Electrical Characterization of Transfer Media for Electrophotography

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Abstract

A novel technique has been devised to characterize dielectric relaxation in transfer media, for better prediction of performance in electrostatic transfer of developed toners to receiving media. In this process, efficient dielectric relaxation in the media enables efficient transfer at moderate bias voltages. A recent theoretical analysis has shown that dielectric relaxation in transfer media is determined, not simply by sample resistance and capacitance, but more precisely by charge density, charge mobility and charge injection properties. In the new characterization technique, the observed decay of voltage over an electrostatically charged sample is interpreted in terms of these transport parameters. Results from representative media samples are presented and discussed.

Introduction

The most common technique for electrical characterization is the closed-circuit measurements, in which a constant voltage V is applied across a distance L in the sample, and the current I is measured. The resistance $R = V/I_{ss}$, or the resistivity $\rho = RL$, or the conductivity $\sigma = 1/\rho$, is calculated from the steady state value of current I_{ss}. However, it has recently been shown that I_{ss} is determined solely by the ability of the electrodes to inject charge, and essentially vanishes unless the charge's lifetime to deep trapping is sufficiently long.[1] Furthermore, the current characteristics I(t) is insensitive to the field dependence of charge mobility, an important feature of (hopping) charge transport in semi-insulators. For these reasons, the closed-circuit measurement is not an ideal characterization technique for semi-insulators, in particular, in electrophotographic applications.

An alternative technique is the open-circuit measurements, in which the surface of a grounded sample is charged (e.g. with corona ions) to a high voltage, and the decay of voltage V(t) is monitored as a function of time t. This voltage decay is commonly known as "dielectric relaxation" of the sample. In the traditional analysis of dielectric relaxation by the equivalent-circuit model, the voltage is expected to decay exponentially with a time constant that is the product of the sample resistance R and capacitance C. However, such exponential decay has rarely been observed in semi-insulator samples of present interest. A recent analysis of dielectric relaxation based on a first-principle treatment of charge transport in semi-insulators has shown that this discrepancy arises from the space-charge effects.[1] The latter, in turn, can be attributed to either or all of the following causes: (a) non-Ohmic and/or asymmetric charge injection from the surface and the grounded electrode, (b) charge lifetime to deep trapping being too short, and (c) field dependent charge mobility.

It has also been pointed out that many applications of semi-insulators in electrophotography are effectively in the open-circuit condition, and hence the above mentioned space charge effects are operative in the processes. An example of such a process is the electrostatic transfer. In this process, efficient dielectric relaxation in the receiving media (paper or intermediate belts) enables efficient transfer at moderate bias voltage.[2,3]

Therefore, the open-circuit measurements should be an ideal characterization technique for electrostatic transfer media, provided the interpretation of the observed data takes into account the space-charge effects in charge transport.

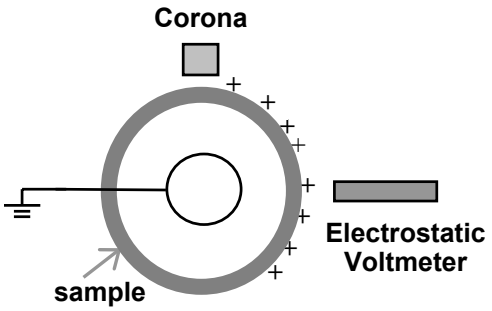

Figure 1. Schematic of Electrostatic Charge Decay (ECD) experimental set up

Electrostatic Charge Decay (ECD) Experiments

Based on the above findings, the "electrostatic charge decay" (ECD) technique, previously introduced for characterization of photoreceptors and charging rollers,[4,5] suggests itself as an ideal experimental technique for monitoring dielectric relaxation in transfer media. In this application, the media sample wrapped around a grounded substrate is corona-charged for a finite time. The subsequent decay of the surface voltage, due to dielectric relaxation induced by the intrinsic charge in the sample and the charge injected from the substrate and surface, is monitored with an electrostatic voltmeter. A schematic of the experimental set up is shown in Fig. 1.

Two examples of data from plain paper samples are shown in Fig. 2. Because of the spatial separation between the corona charger and the voltage probe, a short delay occurs between the charging and the start of voltage measurement. The voltage decay is obviously not exponential. The difference in voltages at the first data points indicates that dielectric relaxation during charging is more efficient in sample PP-1 than in PP-2. This trend continues in the decay after charging.

