Electrical Characterization of Rollers & Belts for High Speed Electrophotography

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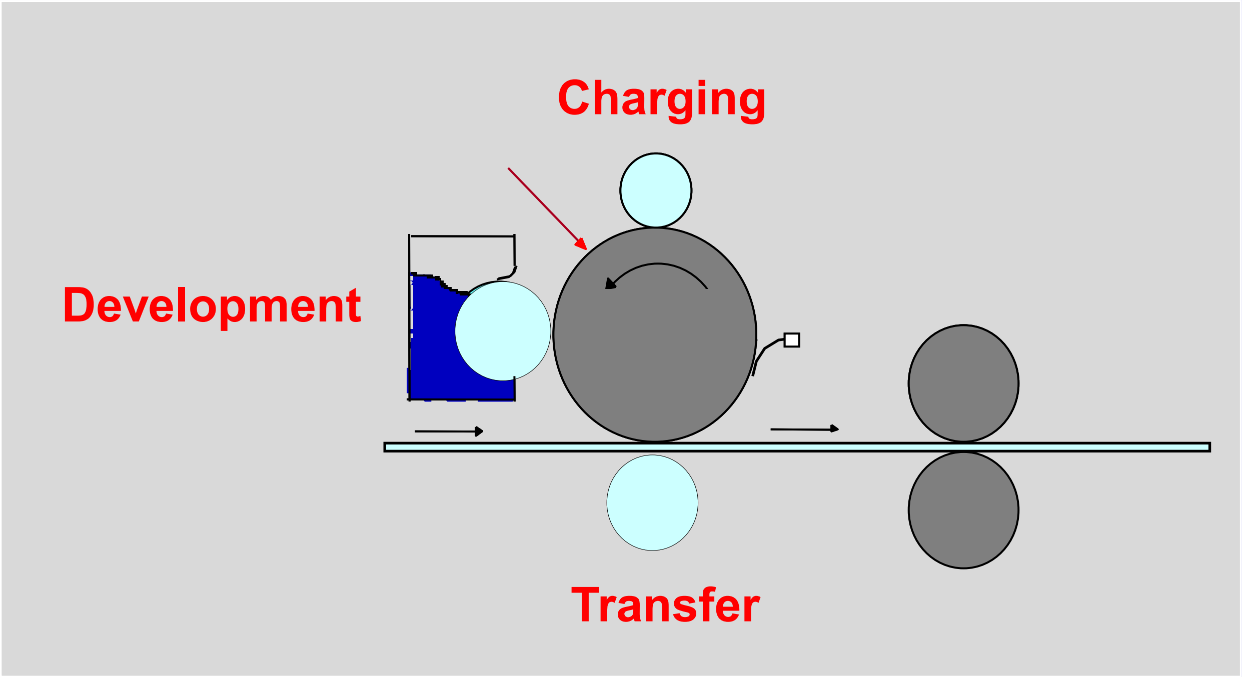
Dielectric Relaxation of Rollers & Belts is Critical to the Performance of Charging, Development & Transfer



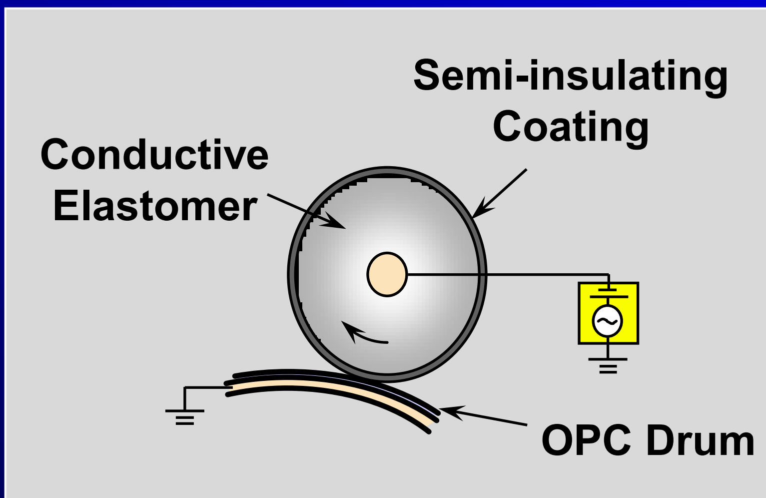
Characterizing the efficiency of dielectric relaxation in each device is the key to predict its performance!

Highlights

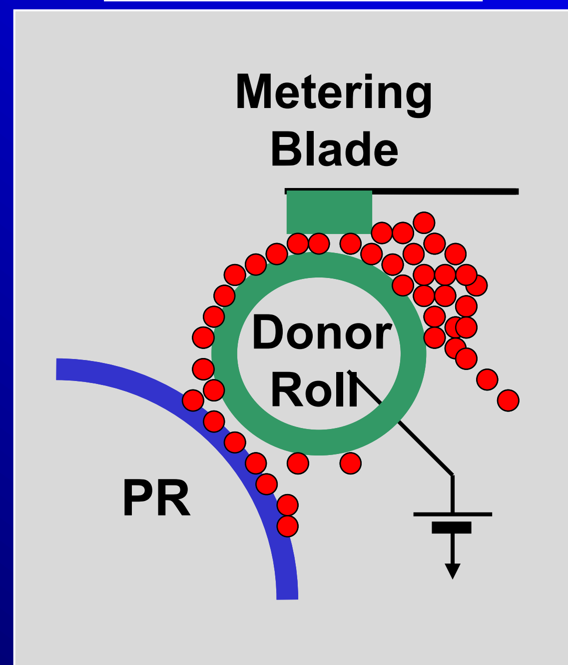
- **Efficient dielectric relaxation is critical to the performance of rollers and belts used in electrophotography.**
- **Dielectric relaxation can be measured by the ECD (Electrostatic Charge Decay) method implemented in the QEA DRA-2000L system.**
- **The ECD principle of the DRA-2000L simulates the physics of the charging, development and transfer processes, resulting in measurements that correlate very well with device performance.**
- **Traditional resistance measurement method is neither consistent nor useful for predicting device performance.**

Why Dielectric Relaxation is Important?

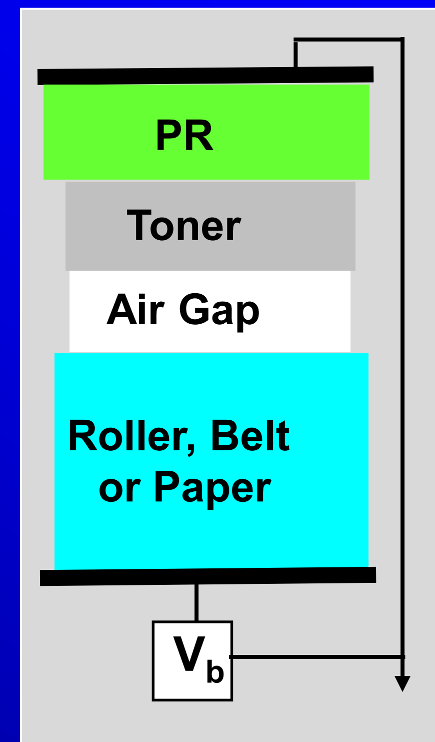
Charging



Development



Transfer Media

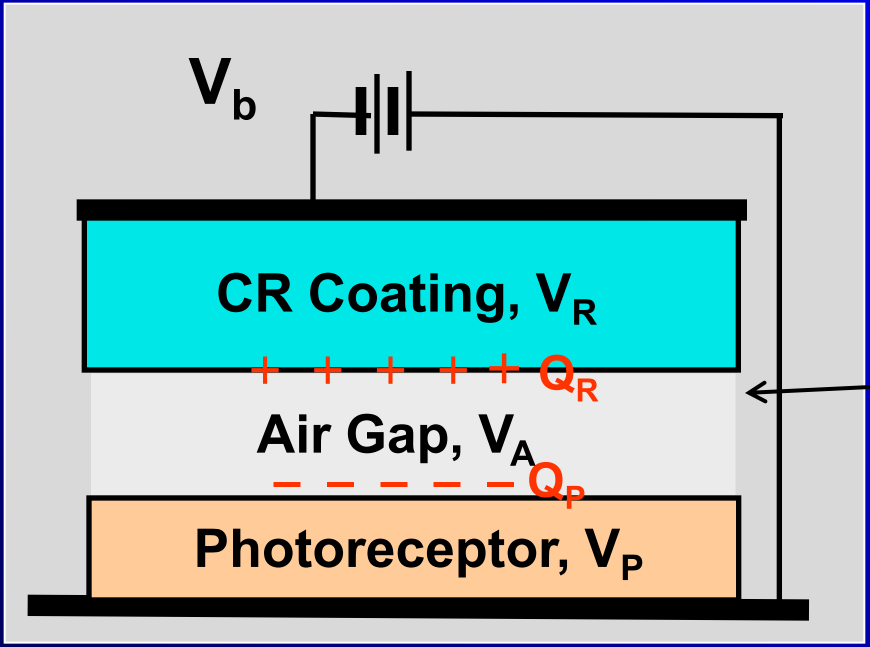


Need to understand the process physics

QEA Publications on Characterization of Semi-insulating Devices in Electrophotography

Year	Conference	Subject
1999	JHC	ECD method for semi-insulators
1999	NIP15	Modeling of electrostatic transfer
2000	NIP16	Transfer media
2001	NIP17	Corona charging current
2002	ICIS	Charge mobility measurement
2004	NIP20	Transfer of color images
2005	JHC	Semi-insulating devices
2005	NIP21	Roller charging of photoreceptor
2006	ICIS	Media non-uniformity issues
2006	NIP22	Counter charge in development rollers
2008	PPIC	Aging of donor rolls
2008	NIP24	Characterization for high speed EP

Dielectric Relaxation in CR Charging



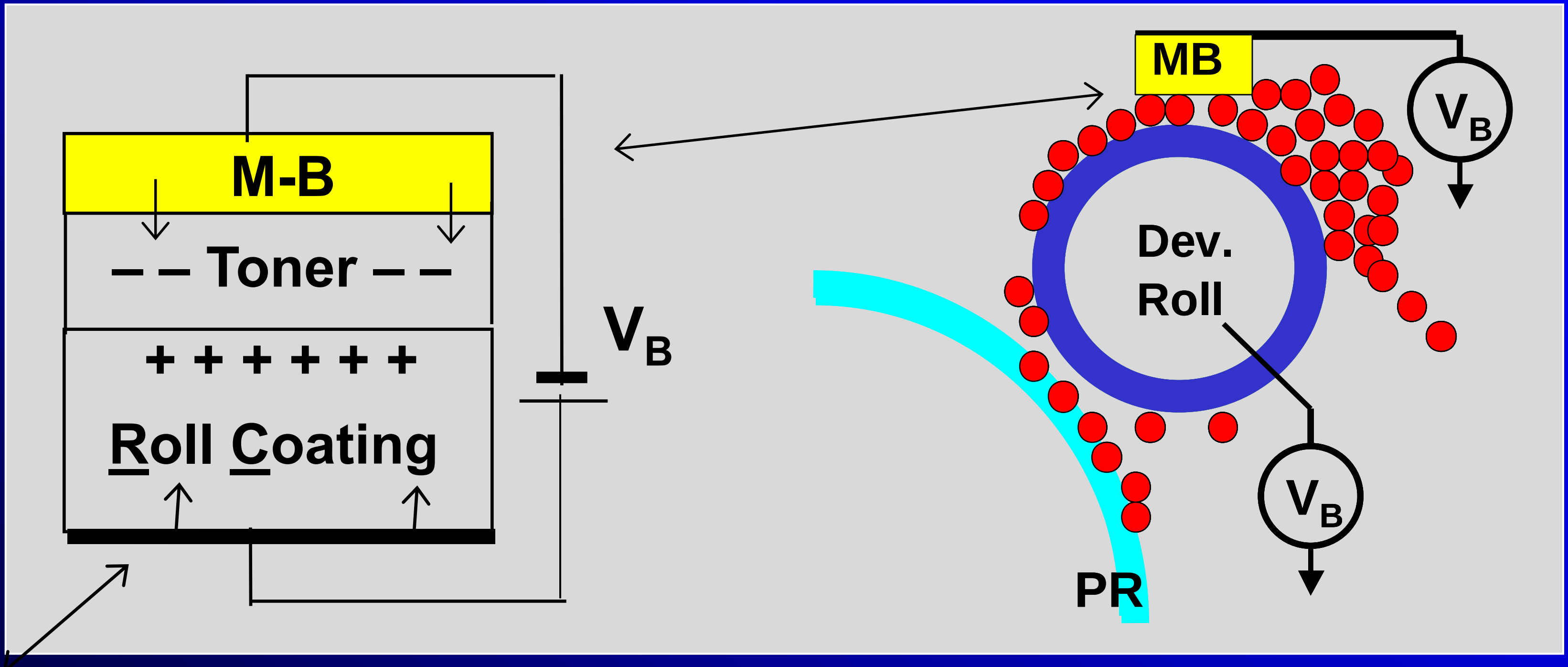
- Roll coating voltage, $V_R \Downarrow$
- Air gap voltage, $V_A \Uparrow$
- V_A > Paschen threshold
- PR surface charged, Q_P

A qualitative description:

- Counter-charge Q_R on Roll
- Air-gap voltage, $V_A \Downarrow$
- V_A < Paschen threshold
- PR charging stops
- To continue charging, Q_R must be neutralized to $\Downarrow V_R$ and $\Uparrow V_A$
- *Dielectric relaxation* in roll coating important for high charging efficiency

