Particle Removal with High Electric Fields and Repeated Bombardment

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Abstract

By placing a thin wire near a coated conducting substrate one can generate high electric fields approaching 30 V/μm. These high electric fields can be used to detach toners from a donor roll in a development nip which can subsequently be developed with smaller electric fields from a latent image. Toners typically have large variations in shape, size, and charge, and thus adhesion. A DC voltage on the wire removes only a small proportion of the particles. If alternatively positive and negative voltages are applied to the wire, the particles removed during the attractive part of the pulse are pushed back to the substrate when the voltage flips. The particle impacts loosen up the remaining particles and the next voltage flip removes more particles. By photographing the area under the wire with a digital camera, we can determine the mass removed as a function of distance from the wire. We use this information to monitor the fraction of particles remove as a function of voltage, frequency, number of particles on the substrate and number of pulses in order to extract the physics of the bombardment process. We find that bombardment can completely remove all particles from the substrate, even when a small fraction are initially removed.

Introduction

In single component development, the toner is charged and transported to the development nip on a donor roll.[1,2] An image develops when the charged toner contacts an oppositely charged area on the photoreceptor.

The image quality depends on the precision with which the toners are attracted to the photoreceptor latent image. If the toner charge and size is uniform, the development subsystem is gentle, the toner supply large, and development time sufficient, the toner will neutralize the latent image and give a high quality developed image. If any of these conditions are not met, the developed image can degrade.

Toner transport across a nip has been studied both experimentally and theoretically. Cloud visualization can look microscopically at the toner flow in the development nip region.[3] By using different imaging tricks, one can experimentally measure the density of toner during the development process, and the structure of the toner as it develops solids and fine lines. The experimental technique is limited, however, and different modeling approaches have been developed to study the toner transport process in more detail. Particle in cell techniques simulate the microscopic forces between a large number of toner particles under the geometrical constraints of development.[4] Hydrodynamic techniques replace the toners with a continuum and study the flow of mass and charge.[5] Both techniques are able to relate physical quantities, such as developed line structure, to the material, geometric, and electrical properties of the development subsystem.

The supply of toner available for development depends in part on the toner adhesion to the donor roll. Various experimental techniques have been developed to study toner particle adhesion and its dependence on the toner and substrate properties.[6,7] Atomic force microscopy can explore in great detail the physics of the adhesion of single toners.[8] Centrifugal detachment can measure the interac-tions between the adhesion of individual charged particles.[9] Electric field detachment simulates the development process with the ability to monitor the toner adhesion distribution as the toners undergo development.[10]

The toner can be removed from the donor with a combination of mechanical and/or electrostatic means. For example, some development processes apply a large AC voltage between the donor and receiver. For large AC voltage amplitudes, the toner will be selectively attracted and repelled from the receiving surface and may move back and forth across the nip before it ultimately develops. The repeated bombardment of the donor from the developing toner may aid in particle removal and increase development efficiency.

In this paper, we use a technique we call toner extraction to explore the increased efficiency AC electric fields have on removing the toner. Specifically, particles are released not only by the strong electric fields, but also mechanically as previously released toners fall back to the donor roll and bombard the remaining toners. We quantify the toner release as a function of the number of bombardments as well as the electric field structure that causes the toner release.

Experimental Technique

In our experimental technique of toner extraction, we directly monitor the process of removal of toner from the donor. We coat the donor with a uniform layer of toner as is done in single component development. A bare metallic receiver is placed in close proximity to the donor. The tendency of toner to move from the donor to the receiver is controlled with a bias applied between the donor and the receiver.

A thin wire is suspended just above the donor roll and runs across the length of the donor roll. The wire serves as a means to provide high electric fields at the donor surface that are strong enough to remove toner from the donor roll.

To initiate the removal of toner, a burst of high voltage pulses is applied to the wire. For voltages on the order of hundreds of volts at the spacings involved, electric fields over 10 volts/μm can occur at the surface of the donor roll. These fields alternatively attract and repel toner, causing it to be removed from and then reattached to the surface.

After this burst, the donor surface is rotated to under the video camera and imaged. This experimental setup is shown in figure 1.