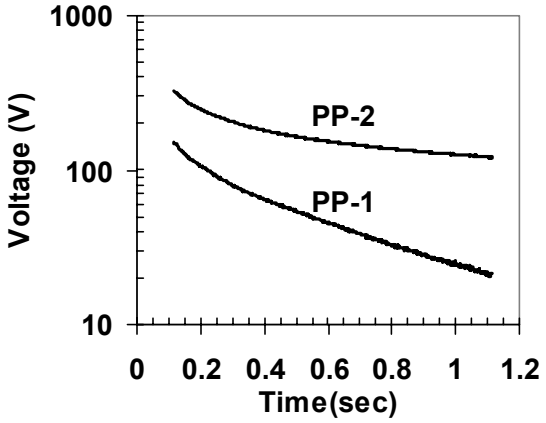

Figure 2. Electrostatic charge decay (ECD) curves of two plain paper samples.

Similar ECD data from a set of intermediate transfer belts are shown in Fig. 3. The belts Gn and Gu, which perform well in toner transfer, decay more efficiently than do Bn and Bu, which show poorer transfer performance. The voltages at the first data points are very close for the new (n) and used (u) samples in both the good and bad pairs, but the voltage data at long time after charging are quite different. The first feature can be attributed to the fact that the decay during charging is caused mainly by the depletion of intrinsic charge, which is unlikely to be affected by usage. In contrast, the voltage decay after charging depends mostly on injected charge, which can be significantly affected by surface deterioration from usage. In the next section, this interpretation will be compared with and confirmed by the results of mathematical simulations based on first principle charge transport theory.[1]

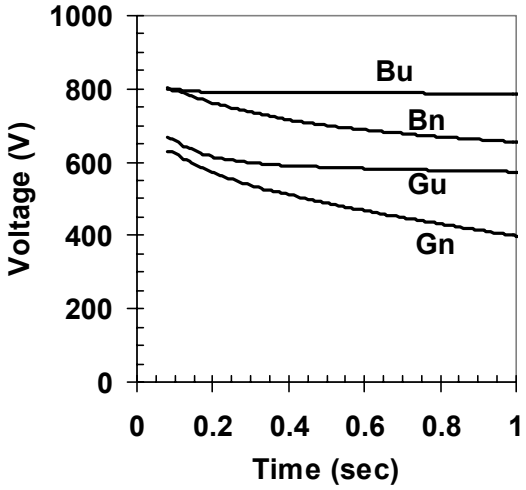

Figure 3. ECD curves of four intermediate transfer belts. Gn and Gu are new and used belts, respectively, that perform well. Bn and Bu are new and used belts that perform poorly

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Space-charge Model of ECD

The mathematical procedure for calculating the sample surface voltage V(t) as a function of time after charging has been described in detail in a previous publication.[1] In the present work, we consider in addition, the build up of surface voltage during corona charging. The build up of voltage by corona current is countered by the depletion of intrinsic charge in the sample and the transit of injected charge from the contacts. Therefore, the surface voltage at the end of charging (at time t_{chg}) is determined by the intrinsic charge density and the injection property at the contacts, as well as the corona current. The time evolution of voltage build up can be calculated by the same set of equations presented before.[1]

Examples of calculated charging voltage as a function of time are shown in Fig.4. In all the following figures, voltage is in units of the corona cut-off voltage V_{mx}, time is in units of $t_o \equiv L^2/\mu V_{mx}$, where L is the sample thickness, and μ is the charge mobility. With typical values of $V_{mx} \approx 10^3$ V, L $\approx 10^{-2}$ cm and $\mu \approx 10^{-5}$ cm^2/Vsec, the time unit is $t_0 \approx 10^{-2}$ sec. The intrinsic charge density q_i, (which is related to the conductivity by $\sigma = \mu q_i$), is varied from 0.01 to 10 in units of $q_o \equiv \varepsilon V_{mx}/L^2$, where ε is the sample permittivity. With the above values of V_{mx} and L, and $\varepsilon \approx 5\text{x}10^{-13}$ F/cm, the unit of charge density is $q_o \approx 5\text{x}10^{-6}$ Coul/cm^3.

With an extended charging time (t_{chg} >> 10 t_o), the charging yields a common surface voltage independent of q_i values. However, if the charging is terminated in a few time units, (e.g. $t_{chg} = 4t_o$, at the dashed line) the voltage at the end of charging decreases significantly as q_i increases.

