Potential Profile Measurement and Mechanism Analysis of Electrostatic Latent Image by Detecting Primary Electrons

Hiroyuki Suhara, Nobuaki Kubo, Takeshi Ueda and Hiroaki Tanaka; Imaging Engine Development Division, RICOH Co., Ltd.; Kanagawa, Japan

Abstract

A new method that makes possible a potential-profile measurement of an electrostatic latent image is proposed. The key technology is to detect a primary electron. When a surface potential is greater than acceleration voltage of the primary electron, the velocity becomes zero before the electron hits a sample. As a result, the primary electron reaches to a detector without reaching the sample. The potential distribution can be measured by detecting primary electrons while changing an applied voltage of a backside. This method is that the means of charging, exposing, and detecting are all incorporated in the same system, making real-time measurement possible.

This system is being used to analyze the basis of an electrostatic latent image formed on a photoconductor. In order to confirm a phenomenon of reciprocity law failure, the latent-image depth was measured by changing the delay time when exposure was carried out a couple of times. As a result, the latent-image depth tends to be formed deep when the delay time becomes long.

Introduction

Recently, a demand for high-quality, color output from digital copying machines and laser printers has risen significantly prompting the development of achieving 1-dot reproducibility and stability. Under such circumstances, it is necessary to measure the electrostatic latent image with high-resolution on the order of microns. However, a spatial resolution of a commercial electrostatic voltmeter is on the order of millimeters at best.

Some methods that use a head sensor, such as a cantilever, and detect an electrostatic attractive force and a dielectric current have been reported [1]. However, it is difficult to set them up in the allowed time because the head sensor must be moved closer to the sample. In addition, it is necessary to solve problems such as natural discharge, absorption, and absolute distance measurement. On the other hand, voltage contrast observations for conductors or insulators have been reported [2]. However, since resistance of an organic photoconductor (OPC) is not infinity, dark decay occurs, and the electric charge decreases with time. Measurements must be taken within a short time after the formation of the electrostatic latent image.

We have proposed a measuring method of a latent-image diameter by detecting secondary electrons in NIP25 (2009) [3]. The significant feature of this method is that the means of charging, exposing, and detecting are all incorporated in the same system. This paper reports a new method for measuring a potential-profile of an electrostatic latent image on a photoconductor by detecting primary electrons [4]. In addition, this paper reports a mechanism analysis of reciprocity law failure using this measuring system.

Measurement Principle

Primary electron detecting method

The measurement principle is shown in Fig. 1. When a charged photoconductor is exposed to light, electron-hole pairs are generated at a charge generation layer (CGL). Holes move through a charge transport layer (CTL), combine with electrons on the photoconductor surface, and disappear. This gives rise to a charge distribution on the photoconductor surface, resulting in the formation of an electrostatic latent image.

This system is configured to apply a voltage to a backside of the photoconductor. The velocity of a primary electron gradually decreases due to influence of the potential of the sample surface. When the surface potential is greater than acceleration voltage of the primary electron, the velocity becomes zero before the electron hits the sample. As a result, the primary electron reaches to a detector without reaching the sample. This measuring method is called a "primary electron detecting method".

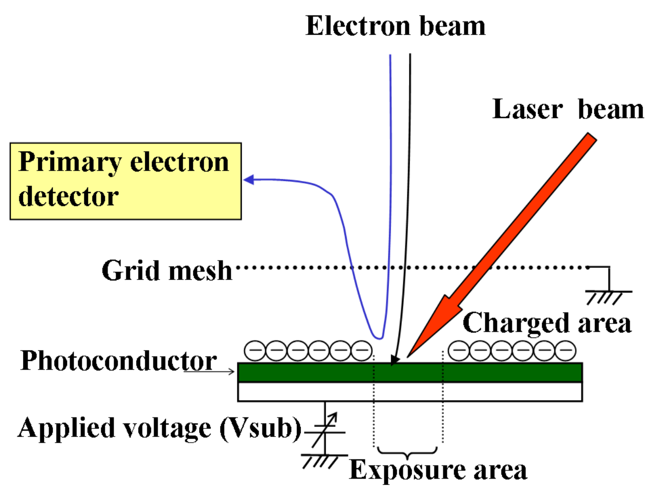

Figure 1. Primary electron detecting method

Physical model of potential energy is shown in Fig. 2. By denoting accelerating voltage as $Vacc$ (< 0), electron mass as m and electron charge as e, initial velocity v_0 of a primary electron can therefore be given by

