Prevention of thin film failures for 5.0-inch TFT arrays on plastic substrates

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Abstract

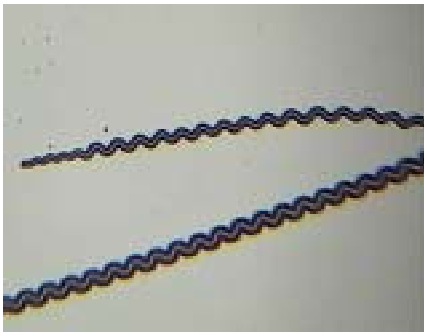
A 5.0-inch transmissive type plastic TFT arrays were successfully fabricated on a plastic substrate at the resolution of 400 X 3 X 300 lines (100ppi). All of the TFT processes were carried out below 150 ℃ on PES plastic films. After thin film deposition using PECVD, thin film failures such as film delamination and cracking often occurred. For successful growth of thin films (about 1um) without their failures, it is necessary to solve the critical problem related to the internal compressive stress (some GPa) leading to delamination at a threshold thickness value of the films. The Griffith's theory explains the failure process by looking at the excess of elastic energy inside the film, which overcomes the cohesive energy between film and substrate. To increase the above mentioned threshold thickness value there are two possibilities: (i) the improvement of the interface adhesion (for example, through surface micro-roughening and/or surface activation), and (ii) the reduction of the internal stress. In this work, reducing a-Si layer film thickness and optimizing a barrier SiNx layer have produced stable CVD films at 150oC, over PES substrates

1. Introduction

A high resolution a-Si TFT based AMLCD device was developed on a Polyethersulfone (PES) substrate. Delamination of PECVD films often occurred after cooling of the substrate from deposition temperature of 150°C to room temperature. A large difference between plastic substrate and PECVD films cause a very high compressive stress of several GPa in the films. A typical delamination type of PECVD films on plastic substrates, which is so called as a telephone-cord delamination. The frequency of such delamination had a very high value especially on aluminum metal surfaces. A poor adhesion between a native aluminum oxide film and PECVD film attributes to a dramatic increase in the frequency of the film delamination.

2. Results and Discussion

PES films of 200 um were used for the plastic substrate. Although PES is not the best in coefficient of thermal expansion (50 ppm) point of view, it has high glass transition temperature (Tg) of 220℃, being highly transparent and commercially available. Even if a-Si layer on plastic substrate was grown at a relatively low temperature of 150°C, large difference in CTE between a-Si layer and plastic substrate generally result in the growth of films having high level of compressive stress. The shear stresses are located at the interface between film and substrate and so the interface results to be a critical region in coating technology. As long as the amount of the elastic energy stored in the film is not prevailing on the adhesion energy, the film does not delaminate. As soon as the elastic energy reaches a critical value, the film undergoes to a failure (buckling or delamination), which usually occurs at a well-defined critical film thickness [1, 2].



(a)

(b)

Figure 1. Optical micrographs showing telephone-cord delamination phenomena of PECVD thin films on plastic substrate occurred (a) on bare plastic surface and (b) along metal lines after active layer deposition (Magnification x100).

The Griffith's law:

$$\sigma_f^2 h_f / 2 E_f \le 2\gamma \qquad (1)$$

establishes a relation between σ_f , total stress in the film, which is sum of intrinsic film stress σ_i and thermal residual stress σ_{th} and γ , the energy per unit area

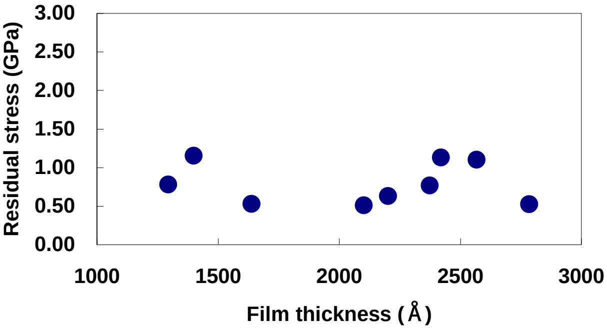


Figure 2. Measured intrinsic residual stress as a function of amorphous Si film thickness.