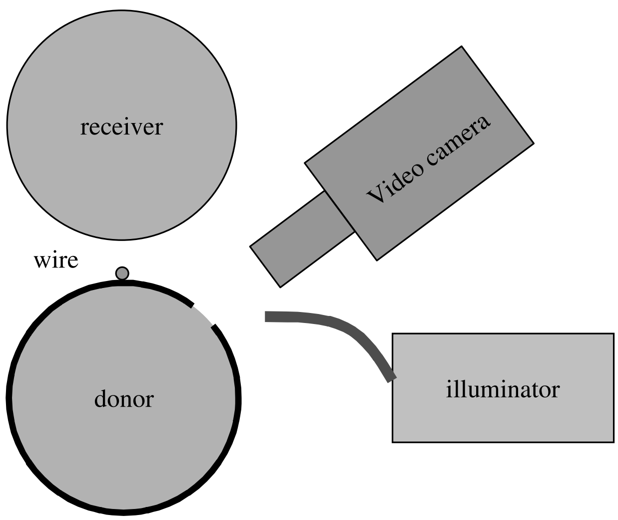

Figure 1. Toner extraction apparatus

Calibration

A typical image of the donor roll after a series of pulses is applied is shown in figure 2. The image is illuminated at approximately 45 degrees and observed normally. In our experiments, we used magenta toner on a black donor roll and the contrast is provided by monitoring the red channel of the camera.

To make a quantitative link to models and fixture experiments, we need to measure the mass of toner removed as a function of position. In order to obtain this quantity, we calibrated the surface reflection as a function of area coverage. We image the surface at different area coverages of toner. At each area coverage, we calculate the average camera response. We also determine the mass per unit area by vacuuming off a known area of the roll and weighing the sample.

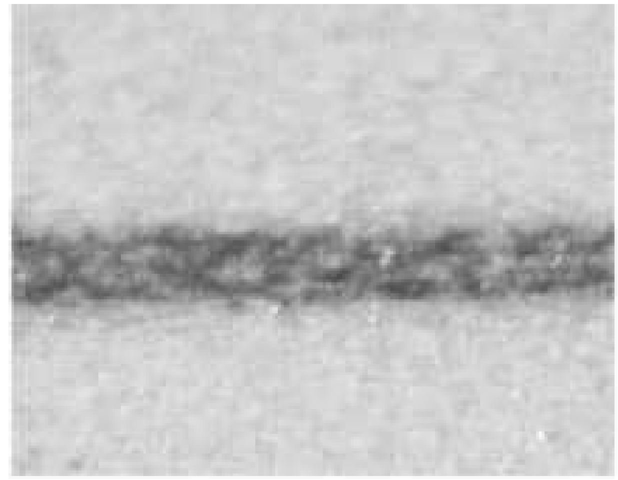

Figure 2. Image of extracted toner. Vertical distance is approximately 400 μm.

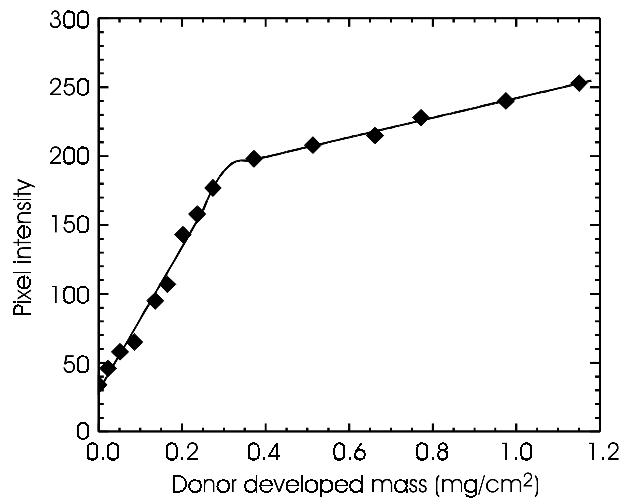

Figure 3. Camera mass calibration

Figure 3 plots the average intensity vs. the developed mass. At low area coverages the intensity increases linearly with the mass, and then the curve bends over and there is another linear increase, but with a smaller slope. This behavior is typical of reflectivity vs. mass curves. The transition occurs at the point where a second monolayer begins to build up. We use this calibration to convert our observation of thinner toner layers to mass density removed.

Dependence on the Number of Applied Pulses

The magnitude of the electric field at the donor surface decreases as a function of distance from the wire. We therefore expect the efficiency of toner removal to also decrease. When the high voltage on the wire is reversed, some of the toner may return to the substrate. This returning toner may hit adhered toner and make it easier to remove with another pulse.

In figure 4 we show a cross section through the extracted toner region taken for a different number of pulses applied to the wire. Each profile was obtained independently.

