

Electro-mechanical Analyses of Thin Film Transistors for Flexible Displays

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Abstract: *Good mechanical properties of thin-film transistors on plastic substrates are an essential parameter in the development of robust flexible displays. In this paper, a careful investigation is carried out on TFT backplane on plastic substrates under cyclic bending conditions. Bending modes of tensile and compressive as well as parallel and perpendicular orientation-dependent bending of channel have been analyzed carefully. This analysis will be helpful in knowing the electro-mechanical performance boundaries of the TFT devices so as to determine the bending limitations of our flexible displays.*

Background:

Presently, flexible displays are becoming a new genre of displays utilizing plastic substrates as the carrier support. These displays are thin, robust, light-weight and can be easily integrated in a wide range of applications ranging from mobile-handset, PDAs to large-size information signages and notebooks. With the usage of plastic substrate, these displays can assume various bendable and foldable shapes, opening up an attractive trend of display products and so flexibility plays a key role in the product development. Secondly, till now plastic display fabrication is carried out with the state-of-art clean-rooms facilities tuned for handling glass carriers,

therefore it is essential to determine the durability of our TFT devices on plastic substrates undergoing similar in-line processes and assembly steps in such harsh environment. Finally, high mechanical reliability of the TFT devices can only guarantees large-scale manufacture of flexible displays.

Here we report mechanical reliability of low-temperature a-Si TFT devices fabricated on 125 μm thick heat stabilized PEN (polyethylene-naphthalate) at 130°C. PEN is first coated with a stack of barrier and overcoat on both sides to prevent moisture absorption from either side of substrate, to obtain good planarization of the top surface and to prevent bending of substrate during the deposition of vacuum-deposited layers for TFT. An inverted bottom-staggered geometry of TFT arrays is fabricated on 2.3" and 4.3" diagonal PEN substrates, wherein first the gate electrodes are coated over PEN, followed by SiNx, a-Si:H, and n+ Si:H deposition by PECVD and later patterned. These is followed by source and drain electrodes deposition and patterned and finally organic passivation layer and IZO pixel electrodes are consecutively placed thereby completing TFT array.

A lot of previous work has been carried out about the mechanical strain effects on a-Si TFT on conformal substrates both plastic and steel foils, but mostly done on a single TFT

device or a small TFT array [1-4]. In our study, we carried out bending test on a 100-TFT array-TAG fabricated on TFT backplane for 'tensile' and 'compressive' bending modes. Since the length and width of the plastic substrate is larger than the device thickness by several orders of magnitude, the applied strain is considered to be uniaxial. The TFTs were also analyzed for orientation-dependent bending with bending strain applied in the longitudinal and transverse directions to the channel to determine the effects of orientation-dependent factor for pixel or ASG design.

The bending measurements were done on 2 sample sizes, 2.3" and 4.3" TFT backplane. These dimensions were chosen because these panels are currently being used to fabricate plastic displays at our lab.

Experiments:

A. Compressive and Tensile Stress

We begin our analysis by considering the fact that the initial residual stress in our TFTs on PEN is tensile in nature i.e. they are normally bend outward at $\sim 40\text{mm}$ dia. due to cumulative effect of stresses in TFT layers and substrate shrinkage. Compressive and Tensile bending stresses were applied in a cyclic manner for up to 1000 cycles at a rate of 300mm/min at experimental radii limits of 7mm for 4.3" and 5mm for 2.3". TFT parameters I_{on} , I_{off} , $I_{leakage}$ and mobility were changed within $\sim 22\%$ for 4.3" whereas larger changes were seen for 2.3" TFT. Maximum compressive and tensile strain was calculated as 0.83% at 7mm for 4.3" and is 1.25% at 5mm for 2.3". These values were calculated by using the following equations mentioned in reference [5] for thin films strain on conformal substrates:-

$$R \text{ (cm)} = \text{length of sample (cm)} / 3.14$$

Strain ϵ

$$= (D_f + D_s) / 2R * (1 + 2\eta + X\eta^2) / (1 + \eta)(1 + \eta X)$$

where $\eta = D_f / D_s$; $X = Y_f / Y_s$

where D_f and D_s are thicknesses of TFT layers and substrate. Y_f and Y_s are young modulus of TFT layers and substrate.

Similarly, mechanical tensile bending stress was applied cyclically @300mm/min. TFT parameters I_{on} , I_{off} , $I_{leakage}$ were seen to degrade more for 2.3" size than 4.3".

Results:

The main results of this analysis shows that tensile stress has worst effects than compressive stress for our TFT devices.

Secondly, large sample dimension shows less degradation of TFT for same number of bending cycles in both 4.3" and 2.3".

