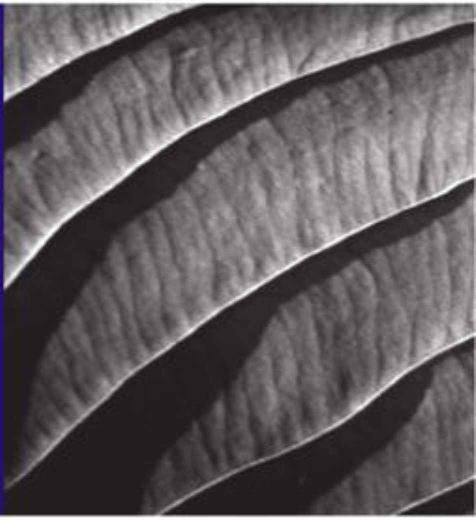
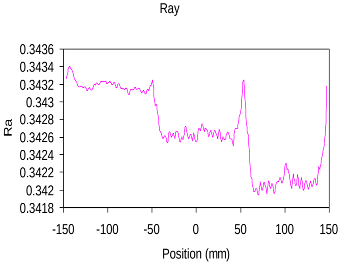
Optimizing the Synergy Between Thermal Wave and Sheet Resistance Measurements for the 15nm Node

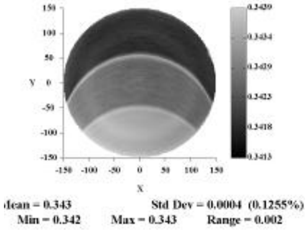
Walt Johnson



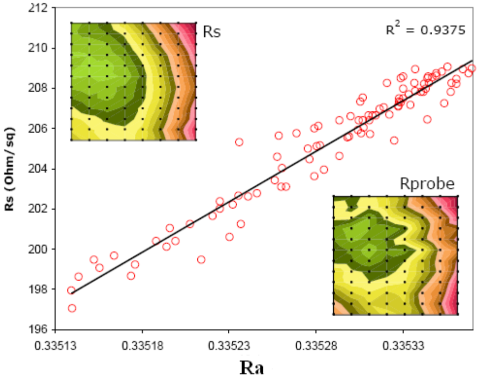
Implant Monitor Solution with RS and TP

Therma-Probe

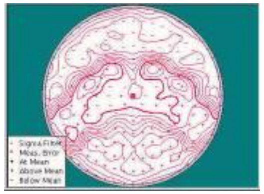


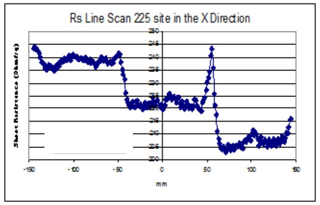


RS



$$Ra = \left(\frac{1-n_0}{1+n_0}\right)^2 - \frac{4\beta}{m_{h,e}} \frac{(n_0-1)}{(n_0+1)^3}\left(1-\cos\left(\frac{4\pi n_0 X_j}{\lambda}\right)\right)N_{active}$$



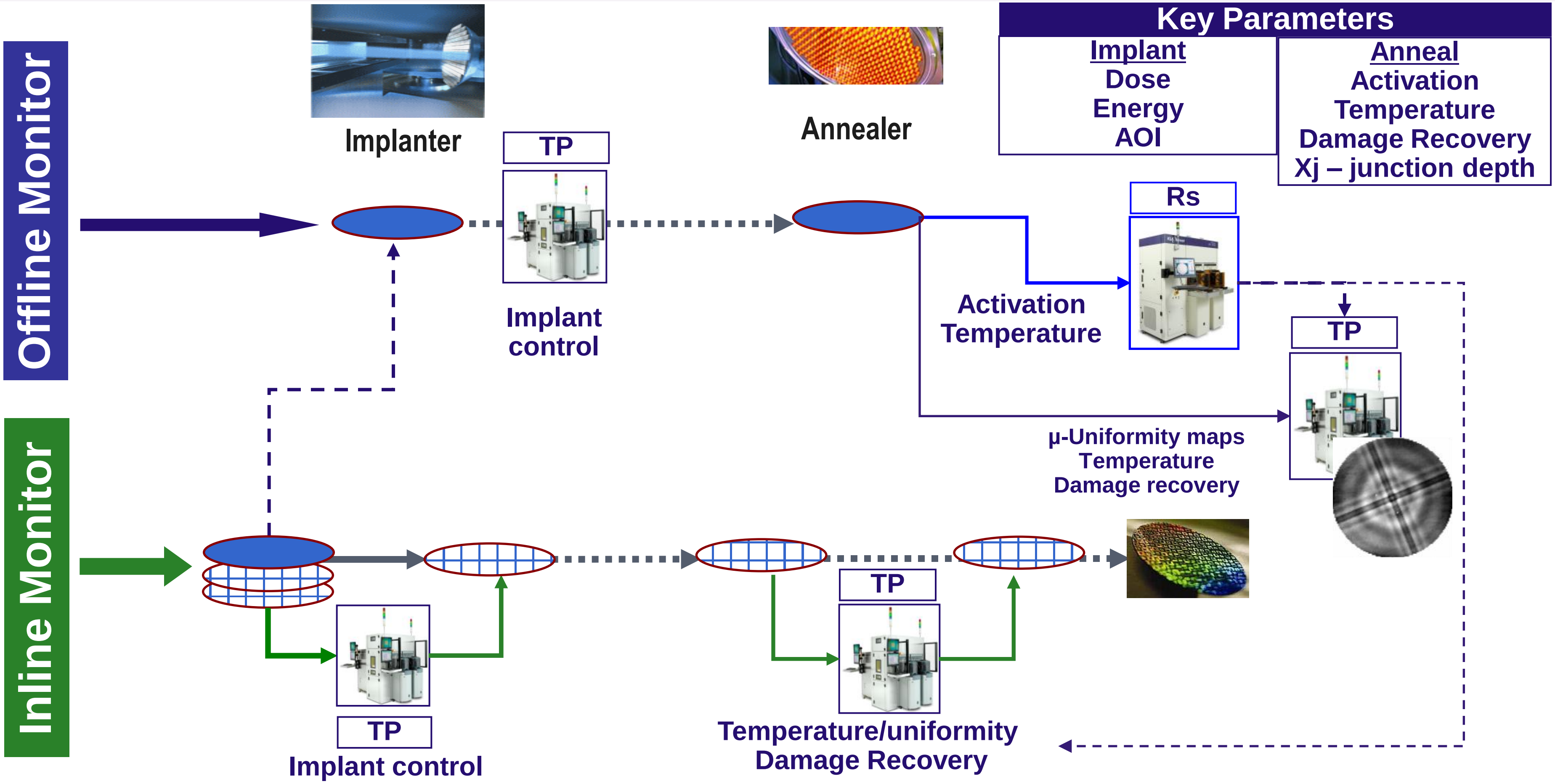


- Relative measurement, In-line on PW process control, optical micro-4PP
- High resolution, sensitive & stable
- Pre- and post- anneal
  - Decouples implant & anneal

- Absolute measurement, providing calibration for TP
- Industry standard NIST-traceable sheet resistances
- Post-anneal
  - activation

Implant & Anneal Control with Therma-Probe (TP) + Rs

TP + Rs provide full implant & anneal critical process parameters



Key Parameters

Implant	Anneal
Dose	Activation
Energy	Temperature
AOI	Damage Recovery
	Xj – junction depth

Offline Monitor

Implanter

TP

Implant control

Annealer

Rs

Activation Temperature

TP

µ-Uniformity maps
Temperature
Damage recovery

Inline Monitor

TP

Implant control

TP

Temperature/uniformity
Damage Recovery

TP + Rs provide complete metrology parameters for implant & anneal process

Rs for “reference” level Activation & junction electrical quality

TP for implant dose and post-anneal parameters (damage recovery & Xj)

TP680 Summary of Improvements

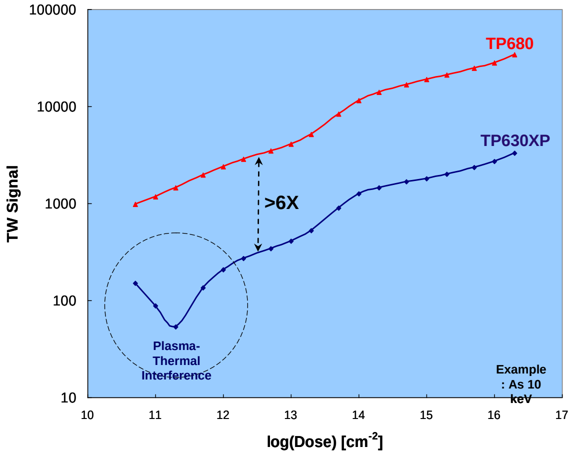
Signal and repeatability define practical tool performance

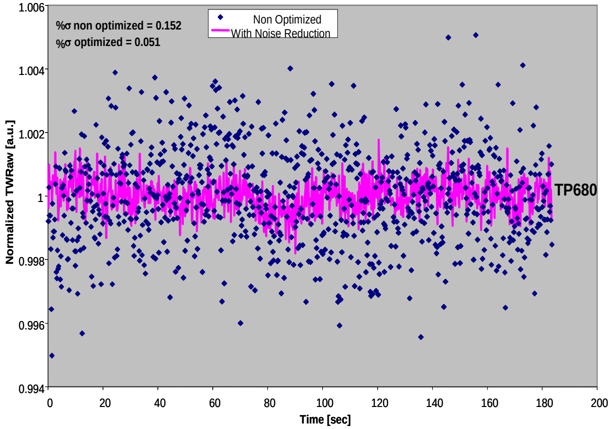
Dose Detectability (DD) = % Repeatability / S $= \dfrac{\%\ 3\sigma\, TW}{S}$

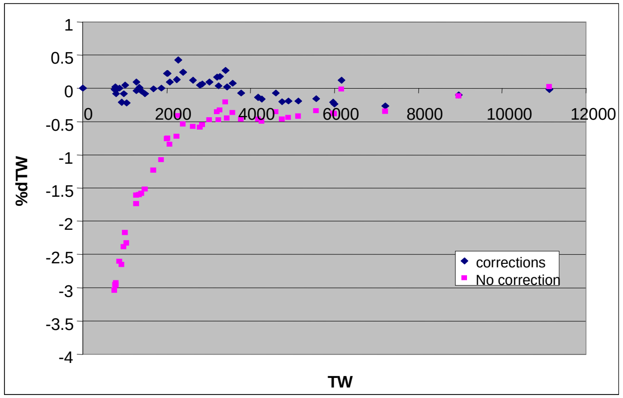
Signal Strength

Low Noise

Stability

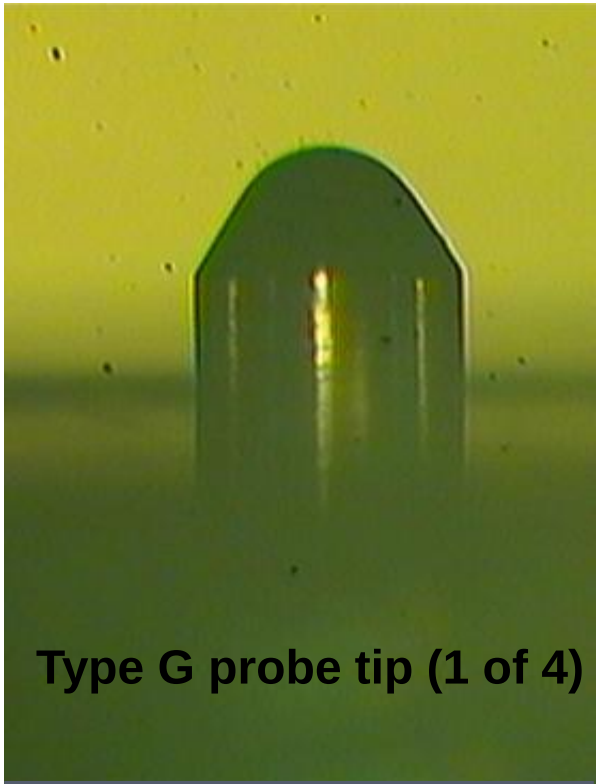






TP680 improves DD by >2x compared to TP630XP

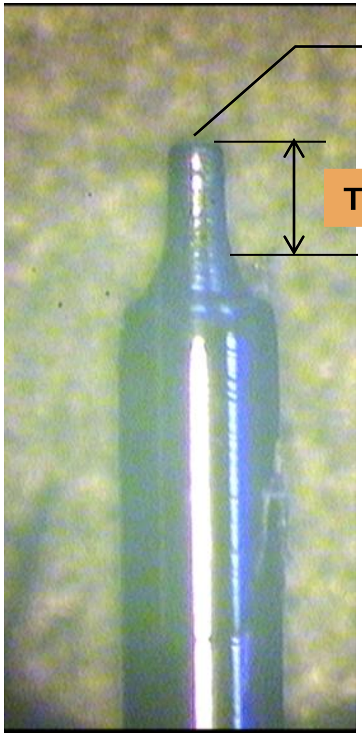
Hx probe tip design



Type G probe tip (1 of 4)

Tip radius:	Tip length:	Pitch:	Force:
~100 um	~ 1mm	25 mil	100 g

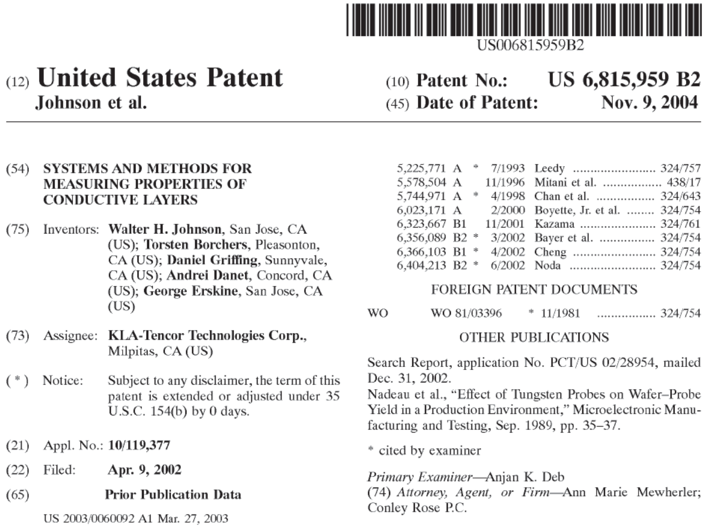
KT patented Hx tip design



Tip diameter: 0.1 mm

Tip length: 0.2 mm

Hx-100



US006815959B2

(12) **United States Patent**
Johnson et al.

