Charge Distribution of Corona Charged Toner Particles

Akihiko Noda†
Graduate School of Science and Engineering, Ibaraki University, Ibaraki, JAPAN

Manabu Takeuchi▲
Department of Electrical and Electronic Engineering, Ibaraki University, Ibaraki, JAPAN

Jun Abe and Shota Oba
Technology and Development Group, Fuji Xerox Co., Ltd., Kanagawa, JAPAN

Toner charge distributions in corona charged toner layers on a grounded metal plate were investigated. The charge distributions were measured through image analysis of the toner particles displaced onto a filter, depending on their charge to diameter ratio, after being blown off from the toner inlet into an electric field and dispersed. It has been confirmed that the toner charge distributions became broader by corona charging. In order to clarify the cause, dual toner layers have been formed by using different color toners, and the charge distributions at the upper and lower layers have been measured separately. The results show that the lower toner layer has a wider charge distribution than that of the upper layer. This result is attributable to the fact that the lower parts of the toner layer are covered with the upper toner layer and difficult to corona charge. The toner particles in the lower layer located at the opening of the overlapped upper layer tend to be highly corona charged, while the toner particles around the opening in the upper layer receive only a small amount of the corona charge. It has thus been shown that difference in charge distribution between the upper and lower parts of the toner layer is caused by the following mechanisms: 1) The toner particles at the lower part of the layer are shielded from corona charging ions by the upper layer; 2) The toner particles in the lower layer, which are located at the opening of the charged particles in the upper layer, receive more charging ions by concentration of the electric field; 3) The toner particles at the upper layer receive fewer charging ions because of higher electric potential owing to a longer distance from the grounded plate.

Journal of Imaging Science and Technology 49: 189–195 (2005)

Introduction

In electrophotography electrically charged toner is developed onto a latent image on a surface of a photoreceptor by an electric field. Then the toner is transferred to a media by an electric field and finally fused. Four kinds of color toner are transferred to the media one after another to obtain full color electrophotography. Because these transitions of toner particles depend on the toner charge and the electric field, the toner charge distribution strongly affects the quality and/or defects of images.

Although toner is usually tribocharged for the development step, occasionally toner transfer process is additionally controlled by corona charging. For example, monocomponent toner on a donor roll is corona charged after tribocharging with a metering blade,[1] and single or multiple developed toner images on a photoreceptor are corona charged to control the amount and sign of charge of the toner particles on the images in preparation for subsequent transfer process.[2–4] The toner charge distribution should be narrow for high image quality in electrophotography.

Experimental results for corona charging of particles in air were reported by several researchers, in work which involved charging of particles in electrostatic precipitators near corona discharge electrodes.[5–8] Corona charging of particles on a grounded rotating cylinder electrode was studied and the saturation charges or the average charges of the particles were discussed.[9–13] However, there have been few reports about control of charge distribution of toner particles by corona charging. This article presents analysis of toner charge distribution in the corona charged toner layer, and proposes a method to make the toner charge distribution narrower by corona charging.

Experimental

Toner layers are formed by the following two methods. One is the formation of a toner layer on a monocomponent development donor roll with a metering blade,

Original manuscript received September 24, 2004

▲ IS&T Member

†Corresponding Author: Akihiko Noda, akihiko.noda@fujixerox.co.jp

TABLE I. Materials, Apparatus, Methods, and Tools Used in This Study

	Items	Materials, Apparatus, Methods, and Tools
Materials	Toner	A-Color toner (Cyan, Yellow); Fuji Xerox Co., Ltd.
	Liquid developer for charge distribution analysis	Liquid developer for VERSATEC (Black); Xerox Corp. Co., Ltd.
	Spherical insulating particle for charge distribution analysis	Tospearl 3120 (the diameter is equally 12 μm); Toshiba Silicone Co., Ltd.
	Insulating layer	Polyimide film (25 μm in thickness) with 50 μm adhesive layer, or 50 μm polyimide mesh film
Apparatus	Corona charging device	Scorotron
	High voltage of toner charge distribution	Trek609 amplifier + Kikusui constant voltage electric power supply, Trek610 power supply
	Observation of toner charge distribution	Charge Spectrograph
	Image analysis apparatus for Charge Spectrograph	Q600HR; LEICA Co., Ltd.
Methods	Toner layer forming 1	Formed on a single component development done roll with a metering blade
	Toner layer forming 2	Atomization and sedimentation deposition method
Simulation Tool	Electric field simulation	Maxwell 2D Field Simulator Ver. 1.2.12; Ansoft Co., Ltd.

