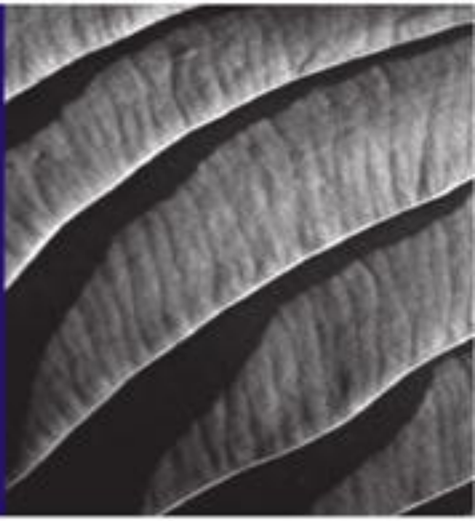
The 4PP: Obsolete or Timeless

Walt Johnson
KLA-Tencor



Short History of the 4PP

- **1978 Tencor introduces the M-gage**
- Replaced my +/- 10% Veeco 4PP with an M-Gage (4PP obsolete?)
- **1983 Prometrix Introduces dual configuration +/-1%**
- Bought an OmniMap
- **1985 Prometrix reviews future**
- Management decides 4PP has 2 yrs life
- **1994 Prometrix merges with Tencor**
- Tencor management drops M-Gage, decides 4PP has 2 more yrs
- **1997 Tencor merges with KLA**
- KLA management decides the 4PP has 2 more years

The Status of the 4PP

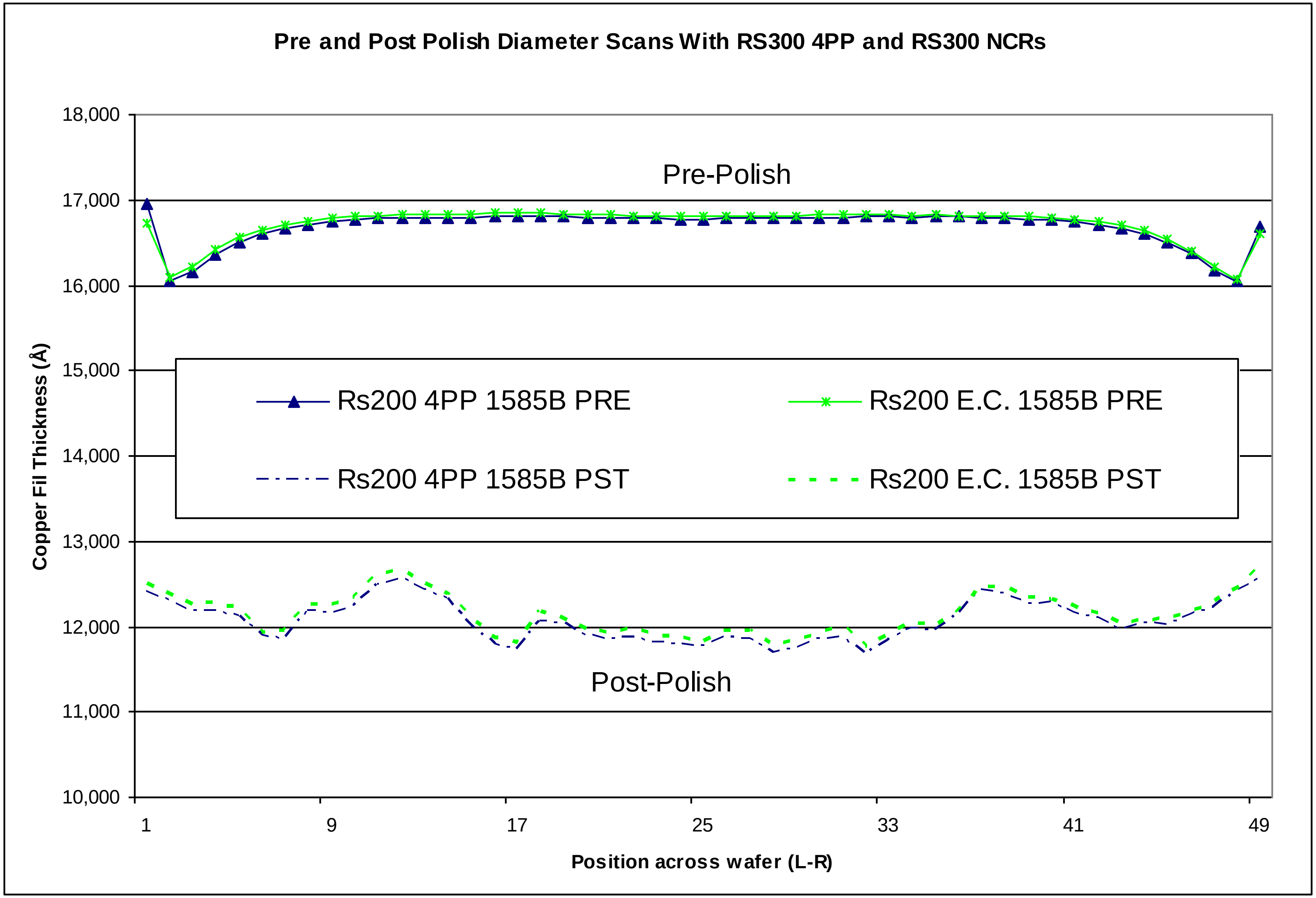
- So where do we stand today?

Markets addressed by the 4PP

- Metals
  - Metal sheet resistance
  - Metal thickness assuming a given resistivity
  - Metal resistivity assuming a given thickness
- Ion Implant
  - Dose monitoring (post anneal assuming a given anneal level)
  - Ion activation (post anneal assuming a given dose level)

NCRs (eddy current) Replaces 4PP for metals

(at least for thick metals on high resistance substrates)



