47.1: High Performance Plastic Substrates for Active Matrix Flexible FPD

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Abstract
Appear™ 3000 and AryLite™ plastic films satisfy most of the necessary requirements for use as substrates in flexible flat panel displays. Preliminary evaluations have shown excellent physical and optical properties and chemical resistance. We now present further progress with respect to poly-Si TFT array fabrication.

1. Introduction
The development of flexible and robust plastic displays will lead to enhancements in both the variety and usage of display products. In particular, flexibility opens up to an entirely new display market where conformability and wearability are leader concepts. Plastic substrates exhibit, as main advantages in comparison with glass, a reduction in weight and thickness of the display and virtually eliminate the problem of display breakage during both fabrication and use. Furthermore, plastic substrates offer the possibility of significant reductions in cost due to their compatibility with R2R (roll-to-roll) processing and printing technology.

Among FPD technologies, high quality displays are achieved by Active Matrix TFT arrays. Plastic substrates are an available alternative to glass in this application, but standard processing techniques for both a-Si and poly-Si TFTs on glass require temperatures higher than those compatible with commonly available plastics (~350 °C for conventional a-Si:H TFTs and ~450 °C for poly-Si TFTs). Organic TFT would be a suitable technology for plastic substrates, but their performance is still far from being acceptable, even if dramatic improvements have been achieved in the latest years [1]. Big effort is being applied to find the process conditions needed to fabricate high-performance silicon TFTs on plastic. The a-Si technology has been demonstrated to be suitable for plastic substrate because of the low temperature process and good electron mobility obtained at temperature of 200 °C [2], but the performance of low temperature a-Si is poor compared with a-Si TFT fabricated on glass and stability issues arise. The development of pulsed laser processing has allowed the temperature limitations for a-Si crystallization in poly-Si TFT to be bypassed. By selectively applying large amounts of energy in the near-surface of a silicon layer [3], pulsed laser annealing has pushed T_{max} for poly-Si TFTs down to ~200 °C. Good quality NMOS poly-Si TFTs have been demonstrated on high temperature plastics such as polyimide (PI) (T_{max} of 250 °C) and polyethersulfone (PES) (T_{max} of 200 °C) [4]. However, device hydrogenation requires very long times at 200 °C, and PMOS devices formed at this temperature are very poor. Thus, a process temperature of at least 250 °C has been found to be needed for high performance CMOS TFT circuitry. The main requirement for direct fabrication of poly-Si TFT on plastic is the thermal resistance of the substrate up to 250-300 °C. The plastic film substrate must have several other properties to make it suitable for display applications: properties related to performances such as transparency, birefringence, light stability and properties related to processing such as dimensional stability (rigidity, heat shrinkage, compaction, CTE, solvent and chemical uptake), adhesion, surface roughness, chemical and scratch resistance.

	Appear™ 3000	**AryLite™ A100HC**
Thermal		
Tg	330 ºC	325 ºC
Decomposition temperature	360 ºC	480 ºC
CTE (-55 to 85 ºC)	74	53
Flammability (UL94)	Burning rate >HB	V-0
Optical		
%Transmission (400-700 nm)	91.6%	90.4%
Refractive index (633 nm)		
Retardation (100µm-thick film)	<10 nm	<10 nm
50% Cutoff wavelength	330 nm	360 nm
Physical		
Young's modulus	1.9 GPa	2.9 GPa
Tensile strength	50 MPa	100 MPa
Elongation to break	10%	17%
Specific gravity	1.16	1.22
Water absorption	0.03%	0.4%
Electrical		
Volume resistivity (ohm.cm)	3.2×10^{16}	8.0×10^{16}
Surface resistivity (ohm/sq)	7.9×10^{15}	2.3×10^{17}
Dielectric constant (1 MHz)	4.1	3.4
Loss tangent (1 MHz)	8.7×10^{-3}	9.0×10^{-3}
Chemical resistance		
both substrates resist all of the chemicals specified as follows: NMP, IPA, Acetone, Toluene, Methanol, Ethanol, THF, Ethylacetate, HMDS, H_2O, HCl-37%, H_2SO_4-98%, HNO_3-70%, H_3PO_4-85%, HBr-48%, CH_3COOH-glacial, $FeCl_3$, KH_2PO_4, H_2O_2-30%, sat. Na_2CO_3, sat. NaOH and sat. KOH.		