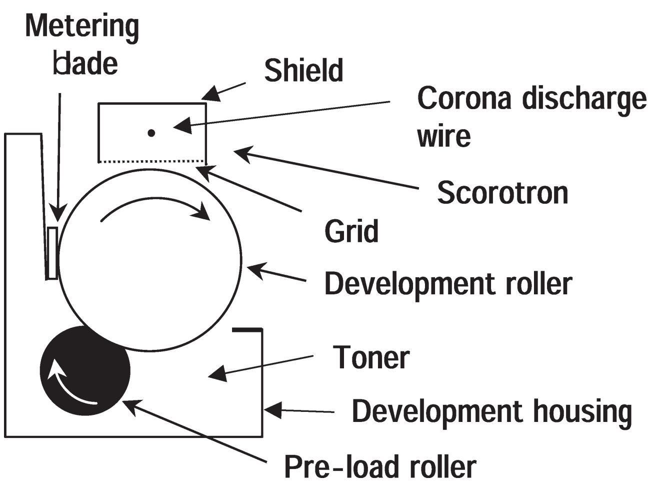

Figure 1. Toner layer forming and charging apparatus 1.

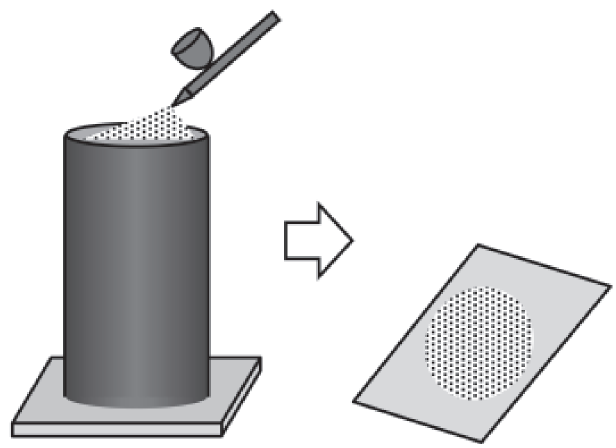

Figure 2. Toner layer forming apparatus 2-atomization and sedimentation method.

which regulates the thickness of toner layer on the rotating donor roll. The other is the formation of a toner layer on the metal plate by the atomization and sedimentation method (Table I).

The toner layers on the donor roller are charged with a scorotron as shown in Fig. 1. The gap between the scorotron grid and the donor roll is 2 mm and the peripheral speed of the donor roll rotation is 100 mm/s. Toner layers on a metal plate and insulating film, or mesh on a metal plate, are formed by the atomization and sedimentation deposition method (Table I). The toner layer on the grounded metal plate is also charged with the scorotron. The gap between the scorotron grid and the plate is 5 mm and the scan speed of the plate is 50 mm/s.

The toner particles in the corona charged toner layers are blown off and led into a Charge Spectrograph apparatus.[14] Then the toner particles are dispersed in an electric field and displaced onto a filter, depending on their charge to diameter ratio, q/d.

Charge distributions at the upper and lower toner layers, which are corona charged, are observed separately. The experimental procedure is as follows. First, upper and lower toner layers are formed on a metal plate with cyan and yellow color toners. The lower toner layer is formed by using one of the color toners with the atomization and sedimentation deposition method, and then the upper toner layer is formed by using the other color toner. The atomization and sedimentation method involves three steps: (1) toner that contains no carrier is blown with N_2 gas spray pump and part of it goes into the top of a metal cylinder; (2) the cylinder is left to stand for about 10 s; (3) the cylinder is placed on the metal plate and uniform toner layer is formed by deposition of slowly falling toner which contains no clumped toner.

The dual color toner layers are corona charged, and the charge distribution of the cyan toner is measured with a Charge Spectrograph. Corona charging of the dual toner layers is carried out under the following conditions: $Vwire/Vgrid$ = –5000 V/–500 V or –5500 V/–1000 V. Image analysis is done for only the cyan toner particles by optical filtering, which means that the yellow color toner is not included in the charge spectrum.