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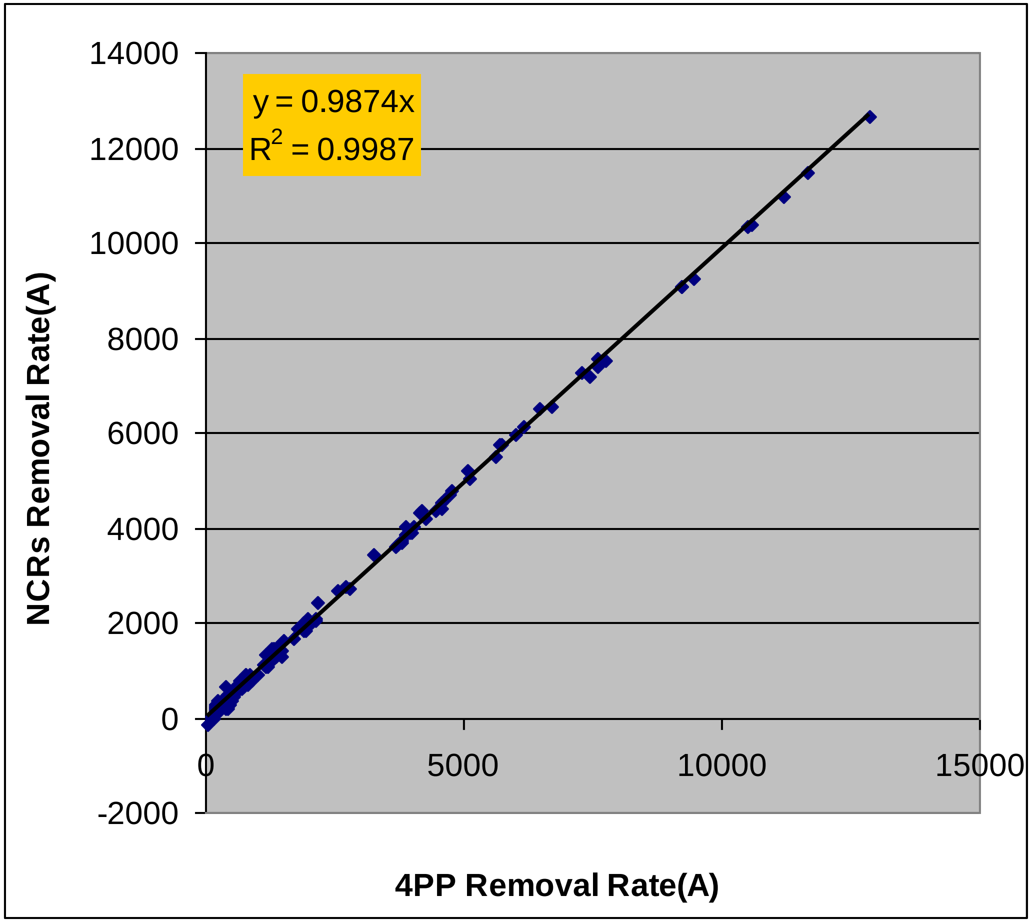
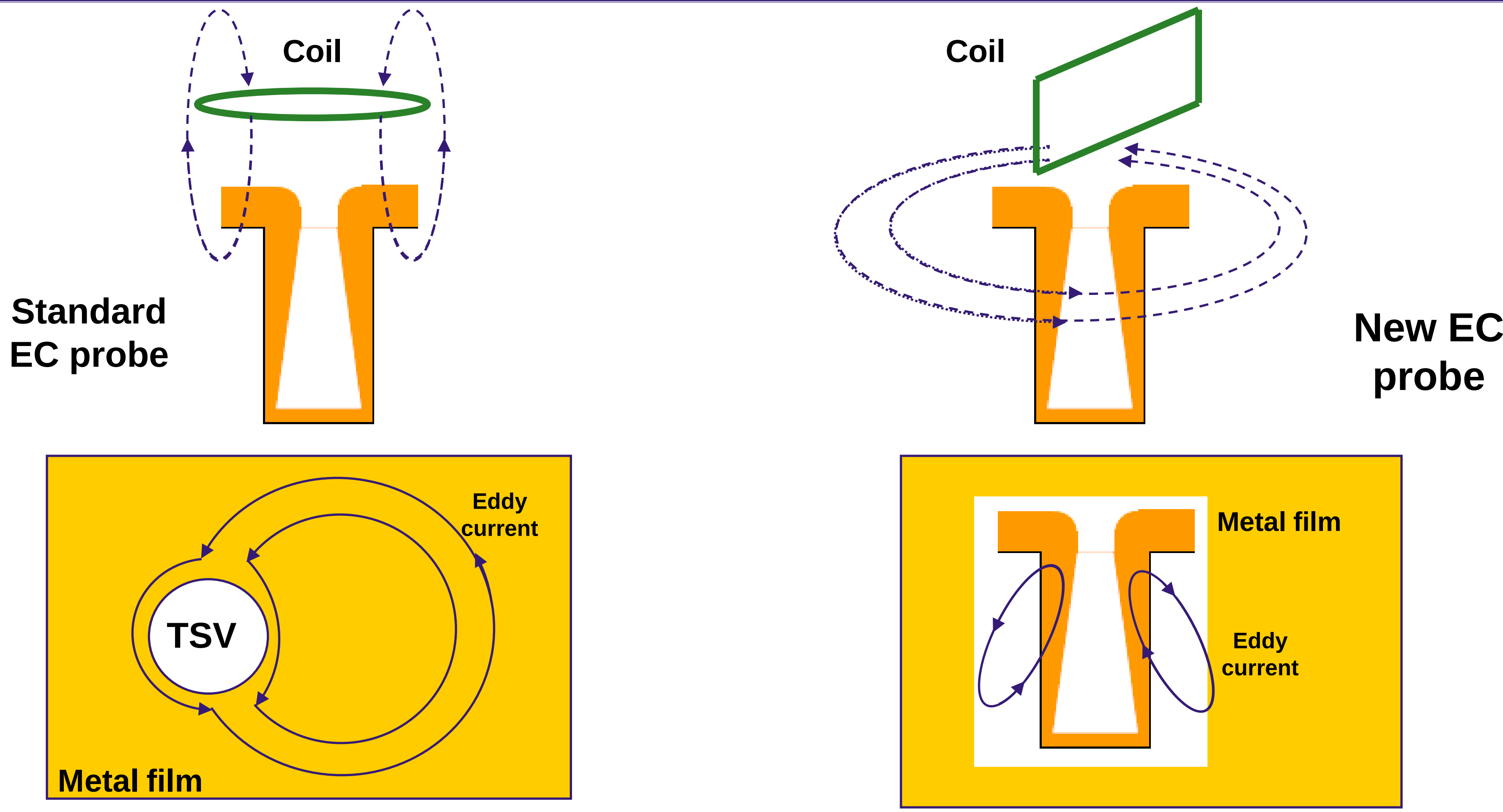
Copper Removal Correlation

- Overall correlation between 4PP and NCRs (on multiple wafer sets)



New Eddy Current Probe Development

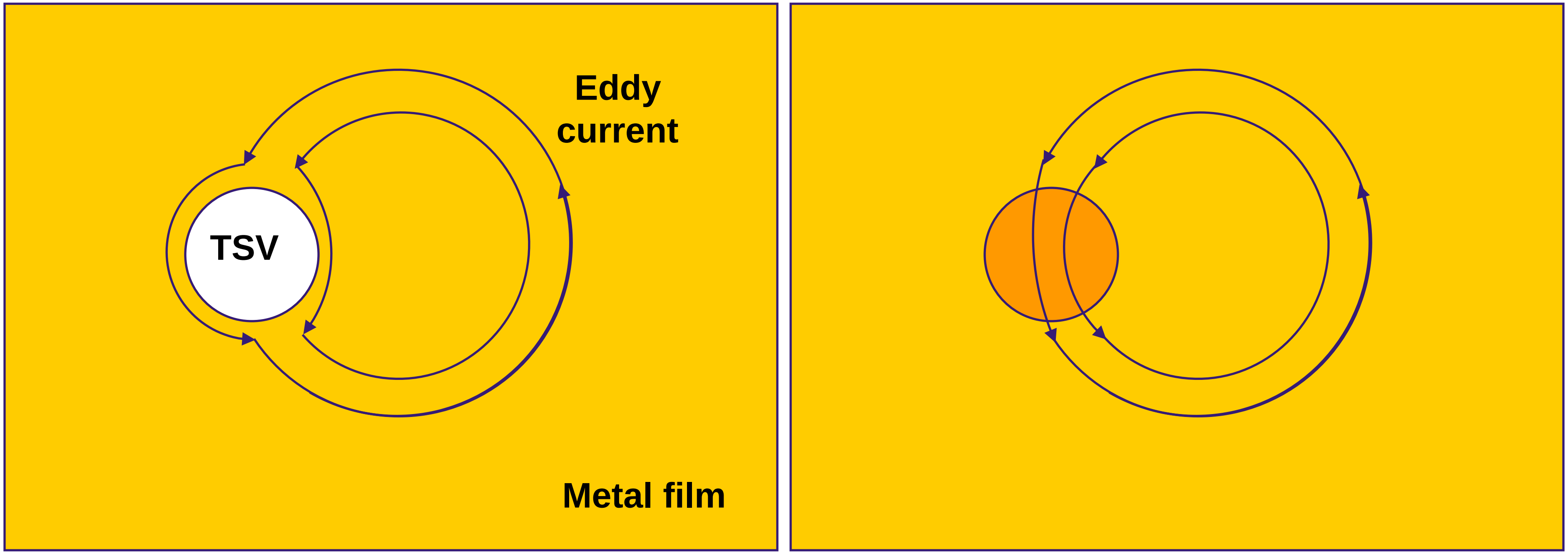
(Patent pending)



