Electrical Characterization of Rollers & Belts for High Speed Electrophotography

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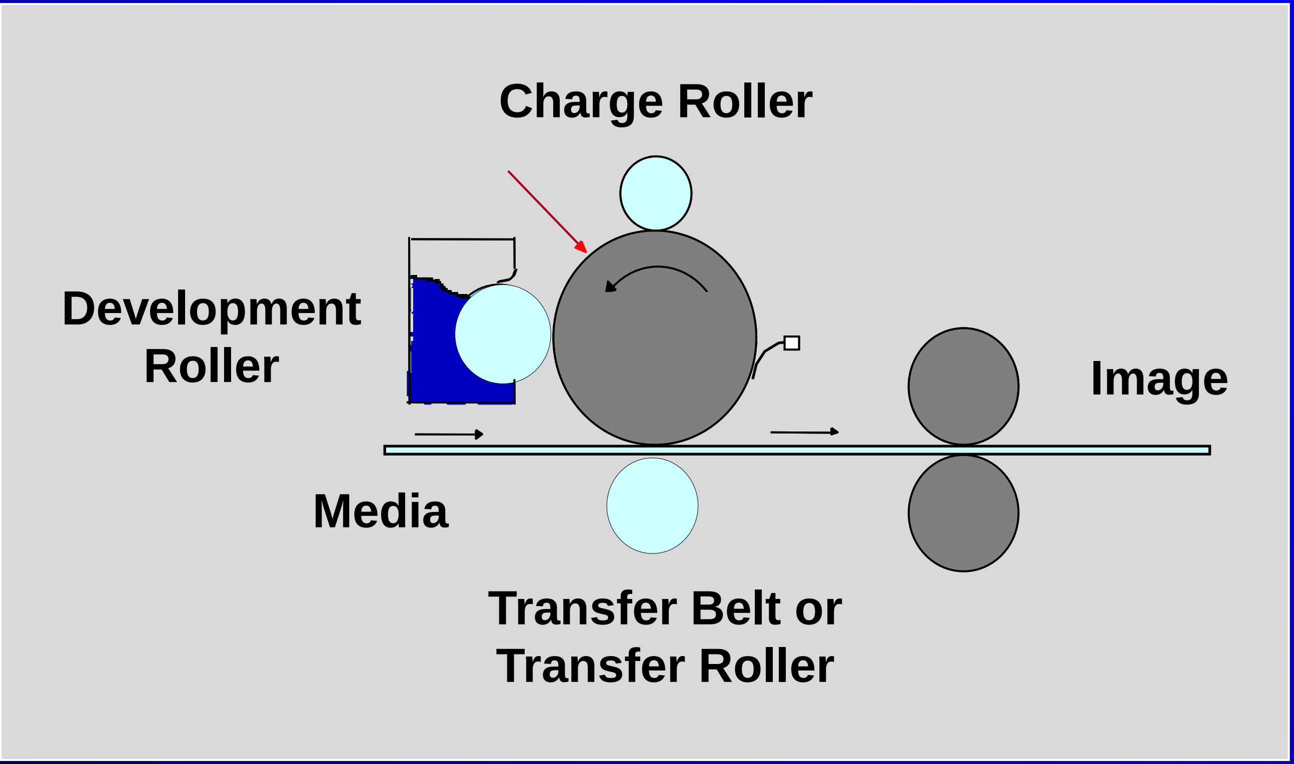
Outline

- What characterization method – measurement of dielectric relaxation
- Why – correlates with process fundamentals
- Traditional resistance measurement method – what's wrong
- ECD method – what's right
- Analysis & Experimental Results

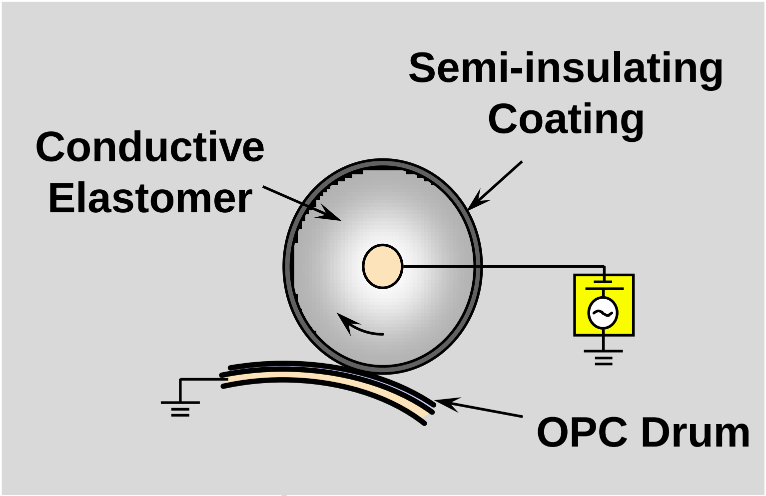
Dielectric Relaxation of Rollers & Belts is Critical to the Performance of Several EP Processes



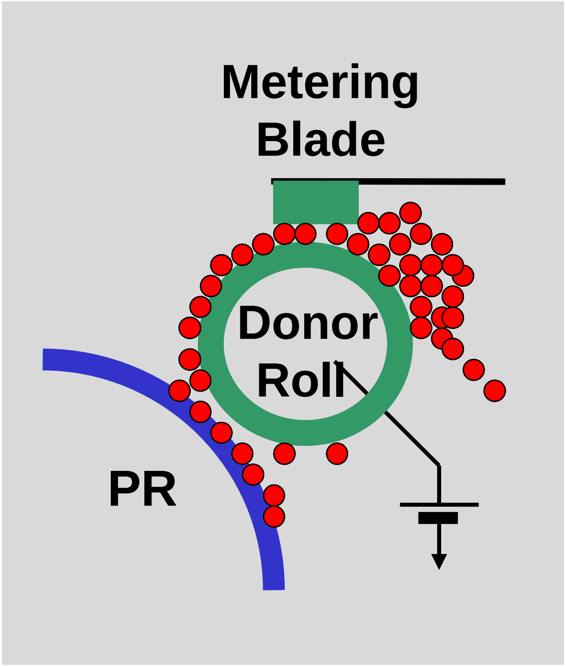
Characterization of dielectric relaxation is the key!

Why Dielectric Relaxation is Important?

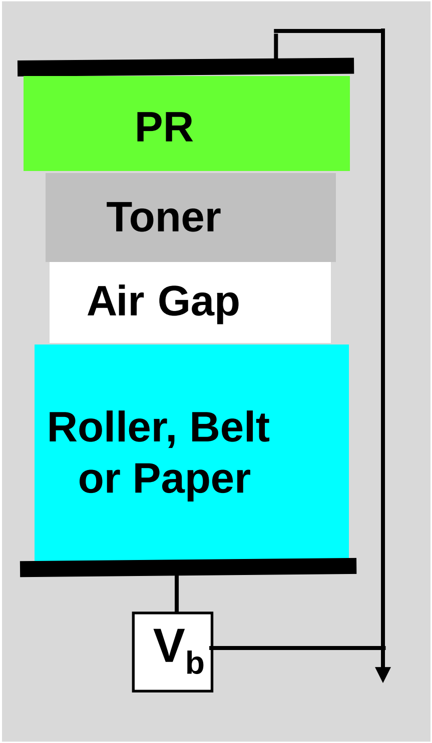
Charging



Development



Transfer Media

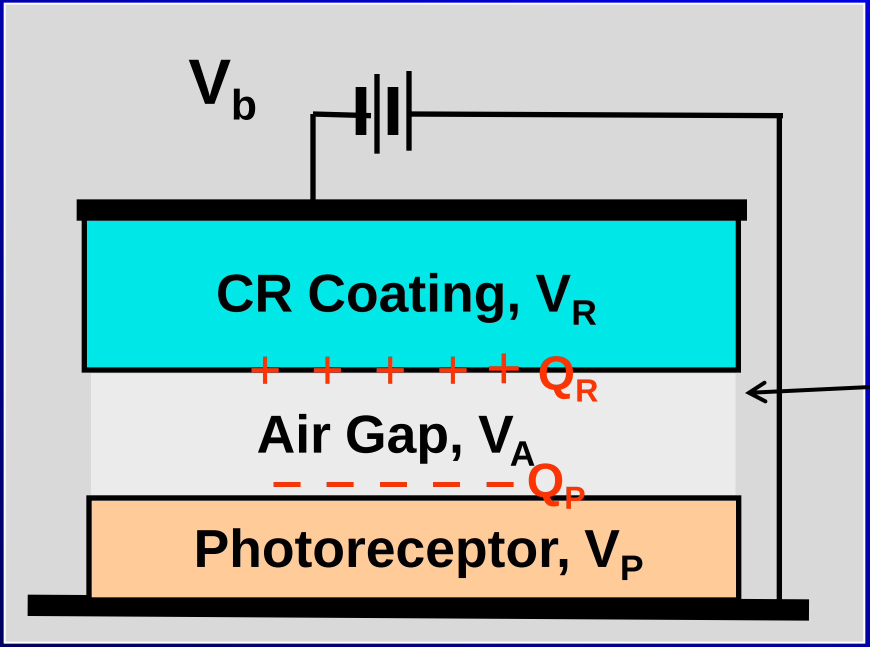


Need to understand the process physics

QEA Research & Publications

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:

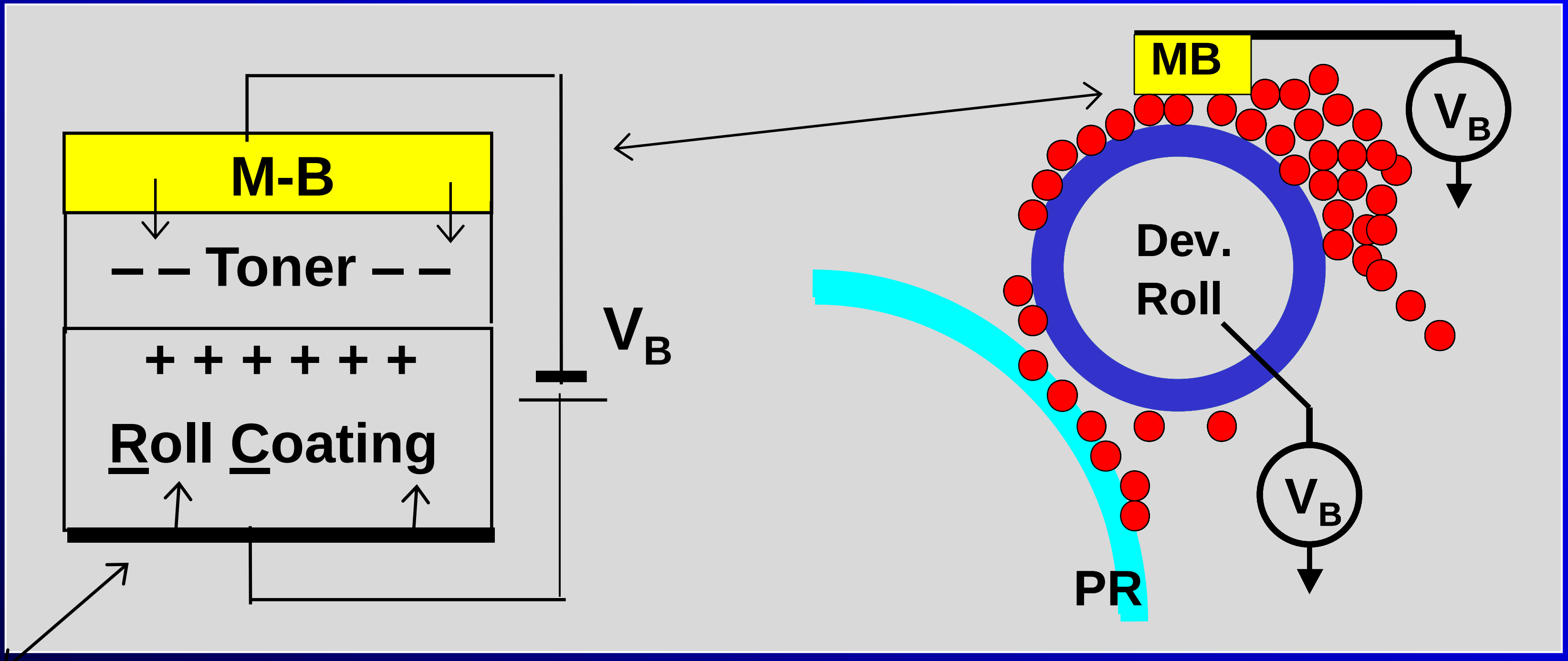
- Counter-charge Q_R on Roll
- Air-gap voltage, $V_A \Downarrow$
- V_A < Paschen threshold
- PR charging stops
- To continue charging,