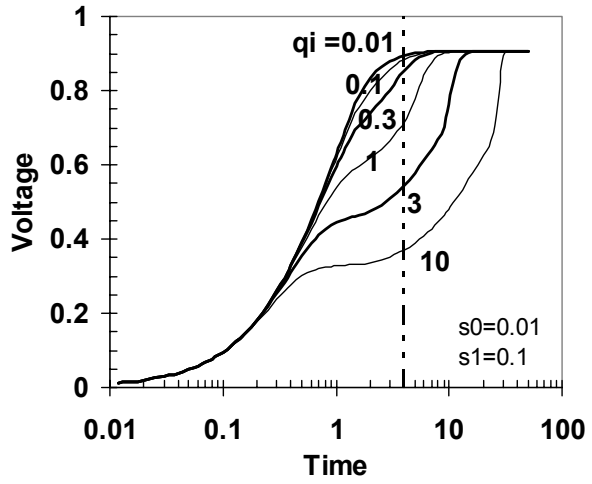

Figure 4. Charging voltages calculated for various values of intrinsic charge density q_i. Weak injections from the contacts (s_0, s_1) are assumed.

The injection current is assumed to be proportional to the field at the boundary,[1] and the proportionality constant s (with the dimension of conductivity) is used to specify the injection level. In the examples of Fig.4, the injection level from the surface is assumed to be $s_0 = 0.01$ and that from the substrate is $s_1 = 0.1$, in units of $\sigma_o \equiv \mu q_o = \varepsilon\mu V_{mx}/L^2$ ($\approx 5x10^{-11}$ S/cm, with the above typical values).

Figures 5A and 5B show the voltages during charging and decay, respectively, for the case of $q_i = 0.1q_o$. The injection from corona charged surface is assumed to be negligible ($s_0 = 0$), and the injection from the substrate s_1 is varied. The charging (Fig. 5A) is assumed to be terminated at $t_{chg} = 4t_o$, and the decay (Fig. 5B) follows. It can be seen from these figures, that for small values of s_1, e.g. in the range $0.01 \le s_1 \le 0.1$, the voltage difference at t_{chg} is very small (about $0.07V_{mx}$). However, the same range of injection causes much larger difference in the decaying voltages, ($0.4V_{mx}$ at $t = 40t_o$ in Fig. 5B).

Similar voltage decay curves for the case of $q_i = q_o$ are shown in Fig. 6. This larger q_i causes the effect of charge depletion during charging to be more severe, and hence the voltage at the end of charging (t = 0) is lower than that in Fig.5. Also, because the depletion of intrinsic charge has more dominant contribution during charging, the voltage at t = 0 is less sensitive to s_1 (even for a larger range of $0.01 \le s_1 \le 1.0$). After charging, and after the depletion of q_i is complete, the discharge is dominated by injected charge and hence, the decay becomes very sensitive to the parameter s_1.

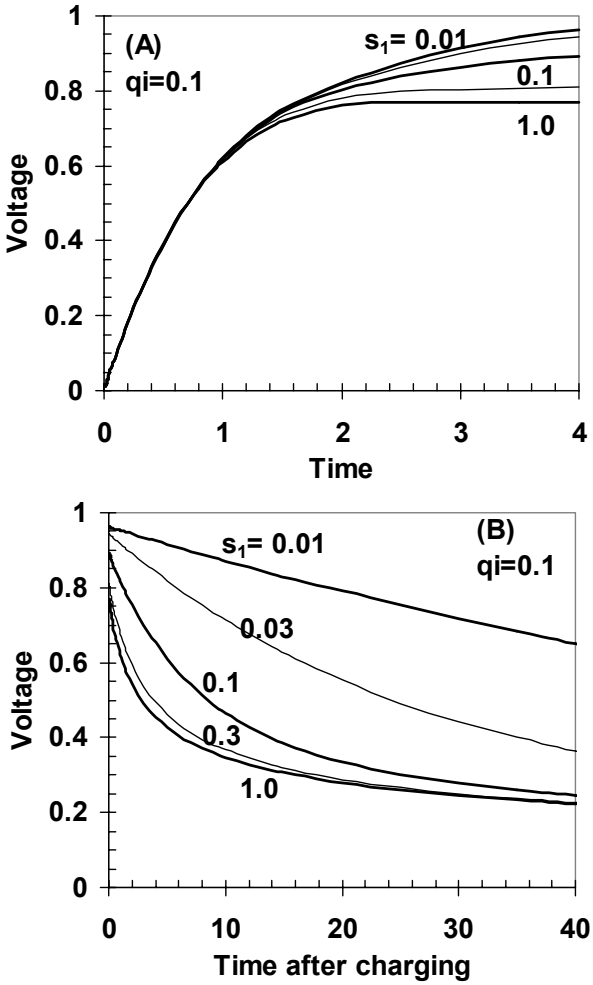

Figure 5. (A) Voltage during charging, and (B) voltage decay after a charging time of $t_{chg} = 4t_o$, calculated for intrinsic charge density $q_i = 0.1q_o$, and various degrees of injection from substrate s_1.