The normal amount of toner deposited on the metal plate is adjusted to about 5 g/m^2, and the amounts of yellow and cyan toners are adjusted to about 4 g/m^2 and 1 g/m^2, respectively, in order to reduce the probability

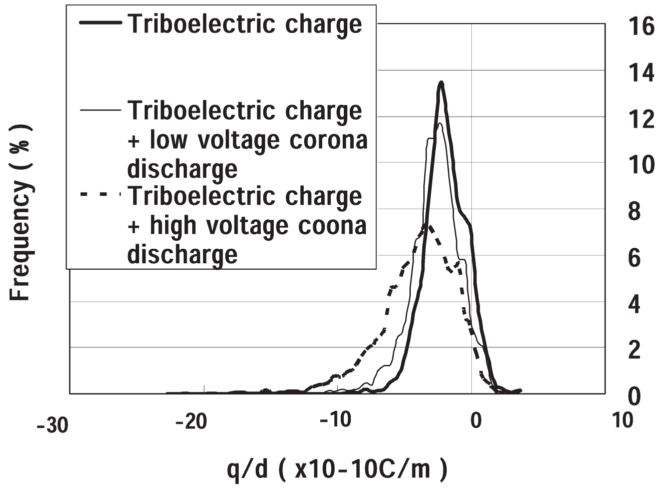

Figure 3. Toner charge distribution with apparatus 1.

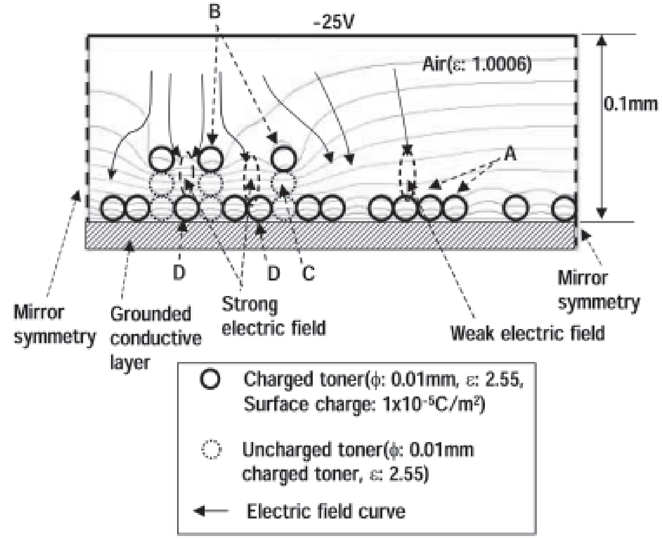

Figure 4. Electric potential simulation.

of toner particles deposited in advance protruding from a lower toner layer into an upper toner layer, or toner particles deposited afterward protruding from an upper toner layer into a lower toner layer.

In order to check the uncharged and charged areas on the surface of insulating layer, the surface is developed with a liquid developer. A polyimide film with adhesive layer (total thickness: 75 μm) is used as the insulating layer.

Materials, apparatus, methods and a simulation tool used in this study are detailed in Table I.

Results and Discussion

Results of corona charging over the single toner layers on a monocomponent development donor roll are shown in Fig. 3. With an increase in corona discharge voltage, the upper limit of toner charge distribution increases, while the lower limit does not.

The objective of this article is to clarify the cause for the broader toner charge distributions after corona charging. In order to do that the possible situations of toner particles in a toner layer on a plate need to be considered as follows:

(A) a toner particle is located at a relatively lower position, and is not overlapped by other overlapping toner particles, and does not overlap another toner particle;
(B) a toner particle is located on another toner particle, which means the toner particle is located at a relatively high position;
(C) a toner particle is overlapped by other toner particles and located at a relatively lower position;
(D) a toner particle is not overlapped by other toner particles, and is located at the opening of an upper toner layer, which means that the toner particle is located at a relatively lower position.

The space potential is calculated for the situations (A), (B) and (D) with Maxwell2D. The calculations are carried out using the following conditions: (1) all the top toner particles are given an equal charge; (2) the toner particles under other toner particles have no charge; and (3) the conductive plate on which the toner particles are placed is grounded. A toner particle is treated as a cylinder extending in the depth direction of the page boundlessly, because the tool used here is two-dimensional.

