22-3. aSi Pixel Circuits on Plastic Substrates for Flexible AMOLED displays

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Abstract
a-Si TFTs with field-effect mobility of 1.2 cm²/V·s have been fabricated on plastic substrate. Pixel circuits on plastic for AMOLED were made with the same low-temperature fabrication process. The circuits compensate for V_T-shift, exhibit high output current, retain functionality and drive current level during long-time continuous operation.

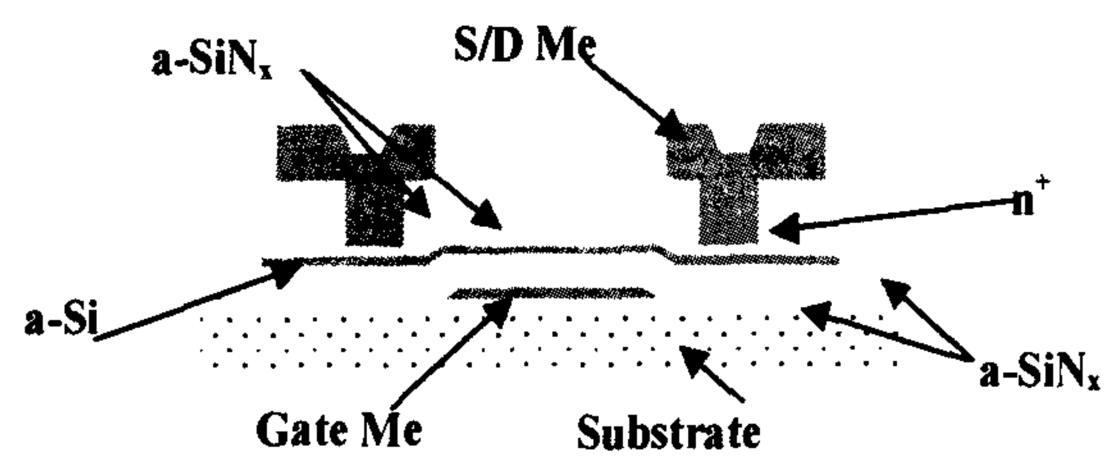

Figure 1 a-Si TFT device structure

1. Introduction
Between the family of competing active-matrix backplane technologies for AMOLED, which includes poly-Si, organic semiconductors and polymers, amorphous silicon (a-Si) technology is very mature, has a large manufacturing base and low production cost. Also importantly, it can be applied to flexible plastic substrates [1,2]. The inherent issue with a-Si thin-film transistors (TFTs) is the instability of the threshold voltage (V_T) under prolonged bias. The effect of V_T-shift in a-Si TFTs on OLED drive current can be managed in multi-transistor pixel circuits [3], although the lifetime of the circuit will be still dependent on the stability of TFTs and bias conditions. Thus the quality of TFT process is critical for stable circuit operation over extended periods of time and an important challenge for AMOLED on plastic with aSi backplane is to achieve high current capability of a-Si TFTs and minimize their V_T- instability while being limited in maximum process temperature. This paper demonstrates a-Si TFTs and V_T-shift compensated pixel circuit for AMOLEDs fabricated on plastic substrates with maximum process temperature of 150°C. Pixel circuits are characterized in terms of current driving capability, OLED current control, and long-term stability of operation.

2. Experimental
Single TFT devices and TFT pixel circuits were based on back-channel-passivated inverted staggered structure incorporating a-Si channel, a-SiN$_x$ films as gate dielectric and channel passivation

