Charge Mobility Determination Using Electrostatic Charge Decay Technique

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Abstract

A novel method of mobility measurement, which is based on the electrostatic charge decay (ECD) technique, is described. Data obtained for organic dual-layer photoreceptor drums are presented to illustrate the application of the method. An important merit of this technique is the use of the soft-contact of corona charging instead of electrodes, achieving the objective of non-destructive and efficient characterization, applicable to finished devices.

Introduction

Charge mobility is an important material parameter in semi-insulating devices used for electrophotography, including photoreceptors, charging/development rollers and transfer media.[1-4] Conventionally, the measurements of mobility in such semi-insulators employ the small signal time-of-flight technique. In this technique the amount of injected charge has to be very small compared to the surface charge density, i.e., one CV's worth, (where C is the capacitance of the sample and V is the applied voltage). In addition, the applicability of this method requires the dielectric relaxation time to be much longer than the charge transit time. The latter requirement is hard to satisfy in less insulating materials of present interest. An alternative method uses the large signal approach, by measuring the space-charge-limited current. This method also applies strictly to monopolar transport and requires an electroded configuration.

In this paper we present a novel method of mobility measurement, which is built on and extends the "Electrostatic Charge Decay (ECD)" technique, previously reported.[5,6,7] In the next section, the theoretical background of the method is presented. This is followed by examples of experimental data collected from commercially available dual layer organic photoreceptors.

Theoretical Background

Consider a layer of semi-insulator on a grounded substrate under corona charging as shown schematically in Fig. 1. The variation of corona current J_C with the surface voltage V usually follows the empirical relation:

$$J_C = J_m (1 - V/V_m) \qquad (1)$$

where J_m and V_m are two empirically determined parameters. J_m is the initial (maximum) current at V = 0, and V_m is the cut-off voltage at $J_C = 0$. The injection of charge from the substrate electrode (at x = 0) and the surface (at x = L) can be specified by assuming the injection currents J(0, t) and J(L,t), respectively, to be proportional to the fields E(x, t) at the interfaces,

$$J(0, t) = s_0 E(0, t); \; J(L, t) = s_1 E(L, t) \qquad (2)$$

where the parameters s_0 and s_1 represent the injection strength, and have the dimension of conductivity. The current J_C is equal to the total current J_T measured in the external circuit, which can be calculated from charge transport equations described previously.[8] The current decreases from the initial value J_m and approaches a steady state value J_{SS} in several transit times. Examples of calculated J_T vs. time curves can be found in Ref. 6.

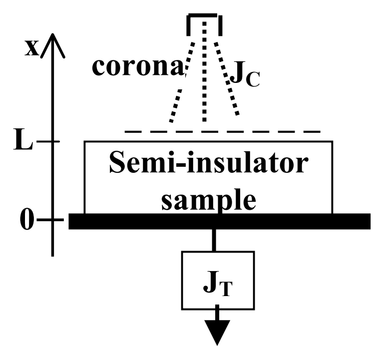

Fig. 1. Schematics of measurements

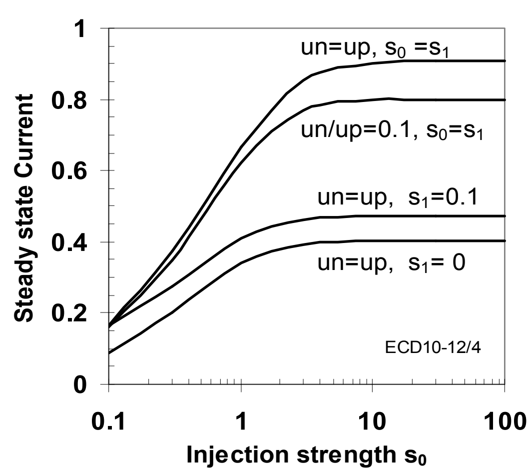

Fig. 2. Steady state currents under various mobility μ and injection conditions

Figure 2 shows the J_{SS} as a function of injection s_0, for different combinations of charge mobilities (μ_p and μ_n for holes and electrons, respectively) and charge injection (s_0 and s_1). The saturation of steady state currents as the injection increases suggests that the limiting value of J_{SS} is equal to or approaching the space-charge-limited current at the steady state voltage V_{SS}. Thus, one can equate the measured steady state current to the well-known expression of space-charge-limited current,

$$J_{SS} = J_m(1 - V_{SS}/V_m) < \approx \varepsilon\mu V_{SS}^2/L^3 \quad (3)$$

where ε is the permittivity and μ is the effective charge mobility, including the contributions from holes and electrons. Eliminating V_{SS} from the corona characteristics, Eq.(1), we have,

$$\mu > \approx J_{SS}L^3/\varepsilon V_{SS}^2 = \mu_o(J_{SS}/J_m)/(1 - J_{SS}/J_m)^2 \quad (4)$$

with $\mu_o = (J_m L^3/\varepsilon V_m^2)$. A change in J_{SS}/J_m, e.g., from 0.01 to 0.99, corresponds to six orders of magnitude change in the mobility value μ/μ_o. It can be seen from Fig. 2 that if the injection is insufficient, J_{SS} is smaller than the corresponding limiting value. Thus, the use of this technique and Eq.(4) should give a lower estimate of the mobility.