(10) **Patent No.: US 6,815,959 B2**
(45) **Date of Patent: Nov. 9, 2004**

(54) **SYSTEMS AND METHODS FOR MEASURING PROPERTIES OF CONDUCTIVE LAYERS**

(75) Inventors: **Walter H. Johnson**, San Jose, CA (US); **Torsten Borchers**, Pleasonton, CA (US); **Daniel Griffing**, Sunnyvale, CA (US); **Andrei Danet**, Concord, CA (US); **George Erskine**, San Jose, CA (US)

(73) Assignee: **KLA-Tencor Technologies Corp.**, Milpitas, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/119,377**

(22) Filed: **Apr. 9, 2002**

(65) **Prior Publication Data**

US 2003/0060092 A1 Mar. 27, 2003

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* cited by examiner

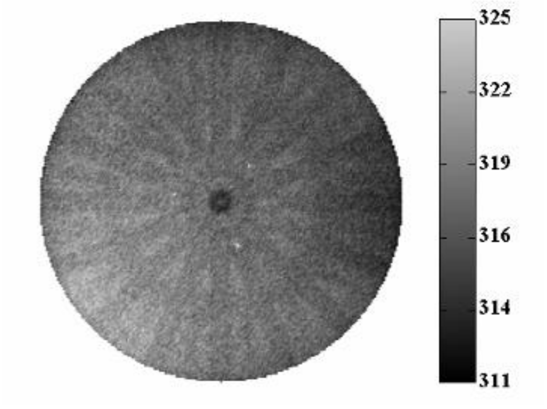
Primary Examiner—Anjan K. Deb
(74) *Attorney, Agent, or Firm*—Ann Marie Mewherler; Conley Rose P.C.

Larger contact area results on lower penetration and lower contact resistance.

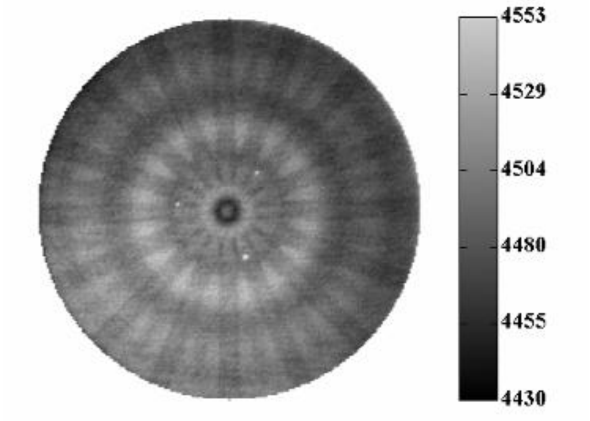
Contact area does not change through useful life.

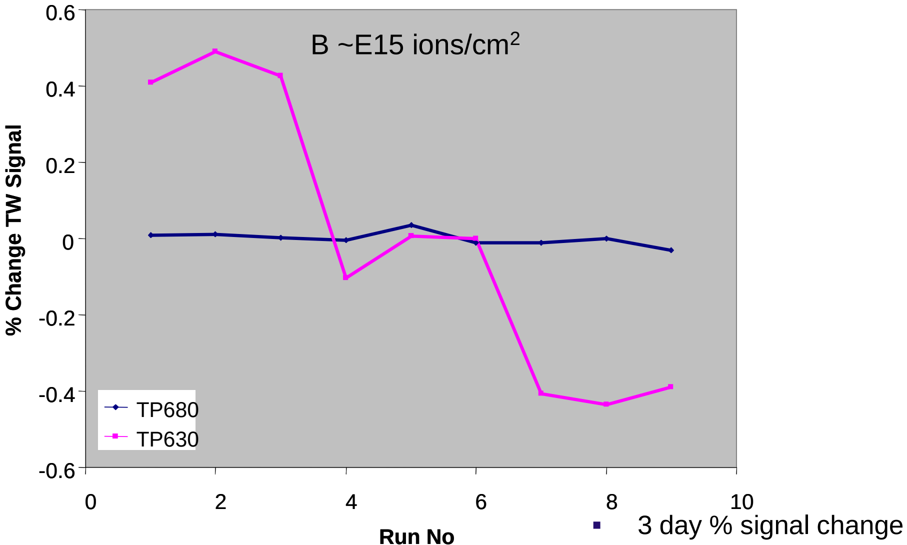
TP680 vs. TP630 Comparison

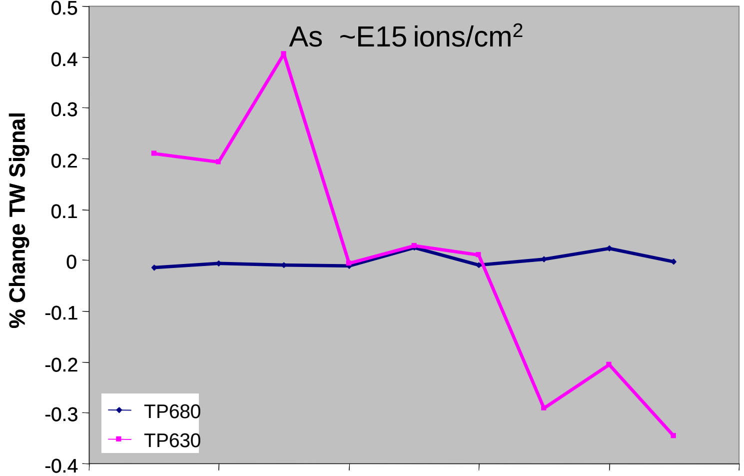
TP630XP



TP680







SN and long term stability of TP680 is greatly improved over TP630

TP & Rs Evaluation of Laser Beam Overlap

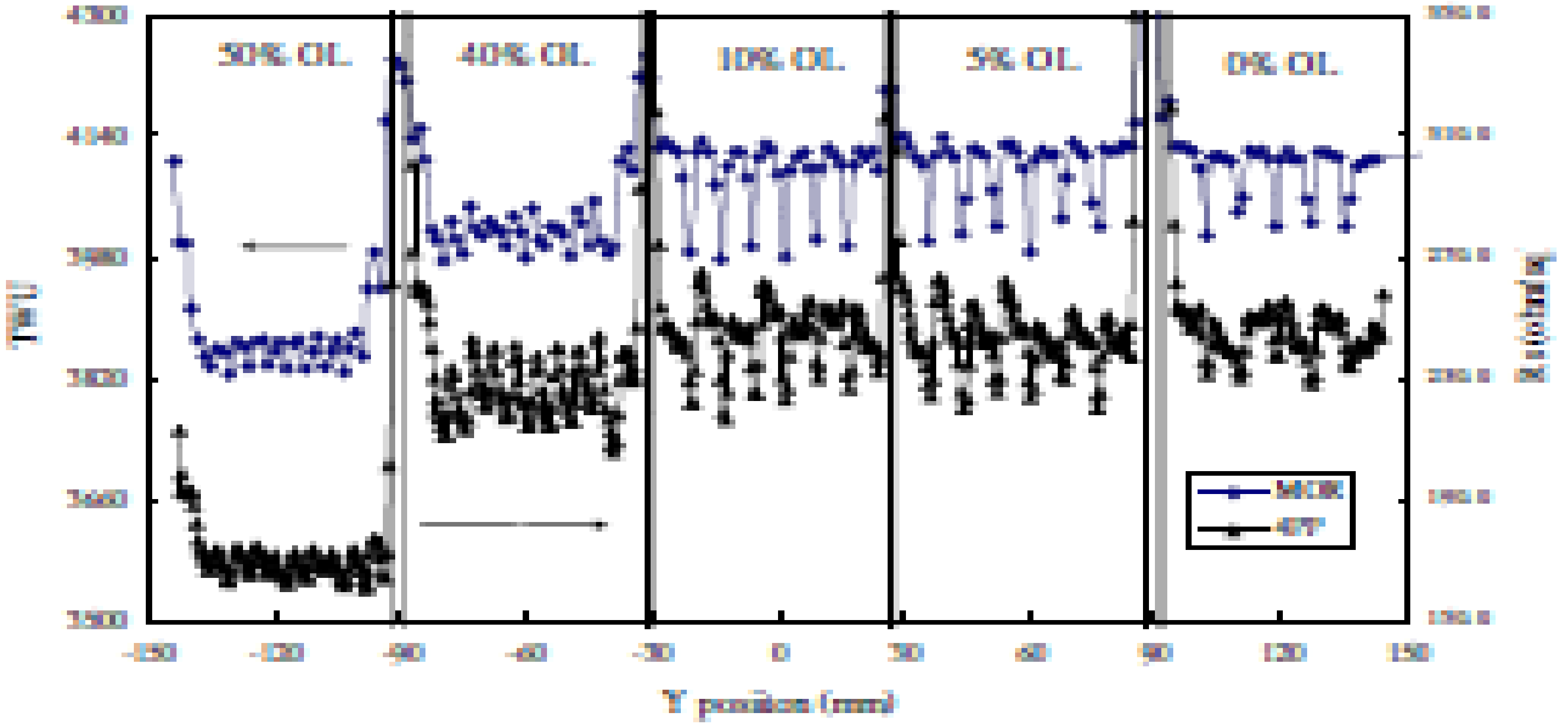
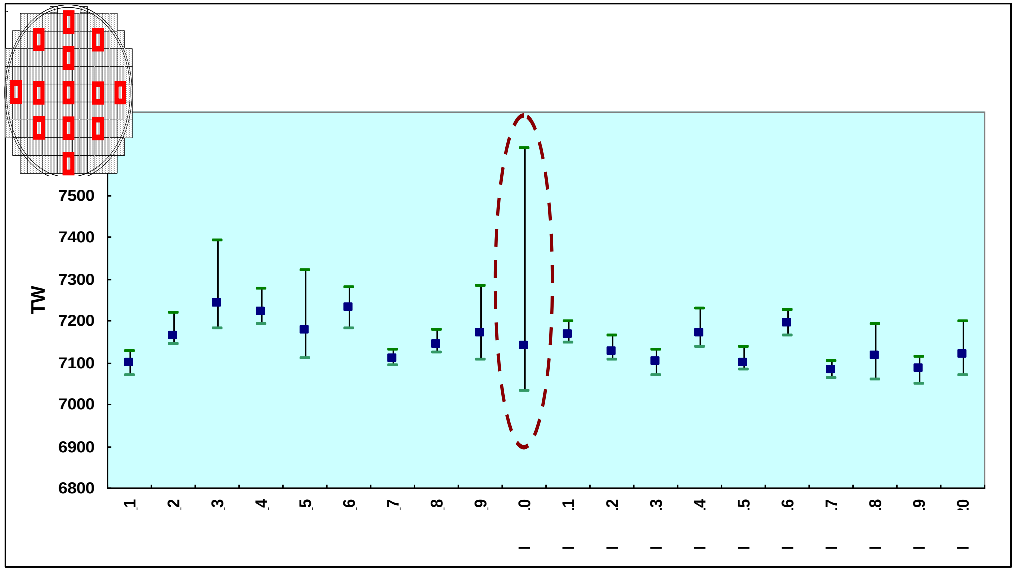


Fig.9: MOR and 4PP diameter scan result of wafer #7

Is there any significance to the asymmetry shown in the Rs data?

