Measurement of Electrostatic Latent Image on Photoconductors by Use of Electron Beam Probe

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Abstract

A novel method that makes possible the measurement of an electrostatic latent image on a photoconductor is proposed. An electrostatic latent image is formed by electron charging and by laser exposing of a photoconductor within a vacuum chamber. The electrostatic latent image is measured by detecting secondary electrons generated by the scanning of an electron beam probe. When a primary electron beam hits the photoconductor, secondary electrons are generated. Secondary electrons generated in a charged area travel to an electron detector. In contrast, secondary electrons generated in an exposed area are pulled back to the photoconductor, thereby decreasing the number of secondary electrons that reach the detector. The exposed and charged areas are determined in this way. The significant feature of this method is that the means of charging, exposing, and detecting are all incorporated in the same system, making real-time measurement possible. This method has good performance with high-resolution measurement on the order of microns.

Introduction

Recently, the 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. In the electrophotographic process, the electrostatic latent image formed on the photoconductor directly affects the behavior of toner particles. Under such circumstances, it is necessary to measure the electrostatic latent image with high-resolution on the order of microns, which is sufficiently smaller than a spot size of a laser beam. 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 the electrostatic attractive force and the 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 using a scanning electron beam have been reported [2]. However, since the resistance of an organic photoconductor (OPC) used for electrophotography is not infinity, dark decay occurs, and the electric charge decreases with time. The time of which the photoconductor can maintain an electric charge is several tens of seconds at most. Measurements must be taken within a short time after the formation of an electrostatic latent image.

This paper has reported a new method for measuring the electrostatic latent image on a photoconductor with high-resolution measurement on the order of microns [3].

Measurement Principle

The measurement principle of the proposed method is shown in Fig. 1. When a charged photoconductor is exposed to light, electron-hole pairs are generated at the charge generation layer (CGL). Holes move through the 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. Figure 1 shows the model in a state in which the charge distribution forms on the photoconductor.

When a primary electron beam hits the photoconductor, secondary electrons are generated. Many secondary electrons generated in a charged area travel to an electron detector by an accelerating electric field.

In contrast, secondary electrons generated in an exposed area are pulled back to the photoconductor, thereby decreasing the number of secondary electrons that reach the detector because the decelerating electric field exists above the exposed area, as shown in Fig. 2. The exposed and charged areas are determined in this way. Namely, the electrostatic latent image is measured by detecting secondary electrons generated by the scanning of an electron beam probe.

As described above, however, the photoconductor exhibits dark decay, requiring measurements to be performed within a short time following the formation of the electrostatic latent image.

In response to this need, a developed measuring system is equipped with a means of forming a latent image and enables the observation of the latent image immediately after its formation.

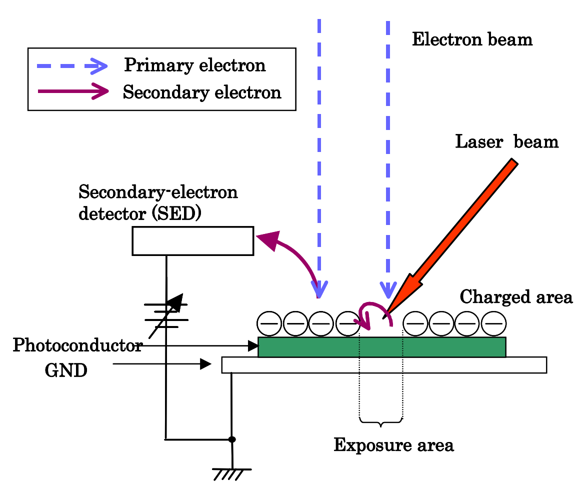


Figure 1. *Measurement principle*

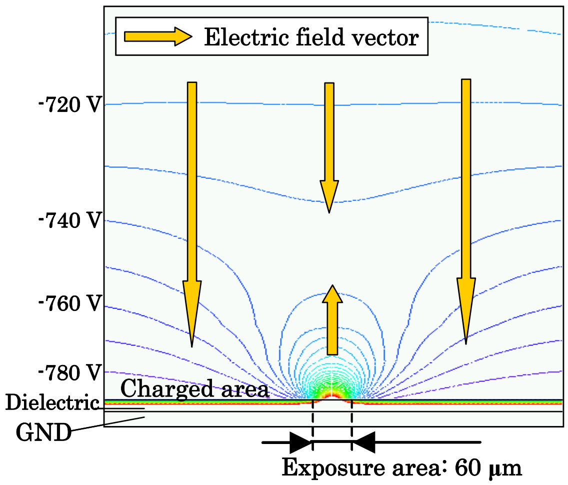


Figure 2. *Calculated contour map of electric potential by surface-charge distribution: Charging potential is –800 V.*

Electrostatic Latent Image Measuring System

The basic layout of the developed measuring system is shown in Fig. 3. 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 sample holder.