Experimental Results

This technique is applied to commercially available organic dual-layer photoreceptors (OPC). The charge injection from the substrate is supplied by photogeneration in the charge-generation layer (CGL). Because the charge-transport layer (CTL) transports holes only, the injection of electrons from the surface is automatically suppressed (s_1= 0 and μ_n = 0). Figure 3 shows an example of the increase and saturation of the steady state currents J_{SS} with increasing light intensity, representing increasing injection. The corona characteristics are determined at various settings of the high voltages applied to the wire, ranging from V_H= 6 to 8 kV. The mobility values determined from the above procedure are shown, together with the J_{SS} values, in Fig. 4. Similar results are obtained with many other commercially available OPC drums.

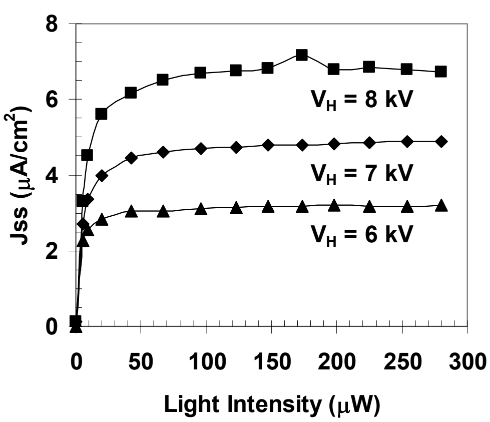

Fig. 3. Steady-state current J_{SS}, measured in a dual layer OPC, versus light intensities at three corona wire high voltage settings V_H.

Discussion and Conclusions

In spite of the large range in the J_{SS} values with different corona settings, the deduced mobility values are in good agreement with one another and with the commonly accepted value, indicating the validity of the technique.

It should be noted that mobility in these charge transport layers is known to be field dependent. Under the space-charge-limited transport condition, the field across the layer is not uniform, and thus the values determined represent an average weighted over the field distribution. In fact, this average mobility is the more meaningful one for practical applications because the photo-induced discharge in laser-exposure (digital) electrophotography proceeds under space-charge-limited condition. Furthermore, in this method the mobility is determined on devices consisting of CGL and CTL. Thus, the effects on mobility from cross contamination and degradation in CTL materials during device fabrication are included and hence, the results represent the true, effective value. Another merit of this technique is the use of the soft-contact of corona charging instead of hard electrodes, achieving the objective of non-destructive and efficient characterization, applicable to large area of finished devices.

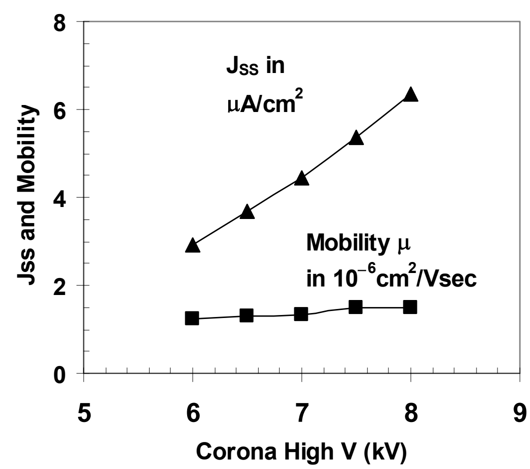

Fig. 4. Measured steady-state current J_{SS}, and the mobility values deduced at five corona wire voltage settings.

References

1. M. K. Tse, D. J. Forrest, and F. Y. Wong, Proc. IS&T's NIP-11, pg. 383 (1995)
2. M. K. Tse and I. Chen, Proc. IS&T's NIP-14, pg. 481 (1998)
3. I. Chen and M. K. Tse, Proc. IS&T's NIP-15, pg.155 (1999)
4. I. Chen and M. K. Tse, Proc. IS&T's NIP-16, pg. 208, (2000)
5. M. K. Tse et al. US patent, 5,929,640 (1999); N. P. Suh and M. K.Tse, US Patent, 4, 443,764 (1984)
6. I. Chen and M. K. Tse, Proc. IS&T's NIP-17, pg. 92, (2001)
7. M. K. Tse, Patents pending, (Quality Engineering Associates, Inc.)
8. I. Chen and M. K. Tse, Proc. IS&T's NIP-15, pg. 486 (1999); also in J. Imag. Sci & Tech. 44, 462 (2000)