"Electron Shading": Inevitable … or Not ?

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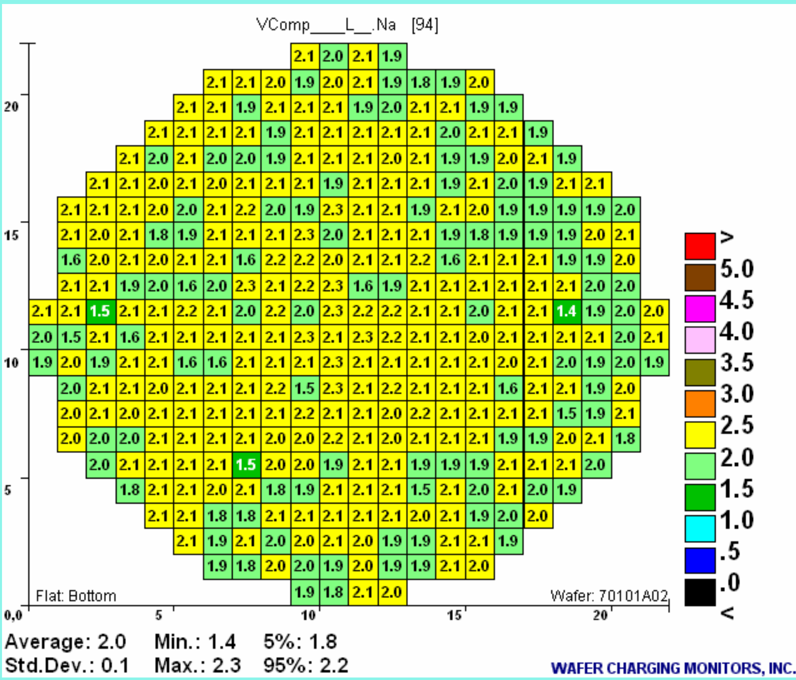
Experiments:

- Use 6-field mask to pattern 1.2 µm resist on CHARM-2 wafers
- Quantify “electron shading” in:
  - Uniform etching plasma
  - Non-uniform etching plasma
  - High energy, high current implants
  - Low energy, high current implants

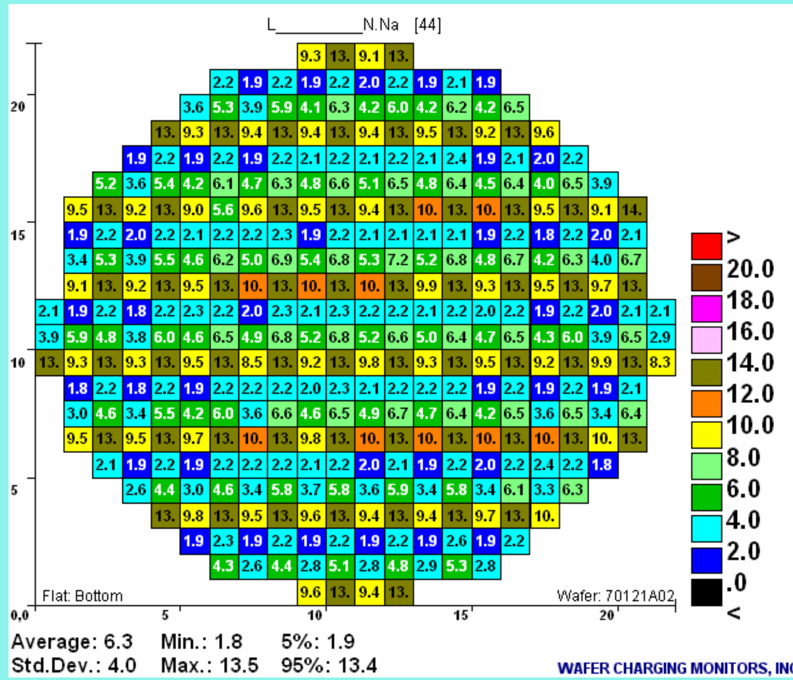
area resist	bare (no resist)
2 µm holes	1.5 µm holes
1 µm holes	0.5 µm holes

Uniform Plasma: Positive Potentials

No resist



Patterned resist



"Electron shading" evident on patterned wafer

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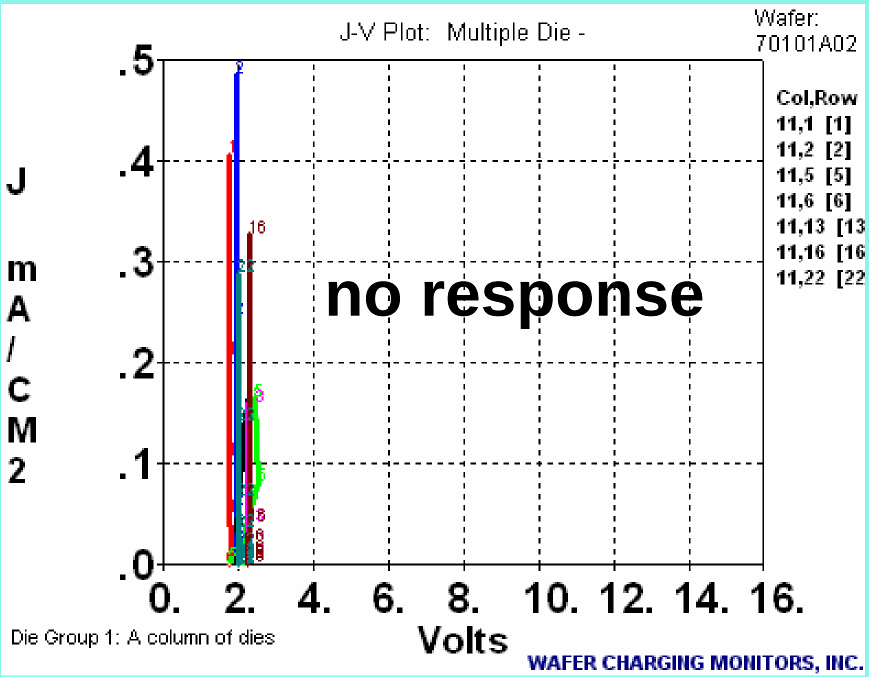
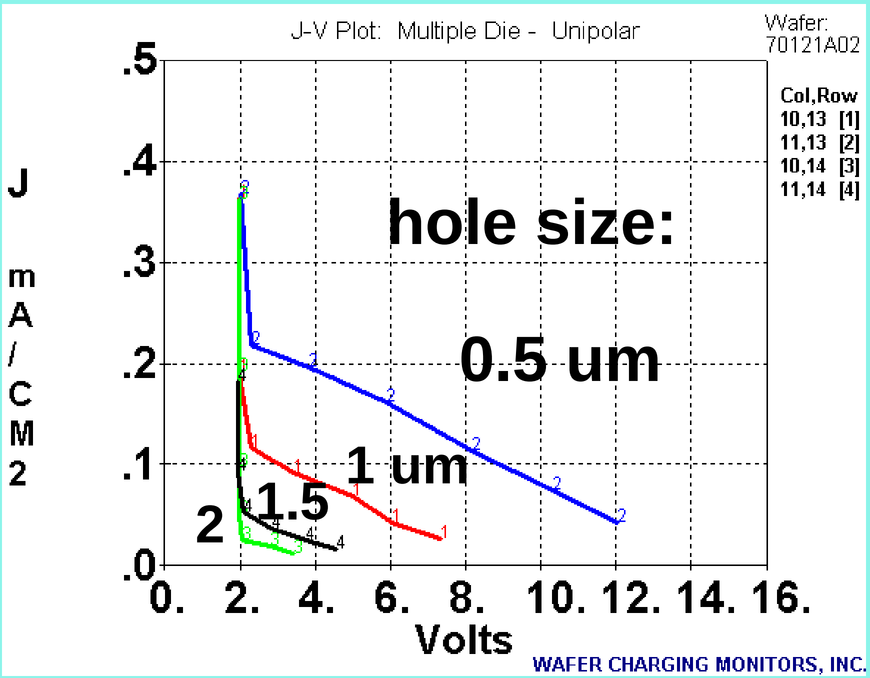
Uniform Plasma: Positive J-V

