Analysis of Low Power Consumption AMOLED Displays on Flexible Stainless Steel Substrates

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Abstract

We present simulations and results to demonstrate the viability of stainless steel foil as a substrate for low power consumption, flexible AMOLED displays. Using organic planarization layers, we achieve very smooth surface properties, resulting in excellent TFT performance, that can be repetitively flexed without significantly affecting device performance. The use of phosphorescent OLEDs enables the design of low power consumption 40″AMOLED displays.

1. Introduction

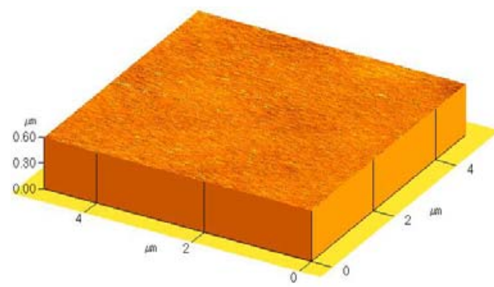
Over the last few years there has been much work to develop AMOLED displays on flexible substrates such as plastic [1] and stainless steel foil [2-5].

One key issue for the fabrication of AMOLED displays on stainless steel foils is ensuring very smooth surfaces for TFT fabrication and subsequent OLED growth.

A second issue is overcoming excessive capacitive coupling from the backplane to the substrate. In this paper we present results showing that using a 2.6 µm organic planarization layer surface roughness of the order of 1 nm can be achieved. Amorphous silicon TFTs grown on these planarized substrates have performances comparable to those grown on glass substrates, and can be repetitively flexed with a strain of 0.6 % for 1,000 flexes without any significant changes in TFT characteristics.

Finally, we simulate the power consumption of a 40″ AMOLED grown on stainless steel foil for three different OLED technologies.

2. Substrate preparation and results



Rms Roughness	Ave. Roughness
10.6 Å	8.07 Å

Fig. 1. AFM micrograph of stainless steel substrate planarized with 2.6 µm polyimide.

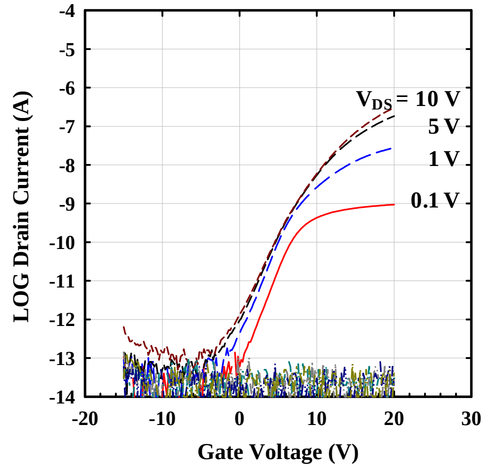
Substrate planarization

Standard mechanical grade stainless steel foil, which typically has an average surface roughness of order 100 nm rms, has to be planarized for use in AMOLED displays.

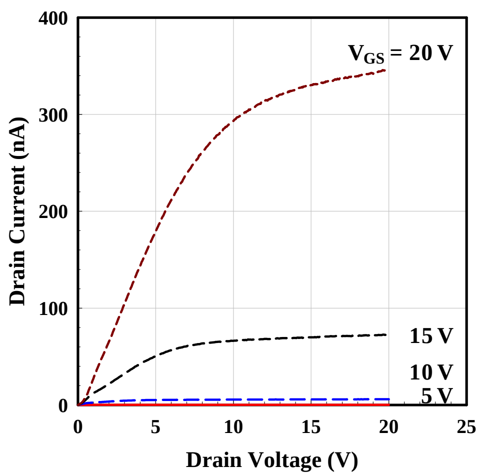
In this paper we report on the use of a 2.6 µm polyimide layer (PI) which serves as both an electrical insulation and surface planarization layer.

TFT Fabrication

We fabricated a-Si:H TFT on the PI planarized stainless steel foil. Cr was deposited on stainless steel foils by DC sputtering for gate bus line [5]. A 400 nm thick silicon-nitride, a 150 nm thick a-Si:H and a 50 nm-thick n^+ a-Si:H layers were deposited consecutively by plasma enhanced chemical vapor deposition (PECVD).

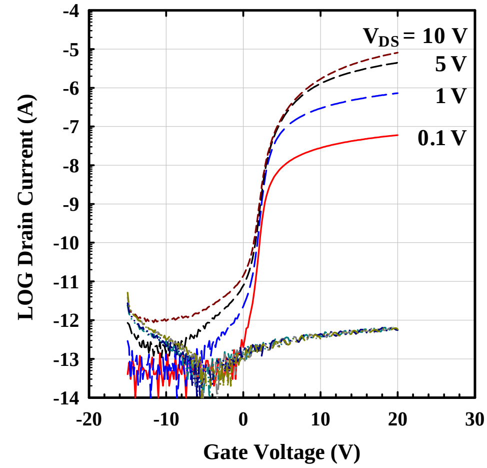


(a)