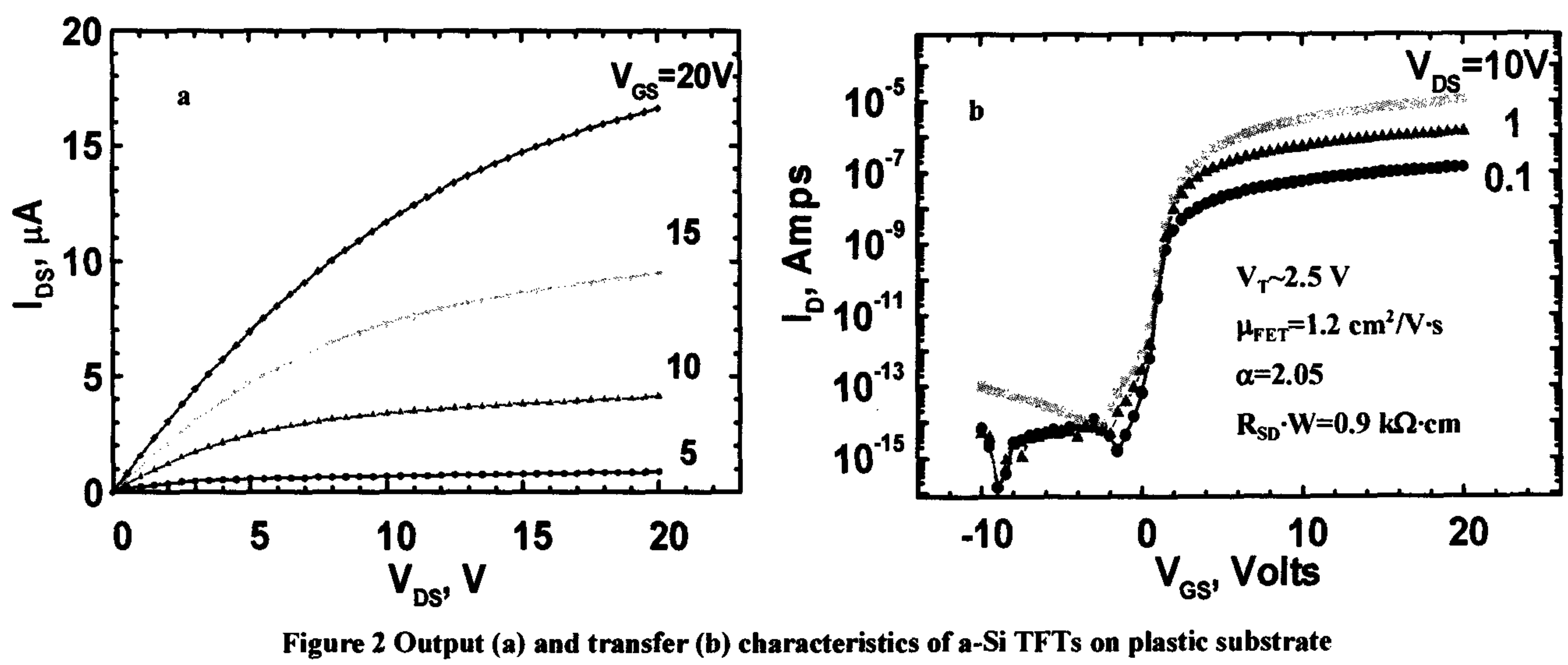

Figure 2 Output (a) and transfer (b) characteristics of a-Si TFTs on plastic substrate

layer and heavily doped n+ contact layer. Fabrication sequence included 5 photolithography steps [2]. The deposition temperature for PECVD layers, a-Si, a-SiN$_x$ and n+-layer, was 150°C. Process conditions were optimized to achieve appropriate material properties and good TFT performance. A 50 µm thick polyimide foil was used as a substrate. Prior to TFT fabrication, the substrate was mounted on a rigid carrier, annealed at ~200 °C and encapsulated with ~300 nm-thick 150°C-a-SiNx layer. This way, the misalignment between layers in a TFT could be reduced to 50-70 ppm. TFT device structure is shown on Fig.1. Sputter deposited

