High Resolution Mapping of Sheet Resistance of Ultra Shallow Implants Can Reveal Implanter or Anneal Non-Uniformities

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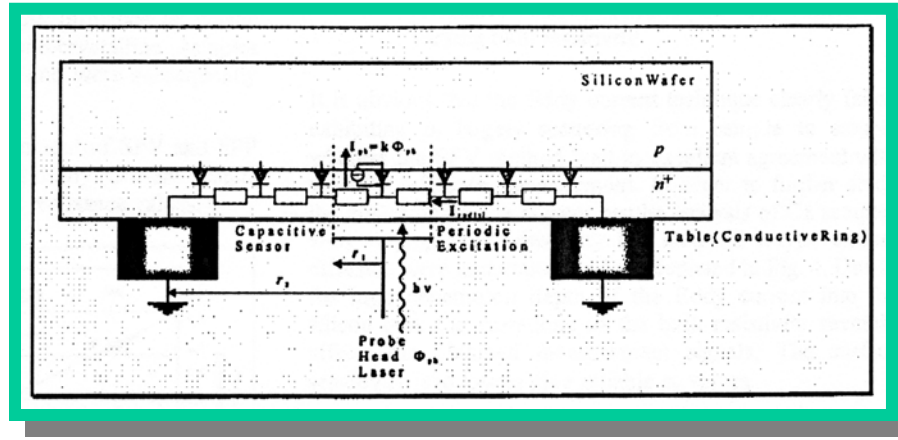
Agenda

- Semilab’s Development of the JPV Measurement Technique
- Simple Theory of Operation
- Sample Measurements
- Performance Variation in JPV Systems
- Additional Wafer Maps
- Summary

Semilab Development of JPV Technique

- Used since 2003 for measuring sheet resistance in solar cells[1]
- EU project to optimize JPV for implants
  - Started in 2006
  - www.sea-net.info SP:11 LEAD-IT (Low Energy And Dose Implant Test)
  - Partners include ST-Micro, Philips, and Fraunhofer



Semiconductor Equipment Assessment for NanoElectronic Technologies

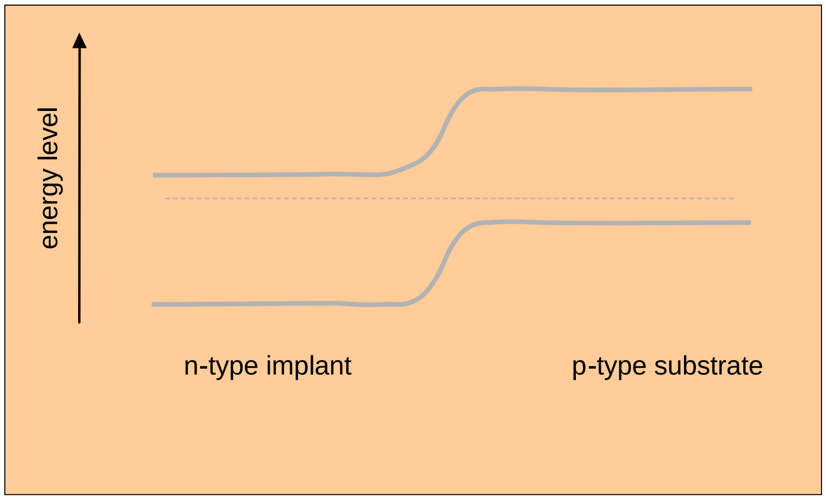
[1] "Comparative Study on Emitter sheet resistivity measurements for in-line quality control" E. Ruland et al., Proc. 3rd World Conf. on PV Energy Conversion, Osaka, Japan May 2003

Junction PhotoVoltage (JPV) Technique

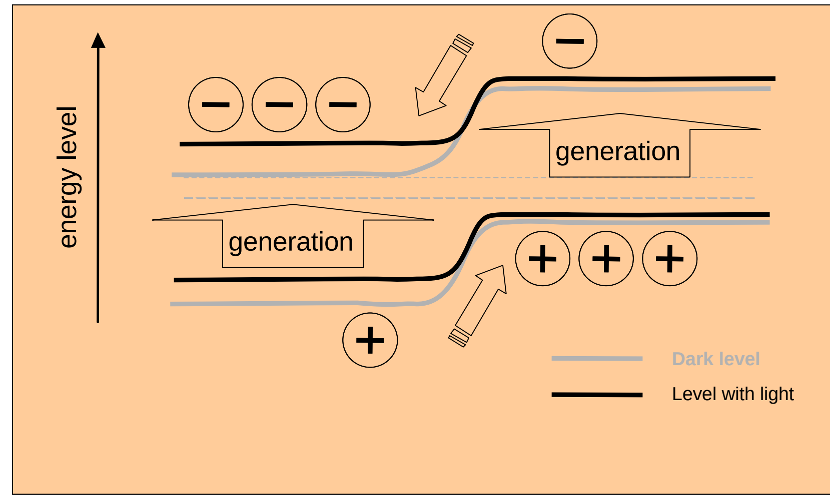
- Measures Sheet Resistivity
  - Alternative to 4-PP; measure after anneal
  - Especially useful for USJ
  - Optimized for ion implant
  - Sensitive to the activated species
- Completely Non-Contact
- High Resolution
- Works through oxide, if necessary

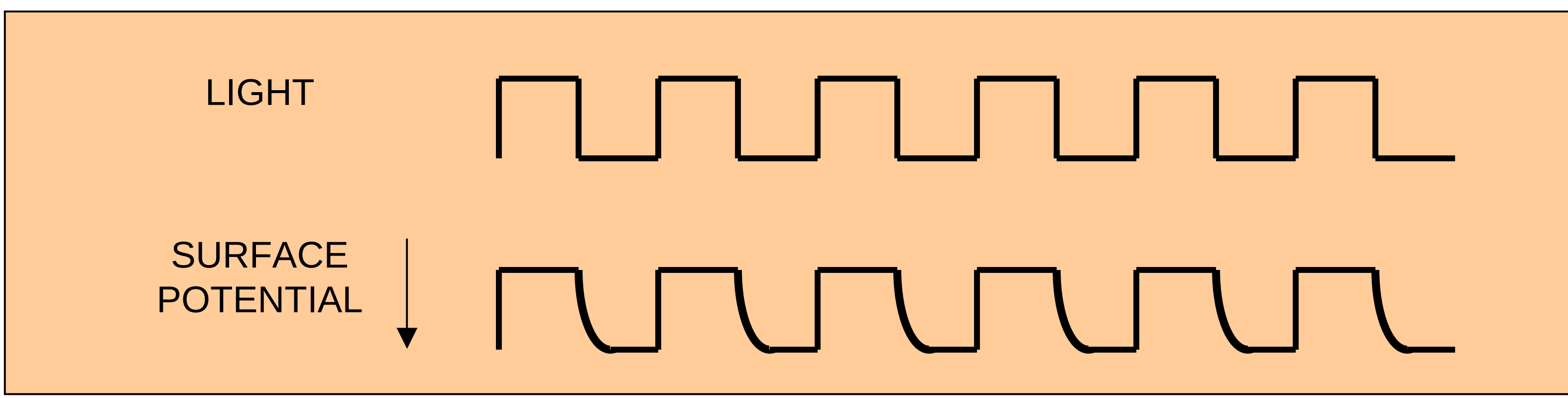
Basic JPV Theory
The Effect of Light on a Junction