Toner Charging in Single Component Development

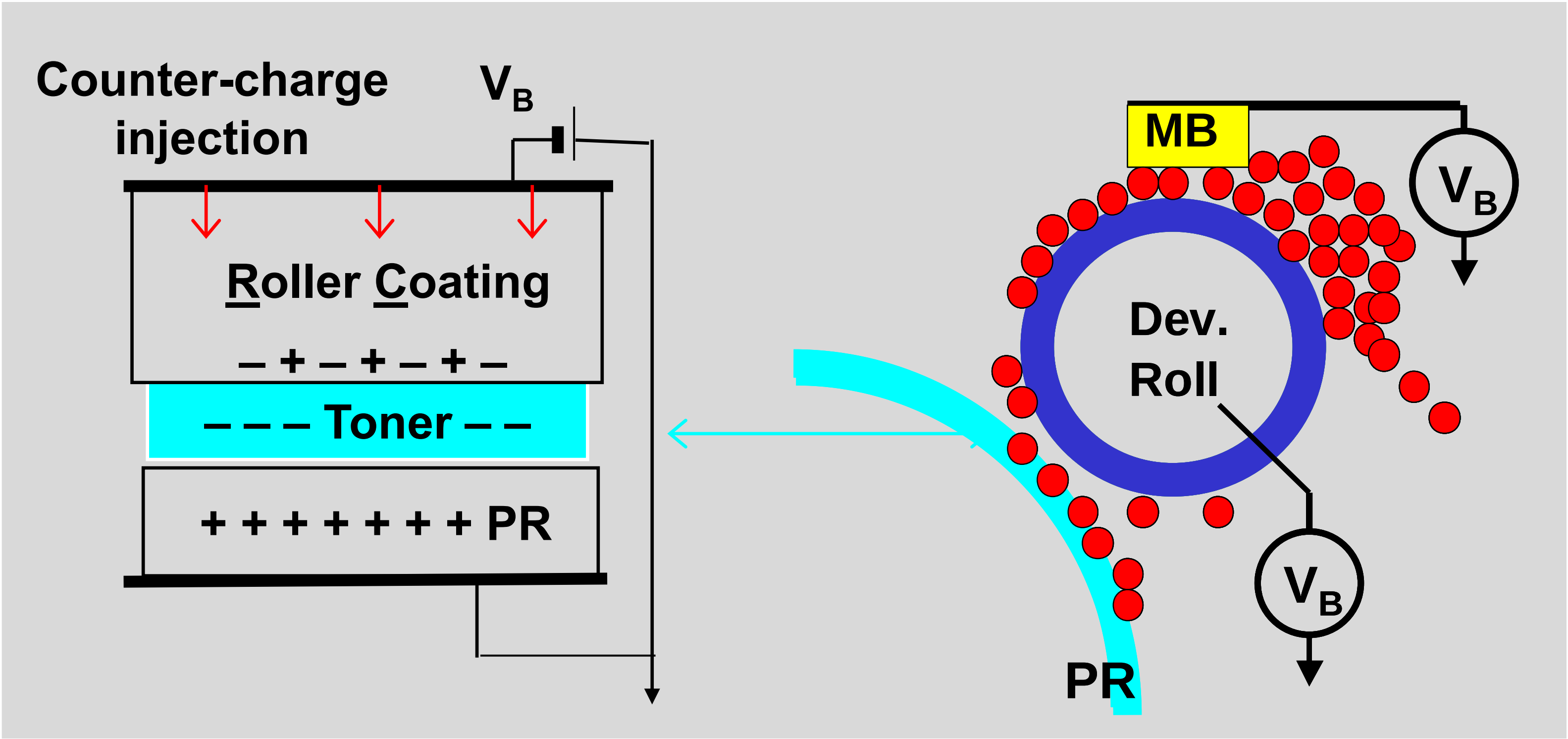
- Donor Roll = Conductive Core + Semi-ins. Overcoat
- Toner Charging (–) at Metering Blade (M-B)



- Counter-charge (+) injection from V_B
- V_{RC} decays, dielectric relaxation of roller coating

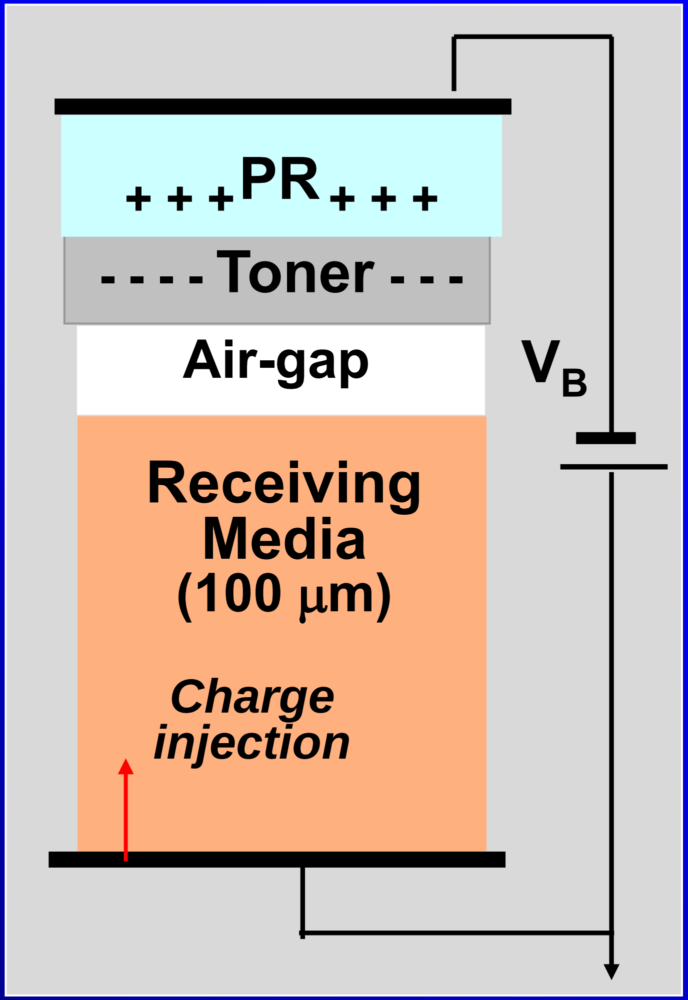
Toner Deposition in Single Component Development

- Toner Deposition on Photoreceptor (PR)
- Counter-charge (–) injection from V_B to Coating
- Dielectric Relaxation of Roll Coating layer



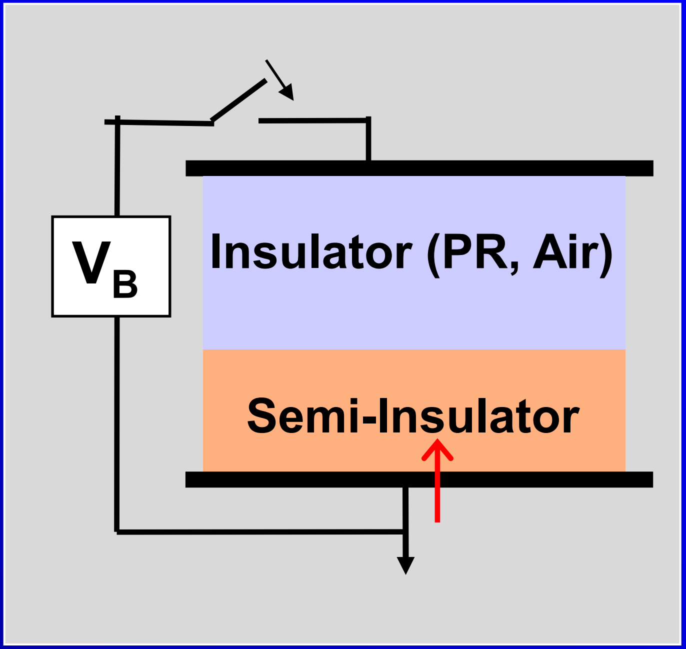
Electrostatic Transfer of Developed Toner

- In transfer, a bias voltage V_B is applied to the multiple layers in the transfer nip
- V_B reverses the field in the toner layer to drive the toner towards the receiving media
- The semi-insulating receiving media (i.e., paper, belt) is typically much thicker than the other layers (see figure)
- *Dielectric Relaxation* in receiving media
  - Shifts most of V_B to the toner layer
  - Enables efficient transfer (without very high bias voltages)
  - Dielectric relaxation is due mostly to *charge injection* into the receiving media (not due to intrinsic charge carriers or conductivity in the media)

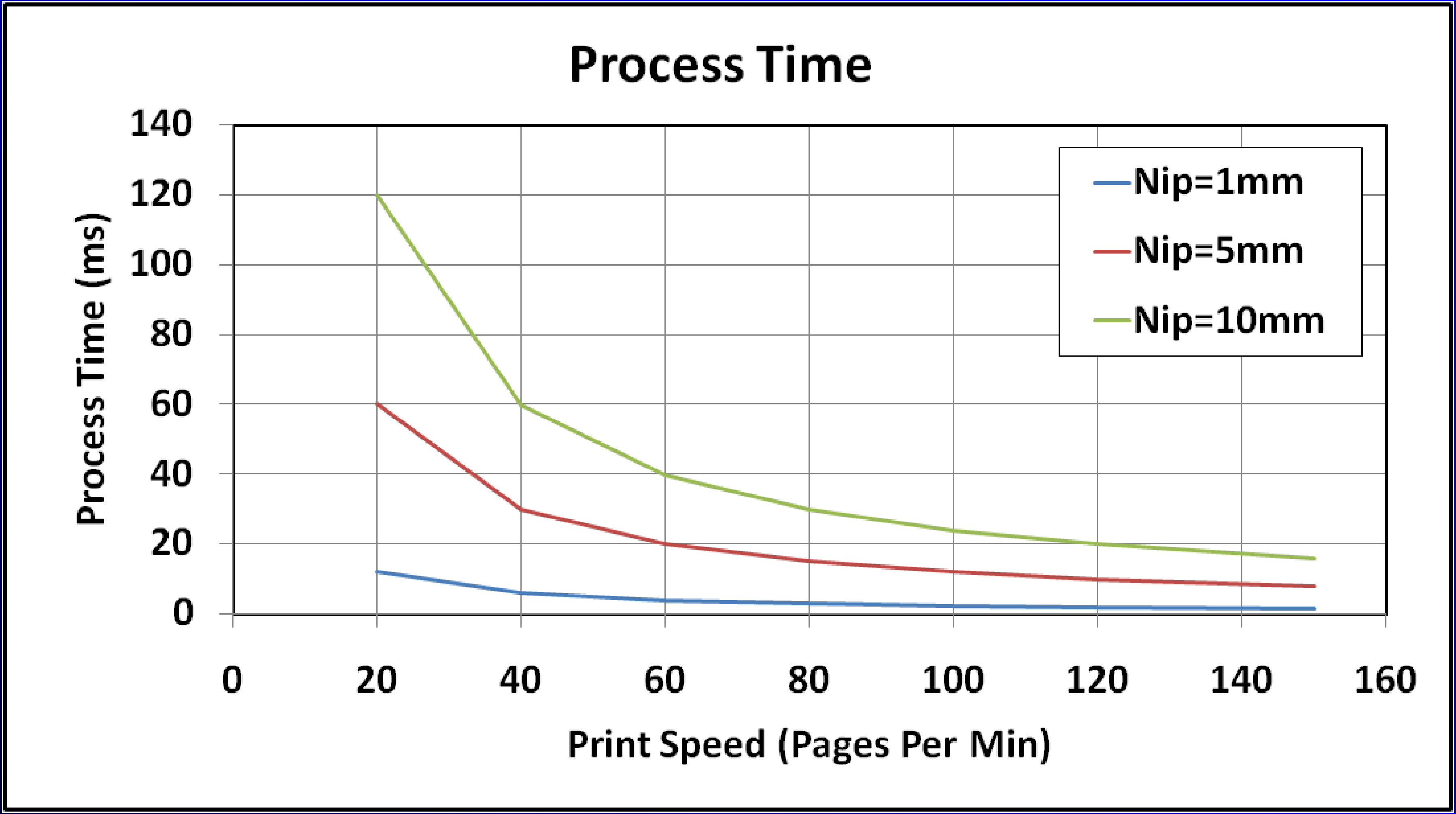


Common Configuration in Semi-insulating Devices & Implications on Characterization Method

- V_B applied to insulator & semi-insulator (charge roller, development roller or transfer roller/belt) in series
- Voltage across semi-insulator decays with time → *Dielectric Relaxation*
- Low intrinsic charge density
- Need charge injection
- Performance of process closely related to efficiency of dielectric relaxation, charge injection and transport
- Due to the complexity in the charge transport processes in dielectric relaxation – **best characterize by a test method that simulates actual device!**