120 nm-thick Al/Cr-stack and ~0.8 µm-thick Al were used as gate and source/drain metal, respectively. The thickness of aSiNx-gate dielectric and channel passivation layers was ~300 nm, aSi channel was 30-40 nm thick and the thickness of n+-contact layer was 60 nm. Completed devices were annealed at ~130 °C to improve contact quality. TFTs and TFT circuits on plastic substrate were characterized by means of DC current-voltage measurements. Similar TFT circuits on glass substrates fabricated with the same low-temperature process were used in life-time tests under pulsed bias conditions

3. Results and discussion

3.1. a-Si TFTs on plastic substrates

Characteristics of a TFT with W/L=100µ/23µm are shown on Fig.2. TFT performance parameters, threshold voltage, V_T, field-effect mobility, μ_{FE}, sub-threshold slope, S, series (contact) resistance, R_{SD}, ON-current exponent, α etc, were extracted from I-V characteristics of test-group devices. The extraction procedure which is based on physical model of an aSi TFT has been described elsewhere [4]. Process dependent device parameters are listed in Table1. Similar parameters for TFTs on glass (process temperature 300 °C) are also given for the comparison. As seen, both sets of aSi TFTs exhibit low contact resistance and good

Parameter	300°C process (glass)	150°C process (plastic)
Threshold voltage, V_T [V]	2.3-2.5	2.5-3.5
Field-effect mobility, μ_{FE} [cm²/Vs]	1.1-1.2	1.0-1.2
α	2.01-2.03	2.04-2.1
Contact resistance, R_{SD}·W [MOhm·µm]	2-5	3-10
Sub-threshold slope, S [V/dec]	~0.3	~0.3
OFF-current, I_{OFF} [A]	~10^{-14}	≤10^{-13}-10^{-14}
ON/OFF-ratio	10^8-10^9	10^8 - 10^9

Table 1 Typical process dependent TFT performance parameters for 300°C-process on glass and 150°C process on plastic.

channel properties: high mobility, low V_T and S, and current exponent α close to 2.0. More importantly, the performance of TFTs on plastic fabricated at 150 °C is as good as that of quality TFTs on glass made with 300 °C- process.

3.2. Pixel circuits for AMOLED on plastic substrates

The photograph of 4-TFT current programmed pixel circuit fabricated on plastic substrate is shown on Fig. 2(a). Its schematic is presented on Fig.2(b). The circuit is designed to-compensate for