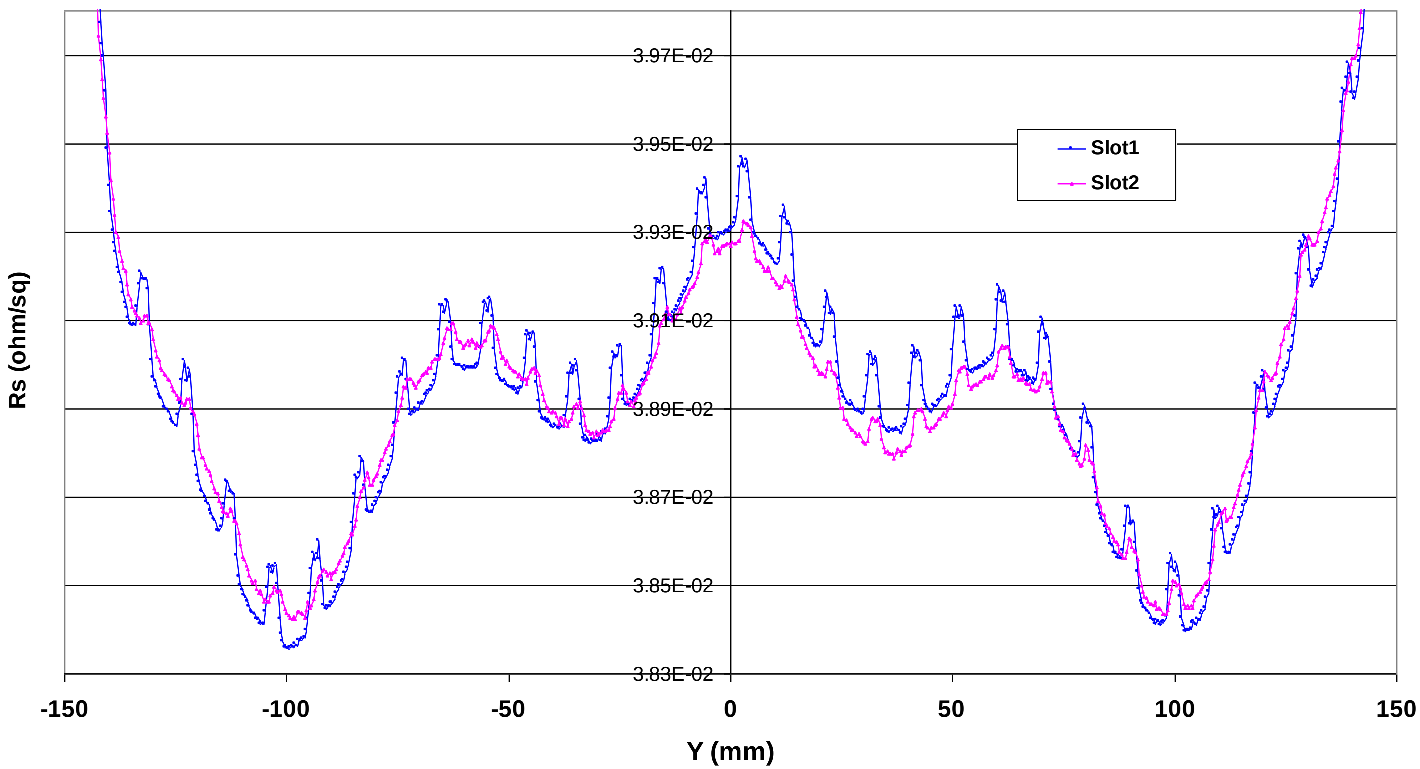
- The direction of eddy current by current probe is parallel to film surface and less sensitive to via sidewall coverage
- The direction of eddy current by new probe is perpendicular to film surface which should have better sensitivity

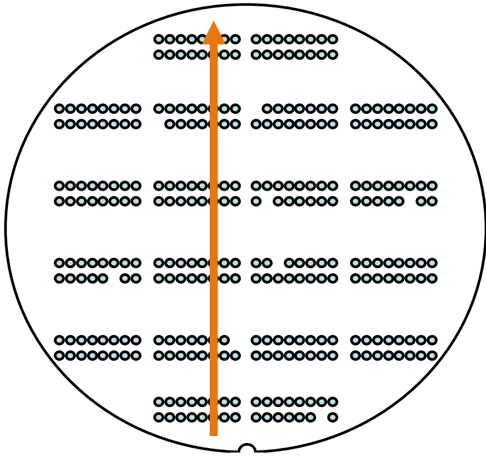
Eddy Current Signal on Unfilled & Filled Via

- Filled and unfilled via shall show difference in eddy current signal



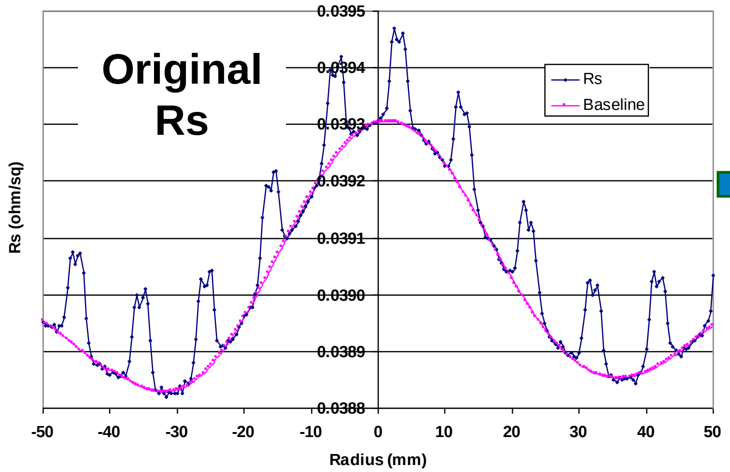
Y-direction Diameter Scan (in arrow direction)



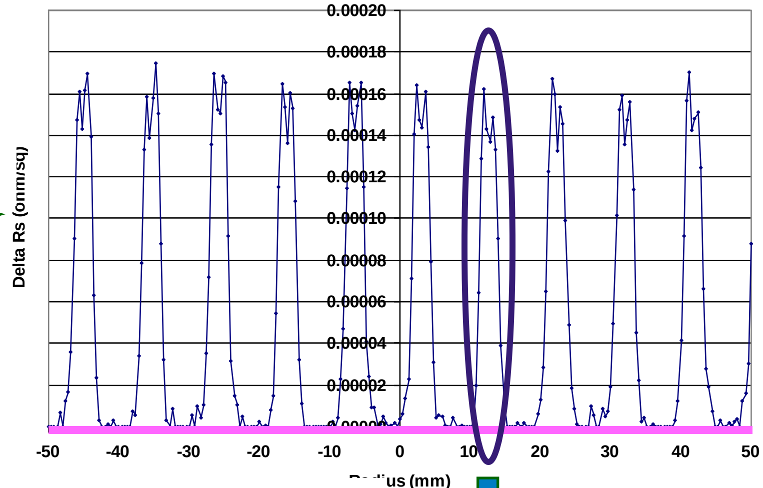


- **Peak area correlates to via coverage**
  - **Repeated via peaks super-imposed on the global Rs non-uniform distribution**