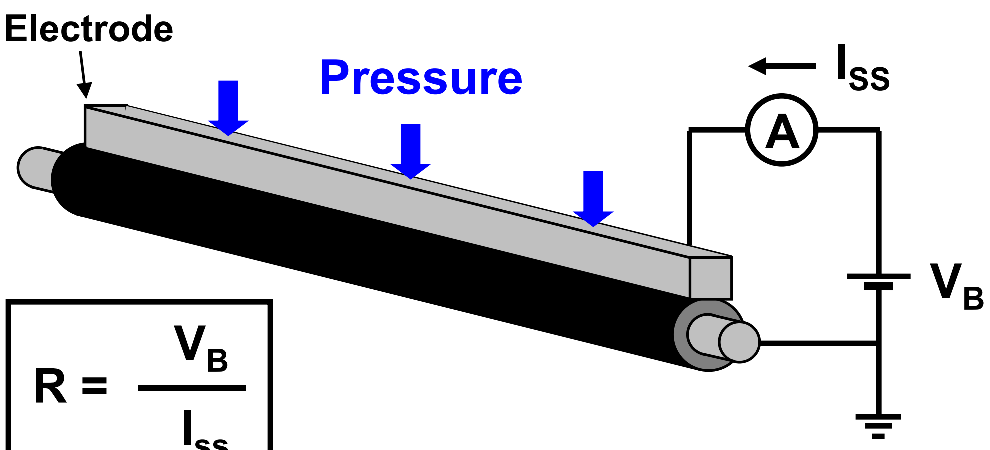


Process Time

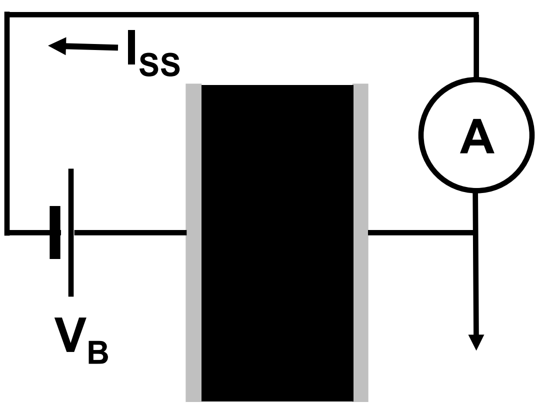


Conventional Roller & Belt Characterization Method

- DC bias voltage is applied between an electrode in contact with the charge roller and the roller shaft. The current flow through the roller I_{SS} is measured, typically at "steady state".
- The roller resistance is the ratio of the applied V_B to the measured I_{SS}.



$$R = \frac{V_B}{I_{ss}}$$



A "Close-circuit" Method

Limitations of Conventional Resistance Method

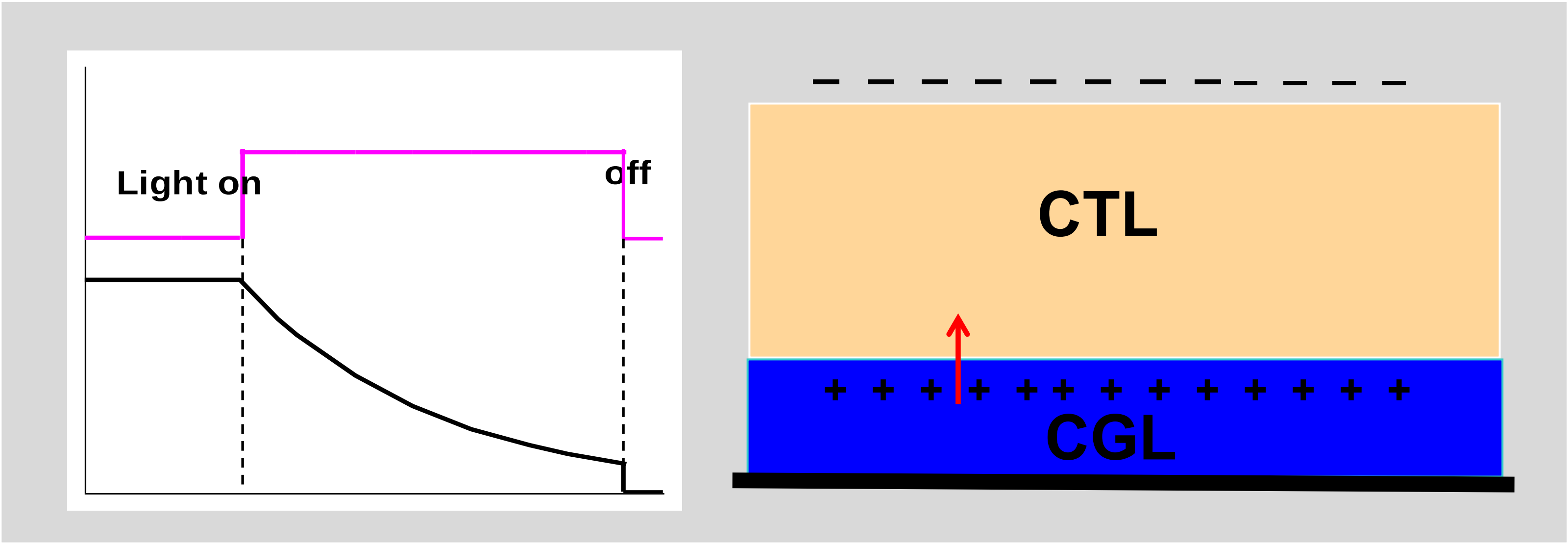
- Most serious is that the underlying physics is not consistent with the process physics:
  - Ohmic relaxation model does not apply
  - Semi-insulator to electrode contact is non-ohmic
  - Test configuration does not simulate process configuration - no way to duplicate charge transport physics crucial to process performance (e.g., electric field dependence)
  - Measurement time scale is wrong
- Practical issues:
  - Contact pressure dependence
  - No mapping capability
- Results do not reliably or consistently predict performance

Ohmic vs Non-Ohmic Contact

- "Ohmic" contacts:
  Supply charge to maintain $q = q_i$ (intrinsic charge density) in sample
  Current density: $J = \sigma E_o = \mu q_i E_o$ (E_o = applied field)
- "Non-Ohmic" contacts:
  Supply more or less charge (injection)
  Charge density $q(x, t) \neq q_i$; $E(x, t) \neq E_o$; $J \neq \sigma E$
- Semi-insulating devices are typically Non-ohmic.
  Injection at interface is key to the relaxation process.
- Conductivity, σ : not a good figure of merit!

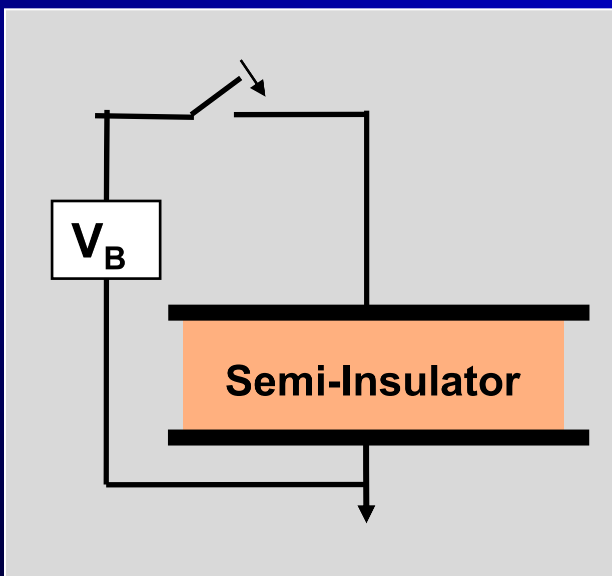
An Example of the Role of Injection – Photo-induced Discharge in Photoreceptor

- In the dark: an insulator with high resistivity with long dielectric relaxation time τ
- Exposed to light: charges photo-generated in CGL; charge injection into CTL $\rightarrow$ Voltage decreases $\rightarrow$ Photo-induced Dielectric Relaxation

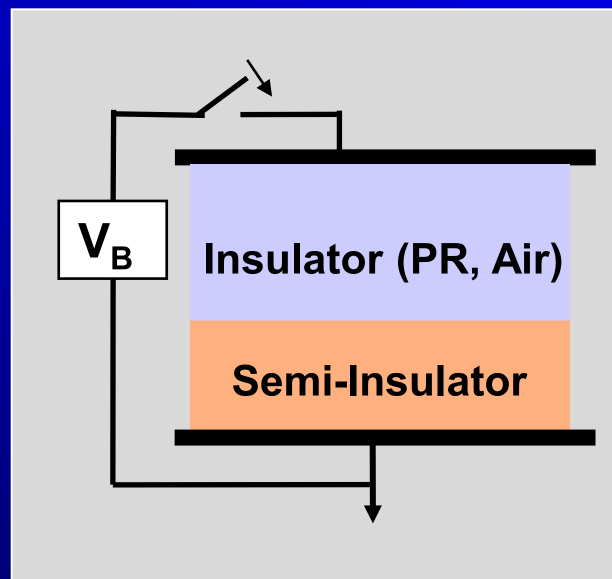


"Open-Circuit" Method is Preferred to Simulate Actual Device Configuration

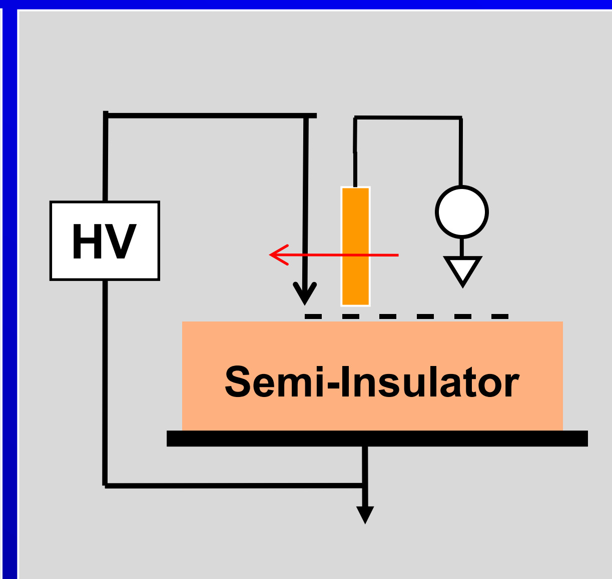
Traditional Method In Closed Circuit	Semi-insulating Devices in "Open" Circuit	DRA-2000L ECD Method In "Open" Circuit



Traditional Resistance Measurement



Actual Device Configuration



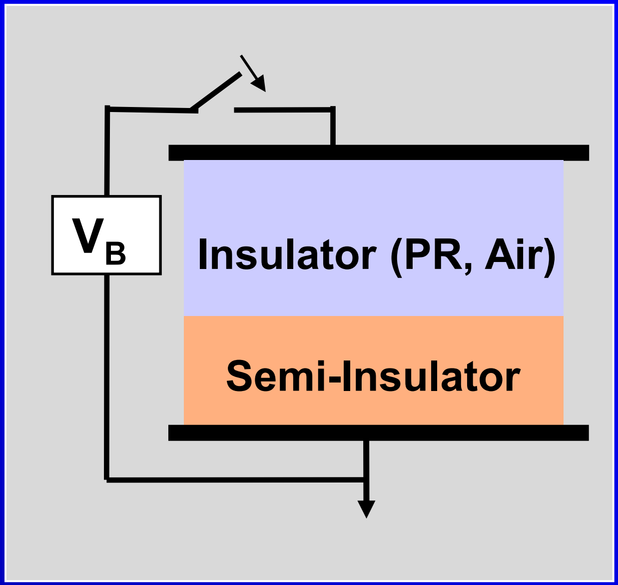
Preferred ECD Method

Charge Transport Model of Dielectric Relaxation (1)

- **Samples characterized by:**
  - **Charge densities: $q_p(x,t)$, $q_n(x,t)$**
  - **Charge mobility: μ_p, μ_n**
- **Charge Continuity:**

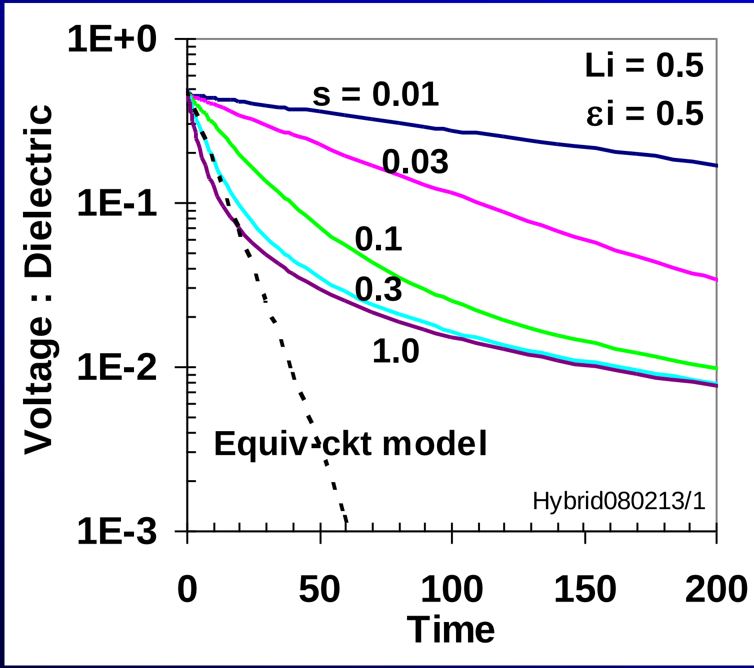
  $\partial q(y, t)/\partial t = -\partial(\mu q E)/\partial y$
- **Boundary conditions:**
  - **Injection current at y = 0**