The main specifications of the electron-beam control device are listed in Table 1. Given the importance of allocating workspace for an exposure optical system within the vacuum chamber, an electron optical system with a long working distance was used. The working distance of an electron optics system is possible up to a maximum of 100 mm.

Moreover, when measurement switches from the charging state to the observation state, the probe current must be changed appropriately so as not to disrupt the latent image. This system has been configured to enable immediate adjustment of the probe current by separately controlling the applied voltage of the electron lens.

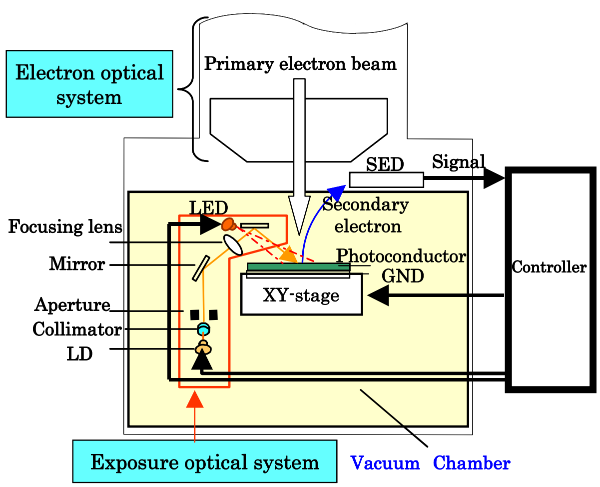


Figure 3. *Electrostatic Latent Image Measuring System*

Table 1 Electron beam control device

Electron gun	Thermal field-emission
Accelerating voltage	~5 kV
Working distance	~100 mm
Measured range	~4 mm
Vacuum chamber size	Φ300 mm
Beam current	~2 nA

The means of detection is configured to efficiently guide the secondary electrons to a scintillator. The electrons that reach the scintillator are converted to an electric signal after current amplification by a photo-electron multiplier tube (PMT). The electric signal is then converted to a contrast image in which the charged area is bright and the exposed area is dark [4].

The sample holder supports photoconductors having a flat or curved shape and features automatic positioning adjustment. Residual charge is erased by incorporating a light emitting diode (LED) for irradiating the entire surface of the sample.

Latent Image Formation Method

Charging method

Charging devices used in standard electrophotography make use of corona discharge in which air is used as a medium. 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. By denoting emitted electrons as Ie and incident electrons as Ip, secondary-electron emission coefficient δ can be defined by

$$\delta = \frac{Ie}{Ip} \quad . \tag{1}$$

Figure 4 shows general secondary-electron emission characteristics [5]. At accelerating voltage $V_{\delta=1}$ corresponding to $\delta = 1$, no charging occurs and the system maintains a balanced state. At accelerating voltage $Vacc$ with $\delta < 1$, negative charging occurs. Conversely, at $Vacc$ with $\delta > 1$, positive charging occurs.

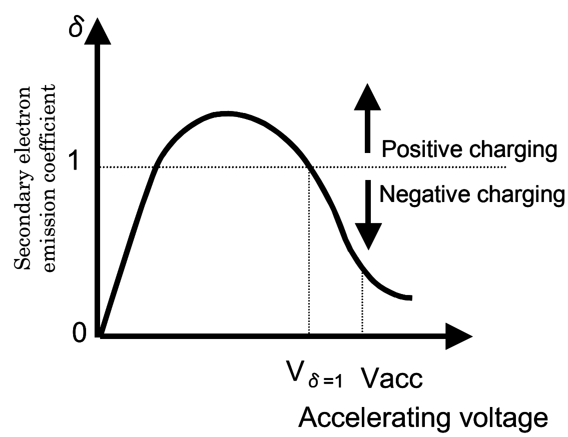


Figure 4. *Secondary-electron emission characteristics*

The general approach to observing a dielectric with a scanning electron microscope (SEM) is to perform under $V_{\delta=1}$. Setting under any other conditions makes detailed observation difficult since the sample will charge up, disturbing the original image.