  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

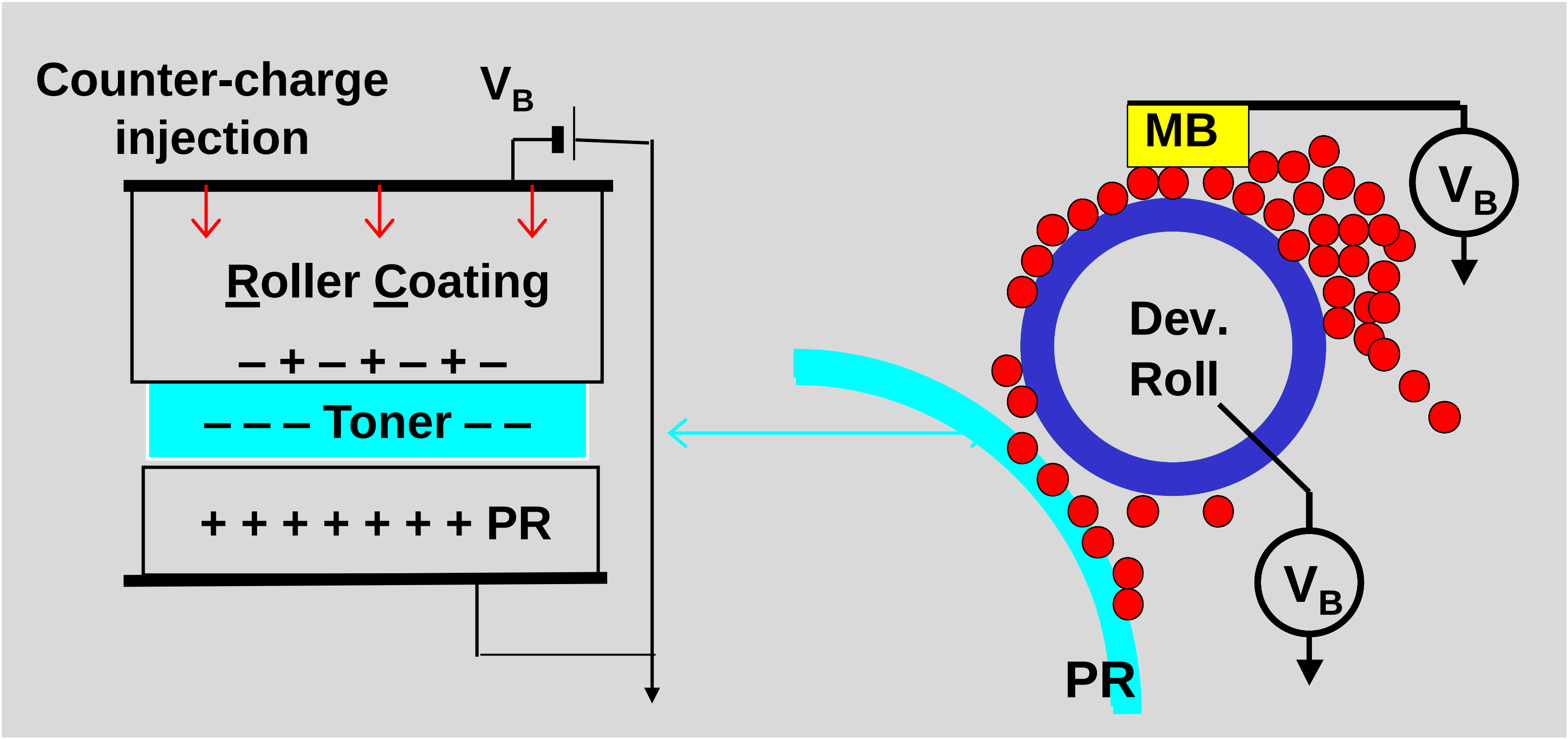
- Donor Roll = Conductive Core + Semi-ins. Overcoat
- Toner Charging (–) at Metering Blade (M-B)



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

Toner Deposition in Single Component Development

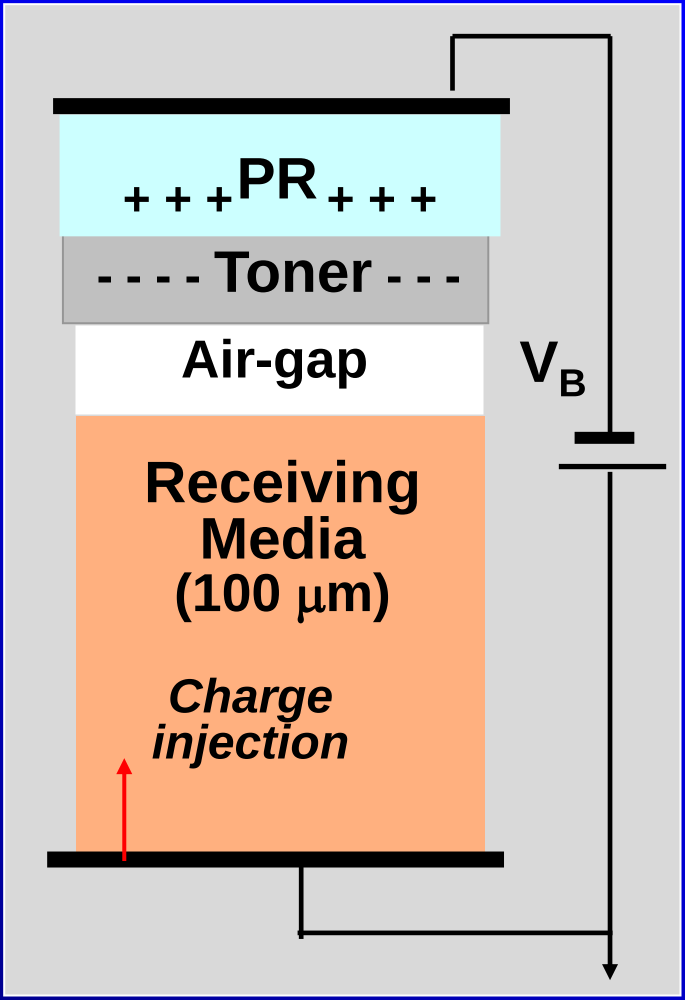
- Toner Deposition on Photoreceptor (PR)
- Counter-charge (–) <u>injection</u> from V_B to Coating
- Dielectric Relaxation of Roll Coating layer



Electrostatic Transfer of Developed Toner

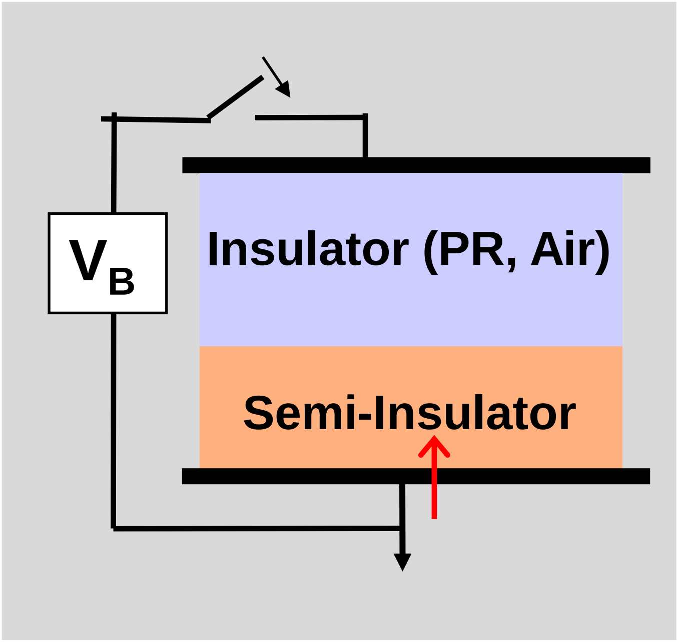
- Bias voltage applied to multiple layers
- V_B reverses field direction in toner layer
- Receiving media (Paper, Belt),

  (semi-insulator) much thicker than other layers
- *Dielectric Relaxation* in receiver
  - Shifts most of V_B to toner layer
  - Enables efficient transfer
  – without very high bias voltages
  - occurs by *charge injection*

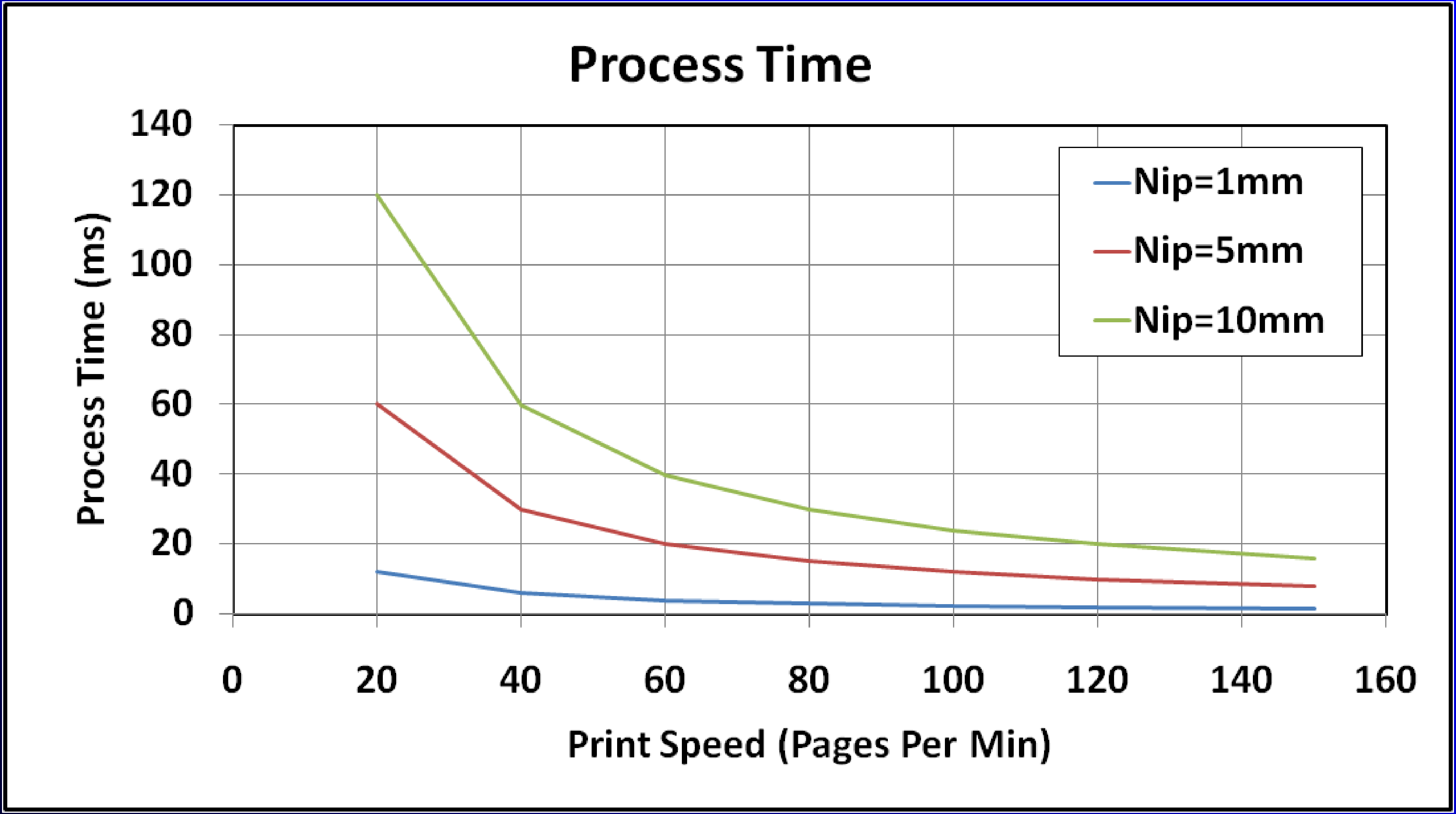


Common Configuration & Implications on Characterization Method

- V_B applied to insulator & semi-insulator 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**!