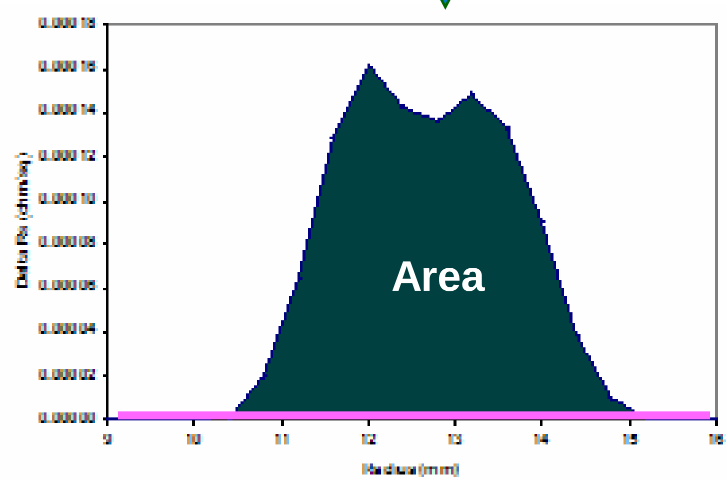
Rs Peak Area Calculation Algorithm



Eliminate Baseline Curve

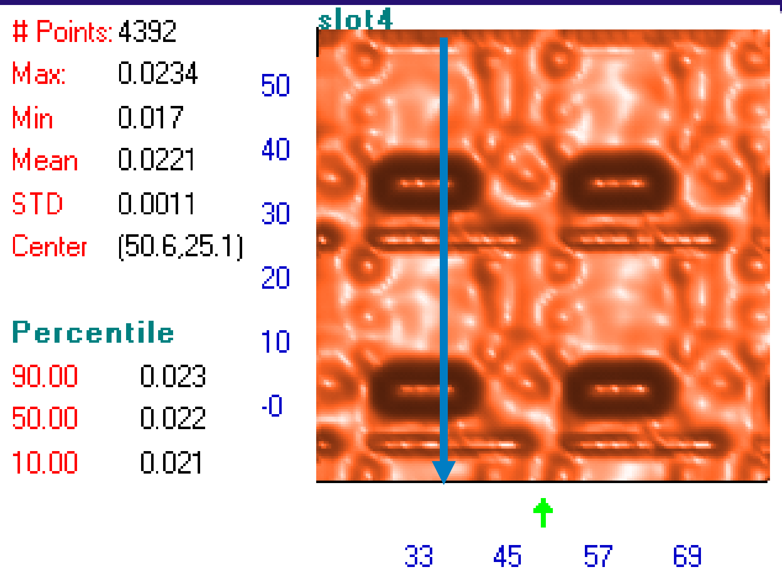


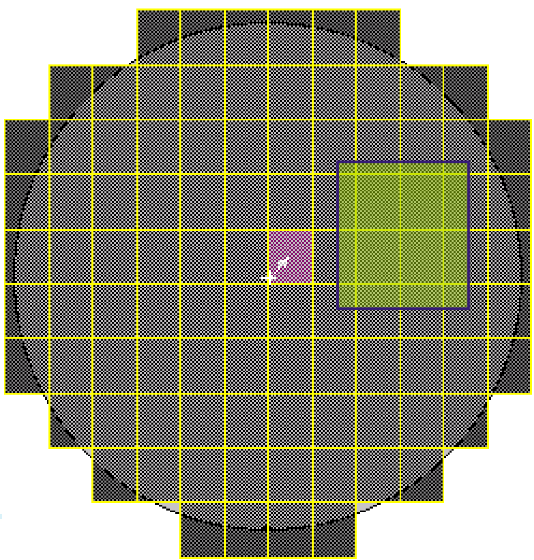
Calculate Peak Area

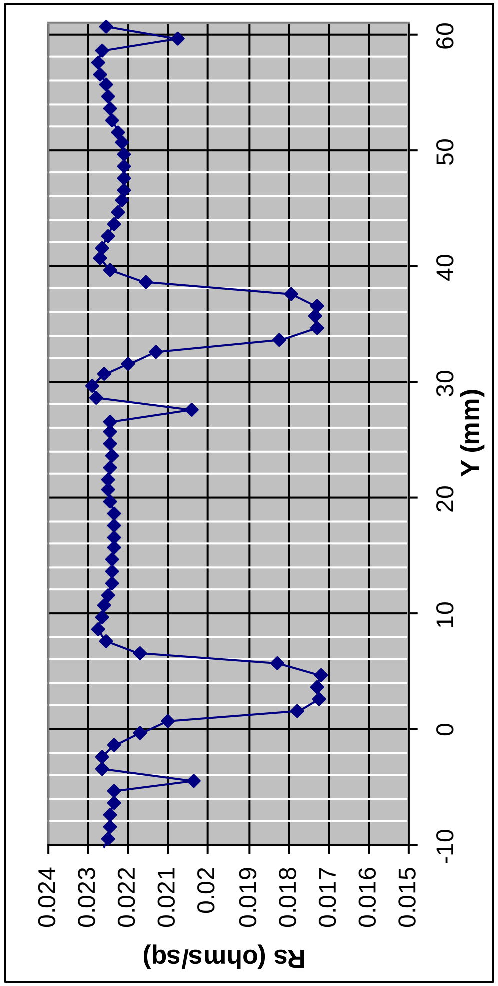


- Rs peak area correlates to via coverage

Hi Density Rs Measurement in Die (Slot 4)







Depending on if Rs variations are of interest, recipe set up will need to be used to either measure those areas or avoid them.

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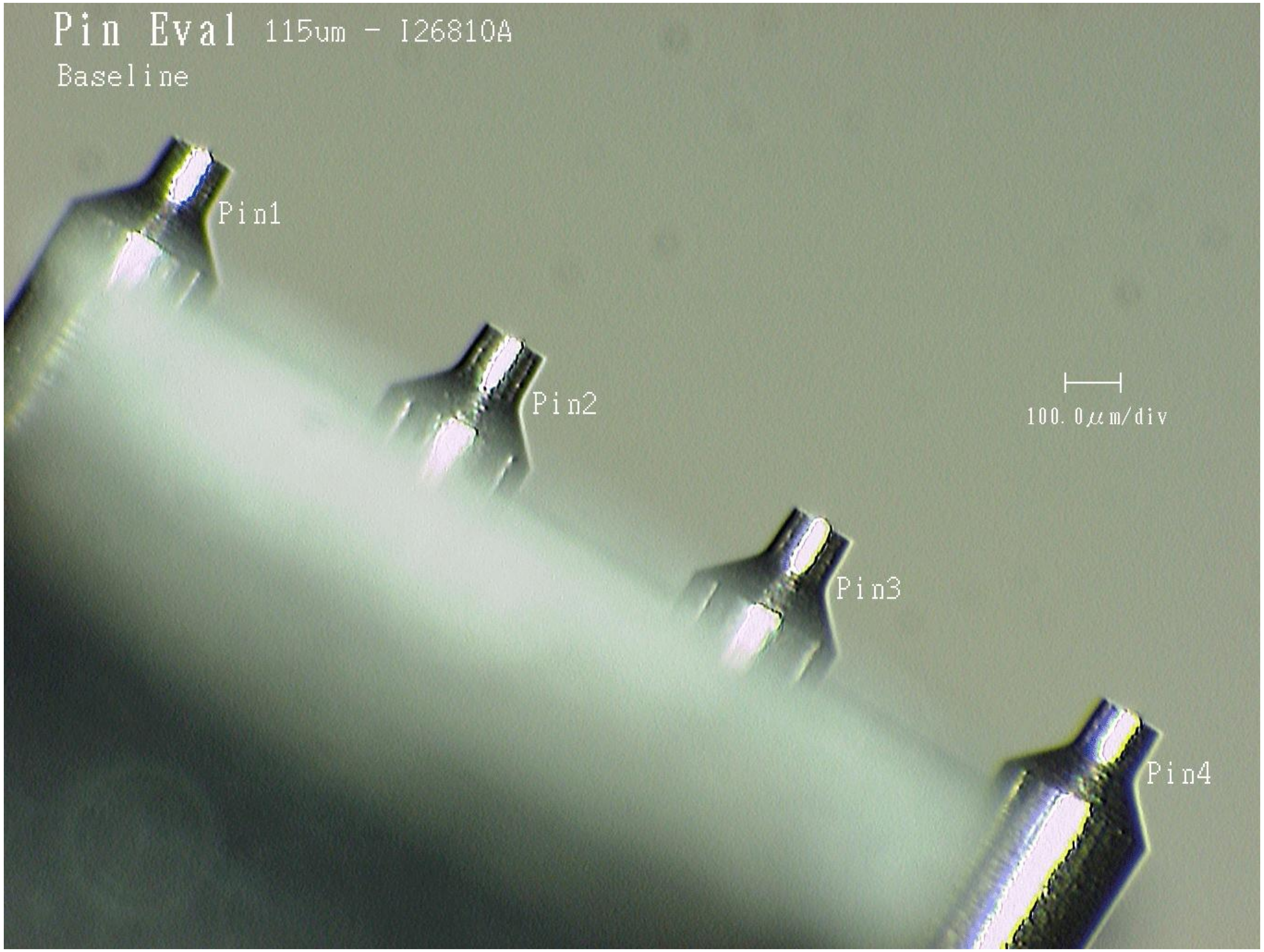
Improved USJ Measurements with Hx probes