No resist



Patterned resist



“Electron shading” depends on feature size

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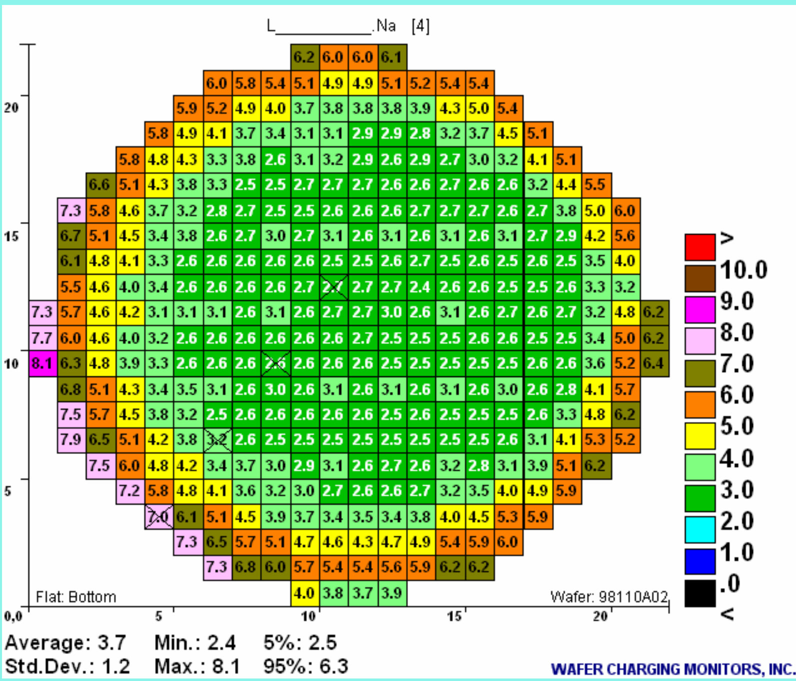
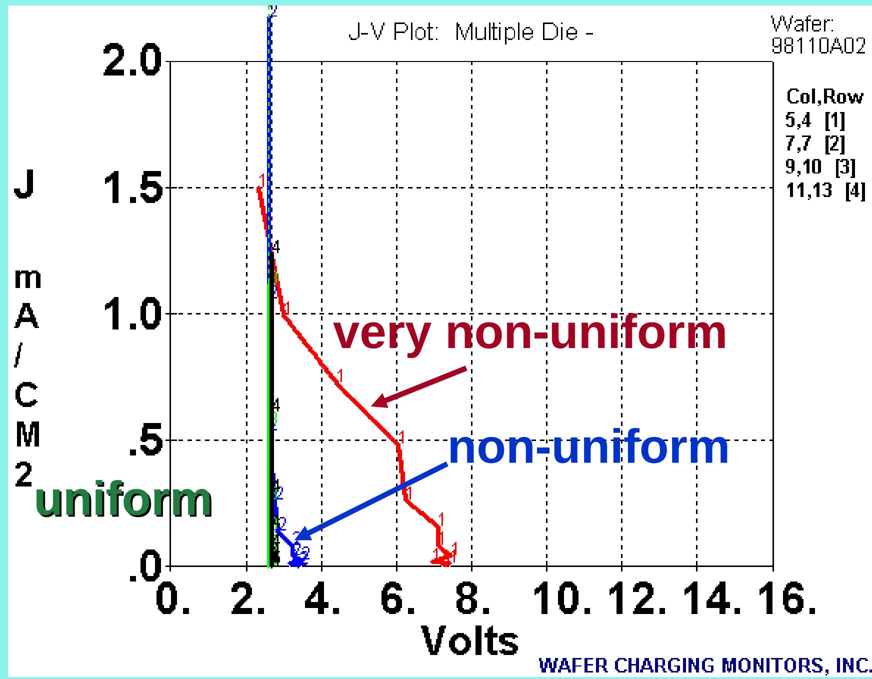
Non-uniform Plasma: Positive Charging

No Resist

Positive potentials



Positive J-V



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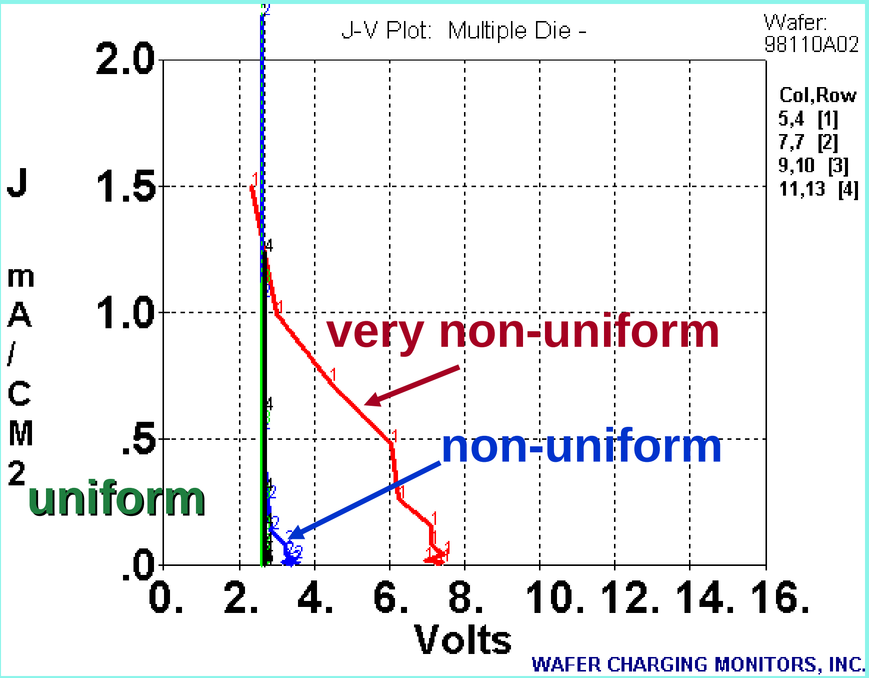
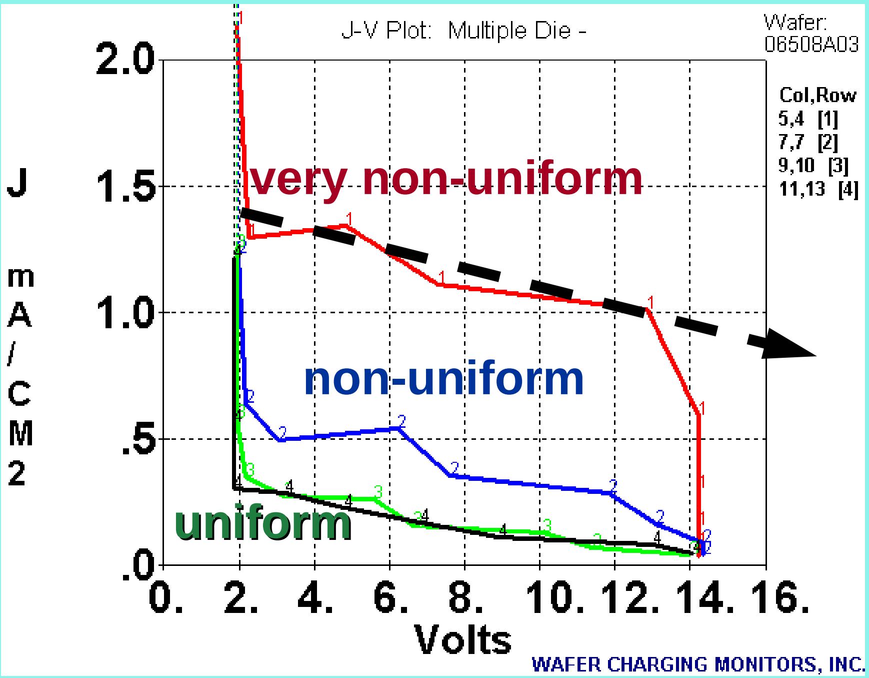
Non-uniform Plasma: Positive J-V

