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A study on the triboelectric charging of display glass during the roller transfer process—modeling and characterization

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A B S T R A C T

Glass substrates for displays are insulating materials capable of generating and maintaining high levels of triboelectric charges posing a risk of electrostatic discharge (ESD) damage to electronic display components. In this work, an apparatus for triboelectric charging characterization of display glass during the roller transfer process was designed and fabricated. In order to establish the reliability of the characterization, the triboelectric charge and the electrostatic potential distribution measurement system was automated. The preconditioning process of the glass and the rollers was also addressed. In order to analyze the measurements' results, a multiphysics model that considered both electrical and mechanical properties was proposed. The test parameters that were expected to affect the triboelectric charging characteristics are defined and discussed, as well as some of the characterization results such as the effects of acceleration/deceleration and maximum velocity, relative humidity and moisture on the glass and the rollers, and the conductivity of the rollers. The peak-to-peak deviation of the de-embedded triboelectric charges, due to a steady-state velocity period with different combinations of acceleration/deceleration and maximum velocities, was 14.2%. The triboelectric charges increased as the relative humidity increased from 30% to 50% with the same temperature. They also increased when the insulating rollers were replaced with dissipative rollers.

1. Introduction

Glass substrates for displays are very good insulating materials capable of generating high level of triboelectric charges and maintaining the charges for a long time [1]. Additionally, the sizes of the display glass are getting larger. The size of the popular eighth generation glass is 2300×2600 mm^2, but some LCD manufacturers are already using the tenth generation glass which has dimensions of 2880×3130 mm^2. Such large glass sizes are used during the array portion of the display fabrication process. The thin film fabrication part of the array process includes cleaning, deposition, photoresistor coating, ultraviolet exposure, developing, etching, and photoresistor removal. These steps are repeated several times because thin-film transistors (TFTs) consist of several thin film layers such as amorphous silicon, metal, indium-tin-oxide (ITO), and insulators. In between the thin film fabrication processes, the glasses are transferred by the force of the static/dynamic friction between the glass and the rollers [2], and the triboelectric charges are separated and accumulate on the bottom side of the glass which comes in contact with the rollers during the roller transfer process [3]. If the accumulated charges result in potential differences between the metal lines on the top side of the glass, then electrostatic discharge (ESD) failure may occur in the form of a dielectric breakdown due to a high level of potential difference followed by a thermal failure due to a high level of ESD current [4].

Triboelectric charging is a physical phenomenon that has been known for over two thousand years, and triboelectric charging between metallic materials is well explained using the concept of work function difference. However, the mechanisms of triboelectric charging between the insulating materials are not completely

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understood. Many different charge transfer mechanisms have been discussed such as electron transfer, ion transfer, and material transfer [5], but few experimental works have been conducted to understand the triboelectric charging of the display glass during the roller transfer process [3,6,13]. Some of the results and properties of the triboelectric charging of the display glass and the related physics and parameters from these experimental works are summarized in Table 1. However, in Ref. [3] they utilized the roller transfer system on real LCD manufacturing lines which were already installed before the study, and it might not be easy to control/change certain test parameters such as the relative humidity, temperature, acceleration/deceleration, transfer velocity, dimensions of the rollers, and so on. In Ref. [6], they mainly characterized the triboelectric charging to prove the effectiveness of their countermeasures.

In this work, an apparatus was designed and fabricated for the triboelectric charging characterization of the display glass during the roller transfer process in order to characterize the triboelectric charging characteristics systematically. Measurements of the triboelectric charges and the electrostatic potential distributions are automated in order to minimize manual processes during the characterization. Test parameters that affect the triboelectric charging characteristics are defined such as environmental/system driving conditions and material properties. Furthermore, a multiphysics model which considers both electrical and mechanical properties is proposed in order to analyze the triboelectric charging characteristics. In Section 2, the automated apparatus and test set-up, including the preconditioning of the materials, are explained. The multiphysics model is introduced, and the test parameters are defined in Section 3. The triboelectric charging characteristics of the display glass during the roller transfer process are discussed in Section 4, followed by the conclusion in Section 5.

