THE IMPACT OF ENVIRONMENT ON DIMENSIONAL REPRODUCIBILITY OF POLYESTER FILM DURING FLEXIBLE ELECTRONICS PROCESSING

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Abstract

DuPont Teijin Films (DTF) have developed engineered substrates specifically for the flexible electronics market. Teonex®Q65 is a biaxially oriented crystalline polyester with a tailored surface and it is emerging as a competitive material for the base substrate in OLED displays and active matrix backplanes. Given the dimensional reproducibility requirements in the display applications, uncontrolled moisture absorption during the processing cycle could potentially be far more significant than the inherent shrinkage of the base substrate. Understanding these effects and optimising the processing steps involved in device manufacture will be critical to achieving the ultimate performance that can be achieved with the base substrate.

1. Introduction

DuPont Teijin Films have two families of polymers based on PET and PEN. To achieve the dimensional stability required for display manufacture, the film is offline stabilized in a process where the internal strain in the film is relaxed by exposure to high temperature whilst under minimum line tension. Although both films have a good balance of properties, Teonex® Q65FA is a higher temperature performance substrate and is emerging as a leading material for the base substrate of OLED displays and active matrix backplanes.

Typically, equilibrium moisture absorption of plastic materials is in the 100-10,000 ppm range. Hence, uncontrolled moisture absorption during a processing cycle could potentially induce dimensional changes that are far more significant than the thermal shrinkage of the substrate.

In addition to the final level, the time at a given temperature that the film takes to reach an equilibrium value will also be a key consideration. This contribution discusses the impact of the processing environment on the dimensional reproducibility of polyethylene naphthalate film (Teonex® Q65) to achieve the ultimate performance.

2. Results

2.1. The Effect of Environmental Conditions on Dimensional Reproducibility

Assuming that film unit volume V_f changes by a volume fraction V_m. Also assuming that each dimension in the film, dx, dy and dz, change by the same fraction Δ, then:

$$V_f + V_m = (1 + \Delta)^3 \Rightarrow \text{for small } \Delta:$$

$$\Delta = V_m/3$$

Where V_m is found from moisture content (fraction by weight, M) according to the ratio of the density of and film and water:

$V_m = M \times (\theta_f / \theta_m) \Rightarrow \sim 1.4 \times M$ at room temperature

This calculation would suggest that for every 100 ppm moisture absorbed the film expands by approx. 45 ppm isotropically in the three dimensions.

With the knowledge of the solubility level of moisture in PEN film and its rate of diffusion as a function of temperature, it is possible to model the impact of various environmental conditions on moisture content changes and hence volumetric changes in the different thicknesses of film.

At room temperature films can typically take over 12 hours to reach equilibrium. Figure 1 indicates the saturation moisture levels at varying relative humidity (RH) levels

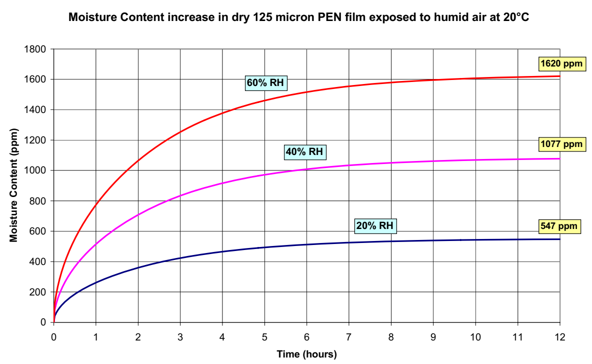

Figure 1: Effect of RH on moisture absorption

In a processing cycle, theory would suggest that these equilibrium moisture levels of 547, 1077, 1620 ppm at 20, 40 and 60% RH at 20°C respectively will be driven off in the oven and will not be taken up again until left for over 12 hours upon cooling. The changes in dimensions related to these levels of moisture would be predicted to be approximately 0.025%, 0.05% and 0.075% respectively.

To verify this experimentally, strips of Teonex® Q65 were allowed to equilibrate at 20%, 50% and 80% RH at room temperature (23°C) and then the samples were heated for 30 mins in an oven. The dimensions of the film were measured in two dimensions (MD & TD) after 10 mins, and after a further 24 hours reconditioning at the same conditions as the films experienced before being placed in the oven. Shrinkages were measured using a Nikon Profile Projector NK-12 that can enlarge and project the marked film onto a large screen with perfect magnification accuracy enabling highly accurate measurements to be taken.

The experimental results in Table 2 show that the shrinkage effect decreases from the initial measurement after 10 minutes until the films have reached the same moisture equilibrium level they had prior to the test. The initial uptake of moisture over 10 minutes assumes that the film is suspended in air in laboratory conditions resulting in very rapid changes in film temperature and moisture over the initial 2 minutes as seen in Figure 2.

