Corona Charging Characterization of Organic Photoreceptors

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Abstract

Corona charging of organic photoreceptors (OPCs) has been characterized by measurement of the time-dependent charging current. With this experimental technique, we have investigated the quantity and the dynamics of charging for times greater than the charger time constant (~0.08 s). With a generic near-infrared sensitive OPC, we observe significant depletion of trapped charge during corona charging. The trapped charge sources are light exposure prior to charging, exposure during charging with the corona-emitted light, as well as thermal generation. This methodology provides a means of quantifying these effects and understanding the interactions of the OPC with the charging and exposure systems in an electrophotographic printer.

Introduction

The corona-charging characteristics of organic photoreceptors (OPC) in an electrophotographic printer are sensitive to many factors, including: OPC "type" (visible or near-infrared sensitive charge generation material, layer thickness, architecture), the charger type (AC roller or DC or AC scorotron), charger set points, environment, OPC "history" (number of cycles, amount of wear), etc. All of these factors influence the OPC surface potential attained, and in many cases feedback processes are used to control and stabilize the OPC charging performance in an electrophotographic engine. The effect of light exposure, prior to charging, on dark decay is widely recognized and has been the subject of several papers.[1–3] One study reported on the charging characteristics of a dual-layer OPC with a charge generation layer (CGL) of 1:1 X-form metal-free phthalocyanine in polyvinylbutyral (PVB) (~0.5 μm) and a charge transport layer (CTL) of 50 wt% hydrazone hole transport materials in bisphenol-Z polycarbonate (~10 μm).[3] Among the conclusions of this study were: (1) the initial stages of charging involved carrier extraction from phthalocyanine crystallites (as high as $0.5–1.0 \times 10^{12}$ charges/cm^2); (2) charge carriers were replenished with red light exposure or by keeping the OPC in the dark; (3) changing the CGL pigment to Y-form titanyl phthalocyanine resulted in a tenfold decrease in the extracted charge.

Experimental

The experimental apparatus is entirely enclosed in a light-tight housing. The apparatus comprises a film-sample holder that can be moved along a rail to various stationary components (corona chargers and electrostatic volt meters). The film sample (~2 in. on a side) is held by vacuum to a platen, which is grounded through a Keithly Model 480 picoammeter.

To characterize the corona-charging current, the film sample was positioned in front of a corona charger (3-wire DC grid-controlled scorotron) and charging was initiated. If desired, when the charging was complete, the film sample was moved to an electrometer to determine the surface potential. The corona power supply was a Trek Coratrol Model 610C in constant current mode (–700 μA and approximately –7 kV). The current to the ground layer was measured during corona charging. Thus, we can determine both the amount of charge and its time dependence. To make the charger time constant as short as possible, the charger was positioned near the OPC (~1.5 mm) and the grid was open (~1 mm^2 openings) and relatively distant from the corona wires (~15 mm). In addition, the film sample was sized to completely encompass the grid, and the film conductive layer was grounded by the application of a very small dab of conductive lacquer on two opposite corners. Conductive lacquer on the OPC surface led to an offset current because of the corona charge flowing directly to the ground through the lacquer.

The OPC used in these experiments had a dual-layer architecture with a CTL of polymer, molecularly doped with charge transport material, and a CGL based on a mixture of near-infrared light sensitive phthalocyanine pigments.[4] The substrate was nickelized poly(ethylene terephthalate) (PET). The total OPC thickness was ~24 μm.

The charger output impedance (R_c) was determined by measuring the current flowing to a grounded metal plate as a function of grid potential (V_g). The charger output impedance for a V_g of –500 V is 7×10^8 ohm-cm^2.

Results and Discussion

Figure 1 shows the current-time charging characteristics of a film of bisphenol-A polycarbonate (22 μm) on nickelized PET. The purpose of using this film was to characterize the charging process for a "perfect" insulator. The film was "erased" after charging by being gently wiped with a cloth dampened with isopropanol. The standard charging model predicts a charging current with an initial value of V_g/R_c followed by an exponential decay with a time constant of $\tau = R_c * C_{opc}$, where C_{opc} is the OPC capacitance. The initial current value agrees with the predicted value. The rise time to 50% of the maximum was ~0.005 s. The current decay from the maximum was fit with a double exponential: 0.073 s (93.5%) and 0.379 s (6.5%). The charger RC time constant is calculated to be 0.076 s. Thus, charging is dominated by the expected RC time constant but there is a small decay component that is considerably longer. A reasonable explanation for the longer time decay is that the charging current is not uniform across the film sample. Because the RC time constant varies with corona current, one actually expects a distribution of time constants in this experiment.

