Characteristics of Intermediate Transfer Process

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Abstract

In this paper we focused a second stage of transfer process in the intermediate transfer system and investigated the electrical properties of a transfer belt and a transfer medium based on a charge transport equation.

We were able to demonstrate that the transfer belt had indeed an ohmic conduction regime and a space-charge limited current regime. The space-charge limited current regime itself characterizes a field independent carrier mobility regime and a field dependent carrier mobility regime. The field dependence of conductivity in the ohmic region can also be found in the transfer medium. The dielectric constant was calculated by a step response under observation of the field dependence of carrier mobility. As a result, the dielectric constant was constant values across the field for both the transfer belt and the transfer medium.

The obtained parameters were then further applied to the second transfer process, in which the electric field distribution and the transfer efficiency were simulated.

Introduction

Transfer belts that are used in many color printers are known as non-ohmic charge injection[1),2),3)] because of inhomogeneity and low purity materials. Thus, the electrical property of the transfer belt has not been investigated sufficiently. Furthermore, although an applied transfer voltage is very high (1~3kV) in a transfer process using a transfer roller, a dielectric constant is measured with a commercial instrument under low voltage(1~5V).

In fact, a transfer voltage is applied as a step waveform in the transfer nip, and it is very transitional phenomenon in high electric field. Therefore, a conventional measurement method underlying assumption of an ohmic conduction in steady state is not a district means for predicting a performance of a transfer belt or a paper in transfer process.

We studied a new measurement method based on the charge transport equation to describe electrical conduction properties of semi-insulating materials considering field dependence of a carrier mobility and a dielectric constant in transient state.

These parameters obtained with above method are applied to the model of the second transfer process in the intermediate transfer system, and a field distribution and the transfer efficiency in the second transfer process can be simulated by using Poison's equation.

Intermediate Transfer Process

In the intermediate color transfer process shown in Fig.1, a toner layer is transferred two times. At first transfer process, the toner layer is transferred from the OPC drum to the transfer belt, and at second, the toner layer is transferred to the medium. Here, the second transfer process is treated.

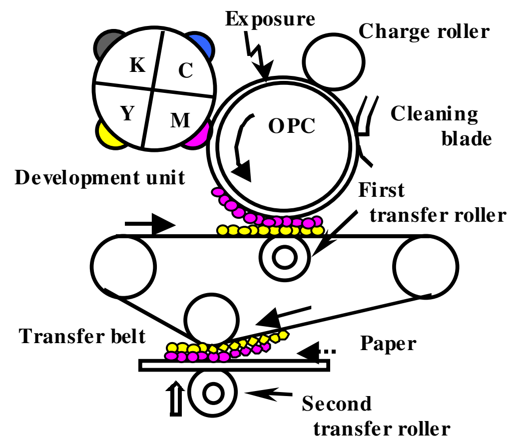

Figure 1. Schematic of intermediate transfer process

Charge Transport Equations

The electric conduction property of the transfer belt or paper is described by charge transport equation. The total current is the sum of drift and displacement currents. The drift current has to be considered two current regimes. One is ohmic regime, and another is space-charge limited current regime. In these regimes, charge transport equations are shown as follows.

・Ohmic regime

$$J(t) = ne\mu E + \frac{\varepsilon}{L}\frac{dV}{dt} \tag{1}$$

・Space-charge limited current regime

$$J(t) = \frac{9}{8}\varepsilon\mu\frac{V^2}{L^3} + \frac{\varepsilon}{L}\frac{dV}{dt} \tag{2}$$

where $J(t)$ is the time dependent current density, n is the carrier density. ε and μ denote the dielectric constant and the carrier mobility, respectively. L is the thickness, and V is the time dependent voltage. t is the time. In the space-charge limited current regime, we assume that traps are filled up with carriers and the carrier moves like trap free. By checking Current-Voltage characteristics, two regimes are distinguished.

Assuming the total current is zero, namely injected charges flow by self-discharge, a relaxation time τ is obtained from Eq.(1) and Eq.(2) as follows,

$$\tau = -V / \left(\frac{dV}{dt} \right) \tag{3}$$

Furthermore, in the space-charge limited current regime, the carrier mobility μ is derived from Eq.(2) as follows,

$$\mu = -\frac{8}{9}\frac{L^2}{V^2}\frac{dV}{dt} \tag{4}$$

Next, in order to obtain the dielectric constant, we consider a model shown in Fig.1.