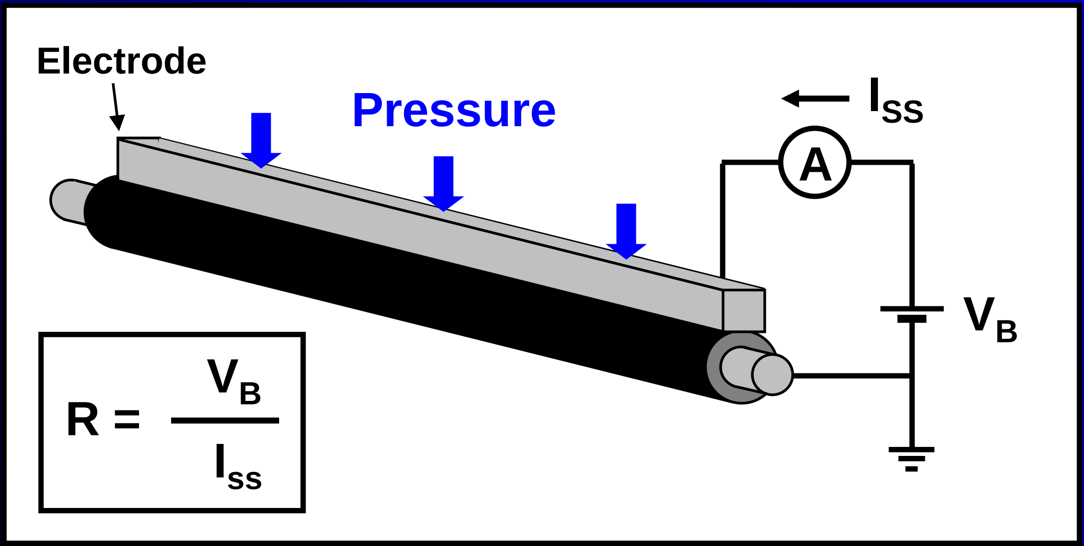


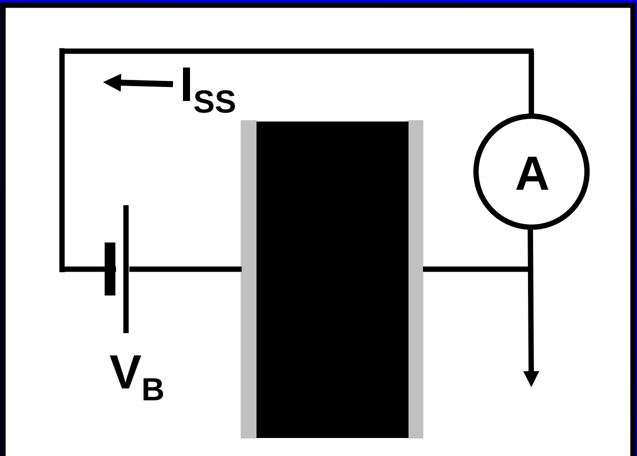
Process Time



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}.





A "Close-circuit" Method

Limitations of Conventional Resistance Method

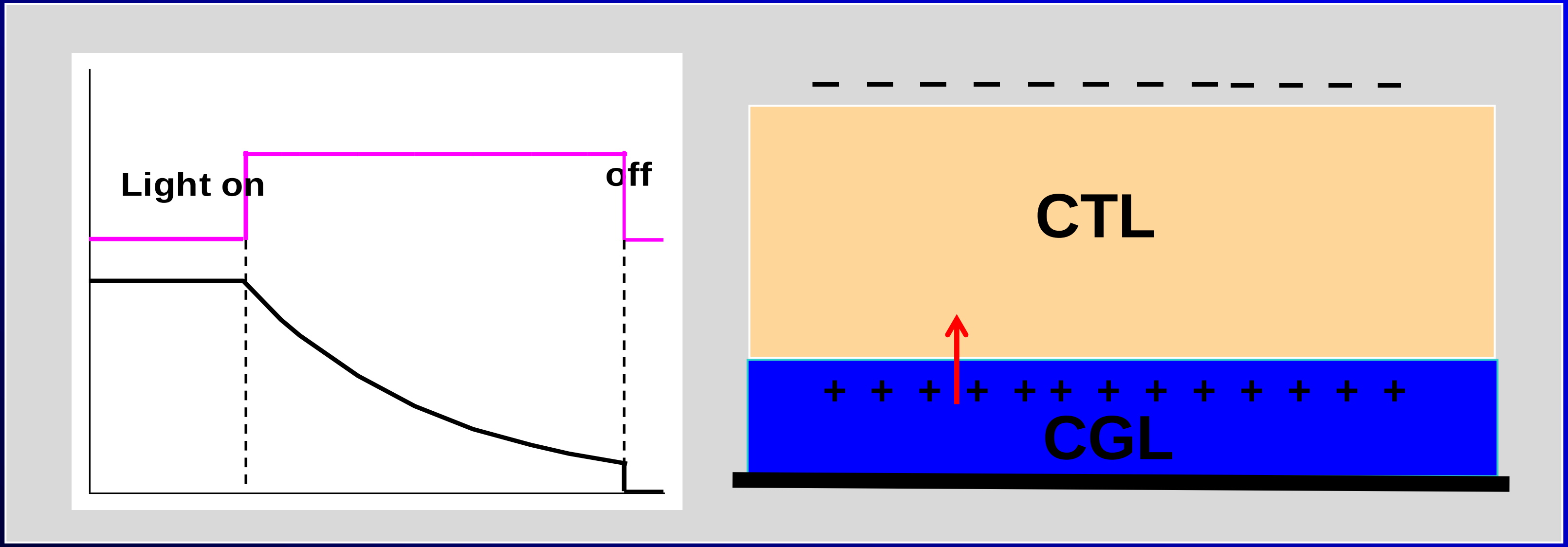
- Most serious is that the underlying physics is not consistent with the process physics:
  - Ohmic relaxation model does not apply
  - Semi-insulator to electrode contact is non-ohmic
  - Test configuration does not simulate process configuration - no way to duplicate charge transport physics crucial 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!**

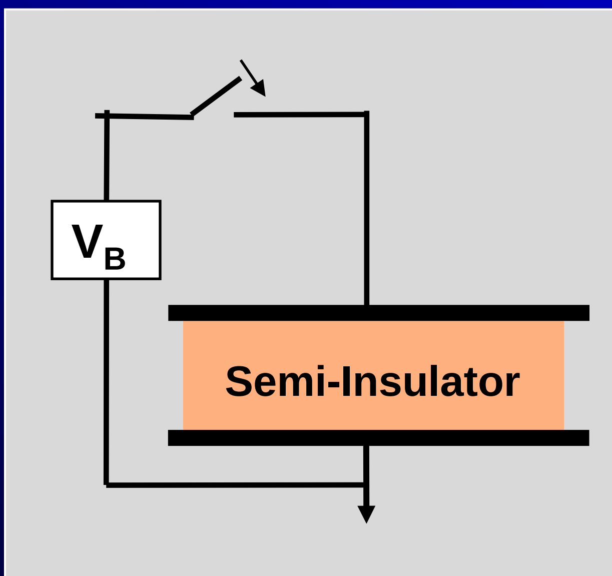
An Example of the Role of Injection – Photo-induced Discharge in Photoreceptor

- 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 → Voltage decreases → Photo-induced Dielectric Relaxation

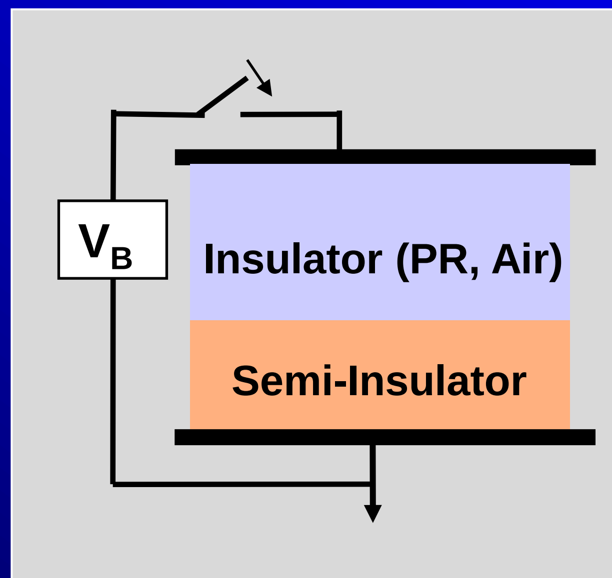


"Open-Circuit" Method is Preferred to Simulate Actual Device

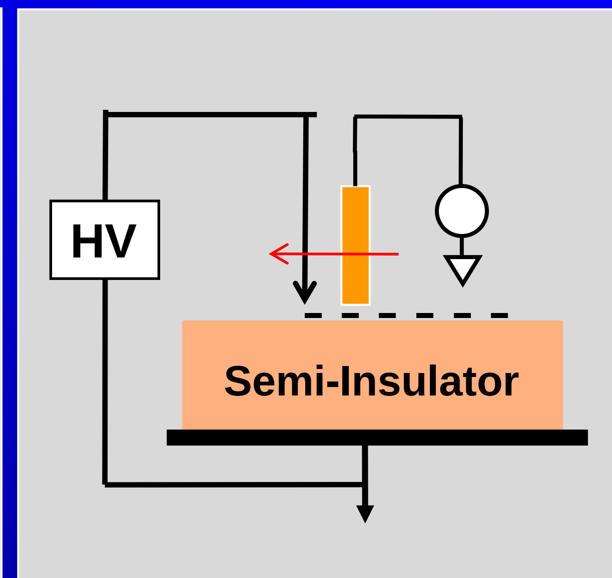
Testing Semi-insulator In Closed Circuit	Semi-insulator in Open Circuit	Testing Semi-insulator In Open Circuit



Traditional Resistance Measurement



Device Configuration



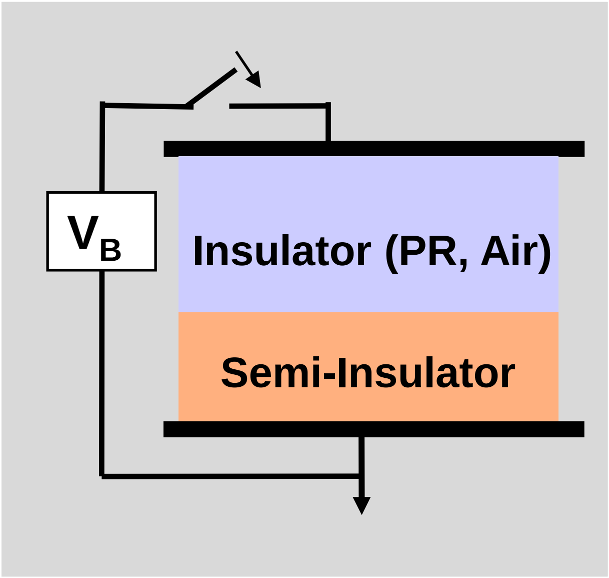
Preferred ECD Method

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 $y = 0$**

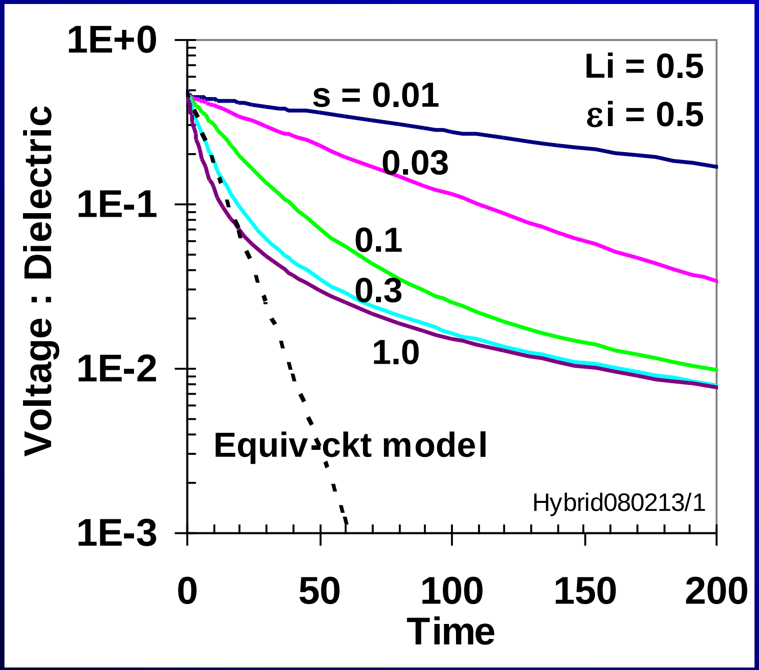
    $J(0, t) = sE(0, t)$, *s = Injection strength*
  - **Interface charge: $Q_L = \varepsilon_I E_I - \varepsilon_D E_D(L)$ *(Gauss' theorem)***
  - **Bias $V_B = V_D + V_I$ *(constant in time)***
- **Solved by Numerical iterations**