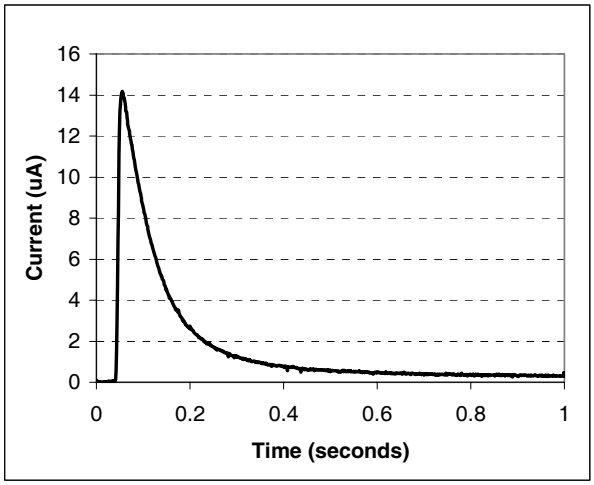

***Figure 1**. Charging current as a function of time for a 22 µm bisphenol-A polycarbonate film with a grid potential (V_g) of –500 V.*

The integrated area under the current-time curve provides a quantitative measure of the amount of charge. The calculated charge (assuming a dielectric constant of 3) is 61 nC/cm^2. In this case, we used the integrated charge to determine the "effective" area of charging as 23.2 cm^2. The actual sample size is approximately 36 cm^2 and the charger opening approximately 20 cm^2.

The near-infrared sensitive OPC was subjected to four sequential charging cycles (V_g –500) in the dark with an 8 min dark rest in between. It was previously determined that 8 min was sufficient to allow the surface potential to decay from –500 V to near zero. The peak currents, and currents at long time, are identical for each charging event but the first charging has extra current at intermediate times. The current-time characteristics of the second, third, and fourth charging cycles are identical. Figure 2 shows the first and fourth charging events and the difference current. Thus, during the first charging cycle, charge trapped in the OPC is depleted and manifests as excess charging current. Because subsequent charging cycles have identical current characteristics, the charge depletion is complete.

The time from the onset of charging to the maximum in the excess current is ~0.07 s. This is essentially the charger time constant and suggests that, in this experiment, the release of trapped carriers is dominated by the charger characteristics.

The current traces of Fig. 2 were integrated. The integrated currents are 83 (cycle 1), 62 (cycle 4), and 22 (difference) nC/cm^2. Because the first charging cycle depletes the OPC of trapped charge, the depleted OPC should have the charging characteristics of a "perfect" insulator. The measured charge (cycle 4) is in good agreement with the calculated value of 61 nC/cm^2. The difference charge represents ~30% excess over the depleted OPC. The depletion charge density is 1.4×10^{11} charges/cm^2. This is approximately the same charge density as reported for an OPC of Y-form titanyl phthalocyanine.[3]

The decay of the charging current for the charge-depleted OPC (cycle 4) was fit to a double exponential: 0.074 s (93.1%) and 0.415 s (6.9%). The rise time of the current to the half-maximum point is ~0.005 s. This is essentially identical to the charging current decay of bisphenol-A polycarbonate. Thus, the OPC, once depleted of trapped charge, has the charging characteristics of an insulating film.

The depletion current decay was fit to a double exponential: 0.092 s (84%) and 0.564 s (16%). Thus, the release of trapped carriers giving rise to the excess current occurs relatively slowly.

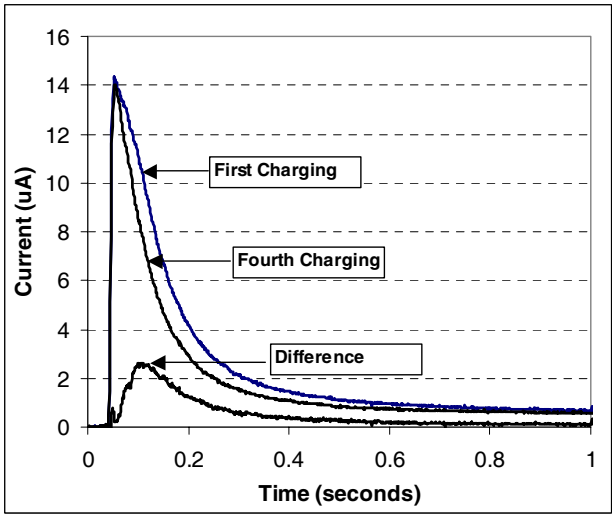

***Figure 2**. Charging current versus time for sequential charging of a near-infrared sensitive OPC. Prior to the first charging cycle, the film was exposed to laboratory lighting; after each charging cycle the film was dark rested for 8 min. The data shown is for the first and fourth charging cycle. Charging cycles 2, 3, and 4 were identical. Also shown is the difference between the first and fourth charging cycle.*

