Real time observation of surface potential distribution with an EFM on CTL

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Abstract

Experiments were conducted with an EFM (Electrostatic Force Microscope) to measure surface potential distribution on CTL (Carrier Transport Layer) having two different charge mobility characteristics. One CTL has lower charge mobility characteristic and other CTL has higher charge mobility characteristic. Four electrodes were placed on each CTL with 100 micrometers and 200 micrometers separation respectively. We had a detector of the EFM scan over three electrodes to measure surface potential distribution on the surface of each CTL. We applied a known voltage on two electrodes and remaining electrodes were connected to ground. We consequently could observe significant surface voltage fluctuation real time basis on both CTL films. The substantial fluctuation of surface voltage distribution could explain charge migration in CTL toward horizontal direction, which is perpendicular to applied electric field. The thickness of each CTL was only 5 micrometer therefore the electric field which was perpendicular to the CTL films was supposed to be very strong and uniform.

Background

Measurement of surface voltage distribution on electrophotographic photoreceptor is commonly made with using an electrostatic voltmeter. Electrostatic voltmeter is conventionally used with a non contacting method with taking a fairly large spacing (around 3 mm) between detector probe and surface of photoreceptor, therefore the expected spatial resolution from measurements with an electrostatic voltmeter is extremely large so it is inadequate to accomplish a direct measurement of electrostatic latent image on a photoreceptor. Surface voltage measurement on photoreceptor with much higher spatial resolution than conventional electrostatic voltmeter has been a critical demand for electrophotography for a long time.

Trek Japan K.K. and Nihon University have been working jointly on a research for the development of electrostatic voltage measurement apparatus having relatively high spatial resolution. Surface voltage on electrophotographic photoreceptor is relatively high namely in the range between the absolute value of 200 V and 800V and area needs to be measured is fairly large. What required on a new surface voltage distribution measurement apparatus, i.e. an electrostatic force microscope (EFM) are (1) having a spatial resolution of 10 μm in diameter, (2) having a capability to measure wide area such as it should cover an area as large as a few 10 cm^2, and (3) the measurable surface voltage should be as high as 1kV.

For the sake of understanding our goals clearly, we have done numerical simulations with the Finite Element Method (FEM) to start with. [1]

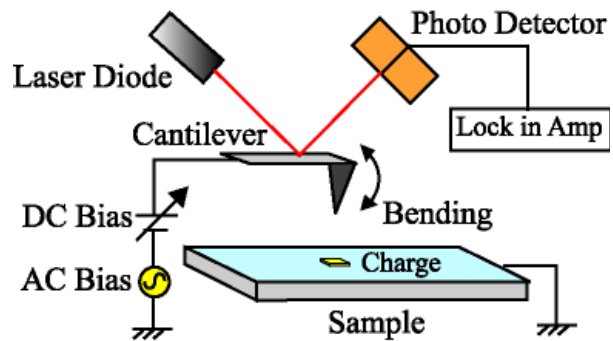## Principle of Electrostatic Force Microscope

Figure 1. Principle of EFM

Tip of detector on an optical cantilever is placed close to surface under test. DC bias voltage (V_{DC}) and AC bias voltage ($V_{AC} \sin \omega t$) are applied to cantilever including detector. If the surface under test is charged, we should be able to expect either attractive or repelling electrostatic force appeared on the detector. Either attractive or repelling force can be detected through measuring bending amount of the cantilever with an optical leverage method. The electrostatic force appeared on the detector consists of two different force components F_ω as well as and $F_{2\omega}$ where F_ω has the same frequency component as the applied AC bias voltage whereas $F_{2\omega}$ has twice higher frequency component as the applied AC bias voltage. If we estimate a parallel plane model on the apparatus as shown in Figure 2, those two forces are obtained with the following equations [2], [3],

$$F_\omega \quad \frac{V_{DC} \quad d_0/_0}{\{d \quad (1 \quad _0/ \quad)d_0\}^2} \, _0 S V_{AC} \sin \quad t \quad \cdots 1$$

$$F_2 \quad \frac{1}{4\{d \quad (1 \quad _0/ \quad)d_0\}^2} \, _0 S V_{AC}^2 \cos 2 \quad t \cdots 2$$