DARK



LIGHT

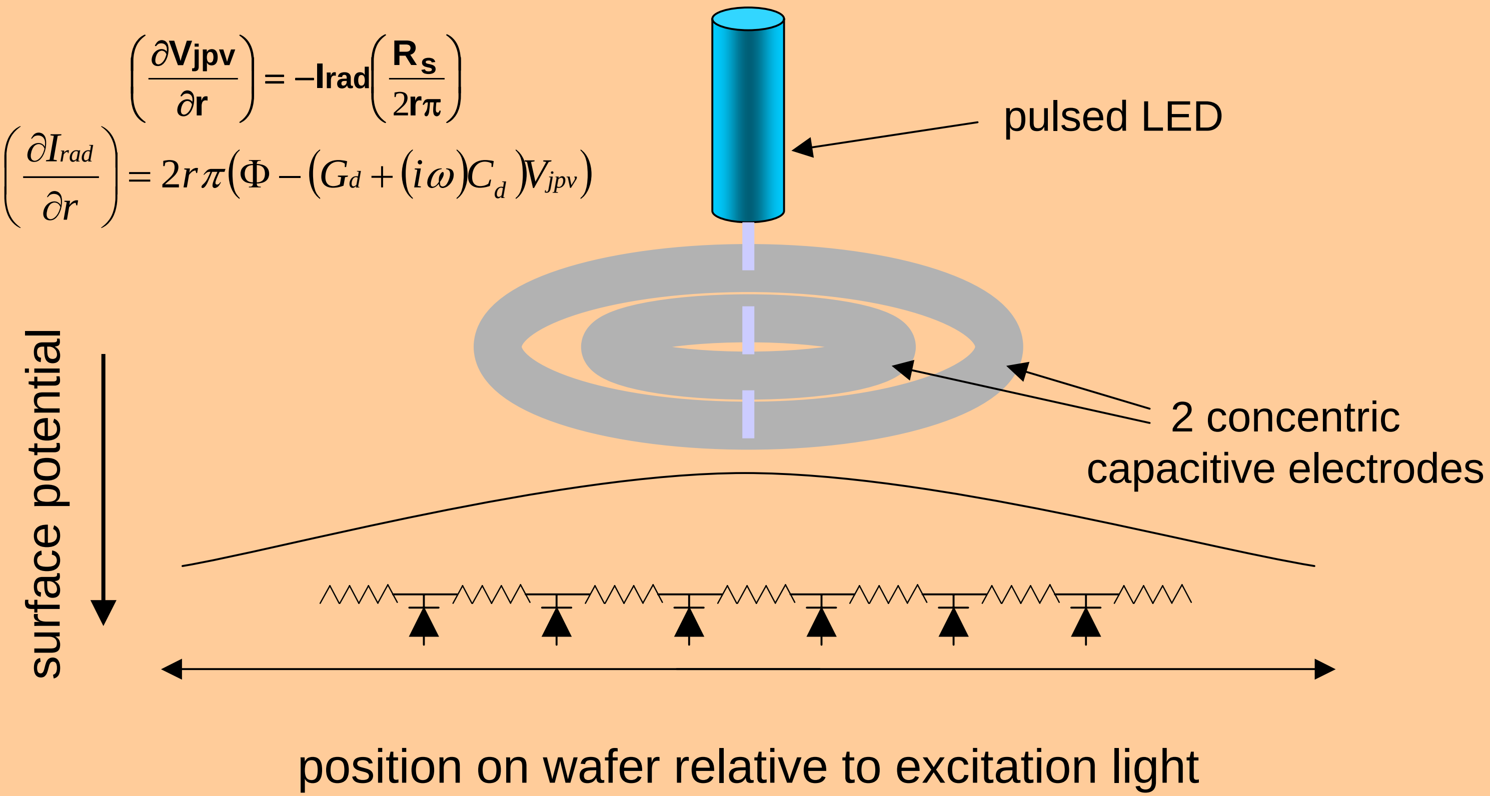




Spatial Variation of the Junction PhotoVoltage

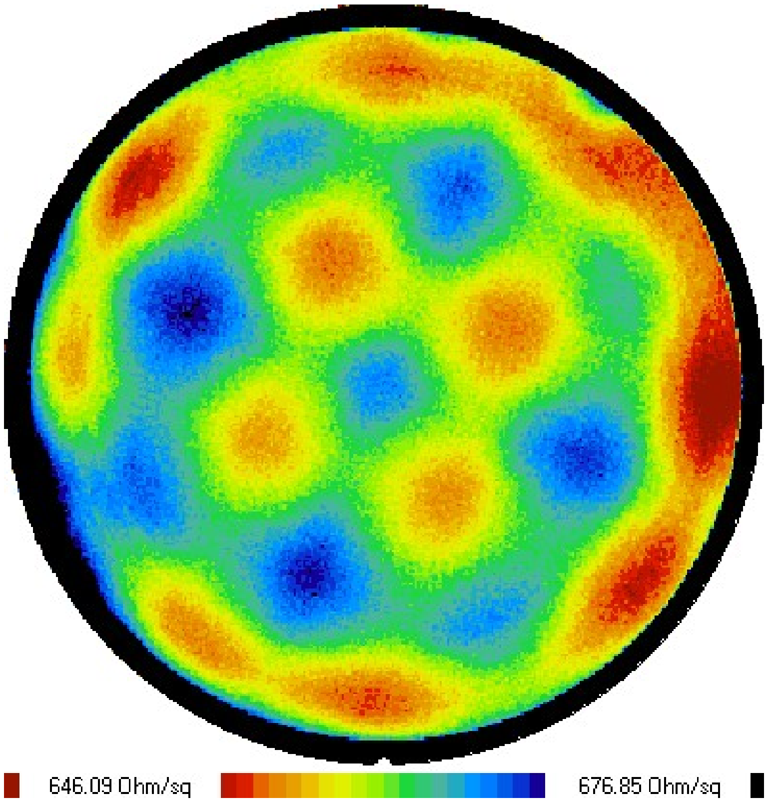
$$\left(\frac{\partial V_{jpv}}{\partial r}\right) = -I_{rad}\left(\frac{R_s}{2r\pi}\right)$$

$$\left(\frac{\partial I_{rad}}{\partial r}\right) = 2r\pi\left(\Phi - \left(G_d + (i\omega)C_d\right)V_{jpv}\right)$$