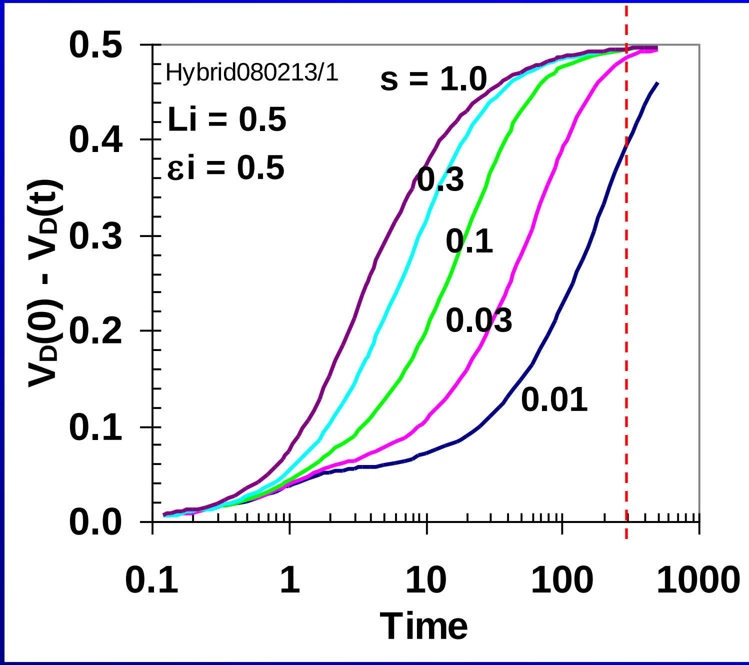
  $J(0, t) = sE(0, t)$, *s = Injection strength*
  - **Interface charge: $Q_L = \varepsilon_I E_I - \varepsilon_D E_D(L)$ *(Gauss' theorem)***
  - **Bias $V_B = V_D + V_I$ *(constant in time)***
- **Solved by Numerical iterations**



Charge Transport Model of Dielectric Relaxation (2)

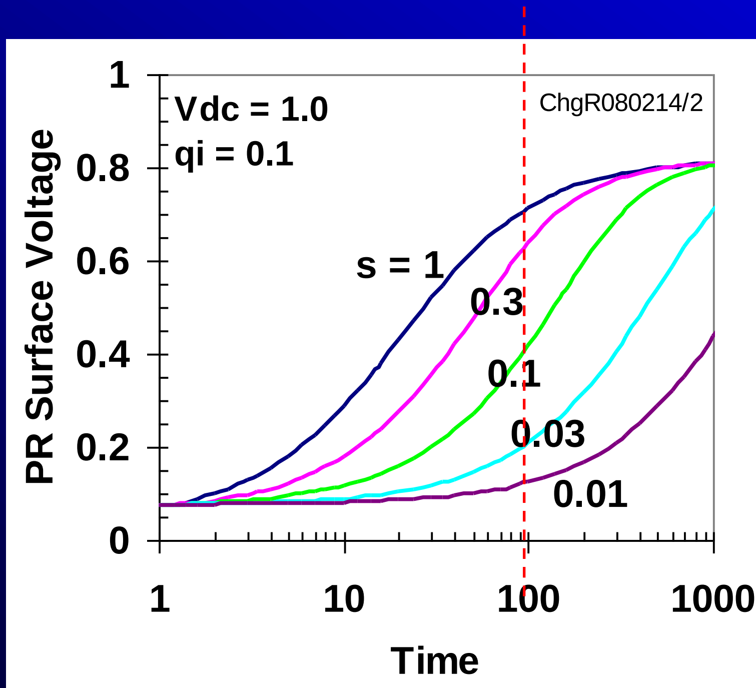
- Voltage $V_D(t)$ across semi-insulator (dielectric) depends strongly on injection strength
- Voltage decay: $V_D(0) – V_D(t)$: significant effect of s in time $t \approx 10$ to $100\ t_o$, ($t_o = L^2/\mu V_B$)

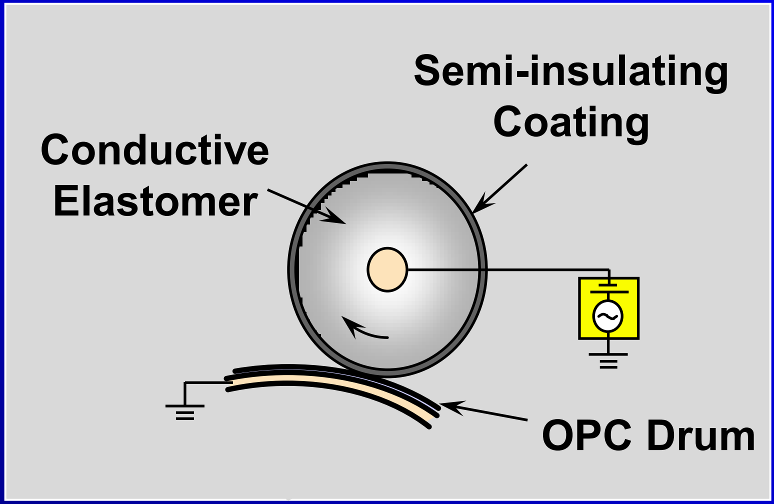




Roller Charging of Photoreceptor

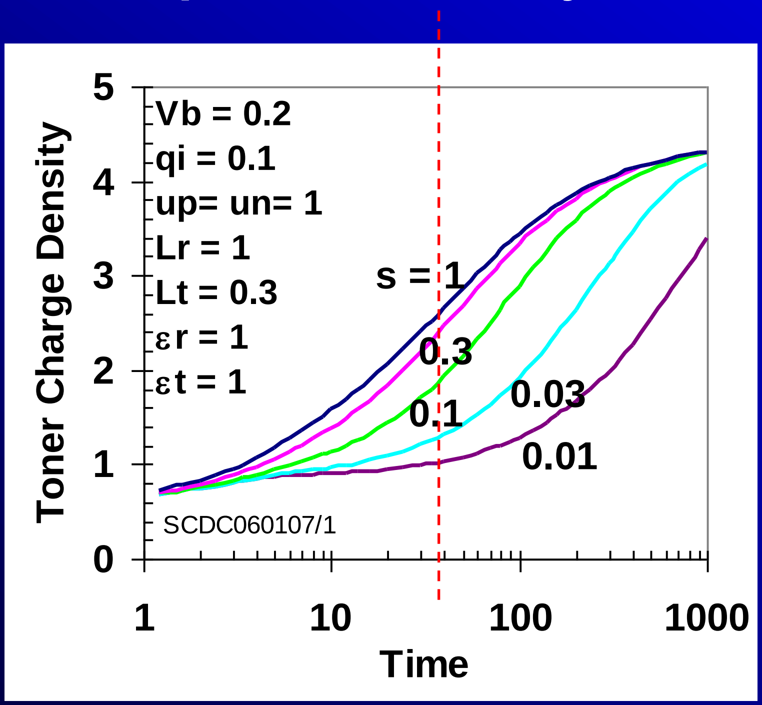
- Photoreceptor surface voltage increases with time
- Significant effect of charge injection strength in time $t \approx 100\ t_o$

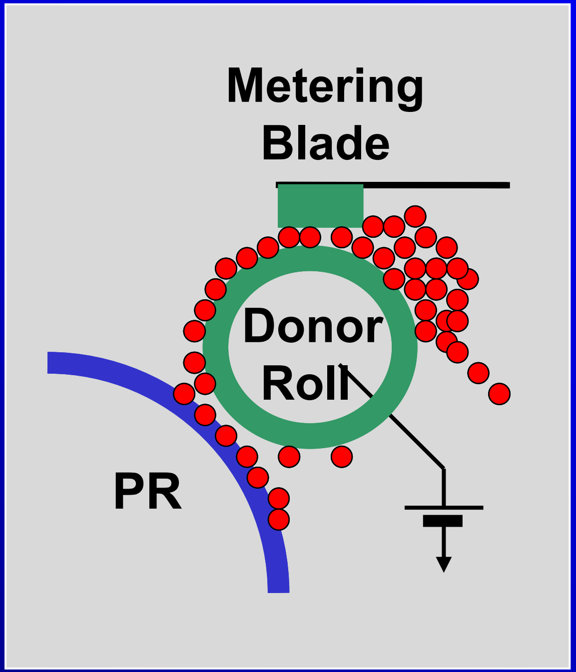




Toner Charging in Single Component Development

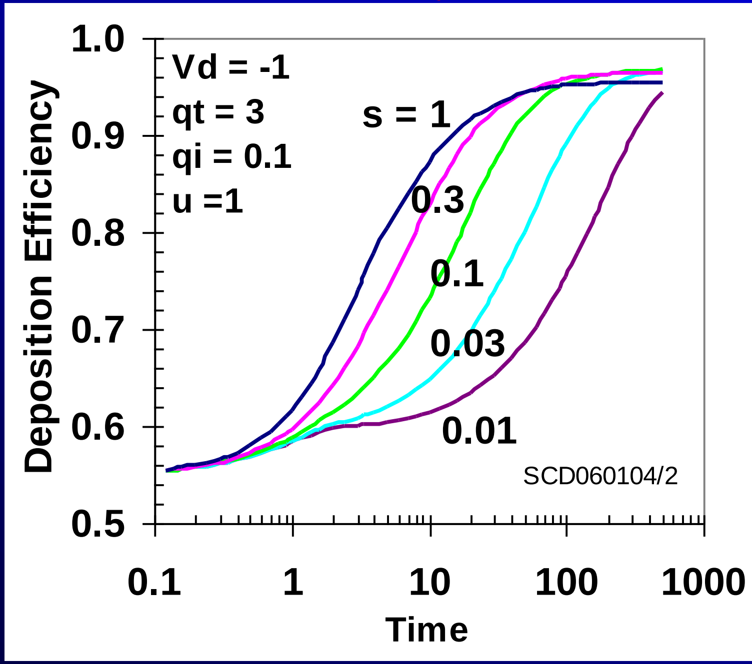
- Toner Charging (–) at Metering Blade (MB)
- Counter-charge (+) *injection* into Roll Coating
- Dependence on *injection strength s* in t ≈ 100 t_o

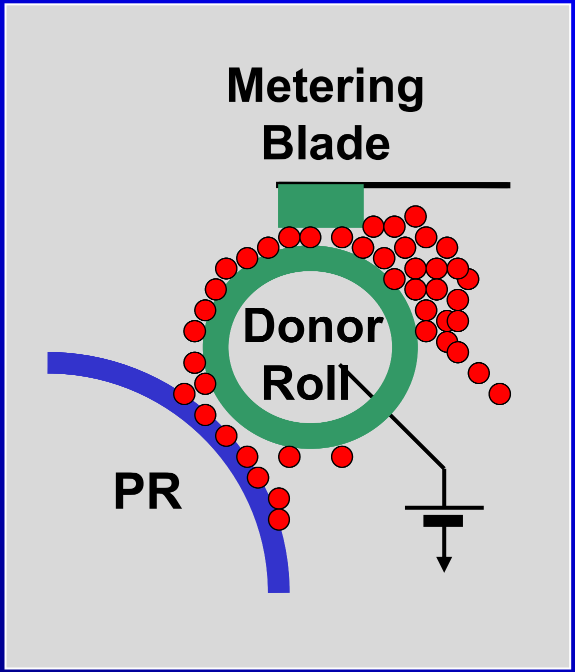




Toner Deposition in Single Component Development

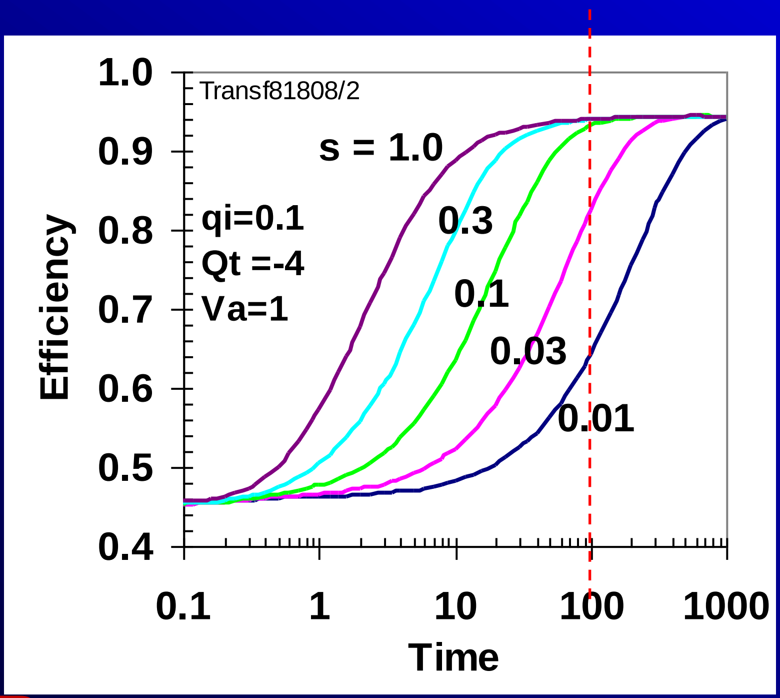
- Toner deposition (–) on photoreceptor PR
- Counter-charge (-) *injection* into Roll Coating
- Dependence on *injection strength s* in t ≈ 100 t_o