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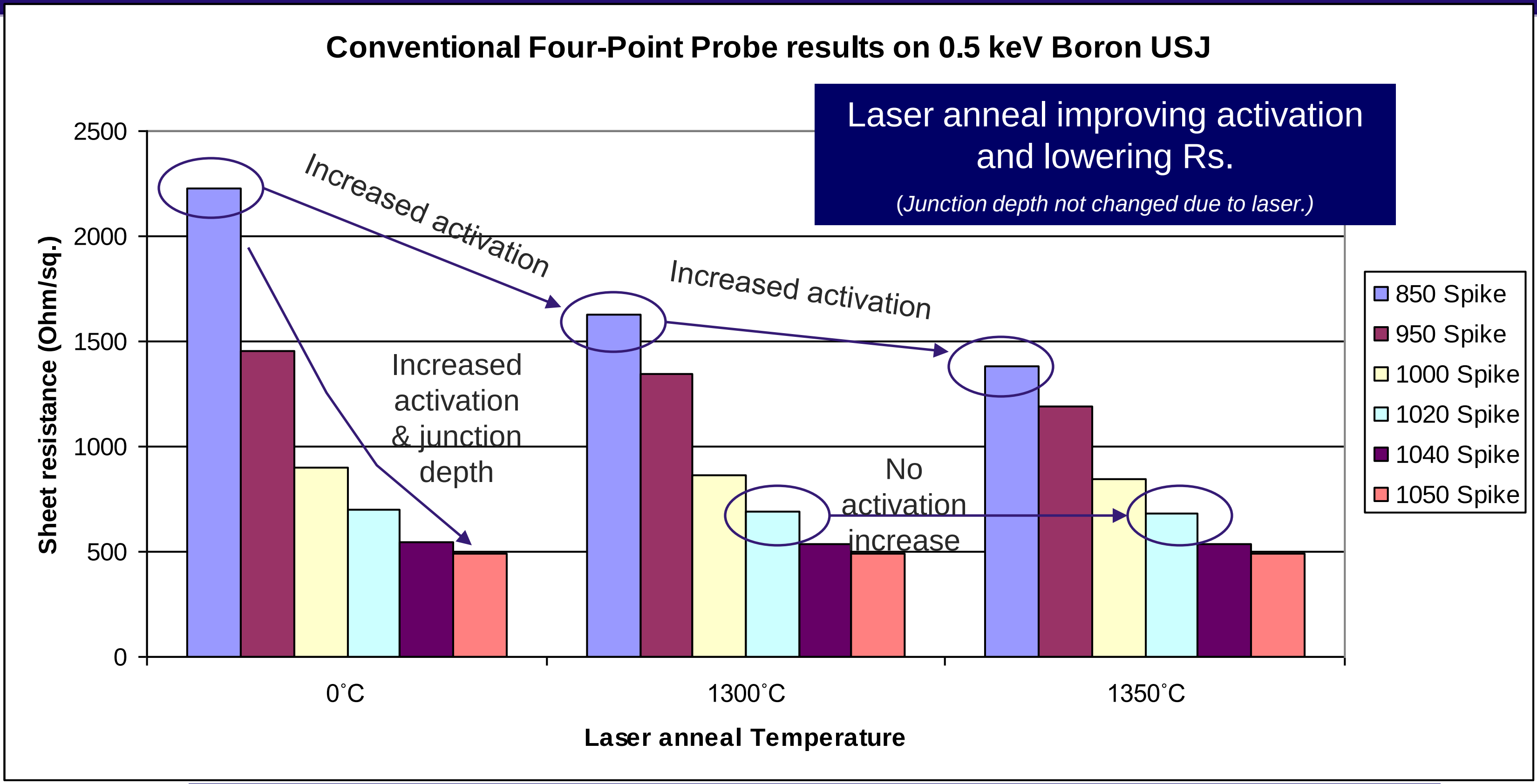
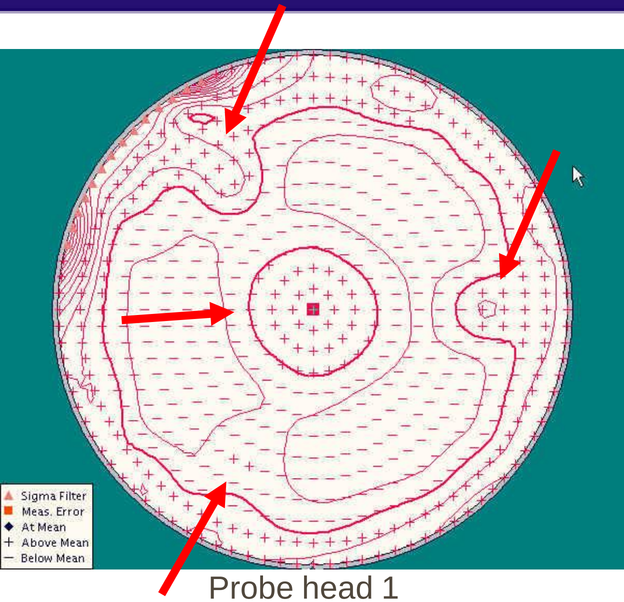
Activation Development & Control



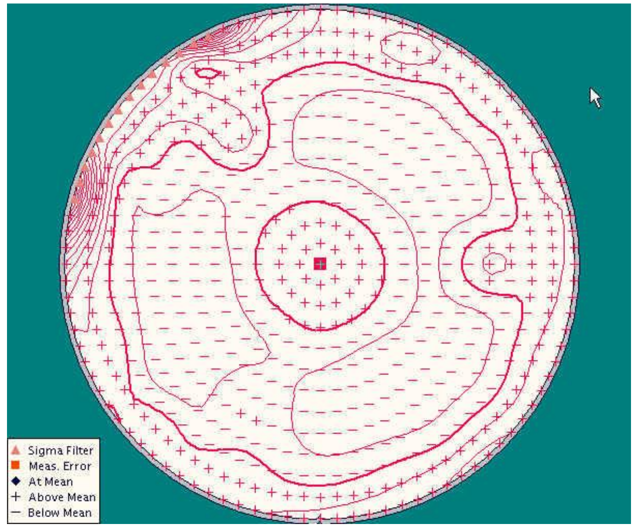
4PP provides sensitivity for process development & monitoring to detect small temperature fluctuations

Customer "A" data

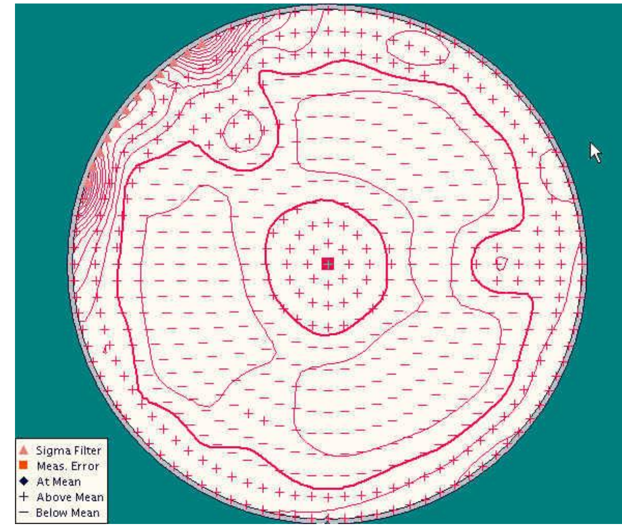
Discovering Annealer Problems on a 0.5 keV B+ implant



Probe head 1



Probe head 2



Probe head 3

- High variations toward upper left edge of wafer
  - 14 points in area show measurement error or data outside sigma filter
- Center ring possibly due to thermocouple from annealer
- Three higher Rs regions around center possibly due to pedestal in annealer
- Excellent matching between probe heads, and results repeatability

Yield-limiting detail analysis of Anneal process equipment

Customer "C" data

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Long-Term Repeatability

Repeatability of Contour Map Results:

	BF2 1.5E14, 8 KEV 25 repeats	BF2 1E14, 5 KEV 25 repeats	As 1E14, 5 KEV 25 repeats	As 1E14, 3 KEV 25 repeats
Mean	1451	2508	1252	1613
% Stdev	0.16%	0.21%	0.14%	0.12%