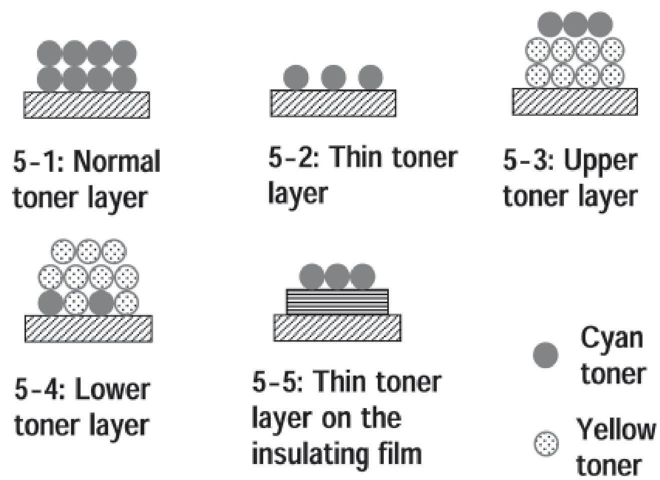

Figure 5. Several toner layer configurations.

The results from the above calculations are given in Fig. 4. The typical electric field curves are drawn as they intersect the perpendicular equipotential lines. The toner particles in situation (D) should be charged more than those in the situations (A) and (B), because the electric field curves are concentrated at the opening. The reason why electric field curves do not head for the toner particles at higher positions and concentrate on the lower toner is that electric potentials conform to distances from the grounded plate. The above result predicts that toner particles at the opening of the higher toner layers show a marked tendency to receive a high level of charge. Additionally, the toner particles in situation (A) should be charged more than those in situation (B) because the electric potentials in the situation (A) are lower than those in situation (B).

Next, investigation of charge distribution at upper and lower parts of toner layers is carried out using the atomization and sedimentation deposition method. Charge distribution in the upper and lower toner layers, which are corona charged, as observed separately. The toner layer configurations prepared for the measurements are as follows (Fig. 5).