No resist



Patterned resist



Non-uniform plasma increases “electron shading”

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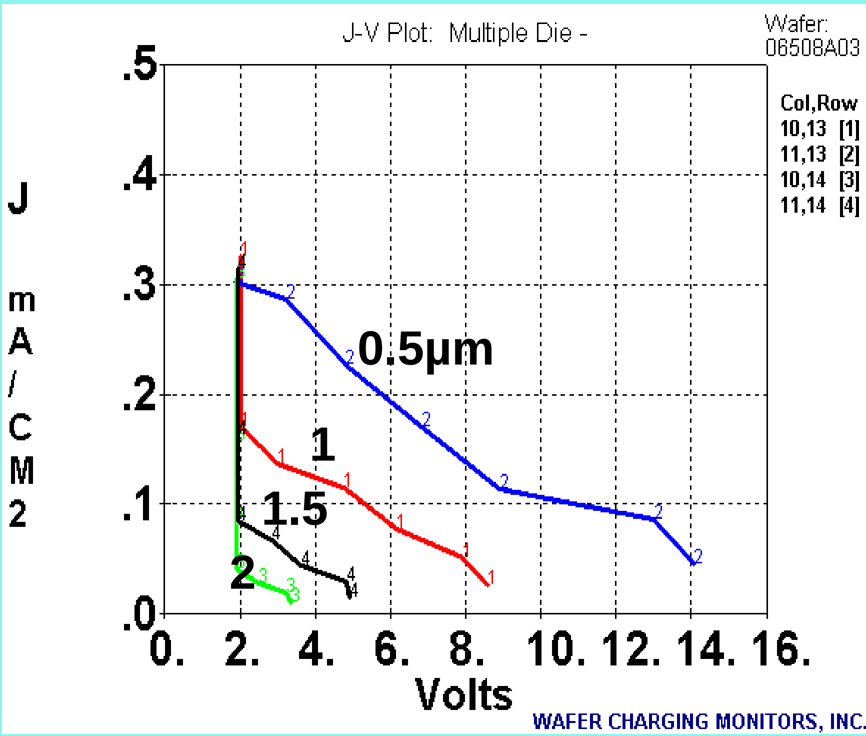
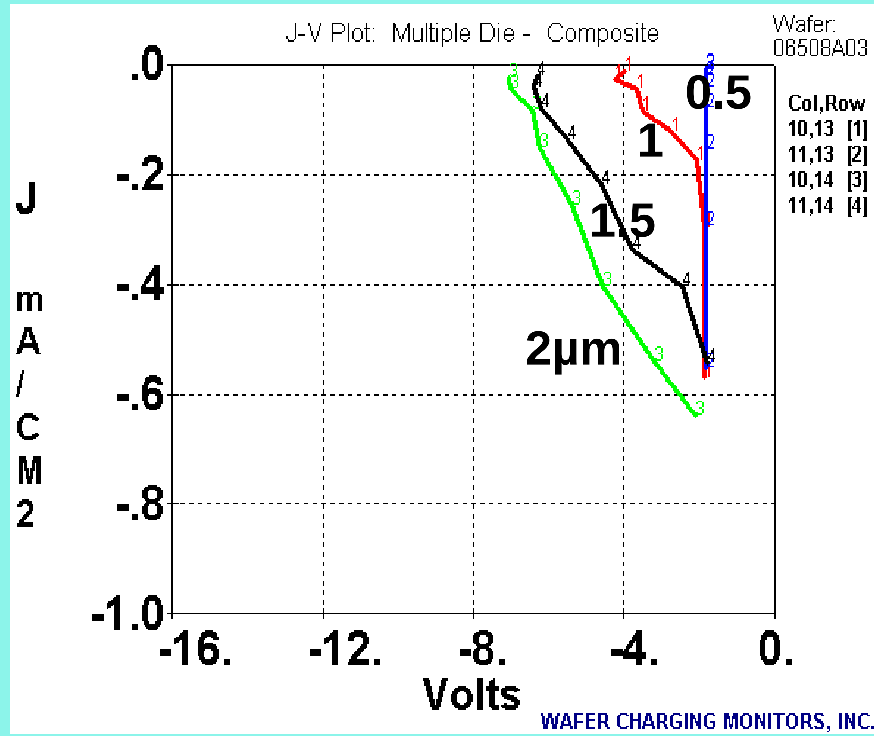
Non-uniform Plasma: pos. and neg. J-V

Positive J-V



Negative J-V



"Electron shading" is bi-polar

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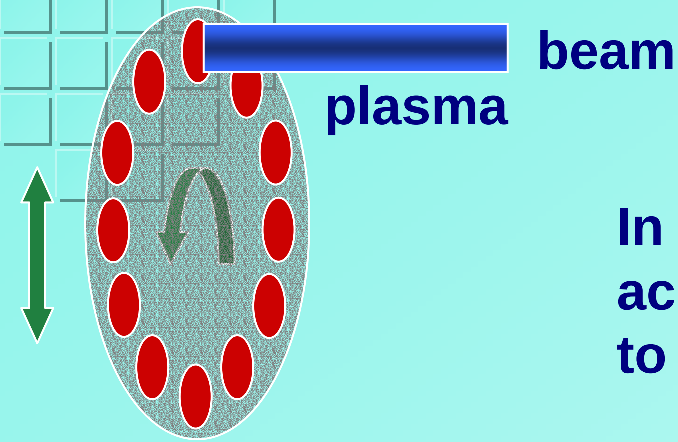
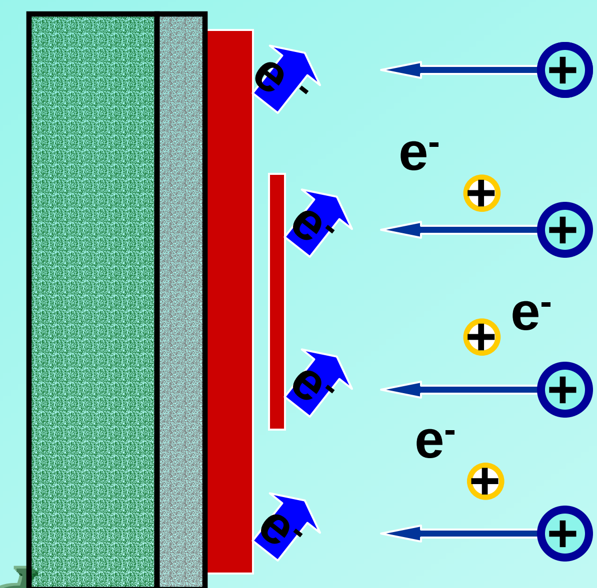
Charging in Ion Implantation



In high current implanters, wafers move across the ion beam ⇒ devices are exposed to positive and negative charging <u>pulses.</u>



Charge fluxes at wafer surface:

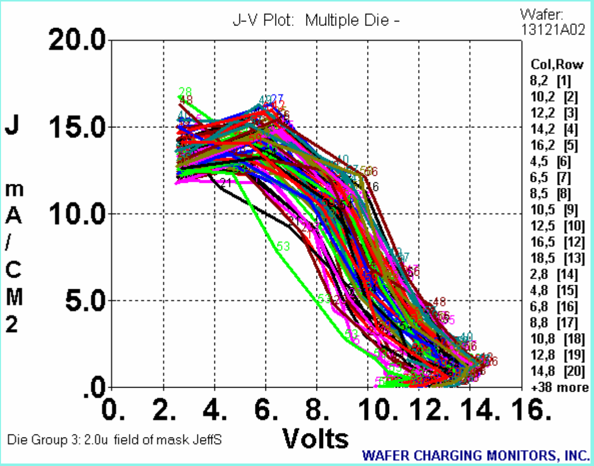
- Implanted ions
- Secondary electrons
- Plasma ions
- e^- Plasma electrons (low energy)

$$J_{net} = J_{beam}(1 + \gamma) + J_p - J_e$$

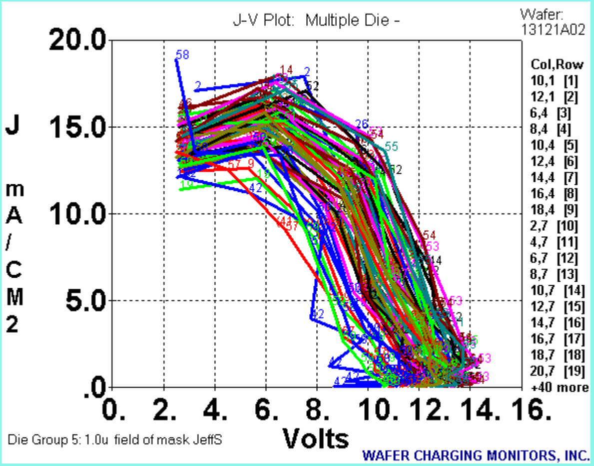
Exp. 1: Positive J-V: 80 keV As^+

PFS: “standard” flood

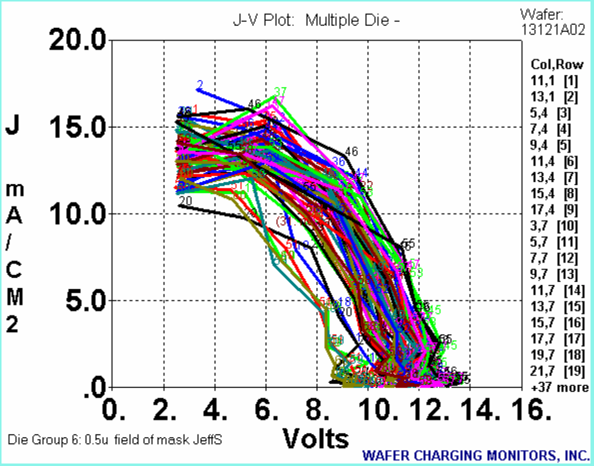
2µm holes



1µm holes



0.5µm holes



Positive charging is independent of hole size.

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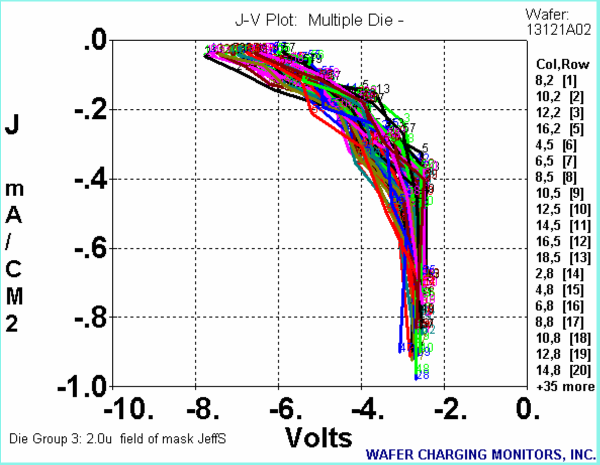
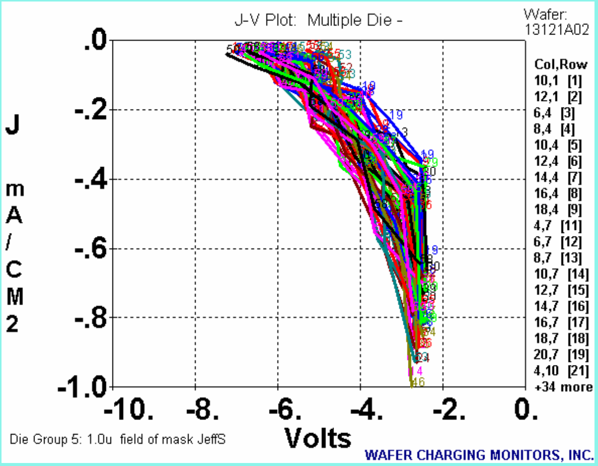
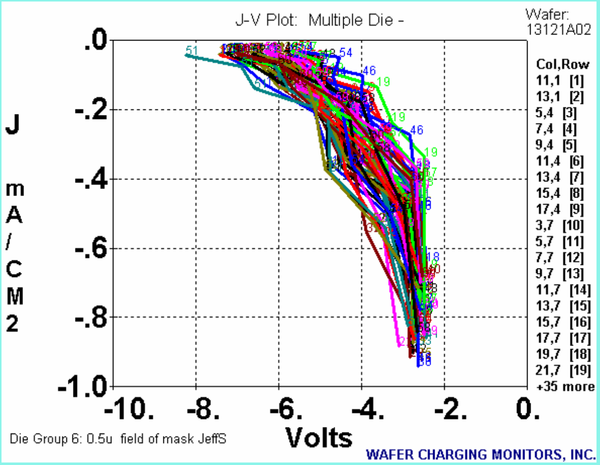
Exp. 1: Negative J-V: 80 keV As^+

PFS: “standard” flood

2µm holes	1µm holes	0.5µm holes







Negative charging is independent of hole size.

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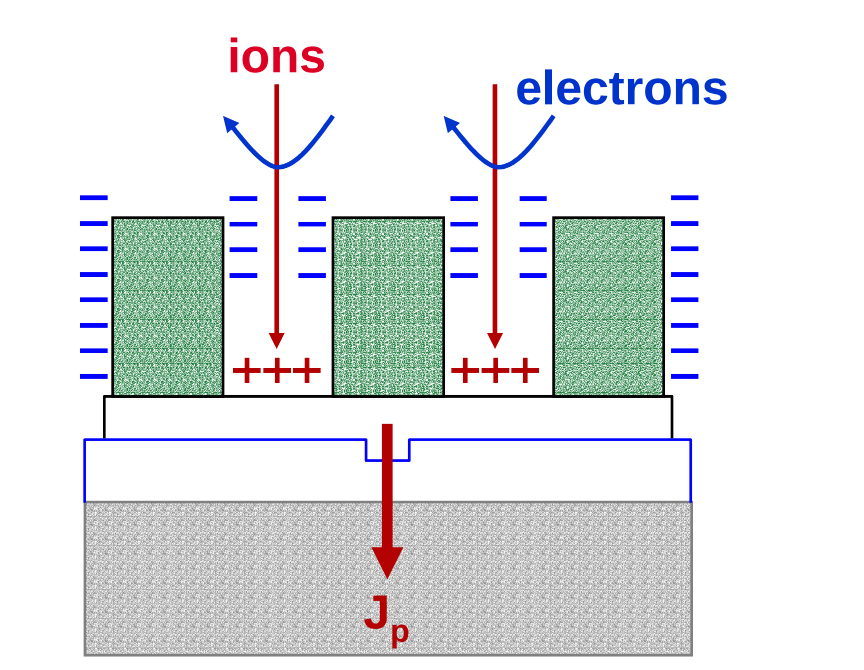
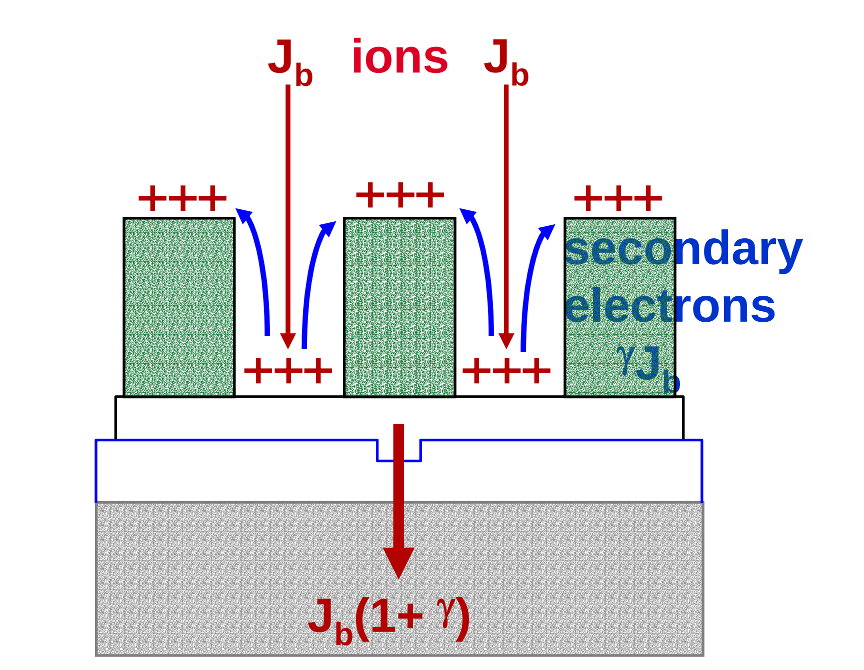
Charging models:

Plasma



Build-up of negative charge at inside top of resist features creates potential barrier for electrons, causing net positive charge collection at bottom of narrow resist holes.

Ion Implant



Collection of secondary electrons by positively-charged resist causes positive charging at bottom of resist holes. Effect is independent of hole size.

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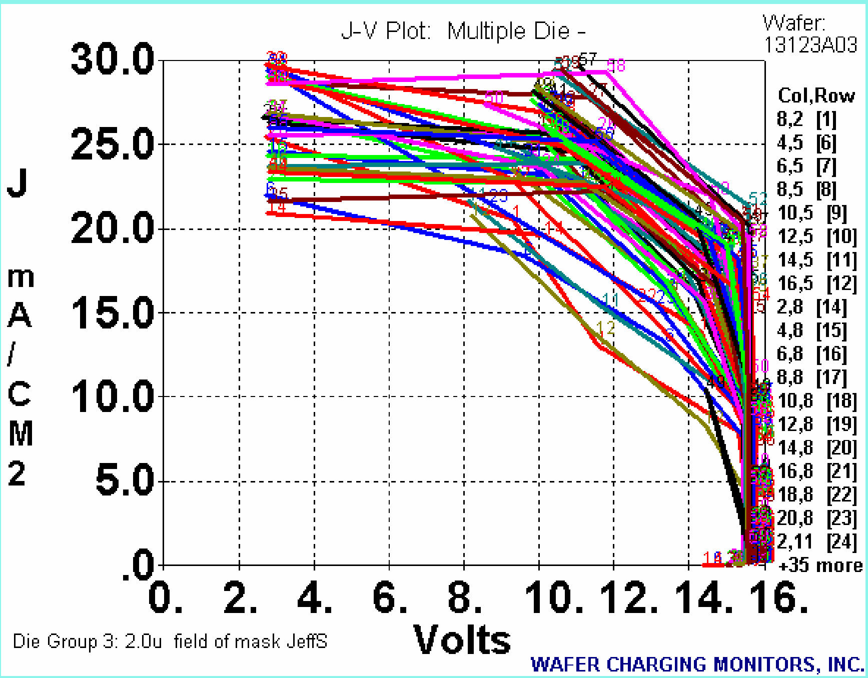
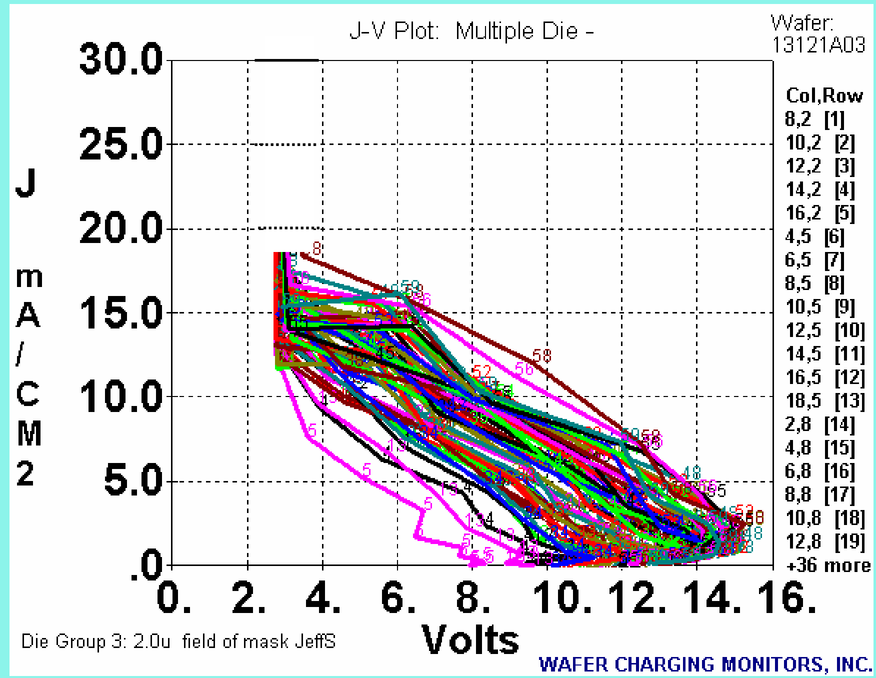
Exp. 2: Pos. J-V: As+; 2um holes

PFS: “low” vs. “high”

Low flood



High flood



Increased flood reduces positive charging.