2. Apparatus and test set-up for the triboelectric charging characterization

2.1. Description of the apparatus for the triboelectric charging characterization

Fig. 1 shows the fabricated apparatus for the characterization of the triboelectric charging between the glass and the rollers where the width, length, and height of the apparatus are 610 mm, 1830 mm, and 990 mm, respectively. The apparatus is designed to fit into a climate chamber in order to control the relative humidity and the temperature during the characterization. The apparatus consists of one AC-to-DC power supply, 17 shafts with 11 rollers per shaft, nine lift pins, one stepper motor to drive the rollers, three stepper motors to move the lift pins, as well as two stepper motors to move the XY scanner and the corresponding six motor controllers. Three RS-485 to USB converter cables are used to support the communication between the motor controllers and the control computer, which is outside of the climate chamber. The glass travels back and forth on the rollers by changing the rotational direction and the velocity of the stepper motor. The lift pins are used to lift the glass up and to put the charged glass into the Faraday cup during the automated triboelectric charge measurements.

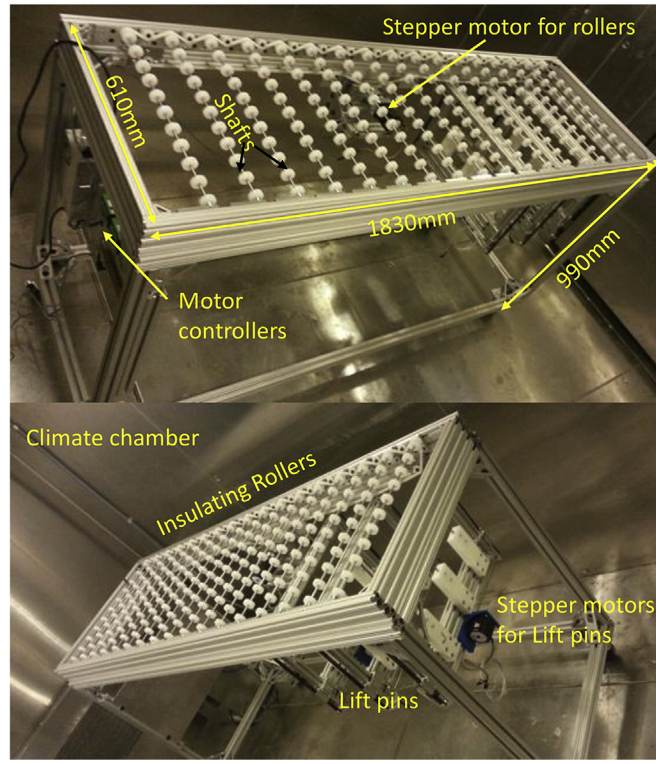

Fig. 1. Apparatus for the characterization of triboelectric charging between the glass and the rollers.

Two different types of materials are used to fabricate the rollers: one is insulating ultra-high-molecular-weight (UHMW) polyethylene, and the other is a dissipative UHMW polyethylene that contains carbon particles to increase the conductivity of the material. The diameter and the spacing of the rollers are 30 mm and 50 mm, respectively, and the gap between the shafts is 100 mm. Alkaline earth boro-aluminosilicate glasses, which are typically used for display substrates, are used in this study. The size of the glass is 457 mm × 457 mm × 0.5 mm.

Fig. 2 (a) shows the XY scanner installed on the roller transfer system for the electrostatic potential distribution measurements. The position of the vibrating electrostatic voltage sensor is automatically controlled using two stepper motors.

The triboelectric charges were measured using a Faraday cup and the ES103 solid state electrometer from ESDEMC Technology LLC. The Faraday cup is replaced by the XY scanner, and placed in

Table 1
Typical properties of triboelectric charging of display glass during roller transfer process.

Property	Related Physics	Parameter
Q↑ as v_{tran}↑ v_{tran}: transfer velocity	Frictional charging/Distance [3,6]	v_{tran}
Q↑ as t_{acc}/t_{dec}↓ t_{acc}/t_{dec}: acceleration/deceleration time	Frictional charging (not clearly explained) [3,6]	t_{acc} and t_{dec}
Q (insulating, large d_{roller}) > Q (dissipative, small d_{roller}) d_{roller}: diameter of roller	Different roller resistance [3]	d_{roller} and types of materials
Q↑ as Area↑	Contact area [13]	Mass of glass