We suspected that one source of the excess current in the first charging cycle was exposure to laboratory lighting during the film loading process. An experiment was carried out to determine the effect of exposure of the uncharged OPC on the excess current. This experiment was a variation of the sequential charging experiment described above with V_g –700 V. The film was loaded and corona charged (first charging cycle). The sample was then allowed to dark decay for 8 min. This was followed by a second charging cycle. The current-time characteristic for this cycle represents the baseline case of a film that has been depleted of trapped charge carriers. After allowing the film to decay for 8 min, the film was given a known exposure (775 nm) and a third charging cycle was performed. The excess current caused by the exposure is the difference between the second and third charging currents. This experiment was repeated varying the exposure time and intensity. The difference currents were integrated and Fig. 3 shows the results. Also shown in this plot are the integrated charge values for the OPC after laboratory light exposure and after depletion. The excess charge depends on the total exposure and not the exposure time, and it increases with exposure to a saturation value that is essentially the same as is observed when the OPC is exposed to laboratory lighting. The

quantum yield of the excess charge (excess charge/cm^2)/(number of absorbed photons/cm^2), is 0.23 for the lowest exposure but rapidly decreases as the exposure increases. The decreasing quantum yield with exposure does not appear to be due to charge recombination as this would be very sensitive to the exposure intensity.

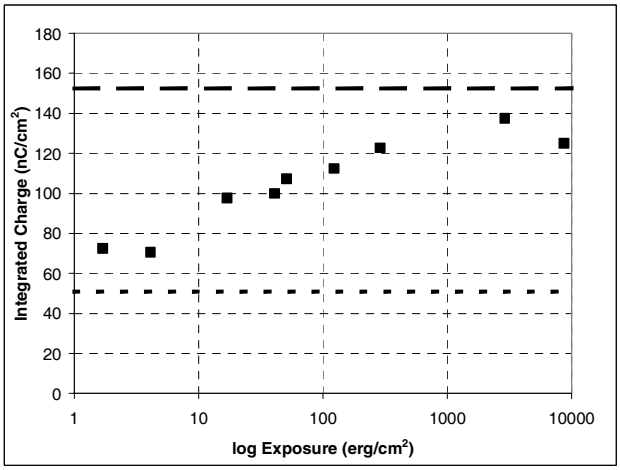

Figure 3. *Integrated charging current as a function of 775 nm exposure (V_g –700). Exposure time (1, 10, 30 s) and light intensity (neutral density filters) were varied. The upper (dashed line) limit is the value obtained after exposure to laboratory lighting (gold fluorescent). The lower (dotted line) limit is the value obtained for the charge-depleted OPC.*

In near-infrared sensitive photoreceptors, it has been reported that charges are thermally generated and trapped in the CGL.[3] Using the photoconductor described above, we determined the excess charge as a function of rest time at ambient and elevated temperatures (71, 91, and 102°F).

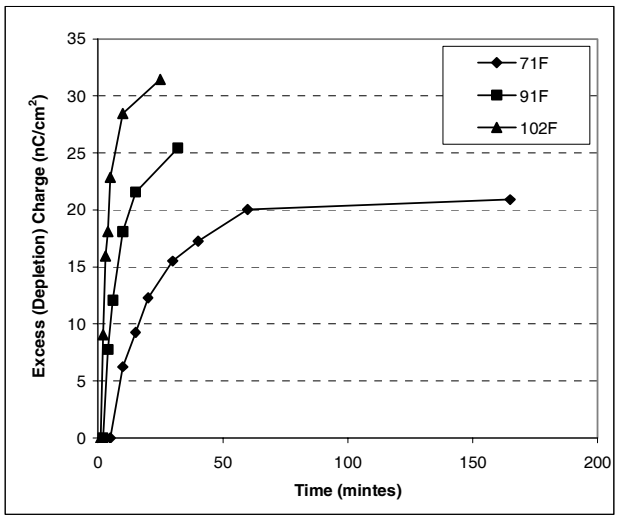

Figure 4. *Excess charge as a function of dark rest time at 71, 91, and 102ºF.*

For the experiment at 71°F, the photoreceptor was loaded (laboratory light exposure) and subjected to a charging–dark-decay cycle to deplete the photoreceptor of trapped charge. The photoreceptor was then recharged after rest times varying from 8 min to 18 hrs. The process was similar for the elevated temperatures except that the rest time was reduced. The results are shown in Fig. 4. At each temperature, there is an increase in excess charge, with time in the dark, to saturation. The saturation values appear to increase with temperature, suggesting that detrapping from deeper centers occurs with increasing temperature. At each temperature, the saturation charge is approximately the same as what is produced with gold fluorescent light exposure, suggesting that thermally and photogenerated charges experience similar trapping processes. The initial charge generation rates were fit to an Arrhenius model with an activation energy of ~1.0 eV (R^2 = 0.984).