Comparison of the photovoltage at the two electrodes determines the sheet resistance

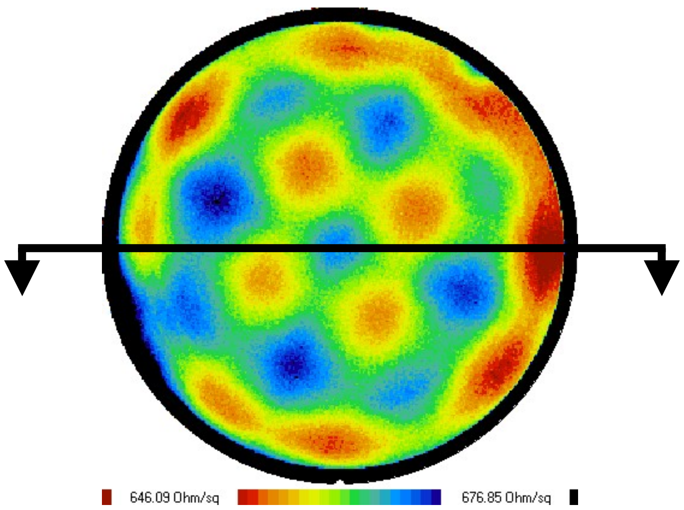
Sample Measurement

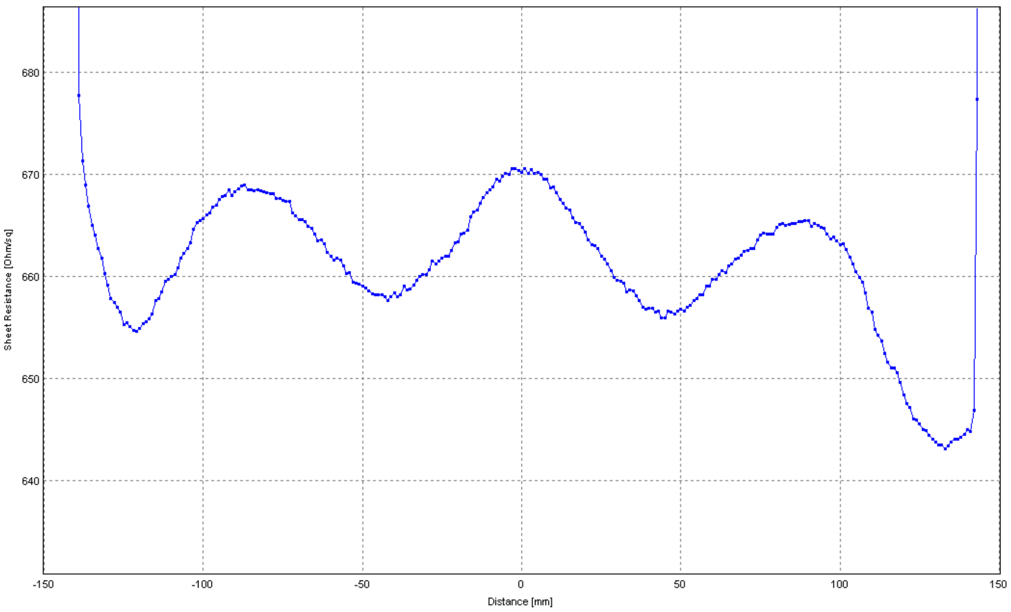


Boron 1KeV; 4E14/cm^2

- Map shows 4-fold symmetry of quad implanter
- The pattern is at 22º, showing the twist and tilt