This system purposely makes use of this charge-up phenomenon, which should be generally avoided. By intentionally setting the accelerating voltage greater than $V_{\delta=1}$, the electrons accumulate in the photoconductor causing the sample to charge up. As a result, the photoconductor can be negatively and uniformly charged.

Exposing method

As illustrated in Fig. 3, the light flux emitted from the 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 a photoconductor as a laser beam spot.

Interference between the electron-beam path and optical components is prevented by having the light beam condense at an incident angle of about 45 degrees relative to the sample.

The exposure optical system can form a beam profile at a desired beam spot diameter on the photoconductor within the vacuum chamber. The desired beam spot diameter can be determined by adjusting aperture size.

The laser power and pulse timing can be appropriately set by controlling the LD driver externally with a computer.

Control of charging potential

We performed an experiment to see whether a charging system by electron-beam irradiation could obtain a desired negative charging potential of several hundred to 1 kV, and we investigated a physical model for this system and the control of charging potential.

Conditions for electron-beam irradiation were an accelerating voltage of – 2 kV and a broad area of about 4-mm square so as to support a commercial electrostatic voltmeter (Trek Model 344).

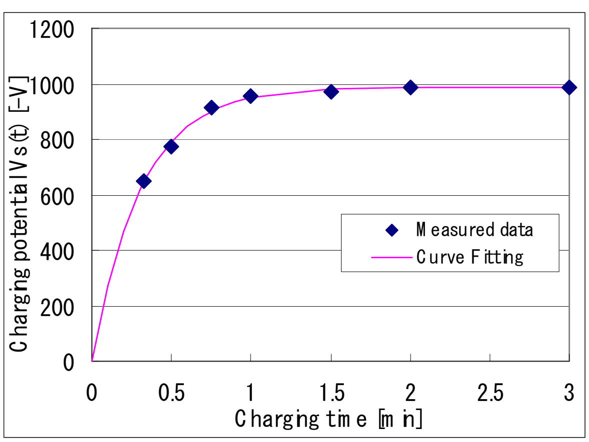


Figure 5. *Charging characteristics of OPC irradiated by electron beam with Vacc = –2 kV*

As shown in Fig. 5, the charging potential $Vs(t)$ rises rapidly just after the commencement of electron-beam irradiation but exhibits a slower rate of change over time, eventually becoming saturated.

From the charging model [6], $Vs(t)$ can be expressed as

$$Vs\,(t) = Vd\,\{1 - \exp(-\alpha t)\}. \qquad (2)$$

The measurement results of Fig. 7 overlap the approximate curve of Eq. (2). In this equation, Vd denotes the saturated charging potential.

As shown in Fig. 6, the accelerating voltage and saturated charging potential have a linear relationship.

Thus, from Fig. 6, Vd is approximately represented by

$$Vd = Vacc - V_{\delta=1}. \qquad (3)$$

$V_{\delta=1}$ can be measured beforehand. The desired charging potential can therefore be obtained by appropriately setting the accelerating voltage and irradiation time.

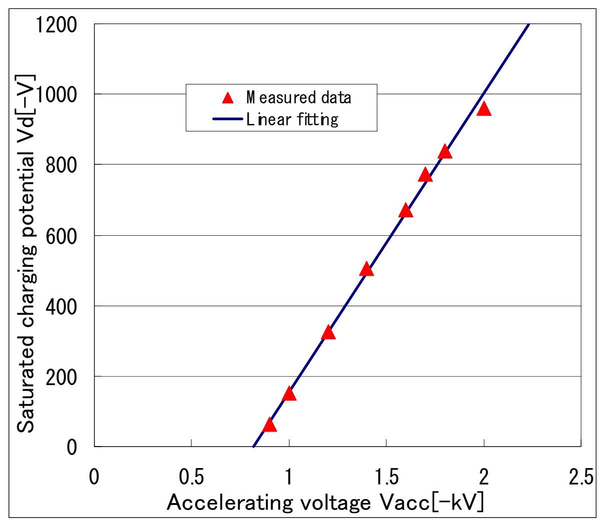


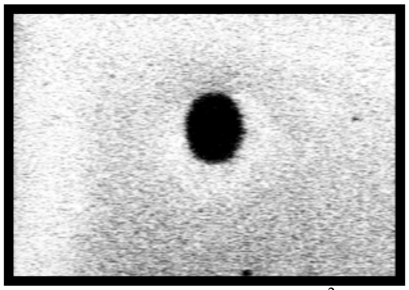
Figure 6. *Relationship between accelerating voltage and saturated charging potential*