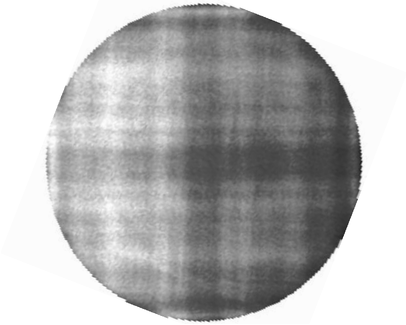
TP Product Wafer Monitoring

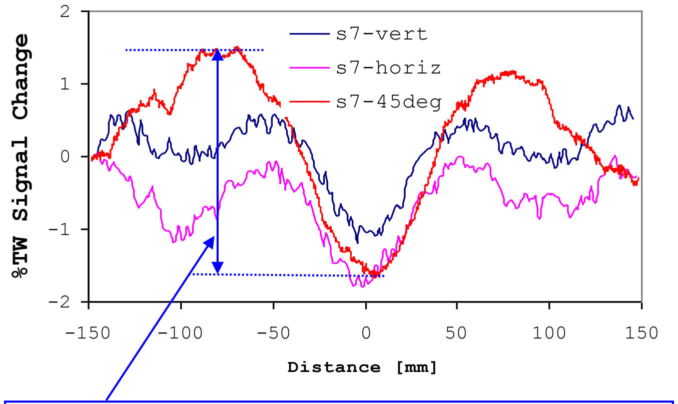
Implant Excursion Monitoring on Product Wafer



- Integration issues are only detected on product wafers
- Process excursions are identified earlier with product wafer monitoring

Implant Uniformity Verification

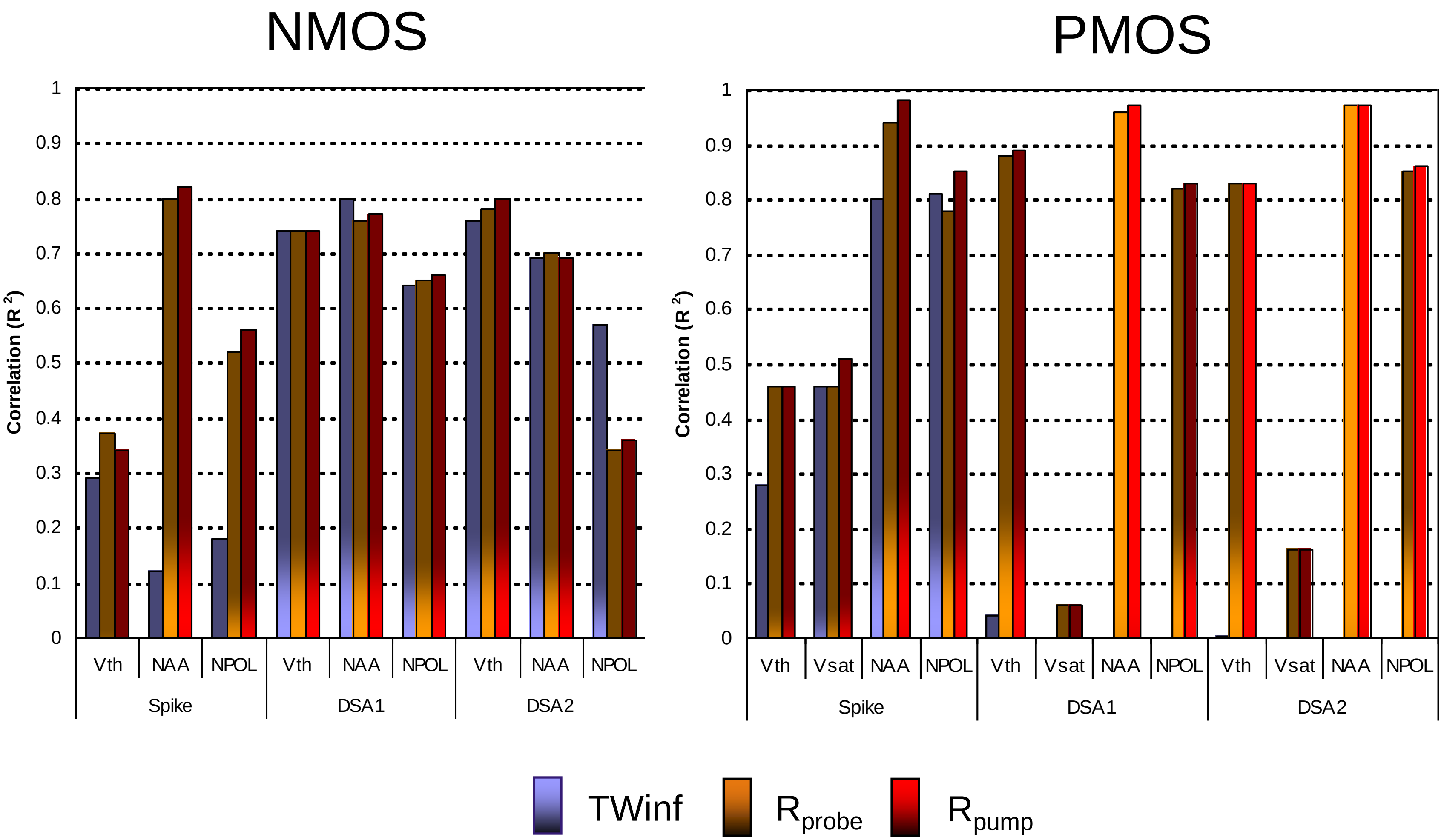




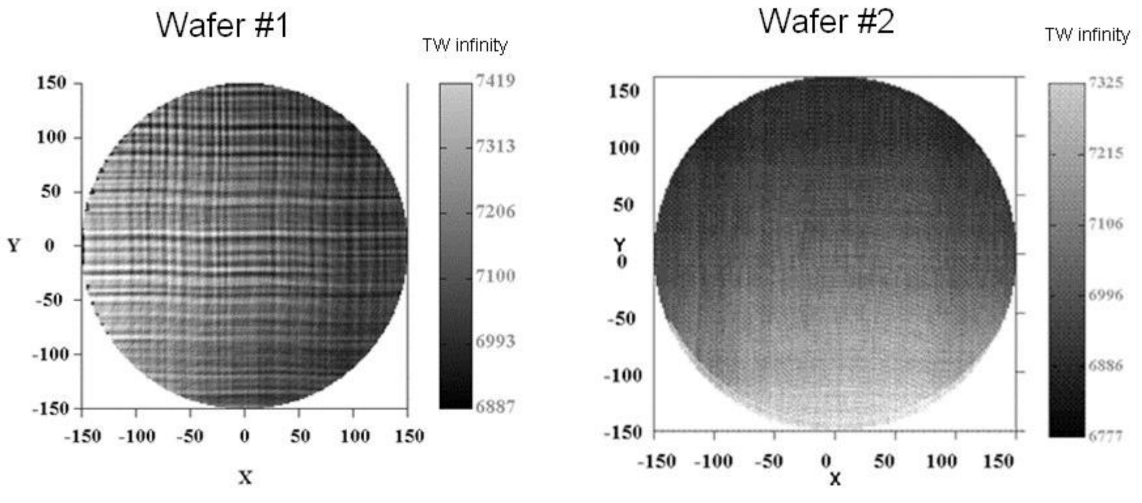
~3% signal change ➡ >10% damage variation

Checker patterns are signatures that result from quad-mode operation of a ribbon beam implanter

Correlation Summary: NMOS & PMOS



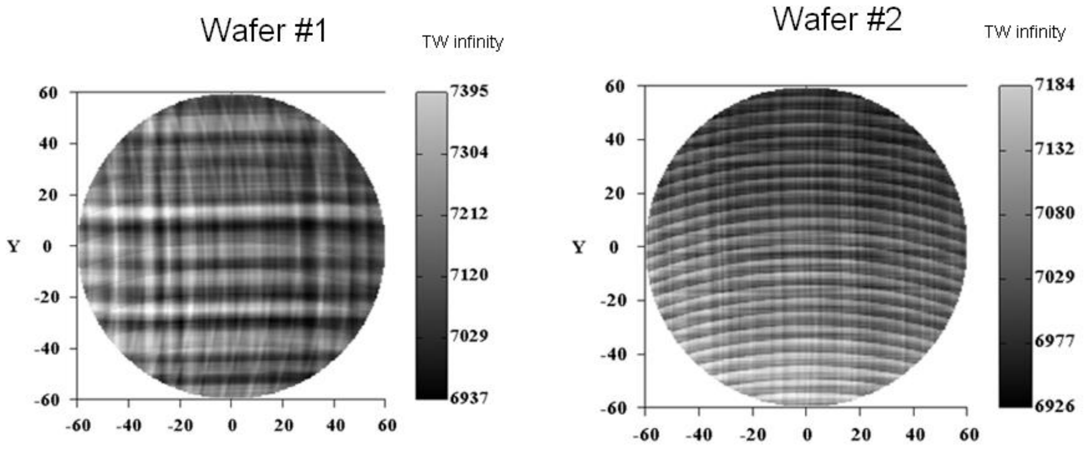
Laser Spike Anneal Macro & Micro Non-uniformity Investigation Using Modulated Optical Reflectance



Mean:7153; Range: 527;Std%: 1.2%

Mean:7051; Range:453; Std.%:1.3%

Fig.2: Thermawave full-mapping for wafer#1 (left) and wafer#2 (right).



Mean:7166; Range: 454; Std%: 1.1%

Mean:7055; Range:245; Std.%:0.6%

Fig.3: Localized MOR mapping with high resolution for wafer#1 (left) and wafer#2 (right).

Yonggen He1, Yong Chen1, Guobin Yu1, Albert Hong1, Jiong-Ping Lu1, Xianghua Liu2, Lu Yu2, Yue Chen2 (SMIC & KT)