Repeatability on BF2 and Arsenic USJ implant maps is excellent

Customer "C" data

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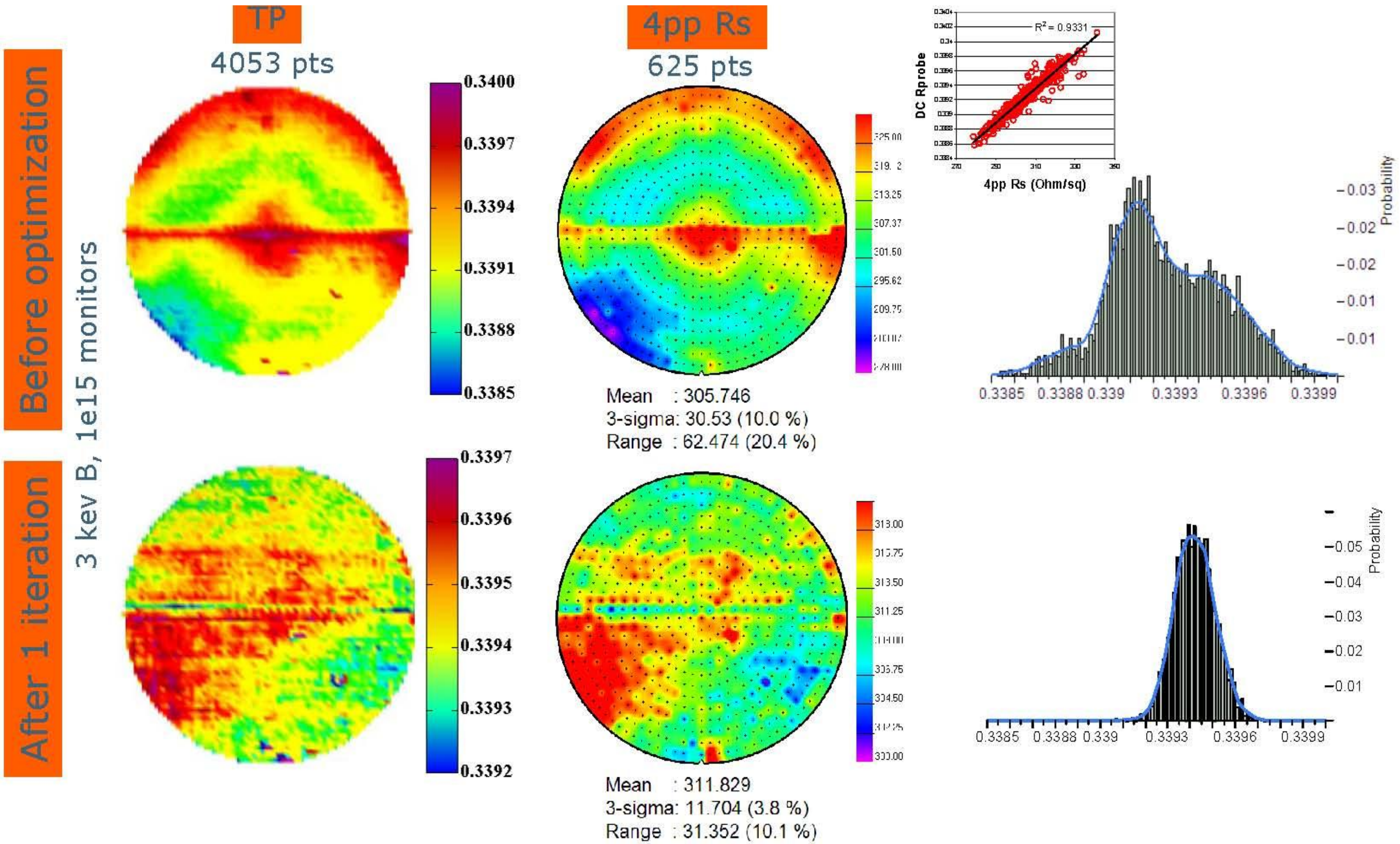
Alternate Implant Monitoring Techniques

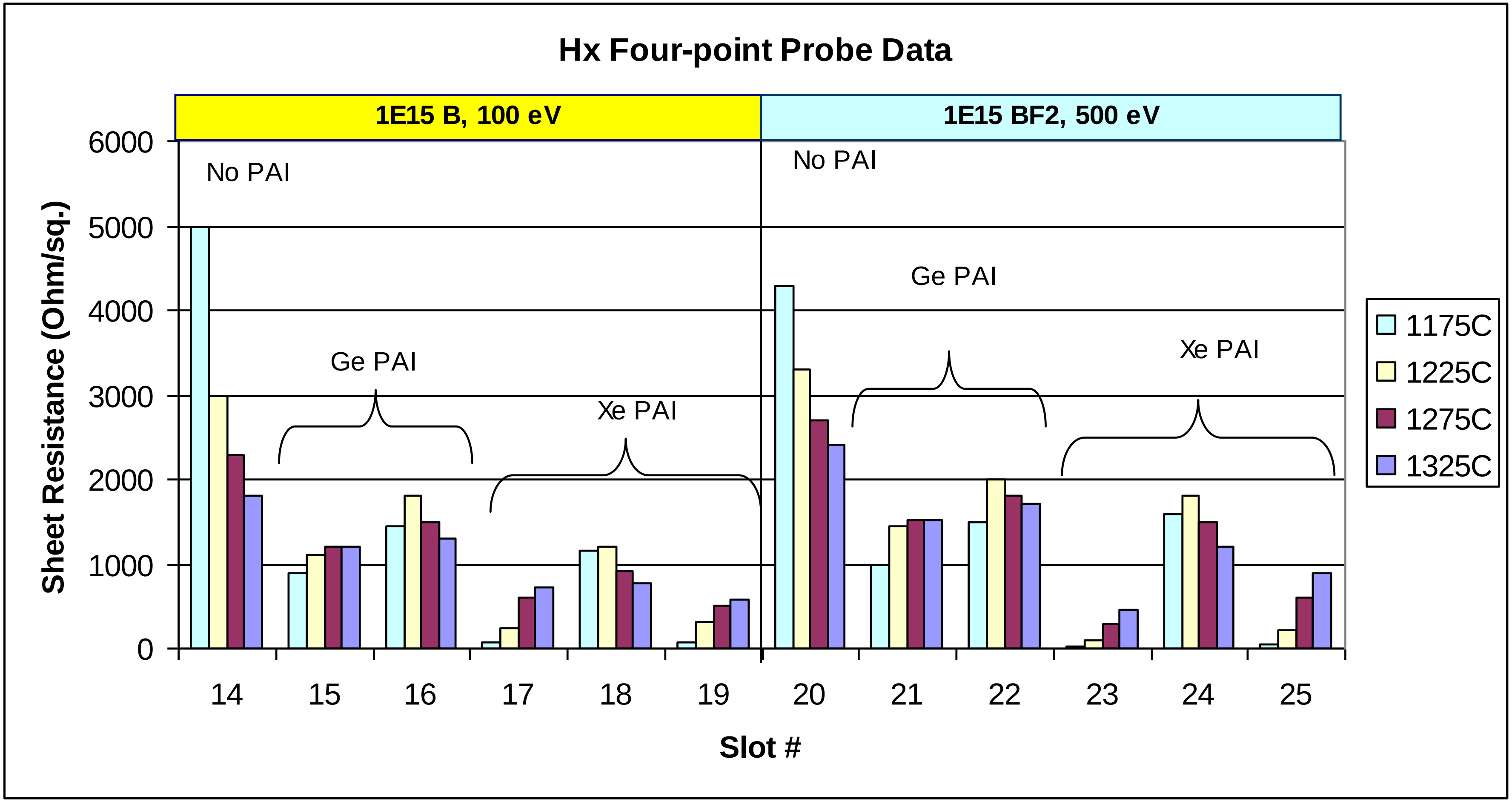
- IonScan
- Metrix e-beam
- TW
- SemiLab / FSM / Quantox (KLA-Tencor)
- Microwave ?