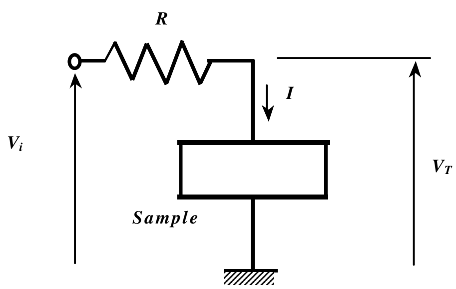

Figure 2. Electrical circuit obtaining dielectric constant

A sample is charged through a resistor ***R***. ***J(t)*** in Eq.(1) and Eq.(2) are expressed as follows,

$$J(t) = \frac{V_i - V_T}{R \cdot S} \tag{5}$$

where ***S*** is an area of the sample.

Then the dielectric constant in the ohmic regime or space-charge limited current regime is given by the same equation from Eq.(1) and Eq.(2);

$$\varepsilon = \frac{V_i - V_T}{\frac{R \cdot S}{L}\left(\frac{V_T}{\tau} + \frac{dV_T}{dt} \right)} \tag{6}$$

Equivalent conductivity σ in the space-charge limited current regime is defined from Eq(4) and Eq(6),

$$\sigma = \frac{9}{8}\varepsilon\mu\frac{V}{L^2} \tag{7}$$

If there were no space-charge limited current regime in J-V characteristic, we cannot obtain the carrier mobility. Therefore, we obtained the conductivity from Eq(3) and Eq(6) as follows;

$$\sigma = \frac{\tau}{\varepsilon} \tag{8}$$

Second Transfer Process

Figure 3 shows the model of second transfer process. A typical second transfer subsystem consists of the transfer belt, the toner layer on the transfer belt, the paper, the transfer roller and a bias voltage $V_T(t)$.

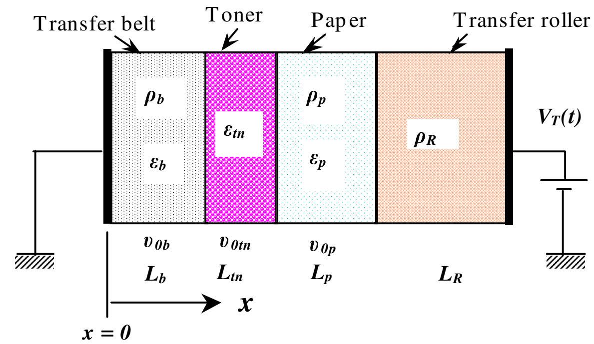

Figure 3. Model of second transfer process

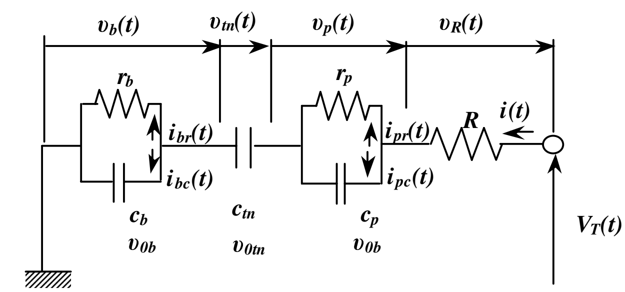

Figure 4. Euivalent circuit of second transfer process

In this model, $v_b(t)$, v_{0b}, $v_{tn}(t)$, v_{0tn}, $v_p(t)$, v_{0p} and $v_R(t)$ show time dependent voltages and initial voltages in each element. ε_b, ε_{tn} and ε_p show dielectric constant, and ρ_b , ρ_p and ρ_R show volume resistivity respectively. Each L's is a thickness. Each capacitance ***c*** is shown as ε/L, and each resistance ***r*** is shown as $\rho L (= L/\sigma)$.

Thus each voltage can be obtained by solving electrical circuit equations, and each electric field can be calculated according to the Poison's equation;

$$\frac{d^2}{dt^2}v(t) = -\frac{q}{\varepsilon} \tag{9}$$

where ***q*** is volume charge density.

In the space-charge limited current regime of the transfer belt, the electric field $E_b(x,t)$ is shown as follows;

$$E_b(x,t) = \sqrt{\frac{2x \cdot i_{br}(t)}{\varepsilon_b \mu}} \tag{10}$$

where ***x*** is displacement, $i_{br}(t)$ is the current of the transfer belt in resistance element.

As the transfer efficiency, it is commonly known that the toner layer is separated at a displacement x_0 where the inner electric field $E(x_0,t)$ is zero. Transfer efficiency η is expressed as follows;

$$\eta = \frac{x_0}{L_{tn}} \times 100\ (\%) \qquad (11)$$

Experimental Results and Simulations

J-V characteristics of the transfer belt and the paper are shown in Fig. 5. The current density of the paper increases lineally together with the applied voltage. Then, an electrical property is an ohmic conduction only. But, the current density of the transfer belt increases steeply beyond 18V. It is clear that the space-charge occurs in this region.