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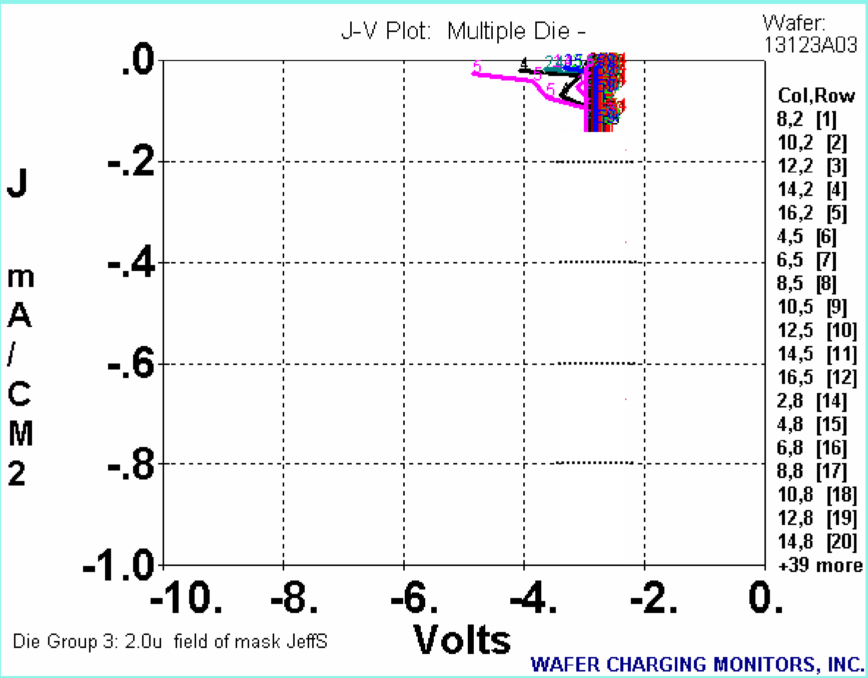
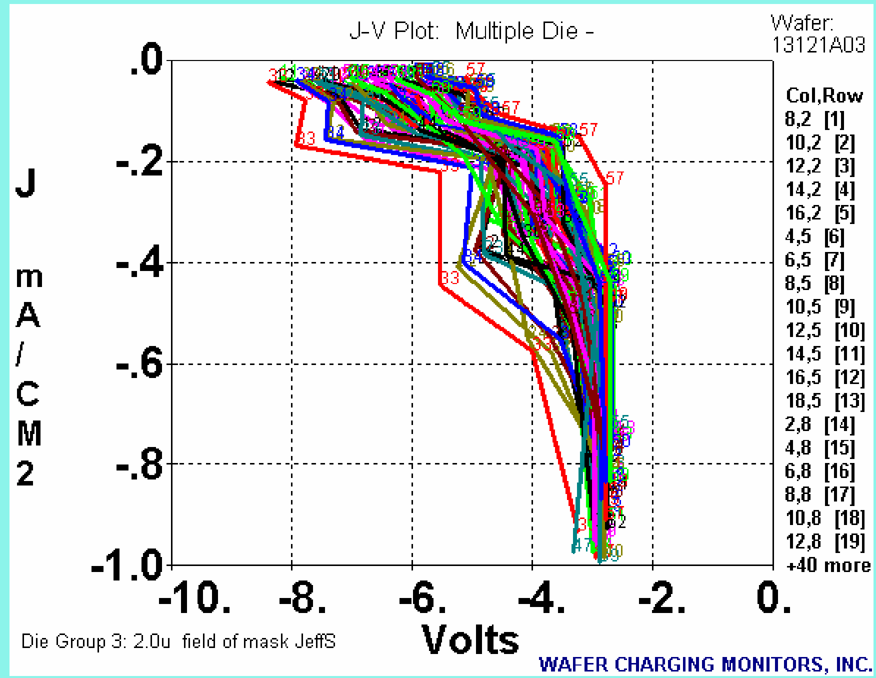
Exp. 2: Neg. J-V: As$^+$; 2um holes

PFS: “low” vs. “high”

Low flood



High flood



Increased flood increases negative charging.

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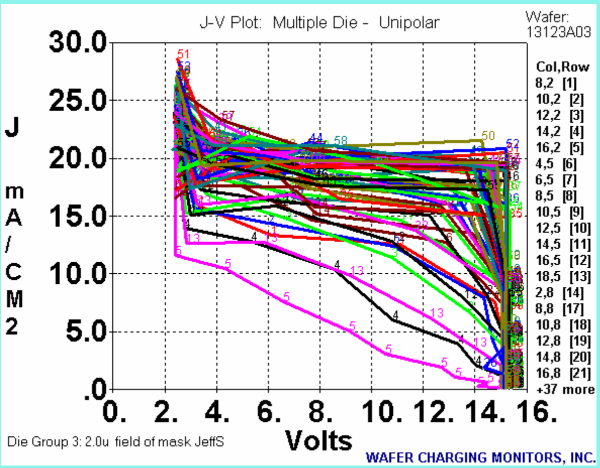
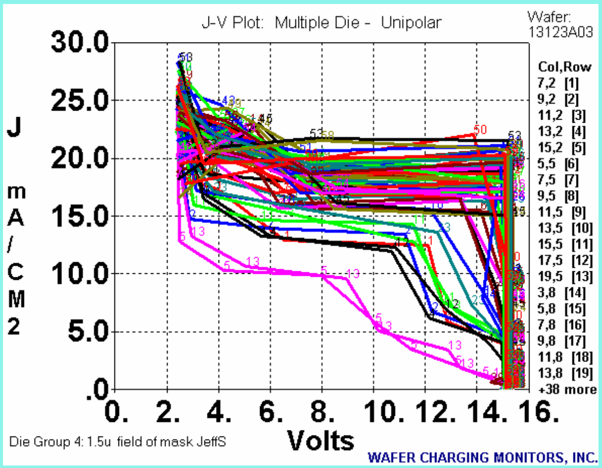
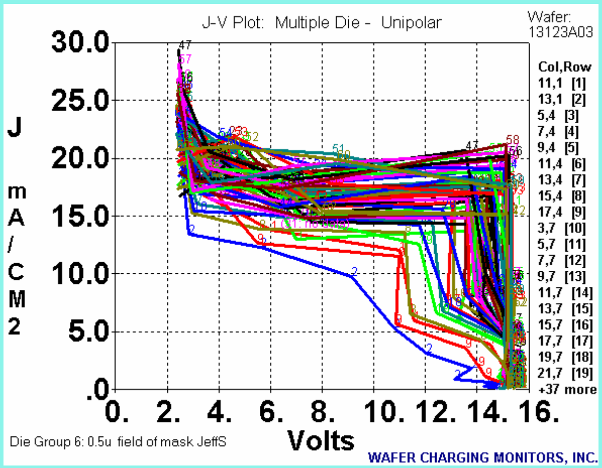
Exp. 3: Pos. J-V: 500 eV B^+

HD-PFS: “bias” mode

2µm holes	1µm holes	0.5µm holes







Positive charging is independent of hole size.

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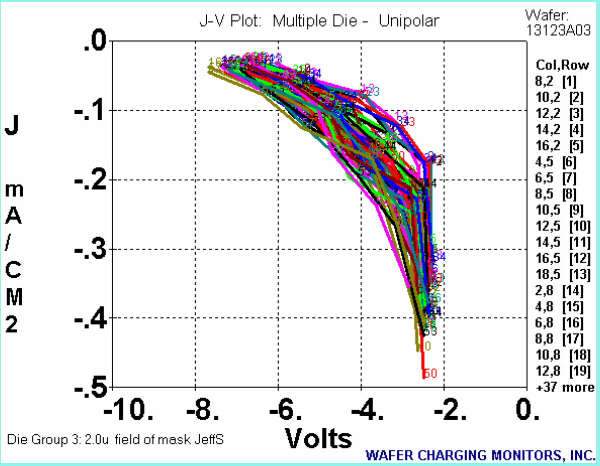
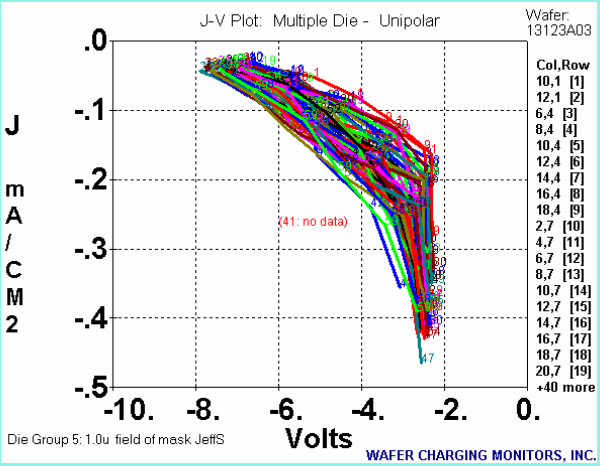
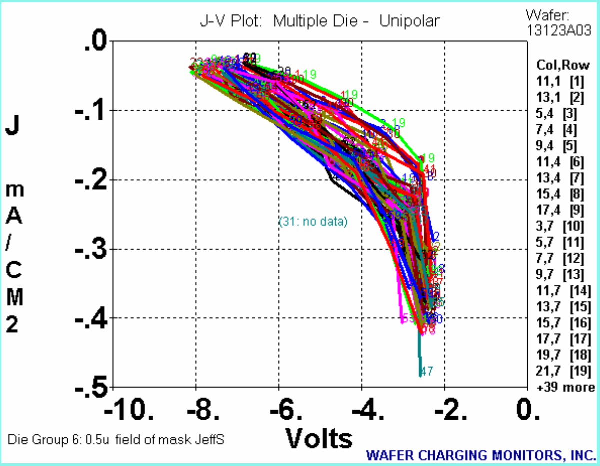
Exp. 3: Neg. J-V: 500 eV B^+

HD-PFS: “bias” mode

2µm holes	1µm holes	0.5µm holes







Negative charging is independent of hole size.

