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Review of Toner-Based Printing Technologies and Fundamentals of Toner Charging Mechanism

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Abstract. *Toner-based printing technologies such as electrophotography have excellent electronic printing characteristics. The toner is controlled by electrostatic force, which is determined by the product of the toner charge and the electric field acting on the toner. In electrophotography the toner is attracted to an electrostatic latent image and forms an image. Because the toner is controlled by electrostatic force, high speed printing on plain paper can be realized. Electrophotography consists of six complex processes: charging, exposure, development, transfer, fixing, and cleaning. Various technologies have been proposed to realize a simpler printing mechanism. An electrostatic printing mechanism is described in which charging and exposure occur within a single process that generates an electrostatic latent image. As examples of direct printing by this simpler mechanism, TonerJet® and toner cloud beam are reviewed. As a fundamental element of toner-based printing technology, the toner charging mechanism is summarized. © 2010 Society for Imaging Science and Technology.*
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INTRODUCTION

Rapid progress has been made in non-impact printing technologies over the last three decades. Various nonimpact printing technologies have been developed[1,2] including toner-based printing, inkjet printing, and thermal printing. Recently, toner-based printing, such as electrophotography, and inkjet printing have become mainstream technologies. These printing technologies are widely used in offices and homes. Electrophotography, which is the principal toner-based printing technology, is used in offices because it has the characteristics of high speed and plain paper printing.

Toner-based printing technologies have a long history of development. After considerable competition among various toner-based printing technologies, electrophotography emerged as the dominant technology. It is important to review the history of toner-base printing technology and also to understand its fundamentals.

This article describes the characteristics of toner-based printing and reviews toner-based printing technologies such as electrophotography, electrostatic printing, TonerJet®, and also printing technologies, which use conductive toner. The toner charging mechanism is very important as a fundamental element of toner-based printing, so its mechanism is summarized from the viewpoint of physics.

CHARACTERISTICS OF TONER-BASED PRINTING

In toner-based printing, printing is performed by forming a toner image using electrostatic force, which is determined by the product of the toner charge and the electric field acting on the toner that is generated by the electrostatic latent image. Toner is composed of pigment, resin, wax, charge control agent (CCA), and external additives. The essential properties of a toner are its ability to be electrically charged and the ability of fixing the pigment on paper. Moving toner by applying an electrostatic force enables high-speed printing and fixing pigment by resin realized pain paper printing. These two properties are critical characteristics for a printing technology.

TONER PRINTING MECHANISMS

Electrophotography

Electrophotography[3] was invented by Carson in 1938. Copying is performed in a dry process by controlling charged toner particles through application of electrostatic force, which is generated by an electrostatic image on a photoreceptor. Numerous improvements and refinements have been made to electrophotography so that it has become a very refined technology. Figure 1 shows the printing mechanism of electrophotography. It involves six processes: charging, exposure, development, transfer, fixing, and cleaning. This printing process has not fundamentally changed since its invention. It is considered noteworthy in the rapidly changing technology age.

Electrophotography consists of many components and materials. It also utilizes many phenomena and mechanism.

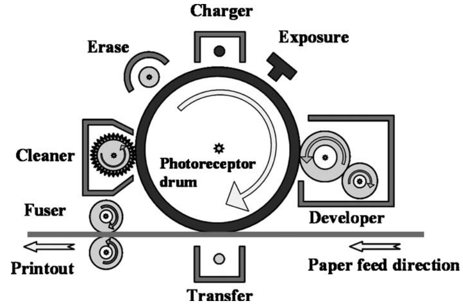

Figure 1. Schematic of electrophotographic printing process.

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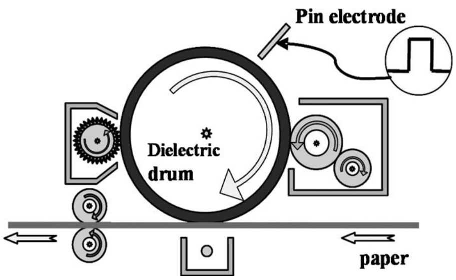

Figure 2. Electrostatic plain paper printing using a multistylus pin head.

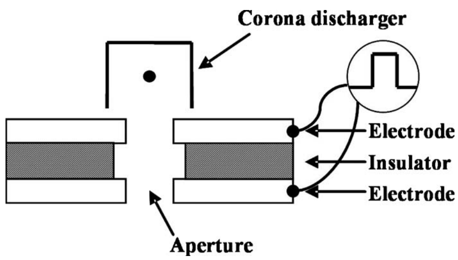

Figure 3. Ion flow control mechanism.