High Resolution Zoomed Imagess

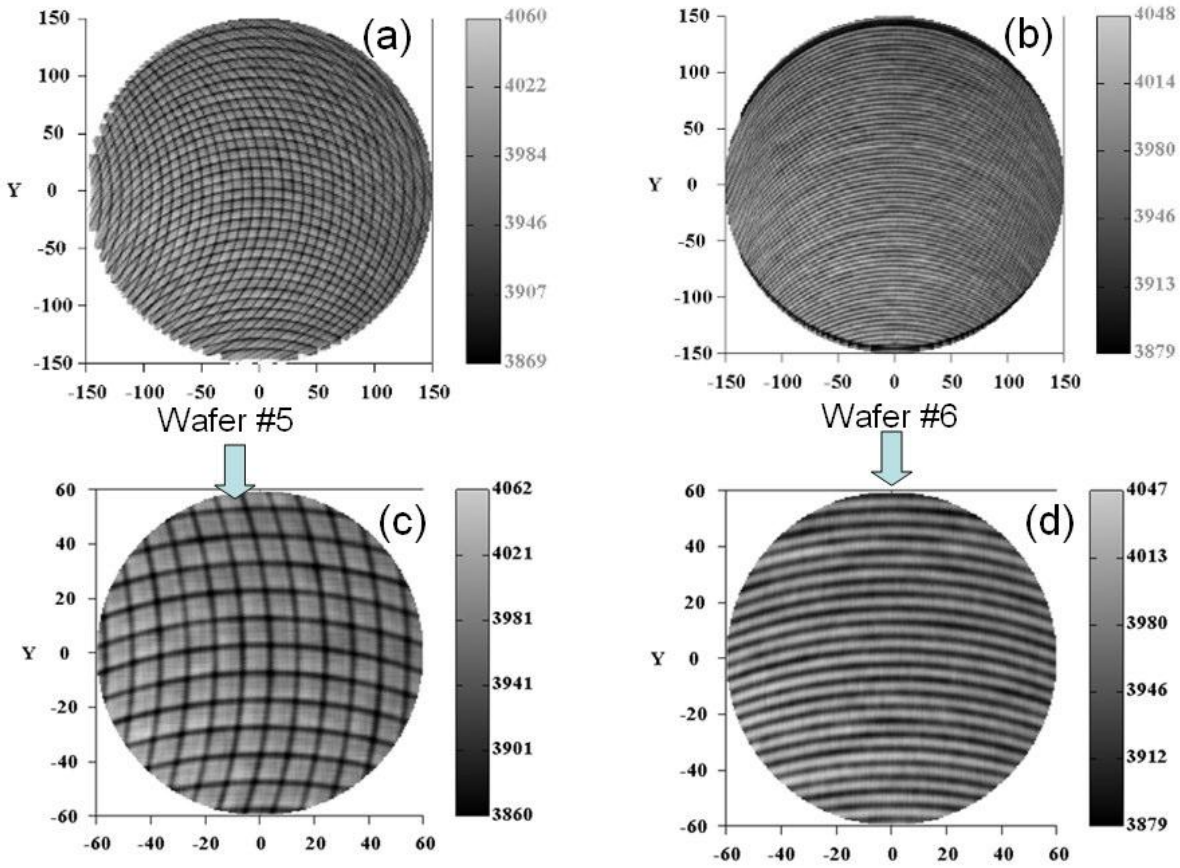
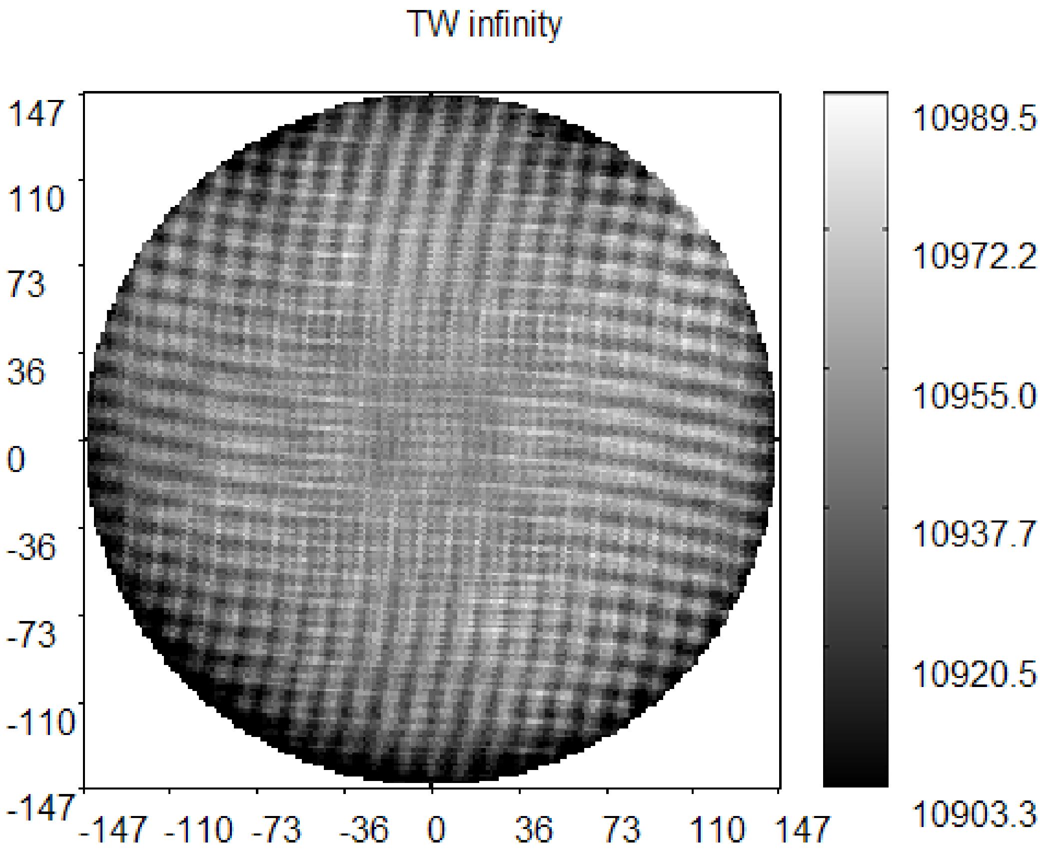


Fig.7: Global (low resolution) and localized (high resolution) MOR map: (a), wafer#5 global, (b), wafer #6 global, (c) wafer #5 local, (d),wafer#6 local.

Due to the two periodic patterns (implanter scan and TP scan) a Moiré effect occasionally can be seen.

A higher resolution image not only gives more information about the wafer pattern but will typically eliminate the Moiré pattern.

One of the More Interesting TP680 μMaps

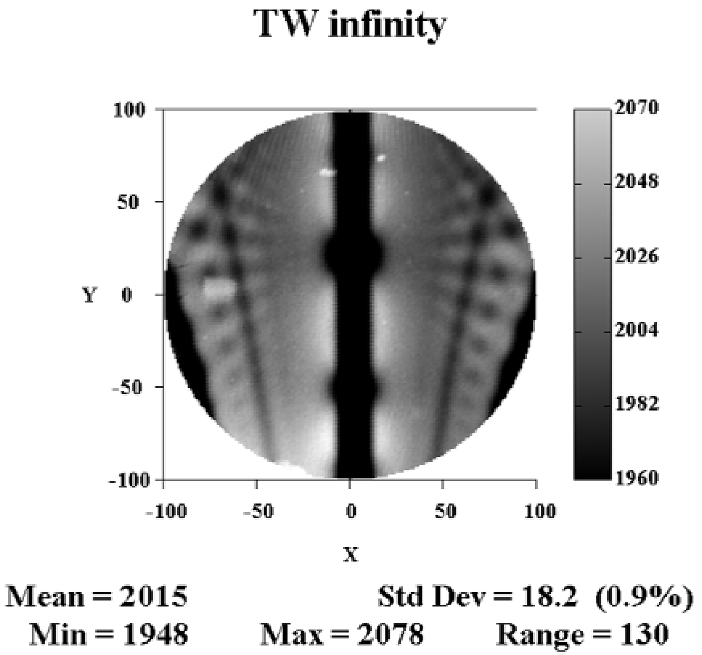


Mean = 10946 Std Dev = 14.37 (0.13%)

Min = 10903 Max = 10986 Range = 83

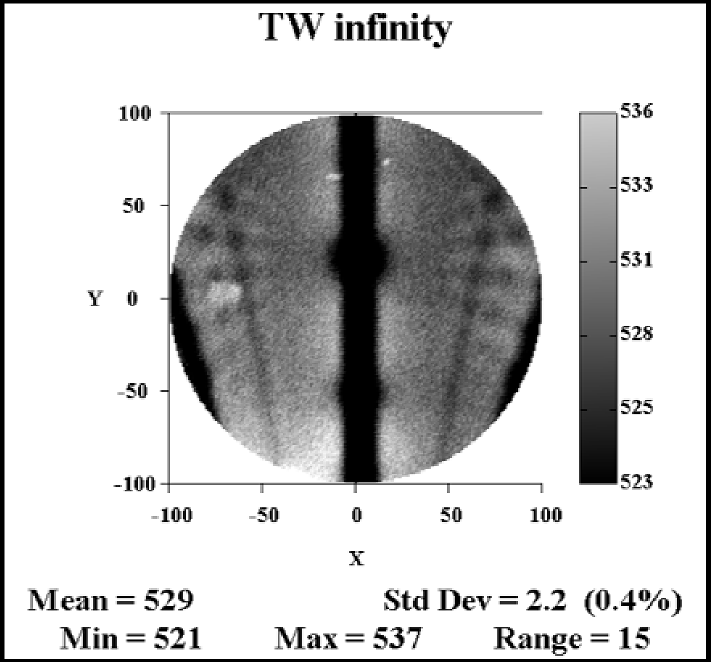
TP680 Twice the Resolution in Half the Time

TP680



Mean = 2015 Std Dev = 18.2 (0.9%)
Min = 1948 Max = 2078 Range = 130

TP630XP



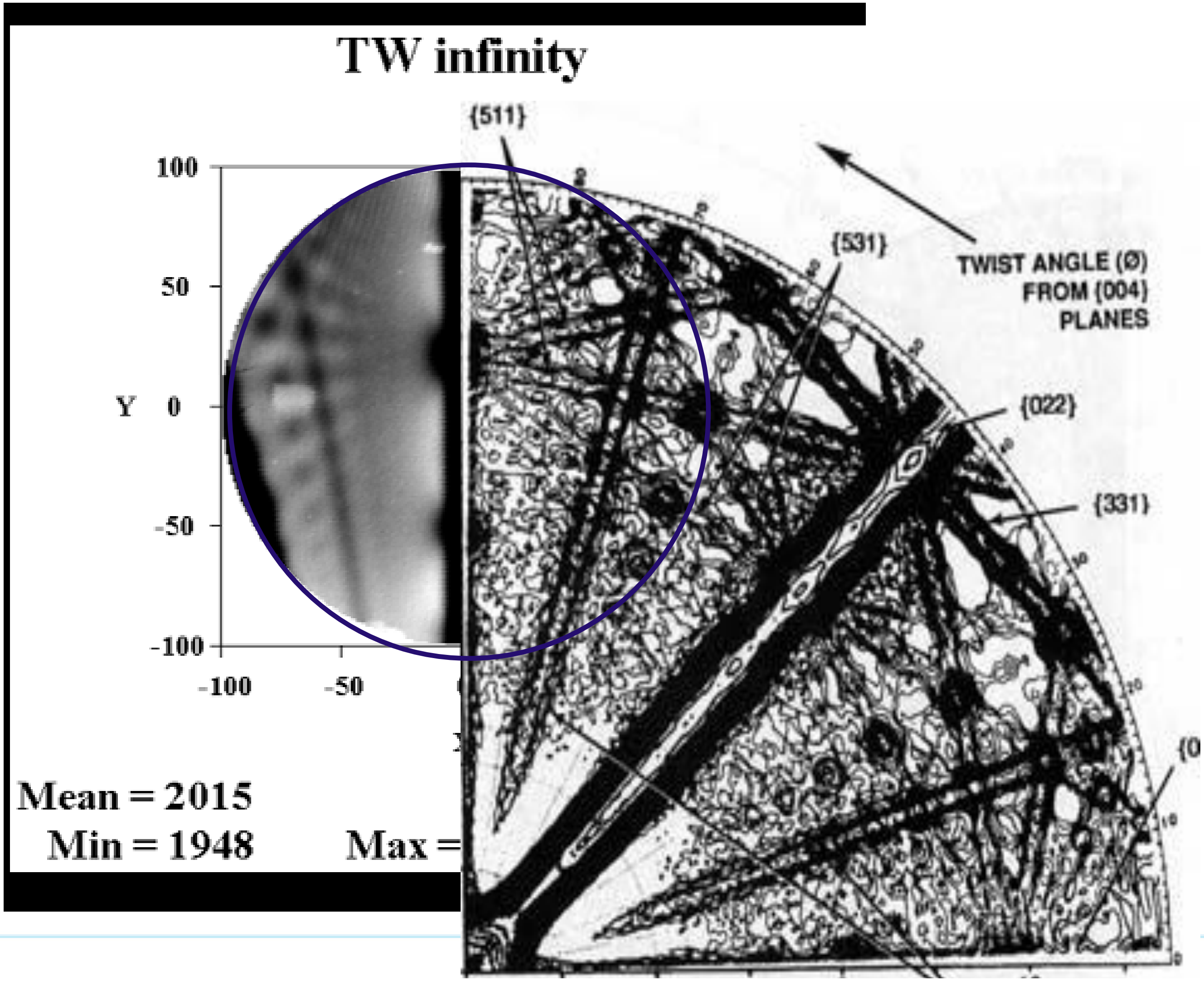
Mean = 529 Std Dev = 2.2 (0.4%)
Min = 521 Max = 537 Range = 15

TP680 map: ~29000 pts, 0.2"/pt, 1mm spacing, 4mm edge exclusion

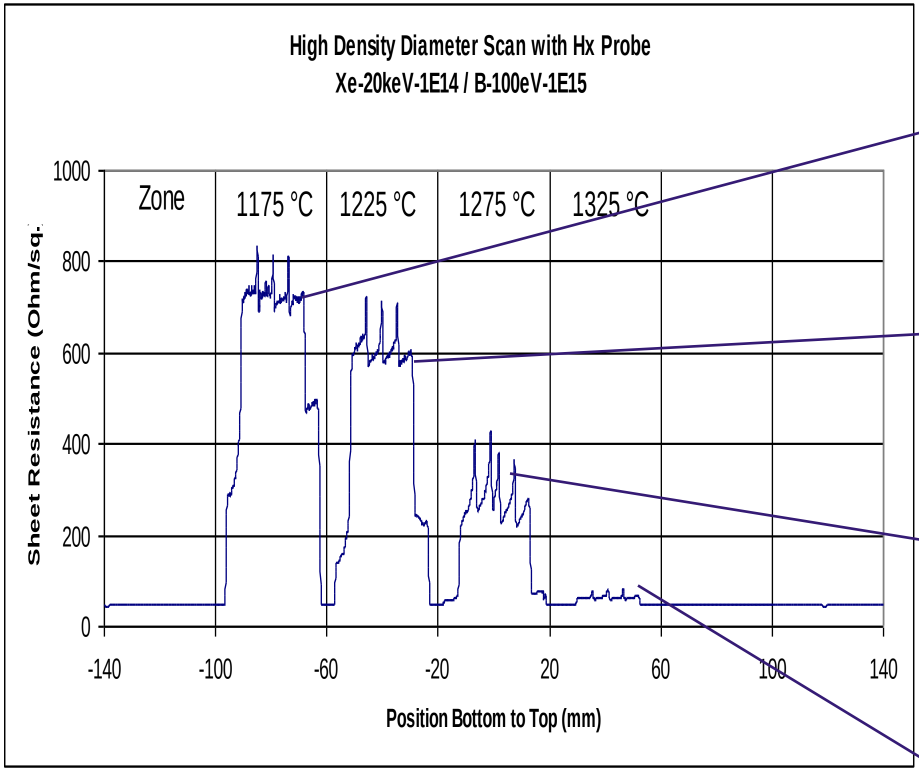
TP630XP map: ~29000 pts, 0.3"/pt, 1mm spacing, 4mm edge exclusion

