A Study of Electrostatic Charge on Insulating Film by Electrostatic Force Microscopy

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Abstract. Electrostatic charge properties on polypropylene film have been characterized by atomic force microscopy and electrostatic force microscopy. The measurements have been carried out after the polypropylene film was electrified by contact and separation process in an atmosphere of controlled humidity. The negative and positive charge in concave surface has been observed. The correlation between concave surface and charge position suggests that the electrostatic charges could be caused by localized contact. On the other hand, positive charge on a flat surface has been observed. The absence of a relationship between surface profile and charge position suggests that the electrostatic charge should be caused by discharge during the separation process. The spatial migration of other positive charges through surface roughness has been observed. The results suggest that there could be some electron traps on the surface roughness and some potentials on the polypropylene film.

1. Introduction
The study of electrostatic charge on an insulating surface is most important for clarifying the elementary process of electrification, controlling of electrostatic charge and finding effective charge relaxation techniques. An insulator is electrified by contact and friction process between two materials and the resulting discharge during the separation process. The amount of charge and its characteristic are determined by materials or their surface characteristics [1]. Some correlation between surface voltage and surface roughness on the insulator has been reported [2, 3]. They suggest that the charge should be transported at localized contact positions. Also, they anticipate that the surface roughness should form some electron traps, which should effect a change in charge amount and characteristic.

Microscopic evaluations of electrostatic charge created by contact process and discharge have been attempted using Atomic Force Microscopy (AFM) and Electrostatic Force Microscopy (EFM) [4-6]. The AFM and EFM have been used to investigate the surface charge properties of semiconductors and insulators [6-14]. In this study, the charge properties on an insulating surface have been characterized by AFM and EFM. The samples were used polypropylene films, which provide excellent electrical insulation. It is expected that the charge feature would be unaffected for a few minutes and could be used to study the detailed surface phenomenon. The obtained AFM and EFM images suggest that the charge transport should be caused by localized contact. On the other hand, other AFM and EFM images suggest that the electrostatic charge on polypropylene films should be caused by discharge during the separation process. Also, the time evolution of some EFM images suggests that the charges from a discharge would migrate to stable positions on the surface.
2. Experiments
The charge and surface properties of polypropylene films were characterized by AFM and EFM at room temperature in air using Innova Scanning Probe Microscope (Veeco Instruments) with a Pt/Tr coated tip (SCM-PIT). Samples were 150 µm thick used polypropylene films. After they were electrified by contact or separation, the AFM and EFM measurement were carried out. In the system, the measurements were performed in a two-pass mode. The first pass (tapping mode AFM) gives the topography of the surface. The second pass (EFM) follows the track obtained in the first pass with a fixed lift-up distance and measures the phase shift caused by the electrostatic force while the tip is biased with a voltage of a few volts. The EFM measurement conditions were the tip bias voltage in the range of 0.1 to 1 V and the lift height in the range of 50 to 500 nm. The humidity was maintained at 50 percent during the measurements.

3. Results and discussion
3.1. Electrostatic charge by contact electrification
Figure 1 (a) and (b) show typical AFM and EFM images of the electrified polypropylene film with positive charge, and figure 1 (c) shows line profiles of the AFM topography and EFM signal intensity. The light color shows areas of positive charge in figure 1(b). Two positive charges in the 7 µm size range were observed on the concave surface. Figure 2 (a) and (b) show typical AFM and EFM image of the electrified polypropylene film with negative charge, and figure 2 (c) shows line profiles of the AFM topography and EFM signal intensity. The dark color shows an area of negative charge in figure 2(b). A negative charge in the 15 µm size range was observed on the concave surface. The scan areas in figure 1 and 2 are 30 µm x 30 µm. The results reveal the presence of a correlation between the concave surface and charge position, although the electrical characteristic is different. They suggest that the electrostatic charges on the polypropylene film could be caused by localized contact. Figure 3 shows a change of the measured EFM images after a period of time at 0 to 37 hours and line profiles of the EFM signal intensity. The scan area is at the same position as shown in figure 2. The decrease

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** Typical (a) AFM and (b) EFM images of the electrified polypropylene film with positive charge, (c) line profiles of the AFM topography and EFM signal intensity.

**Figure 2.** Typical (a) AFM and (b) EFM images of the electrified polypropylene film with negative charge, (c) line profiles of the AFM topography and EFM signal intensity.
of negative charge area and EFM signal intensity was observed. This result means the presence of trapped charge in the insulator migrating over time to cancel those in the surface. Though not shown here, AFM images on the same area remained unchanged during the measurements.

3.2. Electrostatic charge by discharge

Figure 4 shows a change in the measured AFM and EFM images of the electrified polypropylene film with positive charge after a period of time from 0 to 45 minutes. The scan area is 50 µm x 70 µm. In the same way as above, AFM images on the same area remained unchanged while measuring. A positive charge in the 40 µm size range was observed. This result reveals the absence of a relationship between surface profile and charge position, as shown in figure 4 (a) and (b). They suggest that the electrostatic charge on the polypropylene film should be caused by a discharge during the separation process. In the EFM image of the same area after 15 minutes, another positive charge was observed, as shown in figure 4 (c). Then the charges contacted through surface roughness, as shown in figure 4 (d). These results imply that the second positive charge had migrated. Although this should create a repulsive force between positive charges, the second charge could be pulled by a stronger attractive force. Also, the spatial migration of the second charge through surface roughness implies that there

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**Figure 3.** A change of the measured EFM images after a period of time at (a) 0, (b) 12, (c) 30 and (d) 37 hours and (e) line profiles of the EFM signal intensity.

**Figure 4.** A change of measured (a) AFM and EFM images of the electrified polypropylene film with positive charge after a period of time at (b) 0, (c) 15 and (d) 45 minutes.

**Figure 5.** A change of the measured EFM images of the electrified polypropylene with positive charge after a period of time at (a) 130, (b) 200, (c) 230 and (d) 300 minutes.
could be some electron traps on surface structural defects [2, 3]. Figure 5 shows a change in the measured EFM images of the electrified polypropylene with positive charge after a period of time at 130 to 300 minutes. The scan area is wide range 70 µm x 100 µm at the same position as shown in figure 4. The view of second charge has migrated more, and the combined charge of the round shape was formed by the positive charges. The results suggest that there could be some potentials on the polypropylene film [15]. The shape of the combined charge remained unchanged after 300 minutes, and the charge disappeared with time.

3.3. Difference between charge by contact electrification and one by discharge
In the electrostatic charge properties by contact electrification, the charge on polypropylene film disappeared without migrating to other position. This indicates the possibility that surface topography is changed by localized contact. At the same time, electron traps could be formed at the same position. On the other hand, in the electrostatic charge properties by discharge, the charge on the polypropylene film changed position. This indicates the possibility that the charge was adsorbed on the surface after discharge. In that case, it is not always true that the charged position is a stable position for potential. Therefore, the charge could migrate slowly to a position with low potential for a few hours.

4. Conclusions
Electrostatic charge properties on polypropylene film have been characterized by electrostatic force microscopy and atomic force microscopy. The characterization of the charges by contact electrification and discharge indicate the possibility that there could be some electron traps on the insulating surface. Also, the characterization of the charge by discharge indicates the possibility that there could be some potentials on the polypropylene film. This present study suggests that there could be some charges of at least two types, and their characteristics could be difference. These results would support the understanding of the electrification phenomenon.

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