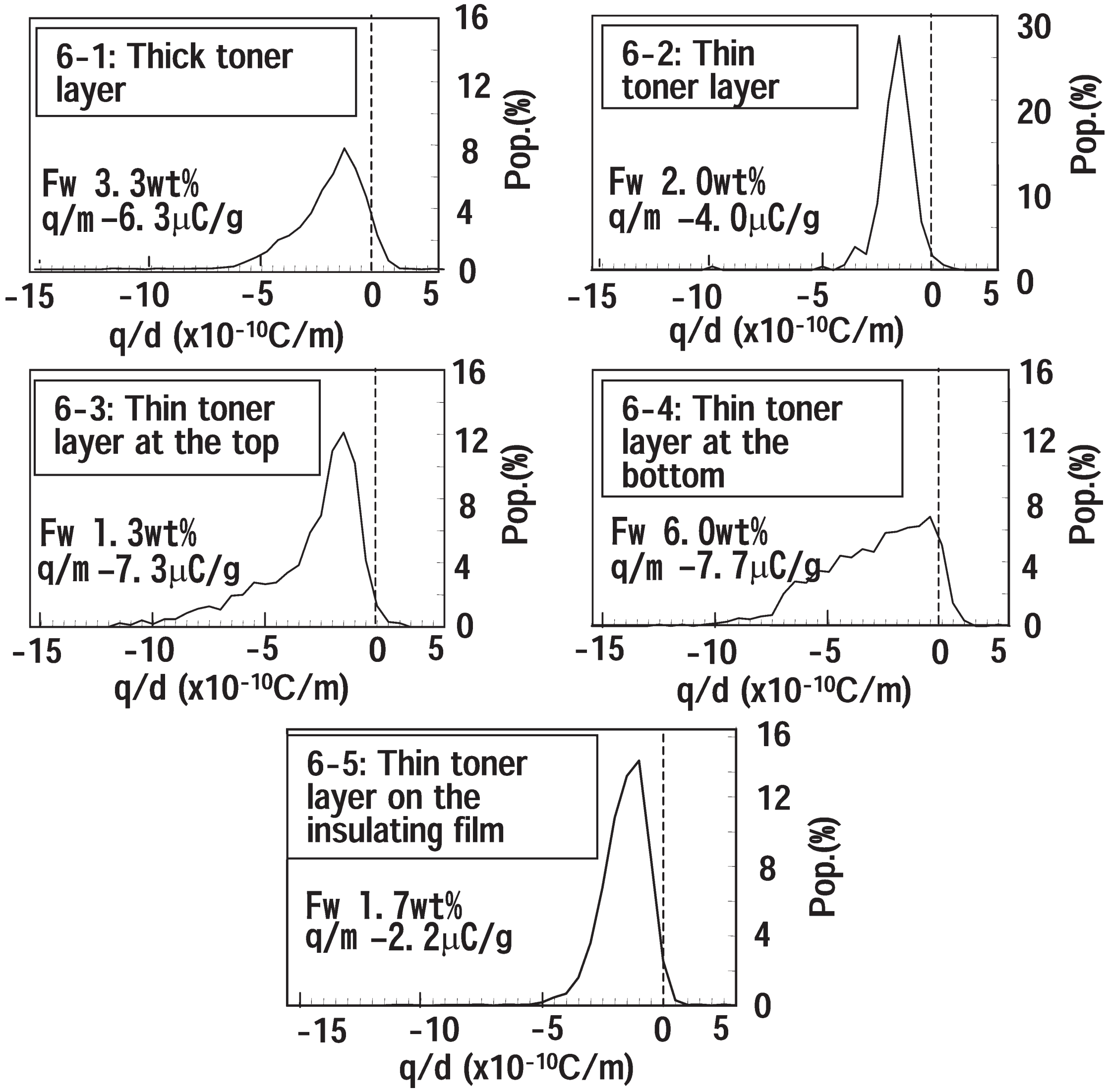

Figure 6. Toner charge distributions of the toner configurations in Fig. 5.

1. Normal (Thick) Toner Layer:
Normal cyan toner layer (toner mass per unit area on the metal plate: $M_t = 5$ g/m^2) is formed on the metal plate.

2. Thin Toner Layer:
Thin cyan toner layer (M_t = 1 g/m^2) is formed on the metal plate.

3. Upper Toner Layer:
Thin cyan toner layer (M_t = 1 g/m^2) is formed over the yellow toner layer (M_t = 4 g/m^2) on the metal plate.

4. Lower Toner Layer:
Thin cyan toner layer (M_t = 1 g/m^2) is formed under the yellow toner layer (M_t = 4 g/m^2) on the metal plate.

5. Thin Toner Layer on an Insulating Film:
Thin cyan toner layer (M_t = 1 g/m^2) is formed over an insulating film (75 μm in thickness) on the metal plate in order to simulate the charge distribution of the upper toner layer. The difference from No. 3 is that no cyan toner particle is dropped into the opening in the lower toner layer.

Charge distributions of the corona charged toner particles for the five layer configurations described above are shown in Fig. 6. The average toner charges (q/m) and the fractions of wrong sign toner (F_W) are also given in Fig. 6.

Since the distribution in Fig. 6-1 is broader than that in Fig. 6-2, it is clear that the charge distribution of toner particles in the layer of a large M_t is broad. The distributions of Fig. 6-2 and Fig. 6-5 are both sharp, and their average charges, q/m, are low. The peak of the distribution in Fig. 6-3 resembles those of Figs. 6-2 and 6-5. The distribution range in Fig. 6-3 is almost the same as that in Fig. 6-4. We can estimate that the toners in the upper and lower layers have narrow and broad distributions, respectively. The broad distribution in Fig. 6-3 is considered to be due to toner particles fallen into the openings of the lower toner layer, which then act as toners in the lower layer. The reason why Fig. 6-1 has a broad distribution can be attributable to the fact that the toner deposit of Fig. 6-1 has both an upper and a lower layer.

The average toner charge in Fig. 6-5 is lower than that in Fig. 6-2. Two causes are considered. One is that lower amount of charge of the toner particles is suffi-