Conclusions

The features of ECD curves shown in Figs. 5 and 6 are in good agreement, at least semi-quantitatively, with the observation and interpretation of the experimental data in Fig.3. The more relevant curves from Figs. 5B and 6 are summarized in Fig. 7 for comparison with the experimental data shown in Fig.3. The intrinsic charge densities in the good and poor samples can be estimated to be of the order of $q_i = q_o$ and $0.1q_o$, respectively. Also, the charge injection level in the new samples is estimated to be of the order of $s_1 = 0.1$, and decreases to $s_1 \le 0.01$ (σ_o) in the used samples.

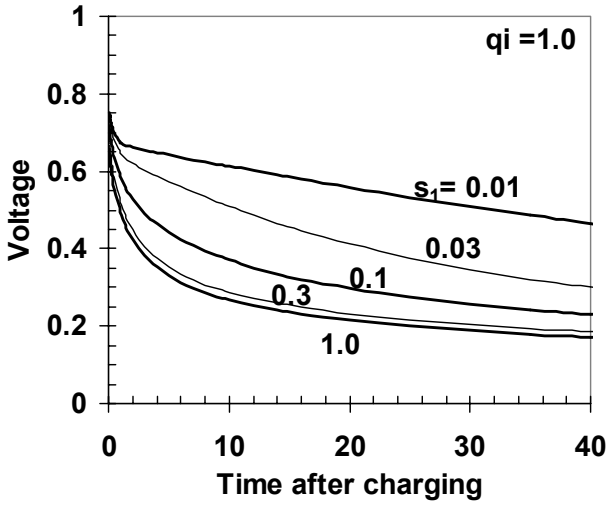

Figure 6.Voltage decay after a charging time of $4t_o$, calculated for intrinsic charge density $q_i = q_o$, and various injection from substrate s_1.

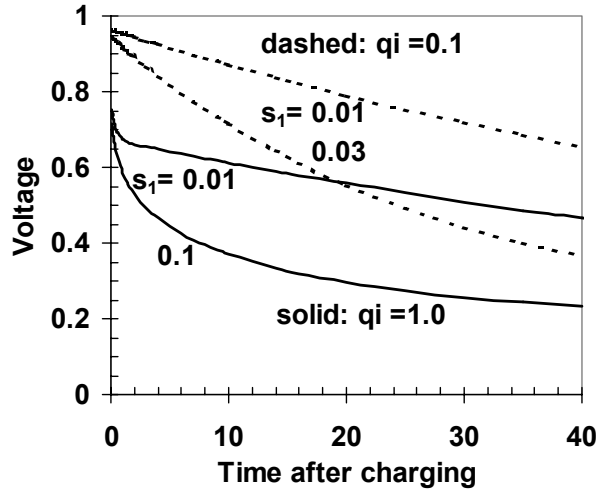

Figure 7. Calculated voltage decay after a charging time of $4t_o$,for comparison with the data from good (solid curves) and poor (dashed curves) samples in Fig.3.

As mentioned before, a full characterization of dielectric relaxation in transfer media (or any semi-insulators) requires the determination of a large number of parameters, including intrinsic charge density, charge injection from both contacts, charge mobility and its field dependence. While the use of the voltage decay has been successfully demonstrated above, the characterization procedure described here is by no means the only approach. Additional experimental observable can be used to determine more precisely or to cross check the parameter values deduced from voltage decay. Furthermore a single figure of merit that consolidates the roles of a large number of charge transport parameters is desirable to simplify the specification of media performance (e.g. for production quality control applications). Work has been in progress along this direction, and it will be reported in the near future.

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Biography

Dr. Inan Chen worked at Xerox Research Laboratories in Webster, NY from 1965 to 1998. Currently, he is associated with QEA, Inc. as a consulting scientist, engaged in the development of theoretical bases for novel characterization techniques in electrophotography. Contact at inanchen@aol.com.

Dr. Ming-Kai Tse founded QEA, Inc. in 1987. The company designs and manufactures automated quality control test systems for digital printing technology. He was a professor of Mechanical Engineering at MIT between 1982 and 1989, specializing in manufacturing, non-destructive testing, and quality engineering. Contact at mkt@qea.com.

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Keywords

Media, Electrostatic transfer, Electrical characterization, Electrophotography