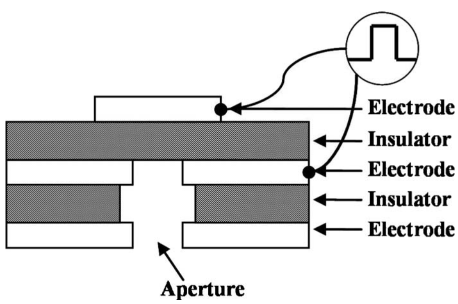

Figure 4. Ion projection mechanism.

From the viewpoints of physics and chemistry, photoconductive phenomena, electrostatic phenomena, corona discharge, etc., are important. Photoconductivity is the functional basis of the photoconductor drum. The drum has the characteristics of charge retention in the dark and charge decay in the light. Charge generation by light and charge transport are fundamental characteristics. Concerning these phenomena, many studies have been carried out, and our understanding of these phenomena and materials has advanced very well. The knowledge is extended to the development of organic electroluminescent displays and organic solar cells.

Electrostatic Printing

Several methods have been developed for electrostatic printing. The first method that was developed uses coated paper. A multistylus pin electrode is used to form an electrostatic latent image on the coated paper. The latent image is then developed by applying toner. This method is very simple, so it was used in the early stages of facsimile technology. This method has also been applied to wide-format color printing.

Subsequently, a method for printing on plain paper was developed. It is depicted in Figure 2. This method forms an

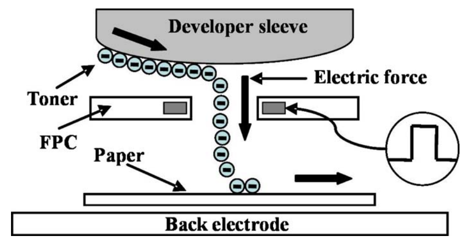

Figure 5. Printing mechanism of Tonerjet®.

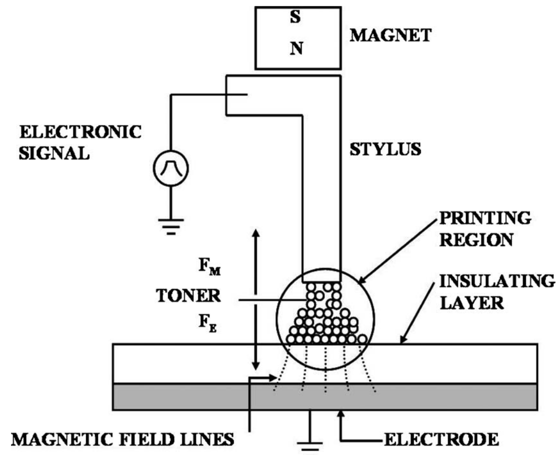

Figure 6. Printing mechanism of magnetic stylus printing.

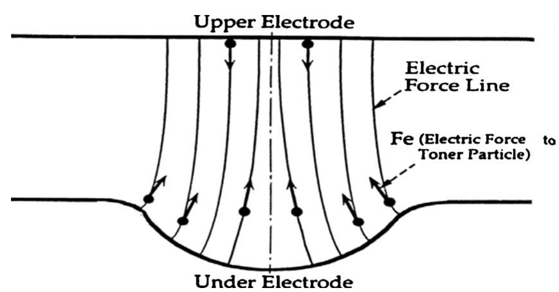

Figure 7. Toner confinement by dented electrode.

electrostatic image directly on a dielectric drum using a multistylus pin electrode. The electrostatic image is then developed by applying toner, and the toner image is transferred to plain paper. The toner image on the paper is fixed by a heat roller. This method has the advantage that it does not require a photoconductive drum. An electrostatic image is formed in a single process.

Instead of a multistylus pin electrode, the corona ion control and ion projection methods have been developed.[4,5] Corona ion flow is controlled by aperture electrodes as shown in Fig. 3, and an electrostatic image is formed on a dielectric drum. This method performs continuous-tone printing.

The ion projection method generates discharges at the required positions and generates charges that are projected to a dielectric drum. This discharge mechanism is shown in Fig. 4. This method is suitable for high-speed printing, and a high-speed printer has been developed based on it.

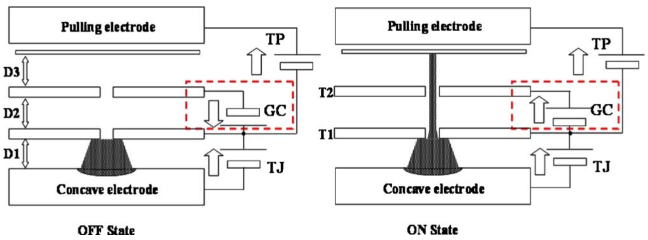

Figure 8. Toner cloud beam control by a pair of aperture electrodes.

TonerJet®

TonerJet® is an excellent concept in which the toner image is formed directly on paper.[6] Figure 5 shows its printing mechanism. A charged insulating toner layer is formed on the developing sleeve and toner is removed from the sleeve by an electric field that is generated between the aperture electrodes and the developer sleeve. The electric field causes the toner to jump onto the paper. This printing mechanism is simple and compact. Compact printers can be produced by this technology, and a color printing engine has also been developed.