$$v_0 = \sqrt{\frac{2e}{m}\left|Vacc\right|}, \qquad (1)$$

in terms of classical mechanics. Landing velocity v_L when arriving at a sample surface with potential Vp can be expressed by

$$v_L = \sqrt{\frac{2e}{m}\left|Vacc - Vp\right|} \cdot \qquad (2)$$

In FIG. 2(a), when $|Vacc| > |Vp|$, the electron can reach the sample at a decreased speed. Therefore, the detector cannot collect the primary electron. In FIG. 2(b), when $|Vacc| < |Vp|$, the speed of the primary electron gradually decreases due to influence of the potential of the sample, and the speed becomes zero before the electron hits the sample. As a result, the electron proceeds to the opposite direction and then reaches the detector. In vacuum having no air resistance, the law of energy preservation is completely established. The potential of a boundary domain agrees with *Vacc* as shown in

$$Vacc = Vp(x, y) \,. \qquad (3)$$

Therefore, the state of the potential distribution can be measured by detecting primary electrons.

Measuring method of latent image profile

When a backside voltage is *Vsub* and a surface-potential with *Vsub* = 0 is *Vs*(x, y) , *Vp*(x, y) is expressed by

$$Vp(x, y) = Vs(x, y) + Vsub \,. \qquad (4)$$

From equations (3) and (4), a threshold potential *Vth* is defined as

$$Vth = Vacc - Vsub \,. \qquad (5)$$

The boundary domain denotes a potential contour line of *Vth* value. Therefore, the surface-potential can be obtained by measuring the latent image profile by scanning the sample surface with electrons while changing the applied voltage *Vsub*. The latent image profile is called *Vth* distribution. *Vth*(x, y) becomes approximately equal to *Vs*(x, y) on condition that *Vth*(x, y) has a smooth charge distribution.

Surface-charge density *Q*(x, y) can be derived according to the procedure of solving the inverse problem from the *Vth* distribution as shown in Fig.4. As a result, the surface-potential *Vs* (x, y) can be measured in higher accuracy.

Electrostatic Latent Image Measuring System

The basic layout of the developed measuring system is shown in Fig. 5. The vacuum chamber includes an electron optical system for guiding the electrons emitted from an electron gun to the sample, a means of forming a latent image to reproduce actual electrophotographic conditions, a means of detection, a means of erasing, and a holder which can apply a voltage to a backside of the sample surface.

The means of primary electron detector (PED) is configured to efficiently guide the secondary electrons to a scintillator. A light emitting diode (LED) erases residual charge on OPC surface.

One factor in achieving latent image measurement was devising a method that would enable observations to be made within a very short time following the formation of the latent image.

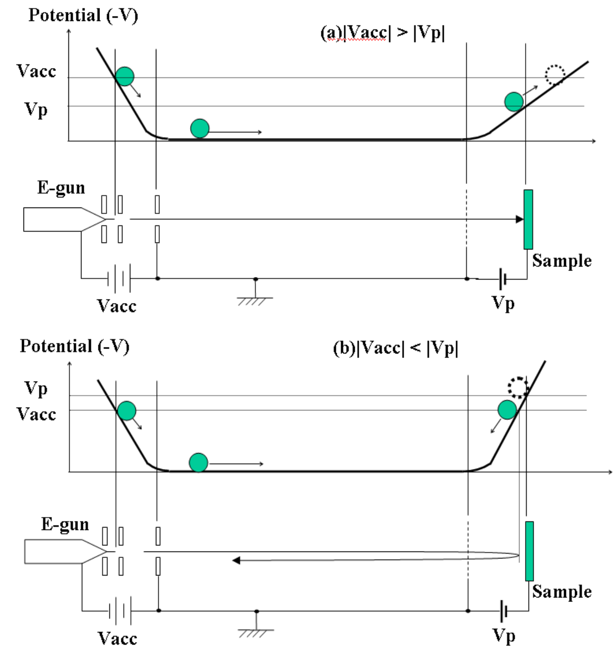

Figure 2. Physical model of potential energy: conditions are (a)|Vacc| > |Vp| and (b)|Vacc| < |Vp|