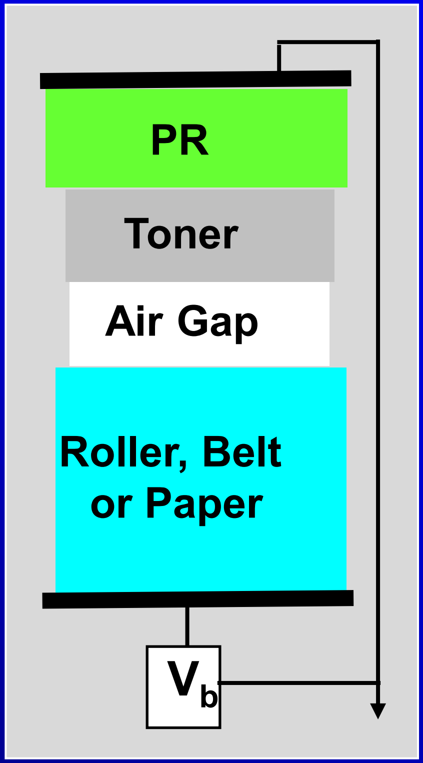




Electrostatic Transfer of Developed Toner

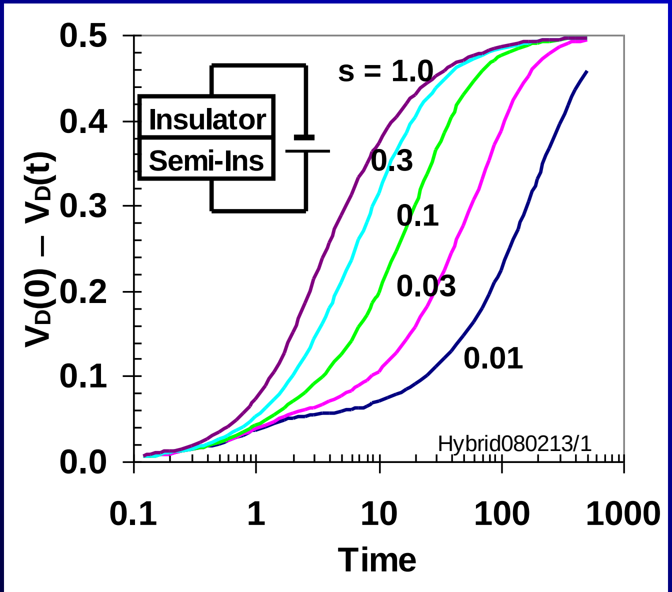
- *Dielectric Relaxation* in receiver
  - Enables efficient transfer without very high V_B
  - increase *transfer efficiency; depends significantly* on *injection strength s*

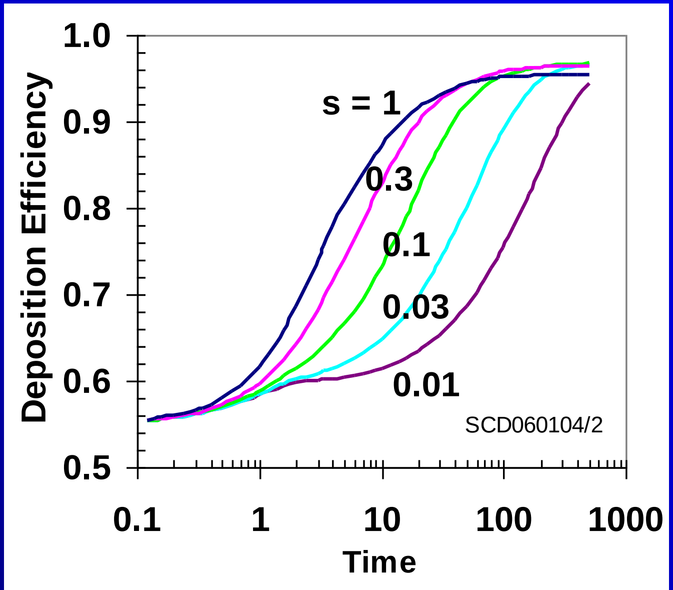




Transient in Dielectric Relaxation is Most Critical to Performance

- Close resemblance in analytical results for voltage decay and processes provides strong support for the critical role of dielectric relaxation on EP performance
- Significant effects of s in t = 10~100 t_o, i.e., transient behavior

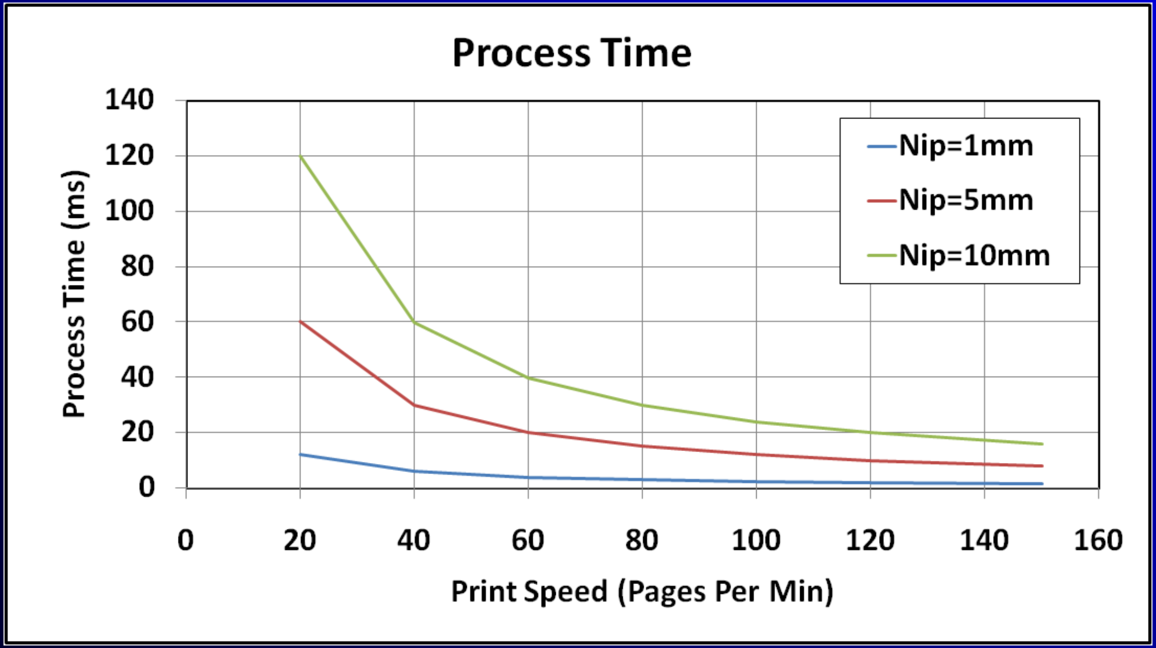




Relaxation Time vs Process Time

- **Roller or Belt Relaxation Time:**

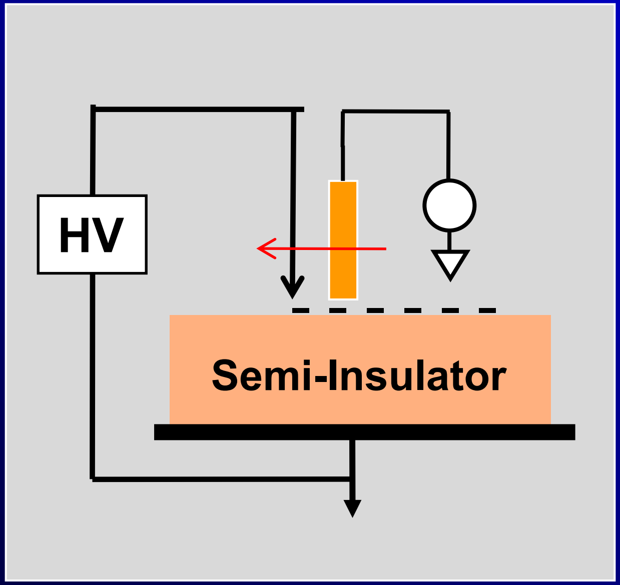
  Charge transit time $t_o = L^2/\mu V_B \approx 5$ ms; with: $L \approx 50$ μm, $\mu \approx 10^{-5}$ cm²/V-s, $V_B \approx 500$ volts; full relaxation time is $t_P > 100 t_o \approx 0.5$ sec or 500 ms.

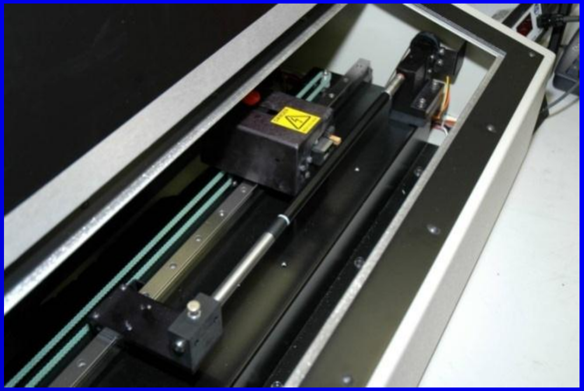


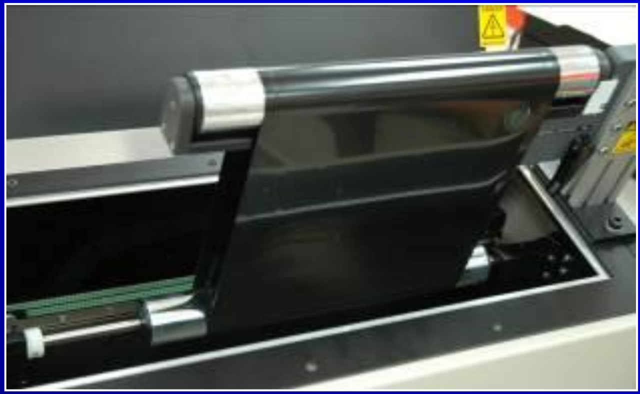
- Therefore must consider transient behavior in characterization; particularly for high speed printing.

Implementation – the ECD Method

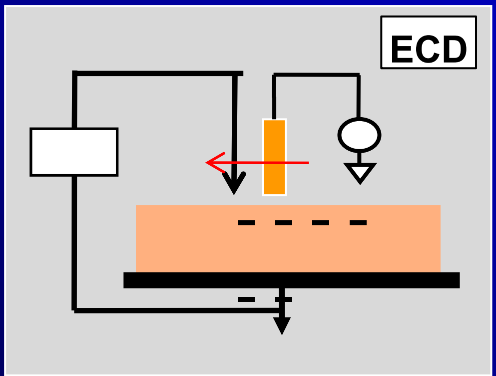
Testing Semi-insulator In Open Circuit

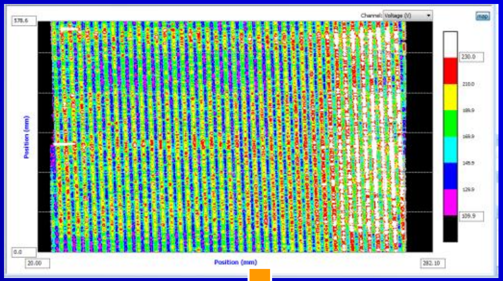




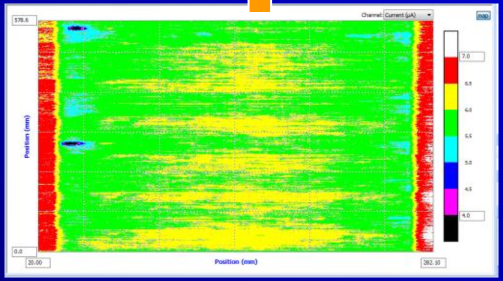


Primarily Measurements in The ECD Method: V, I and Re Mapping

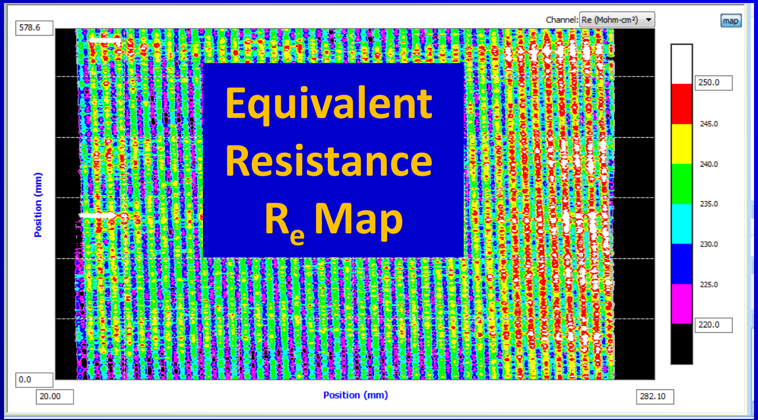




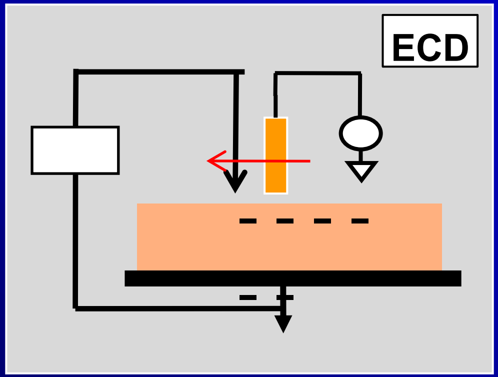
ECD Voltage Map



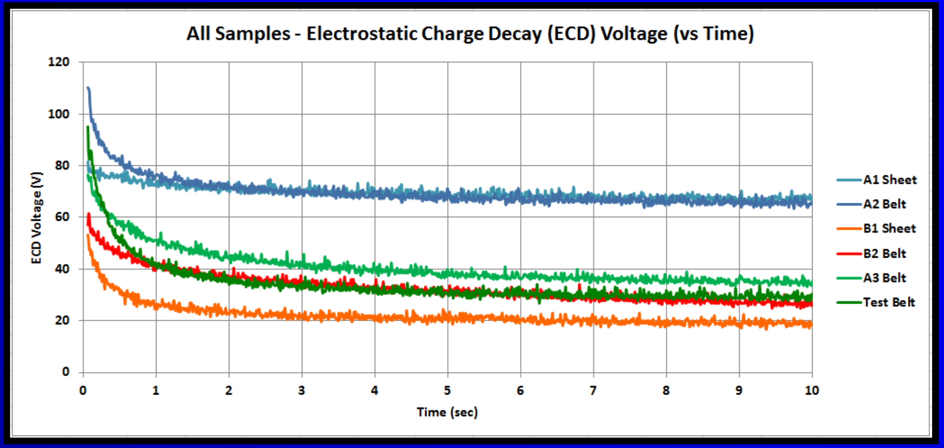
Charging Current Map



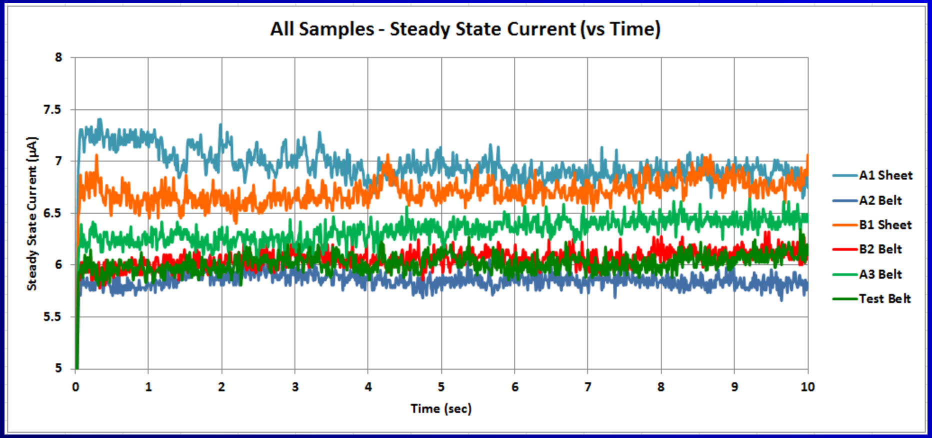
Other Measurements:
ECD Voltage Decay & Steady State Current