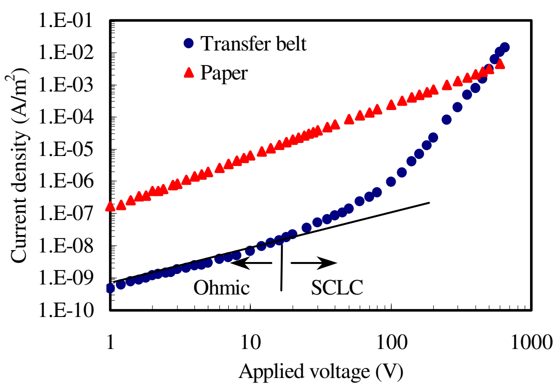

Figure 5. J-V characteristics of the transfer belt and the paper

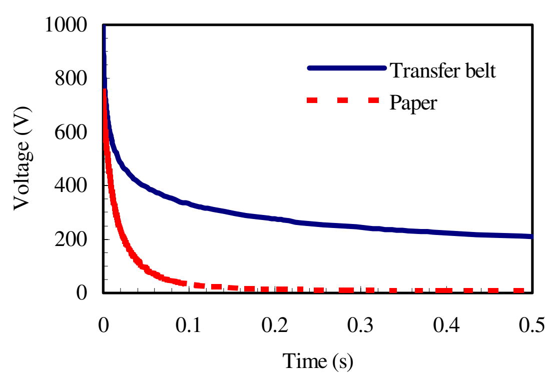

Figure 6. Voltage decay vs. time

Next, we show voltage decay characteristics of the transfer belt and the paper in Fig. 6. The carrier mobility of transfer belt, which thickness is 141μm, can be calculated from this graph by using Eq(4). The carrier mobility is shown in Fig. 7. Voltage dependence of the carrier mobility beyond 56V region can be expressed by Pool-Frenkel type equation.

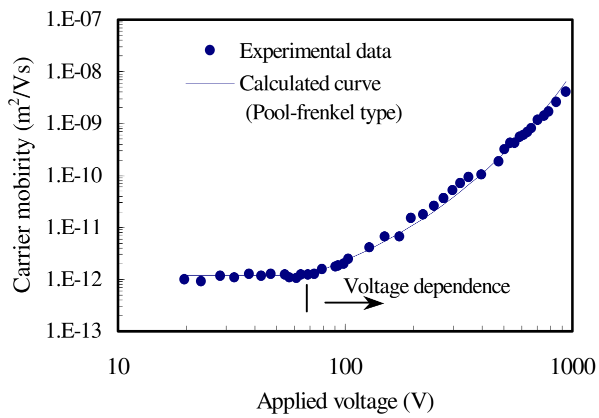

Figure 7. Voltage dependence of carrier mobility

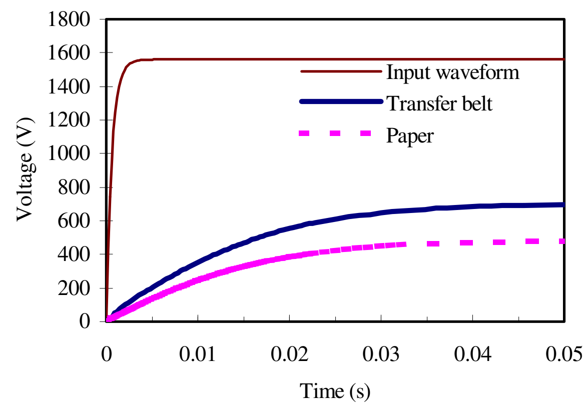

Figure 8. Step response

Dielectric constant is obtained from a step response as shown in Fig. 1. The resister is 30M**Ω**, and a rising waveform is measured with a surface potential meter. In Fig. 8, experimental results of step response are shown. Then, a dielectric constant is derived from an input waveform and a rising waveform by using Eq.(6) at any voltage. The voltage dependence of relaxation time is calculated from voltage decay curve shown in Fig.(6), and it is substituted in Eq.(6).

Figure 9 shows relative dielectric constants of the transfer belt and the paper. This graph shows that a relative dielectric constant does not depend on the voltage.

The Conductivity can be obtained from Eq.(7) and Eq.(8) substituting the carrier mobility and the dielectric constant shown in Fig. 7 and Fig. 9.

These parameters are substituted to the circuit equations, and an electric field distribution can be calculated. For example, considering magenta toner, the other parameters are: t=0msec (initial value), t=16.5msec (final value), $V_T(t)$=1200V(constant), v_{0b}=-50V, v_{0p}=0V, v_{0tn}=-129V, ε_{tn}=2.83×10^{-11} F/m, L_{tn}=13.7μm, L_R=3mm, ρ_R=7.2×10^7Ω·cm. Initial voltage and thickness of magenta toner are experimental data that are measured before second transfer process.