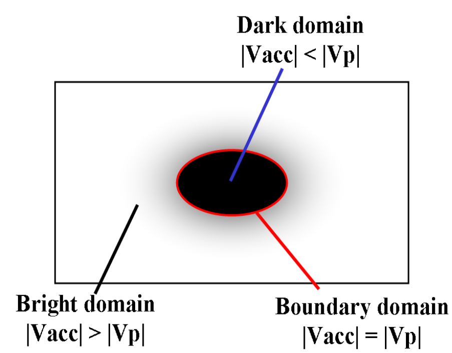

Figure 3. Contrast image

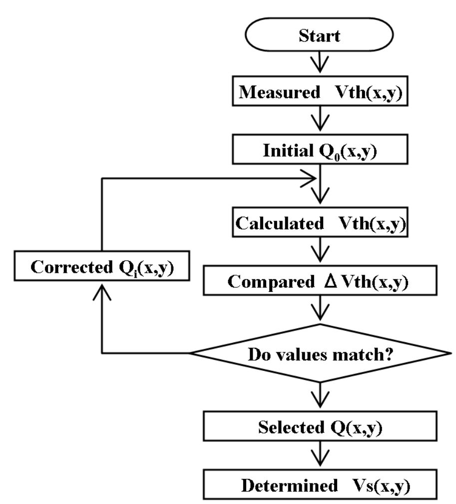

Figure 4. Flowchart of process of measuring potential distribution

The significant feature of this method is that the means of charging, exposing, and detecting are all incorporated in the vacuum system, making real-time measurement possible.

Since this method cannot be used in a vacuum, a charging system based on electron-beam irradiation is adopted. Secondary electrons are emitted when irradiating a dielectric targeted for measurement. This system purposely makes use of this charge-up phenomenon, which should be generally avoided. By intentionally setting the accelerating voltage greater than no-charging condition, the electrons accumulate in the photoconductor causing the sample to charge up. As a result, the photoconductor can be negatively and uniformly charged [5].

An exposure optical system can form a beam profile at a desired beam spot diameter on the photoconductor. A light flux emitted from a laser diode (LD) is converted into a parallel laser beam by a collimator lens. Next, the laser beam passes through an aperture, a focusing lens and a reflecting mirror, and condenses on the photoconductor as the laser beam spot.