Table 1. Films Properties

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2. Experimental

2.1 Materials

Appear™ 3000 and AryLite™ films are under development in order to match the above mentioned requirements (See table 1). Appear™ 3000 and AryLite™ A100HC films, used in the present paper, are 100 microns thick with hardcoat on both sides to form symmetric multilayered structures. The high thermo-mechanical resistance and good optical properties together with the resistance to solvents and chemicals, achieved by using appropriate hardcoating layers, satisfy the basic requirements both for their end-use and processing. Objective of this work is to show the preliminary evaluation of Appear™ 3000 and AryLite™ films for their use as substrate in a Low Temperature poly-Si process for direct TFT fabrication on plastic.

2.2 Film Testing and characterization

A multi-step lithography process requires the dimensional stability of the substrate. The causes of dimensional changes of plastic during the process are related to the high temperature reached in several steps and the absorption of water and solvents used in the etching and washing steps [5]. Both these aspects have been evaluated for the plastic substrates.

We have studied dimensional stability of Appear™ 3000 and AryLite™ in a standard semiconductor processing. The results are shown in Figure 1. The cumulative dimensional changes, after the 7 processing steps, of Appear™ 3000 and AryLite™ are respectively -0.003% and 0.000%, results that are quite interesting although the dimensional change of each step is important as well.

It has been shown that plastic, as well as glass, can be stabilised by reducing the heat shrinkage - irreversible dimensional change due to molecular rearrangements and free-volume reduction - by an appropriate thermal pre-treatment. When such a pre-treatment is performed, subsequent treatments at lower temperature or for a shorter time cause only small dimensional changes. Substrates having a shrinkage rate (compaction) of <3 ppm/hr ensure accurate registration between steps (i.e., a movement of <1 µm over an entire 12”x12” display) [6].

The shrinkage of hardcoated Appear™ 3000 and AryLite™ films has been measured at temperatures in the range of 250-300 ºC. The results at 300 ºC are shown in Figure 2. Both films reach the target shrinkage rate (3 ppm/hr) after ~50 hours of treatment under vacuum (10^{-3} Torr). Another intrinsic property that plays a fundamental role in the processability of plastic substrates is the thermal expansion or CTE - reversible dimensional change due to polymer structure and molecular mobility. CTE of Appear™ 3000 and AryLite™ has been measured at temperatures in the range of 50-230 ºC. Figure 3 shows the results obtained for Appear™ 3000 and AryLite™ film after thermal pre-treatment. PES (Sumilite® FST X012S) and PI (Kapton 300FPC) have been measured as a reference. Poly-Si TFTs can be formed at low temperature using the excimer laser crystallisation of PECVD amorphous silicon and this enables the integration of high-performance and stable drive circuitry on plastic [6].