ECD Voltage Decay



Steady State Current

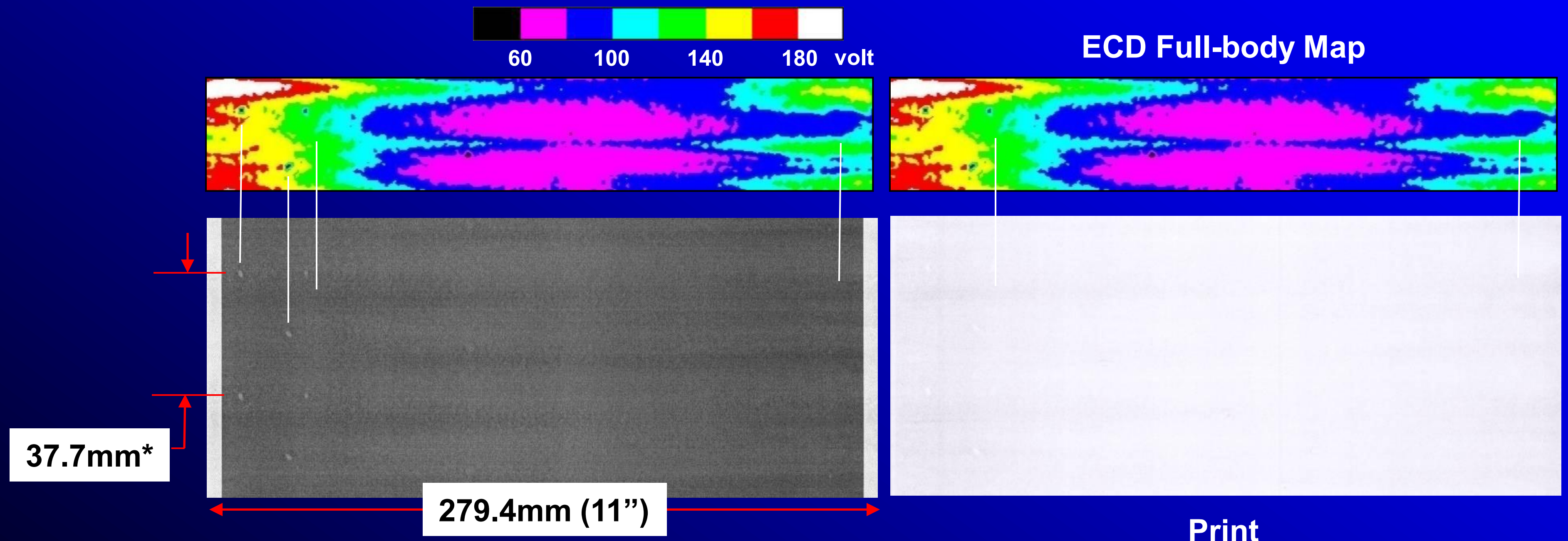


Application Examples

- Charge Roller
- Development Roller
- Transfer Belt

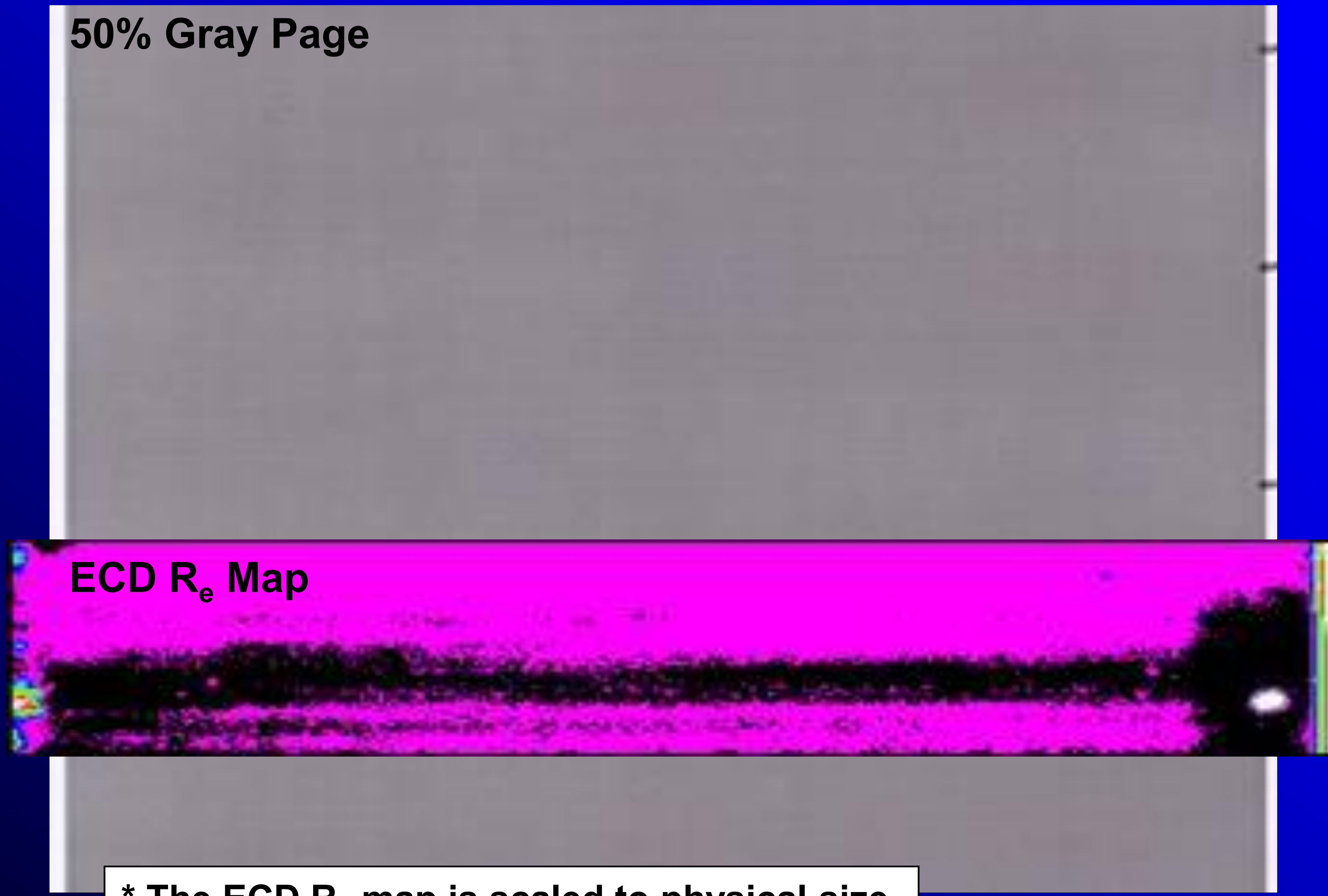
Charge Roller Mapping

- The full-body ECD map shown below for a poor charge roller clearly demonstrates the correlation between V_{ECD} and print quality.
- The non-uniformity in V_{ECD} can be mapped directly to a print density variation map (on a gray page) and a background map (on a white page). Such results clearly demonstrate the efficacy of the ECD method.



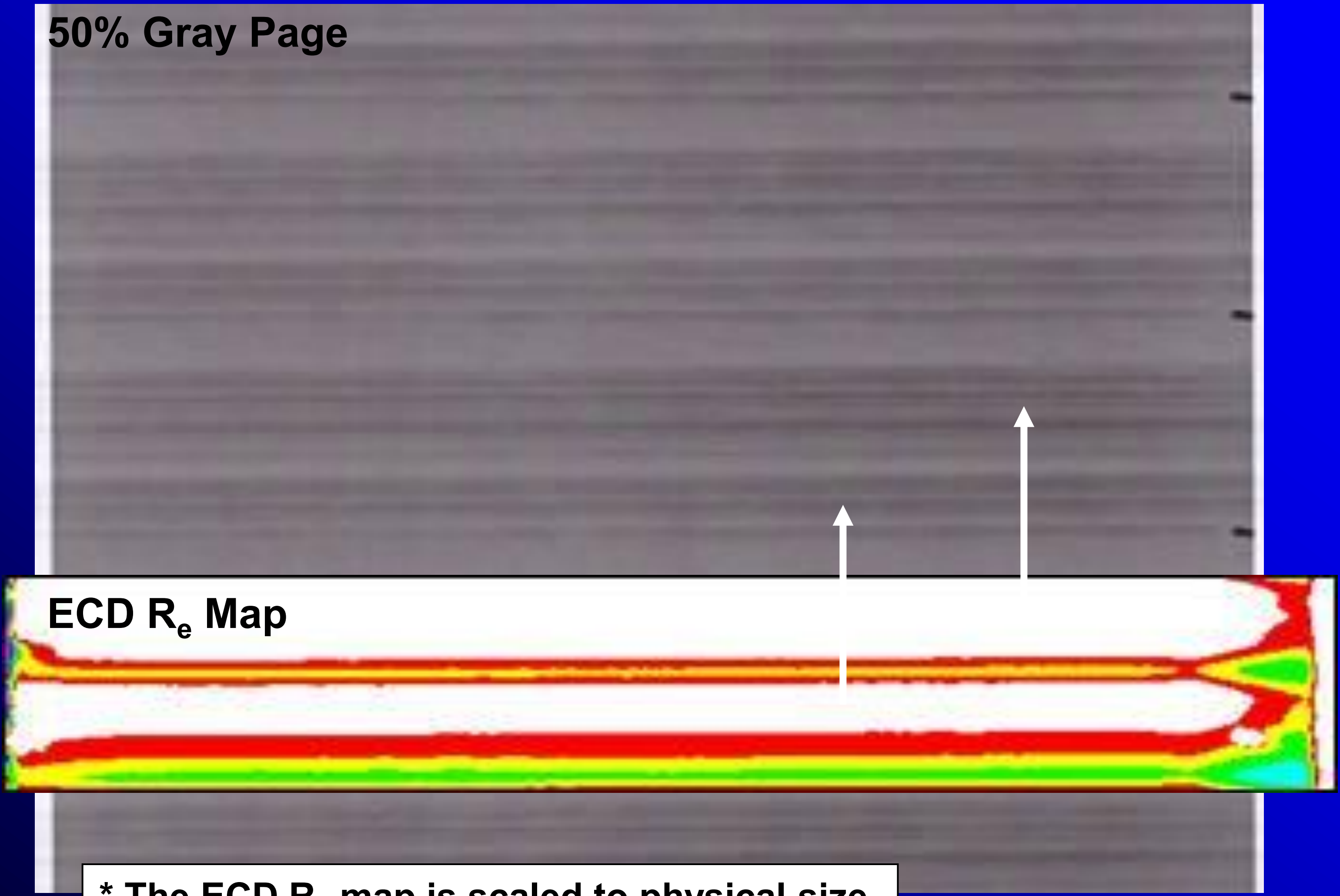
* Charge roller circumference

Good Roller



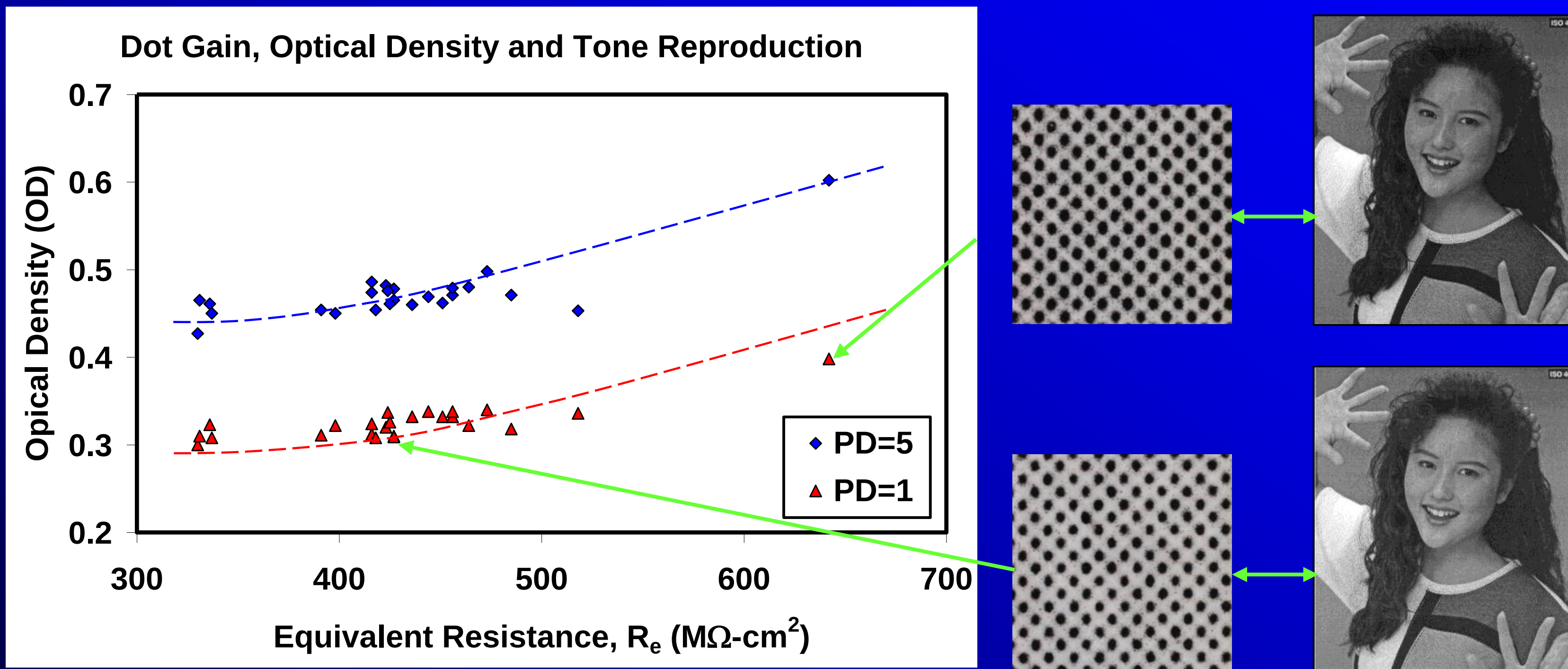
* The ECD R_e map is scaled to physical size.