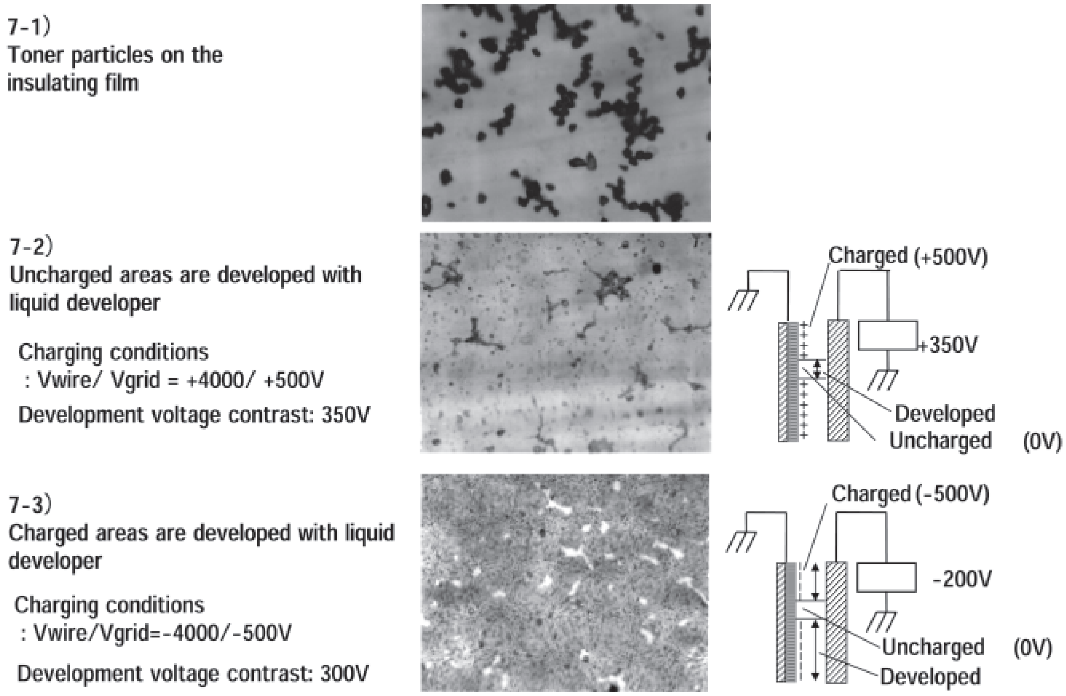

Figure 7. Non-charged area visualized by liquid development.

cient to neutralize the electric field between the toner layers on the insulating film and the scorotron grid, because the surface voltage of the toner layer in Fig. 6-5 is influenced by the thickness of the insulating film. The second is that the surface of insulating film layer is also charged and the charged film surface contributes to the neutralization.

The mechanisms that make the charge distributions of toner particles at lower layers broad should be dependent on how corona charges are captured by toner particles in the cases of (C) and (D). The following two hypotheses can be made about the mechanisms which make the charge distributions of toner particles at lower layers broad.

Hypothesis 1: The toner particle in the lower toner layer overlapped with the upper toner layer, will either be not charged or charged to a low level.
Hypothesis 2: At the opening of the upper toner layer, there is an electric field that highly charges the toners in the lower layer.

The following experiments have been carried out in order to check whether charging ions flow into the area under a toner particle or not. Toner particles are sprayed using the atomization and sedimentation deposition method onto the insulating film on the grounded metal plate. Then, they are corona charged. Next, toner particles are blown off from the insulating film surface. Following that the surface of the insulating film is liquid developed in order to examine the uncharged and charged areas. The same experiment has been carried out for insulating spherical particles (12 μm in diameter) instead of toner particles in order to compare the uncharged areas with the cross section of the particles. Figure 7-1 shows the micrograph of toner particles on the insulating film.

Figures 7-2 and 7-3 show the micrographs of the uncharged and charged areas after liquid-development, respectively. The plate surface, on which toner particles are sprayed, is positively charged to about 500 V and the toner particles are blown off, and then the uncharged area is developed with a positively charged liquid toner (Fig. 7-2). Conversely the plate surface is negatively charged to about –500 V and the charged area is developed with positively charged liquid toner (Fig. 7-3). The uncharged areas in Figs. 7-2 and 7-3 bear some resemblance to the shapes of toner particles aggregated. However, it is difficult to recognize directly that the shapes of the uncharged areas correspond to the aggregated toner particles. Therefore, the same experiment was performed by using insulating spherical particles instead of toner particles. The toner particles aggregate with each other as shown in Fig. 7-1, while, the insulating spherical particles are isolated from each other as shown in Fig. 8-1. Figure 8-2 shows the micrograph of uncharged area, which was developed with liquid developer. The diameter of the uncharged circular area in Fig. 8-2 is 5 μm, although the diameter of the spherical particles is 12 μm.

This result confirms that the area under a toner particle is hard to corona charge although some charging ions flow into the area under the toner particle, confirming Hypothesis 1.