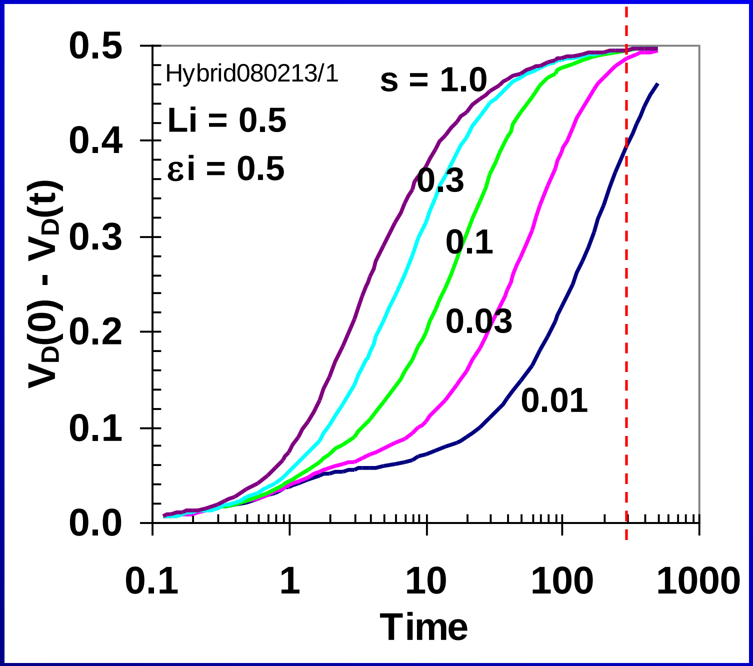


Charge Transport Model of Dielectric Relaxation (2)

- Voltage $V_D(t)$ across semi-insulator (dielectric) depends strongly on injection strength

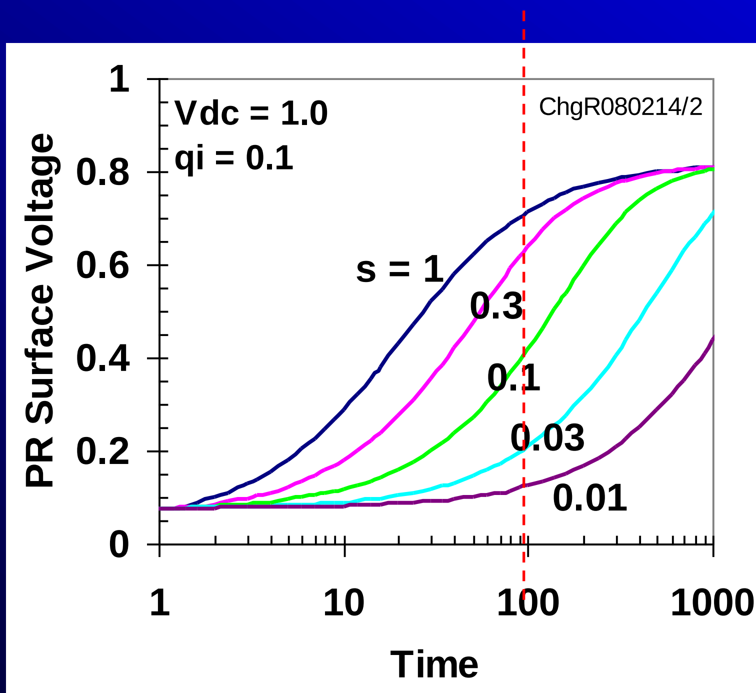
- Voltage decay: $V_D(0) – V_D(t)$: significant effect of s in time $t \approx 10$ to $100\ t_o$, ($t_o = L^2/\mu V_B$)

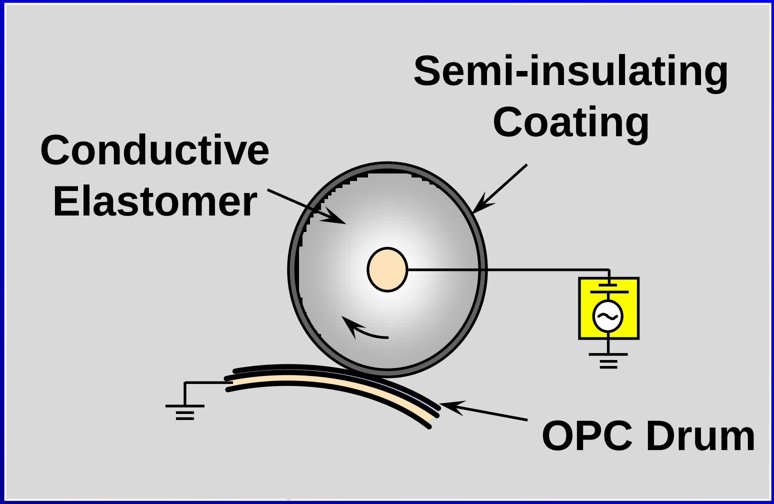




Roller Charging of Photoreceptor

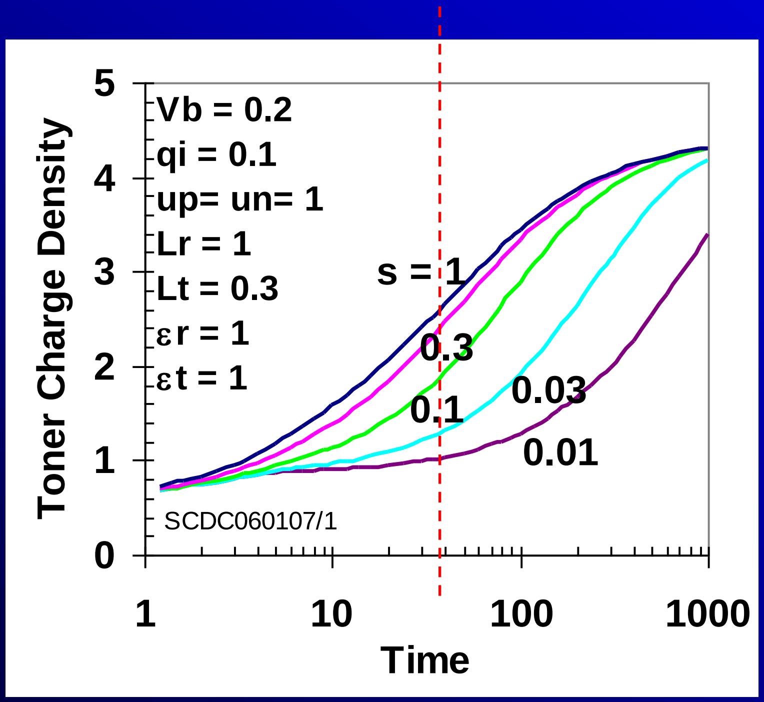
- Photoreceptor surface voltage increases with time
- Significant effect of charge injection strength in time t ≈ 100 t_o

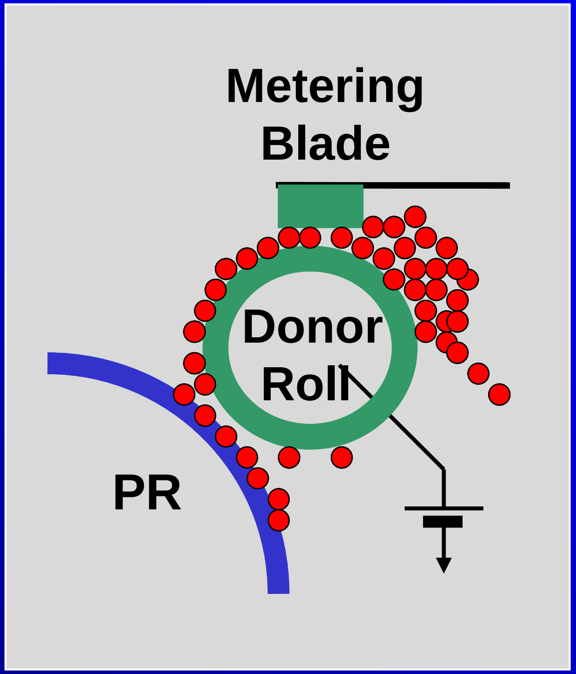




Toner Charging in Single Component Development

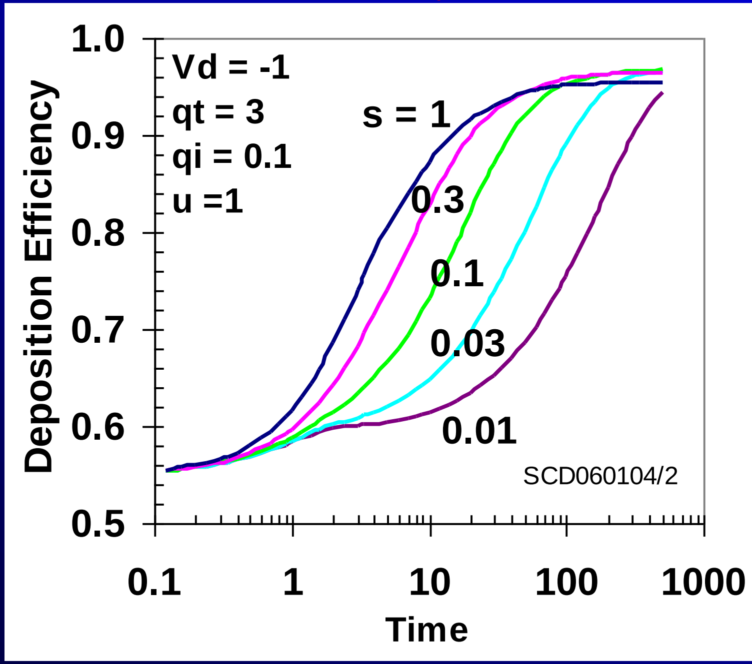
- Toner Charging (–) at Metering Blade (MB)
- Counter-charge (+) *injection* into Roll Coating
- Dependence on *injection strength s* in t ≈ 100 t_o

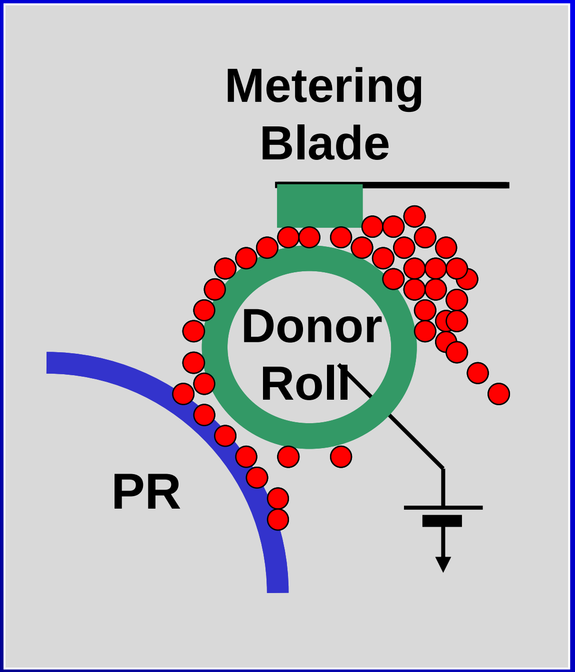




Toner Deposition in Single Component Development

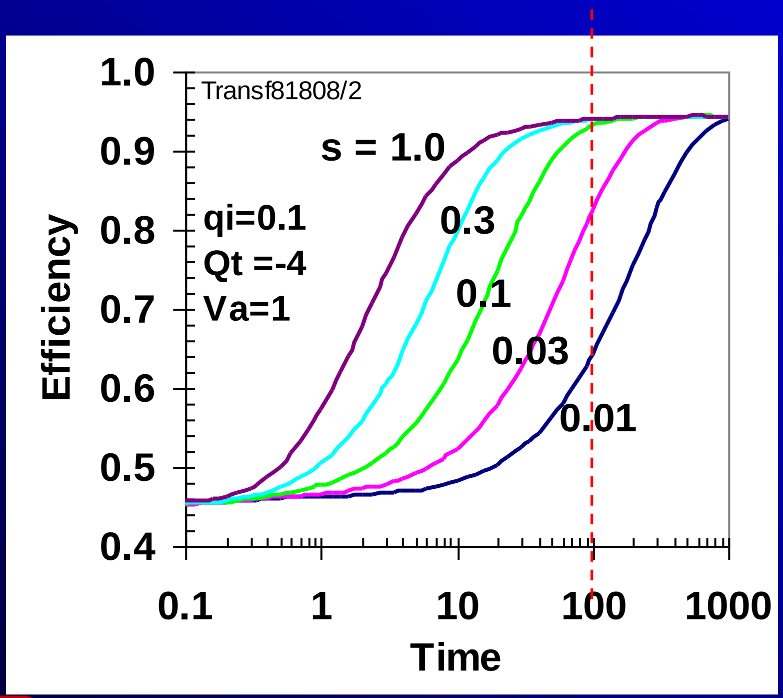
- Toner deposition (–) on photoreceptor PR
- Counter-charge (-) *injection* into Roll Coating
- Dependence on *injection strength* **s** in t ≈ 100 t_o