occurs when the left side of Eq. (1), equals the right side. Here, h_f and E_f are thickness and elastic modulus of the film, respectively. Considering now the possibility to grow a stable CVD films on flexible substrates, before delamination, then two ways are possible: (i) by increasing the adhesion energy, and/or (ii) by lowering the elastic strain energy in the film. In the first case, surface cleaning and preparation are important steps before thin-film deposition. It is possible to activate the surface (by chemical etching or laser irradiation) thus generating a high number of unsaturated chemical bonds or by producing a micro-roughening of the surface that increases the real contact area thus favoring mechanical adhesion. In the second case, three lines are suggested: (i) lowering deposition temperature below 150°C, (ii) reducing intrinsic residual stress of the thin film σ_i (growth of stress-free films), and/or (iii) decreasing the film thickness h_f , only if film stress σ_i is independent of film thickness.

First of all we have established the relationship between the film thickness, h_f, and the residual stress of PECVD film σ_i (the other parameters being kept constant). The measured values fluctuated in the range from 500 MPa to 1.3 GPa.

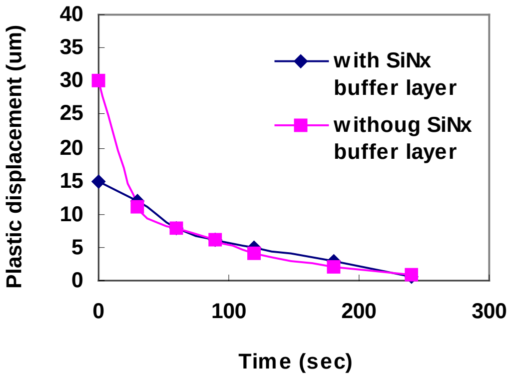


Figure 3. Changes in plastic displacement measured as a function of elapsed time. Initial displacement was measured immediately after PECVD deposition at 150°C.

The residual stresses of a-Si films grown by PECVD at 150°C had no dependence of film thickness (Figure 2). Therefore, the best way of lowering the elastic strain energy in the PECVD film is reducing the thickness of the film.

During the TFT process on plastic substrate, large amount of moistures permeate into the substrate. The PES substrate expanded up to 30 um right before CVD deposition due to the water adsorption . In this case, CVD films are grown on a highly elongated substrate. After deposition, the substrate undergoes a rapid shrinkage with a slope of 0.01 um/sec within initial 30 min. Such a large displacement in plastic substrate during the initial cooling period causes a high compressive stress in the film, which is sufficient for the film delamination. The larger the displacement of the substrate is, the more compressive stress is induced in the film. The possibility of film delamination due to high compressive stress is proportional to the change of plastic displacement.

The degree of water permeability into the substrate is closely related with the thickness of barrier layer of the substrate. The amount of moisture decreases with increasing the thickness of the barrier SiNx layer, which is covering the plastic substrate.

The plastic substrate with a thick buffer SiNx layer, the degree of expansion of the substrate was quite small compared with that of the substrate thin SiNx layer (Figure 3). However, increasing the thickness of barrier SiNx often causes the cracking of the substrate in the subsequent annealing process. Therefore, the optimization of the thickness of the barrier layer was inevitable for both film delamination and cracking. In our results, the optimized thickness of SiNx was 2000 Å

3. Conclusions

We have optimized a-Si and SiN_x properties for 150°C deposition and demonstrated ability of high-quality a-Si TFT fabrication on relatively large 5 inch PES substrates. It has been shown that TFT fabrication on the plastic requires optimization both materials properties for low temperature deposition and process architecture parameters in order to achieve required TFT performance. The failure problems related to delamination of PECVD films on PES substrate have been addressed in connection with the film thickness parameter. The Griffith’s theory was used to analyze the experimental values related to the compressive stress present in the films. By appropriate control of thickness of PECVD films, we succeeded in high density TFT array on plastic substrates without any film failures.

4. References

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