Next, in order to check the Hypothesis 2, the following model charging experiment has been carried out for toners corresponding to situations (A), (B) and (D) described above and as shown in Fig. 9. The results of (A) and (B) are compared with each other. Toner particles are sprinkled, using the atomization and sedimentation method, over a polyimide mesh (thickness: 25 μm, openings: 1 mm × 3 mm) placed on a metal plate. The density of sprinkled toner is so small (0.5 g/m^2) that toner particles hardly overlapped with each other. The toner particles on the mesh placed on the metal plate are corona charged by a scorotron (*Vwire*/*Vgrid* = –4500 V/–500 V; Speed = 50 mm/s). Then the toner charge distribution is observed.

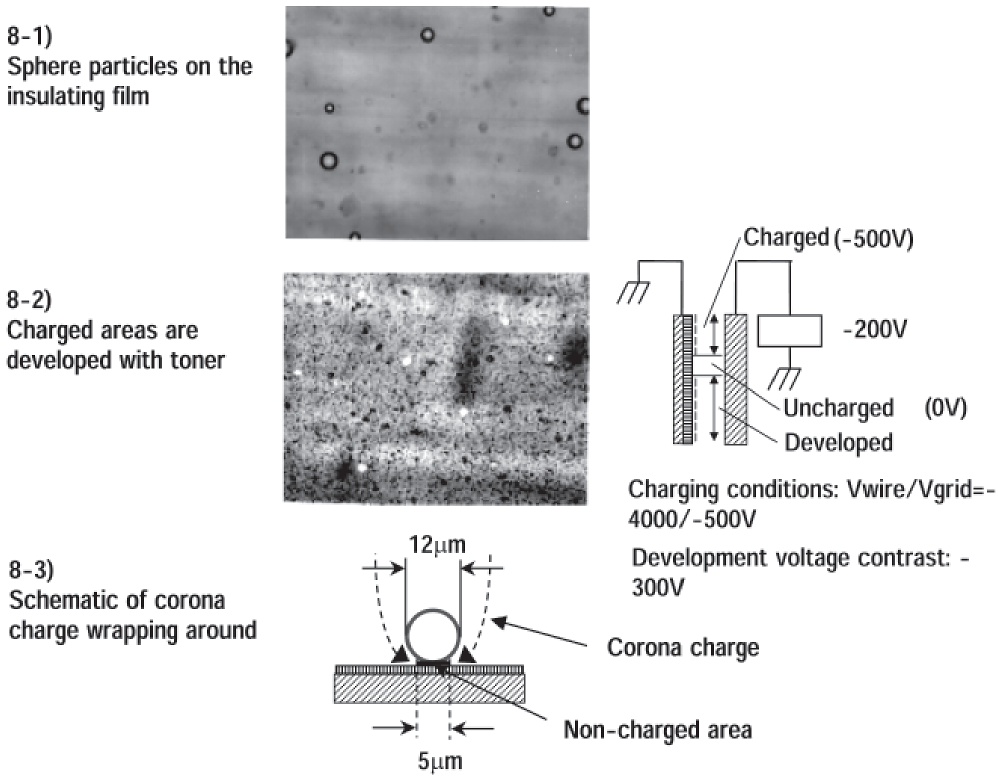

Figure 8. Non-charged area under spherical particles on insulating layer and a schematic of corona ion wrap around.

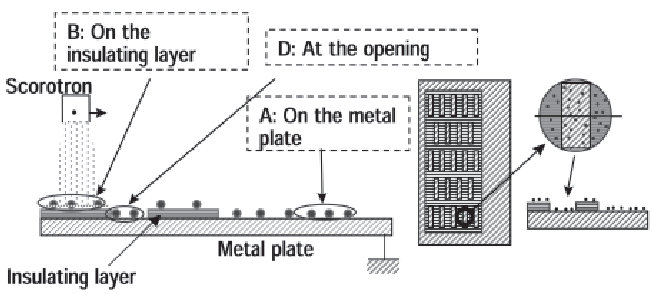

Figure 9. Toner charging experiment using insulating mesh.

Figure 10 shows the toner charge distributions for the situations (A), (B) and (D). The charge of the toner on the metal plate is higher than that on the polyimide layer, and the charge of the toner at the opening is the highest. Therefore, Hypothesis 2 is also substantiated.