If the distance between detector and surface under test ($d - d_0$) as well as the dielectric constant of a material under test ( ) are evident, we can measure F_ω with applying a pre-set V_{DC} to cantilever and detector so that we can simply calculate the voltage on surface under test ($d_0/$) with aforementioned equation (1). However, since high voltage is in existence on the surface under test, an arcing between detector and surface under test may occur. To prevent from the occurrence of any contingent arcing between detector and surface under test, we discussed a zero voltage method. We obtained a V_{DC} with which F_ω became to be zero in advance.
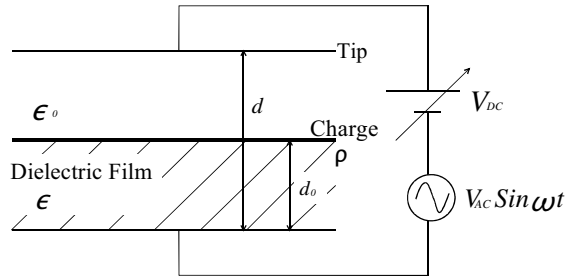
Figure 2. *Parallel Plane Model*

Verifications of Spatial Resolution Capability

We have attained measurements with an apparatus designed based on aforementioned principle. A cantilever with a detector was made out of a nickel foil having a thickness of 5 μm. The tip of the detector was sharpened by a Focused Ion Beam (FIB) system. In parallel with conducting experiments, we also have carried out simulations for analysis of electric field distribution with the Finite Element Method (FEM) to verify the performance of the EFM. [1], [2], Two graphs are shown in Figure 3 which is the comparison of actual data and simulation results in spatial frequency. The blue line shows the actual measurement obtained with the EFM, whereas the red line shows the results of the FEM simulation with using comb-shaped electrodes furnished on a glass substrate for both experiments and simulation. Each plot was normalized as spatial frequency to be "1" with signal strength from a detector when the detector was placed exactly over the center of each electrode. From this comparison, the overall differences between actual data and simulation results were within the range of 5% therefore if we define the spatial resolution capability of the EFM at a half value of each signal strength, we can conclude that we have accomplished one of our goals of voltage measurement with a spatial resolution of 10 μm (approximately 2,400 dpi).
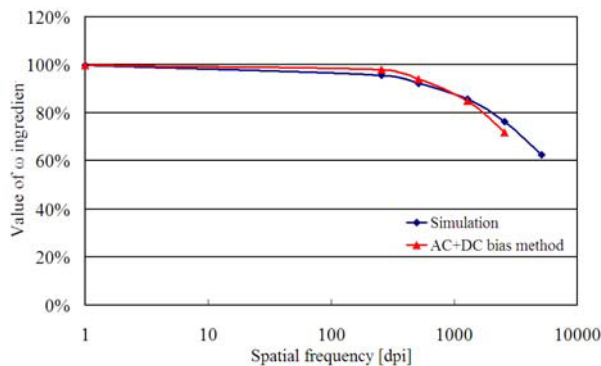

Figure 3. *Spatial frequency of EFM*

Specimens for Measurements

We have created two specimens with Organic Photo-Conductor (OPC) having two different charge mobility characteristics, i.e. a film with higher charge mobility (a-1) and other film with lower charge mobility (d-1). They were the OPC films commonly used for the Carrier Transport Layer (CTL) of which dominant charge carriers are holes. The details of the structure of those specimens are shown in Figure 4. A CTL film having a thickness of 5 μm was deposited on an aluminum substrate then electrodes made out of aluminum of which thickness

was 0.2 μm each were placed later on the CTL film. In order to ensure that the electric field appeared with the voltage applied to those electrodes are parallel in reference to the surface of the specimen, we took a 100 μm distance between Electrode A and B and a 200 μm distance between Electrode A and C respectively. We chose a width of 300 μm for Electrode A and we also set a width of a few mm for Electrode B and C.

We have decided the scanning direction of the EFM detector to be perpendicular to the length direction of electrodes. We have set a 5 μm distance between tip of the detector and the specimen surface and scanned with an incremental movement in a 2 μm toward horizontal directions (both right to left and left to right) throughout scanning.
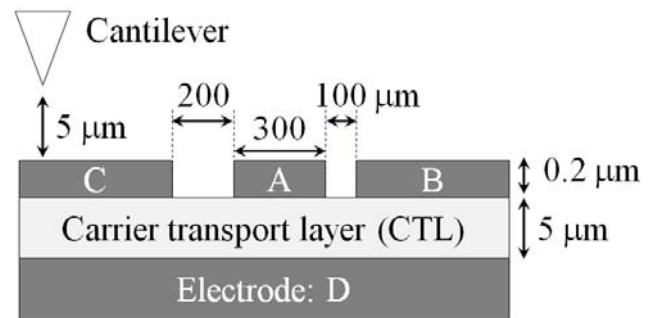

Figure 4. *Structure of Specimen and Position of Detector*

Results and Discussions

Surface Potential Distribution Measurement

The data with applying -150 V on Electrode A and 0V to Electrode B, C and D on the CTL (a-1) are shown in Figure 5. When this measurement was conducted, we have scanned the detector started from Electrode B, Electrode A then Electrode C (From right to left if you refer to Figure 4). We have spent for 20 minutes of duration from one complete scanning sequence. We also set an interval for 20 minutes between the first scanning and the second scanning, therefore we have to identify an interval for 40 minutes between the first scan and the second scan in measurement over the same point.