The current-time data of the OPC, Fig. 2, exhibit a steady-state offset current at long time that is greater than that observed with bisphenol-A polycarbonate, Fig. 1. In subsequent experiments with bisphenol-A polycarbonate, the offset current was found to be near zero. The OPC steady-state offset current increases with increasing corona voltage, as shown in Fig. 5.

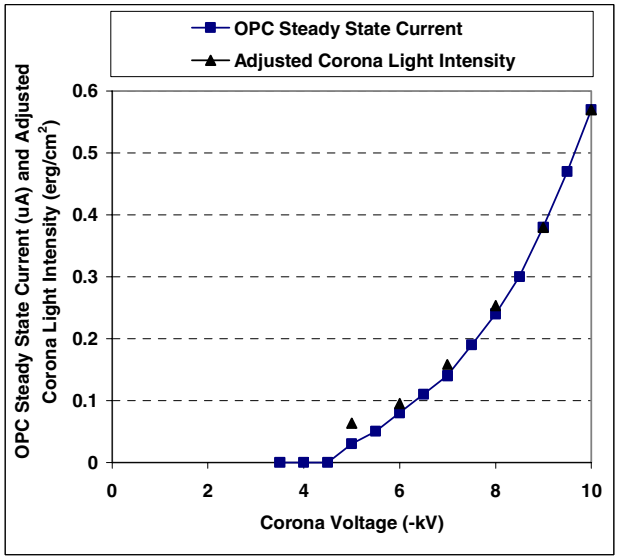

Figure 5. *OPC steady-state current during charging, and the intensity of light emitted by the corona charger, as a function of corona voltage. The light intensity was determined by discharging the OPC with light from the corona using the known photosensitivity for a 775 nm exposure. The light intensity at –10 kV was normalized to the OPC current value at –10 kV.*

An experiment was carried out to determine if exposure of the OPC to light generated in the corona was the cause of the steady-state offset current. Light emission from an air corona is primarily from excited nitrogen and is mostly ultraviolet with a small visible component.[5] We used the OPC photodischarge characteristics at 775 nm to estimate the intensity of the light from the corona as a function of corona voltage. The film sample was moved at a constant velocity past two corona

chargers to a voltmeter. The grid of the second charger was covered with a quartz plate to block the corona ions but allow the light to pass. The first corona charger was adjusted to obtain a surface potential of –500 V at the voltmeter with the second corona charger turned off. The experiment was repeated with the second corona charger turned on with varying corona voltage. The decrease in the OPC surface potential resulting from light exposure from the second charger was converted into a 775 nm exposure (erg/cm^2) using the known OPC photodischarge characteristics. Figure 5 is a plot of the measured offset current, and adjusted corona light exposure, as a function of corona potential. The exposure was normalized to match the value of the offset current at –10 kV. The observation that the offset current and the corona exposure have essentially identical dependences on corona potential strongly suggests that the steady-state offset current is caused by corona light exposure of the OPC.

Conclusions

Trapped charge in a near-infrared sensitive OPC has a large effect on its corona charging characteristics. Our studies of the charging currents have identified the following sources of trapped charge:

- Exposure of the uncharged OPC to light.
- Thermal (dark) charge generation.

Exposure of the OPC to light from the corona during charging produces a small steady state charging current.

References

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Author Biography

David S. Weiss is a Scientist Fellow at Eastman Kodak Company. He received his Ph.D. in Chemistry from Columbia University in 1969. His work focuses on electrophotographic technologies with emphasis on organic photoreceptors. He holds 17 U.S. patents and is author on more than 90 publications. He is co-author of Organic Photoreceptors for Imaging Systems *(Marcel Dekker, Inc., 1993),* Organic Photoreceptors for Xerography *(Marcel Dekker, Inc., 1998) and co-editor of the* Handbook of Imaging Materials, Second Edition *(Marcel Dekker, Inc., 2002). His IS&T activities include Associate Editor of the Journal of Imaging Science and Technology since 1988, NIP17 General Chair, and election to the position of IS&T vice president in 2006. In 1999, he received the Carlson Memorial Award and, in 2004, was named a Senior Member of the IS&T.*