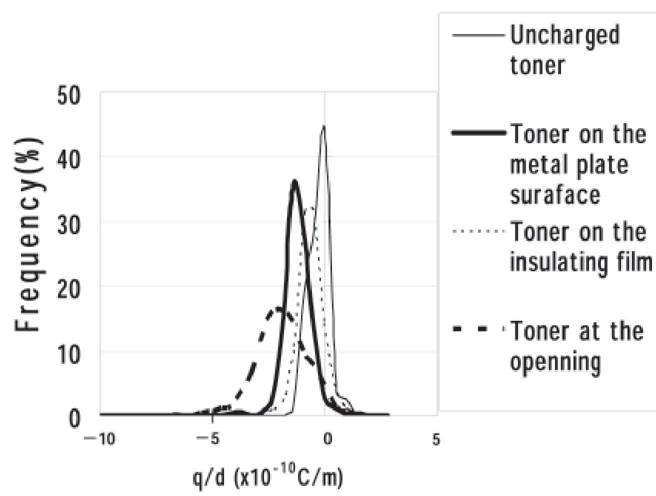

Figure 10. Toner charge distribution in Fig. 9.

Conclusions

It has been confirmed that the upper limit of the toner charge distribution increases by corona charging of a toner layer, while the lower limit does not. The cause has been investigated and the following results have been obtained.

1. The toner particles in the lower layer, under the upper layer, are difficult to corona charge because the electric field is blocked.
2. The toner particles in the lower layer, at an opening in the deposit of the upper layer toner particles, are highly charged because of an electric field concentration by the electric potential.
3. The broad charge distribution of the corona charged toner is caused by overlapping of toner particles. Therefore, forming a thin toner layer is one of the principal means to obtain a sharp toner charge distribution.

References

1. J. Abe, N. Yamazaki, A. Noda, S. Kuramoto, and S. Oba, US Patent 5,887,233 (1999).
2. T. Bisaiji, US Patent 5,371,579 (1994).
3. K. W. Pietrowski, L. G. Hogestyn and D. G. Parker, US Patent 5,351,113 (1994).
4. C. H. Tabb, US Patent 5,258,820 (1993).

5. J. R. McDonald, M. H. Anderson and R. B. Mosley, Charge measurements on individual particles exiting laboratory precipitators with positive and negative corona at various temperatures, *J. Appl. Phys.* **51,** 3632–3643 (1980).
6. T-K. Chiang and T. W. Lugar, Particle charging characteristics of a pulse corona discharge, *Conf. Record of the IEEE Industry Applications Conf.*, IEEE Press, Los Alamitos, CA, 1982, pp. 1102-1106.
7. I. I. Inculet, Particle charging in DC corona fields, *IEEE Trans. Electrical Insulation* **EI-17,** 168–171 (1982).
8. X. Dexuan, S. Lianxi, Z. Jingsheng, and Z. Jianwei, Positive short-pulse corona discharge charging of aerosol particles, *Jpn. J. Appl. Phys.* **42,** 1766–1769 (2003).
9. A. Samuila and L. Dascalescu, Charging of cylindrical insulting particles in mono-ionized fields, *Conf. Record of the IEEE Industry Applications Conf.*, IEEE Press, Los Alamitos, CA, 1996, pp. 1891–1894.
10. L. Dascalescu, D. Rafioju, A. Samuila, and R. Tobazeon, Charging of insulating spheres on the surface of electrode affected by monopolar ions, *IEEE Trans. Industry Appl.* **34,** 35–42 (1998).
11. A. Samuila and L. Dascalescu, Unipolar charging of cylindrical insulting particles near electrode surfaces, *IEEE Trans. Industry Appl.* **34,** 51–56 (1998).
12. A. Urs, A. Samuila, A. Mihalcioiu, and L. Dascalescu, Charging and discharging of insulating particles on the surface of a grounded electrode, *Conf. Record of IEEE Industry Applications Conf.*, IEEE Press, Los Alamitos, CA, 2002, pp. 990–994.
13. L. Dascalescu, L. M. Dumitran and A. Samuila, Charging of one or several cylindrical particles by monopolar ions in electric fields, *IEEE Trans. Industry Appl.* **39,** 362–367 (2003).
14. R. B. Lewis, E. W. Connors and R. F. Koehler, A charge spectrograph for xerographic toner, *Electrophotograhpy* **22,** 85 (1983).