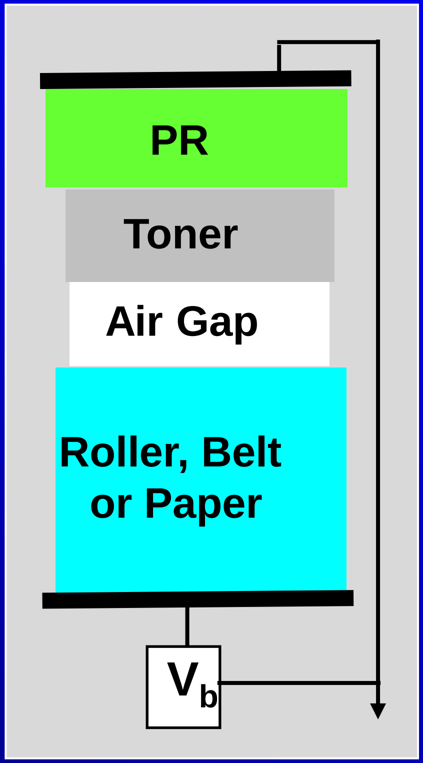




Electrostatic Transfer of Developed Toner

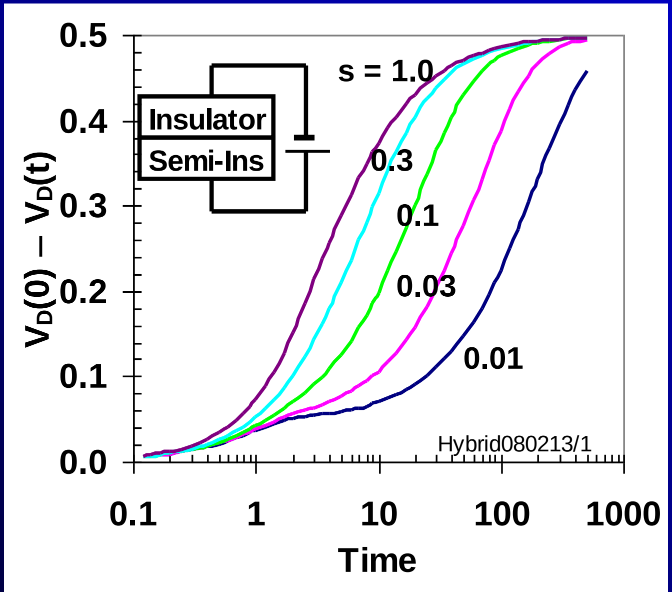
- *Dielectric Relaxation* in receiver
  - Enables efficient transfer without very high V_B
  - increase *transfer efficiency; d*epends significantly on *injection strength s*

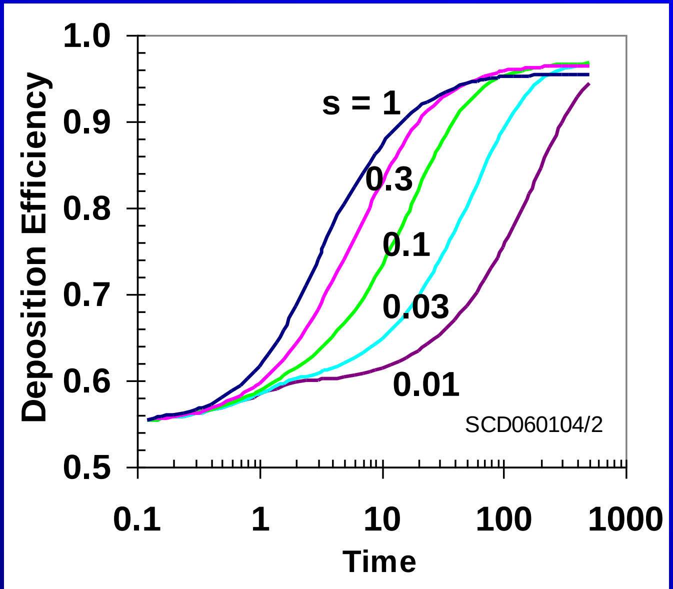




Transient in Dielectric Relaxation is Most Critical to Performance

- 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

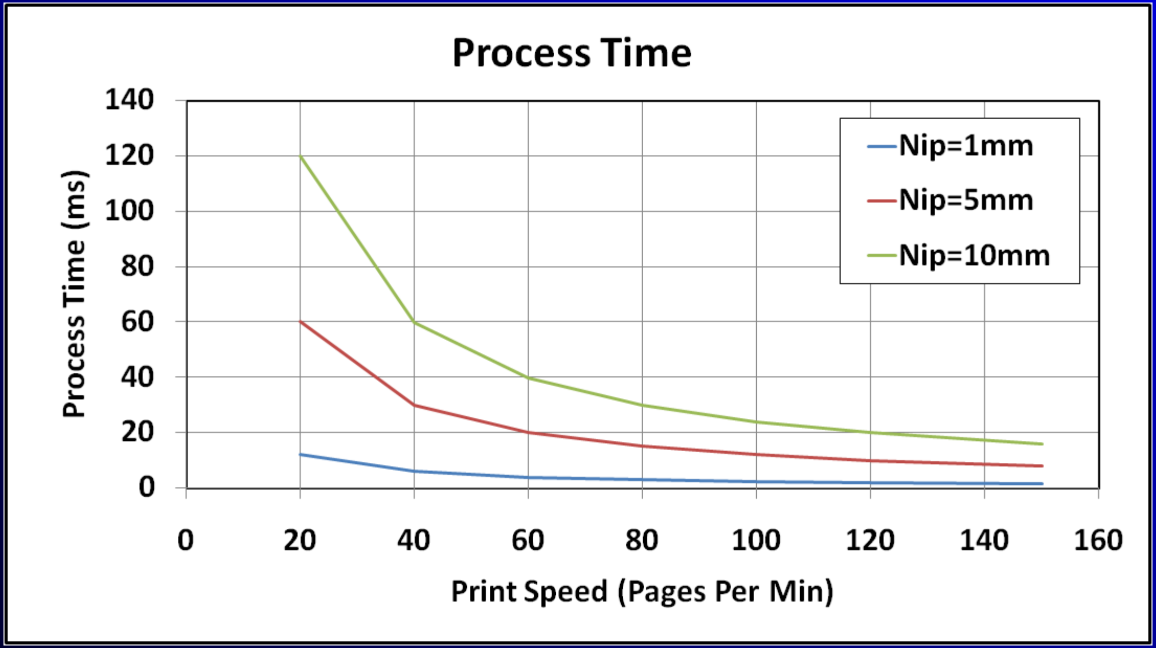




Relaxation Time vs Process Time

- **Roller or Belt Relaxation Time:**

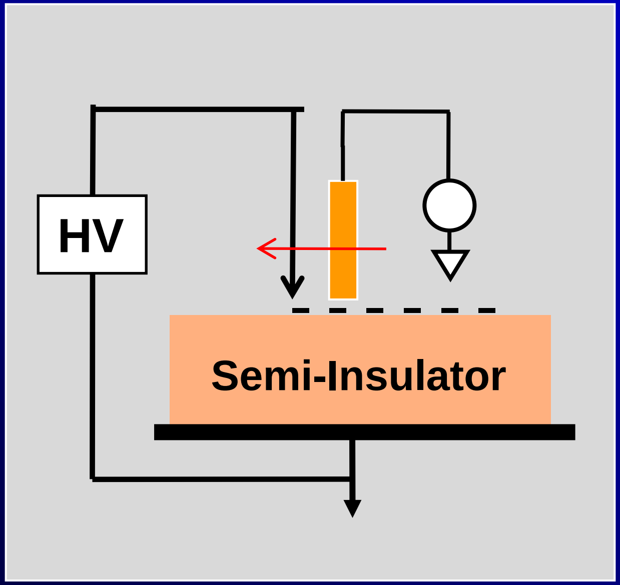
Charge transit time $t_o = L^2/\mu V_B \approx 5$ ms; with: $L \approx 50\ \mu m$, $\mu \approx 10^{-5}\ cm^2/V\text{-}s$, $V_B \approx 500$ volts; full relaxation time is $t_P > 100t_o \approx 0.5$ sec or 500 ms.

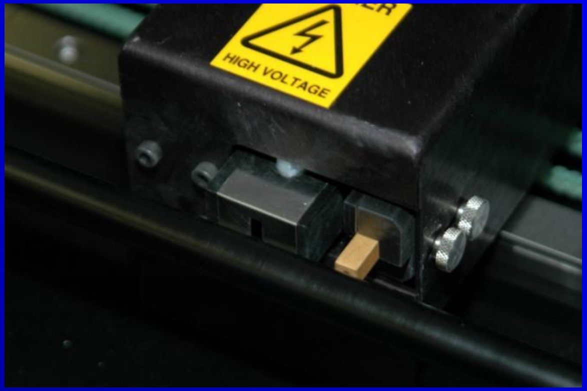


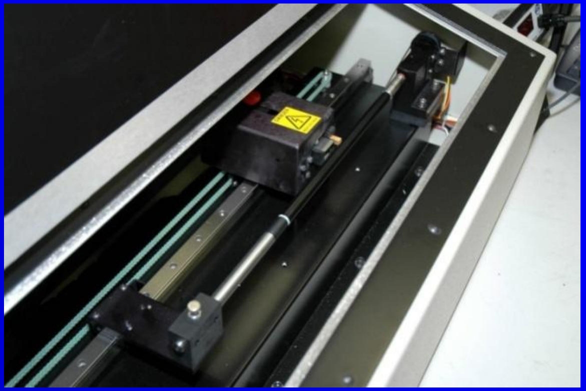
- **Therefore must consider transient behavior in characterization; particularly for high speed printing.**