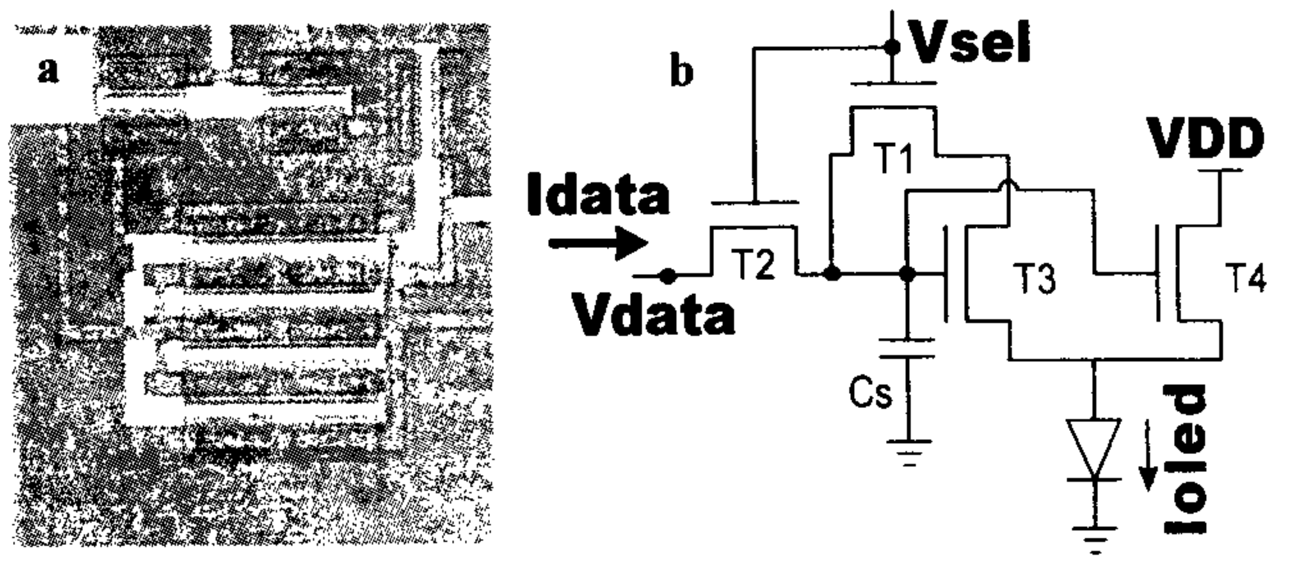

Figure 2 Photograph (a) and schematic (b) of current-programmed 4-TFT pixel circuit

V_T-shift in drive TFT, T4 [3]. Here, T3 and T4 are under the same gate bias and form a current mirror. I_{OLED} is proportional to I_{DATA} and the current gain, I_{OLED}/ I_{DATA}, is determined by the dimensions of T3 and T4. Ideally I_{OLED} does not depend on V_T of T4 while the voltage at the input node will increase over time if constant value of I_{OLED} has to be maintained. The transfer characteristics of this circuit fabricated on plastic substrate are shown on Fig. 3. As seen.