- *300mm wafer*
- *1mm raster; XY scanning*
- *70K points*
- *~1K points/minute*

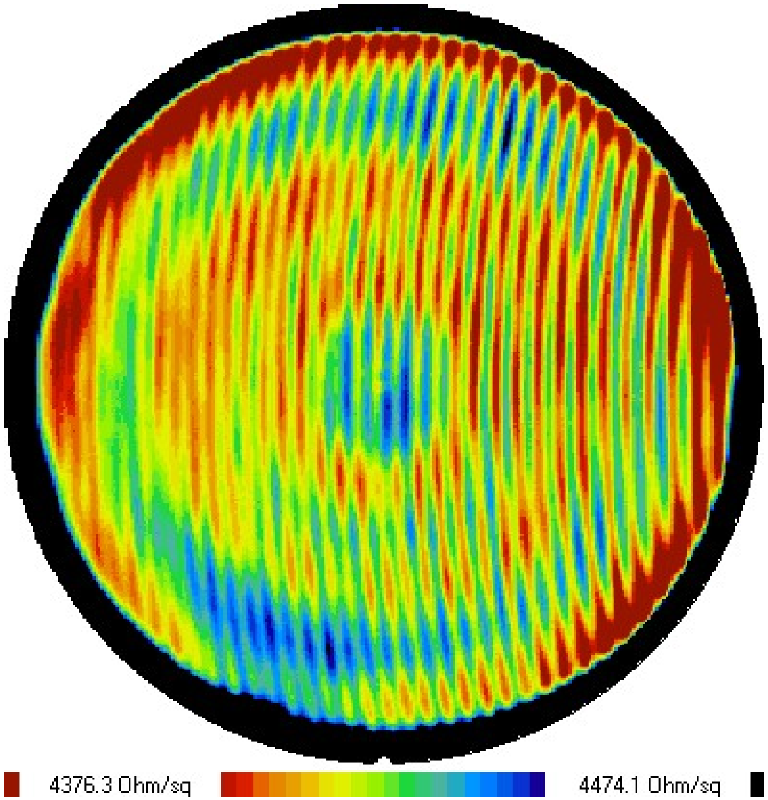




Line Scan

- Variation in Rs of ±2%
- Edge exclusion of ~10mm

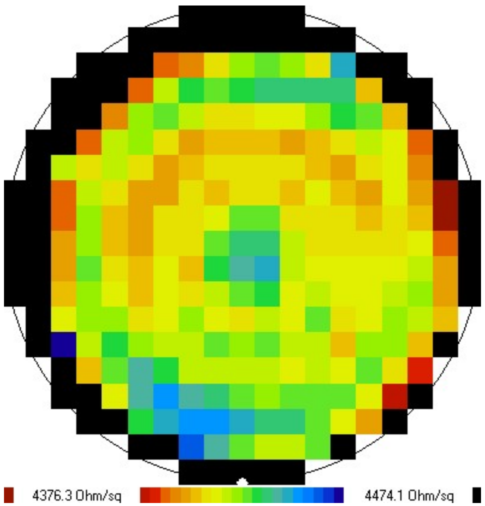
Batch Implant

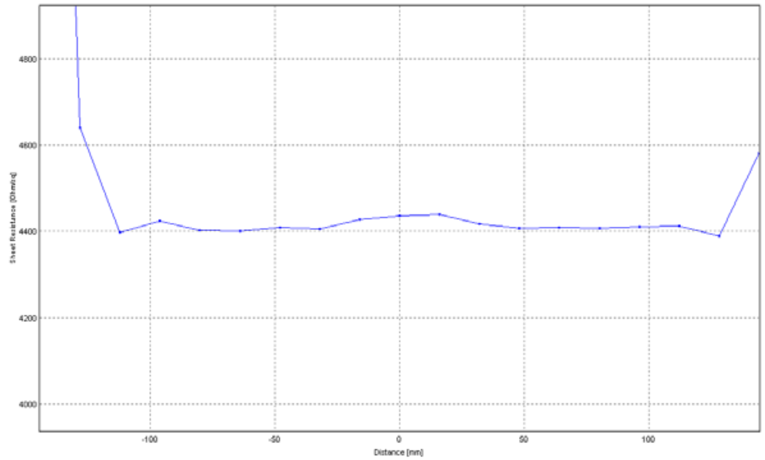


As 1.5KeV; 4E13/cm^2

- Non-Uniformities in the annealing cause the ring pattern
- Batch implanter produces the arcs
  - 8.3mm pitch
  - 120cm radius
- Rs variation >1%

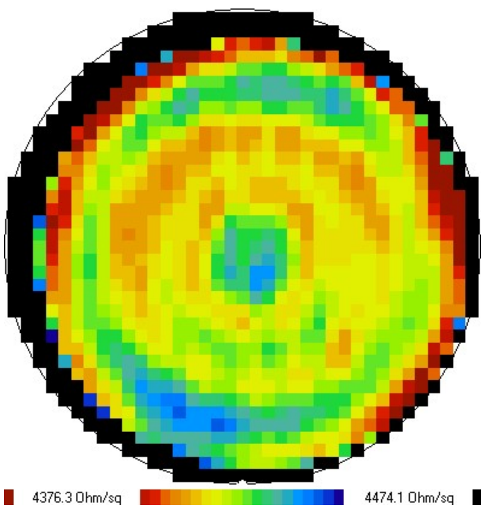
Nyquist Was Right !

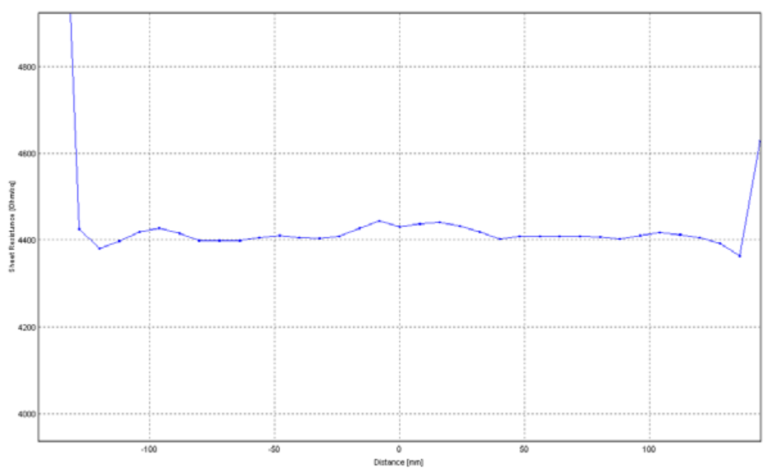




16mm raster shows no arcs

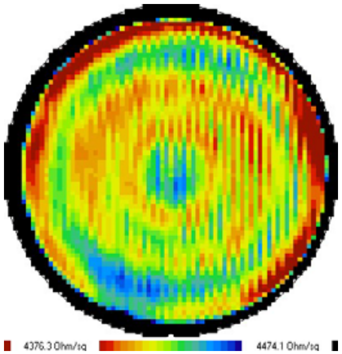
(same wafer)