TP to Rs Comparison



- Another example of laser anneal optimization with TP including comparison with Rs

Junction Leakage Limits 4PP Usage



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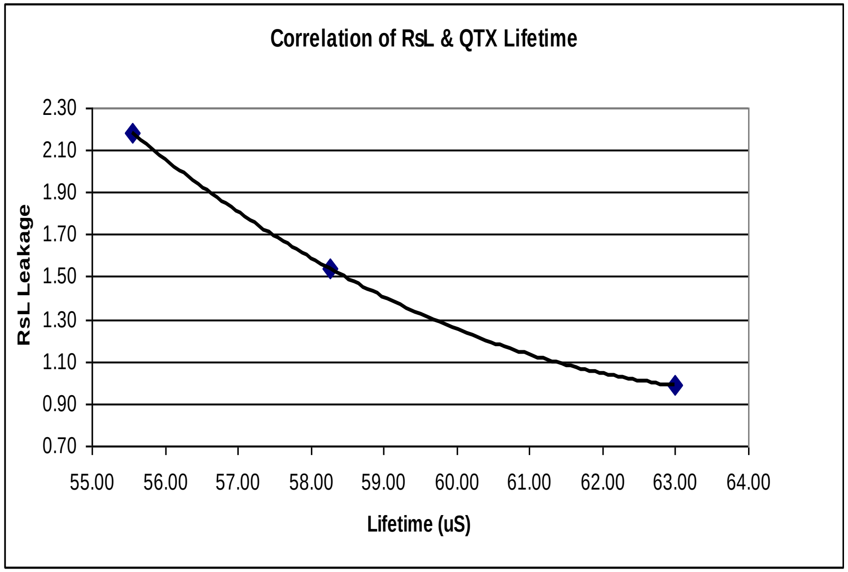
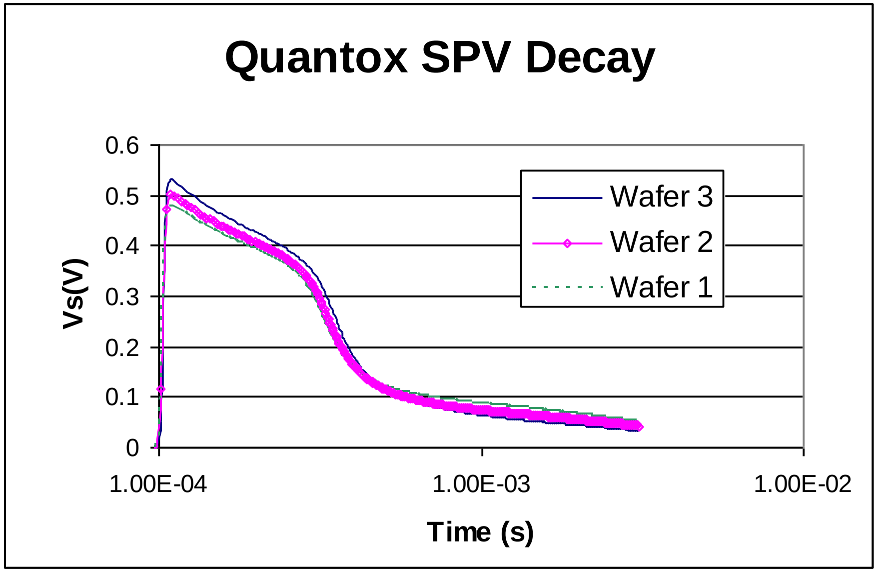
SPV, JPV or LPV

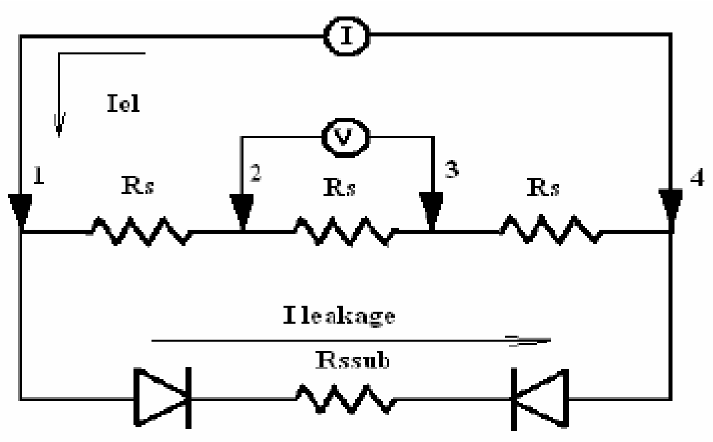




4PP Method

- The 4PP leakage through substrate can be modeled by following equivalent circuit

When Ileakage<<Iel, the distribution of the measured potential is determined only by the current going through top layer with sheet resistance Rs



$$V(x,y) = \frac{I_{EL}Rs}{2\pi}\ln\left(\sqrt{\frac{(x-x_1)^2+(y-y_1)^2}{(x-x_2)^2+(y-y_2)^2}}\right)$$

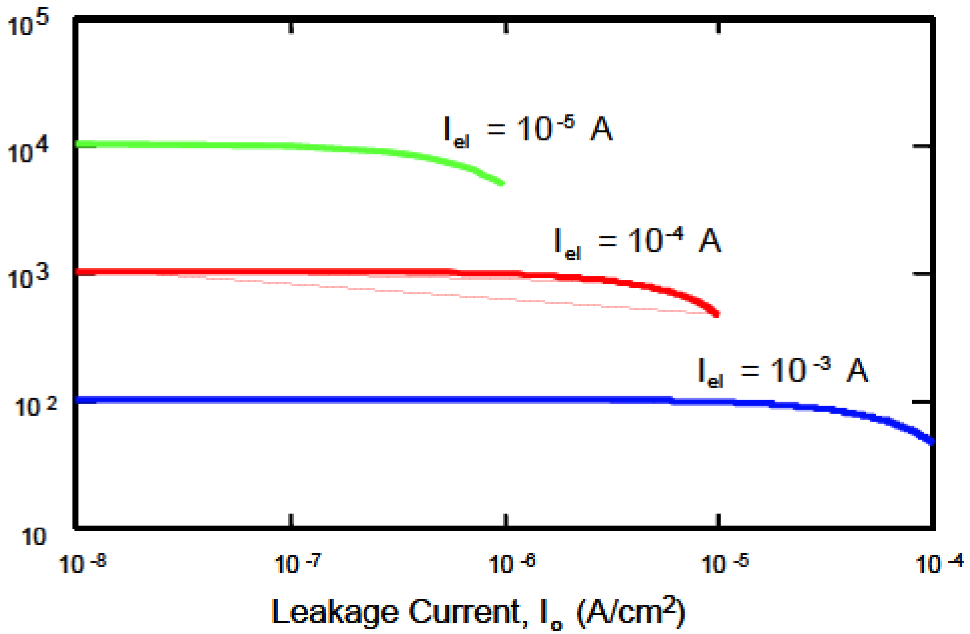
Where Iel is the current, which flows through the probes 1 and 4 with coordinates (x1,y1) and (x2,y2) on the other. Approximately consider half of the area as forward bias diode, the other half as reverse biased diode.

4PP Method (for leakage)

Measured Rs is a function of applied current for a fixed diode leakage density

$$I_{LEAK} = \iint_S j(x,y)dxdy = I_0 \iint_S \left[\frac{\sqrt{(x-x_1)^2+(y-y_1)^2}}{\sqrt{(x-x_2)^2+(y-y_2)^2}} \exp\left(-\frac{q \cdot I_{EL} \cdot Rs}{2\pi kT} \right) - 1 \right] dxdy$$

$$Rs_{measured} = \frac{\pi}{\ln 2} \frac{V_m}{I_{EL}}$$, where $$V_m = \frac{\ln 2}{\pi}(I_{EL} - I_{Leak})Rs$$