Experimental Results

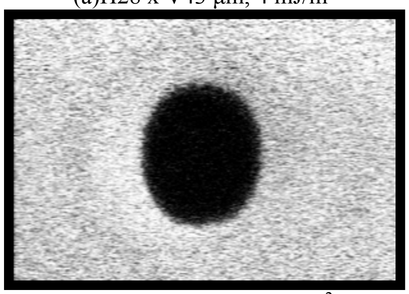
Electrostatic latent image measurements are shown in Figs. 7 and 8. The sample was an OPC with a film thickness of 30 µm. The exposure light source was an LD with a wavelength of 655 nm. The image observation area was uniform at 0.27 mm.

Figure 7(a) shows the measurement results of the electrostatic latent image for static exposure with an elliptical beam of dimensions 28 µm horizontal and 43 µm vertical (H28 x V43 µm) and with an exposure energy density of 4 mJ/m^2. The charged area was detected as bright and the exposed area as dark with an elliptical shape. These results demonstrate that the proposed method can visualize an electrostatic latent image.

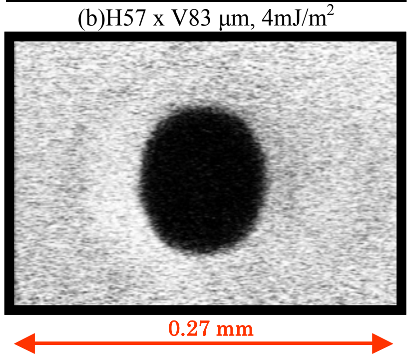
Next, Fig. 7(b) shows the measurement results for a larger beam of H57 x V83 µm and with the same energy density as (a). These results show that differences in electrostatic latent images due to different beam spot sizes can be clearly identified.



(a)H28 x V43 µm, 4 mJ/m^2



(b)H57 x V83 µm, 4mJ/m^2



(c)H57 x V83 µm, 4.8 mJ/m^2

Figure 7. *Measurements of electrostatic latent image of one beam spot: exposure conditions are (a)H28 x V43 µm, 4 mJ/m^2 ,(b)H57 x V83 µm,4 mJ/m^2 and (c)H57 x V83 µm, 4.8 mJ/m^2.*

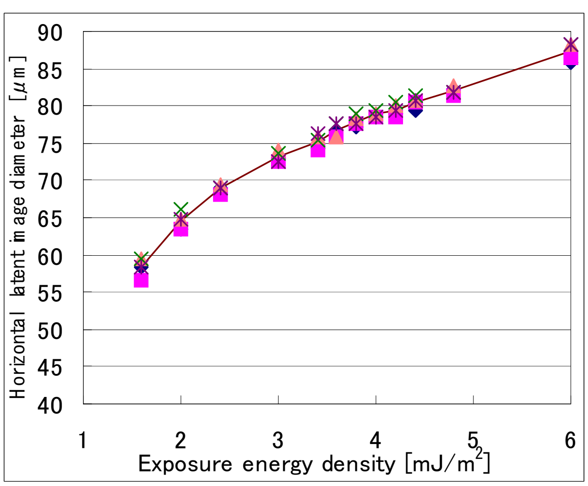


Figure 8. *Measurement results of horizontal latent image diameter with H57 x V83 µm*

Finally, Fig. 7(c) shows the measurement results for exposure by the same beam spot size as (b) but with an exposure energy density about 20% larger at 4.8 mJ/m^2. Despite the fact that the beam spot size was fixed, it can be seen that the diameter of the resulting latent image had changed. We can see that exposure energy density has affected the latent-image diameter.

Figure 8 shows the results of measuring the horizontal latent image diameter while varying exposure energy but keeping beam spot size fixed at H57 x V83 µm. These results clearly show that the horizontal latent-image diameter becomes larger as exposure energy increases. By evaluation of reproducibility, the measurement accuracy was 1.5 µm or better with respect to the latent-image diameter. This system has sufficiently small measurement sensitivity compared to the beam spot size.

Conclusion

A novel method has been proposed that enables the measurement of an electrostatic latent image on a photoconductor. The significant feature of this method is that the means of charging, exposing, and detecting are all incorporated in the same system.

The proposed charging means by electron beam irradiation enables charging potential to be set as desired within a vacuum. The electrostatic latent image is measured by detecting secondary electrons generated by the scanning of an electron beam probe.

This system has good performance with a measurement accuracy of 1.5 µm or better with respect to the latent-image diameter. 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.