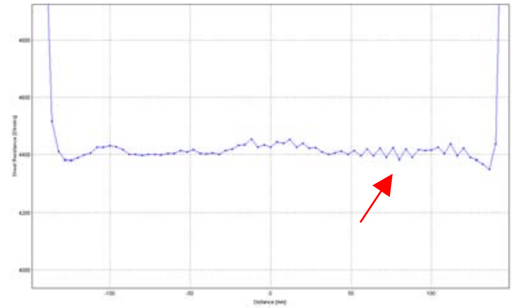




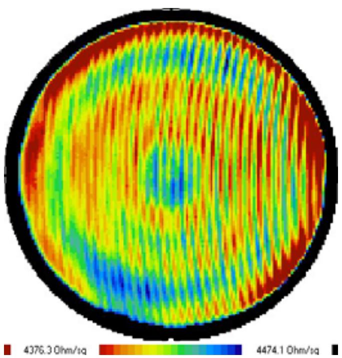
8mm raster shows no arcs

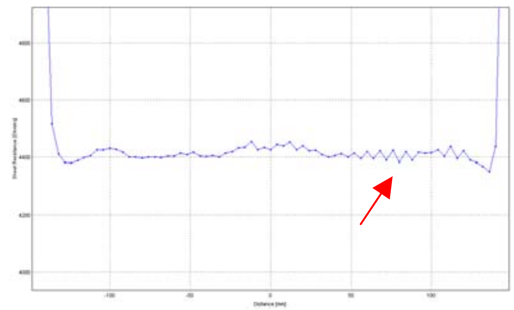
Higher Resolution



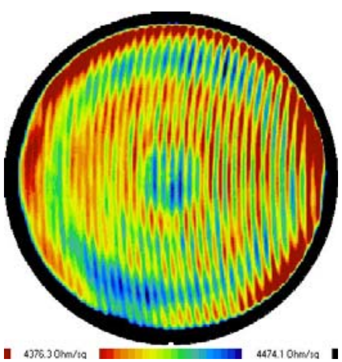


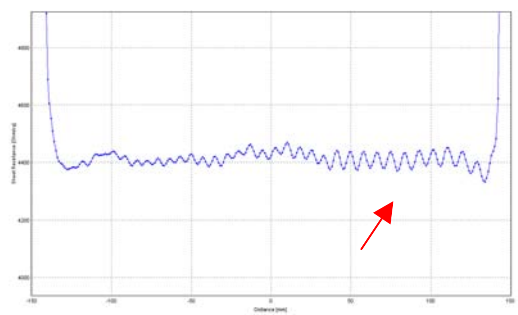
4mm raster begins to shows arcs





2mm raster definitely shows arcs

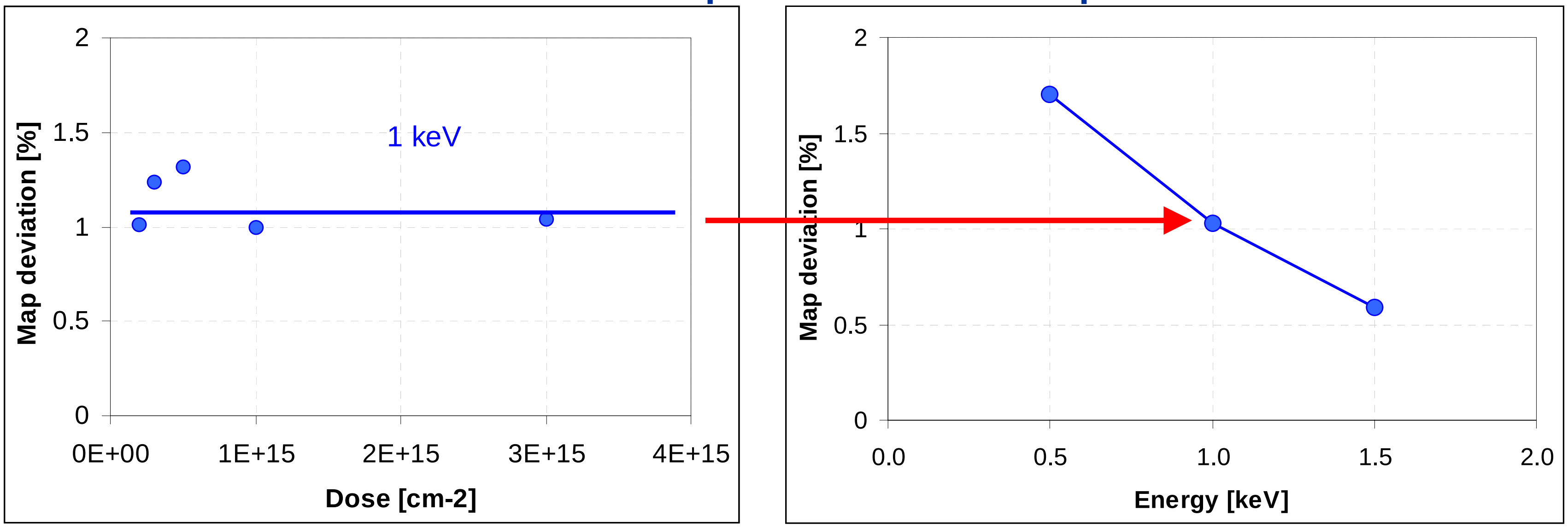




1mm raster shows arcs in high fidelity

Boron Implants Show the Implanter

Dominant map structure: implant

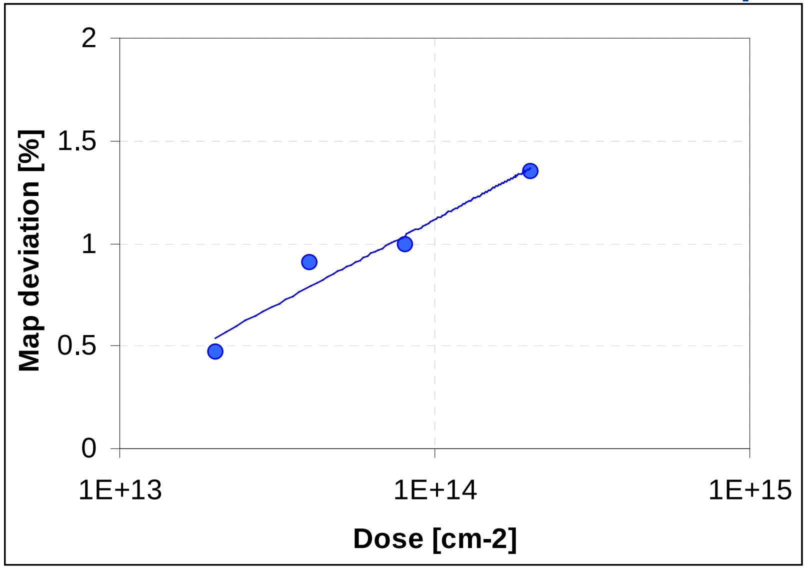


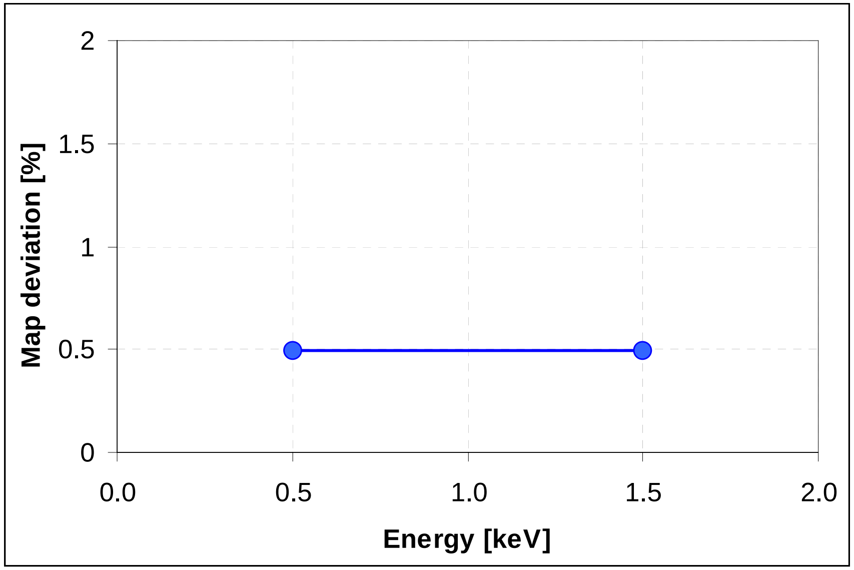
Boron implant

- The solid solubility of boron is low, about 1E20/cm^3
- Increasing the dose does not change the sheet resistance
- Increasing the energy creates a deeper junction, with lower sheet resistance

