

Dissipation of Electrostatic Charges

Fundamental Study by Scanning Probe Microscopy

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Atomic force microscopy electrical modes are used to study the charge dissipation mechanisms in antistatic felts at the microscopic level. Fiber surface electrical conductivity is studied by current-sensing AFM (CS-AFM). Kelvin probe force microscopy (KPFM) is used to measure the surface potential distribution. Dynamic charge behaviors depending on the applied bias are observed on a single polyester fiber or between two conductive fibers in non-galvanic contact.

properties (surface electrical conductivity, surface potential and charges, ...). These AFM-based electrical techniques appear as ideal tools to investigate the charge dissipation mechanisms in antistatic felts at the microscopic (fiber) level.

Introduction

The demand for antistatic textile has been growing up in the recent years due to the large number of potential applications in the electronics industry, in the chemical industry and in industries using filters [1,2]. Many efforts have thus been done to understand the charge dissipation mechanisms in order to better control static electricity [3-6]. However, most of the studies realized up to now were

done at the macroscopic and mesoscopic levels. Microscopic electrical characterizations are greatly needed to complement existing theories. Thanks to the development of scanning probe microscopy, a number of new electrical modes using conductive probes, such as current-sensing AFM (CS-AFM) [7,8], electrostatic force microscopy (EFM) [9-11] and Kelvin probe force microscopy (KPFM) [12-15], have been developed and used to characterize different microscopic electrical

Materials and Methods

All experiments were performed on an Agilent 5500 multimode AFM (Agilent Technologies, USA) with a close-loop scanner having a maximum horizontal scanning range of $90 \times 90 \mu\text{m}^2$ and a vertical scanning range up to $8 \mu\text{m}$. n+-doped silicon cantilevers coated with a layer of Pt/Ir on tip and detector sides obtained from Nanosensors were used for both the CS-AFM and KPFM experiments. CS-AFM

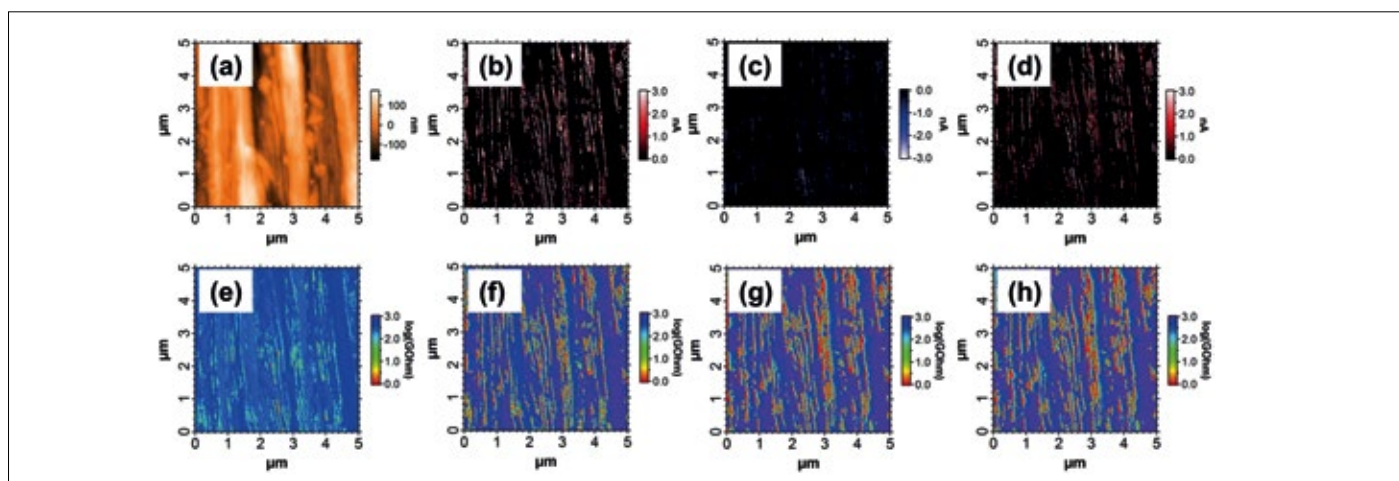


Fig. 1: Topography, surface current distribution, surface resistance distribution images obtained at the same location on a Bekinox fiber. (a) Topography, (b) (c) (d) electrical current distribution at 2 V, -2 V and 2 V again, (e) (f) (g) & (h) electrical resistance distribution at 1 V, 1.5 V, 2 V and 3 V, respectively.