Bad Roller

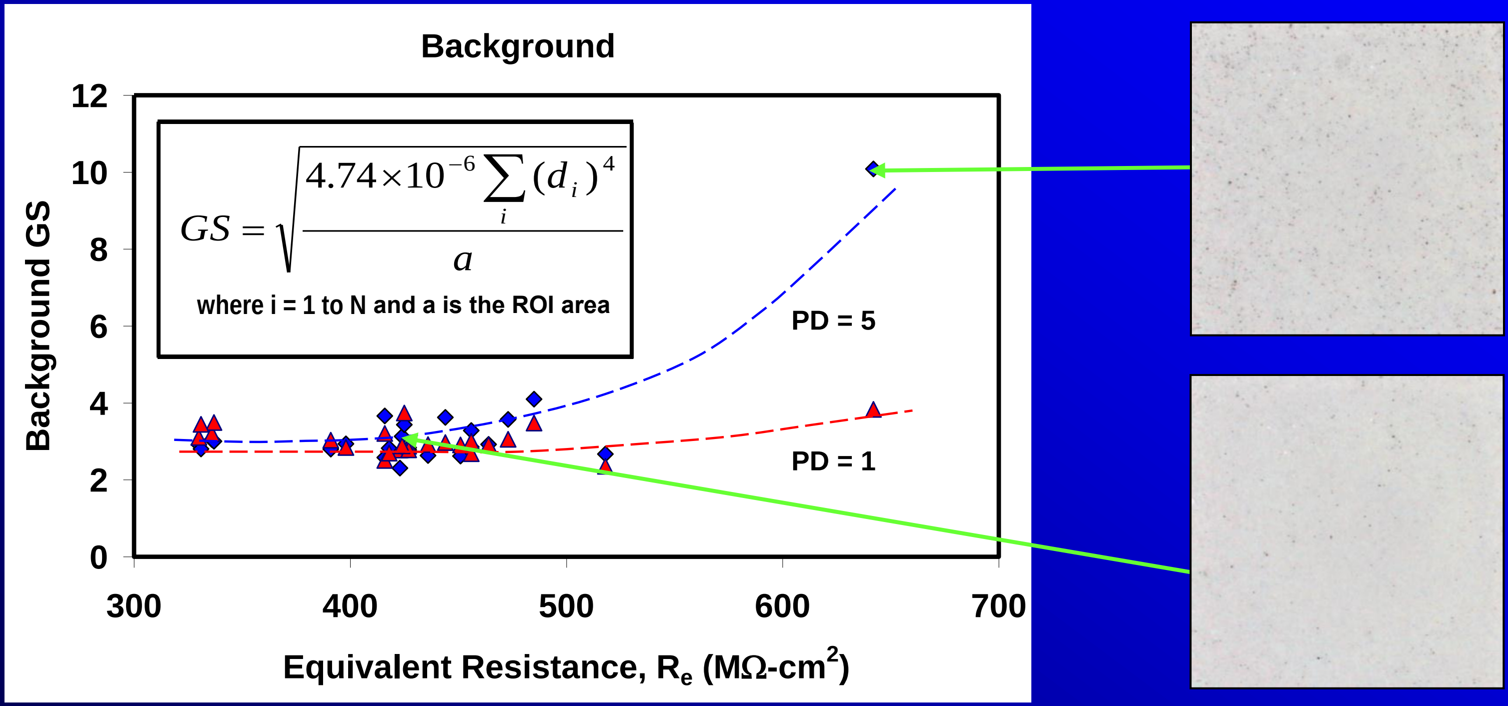


* The ECD R_e map is scaled to physical size.

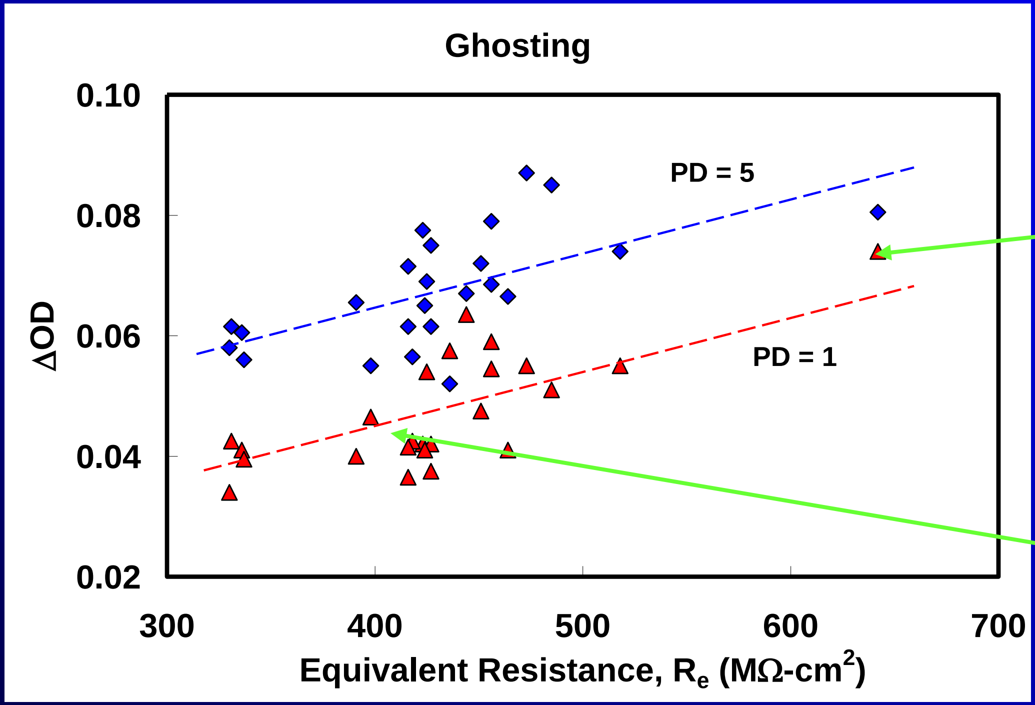
Dot Gain, Optical Density & Tone Reproduction



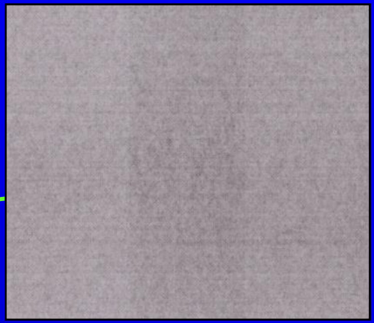
Background

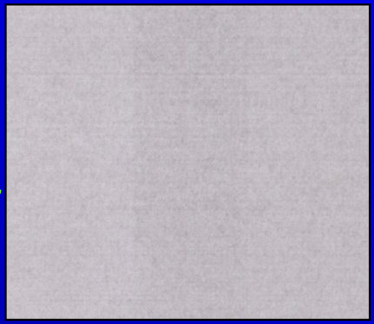

Background
$GS = \sqrt{\dfrac{4.74\times10^{-6}\sum_i (d_i)^4}{a}}$
where i = 1 to N and a is the ROI area
PD = 5
PD = 1
Background GS
0
2
4
6
8
10
12
300
400
500
600
700
Equivalent Resistance, R_e (MΩ-cm^2)

Ghosting

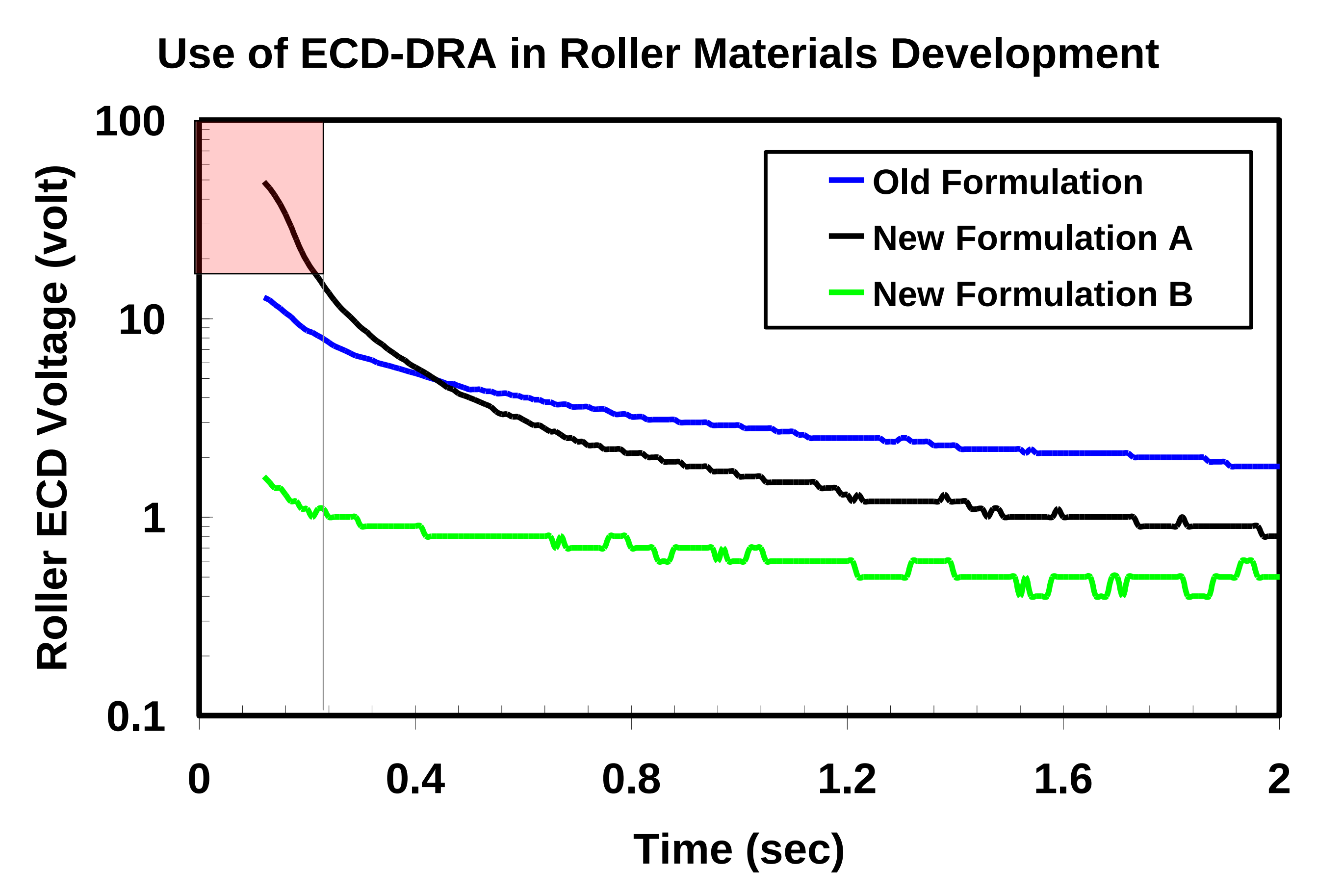


Ghosting
0.10
0.08
0.06
0.04
0.02
ΔOD
PD = 5
PD = 1
300
400
500
600
700
Equivalent Resistance, R_e ($M\Omega$-cm^2)