As Implants Show the Anneal

Dominant map structure: anneal





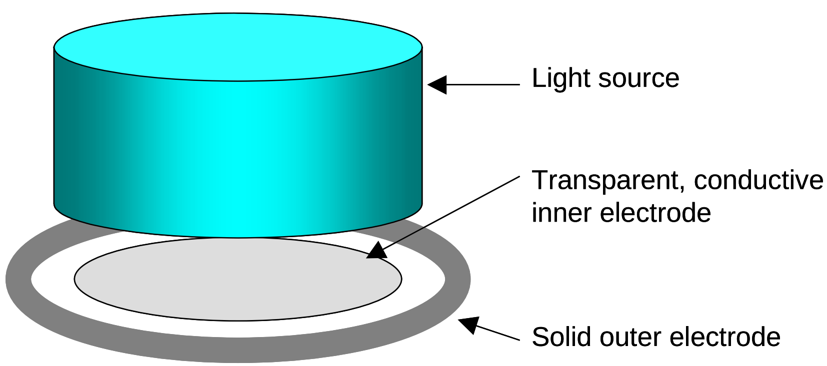
Arsenic implant

- The solid solubility of As is about 2E21
- Increasing the dose decreases the resistivity
- Increasing the energy makes the junction deeper but does not change the sheet resistance

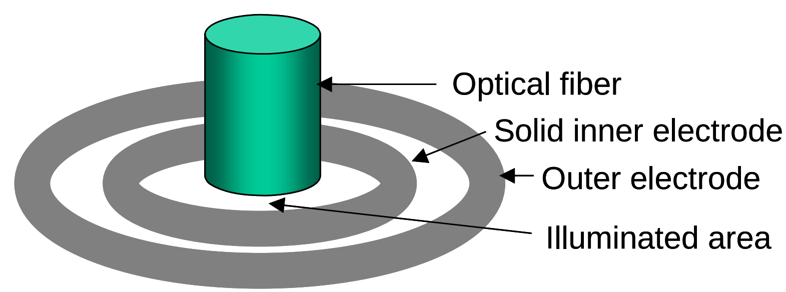
Performance Variations Within JPV Systems

- Electrode Design is Key
  - Determines resolution
  - Determines sensitivity to surface charge
  - Can influence edge exclusion
- Two General Designs in Common Usage
  - Illimuniated, transparent electrode
  - Opaque, solid electrode