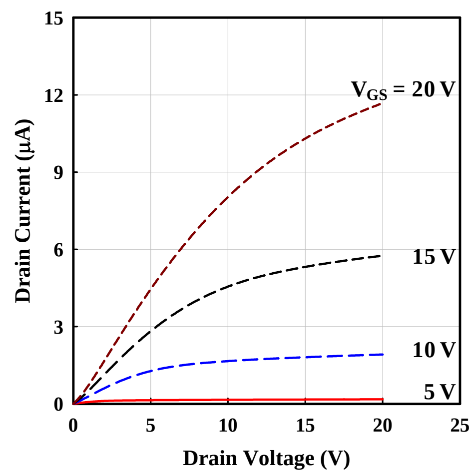


(b)

Fig. 2. Transfer (a) and output (b) TFT characteristics on steel foil without planarization.



(a)



(b)

Fig. 3. Transfer (a) and output (b) TFT characteristics on steel foil with planarization.

After forming a-Si:H islands by dry etching. Cr was deposited on the n^+ a-Si:H and then patterned for data bus lines. The n^+ layer between the source and drain electrodes was subsequently etched away. Finally, a 400 nm thick SiN_x was deposited for passivation and via-holes were formed.

Figure 2 show the transfer and output characteristics of a-Si:H TFT grown on stainless steel foil without a planarization layer, but with a 1 μm-thick SiO_2 coating. The TFT exhibited a field-effect mobility of 0.07 $cm^2/V{\cdot}s$, and threshold voltage of 8.5 V, and a sub-threshold slope of 2.16 V/decade. The low mobility is due to surface scattering.

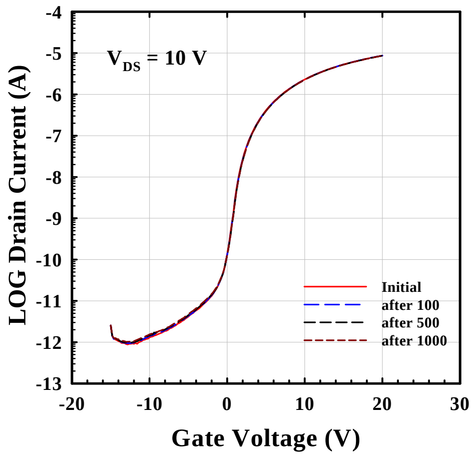
Figure 3 shows the performance of a similar a-Si:H TFT on steel foil deposited on a planarized surface.

Table 1 indicates a comparison of the TFT performances with/without a planarization layer.

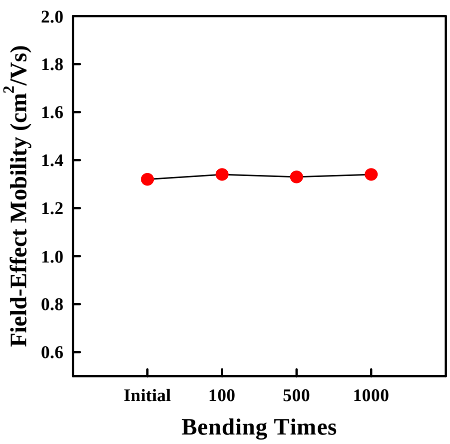
Very smooth substrates enable a-Si:H TFTs with a mobility of 1.37 $cm^2/V{\cdot}s$, a threshold voltage of 3.67 V, and a sub-threshold slope of 0.87 V/decade.

Table 1. The comparison of the performances of a-Si:H TFTs made on stainless steel foil with and without a planarization layer (W/L = 25 μm / 5 μm)

	RMS Roughness (nm)	μ_{fe} ($cm^2/V{\cdot}s$)	V_{th} (V)	S (V/dec.)
Without Planarization	81.4	0.07	8.5	2.16
With Planarization	1.06	1.37	3.67	0.87



(a)



(b)

Fig. 4. The variation of transfer characteristics (a) and field-effect mobility (b) of a-Si:H TFT after repetitive flexing with bending of 2.5 cm diameter.

Flexibility Testing

Figure 4 a) and b) show the transfer characteristics and field effect mobility for a typical a-Si:H TFT fabricated on the planarized stainless steel substrate, after repetitive flexing around a 2.5cm diameter, representing a strain of 0.6%. As can be seen, there is virtually no change in TFT performance after flexing 1,000 times at 0.6% strain.

Phosphorescence

Low power consumption AMOLED displays can be achieved with high efficiency phosphorescent OLEDs (PHOLEDs). In conventional fluorescent OLEDs, the internal quantum efficiency is limited to approximately 25% as only singlet excitons recombine to emit light. In a PHOLED, however, heavy metal atom centers enable efficient spin-orbit coupling [6]. The spin-orbit coupling allows both singlet and triplet excitons to be harvested as phosphorescent radiation, leading to internal quantum efficiencies of up to 100 % [7]. The higher efficiencies reduce the temperature rise by at least a factor of three compared to a fluorescent OLED display [8], an important consideration for handheld mobile devices.