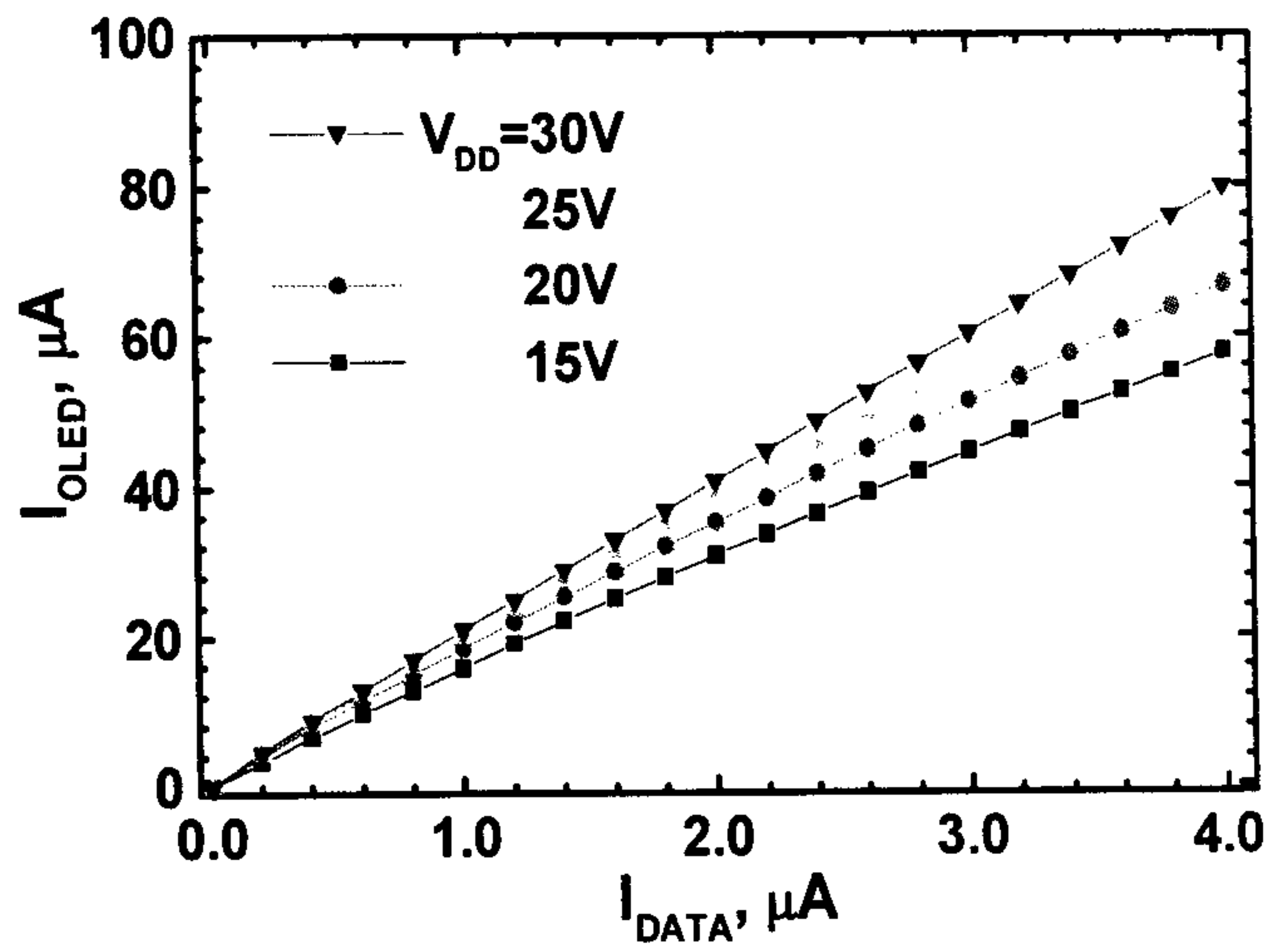

Figure 3 The dependence of I_{OLED} on I_{DATA} for 4-TFT pixel circuit on plastic substrate

the circuit provides good linearity and current control for a wide range of I_{DATA}. Some sensitivity of I_{OLED} to supply voltage V_{DD} is due to the fact that, in the saturation, drain current of a TFTs is still dependent of drain voltage (Fig.1 a). To verify the stability of the operation, the circuit was subjected to long-term test under pulsed bias conditions that closely resembled display operation [5]. Each frame the same I_{DATA} pulse of ~0.5 μA arrived at the input node while I_{OLED} and the voltage at the input node, V_{DATA}, were read out and stored. After initial burning-in, I_{OLED} approached value of ~ 8μA and then just slightly increased with time (Fig.4). Although noticeable increase of input-node voltage over time indicates that V_T shift of T4 is progressing, the performance of the circuit is not corrupted after 2800 hrs of the operation. Very similar behavior and the magnitudes of the change for output current, I_{OLED}, and input-node voltage, V_{DATA}, were observed for a pixel circuits fabricated at 300°C [5].

The pixel circuits here were made with a design rule of L=23 μm and fit into pixel size of ~440x440 μm. Assuming vertically stacked top-emitting pixel structure with aperture ratio of ~90% and realistic OLED efficiency of 5Cd/A, the circuit should support up to ~2000 Cd/m^2 peak brightness, while the value of I_{OLED}=8 μA corresponds to 185 Cd/m^2. Such brightness level would be sufficient for the most of applications. The results of Fig.3 and 4 show that low-temperature aSi TFT process on plastic substrates can deliver appropriate pixel output current and pixel circuit stability to be suitable for AMOLED backplanes.