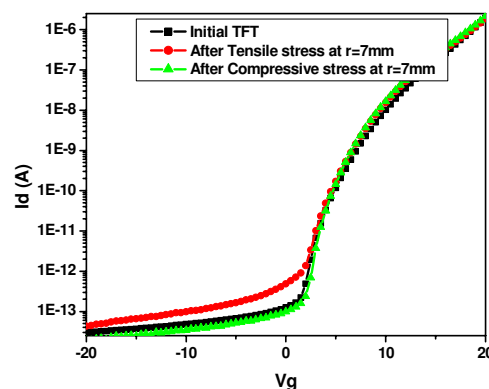


Fig 1: Id Vs Vg for 4.3 inch test-cell

Tensile stress shows $\Delta I_{on}/I_{on} \sim 0.22$

Compressive stress shows $\Delta I_{on}/I_{on} \sim 0.15$

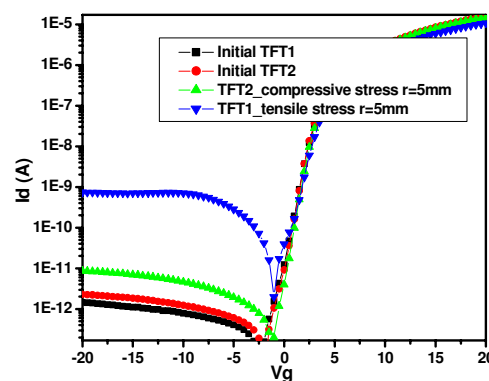


Fig 2: Id Vs Vg for 2.3 inch test-cell

Tensile stress shows $\Delta I_{on}/I_{on} \sim 0.5$

Compressive stress shows $\Delta I_{on}/I_{on} \sim 0.3$

Similarly, when a continuous tensile and compressive bending stress is applied for ~ 240 -300 hours, we see a marginal change in I_{on} but I_{off} and $I_{leakage}$ increased by 2 orders of

magnitude under tensile stress as seen in Fig 3A whereas remains unchanged under compressive stress for 240 hours (Fig 3B).

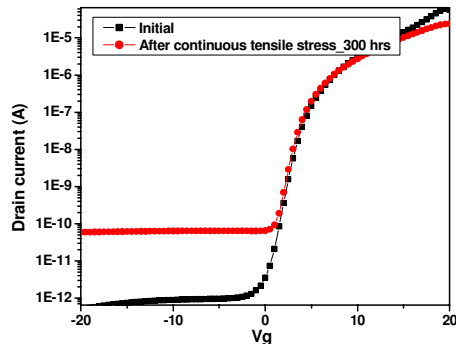


Fig 3A: TFT transfer curve is plotted (I_d vs V_g) under continuous tensile stress for 300 hours.

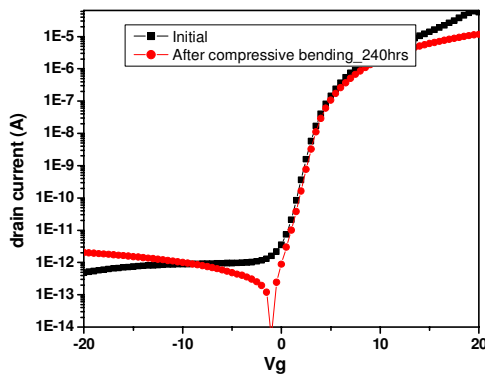


Fig 3B: TFT transfer curve is plotted (I_d vs V_g) under continuous compressive stress for 240 hours.

As mentioned before, the main cause for the degradation of a-Si TFT array analyzed here under tensile bending can be related to the fact that the initial residual stress in our TFT backplane is tensile in nature and with additional tensile bending, causes more degradation, whereas under compressive bending, overall TFT stress is slightly compensated. These results seem to work in parallel with inherent phenomenon observed in amorphous materials where they cannot release internal strain by dislocation motion by itself and therefore cracks under the effect of tensile stress. On the other hand, under compressive stress, the film delaminates from the substrate only after the film has buckled

which requires a large enough area of unbonded film of several microns larger than device layer, in our case is approximately calculated to be around $15\mu\text{m}$ [6-7].

B. Orientation-Dependent Bending

We also carried out orientation-dependent or directional bending on the TFT devices. This analysis was essential to determine the impact of orientation of pixel circuits for strain-tolerant TFT backplanes.

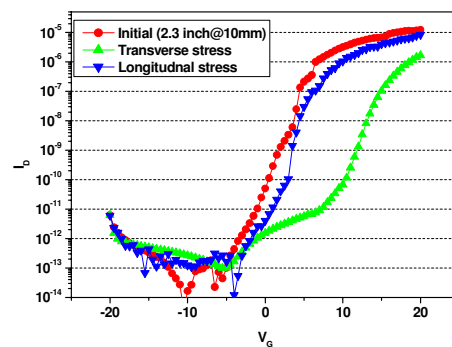


Fig 4: TFT transfer curve is plotted (I_d vs V_g). It clearly shows the high sensitivity of I_d under transverse bending direction as compared to longitudinal direction

Here the bending stress is applied parallel (longitudinal) and perpendicular (transverse) to the channel. Fig 4 shows the TFT transfer curve (I_d vs. V_g) under no bend condition, longitudinal and transverse bend direction, all compressive in nature. Sample size 2.3" was chosen to apply the max strain at $r=5\text{mm}$. I_{on} current is seen to show high sensitivity for transverse bending than for longitudinal bending. TFT current degrades more when applied bending stress is perpendicular to the TFT channel. This analysis complies well with the fact that there can be additional presence of non-directional sensitivity of Fermi energy of amorphous silicon channel as stated in [8].

Conclusion:

Our analysis has shown that the amorphous-silicon TFT with residual tensile stress undergo more degradation with tensile bending than compressive bending with less

stress effects on large sized sample. Secondly, the TFT show more sensitivity for transverse bending than longitudinal direction. Finally, unlike previous work reported mechanical reliability on single TFT or small TFT array, here we showed our analysis on 100-TFT array on active-matrix backplane applied to actual display on plastic substrate.

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