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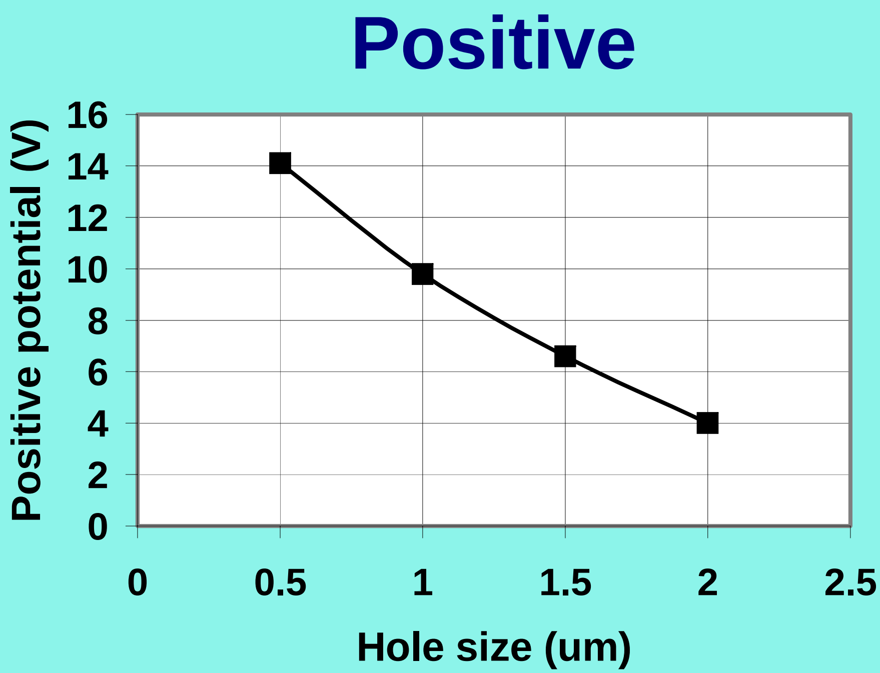
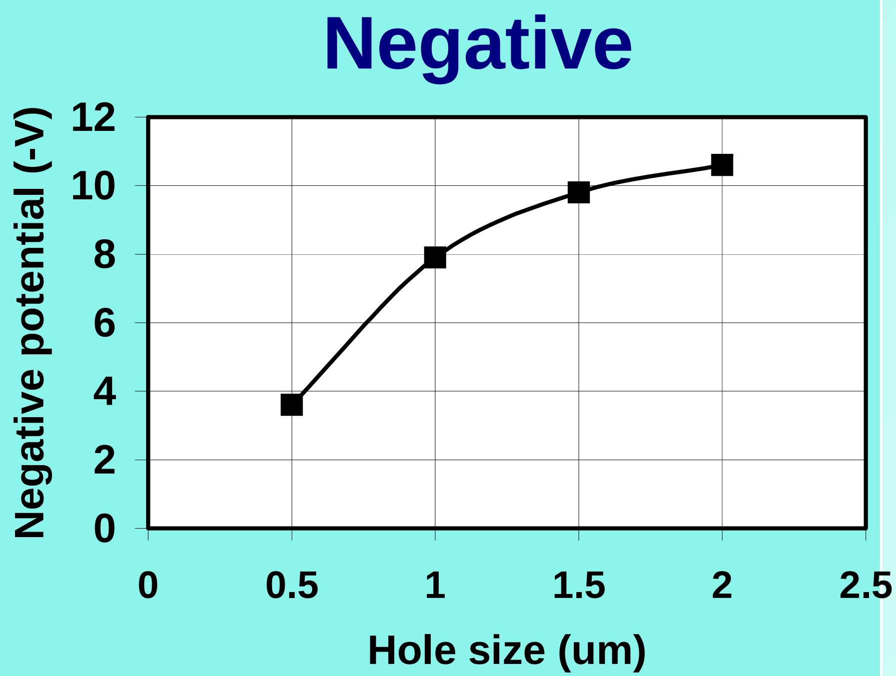
Exp. 3: Potentials: 500 eV B^+

HD-PFS: A/D mode (rec.)





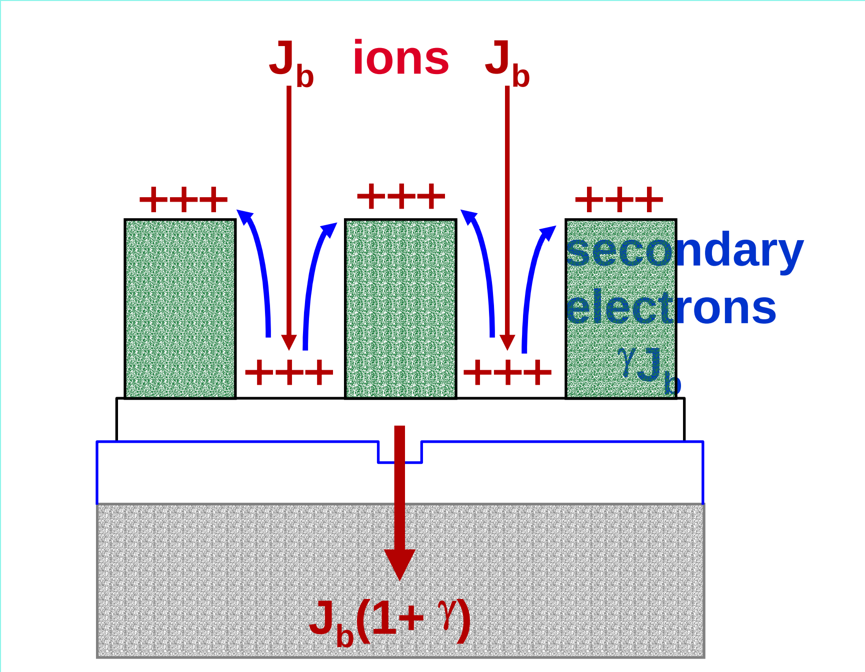
Potentials depend on hole size ⇒"electron-shading".

Current densities below detection level (<15µA/cm^2)

⇒ **nearly perfect charging balance**.

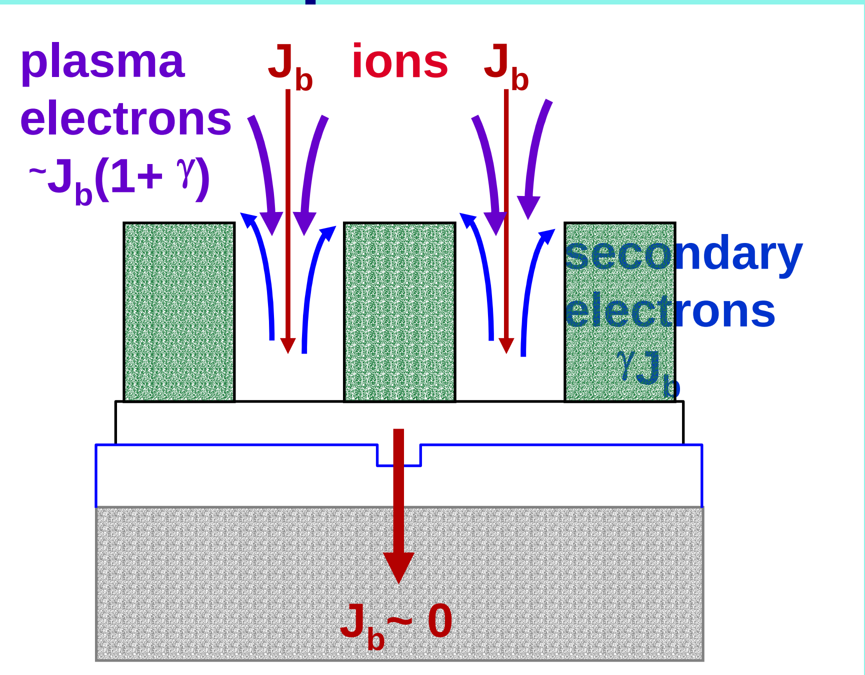
Charging models:

Under-flood



Collection of secondary electrons by positively-charged resist causes positive charging at bottom of resist holes. Effect is independent of hole size.