2.3 Poly-Si fabrication process

In the present paper, the preliminary work of array fabrication on AryLite™ film support is reported. The film substrate is previously cleaned by common glass washing procedure (detergent, HNO_3 35%). A thermal treatment of 24 hours at 275 °C in vacuum (10^{-3} torr) reduces then the thermal shrinkage to the desired value. On one side of the plastic support, the backside of the device, a 0.5 micron-thick SiO_2 layer is sputtered at a relatively low temperature to compensate compressive stresses generated in the multilayer structure during the stack deposition. These stresses without proper compensation could cause curling of the substrate. On the other side, the surface is thermally protected by a 0.1 microns layer of sputtered SiO_2 which also helps the adhesion of the stack films to the plastic substrate. The stack films of 0.2 microns SiNx, 0.2 microns SiO_2 and 0.04 microns a-Si are deposited onto the front side by PECVD at temperatures of 200-275 °C. In the above processes, adhesion is also promoted by a proper surface activation with Ar plasma treatment. The plastic substrate is flat coming out of this coating process. The a-Si layer is first dehydrogenated by scanning the surface with an excimer laser using 20 pulses per point with a peak energy of 230 mJ/cm^2/pulse, then crystallized using 20 pulses per point with a peak energy of 320 mJ/cm^2/pulse. Due to accumulated internal stresses, optimisation of composition, stress and adhesion for each layer is needed in order to avoid warping of the substrate and cracking of the layers during deposition and/or

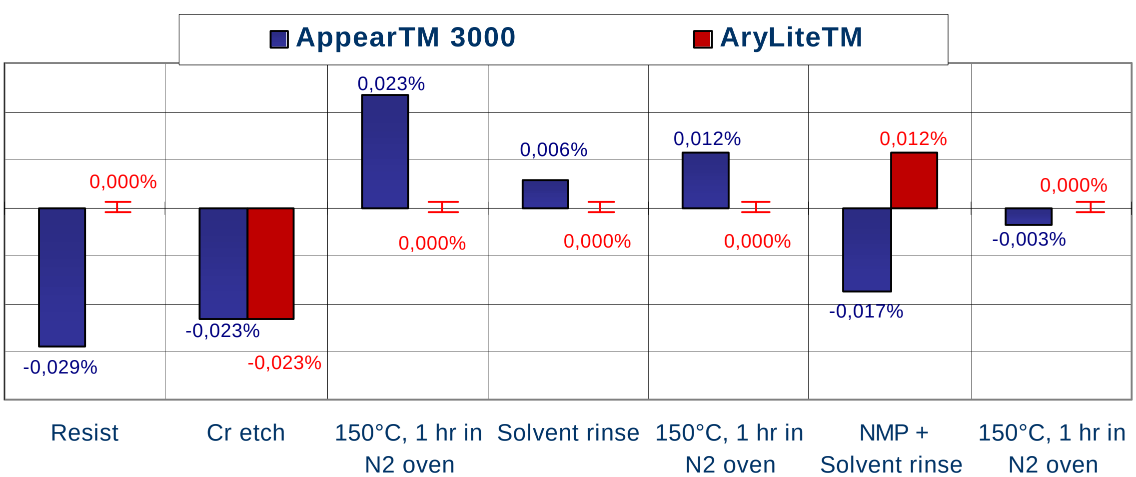

Figure 1. Dimensional changes of Appear™ 3000 and AryLite™ in a representative semiconductor process.