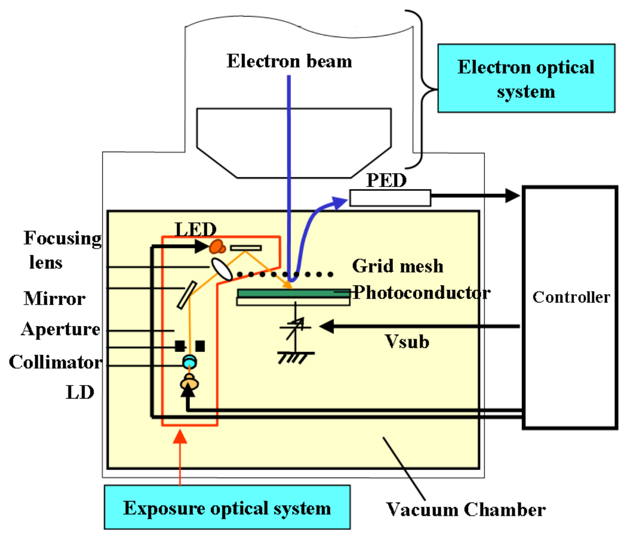

Figure 5. Electrostatic Latent Image Measuring System

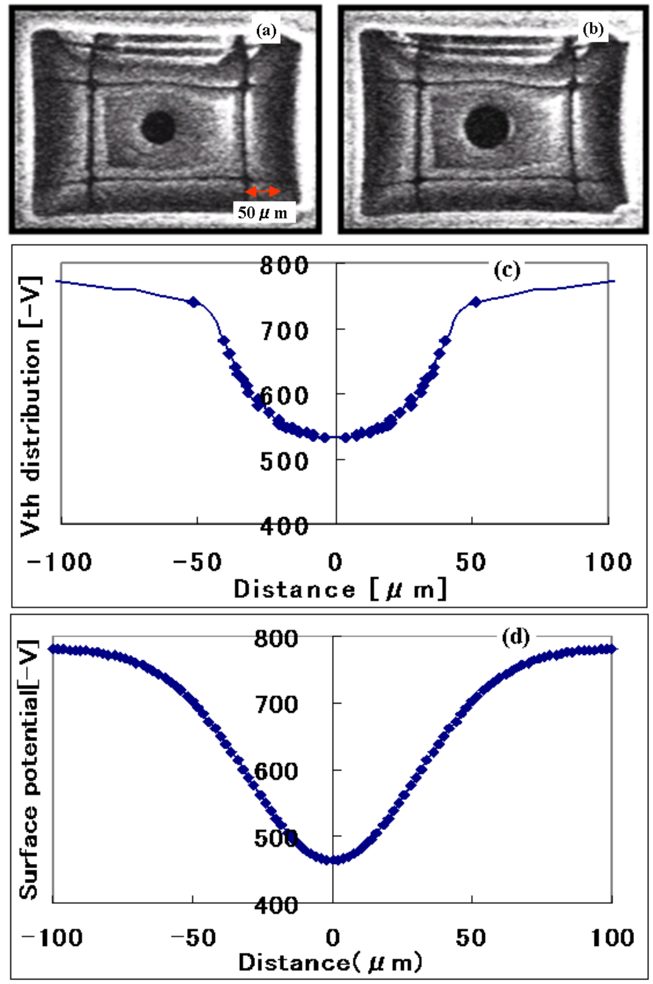

Figure 6. Measurement results: (a) image with Vsub:-1230V ,(b) image with Vsub:-1200V, (c)Vth distribution of horizontal latent-image and (d)surface potential

Experimental Results

Measurement results of electrostatic latent image are shown in Fig. 6. The sample was an OPC with a film thickness of 30 μm. Charging potential was –800 V. The exposure light source was an LD with a wavelength of 655 nm. The beam-spot diameter was 57 μm horizontal and 83 μm vertical.

Figures 6(a) and 6(b) show the contrast images for static exposure with applied voltages of –1230 V and –1200 V, respectively. These results show that differences in latent-image diameters due to different applied voltages can be clearly identified. The latent-image profile can be measured with potential resolution of 2 V.

Next, Fig. 6(c) shows *Vth* distribution of horizontal latent-image. This result demonstrates that the proposed method can measure the latent-image profile with high potential spatial resolution. Finally, Fig. 6(d) shows the measurement results of the surface potential obtained by analyzing *Vth* distribution.

Mechanism Analysis of reciprocity law failure

This system is being used to analyze the basis of the electrostatic latent image formed on a photoconductor. The photoconductor has the occurrence of a phenomenon of reciprocity law failure that even when the total exposure-energy density given to the photoconductor is the equal condition, a latent-image depth is different.

In order to confirm the mechanism, the latent-image depth was measured by changing the delay time when exposure is carried out a couple of times. Figure 7 shows a light-emitting pattern for double-pulse exposure including first exposure and second exposure after a delay time ΔT. That is, the same area was exposed twice. All other conditions except ΔT are kept constant. Figure 8 shows the measuring results of surface-potential distribution when the delay times ΔT are 1 μs, 100 μs and 10 ms. As a result, the latent-image depth tends to be formed deep when the delay time becomes long.

Figure 9 shows the measuring results of the latent-image depth when the delay times ΔT change from 400 ns to 10 ms.