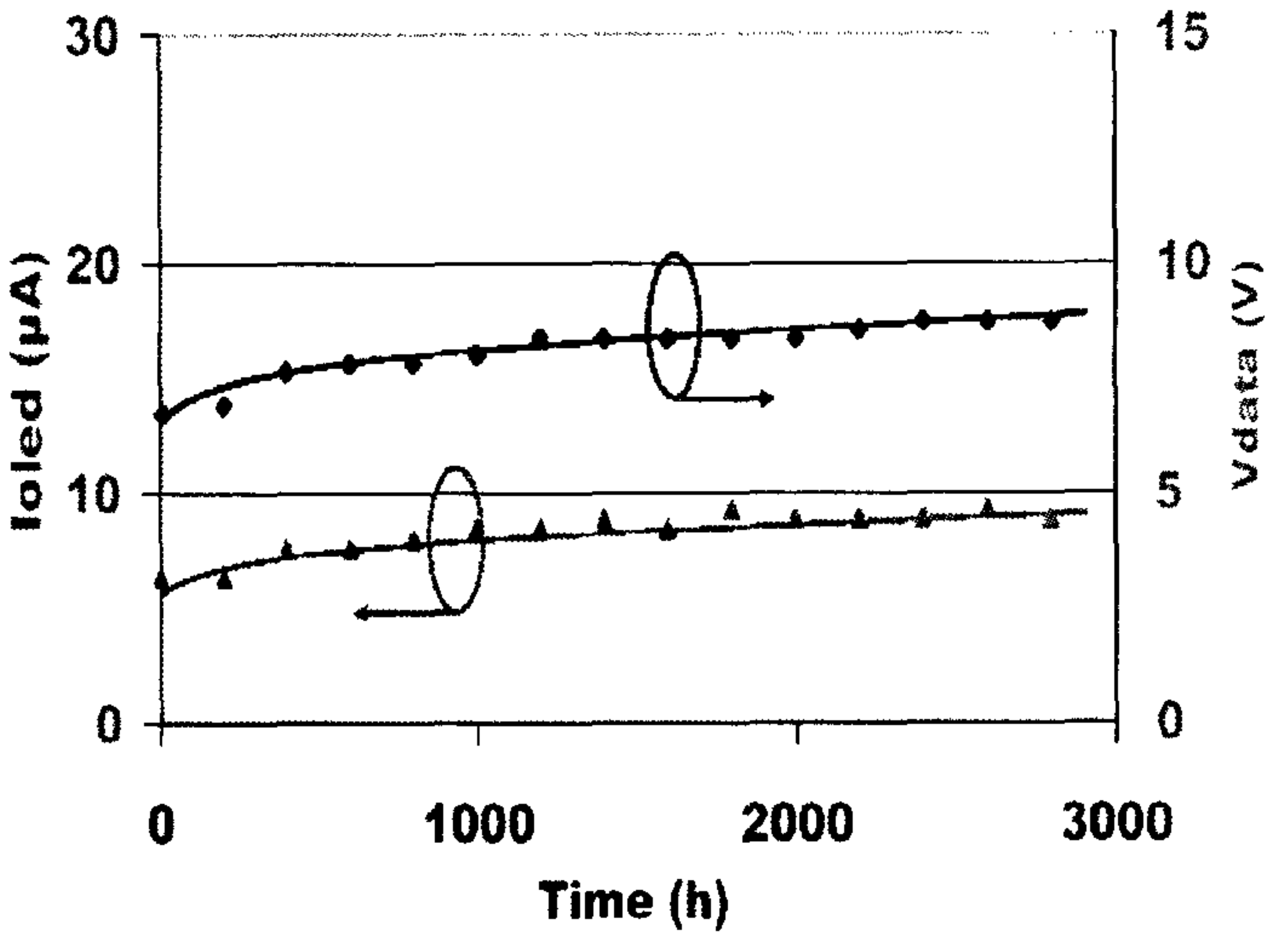

Figure 4 Evolution of OLED current and input-node voltage during 2800 hrs-continuous operation

4. Conclusion

a-Si TFT process with maximum temperature of 150° C has been developed. TFTs on plastic substrate with high field effect mobility of ~1.2 cm^2/Vs, steep sub-threshold slope (~0.3 V/Dec) and ON/OFF ratio ~ 10^9 have been fabricated. TFT pixel circuits for AMOLED made with this process demonstrate good output currents. The pixel retains its functionality and output current control after ~2800 hrs of continuous operation. These results support the idea that AMOLED backplanes on plastic substrates with a low-temprature aSi TFT process are feasible.

5. Acknowledgements

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