Proper flood



Low T_e plasma electrons from HD-PFS neutralize positive charge from the ion beam and secondary electrons. Nearly perfect neutralization was achieved.

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Conclusions:

- "Electron shading" effect is measurable with resist-patterned CHARM-2 wafers.
- Non-uniform plasmas significantly increase the "electron shading" effect in etching tools.
- Charging in ion implanters depends on plasma flood system design and set-up, <u>not</u> on ion energy.
- Nearly perfect charge neutralization was achieved for 500 eV B^+ using low T_e HD-PFS.
- This suggests that "electron shading" in etchers might be avoided if ion and electrons are independently controlled, as in high-current ion implanters.

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Acknowledgments:

- Special thanks go to Dr. Jeffrey Shields, Dr. Sonu Daryanani, and Rohan Braithwaite of Microchip Technology Inc. for providing CHARM-2 equipment characterization data.
- Special thanks go Dr. Mike Vella for discussion of ion implant results.

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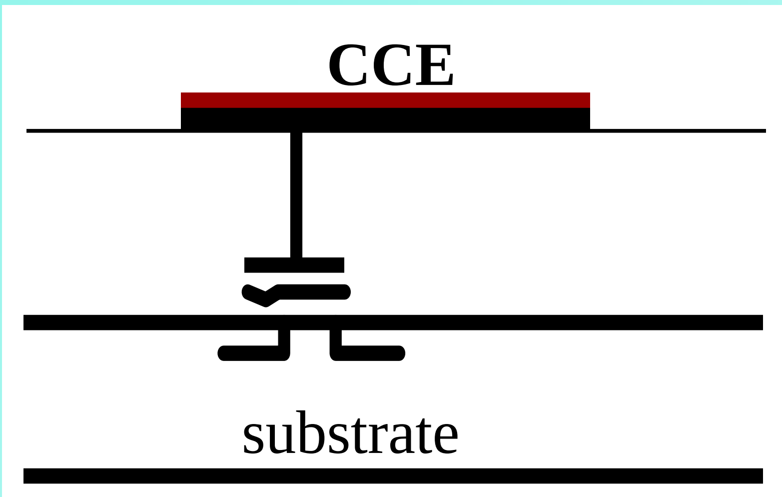
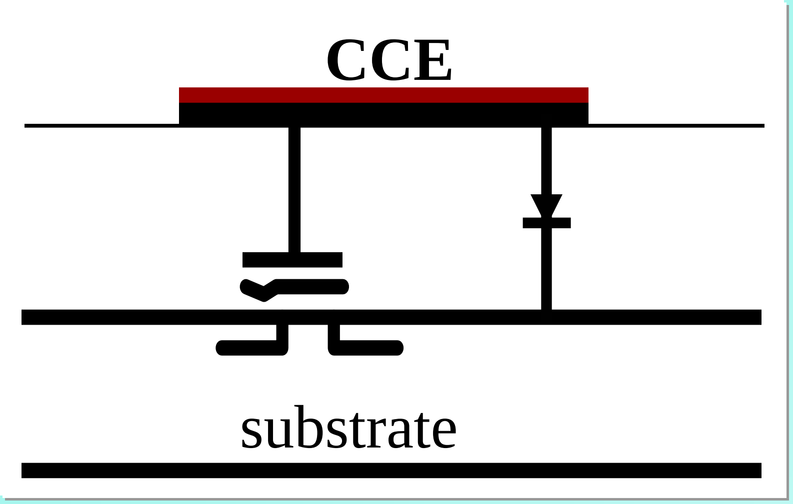
CHARM® -2 Potential Sensors



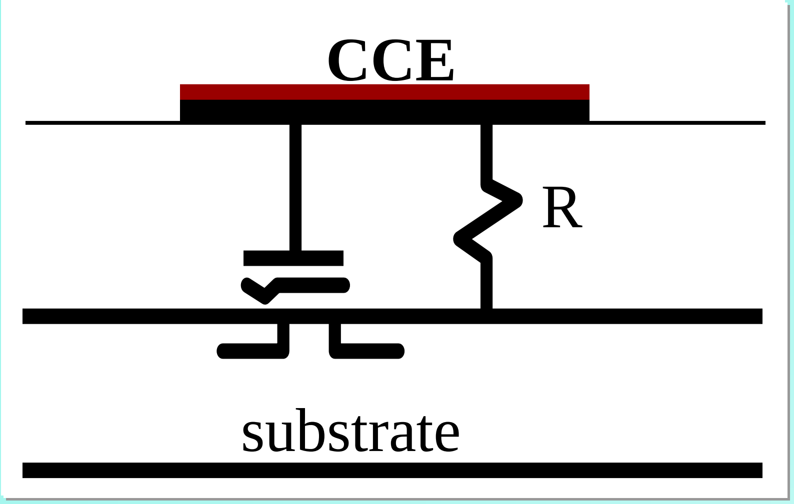
- Analogous to “antenna capacitors”
- EEPROM senses and records CCE potential
- More sensitive than “antenna” capacitors
- Calibrated to measure in Volts (incl. polarity)

CHARM® -2 Unipolar Potential Sensors



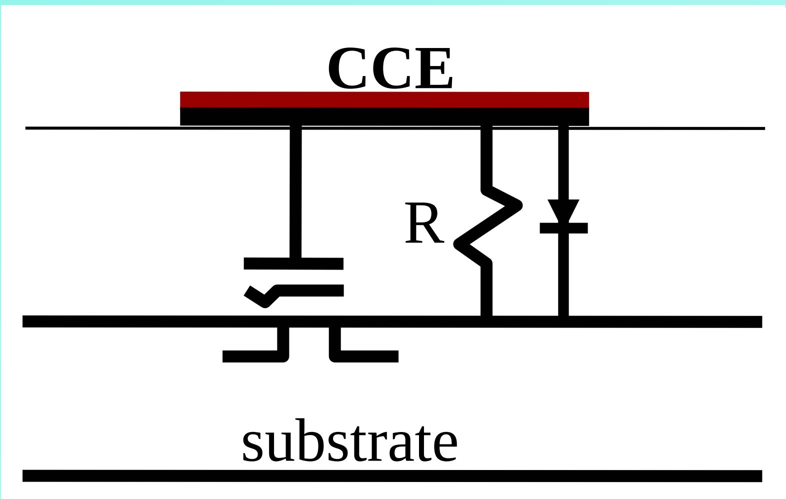
- Analogous to “antenna capacitors”
- EEPROM senses and records CCE potential
- More sensitive than “antenna” capacitors
- Calibrated to measure in Volts (incl. polarity)
- Cannot be “over-written” by opposite polarity

CHARM® -2 Charge-Flux Sensors



- Potential sensors with calibrated current-sensing resistors
- EEPROM records the potential across the current-sensing resistor
- Calibrated to measure charge-flux in Amps/cm^2 (incl. polarity)

CHARM® -2 Unipolar Charge-Flux Sensors



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