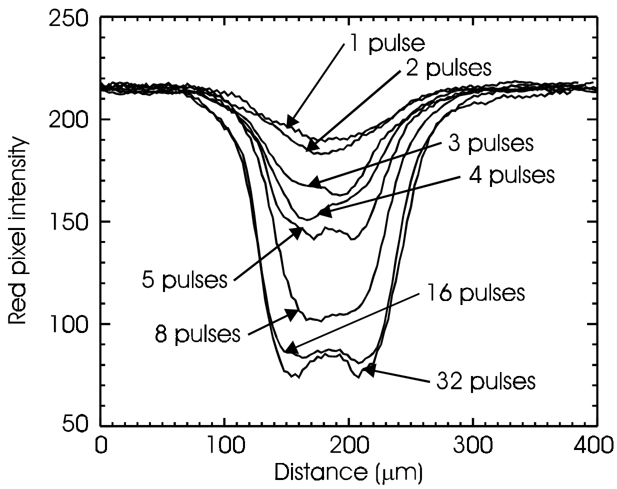

Figure 4. Extracted toner profiles

A number of trends can be observed. The more pulses applied, the more toner is removed. Also, the dependence of the amount of toner removed as a function of distance from the wire changes slowly, not abruptly. This is probably due to the large variations in adhesion of each toner to the surface due to the size, shape, and charge variations. Electric field detachment also shows large adhesion variations for the same toner used in these experiments.[10] In addition, the extraction width is roughly independent of the number of pulses. That is, more toner is extracted from the same area rather than from more remote regions with additional pulses. At 32 pulses there is complete toner removal.

In figure 5 we plot the total mass of toner removed from under the wire as a function of the number of pulses for different development voltages. The mass removed was determined by measuring the reflectance where the toner was removed, converting the reflectance to mass, and integrating over the region of toner removal. The data shows that the amount of toner removal is roughly linear with the number of pulses and then saturates. There seems to be no strong dependence on the mass removed and the development voltage. This indicates that the strong fields near the wire must dominate the removal process. Also, the linear part of the curve at the low number of pulses does not intersect the y axis at zero. This indicates that a large amount of toner is removed with the first pulse and smaller amounts are removed as avalanching occurs.

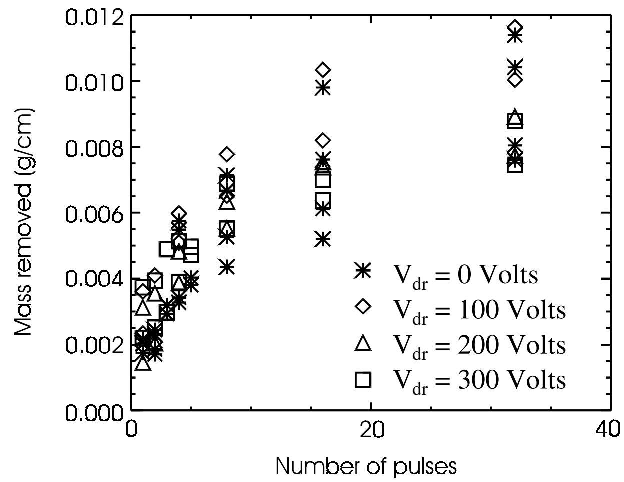

Figure 5. Mass extracted vs. number of pulses

Dependence on Duty Cycle and Frequency

The results of the last sections help identify the way toner is pulled from the donor by the wire. However, these experiments do not address over what time scale the toner is removed. This can be explored by looking at the duty cycle dependence of the burst of high voltage pulses.

In figure 6, we show the mass of toner removed as a function of the frequency and duty cycle of a burst of 8 pulses. For the higher two frequency bursts, the high voltage power supply cannot respond quickly and the true voltage applied is lower, resulting in a small amount of toner removed. If one ignores these points, then the data shows that the mass removed varies from around 0.006 g/cm at a 20% duty cycle to around 0.010 g/cm at a 80% duty cycles. The scatter about these values is significant, but smaller than the trend. The y-axis intercept of a straight line fit to the mass extracted is nonzero. This means that most of the toner is removed immediately when the high voltage signal is applied to the wire.