analyses were performed with a current sensing module. KPFM was performed with an AC module MACIII and an extender electronics module. CS-AFM combined with KPFM measurements were also realized using a Resicope module. This module uses a higher performance amplifier (HPA) allowing the measurement of the current/resistance over 10 decades with high sensitivity and resolution (100 fA to 1 mA / 0.1k Ω to 1T Ω). Two types of materials were used in this study: insulating polyester fibers and conductive stainless steel fibers (Bekinox fibers produced by the company Be-kaert). The fibers were stored under ambient conditions and analyzed as-received without any surface treatment.

Results and Discussion

The surface conductivity distributions were measured by CS-AFM on single Bekinox fibers, as shown in figure 1. The topographic image reveals stripes on the fiber surface oriented along the fiber axis. Correspondingly, the conductive zones (red regions on resistance images), are oriented along the stripes. In figure 1 (b, c & d), along with the topographic image, images obtained with positive and negative bias voltages (+2 V, -2 V, +2 V) are presented. They demonstrate that the surface is more conductive for positive bias voltages than for negative ones. Resistance images for increasing positive bias voltages (1, 1.5, 2 and 3 V) are given in figure 1 (e, f, g & h). The surface resistance progressively decreases when the bias voltage increases. In order to compare the surface conductivity distribution and the surface potential distribution at the same location, combined CS-AFM and KPFM measurements were performed with the Resicope module. The KPFM surface potential map obtained with the Resicope. Figure 2(c) is consistent with that obtained with standard KPFM Fig. 2(d). The difference

between both images mainly resides in the noise level and the achieved lateral resolution. The regions with different surface potential are also distributed along the longitudinal stripes, as it is observed for the surface resistance. The average surface potential has a value around -0.5 V. The surface potential value results from the work function difference between the tip and the sample materials. The tip used was coated with a layer of Pt/Ir (Pt: work function around 5.5

eV, Ir: work function around 5.3 eV). On the basis of these values, the average work function of the fibre surface is estimated around 6.0 eV.

Dynamic charge and discharge behaviors depending on the applied bias and observed by KPFM between two conductive Bekinox fibers in non-galvanic contact (B+B configuration) (a-c) and on a single insulating polyester fiber (P configuration) (d-f) are presented in figure 3. The average surface po-

tential of each scan line was calculated and plotted as a function of scan time to obtain charge and discharge curves (fig. 3g) & h)). These curves monitor the kinetics of charge dissipation. For the configuration of conductive fibers in non-galvanic contact, the progressive charging of the 2nd fiber can be clearly observed when a bias voltage of 5 V is applied on the 1st conductive fiber. The galvanic contact between two conductive fibers was

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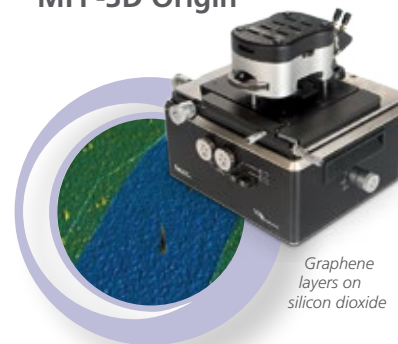


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also tested and an instantaneous charging of the 2nd fiber was observed. The log-lin plots of the charge and discharge curves clearly reveal a two-stage charge transfer process in both cases. For a single polyester fiber configuration (P), the progressive increase of the surface potential is also observed when the fiber is biased from 0 to 5 V, figure 3(h). In this case, different behaviors are observed for the charging process and the discharging process.

Conclusion

Surface electrical characterization is the first important step for understanding the surface conduction mechanisms. The CS-AFM and KPFM images reveal that the electronic properties show distributions that are aligned along the longitudinal topography of the fibers. Resistance mapping at various bias voltages show that the surface resistance present mainly a semi-conducting behavior with a dominating p-type character. This behavior is accounted for by the presence on the surface of the stainless steel fibers of a passivation layer mainly composed of chromium oxide. Surface potential measurements were then performed using KPFM to monitor the kinetic of charge transfer on the polyester fiber or between conductive fibers in non-galvanic contact. Different behaviors with different time constant were observed. For the charge transfer between two conductive fibers, it is likely that the mechanism in play is mainly charge induction and that the processes are similar to the charging and discharging processes of parallel plate capacitors. The charge transfer processes observed on the polyester surface are more complex, implying different mechanisms. Further experiments and more precise simulations would be required to interpret the mechanisms.