Magnetic Stylus Printing

The printing mechanism[7] is shown in Figure 6. Conductive magnetic toner is supplied to a magnetic stylus array. When printing signal voltage is applied to the stylus, the toner, which contacts with the stylus, is charged because the toner is conductive. The force is generated between the charged toner and the dielectric printing medium, and the toner is attached to medium to generate a toner image on the medium. This printing mechanism is simple and resolution of 16 dots/mm is attained.

Toner Cloud Beam

Another printing mechanism using conductive toner is introduced as follows.[8–14] It is known that conductive toner jumps up and down between electrodes across when a voltage is applied. It has accordingly been found that the conductive toner is confined like a cloud around the dented electrode as shown in Figure 7 and proposed that the cloud-state toner is extracted to paper by controlling the voltage between two aperture electrodes. The printing mechanism which is called toner cloud beam (TCB) printing is shown in Figure 8. Representative dots produced by TCB are shown in Fig. 9.

Photoinduced Toning Electrophotography

Other toner-based printing technologies are briefly explained below. A novel printing technology using photoconductive phenomena is called photoinduced toning electrophotography (PITE).[15] In PITE the toner image is formed on a photoreceptor drum where the light image is projected form the back of the photoconductive layer. In this method, a scanning light source is inside the photoreceptor drum, so there is the possibility of realizing simple and compact printing mechanism.

Among other toner printing technologies, there is magnetography.[16] A magnetic image is formed on a magnetic drum, magnetic toner is attracted from the magnetic image, and a toner image is formed on the drum. This method has the characteristic of using magnetic force instead of electrostatic force. Another novel simple printing method using conductive toner and a photoreceptor have been proposed and demonstrated experimentally.[17] Due to the use of conductive toner, the printing mechanism becomes simple and also tone gradation printing is possible.

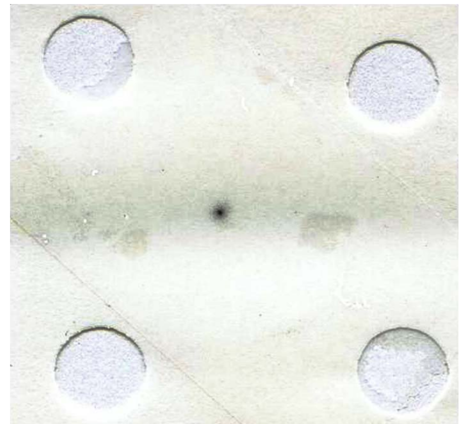

Figure 9. Example of dot generated by TCB.

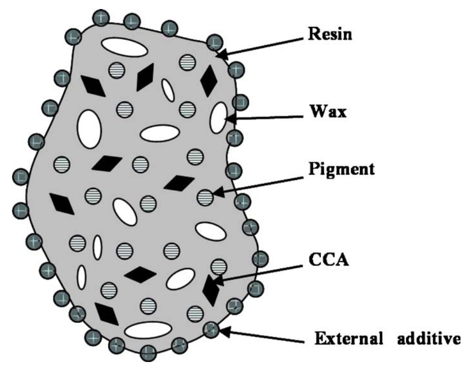

Figure 10. Toner model.

TONER CHARGING MECHANISM

Toner charge is important in electrophotographic printing and other toner printing methods. Many studies on the toner charging mechanism have been carried out. These fundamental physical studies have been carried out from various viewpoints. The charging mechanisms are reviewed for the two cases of insulating toner and conductive toner.

Insulating Toner

Toner is charged by contact or rubbing with other materials such as carrier. Charging by contact between two materials is known as triboelectric charging and is governed by the triboelectric series. Many requirements are imposed on the toner, including amount of charge, charge distribution, charging time, temperature/humidity dependence, attaching force, preservation characteristics, etc. Toner is composed of many different materials including resin, pigments, CCA, wax, and external additives. The schematic explanation of toner structure is shown in Figure 10.