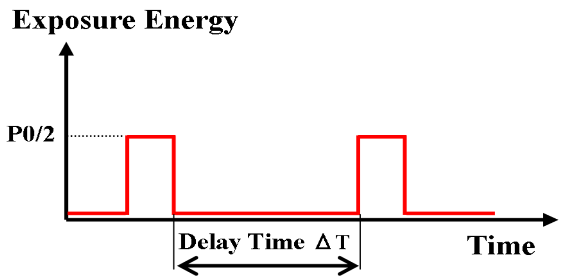

Figure 7. Light-emitting pattern for double pulse exposure

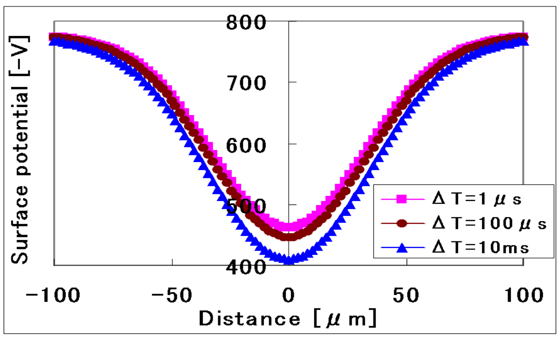

Figure 8. Measurements of surface potential with delay time ΔT of double pulse exposure

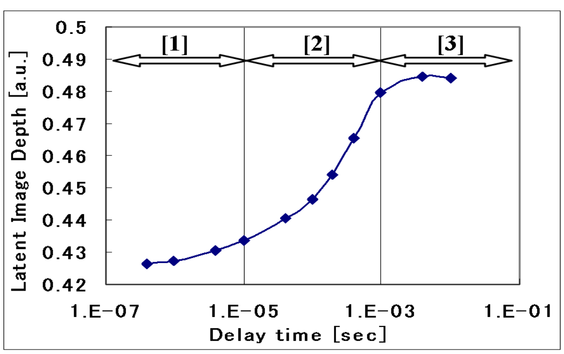

Figure 9. Relationship between delay time and latent-image depth

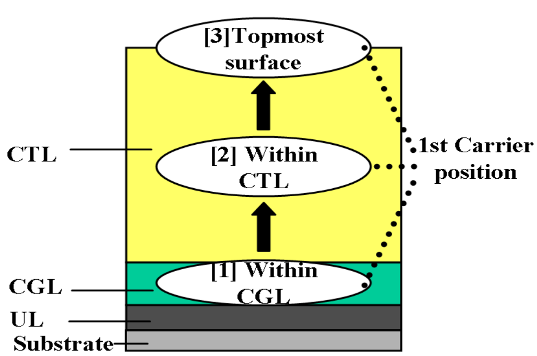

Figure 10. Mechanism of reciprocity law failure for explaining relation between 1st carrier position and 2nd exposure time

As described above, when the delay time becomes long, the latent-image potential tends to be formed deep, and changes in the S-shaped curve along the delay time, as a whole. Here, a latent-image depth is defined as peak-to-valley of latent image profile to a charging potential.

The phenomenon indicates that the latent-image depth is relevant to first generated carrier position at the second exposure time as shown in Fig. 10. The first generated carriers have the action which weakens electric field in CGL. The further the first generated carriers are away from CGL, the stronger an electric field in CGL becomes. Therefore, since the quantum efficiency become higher, second generated carriers increase. When the delay time is greater than the time that the first careers arrive at the surface, the generation amount of carriers do not change. As a result, the latent-image depth becomes constant. In this way, the mechanism of reciprocity law failure has come to light.

Conclusions

A new method that makes possible a potential-profile measurement of an electrostatic latent image is proposed. The key technology is to detect a primary electron that is reversed before reaching a sample surface. The latent-image profile can be measured with potential resolution of 2 V and with spatial resolution on the order of microns.

In order to analyze the mechanism of reciprocity law failure, the latent-image depth was measured by changing the delay time when exposure is carried out a couple of times. As a result, the latent-image depth tends to be formed deep when the delay time becomes long. The phenomenon indicates that the latent-image depth time is relevant to a carrier position generated at the first exposure in the second exposure. The system can be used to analyze the basic characteristics of an electrostatic latent image formed on a photoconductor.

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Author Biography

Hiroyuki Suhara received his Master of science and engineering degree from Waseda university in 1989 and entered Ricoh company, Ltd. He has worked in the Imaging Engine Development Division, and engaged in the research and development of methods for measuring optical elements and methods for analyzing electrophotographic process mechanism. His fields of expertise are optical interferometry and applied charged particle optics.