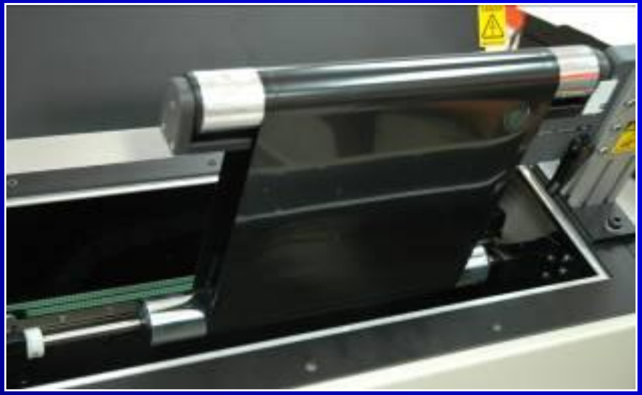
Implementation – the ECD Method

Testing Semi-insulator In Open Circuit



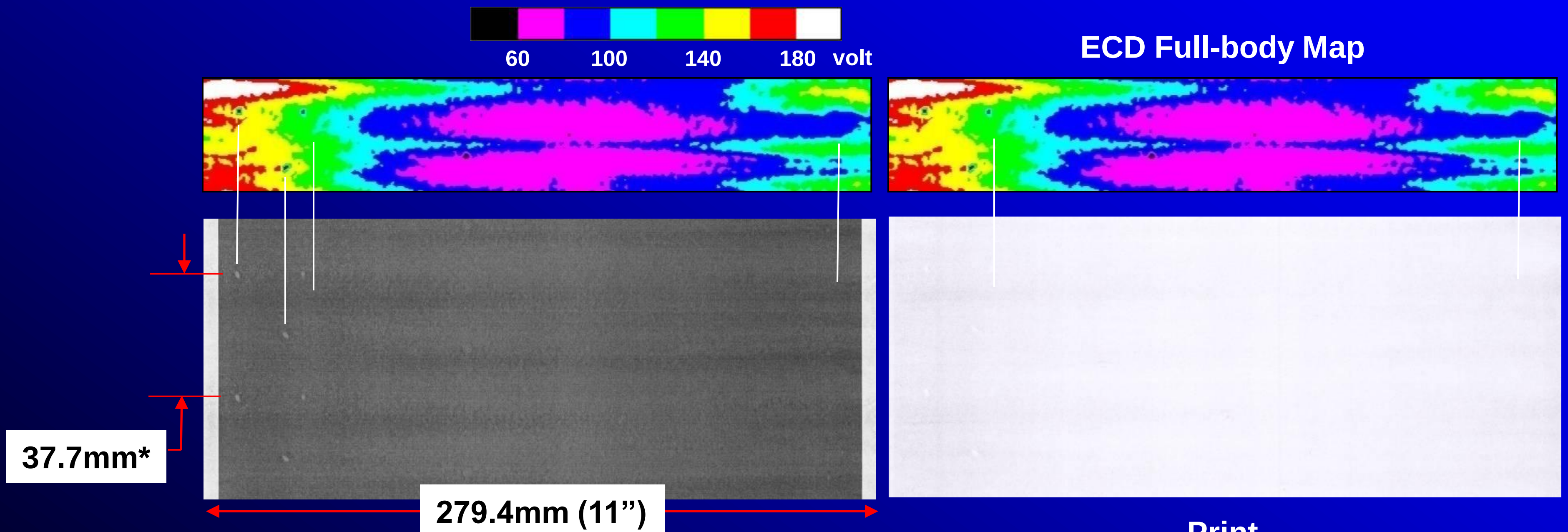






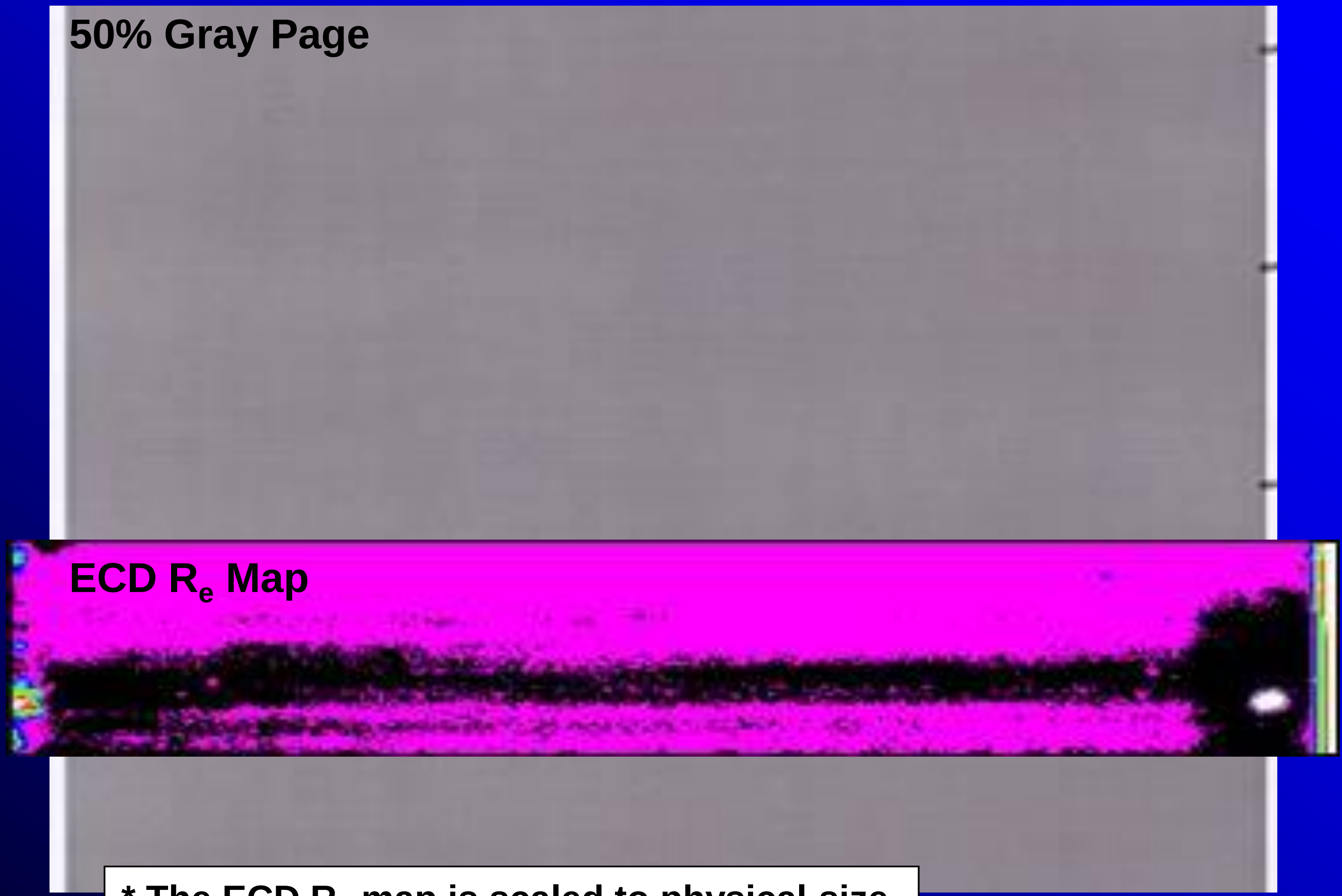
Charge Roller Mapping

- 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.



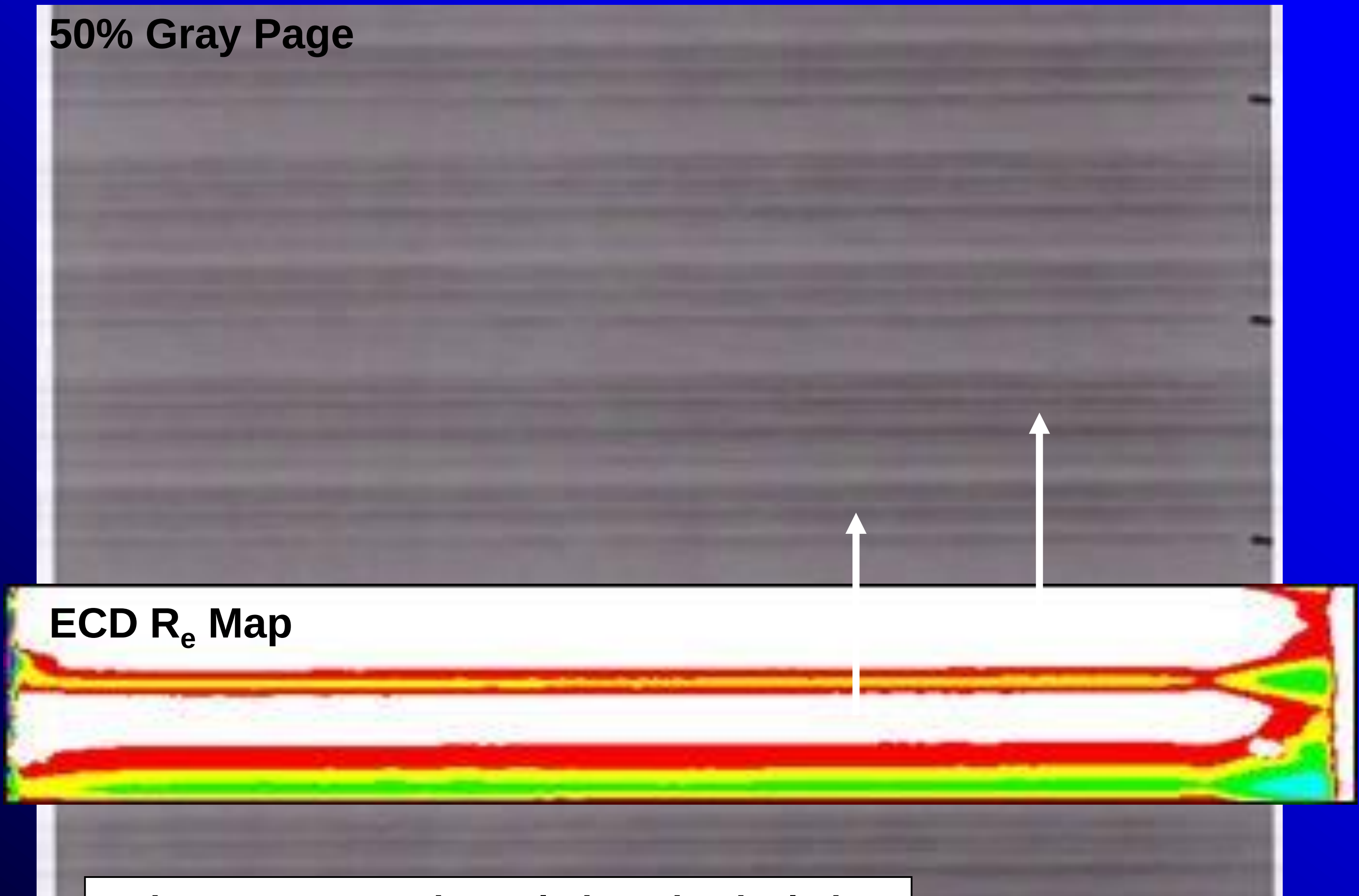
* Charge roller circumference

Good Roller



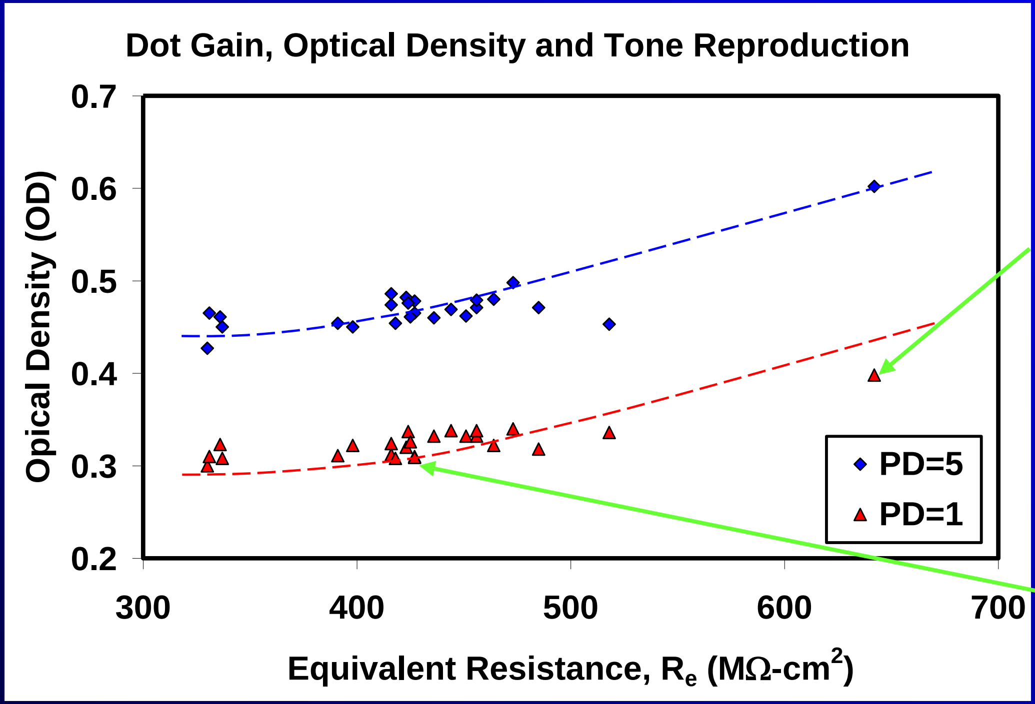
* The ECD R_e map is scaled to physical size.

