Contact Electrification of Adhesion Films on Flat Panel Displays

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Abstract. Contact electrification of a protective adhesion film on a flat panel display may result in high charge accumulation on an electrically insulating surface affecting production yield and field failures. Tendency for triboelectric charging on planar surfaces was evaluated with the different film structures and different plane materials. Manual separation and constant speed separation techniques were adopted in the experiments. Triboelectrification had random effects that may be difficult to control without electrical conductivity. Electrostatic dissipative properties on the adhesion surface may increase charging of the insulating display. An inherently dissipative layer of the adhesion film significantly mitigated charge accumulation of the film itself.

1. Introduction
Electrostatic control has become increasingly important in a flat panel display (FPD) manufacturing for prevention of ESD damage and contamination by electrostatic attraction [1]. New multilayer technologies and increasing sizes of the displays require improved electrostatic control to increase the production yield and decrease field failures on TVs, monitors, notebooks, tablets and mobile devices.

The use of protective adhesion films may result in high surface charge densities on the displays. Traditionally electrostatic dissipative or conductive materials are used for passive control of electrostatic charge accumulation. In the case of FPD, surface resistivity of the display cannot generally be decreased. Controlling charge accumulation on insulating surface is a challenging task due to the complex nature of triboelectrification. Theoretically, charging depends on the density of surface states and actual contact area between the objects. In one model based on electron transfer for metal-metal contact, electrons flow from the material with a lower work function to material having a higher work function. The charge flow terminates when the Fermi levels are equalized [2]. In other models based on electron transfer, insulators are considered to be wide band-gap semiconductors [3, 4]. The role of ion transfer in charging mechanisms cannot be disregarded, but calculations are difficult because we know so little about the population of surface ions [3, 4]. In practice, there are many uncontrollable factors affecting charging processes. Even in a controlled laboratory, tolerable repeatability is difficult to achieve. Outcome is highly influenced by the test arrangement.

Charge accumulation can be mitigated by ionization or by controlling charging and discharging current. ESD control items are typically bonded and connected to the earth preventing floating energy.
states. When a conductive or dissipative [5] contacting surface is forced to stay at zero potential, the electrostatic potential of the opposite insulating surface will increase to a higher level on separation than with floating objects [6].

In this study, we have demonstrated contact electrification of different film structures on four insulating planar reference material surfaces with manual and constant speed separation techniques.

2. Experimental
Contact electrification tests were made for neutralized reference surfaces and sample films. Both sides of the samples and references were neutralized by ionization before the contact. Sample films were brought into contact with the reference surfaces with a squeegee and constant force, and then neutralized again. Charge accumulation was measured when the samples were separated. The following techniques were used: automated control, manual separation and manual separation with continuous monitoring. Charge induced on induction plates in close proximity to sample films and reference surfaces was measured with charge meters connected to an oscilloscope. Figure 1 shows the principles of the separation methods. Surface and volume resistivity of the samples were measured with an electrometer and concentric ring electrodes in accordance with ASTM D257 [7]. All experiments were made in laboratory conditions (12 ± 3) %rh and (23 ± 2) °C.

2.1. Method 1, automated control of separation
The sample film was peeled off from the planar reference with the constant separation speed of (200 ± 20) mm/s with the modified triboelectric test station of EN 1149-3 [8]. Charge induced by the planar reference and the sample film was simultaneously recorded with an oscilloscope.

2.2. Method 2, manual separation
The sample film was peeled off from the planar reference surface manually. Both the sample film and the reference were earthed through the operator. Charge induced by the sample film and reference was measured after separation.

2.3. Method 3, manual separation and continuous monitoring
The sample film was peeled off from the reference manually. The earthed sample film was placed on the induction plate. Charge induced by the reference was recorded with an oscilloscope. Charge induced by the sample film was measured after separation.
3. Results

Low density polyethylene (LDPE) sample films with inherently dissipative polymer (IDP) layers are identified in Table 1. Figures 2 and 3 summarize two charging test series of the samples with electrically isolating polyethylene terephthalate (PET) reference ($\rho_s > 10^{15} \Omega, \rho_v > 10^{15} \Omega$ m). The results are expressed as a minimum, a maximum and an arithmetic mean of ten measurements.

Variation between the test series with sample film A was observed. Polarity changed randomly, keeping the median relatively close to zero. The IDP contact surface of sample film C resulted in different polarity to the LDPE surface of sample films B and D, presumably due to different locations in a triboelectric series.

Figure 4 shows ten separations of the middle dissipative sample film B from LDPE reference ($\rho_s = 10^{14} \Omega$). A slowly dissipative [9] adhesion surface was considered the main reason for repeatable charging effect between two LDPE surfaces. In Figure 5 sample film B was connected to earth with a conductive rubber (shore A 60, 3 mm × 10 mm × 100 mm). Despite the insulating surface, charge decay of the earthed sample film B was approximately 2 seconds.

Figure 6 summarizes ten charging measurements of the sample films with an electrically insulating polymethyl methacrylate (PMMA) reference ($\rho_s > 10^{15} \Omega, \rho_v > 10^{15} \Omega$ m). Results of an insulating polycarbonate (PC) reference ($\rho_s > 10^{15} \Omega, \rho_v > 10^{15} \Omega$ m) are shown in Figure 7.

| Sample film | Identification | Volume resistivity $\rho_v$ (Ω cm) | Contact surface $\rho_s$ (Ω) | Outer surface $\rho_s$ (Ω) |
|-------------|----------------|----------------------------------|-----------------------------|-----------------------------|
| A           | Insulating     | $> 10^{14}$                      | $> 10^{14}$                 | $> 10^{14}$                 |
| B           | Dissipative middle layer | $> 10^{14}$ | $> 10^{14}$ | $> 10^{14}$ |
| C           | Dissipative contact surface | $> 10^{14}$ | $5 \times 10^{10}$ | $> 10^{14}$ |
| D           | Dissipative outer surface | $> 10^{14}$ | $> 10^{14}$ | $5 \times 10^{10}$ |

Figure 2. Method 2, PET reference, Earthed sample films

Figure 3. Method 2, PET reference, Repetition of the test series

Figure 4. Method 1, Sample film B and LDPE reference, Floating samples

Figure 5. Method 1, Sample film B and LDPE reference, Earthed samples
The insulating sample film A showed higher charge accumulation on the PMMA reference than the sample films with an IDP layer. A dissipative contact surface of sample film C resulted in higher charge accumulation than the sample films B and D with insulating contact surfaces. The highest charge for the PC reference was recorded with the dissipative contact surface of sample film C.

4. Discussion & Conclusions

To achieve a low charging pair of an adhesion film and FPD, both surfaces should have conductive or dissipative properties for dissipation and recombination of separated charges. Relatively high surface resistivity of the slowly dissipative surface up to 100 TΩ may increase the backflow current and help limit charge accumulation. Based on the results and observations, we infer that reliable low charging behavior in practice means that the materials have some electrical conductivity, even if they are classified insulating with surface resistivity above 1 TΩ. Further studies are needed to attest this insight.

Contact electrification of insulating surfaces had random effects that may be difficult or impossible to control with passive material selection in applications. An inherently dissipative contact, middle or outer layer efficiently mitigated charge accumulation of the film itself when earthed by an operator. A multilayer film structure can provide useful charge reduction for general purposes. For some FDP materials a dissipative adhesion surface may result in higher charge accumulation than an insulating contact surface. IDP in the middle or outer layer reduced variability of the insulating surface charging. Case specific evaluation is recommended for material pairs in applications.

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