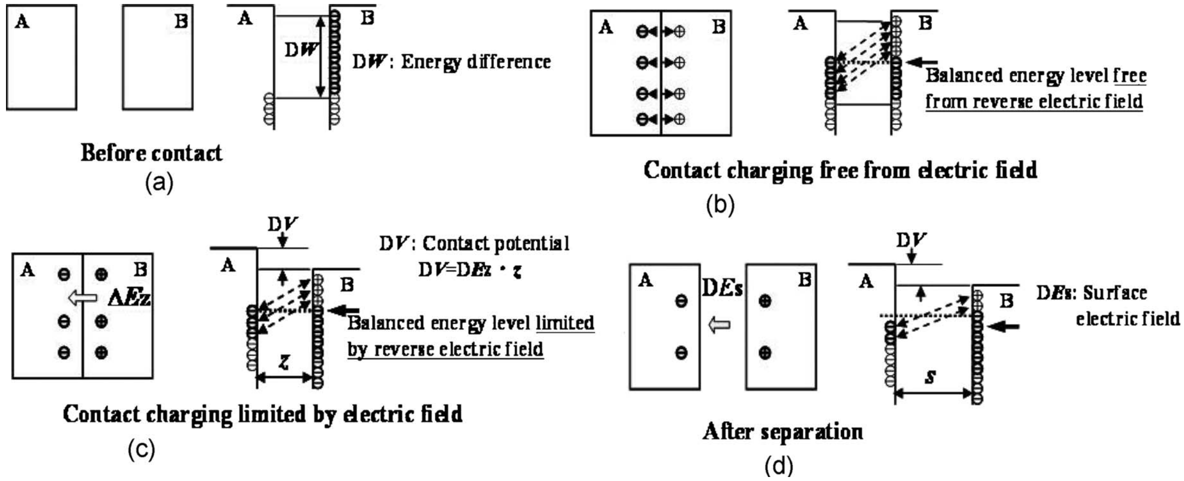

Figure 11. Contact charging model.[19]

Many studies on the charging mechanism of toner have been carried out. The mechanism is very complex and it is generally accepted that a satisfactory understanding has not been obtained yet. Kondo proposed the theory that toner charge represents an equilibrium between the electric potentials at the contact area between toner and carrier and reflects the difference of charging strength of these two materials. The contact charging model as proposed is shown in Figure 11, and this theory has been applied to many experimental results. Schein summarized toner charging theory.[18] Okada recently reexamined the toner charging theory.[19]

The mixing of toner and carrier is, in itself, an interesting example of a powder mixing system. The charging characteristics are thus understood both by the contact phenomena and also the effects of powder mixing. Typical toner made by the pulverizing method is shown in Figure 12. Toner particle shapes have variety, from the irregular shape as shown in Fig. 12 to spherical shape. A measured example of specific toner charge distribution is shown in Figure 13. Usually toner charge is distributed, but the reason for the distribution is not yet understood well.

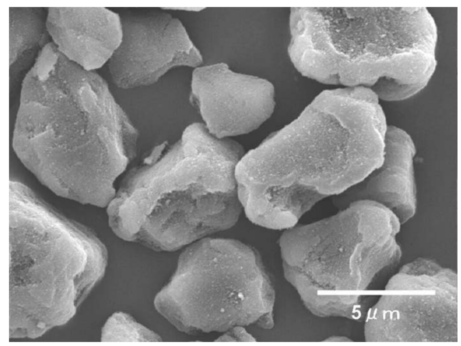

Figure 12. Shape of typical pulverized toner.

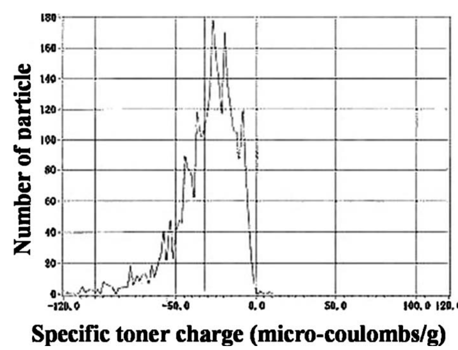

Figure 13. Example of toner specific charge distribution.

Conductive Toner

When toner is conductive, toner charging is carried out by conduction of charge on contact with other conductive material. The schematic explanations are shown in Figure 14. When the toner is insulating, the toner charge is unaffected by electric field application and retains its charge; on the other hand, when the toner is conductive and in good contact with an electrode, the potentials of the toner and electrode equalize, and the toner is charged by application of an electric field.[20] In some cases, contact potential and nonlinear conductivity between toner and electrode cannot be neglected.

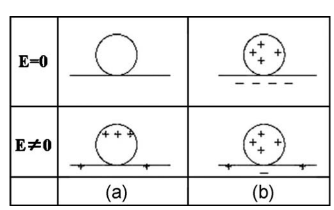

Figure 14. Illustration of toner charge dependence on external electric field: (a) conductive toner and (b) insulator toner.[20]

SUMMARY

Toner-based printing technology is important for non-impact printing, and various aspects of it are being developed including mechanism, materials, components, and design. In this article, the characteristics of toner-based printing systems were described and toner-based printing technologies such as electrophotography, electrostatic printing, TonerJet®, magnetic stylus printing, and toner cloud beam printing, which uses a conductive toner, were briefly reviewed. Fundamental understanding from the viewpoints of physics and chemistry remains necessary for progress, and looking ahead, we expect more understanding. Toner printing technology will accordingly provide an interesting theme for physics and chemistry.

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