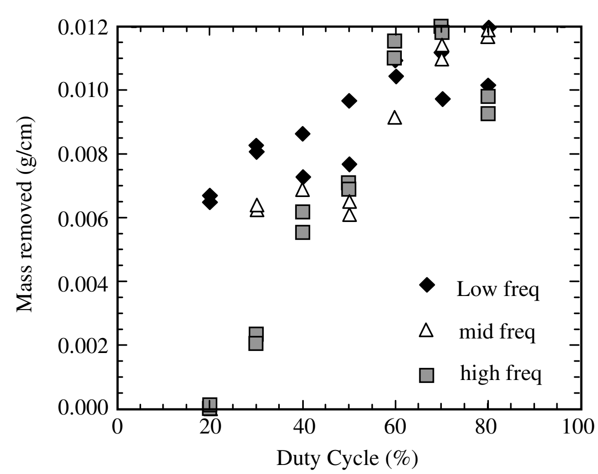

Figure 6. Duty cycle dependence of toner extraction

As the duty cycle changes, the average voltage on the wire and thus the average nip electric fields change. We believe that this is the source of the duty cycle dependence rather than the additional time the positive wire voltage is on. An experiment to test this would be to adjust the amplitude of the negative wire voltage to obtain a consistent average wire voltage, independent of the duty cycle.

Test for Avalanching

A single wire pulse is insufficient to remove all the toner near the wire. One can propose two competing theories, avalanching and space charge, of why the toner removal increases with the number of pulses.

In avalanching, the first pulse removes the weakly adhering toner. On the next cycle, this toner hits the donor roll and can dislodge the even more strongly adhering toner. On the third pulse there is even more toner available to dislodge toner and the amount removed keeps increasing.

For the space charge hypothesis, toner begins to left up from the donor during the first pulse. However, the charge on the removed toner repels somewhat slower toners that haven't left the roll yet. Eventually enough toners lift up to prevent the removal of subsequent toner. As some of these develop out, more toners can lift up some more toners with the second and subsequent pulses.

Toner extraction can experimentally test these hypotheses. Each has a different prediction of the donor roll coverage dependence of toner extraction. Avalanching should show a strong coverage dependence. At low coverages, the odds of the released toner coming back down and hitting another toner is reduced. The total mass removed as a function of the number of pulses should decrease with the donor coverage. On the other hand, the amount of toner removed with each pulse should be independent of the coverage if space charge is limiting the removal.

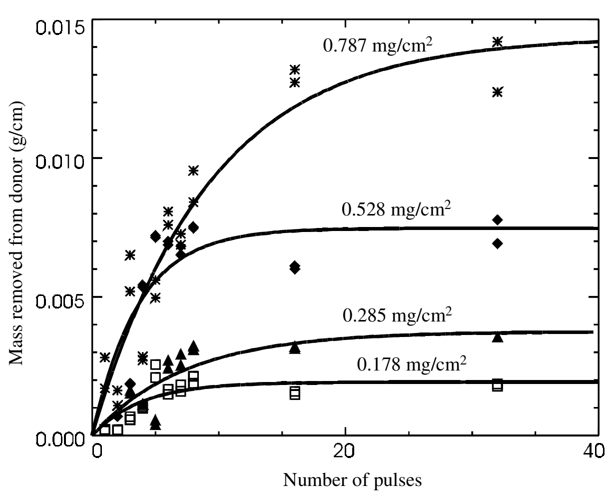

Figure 7. Test of avalanching

We measured the toner extraction as a function of the number of pulses at 4 donor roll coverages. In figure 7 we plot the mass removed vs. the number of pulses applied for the 4 donor roll coverages. The data is shown with the symbols, and the lines show a least squares fit of the function $m=a+b(1-\exp(-cp))$ to the data, where m is the mass removed, p is the number of pulses, and a, b, and c are fitting constants. The data shows clearly that the slope of these lines increase as the donor coverage increases and is evidence that the avalanching theory is correct.

Conclusions

The adhesion of toner to the donor roll is an important factor in making high quality single component development systems. Experimental techniques have previously been developed to measure this adhesion independent of the development process. We describe a variety of experiments that have been used to study particle adhesion as it occurs in the development process. These techniques have been used to gain insight into the development process, test alternative hypotheses of development, and provide parameters to models of single component development.

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Biography

Howard Mizes received his B.S. degree in Physics from the University of California at Los Angeles in 1983 and a Ph.D. in Applied Physics from Stanford University in 1988. Since 1988 he has worked in the Wilson Center for Research and Technology at Xerox Corporation in Webster, NY. His work has primarily focused on the development process, including toner adhesion, toner transport and image quality issues. He is a member of the IS&T and the American Physical Society. **e-mail: hmizes@crt.xerox.com**