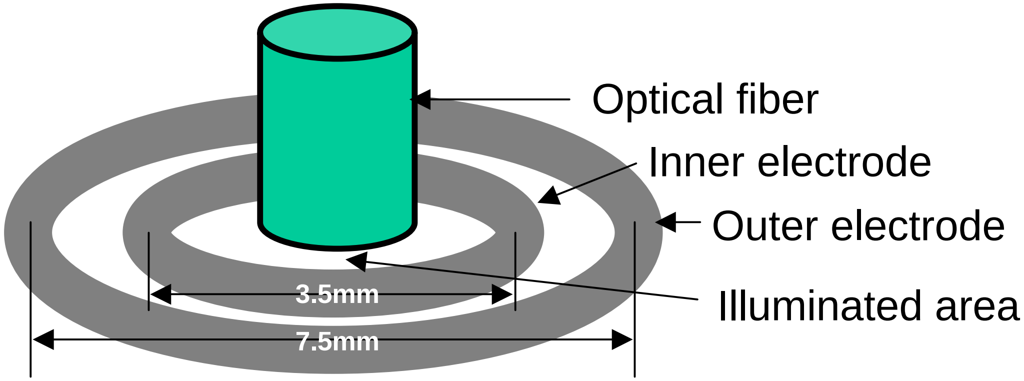
Transparent Electrode Concept

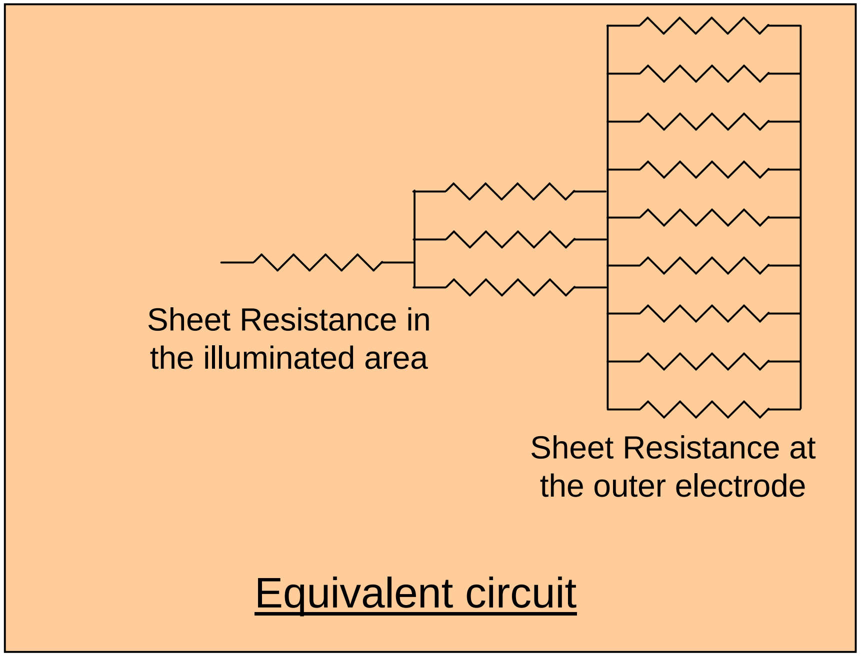


Solid Electrode Concept



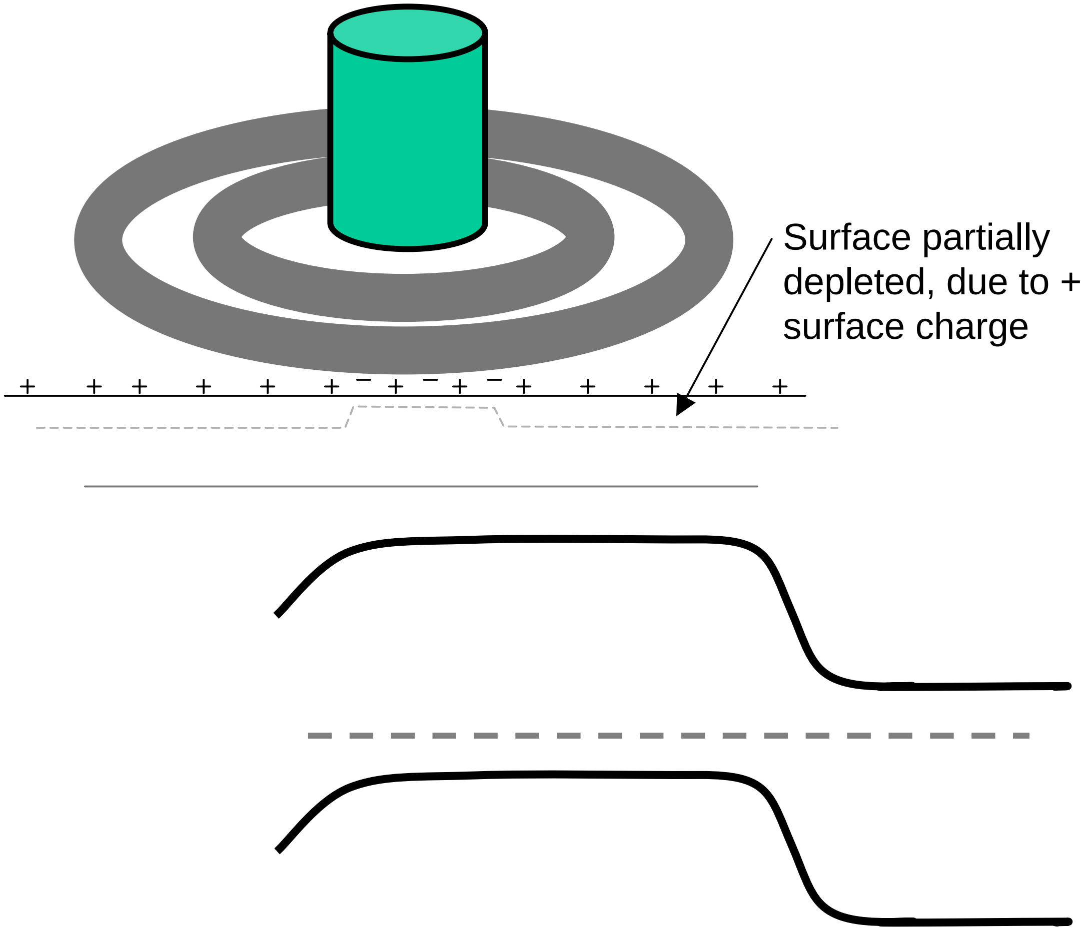
Resolution of Solid Electrode Design





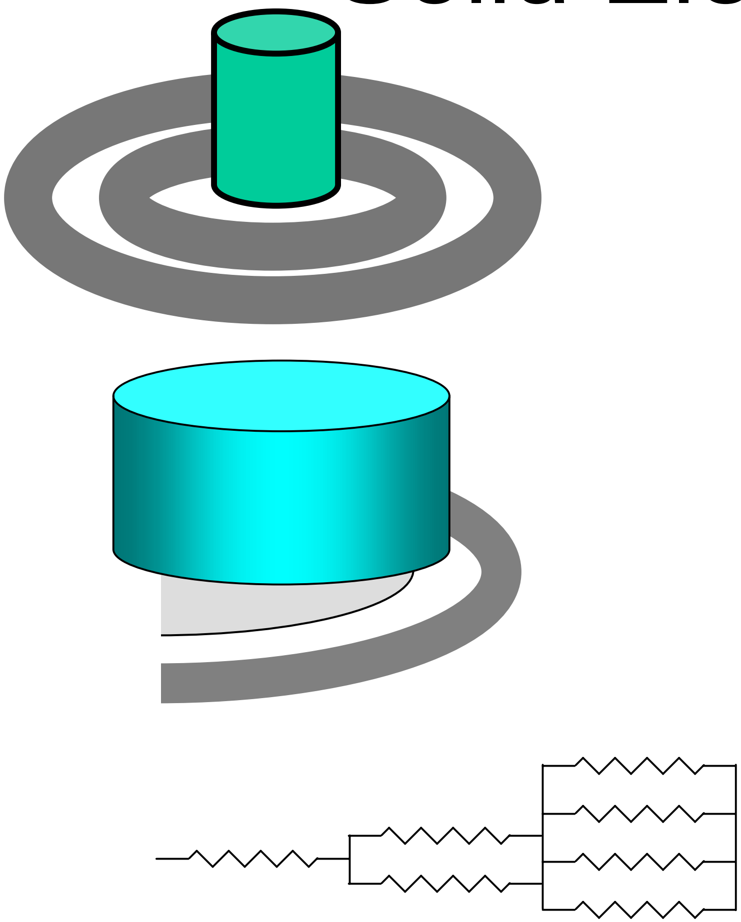
- The illuminated area is <2mm in diameter
- The measurement is much more sensitive to the sheet resistance in the illuminated area than the neighboring sheet resistance
- The practical resolution is 1-2mm

Sensitivity to Surface Charge with Solid Electrode Design



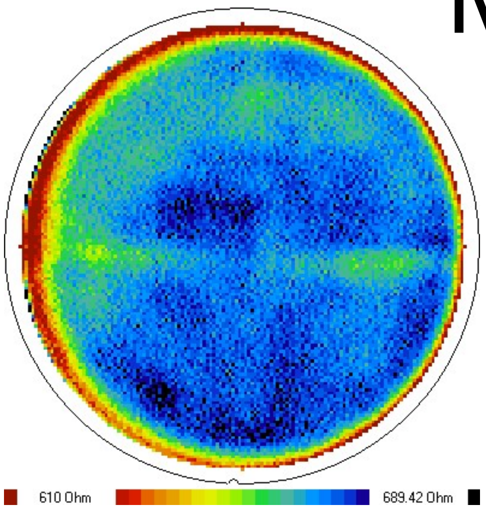
- If the surface is in depletion, illumination causes an SPV signal as well as a JPV signal
- The SPV signal is in series with JPV signal and opposite in sign
- While the JPV signal causes current flow, the SPV does not
- Therefore a solid electrode will measure only the JPV signal

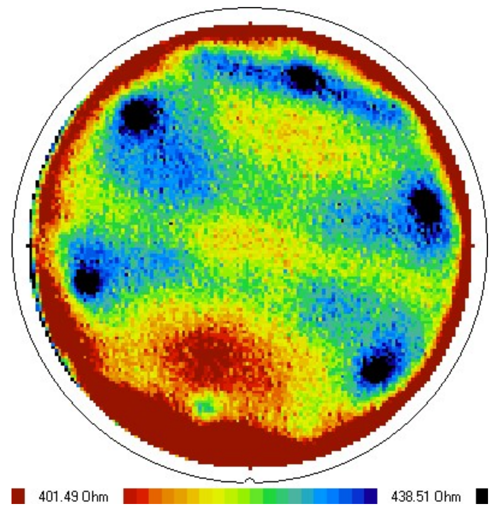
Edge Exclusion of Solid Electrode Design