Humidity at 23°C (%RH)	Moisture uptake			Dimensional change (%)
	10 min	24 hours	Differential	
20 RH	285	555	270	0.013
50 RH	285	1371	1086	0.051
80 RH	285	2201	1916	0.089

Table 1: Predicted differential shrinkage of film equilibrated at different levels of humidity

Within experimental error, there is good agreement between the order of magnitude change measured with the change predicted from moisture content change predictions in Table 1 when you take into account the moisture uptake the film experiences as it is allowed to cool in the lab environment over the initial 10 minutes.

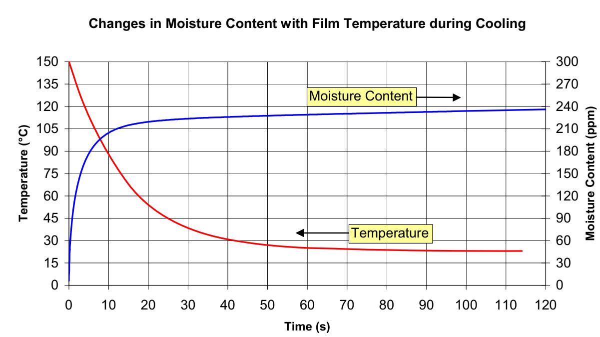

Figure 2: Effect of cooling from 150°C on moisture content

Humidity at 23°C	Orientation	Number of specimens	Shrinkage after cooling (%)	Std. Dev.	Shrinkage after equilibrating (%)	Std. dev.	Shrinkage difference after equilibrating (%)
20 RH	MD	5	0.032	0.024	0.015	0.012	0.018
	TD	5	-0.009	0.019	-0.013	0.020	0.005
50 RH	MD	4	0.073	0.015	0.021	0.005	0.052
	TD	5	0.018	0.020	-0.024	0.023	0.042
80 RH	MD	5	0.088	0.009	0.015	0.006	0.073
	TD	4	0.037	0.025	-0.033	0.007	0.070

Table 2: Measured Shrinkage of Film Equilibrated at Different RH

To highlight the importance of environmental control on dimensional reproducibility the model has been used to investigate a few hypothetical processing cycles for PEN film. The three cycles chosen represent

a) heating a dry film (by holding in vacuum for over 12 hours) up to a temperature of 100°C and processing at that temperature in hot air with lab levels of humidity (0.6% absolute equivalent to 41% RH at 20°C)
b) similarly heating a dry film and processing up to a temperature of 150°C in similar humid air
c) heating a dry film and processing at 150°C in wetter air (1% absolute humidity equivalent to 68% RH at 20°C)

Cycle length was allowed to vary between 5 and 15 minutes and levels of moisture pick up for all the 3 cases are shown in Figure 3.

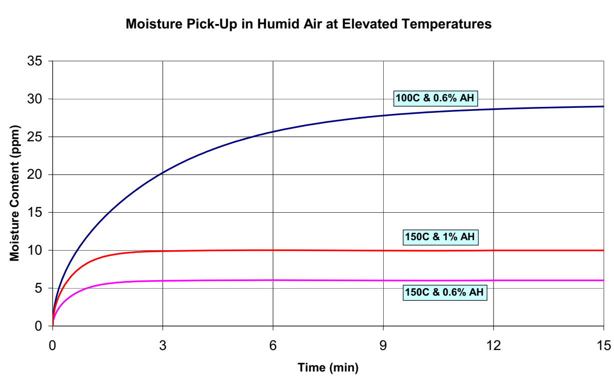

Figure 3: Effect of processing at 100 and 150°C in humid air on moisture absorption.

Not only does the level of absorption change, but also the timescale over which it happens changes as the temperature is lowered. This is on a substrate with relatively low solubility of < 0.2% at ambient conditions. One can expect a fivefold increase in this when dealing with substrates with solubility of 1% or more and at diffusion rates comparable to PEN film.

The implications of the above are:

(i) if the film is being processed at 100°C then the film may take a longer time to reach equilibrium moisture level than the time at temperature taken to carry out the processing step i.e. ideally the film should be allowed to equilibrate before any registration points are established.

(ii) Processing at 150°C reduces the time to reach equilibrium moisture level to less than two minutes and is fairly independent of lab conditions i.e. the processing step can be carried out almost immediately. However on cooling to room temperature, subsequent thermal shrinkages need to be referenced against equilibrium moisture levels at ambient conditions as discussed above.

2.2. Examples of Film in Use

Results will be presented using data from companies that are fabricating on Teonex® Q65 which illustrate the control of dimensional reproducibility that can be achieved with Teonex® Q65.

3. Conclusion

As discussed above, all plastic based substrates absorb moisture and the amount of moisture absorbed will depend on the substrate type and processing environment. Dimensional reproducibility is a key requirement for flexible display manufacture and this paper has illustrated the impact uncontrolled moisture absorption can have on this key parameter. If the environment is controlled, the dimensional reproducibility of Teonex® Q65 is sufficient to successfully build a-Si TFT backplane arrays. Studies of this kind will be essential to achieving the demanding performance criteria required for substrates in flexible electronics applications.

4. References

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