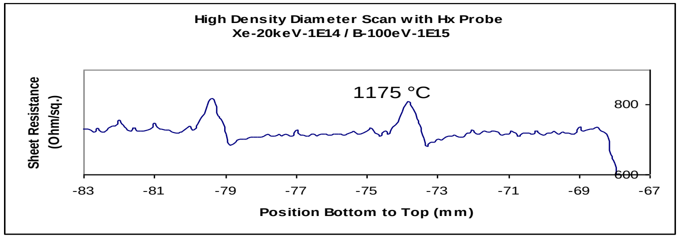
Data outside +/- 3σ from the mean are excluded from the maps

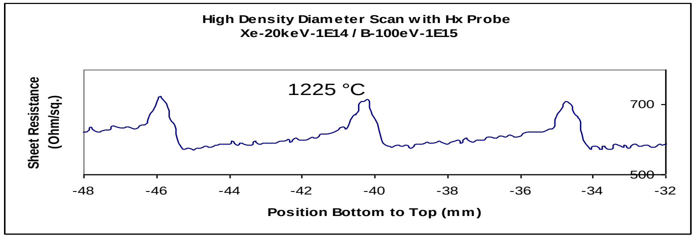
TP680 µMap and Crystal Channel Map

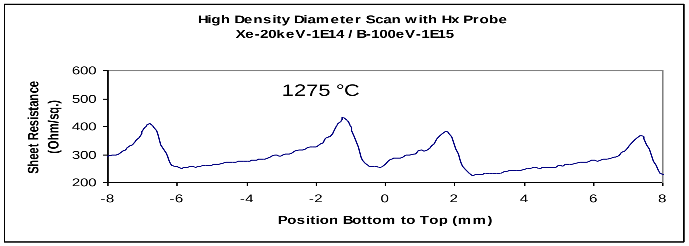


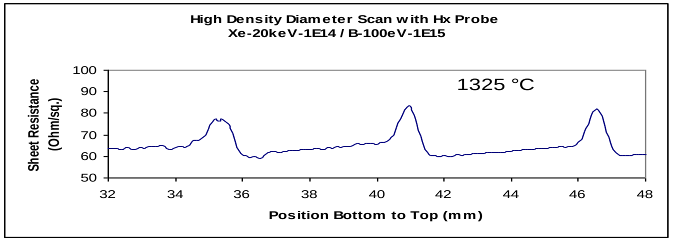
Hx Probe Better s/n for USJ uniformity
--- Intel 22nm Node USJ Implant (~5nm X_j)





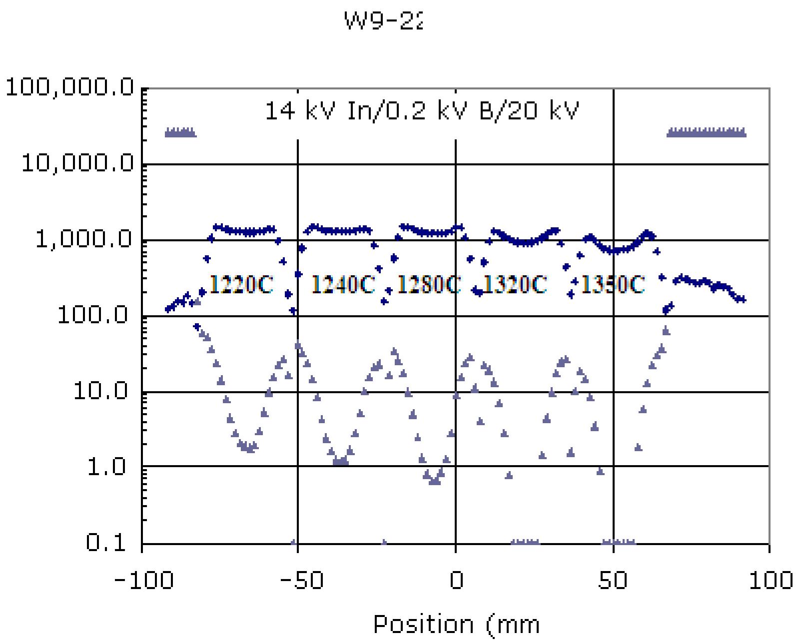


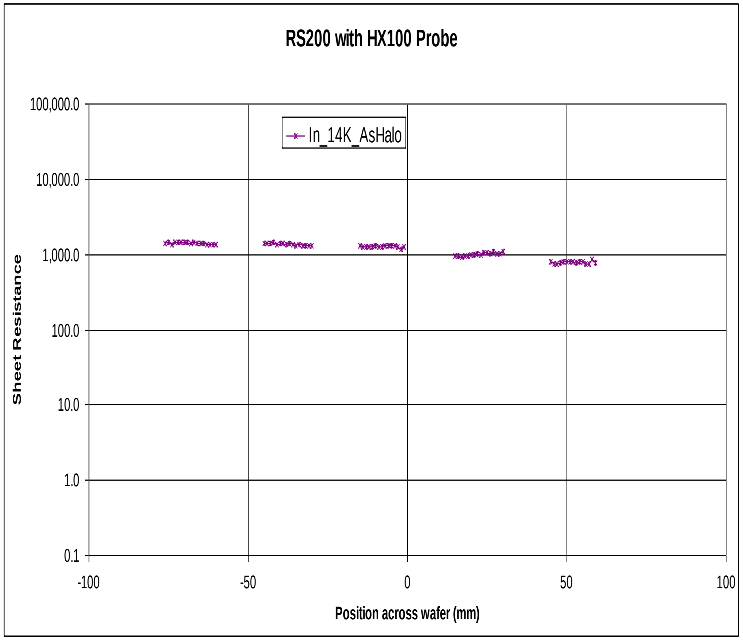




Each temperature Zone shows the stitching pattern of the laser annealer.

As-HALO 14keV In-PAI RsL & Hx results

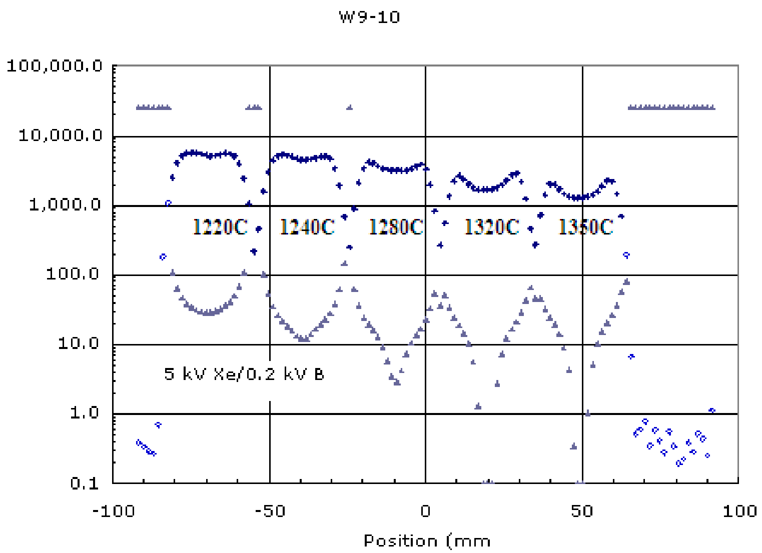


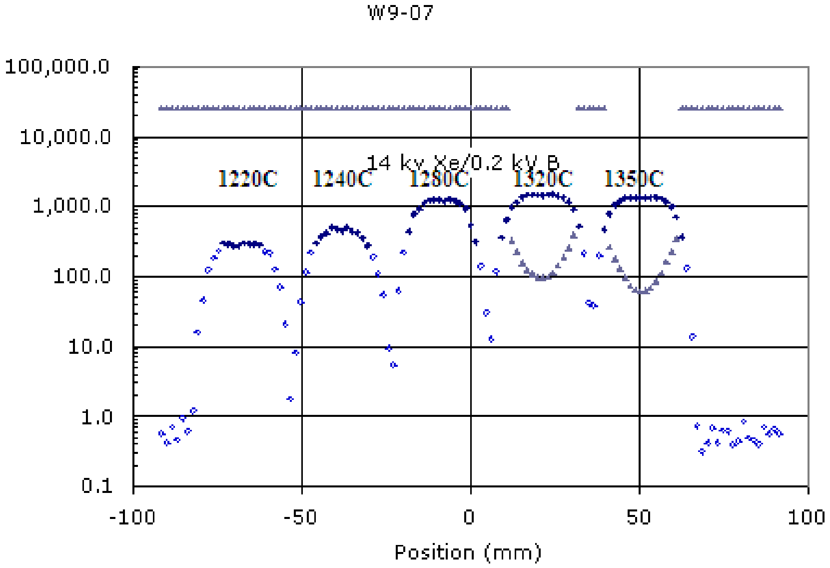


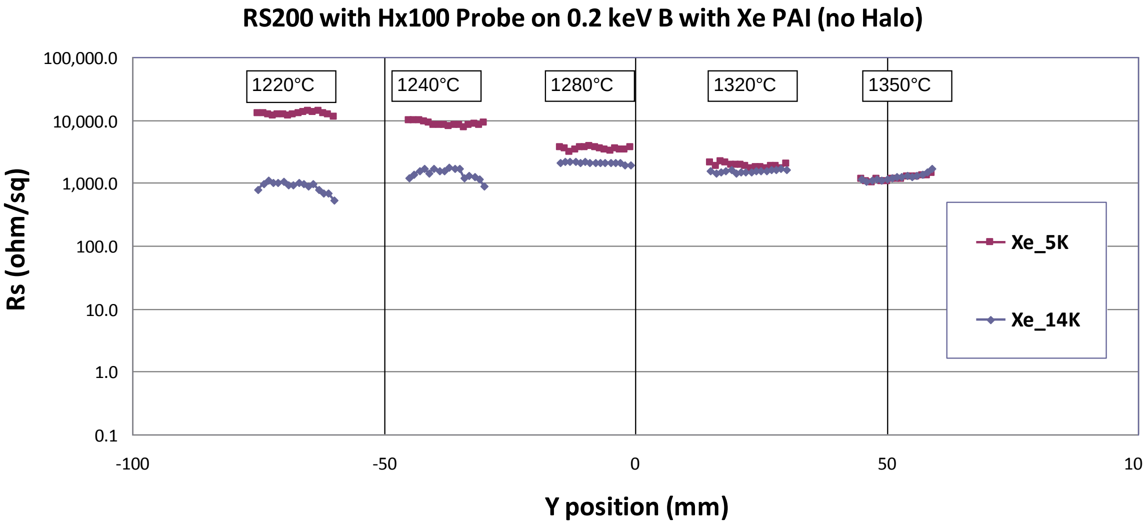
22nm Node p+ USJ Formation Using PAI & HALO Implantation With Laser Annealing