We have plotted surface voltage on the Y-axis, whereas we have plotted relative position on the X-axis of the graph in Figure 5. We have indicated in the graph "1st" for the data that we have acquired from the first scanning and "2nd" for the data acquired from the second scanning.

A very interesting phenomenon was observed through the measurements. Those voltages on CTL between Electrode C and A as well as between Electrode A and B were further increased toward negative polarity direction for both. It looks as though the charge was migrated horizontally in the OPC film although we applied the electric field only toward perpendicular direction to the OPC film. We did exactly the same experiments with using the OPC (d-1), we could observe little charge migration toward horizontal direction.
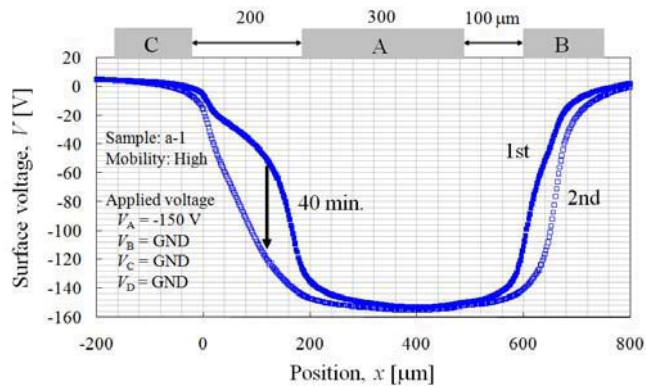
Figure 5. 2 Times Scanning over High Charge Mobility OPC

An attention was paid to the charge mobility characteristic as well as the surface voltage fluctuation. We have done further experiments with applying -150 V to both Electrode A and B then we set 0 V on both Electrode C and D. The same experiments were conducted on both the CTL (a-1) and the CTL (d-1). The scanning method as well as the time intervals were identical to the experiments as described in the above. The results with CTL (d-1) were shown in Figure 6 and the results with CTL (a-1) were shown in Figure 7.

We were able to observe that the voltage increase toward negative direction on the CTL (d-1) between Electrode A and B in proportional to the elapse of measurement time as shown in Figure 6. However, the voltage on the CTL (a-1) stayed the same at -150 V and unchanged.
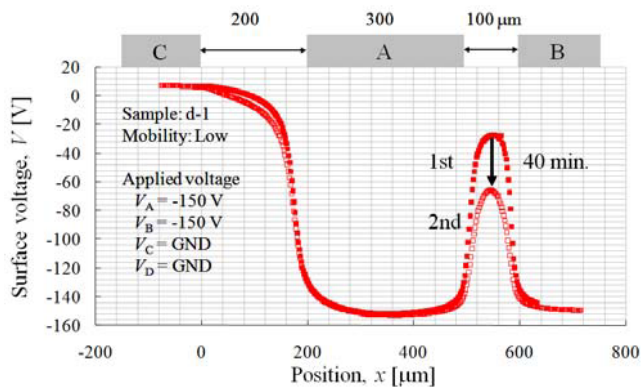

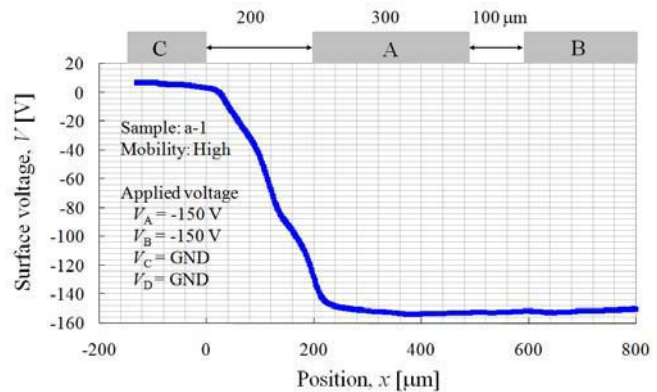*Figure 6.* 2 Times scanning over Low Charge Mobility OPC

Figure 7. 2 Times scanning over Low Charge Mobility OPC

Surface Potential Fluctuation in Time

We have observed the surface voltage change in time on CTL as shown in Figures 6 and 7. In order to confirm how the surface voltage changes as time elapsed, we have fixed the location of the detector at a certain point between Electrode A and B then we monitored the surface voltage change in time on both CTL films.