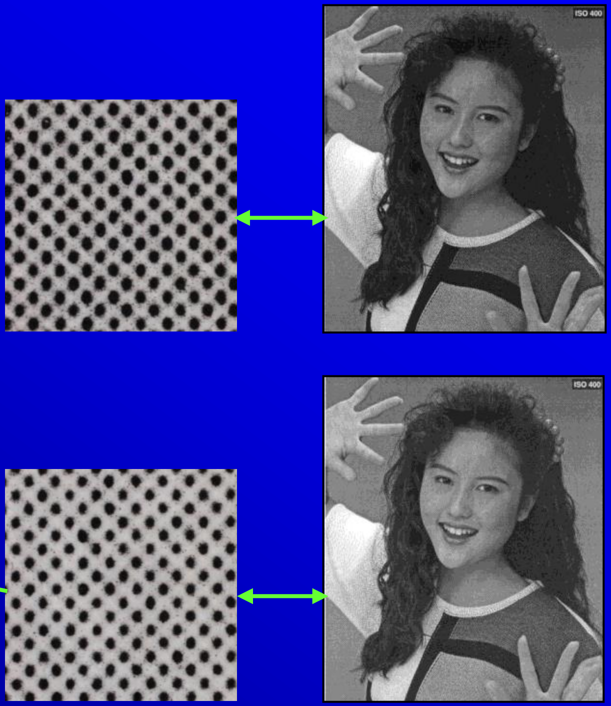
Bad Roller



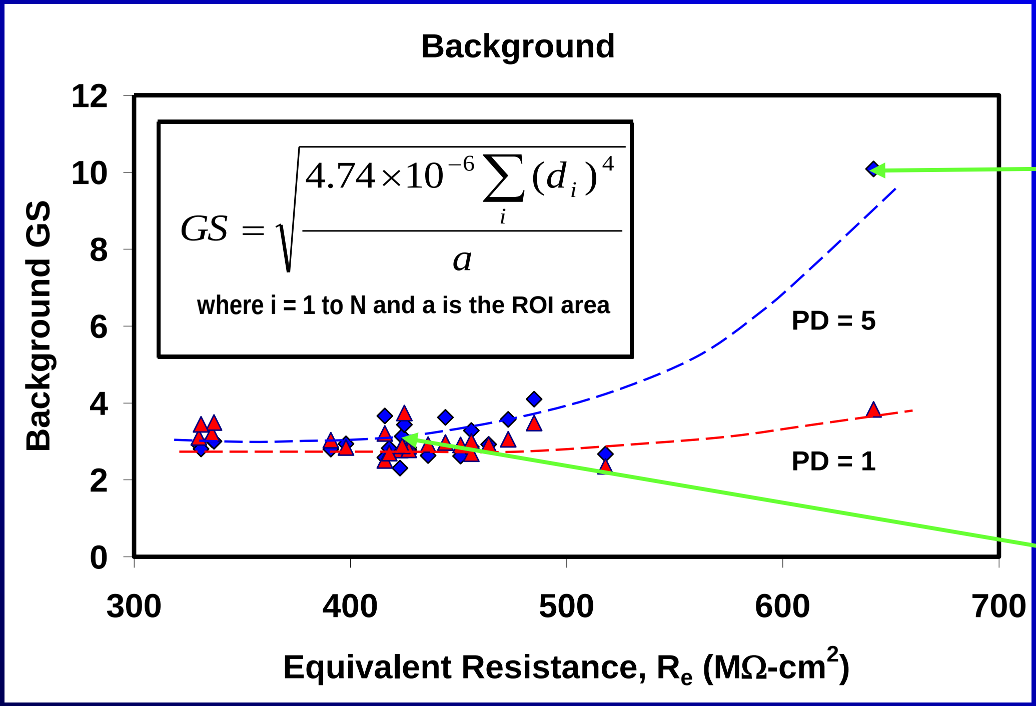
* The ECD R_e map is scaled to physical size.

Dot Gain, Optical Density & Tone Reproduction

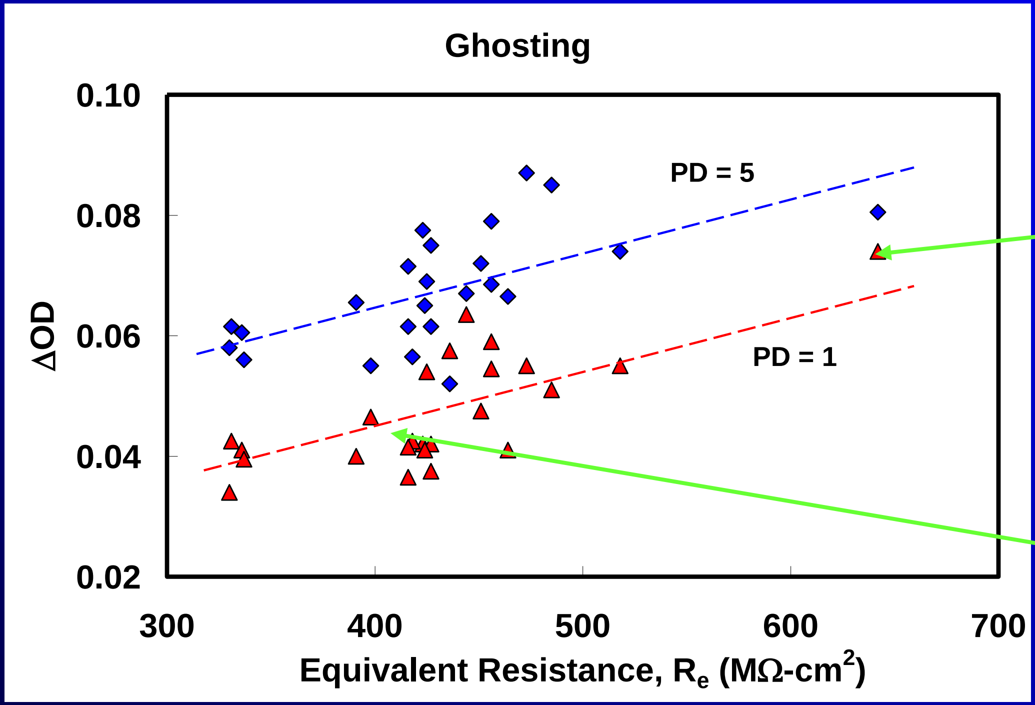




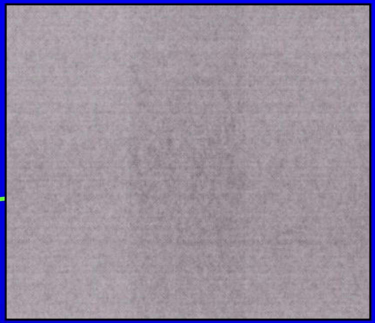
Background

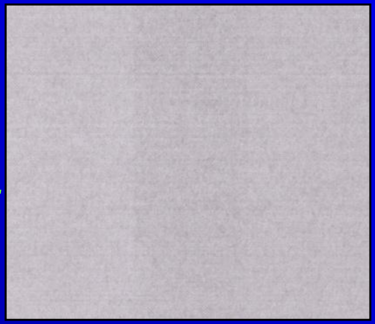

Background
$GS = \sqrt{\frac{4.74\times10^{-6}\sum_i (d_i)^4}{a}}$
where i = 1 to N and a is the ROI area
PD = 5
PD = 1
Background GS
12
10
8
6
4
2
0
300
400
500
600
700
Equivalent Resistance, R_e (MΩ-cm^2)

Ghosting

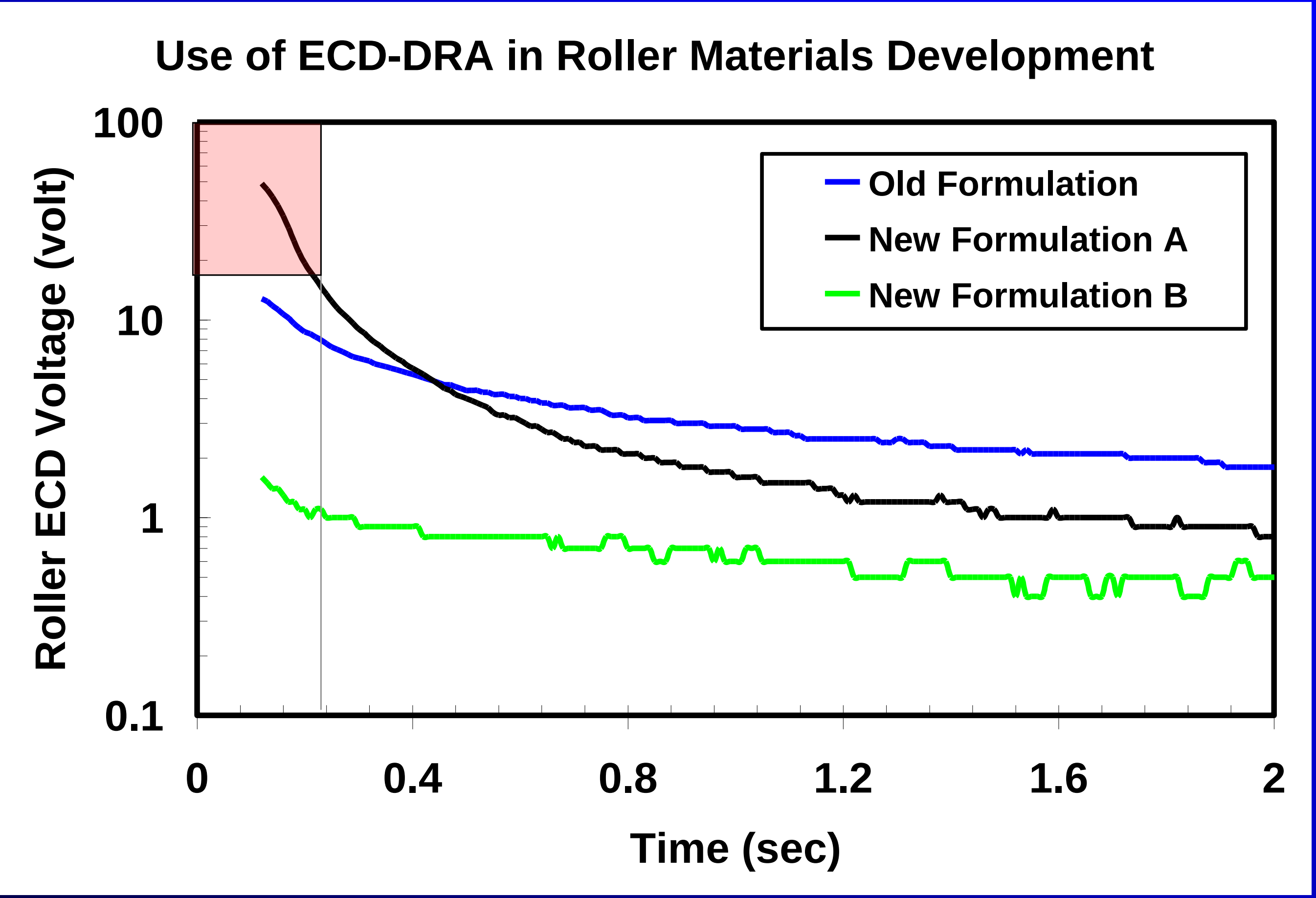


Ghosting
0.10
0.08
0.06
0.04
0.02
ΔOD
300
400
500
600
700
Equivalent Resistance, R_e ($M\Omega\text{-}cm^2$)
PD = 5
PD = 1