John O. Borland1, John Marino2, Michael Current3 and Blake Darby4

No HALO 5 & 14keV Xe-PAI

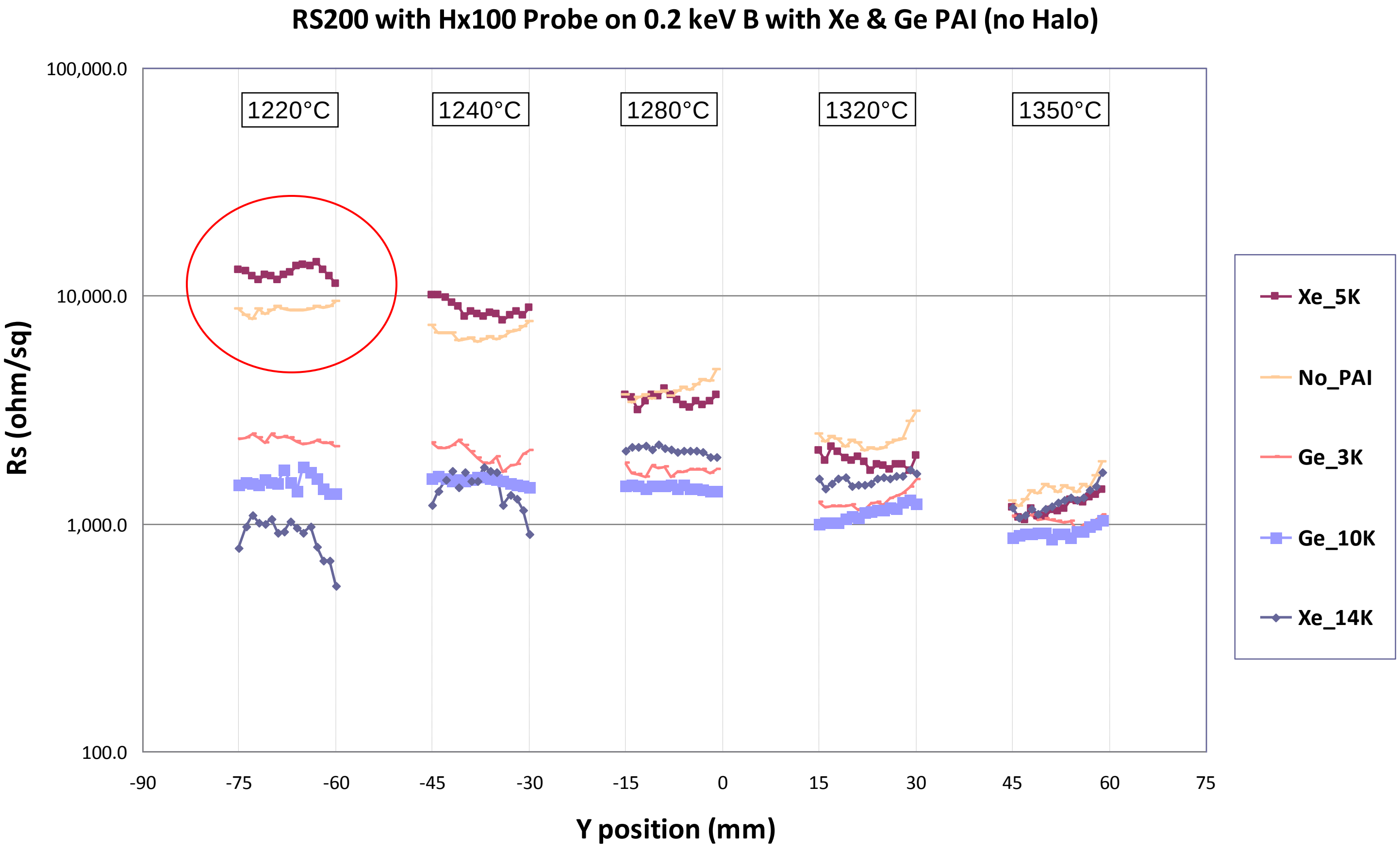






Hx probe shows higher Rs (less leakage?) for 1220 ° C and 1240 ° C anneals for both 5K and 14K Xe PAI.

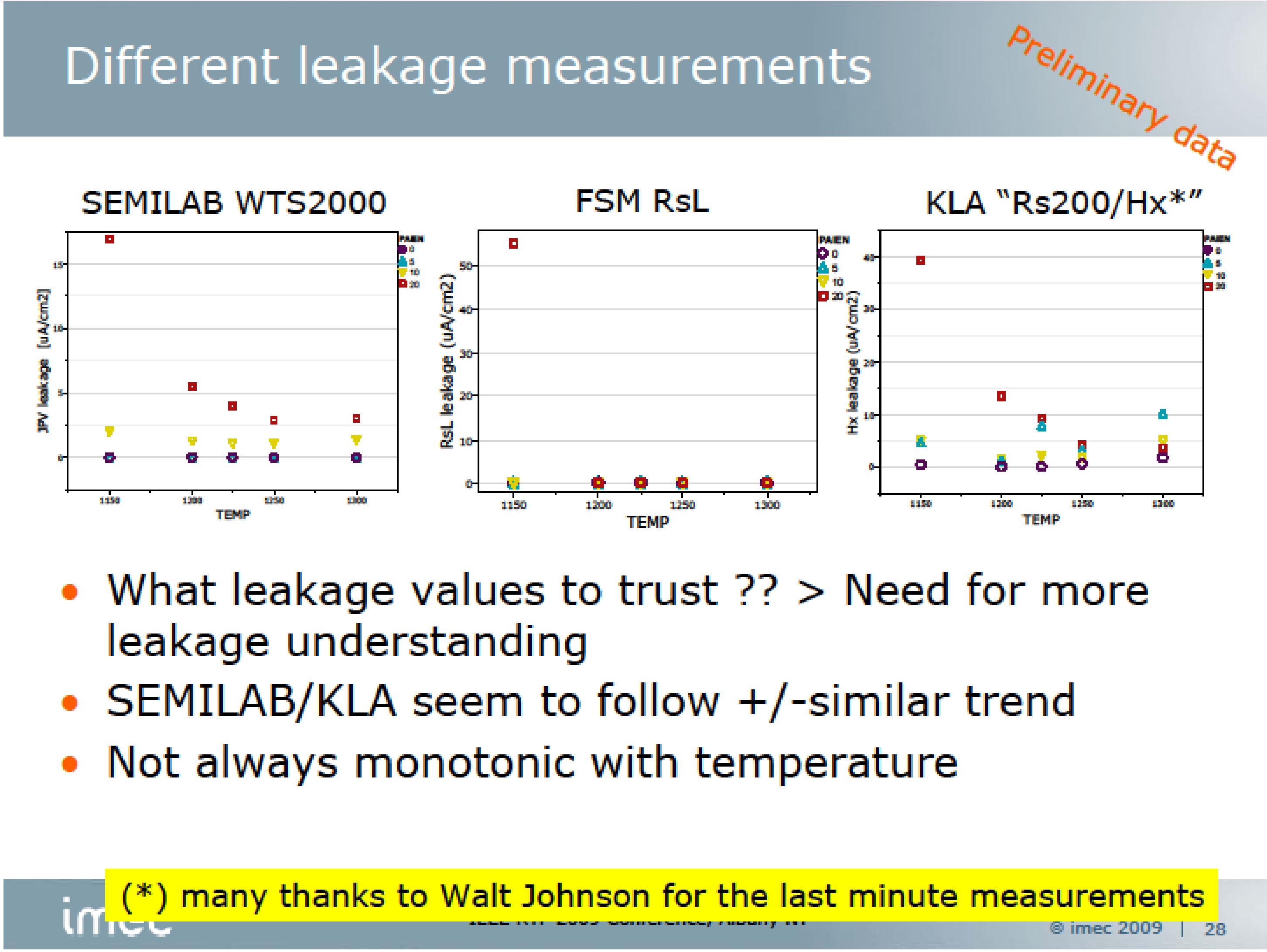
Hx Probe on Xe and Ge PAI Implants



Hx probe results indicated higher Rs for the low temperature 5K Xe implants relative to the no PAI reference. RsL results showed the opposite.

Is this real?

Study of sub-melt laser damage annealing using Therma-Probe



Different leakage measurements

Preliminary data

SEMILAB WTS2000

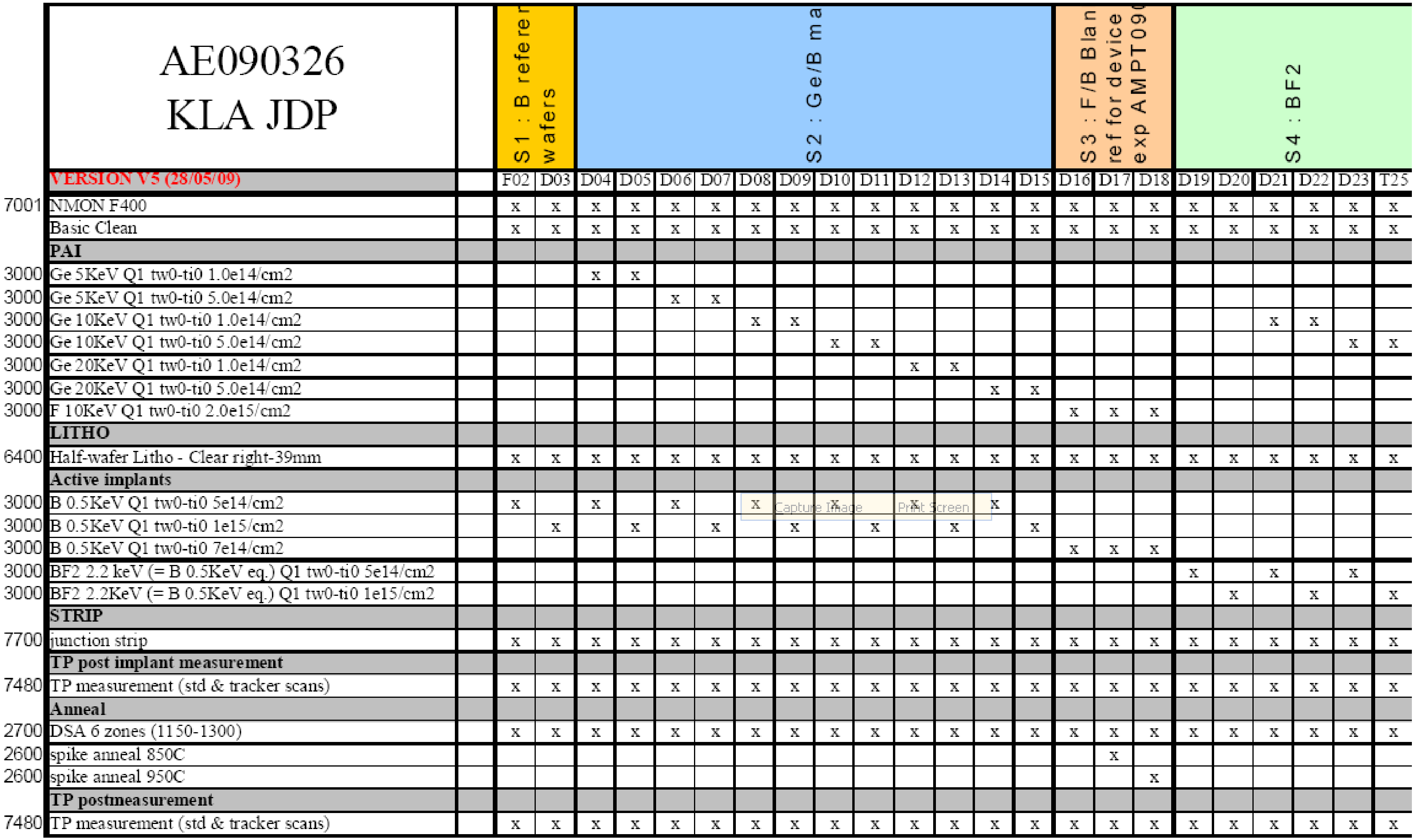
FSM RsL

KLA "Rs200/Hx*"

- What leakage values to trust ?? > Need for more leakage understanding
- SEMILAB/KLA seem to follow +/-similar trend
- Not always monotonic with temperature