We chose the stationary monitoring point for both (a-1) and (d-1) CTL films where the voltage was the highest in positive direction between Electrode A and B then the detector was fixed over each of the particular point on (a-1) and (d-1) CTL films. The voltage applied to each of Electrodes was the same as described the above. (-150 V to both Electrode A and B and 0 V on both Electrode C and D)

Since this experiment was commenced over an electrode of which voltage was not confirmed as 0V, we have spent the duration of 136 seconds for increasing the applied voltage which eventually reached -150 V for preventing any arcing from accidentally happening.

The results were shown in Figure 8. The surface voltage on CTL (d-1) gradually increased toward negative direction as we increased the applied voltage on the electrodes toward negative direction. We were able to observe a consecutive voltage fluctuation at the rate of approximately -25 mV/s right after the applied voltage on the electrodes reached at -150 V.

During the course of a 2,200 seconds measurement on CTL (d-1), we were not able to see the saturation of the surface voltage increase and it consequently reached at -80 V, whereas the surface voltage on CTL (a-1) increased toward negative direction in proportional to the increase of the voltage applied to the electrodes. The voltage on the CTL (a-1) became approximately -150 V in 60 seconds after the voltage applied to the electrodes reached at -150 V. The voltage fluctuation rate on the CTL (a-1) was -310 mV/s.

From those results, we have confirmed that the EFM has a capability to monitor the difference of the charge mobility characteristic of the CTL of OPC real time basis.

These phenomena are consistent with previous study that showed the latent image profiles from a higher charge mobility CTL looks to be broader and shallower by means of horizontal spreading of charge distribution on the surface. [4]
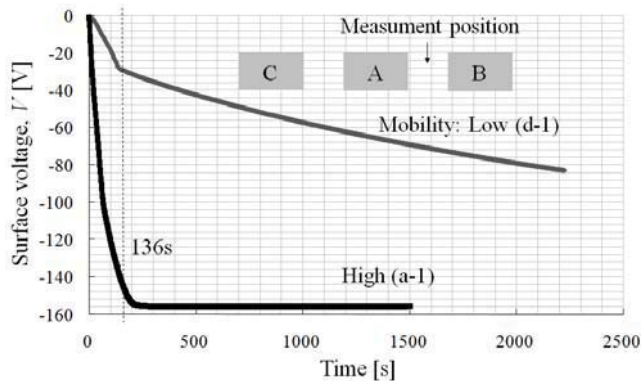
Figure 8. Surface Voltage Fluctuation in Time as referred to Applied Voltage on Electrodes

Conclusion

Electrostatic voltmeters commonly available have spatial resolution in a range as high as a few mm which is far from adequate performance for reading electrostatic latent image on a photoreceptor. A Scanning Probe Microscope (SPM) has been available for electrostatic surface voltage measurement with high spatial resolution on a photoreceptor however it may not accomplish accurate measurement because the length of detector may not be long enough for attaining accurate measurements. Therefore, we have been working on the development of an EFM which can accurately measure electrostatic surface voltage with a spatial resolution of 10 μm or better. The EFM has a relatively long detector of which length is greater than 100 μm and it has a capability to measure surface voltage as high as what is demanded by the electrophotography as well. We have completed measurements on CTL films with a 2 μm incremental scanning. Through those real time measurements on surface voltage on the CTL films, we were able to measure the charge mobility difference from those two CTL films in real time basis.

The data of surface voltage difference in transient response obtained with this EFM may explain reasons why blurriness takes place upon usage of high charge mobility film for a photoreceptor. We have confirmed that the EFM can provide an epoch making progress for the analysis as well as the development of electrophotographic materials for obtaining better quality pictures.

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[4] K. Aizawa, M. Takeshima, and H. Kawakami, "A study of 1-dot latent image potential", Proc. NIP17, pg. 572 (2001).

Author Biography

Toshio Uehara is CEO of Trek, Inc. and President of Trek Japan K.K. He graduated from Nihon University College of Science & Technology. He has been involved in the measurements on electrophotography for more than 25 years and is currently doing joint research on electrostatic microscope with Nihon University. He received President's Award of the Electrostatic Institute of Japan in 2002 and President's Special Award of Imaging Society of Japan in 2005.