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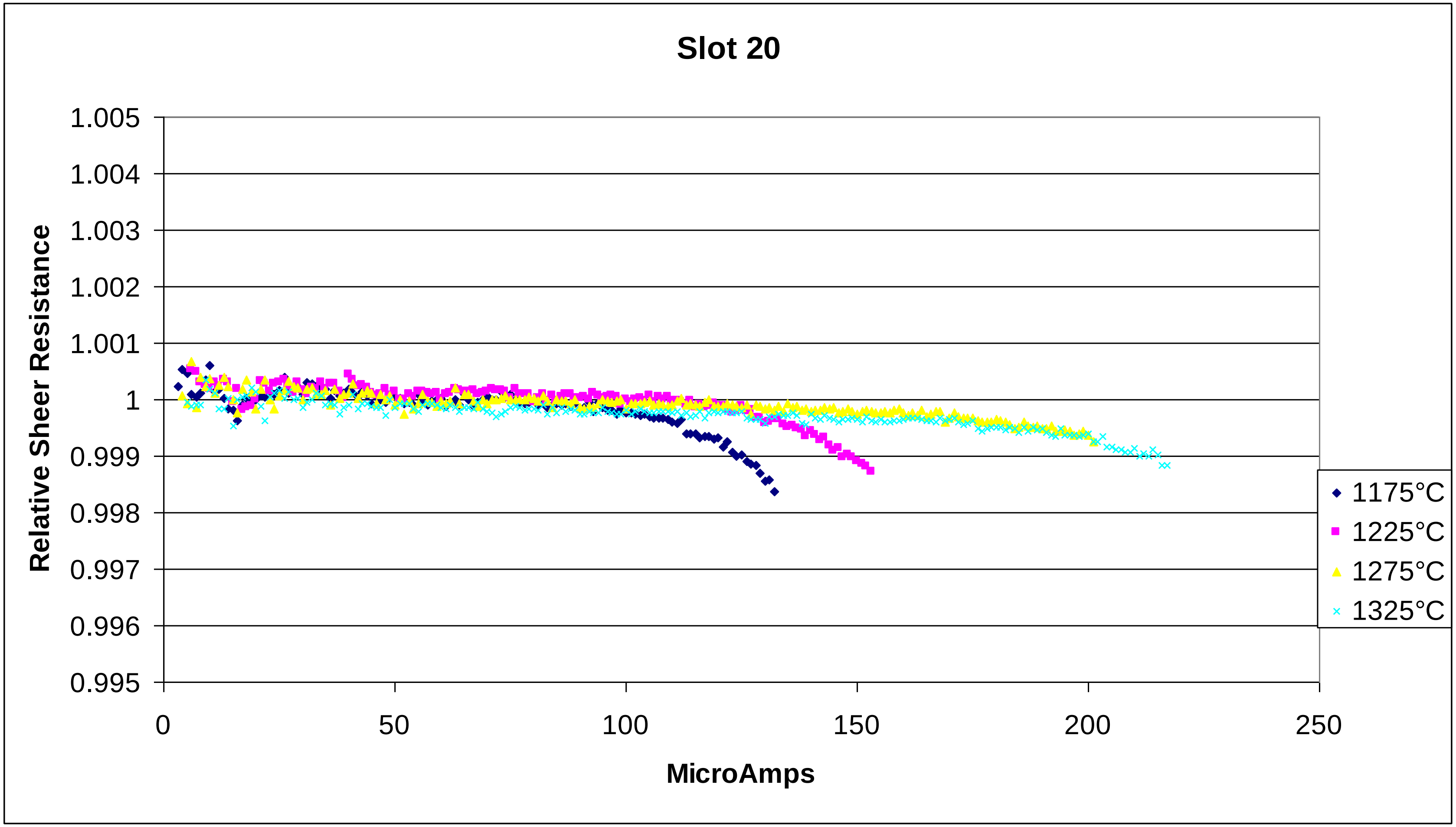
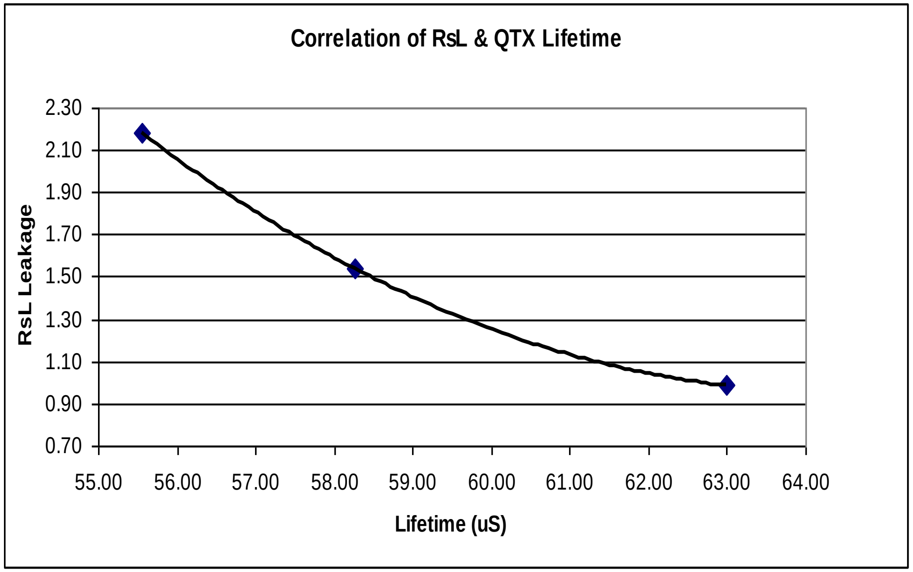
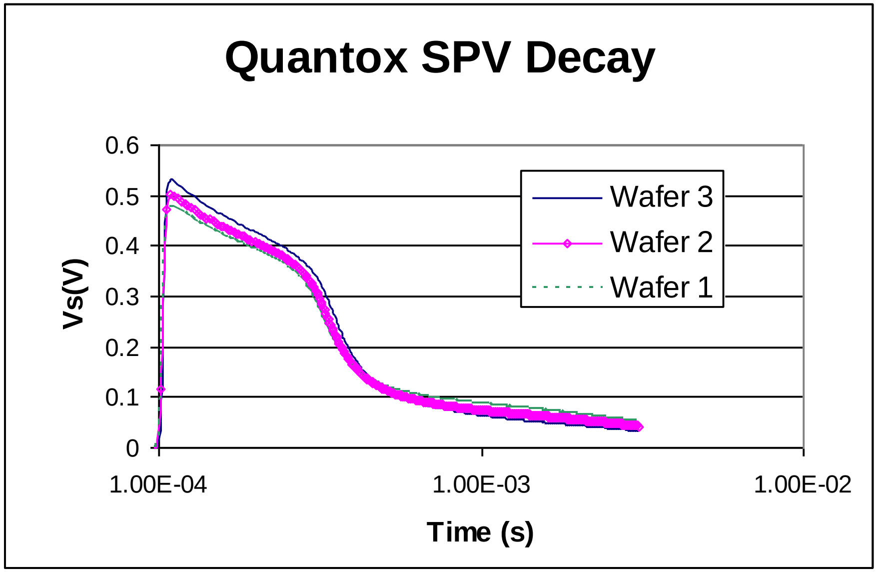
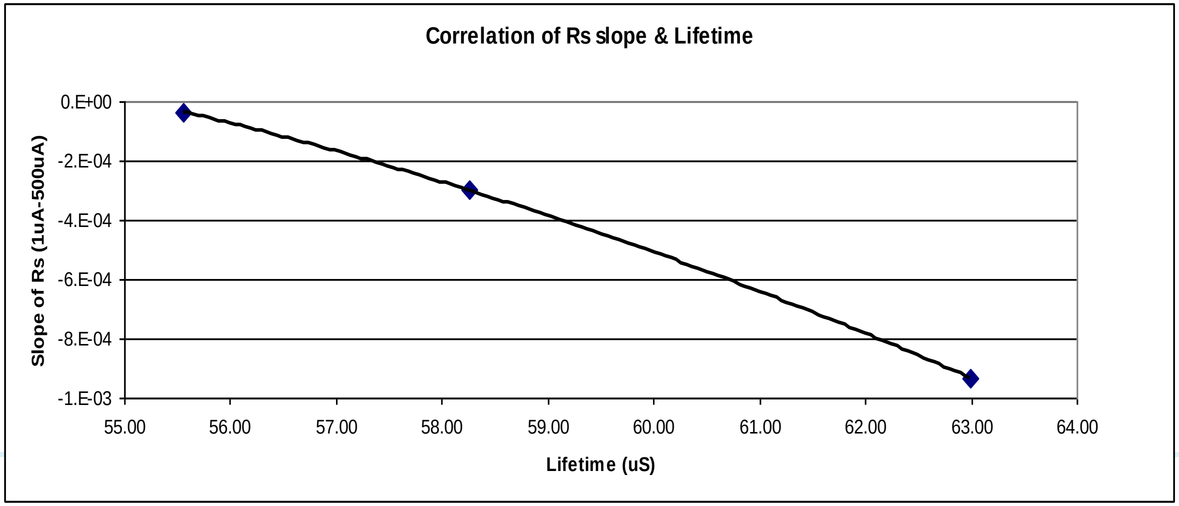
Increased Leakage below 1275˚ Anneal



Current Ramp Comparison to SPV







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Present Status of the 4PP

New (and older) technologies eddy current, TW, SPV etc. adding information on traditional 4PP applications

BUT!!!

4PP

Still not ready to give up