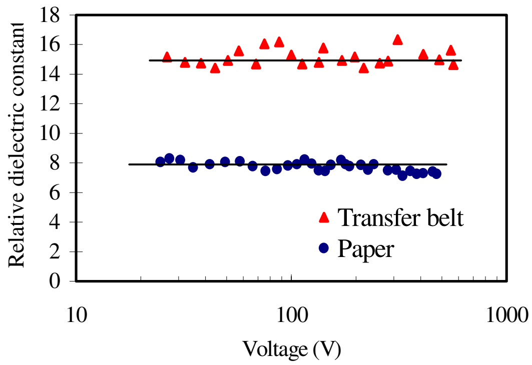

Figure 9. Relative dielectric constant vs. voltage

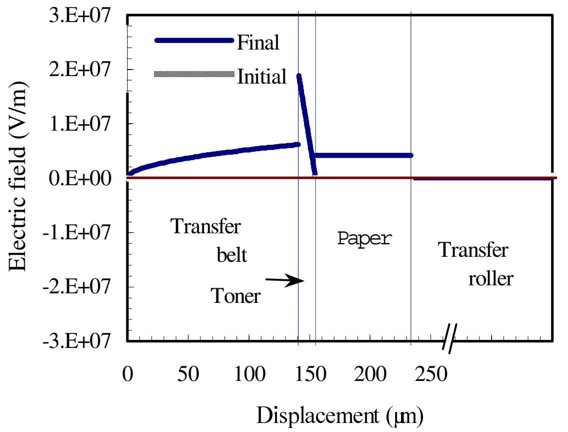

Figure 10. Electric field distribution at second transfer process

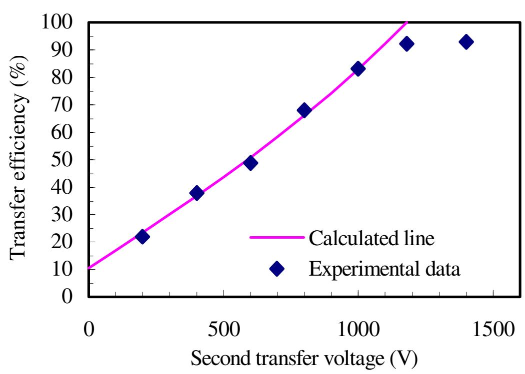

Figure 11. Relationships between transfer efficiency and second transfer voltage for magenta toner

Calculated results of field distribution at the initial and final condition are shown in Fig.10. The transfer belt plays almost in the space-charge limited current regime, so onset of the electric field is zero. Electric field of the toner layer, which is negative charge, changes from negative to positive polarity. When all inner electric field of the toner layer changes sign, all toners are transferred theoretically. Fig.11 shows the relationship between the transfer efficiency and the second transfer voltage. The transfer efficiency increases together with applied voltage, experimental data agree well with the calculated line.

The other toner layers are calculated by similar method. But it is important to measure the initial voltage of toner layer. Because the volume charge density increases past the fist transfer process.

Conclusion

We have proposed novel measurement techniques for characterizing the electrical properties of a transfer belt and a paper. The method yields measurements that are relevant to the transfer process. The voltage dependent carrier mobility and the dielectric constant measurements, taking into consideration the space-charge limited current in high electric field, have been developed to analyze the transfer process. Then, the transfer belt is clarified to have the ohmic regime and the space-charge limited current regime. The carrier mobility depends on the voltage that is higher than 56V, and can be expressed with the Pool-Frenkel type equation. These parameters are taken into the equivalent circuit equations of second transfer process to simulate the phenomenon.

The electric field in the second transfer process is calculated from the electrical equivalent circuit equations according to the Poisson's equation. Transfer efficiency is calculated from the field, it is known that toner transfer requires a reversal of the field direction in the toner layer. Then, the experimental transfer efficiency proved to be in accordance with the calculated transfer efficiency.

Thus, a complete characterization of second transfer process in intermediate transfer system must be carried out under conditions closely measuring parameters in the actual transfer process.

References

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Biography

Tsuneo Mizuno received his B.S. degree in electronic engineering from the Shinshu University in 1974, and a M.S. degree in electric engineering from the Shinshu University in 1976. Since 1976, he has worked in the Fujitsu Limited. His work has primarily focused on the development electro photographic process. He is a student of graduate school of Tokyo Institute of Technology from 1999. E-mail: GDC02173@nifty.ne.jp