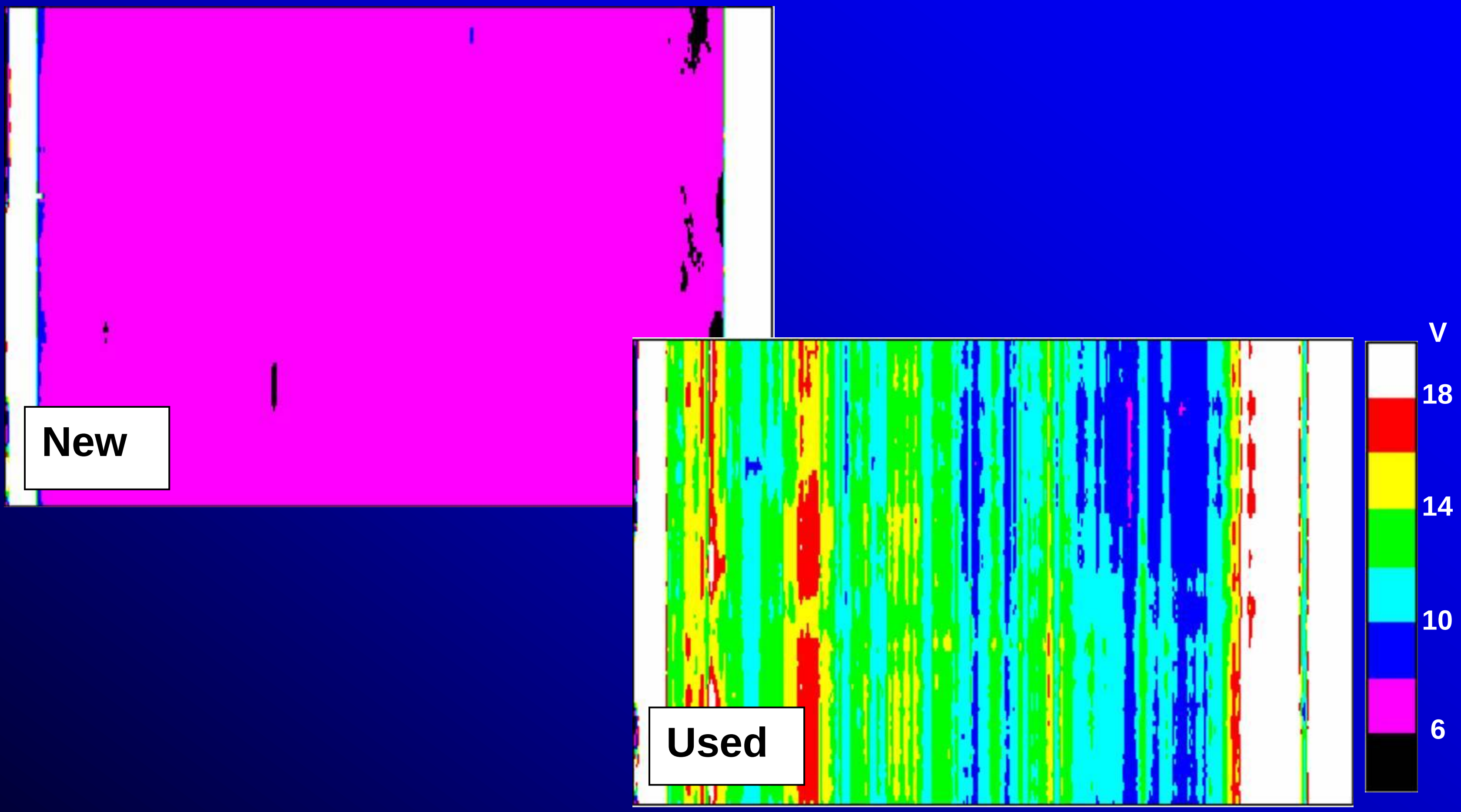




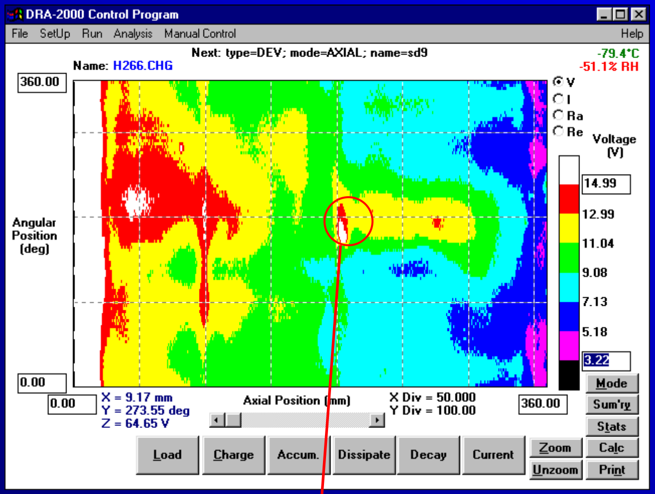
Application Example – Material Formulation

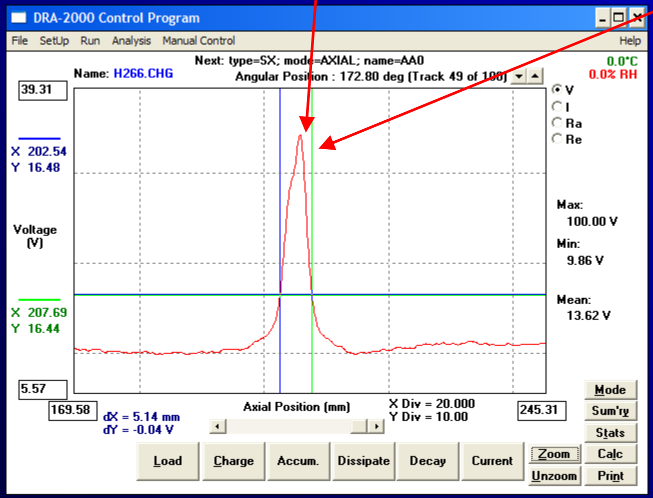


Application Example – Roller Aging



Development Roller



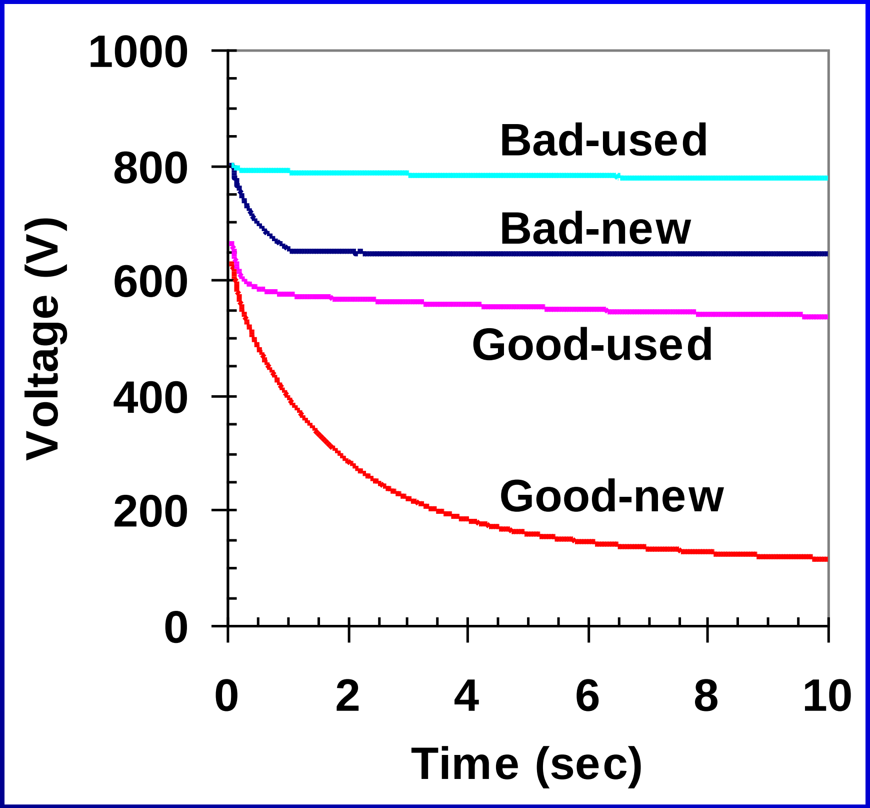


A cut in the roller

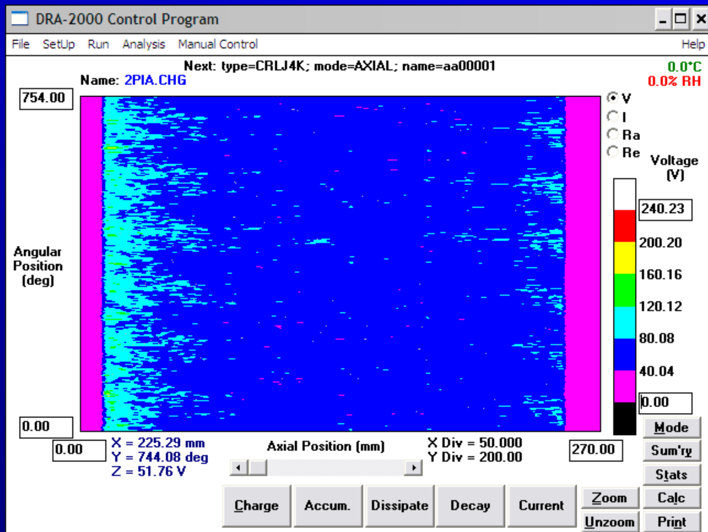
ITB – Failure Analysis

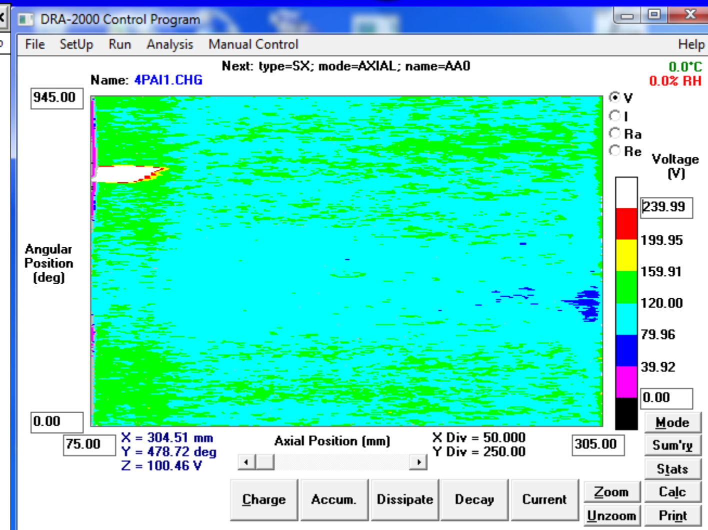
First data points V(0):
- Low for good,
- high for bad
- same for new and used
- → intrinsic charge

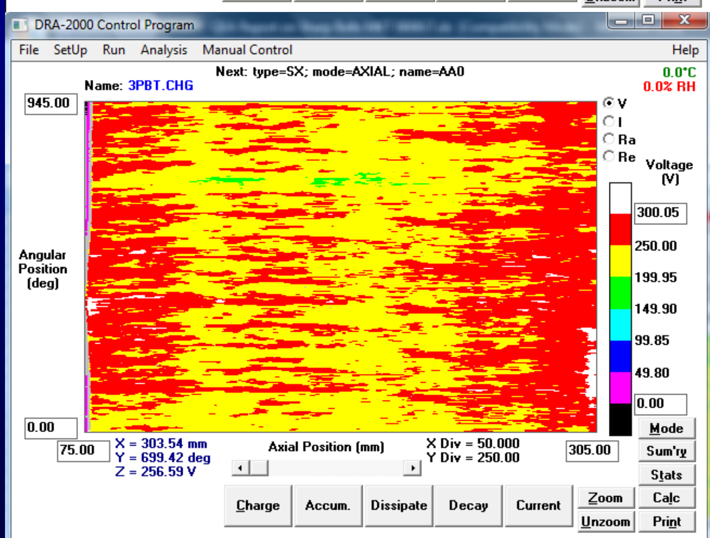
Voltage decay V(t):
- Fast for new
- Slow for used
- → injected charge

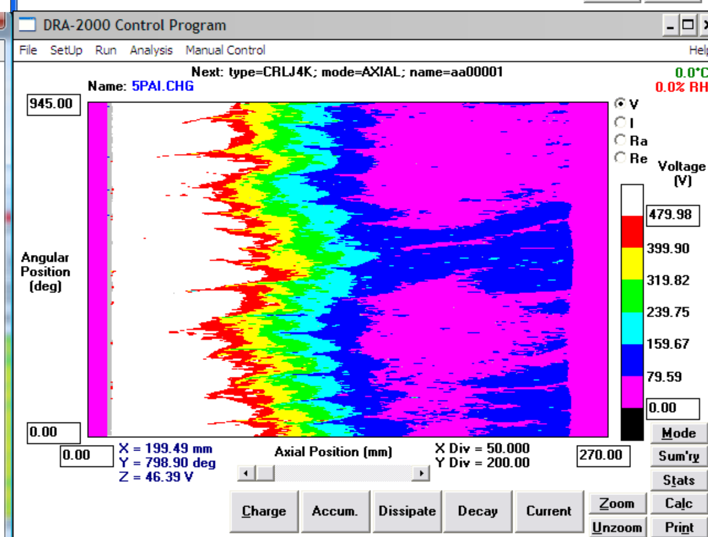


ITB - Benchmarking









Summary

- Performance of EP sub-processes using rollers and belts is controlled by dielectric relaxation (DR) of semi-insulating (SI) layer
- Dielectric relaxation induced by charge injection from bias voltage
- Full relaxation of SI 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

Thank you for your attention

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See you in the Exhibit Hall