Phosphorescent device lifetimes are rapidly increasing, and are now competitive with the best in the industry. Red PHOLEDs with external quantum efficiency (EQE) values of 20% (luminance efficiency, LE, of 24 cd/A at (0.65, 0.35)) have reported LT50 lifetimes of > 300,000 hours at display level luminance of 1,000 cd/m^2. Recent progress for green (0.38, 0.59) PHOLEDs has been reported with 250,000 hours lifetime at an initial luminance of 1,000 cd/m^2 with EQE = 19%, equal to 67 cd/A, and advancements are continuously being made in blue PHOLED performance.

Display Power Consumption – AMOLED Pixels

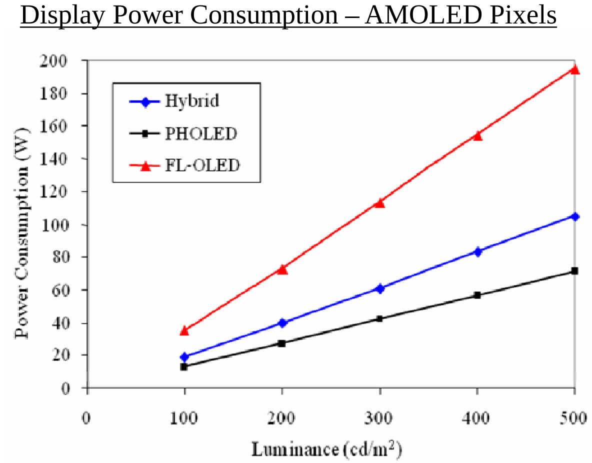


Figure 5. Simulated power consumption of 40″ AMOLED HDTV for three OLED technologies;

Fl-OLED: All fluorescent
(G = 20 cd/A, R = 8 cd/A, B = 7 cd/A)
Hybrid: Phosphorescent green/red, fluorescent blue
(G = 60 cd/A, R = 20 cd/A, B = 7 cd/A)
PHOLED: All phosphorescent
(G = 60 cd/A, R = 20 cd/A, B = 16 cd/A)

We calculated the power consumption of a 40″ AMOLED display under the following assumptions:

- Resolution : 1920 × 1080 × 3
- V_{gate} = -5 V to 20 V, V_{data} = 0 V to 12 V
- VDD = 15 V
- Polarizer efficiency = 45 %

Figure 5 shows the pixel power consumption of a 40″ AMOLED for three different OLED technologies: Fl-OLED: All fluorescent, Hybrid – Phosphorescent green/red, fluorescent blue, and PHOLED – All phosphorescent. The use of an all phosphorescent AMOLED leads to over a factor of three reduction in display power consumption as compared to an all fluorescent AMOLED. Even assuming a 15 V power supply, a 40″ AMOLED on metal foil driven by a-Si:H TFTs consuming only approximately 65 W at a luminance of 500 cd/m^2 should be realizable.

Table 2 shows the power consumption of the 40″ AMOLED display fabricated either on stainless steel foil or glass. The OLED power is independent of substrate, as this is determined by the combined voltage drop across the OLED and driver TFT multiplied by the OLED drive current. Capacitive coupling of the data lines to the metal substrate leads to a small increase in data line power (as compared to glass substrate), but overall the power consumption is relatively independent of substrate choice.

TABLE 2. Power consumption of the 40″ hybrid AMOLED at 500 cd/m^2 fabricated either on stainless steel foil or glass substrate using phosphorescent green and red sub-pixels with a fluorescent blue sub-pixel

Power Consumption (W)	TV on Steel Foil	TV on Glass
Pixel Power (OLED + TFT)	105	105
Gate Line Power	0.016	0.012
Data Line Power	4.18	1.05
TOTAL Power (W)	**109**	**106**

Figure 6 Flexible full color QVGA display on metal substrate made in collaboration by LG.Philips LCD and Universal Display Corporation. Vitex Systems provided the thin film encapsulation.

Flexible AMOLED on Metal Foil

At SID 2007 we demonstrated a full color AMOLED on metal foil, combining LG Philips LCD's innovative a-Si:H backplane with UDC's high-efficiency PHOLED and FOLED® flexible technologies. The prototype is a portrait configured, 4" QVGA, 100 ppi full-color OLED display, as shown in Figure 6. The razor thin display was built on 76 micron thick metal foil. The display can portray both images and full-motion video.

3. Summary

We have shown that by planarizing low cost stainless steel foils, it is possible to obtain a very smooth surface finish, and produce high performance a-Si TFTs, with similar characteristics to those grown on glass. These devices can be repetitively flexed with a strain of 0.6 % for 1,000 flexes without any significant changes in TFT performance. Phosphorescent OLEDs enable the design of low power consumption 40″ AMOLED displays.

Finally, we have shown that low power consumption displays can be implemented on steel substrates, with power consumption only a few percent higher than their glass counterparts.

4. References

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