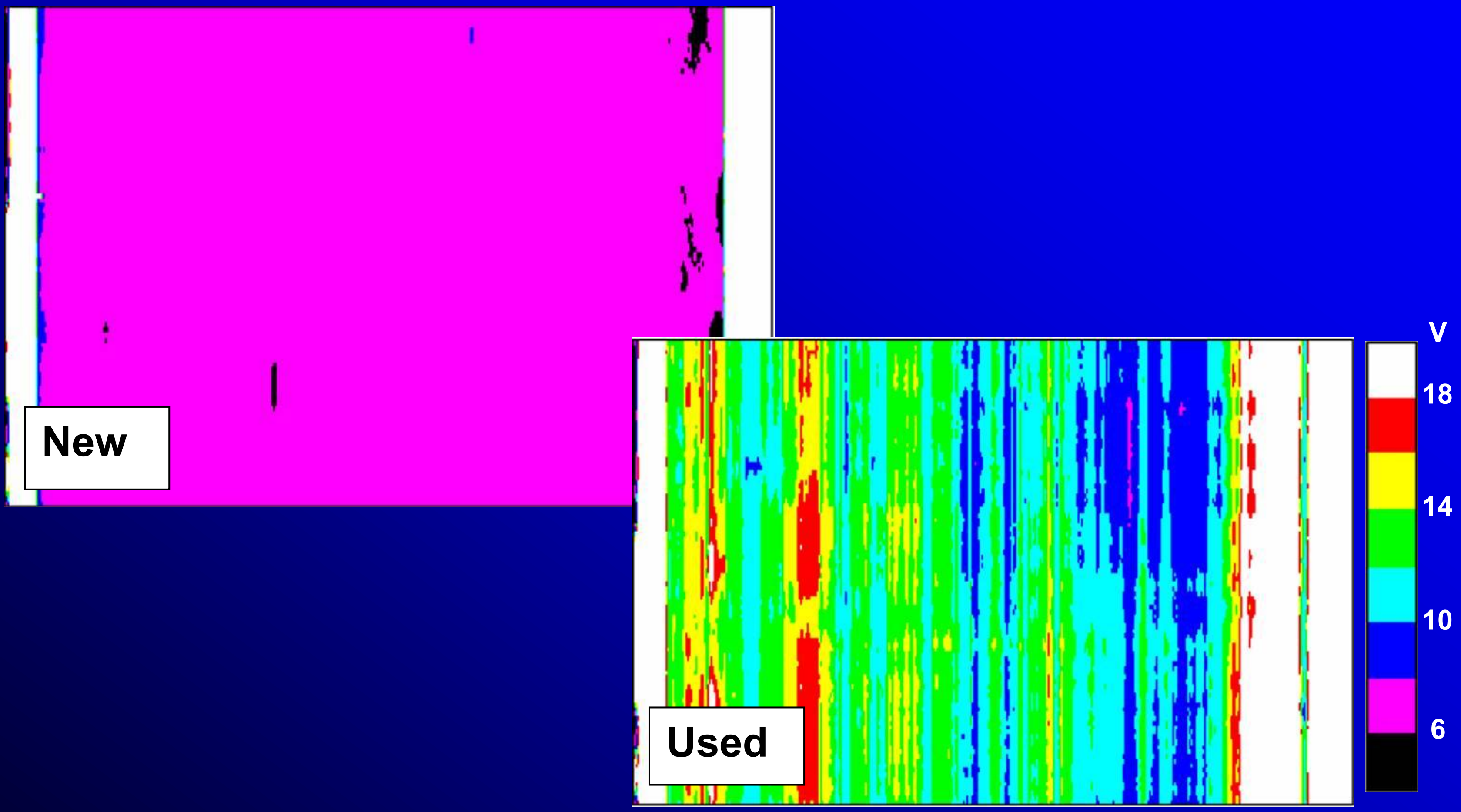




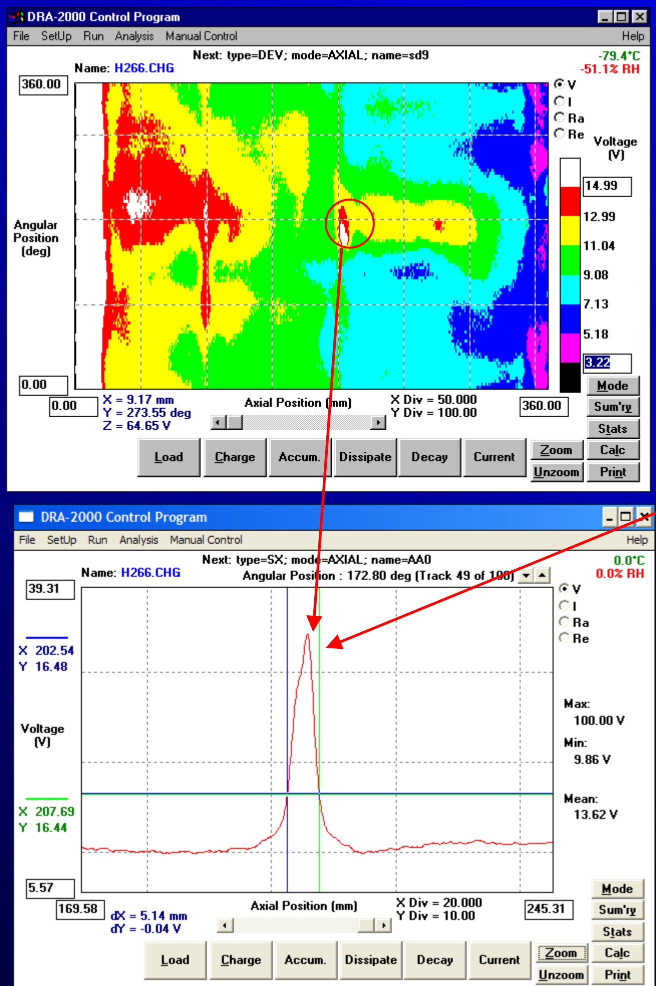
Application Example – Material Formulation



Application Example – Roller Aging



Development Roller



A cut in the roller

ITB – Failure Analysis

First data points V(0):

Low for good,

high for bad

same for new and used

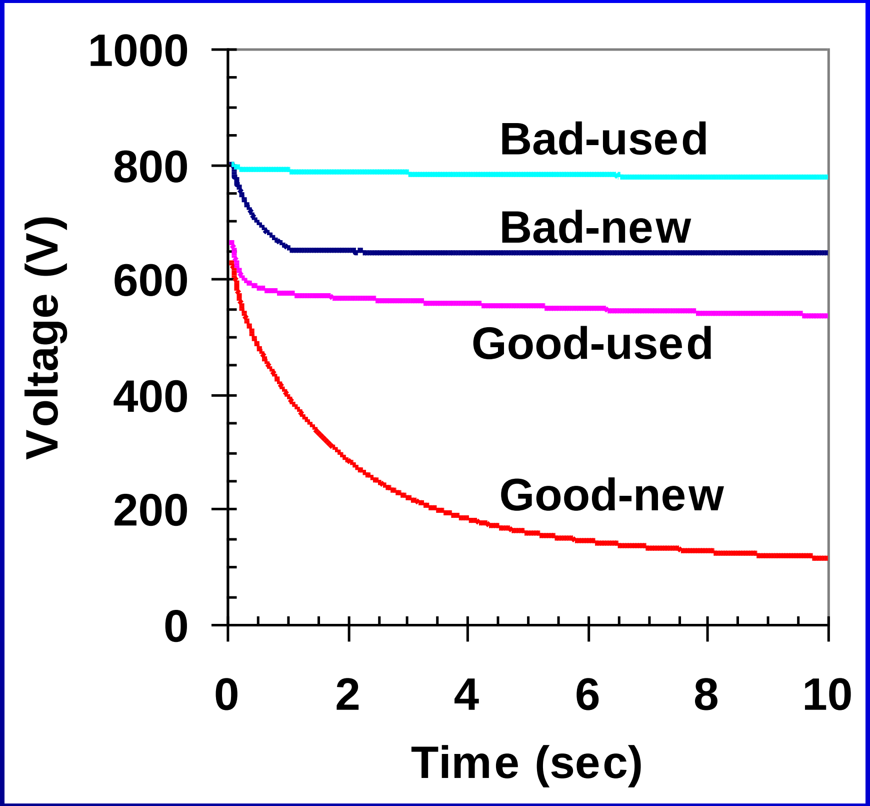
→ intrinsic charge

Voltage decay V(t):

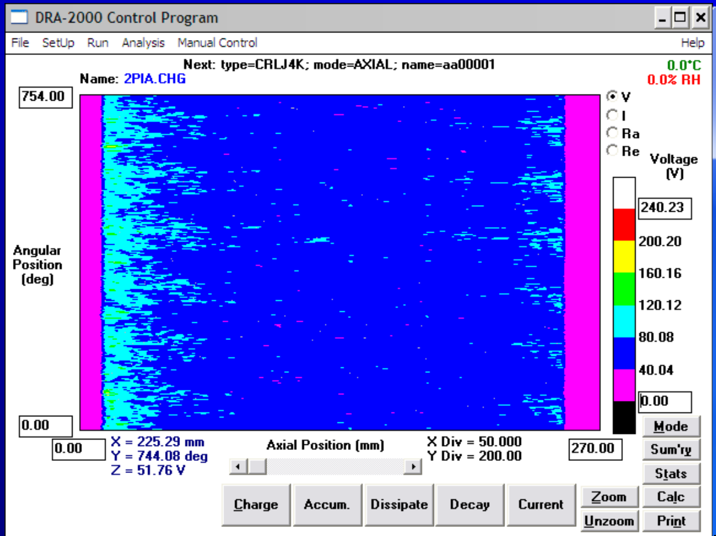
Fast for new

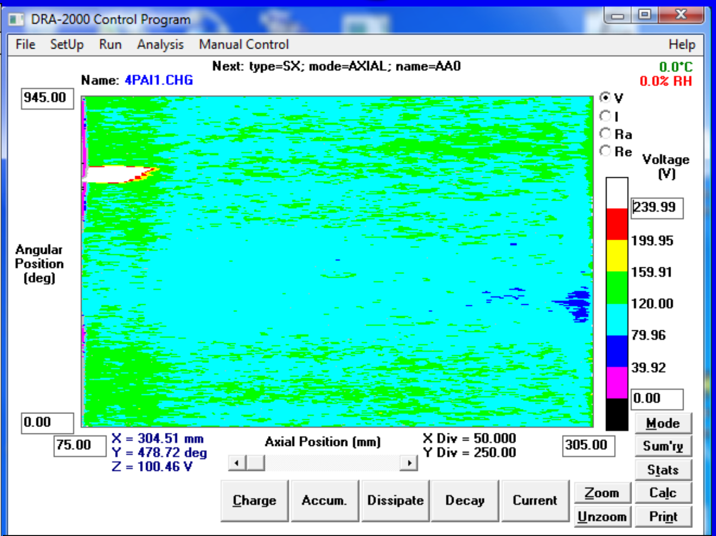
Slow for used

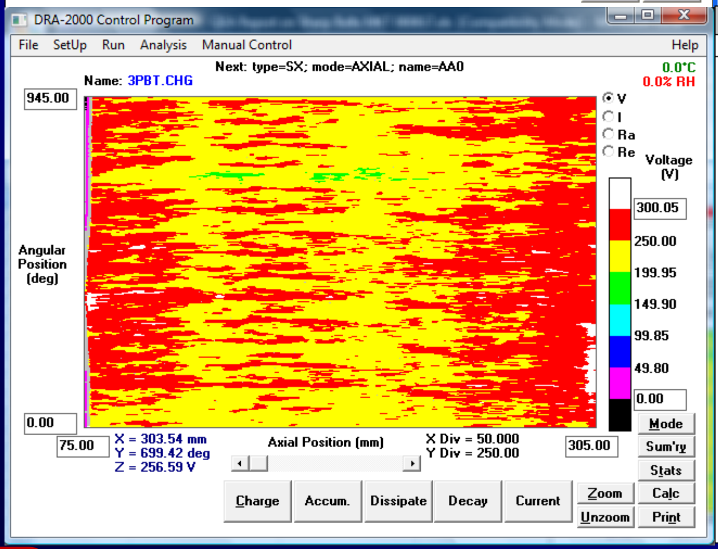
→ injected charge

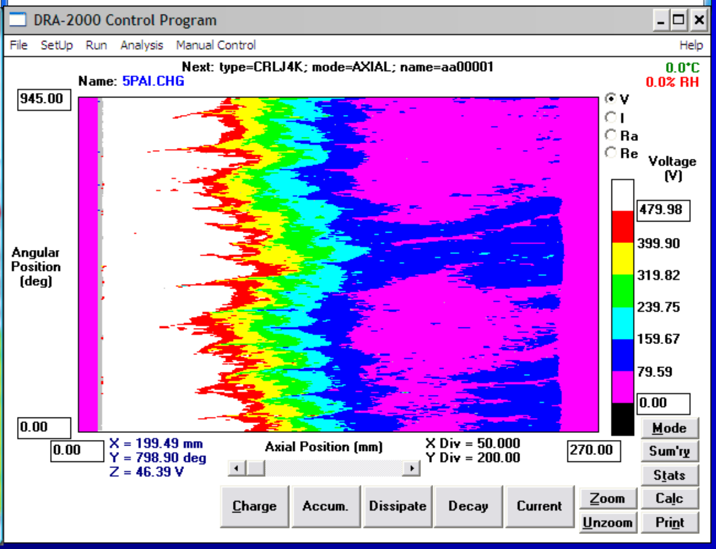


ITB - Benchmarking









Summary

- Performance of EP sub-processes using rollers and belts is controlled by dielectric relaxation (DR) of semi-insulating layer
- Dielectric relaxation induced by charge injection from bias voltage
- Full relaxation of semi-insulator often requires time longer than available in high speed Electrophotography

Conclusions

- Electrical characterization of rollers and belts should emphasize transient values & spatial variations in DR
- Observations of spatial averages, at fully relaxed states are insufficient
- Open-circuit voltage measurements, efficiently scanning large area of sample – an extremely valuable tool for R&D, QC and failure analysis