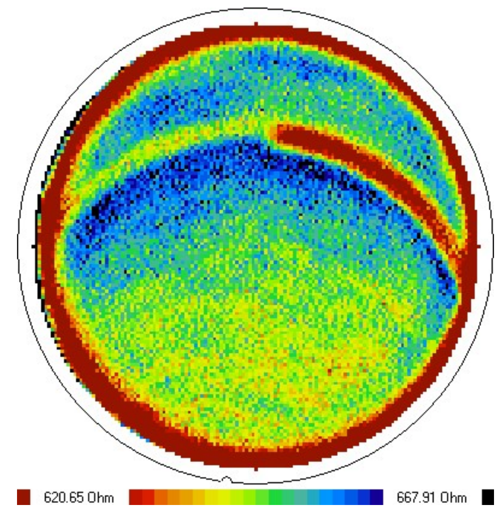


- A symmetric design measures the area at the center of the electrode
- An asymmetric transparent electrode measures an off-center average
- An asymmetric design, using a solid electrode will be most sensitive to the sheet resistance of the illuminated area

Additional Interesting Measurements







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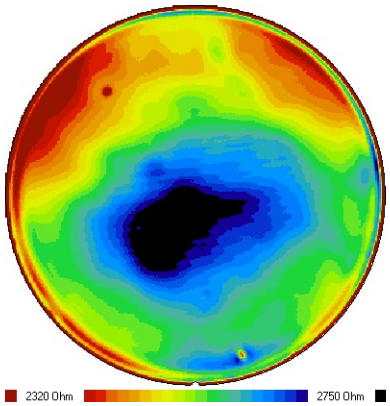
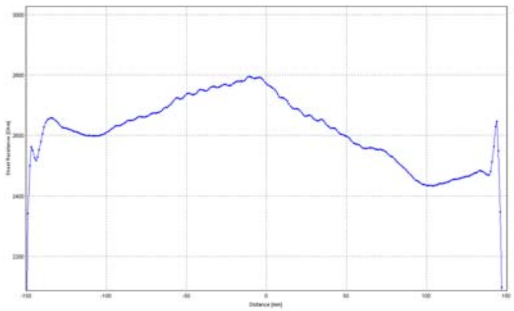
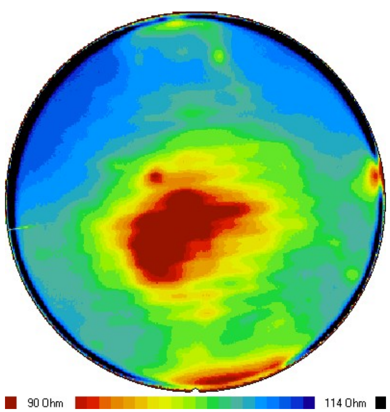
More Measurements

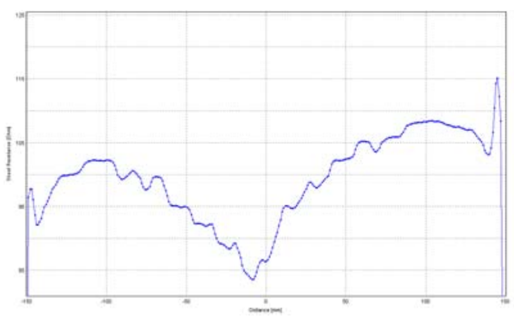




Boron 0.5KeV, 1E15

Flash anneal

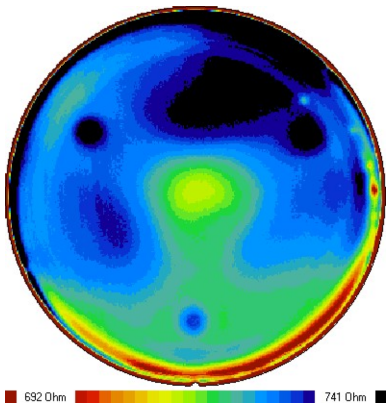


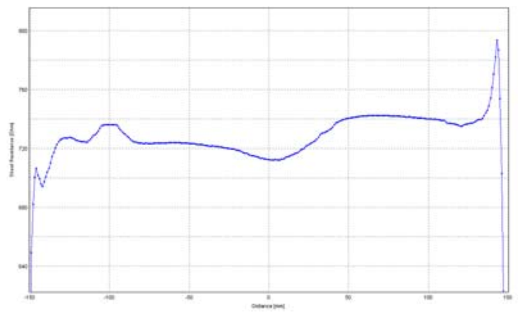


Ge-PAI+B 0.5KeV, 1E15

1000ºC Spike + Flash

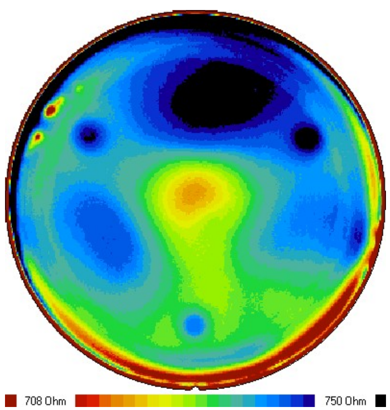
More Measurements

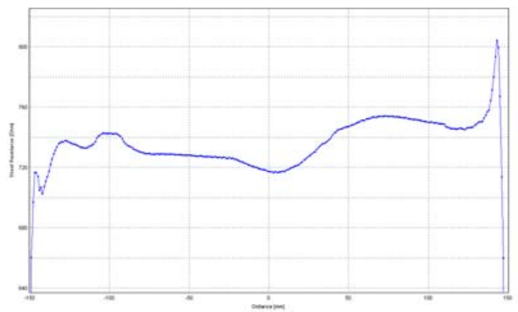




Boron 0.5KeV, 1E15

1000ºC Spike anneal





Boron 0.5KeV, 1E15

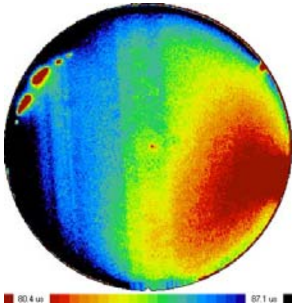
1000ºC Spike + flash

Summary

- Maps of Rs show significant non-uniformities
- Non-Uniformities can occur both from implanter and annealer
- High resolution maps reveal information not available previously

PL Claims to Show Contamination Lifetime Measurements Don't Agree

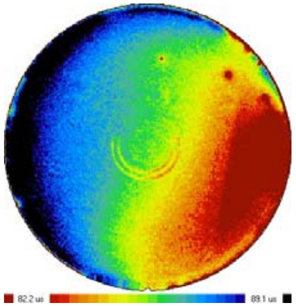
B 1000ºC Spike + Flash -037/3



3 pins not visible

Center not visible

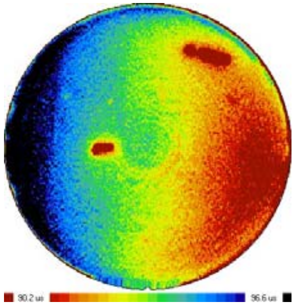
B 1000ºC Spike -037/4



1 pin not visible

Center slightly visible

B 900ºC Spike + Flash -037/2



1 pin not visible

Center slightly visible