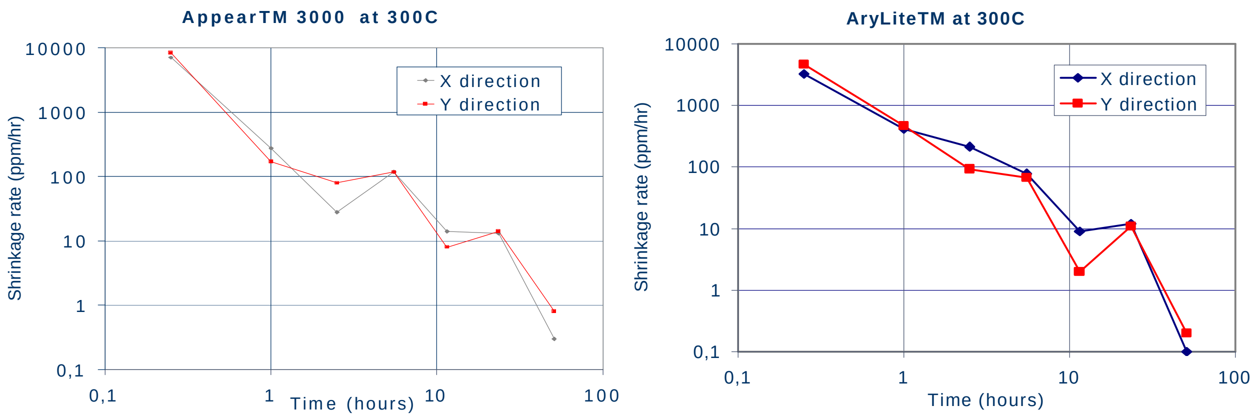

Figure 2. Thermal compaction of Appear™ 3000 and AryLite™ films at 300 °C, 1 mTorr.

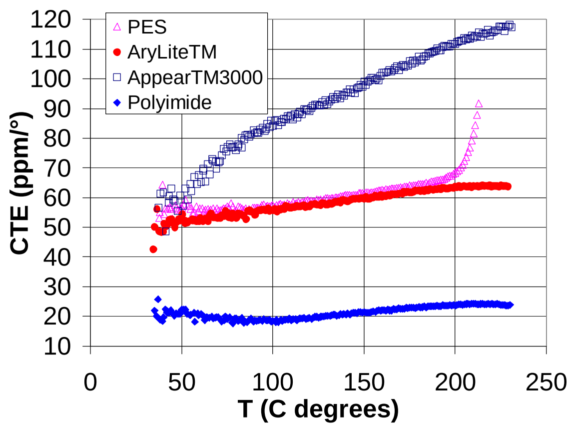

Figure 3. Coefficient of thermal expansion as a function of temperature (C).

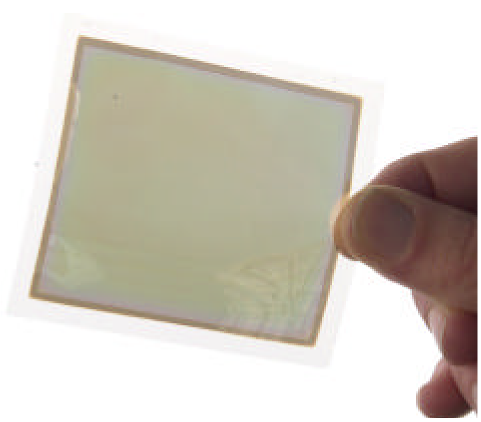

Figure 4. Poly-Si coated AryLite™ A100HC made at 250°C.

laser annealing. Such stresses arise, for the most part, from difference in CTE of the plastic substrate and inorganic layers. Figure 4 shows the prototype fabricated on AryLite™ at 250 °C degrees with homogeneous flat surface of crystallized poly-Si. A similar fabrication approach is being evaluated on Appear™ 3000 as well. Initial experiments provide promising results. The success of deposition of poly-Si on AryLite™ film opens up the possibility of fabricating poly-Si TFTs on plastics.

Our previous work [4,6] reports that poly-Si TFTs made on glass and plastic substrates (PI) at 250 °C have identical characteristics and show as good stability to gate and drain bias stresses as devices formed more conventionally at higher temperatures. The only polymer substrate available then for this process was PI which had a strong drawback due to its poor optical properties. Results presented here demonstrate that both Appear™ 3000 and AryLite™ are viable substrate candidates for this technology.

3. Conclusions

Promerus LLC and Ferrania Imaging Technologies have successfully developed a set of high-temperature films for plastic AryLite™ films are being manufactured in a continuous process. Further optimization of these engineered substrates is underway to reduce oxygen and moisture transmission. Successful deposition of poly-Si layer for TFT arrays has been demonstrated on AryLite™ and Appear™ 3000 substrates. Fabrication of high-performance TFTs on these substrates is in progress at Philips Research Laboratories in Redhill. The results presented in this paper open up, with reasonable confidence, to the successful fabrication of high-performance TFT arrays on plastic substrate.

4. References

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