wide bandgap devices, and superconductor-semiconductor interactions. Dr. Jackson teaches courses in solid-state device physics and device fabrication technology and is the author or co-author of more than 150 publications and 22 U.S. patents. Dr. Jackson is a member of the Institute of Electrical and Electronic Engineers, the American Vacuum Society, the Electrochemical Society, and serves as treasurer for the Device Research Conference.