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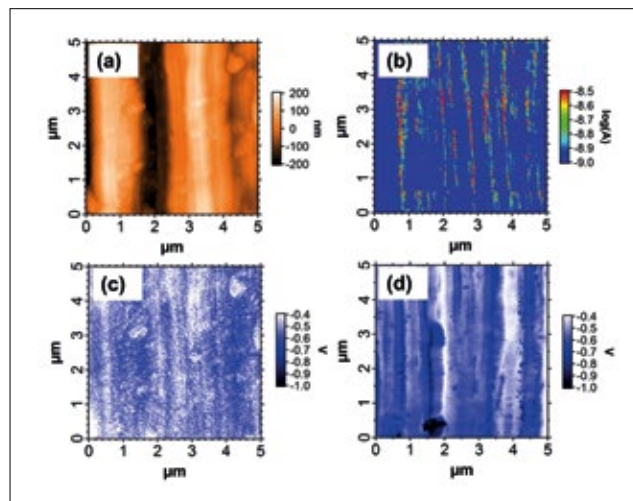


Fig. 2: Combination of KPFM and CS-AFM images obtained with the Resi-scope module: (a) topography, (b) surface current image with an applied voltage of 2 V, (c) surface contact potential image measured with the Resi-scope and (d) with standard KPFM.

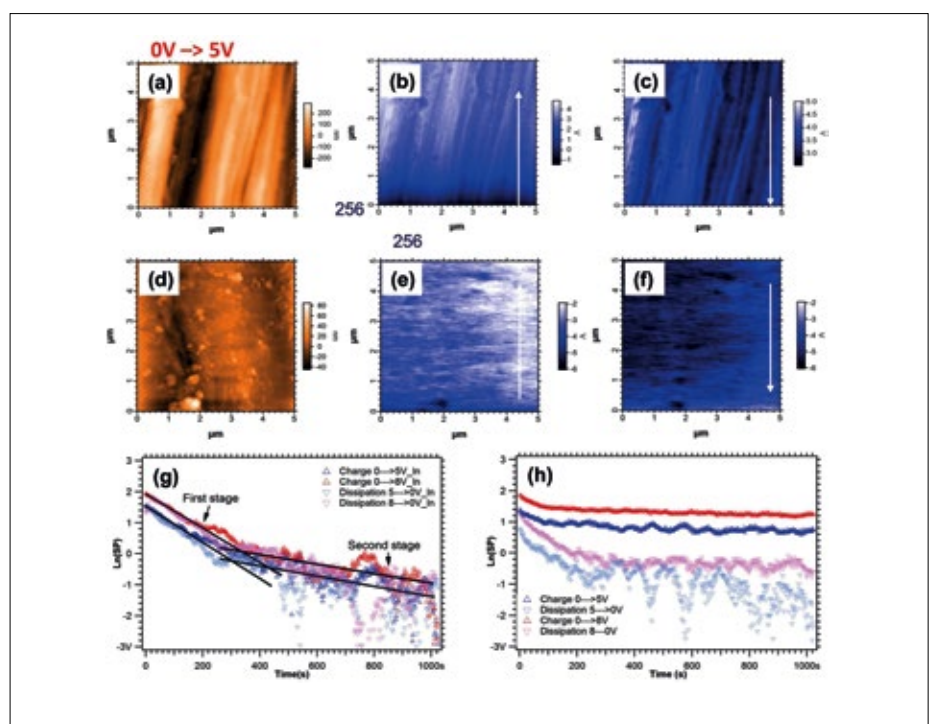


Fig. 3: Dynamic charging behaviors: (a) topographic image of conductive fiber, (b-c) two successive surface potential images for the configuration B+B, (d) topographic image of polyester fiber, (e-f) two successive surface potential images for the configuration of P. The white arrows represent the scan direction. (g) Charge and discharge curves for the configuration B+B for 4 ramps: 0 → 5 V, 5 → 0 V, 0 → 8 V, 8 → 0 V, (h) Charge and discharge curves for the configuration P for the same 4 ramps.

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