(*) many thanks to Walt Johnson for the last minute measurements

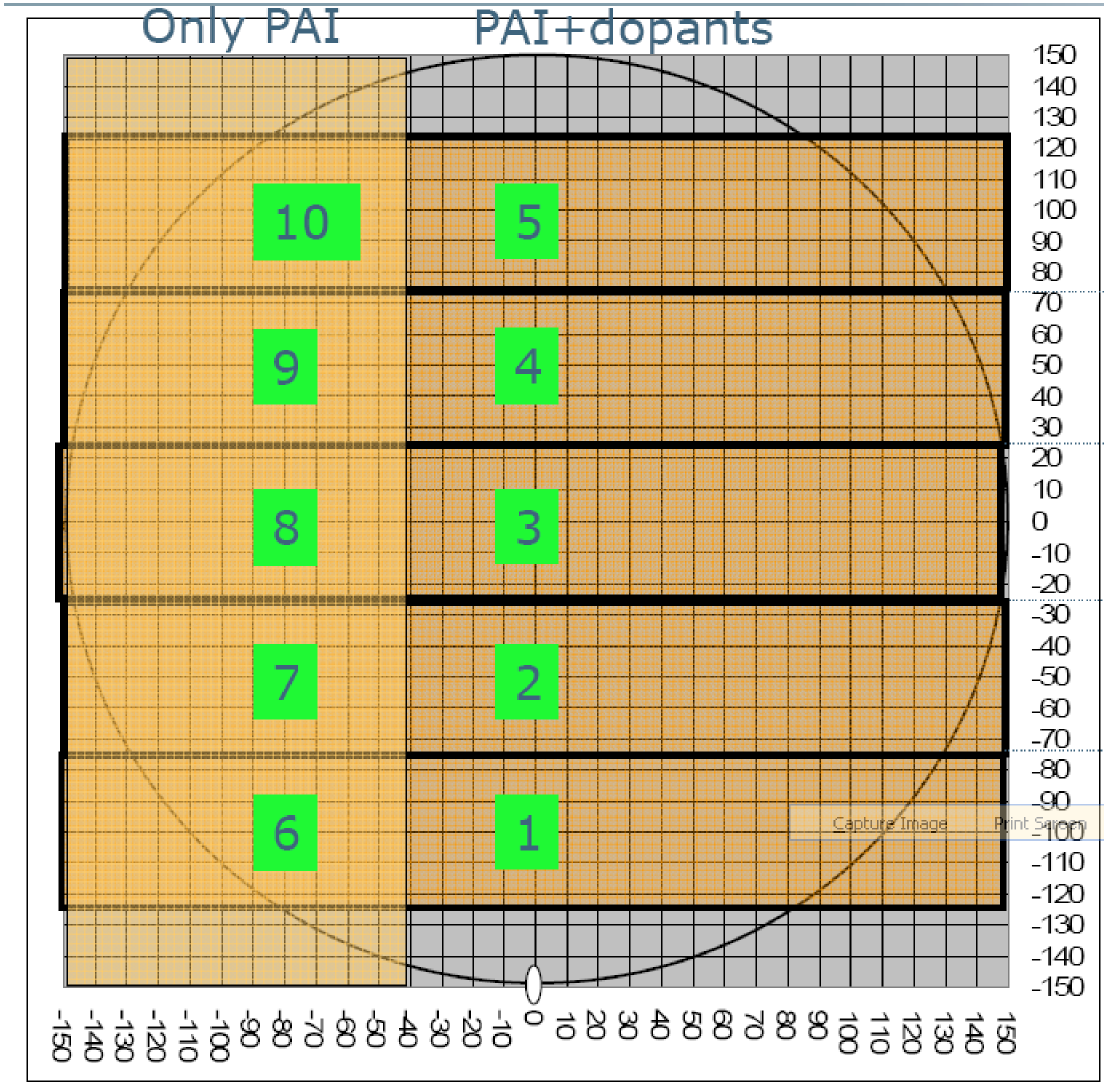
EOR damage Study



	AE090326 KLA JDP		S1 : B referer wafers		S2 : Ge/B ma												S3 : F/B Blan ref for device exp AMPT09			S4 : BF2					
	VERSION V5 (28/05/09)		F02	D03	D04	D05	D06	D07	D08	D09	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	T25
7001	NMON F400		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Basic Clean		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	PAI																								
3000	Ge 5KeV Q1 tw0-ti0 1.0e14/cm2				x	x																			
3000	Ge 5KeV Q1 tw0-ti0 5.0e14/cm2						x	x																	
3000	Ge 10KeV Q1 tw0-ti0 1.0e14/cm2								x	x												x	x		
3000	Ge 10KeV Q1 tw0-ti0 5.0e14/cm2										x	x												x	x
3000	Ge 20KeV Q1 tw0-ti0 1.0e14/cm2												x	x											
3000	Ge 20KeV Q1 tw0-ti0 5.0e14/cm2														x	x									
3000	F 10KeV Q1 tw0-ti0 2.0e15/cm2																x	x	x						
	LITHO																								
6400	Half-wafer Litho - Clear right-39mm		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Active implants																								
3000	B 0.5KeV Q1 tw0-ti0 5e14/cm2		x		x		x		x		x		x		x										
3000	B 0.5KeV Q1 tw0-ti0 1e15/cm2			x		x		x		x		x		x		x									
3000	B 0.5KeV Q1 tw0-ti0 7e14/cm2																x	x	x						
3000	BF2 2.2 keV (= B 0.5KeV eq.) Q1 tw0-ti0 5e14/cm2																			x		x		x	
3000	BF2 2.2KeV (= B 0.5KeV eq.) Q1 tw0-ti0 1e15/cm2																				x		x		x
	STRIP																								
7700	junction strip		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	TP post implant measurement																								
7480	TP measurement (std & tracker scans)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Anneal																								
2700	DSA 6 zones (1150-1300)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2600	spike anneal 850C																	x							
2600	spike anneal 950C																		x						
	TP postmeasurement																								
7480	TP measurement (std & tracker scans)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

KLA Tencor
Accelerating Yield

Wafer Layout



DSA temps:

1300°c

1250°c

1225°c

1200°c

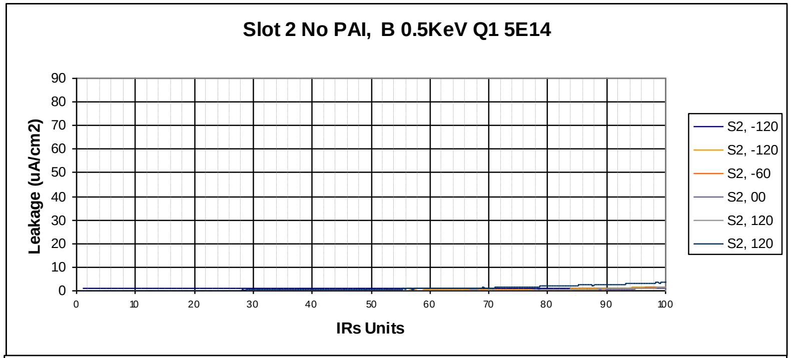
1150°c

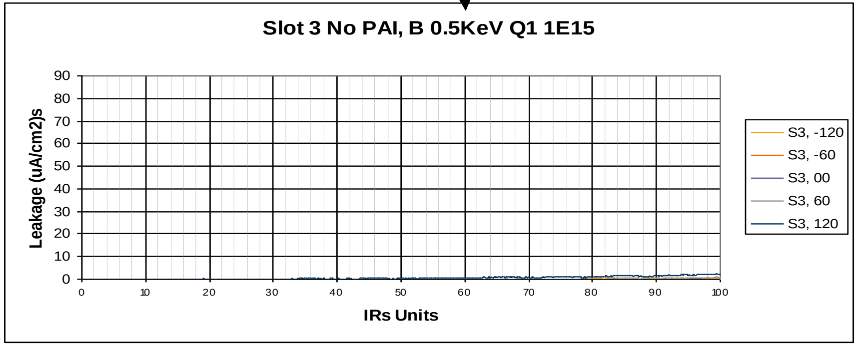
Minimal Leakage with 5 keV Ge PAI

5E14B implants

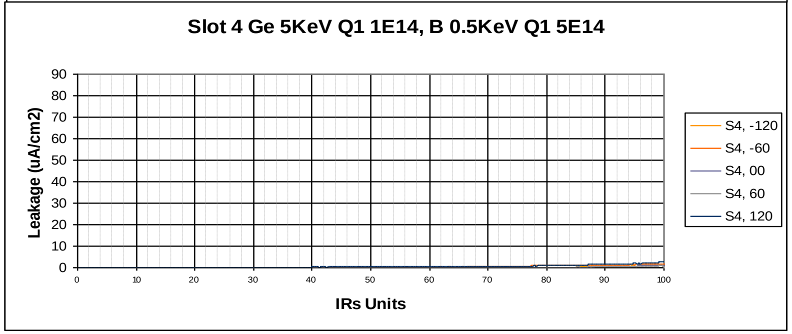
1E15B implants

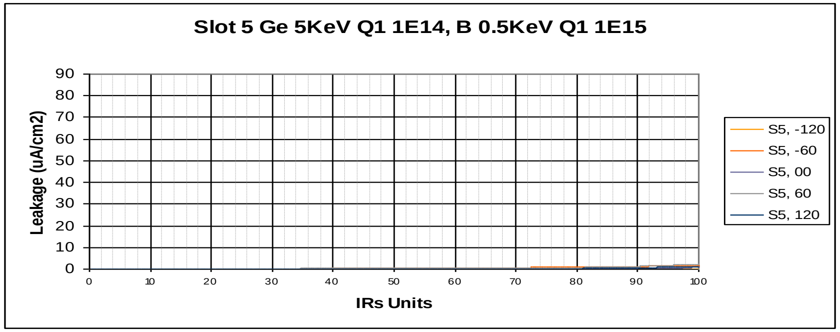
No PAI


Slot 2 No PAI, B 0.5KeV Q1 5E14

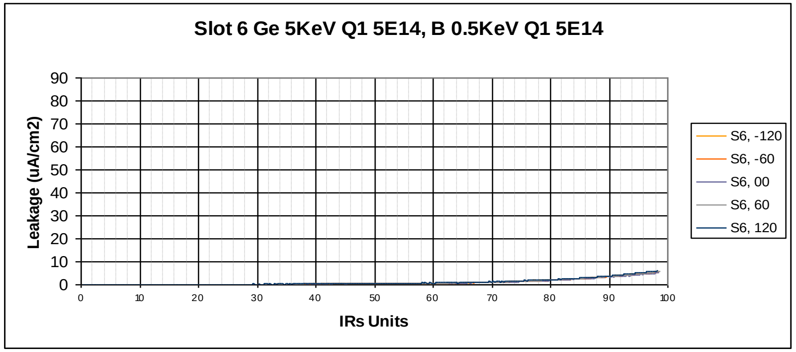

Slot 3 No PAI, B 0.5KeV Q1 1E15

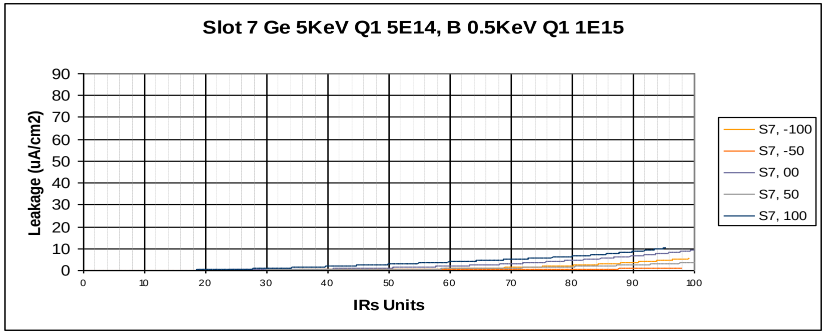
1E14 5k Ge PAI


Slot 4 Ge 5KeV Q1 1E14, B 0.5KeV Q1 5E14


Slot 5 Ge 5KeV Q1 1E14, B 0.5KeV Q1 1E15

5E14 5k Ge PAI


Slot 6 Ge 5KeV Q1 5E14, B 0.5KeV Q1 5E14

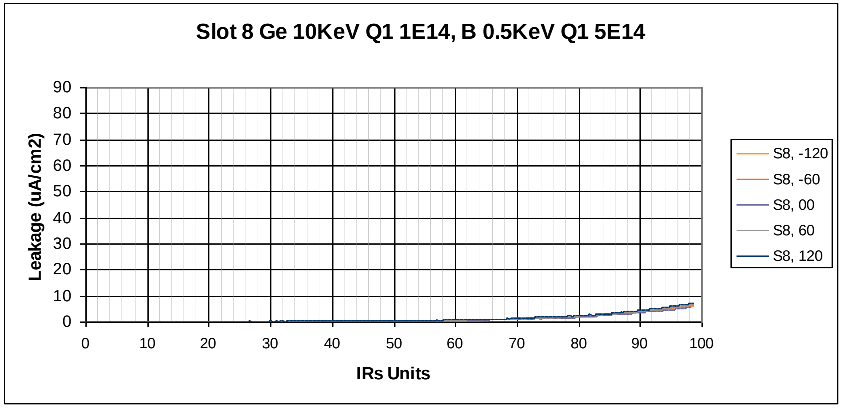

Slot 7 Ge 5KeV Q1 5E14, B 0.5KeV Q1 1E15

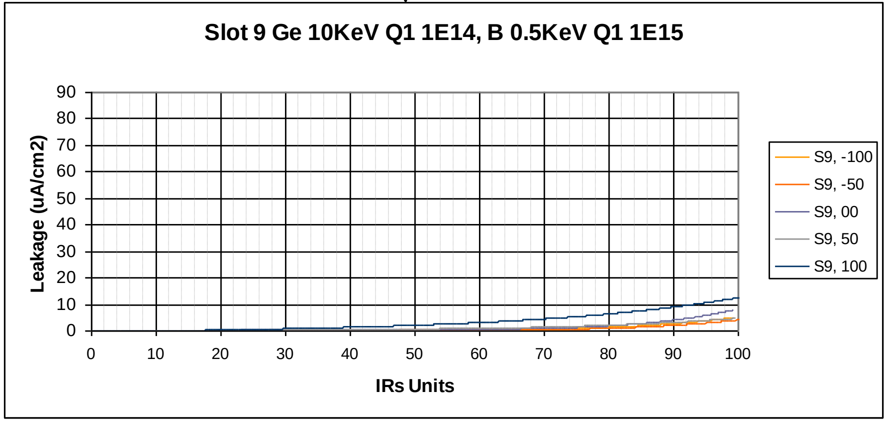
Higher Dose 10 keV Ge PAI Shows Leakage

5E14B implants ↓

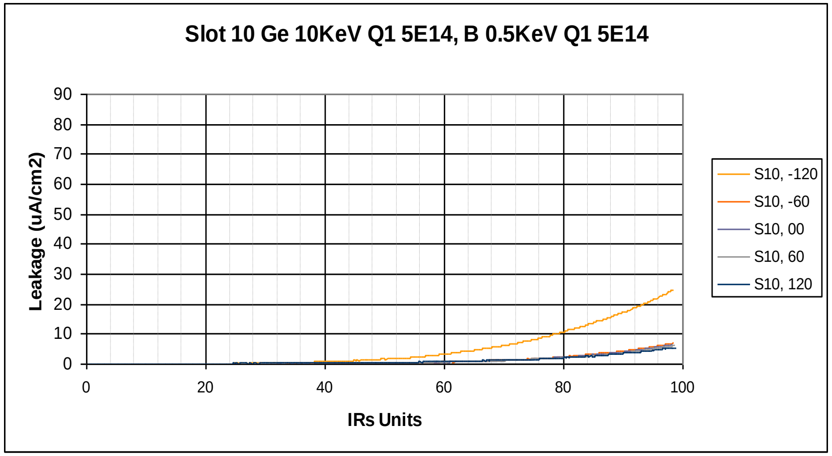
1E15B implants ↓

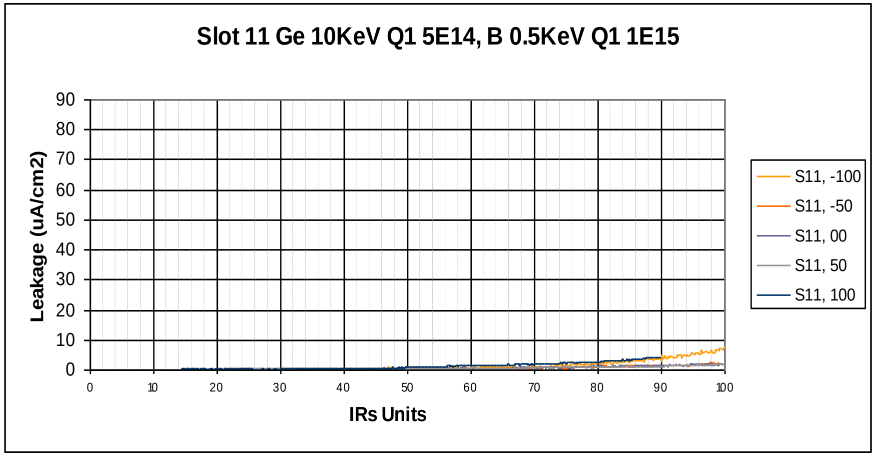
1E14
10k
Ge →


Slot 8 Ge 10KeV Q1 1E14, B 0.5KeV Q1 5E14


Slot 9 Ge 10KeV Q1 1E14, B 0.5KeV Q1 1E15

5E14
10k
Ge
PAI →


Slot 10 Ge 10KeV Q1 5E14, B 0.5KeV Q1 5E14

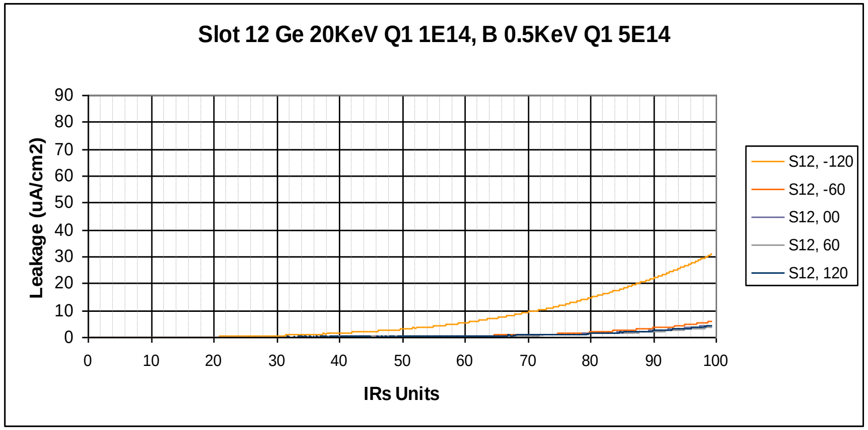

Slot 11 Ge 10KeV Q1 5E14, B 0.5KeV Q1 1E15

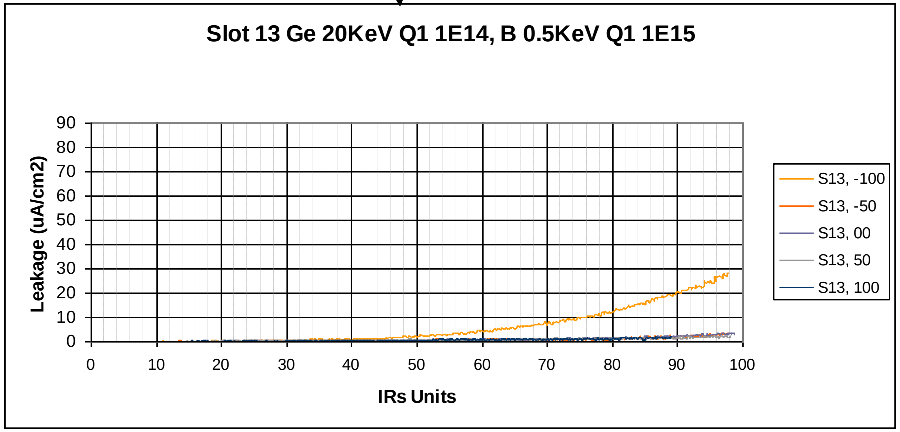
Substantial Leakage with 20keV Ge PAI

5E14B implants

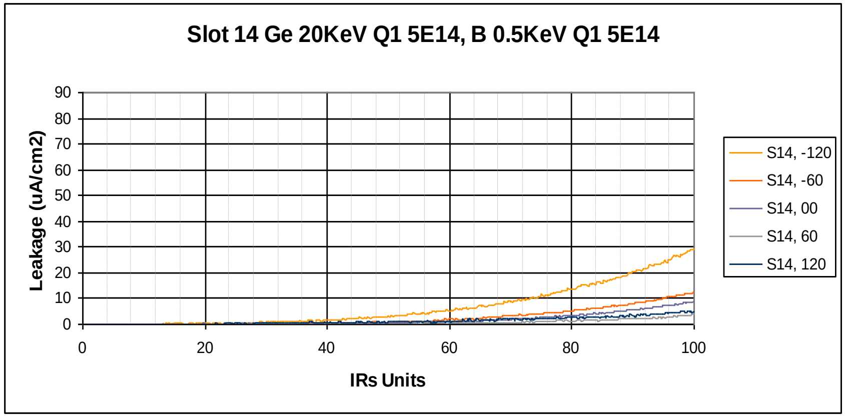
1E15B implants

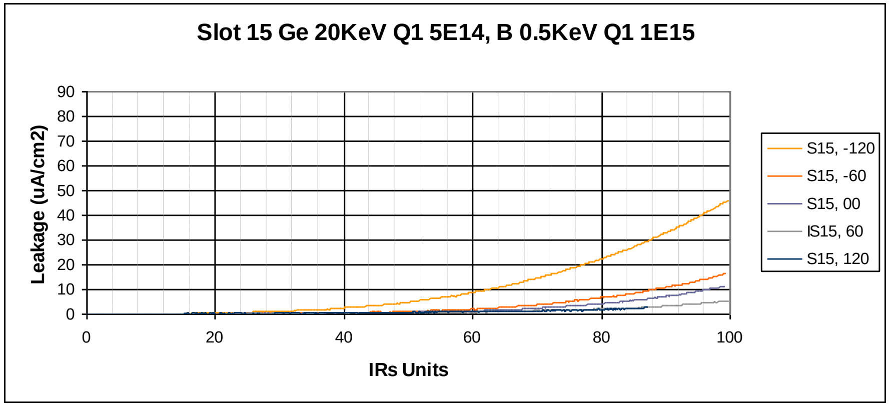
1E14
20k
Ge
PAI


Slot 12 Ge 20KeV Q1 1E14, B 0.5KeV Q1 5E14

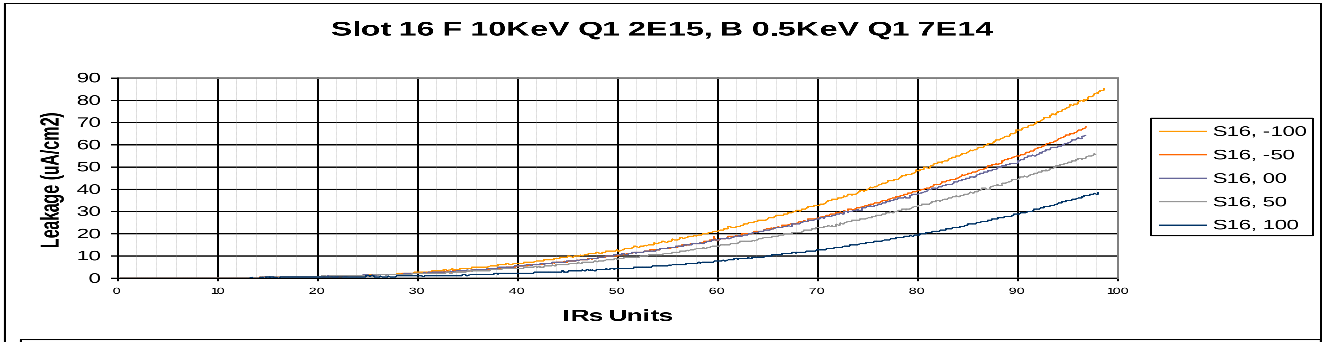

Slot 13 Ge 20KeV Q1 1E14, B 0.5KeV Q1 1E15

5E14
20k
Ge
PAI

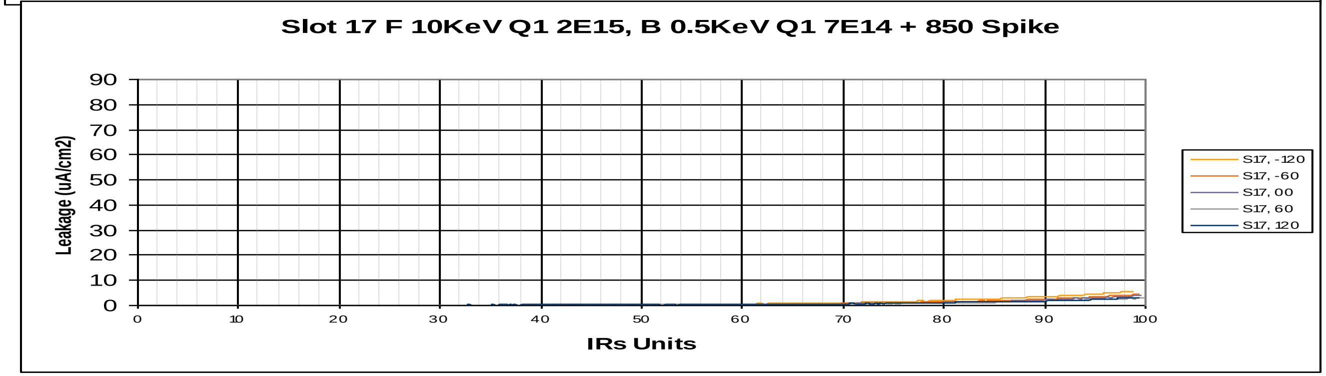

Slot 14 Ge 20KeV Q1 5E14, B 0.5KeV Q1 5E14


Slot 15 Ge 20KeV Q1 5E14, B 0.5KeV Q1 1E15

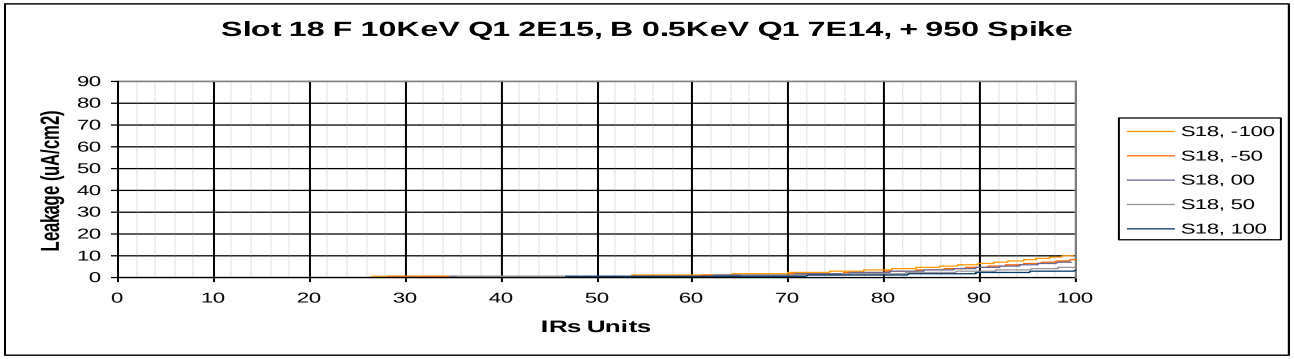
Spike Substantially Reduces Leakage



Slot 16 F 10KeV Q1 2E15, B 0.5KeV Q1 7E14

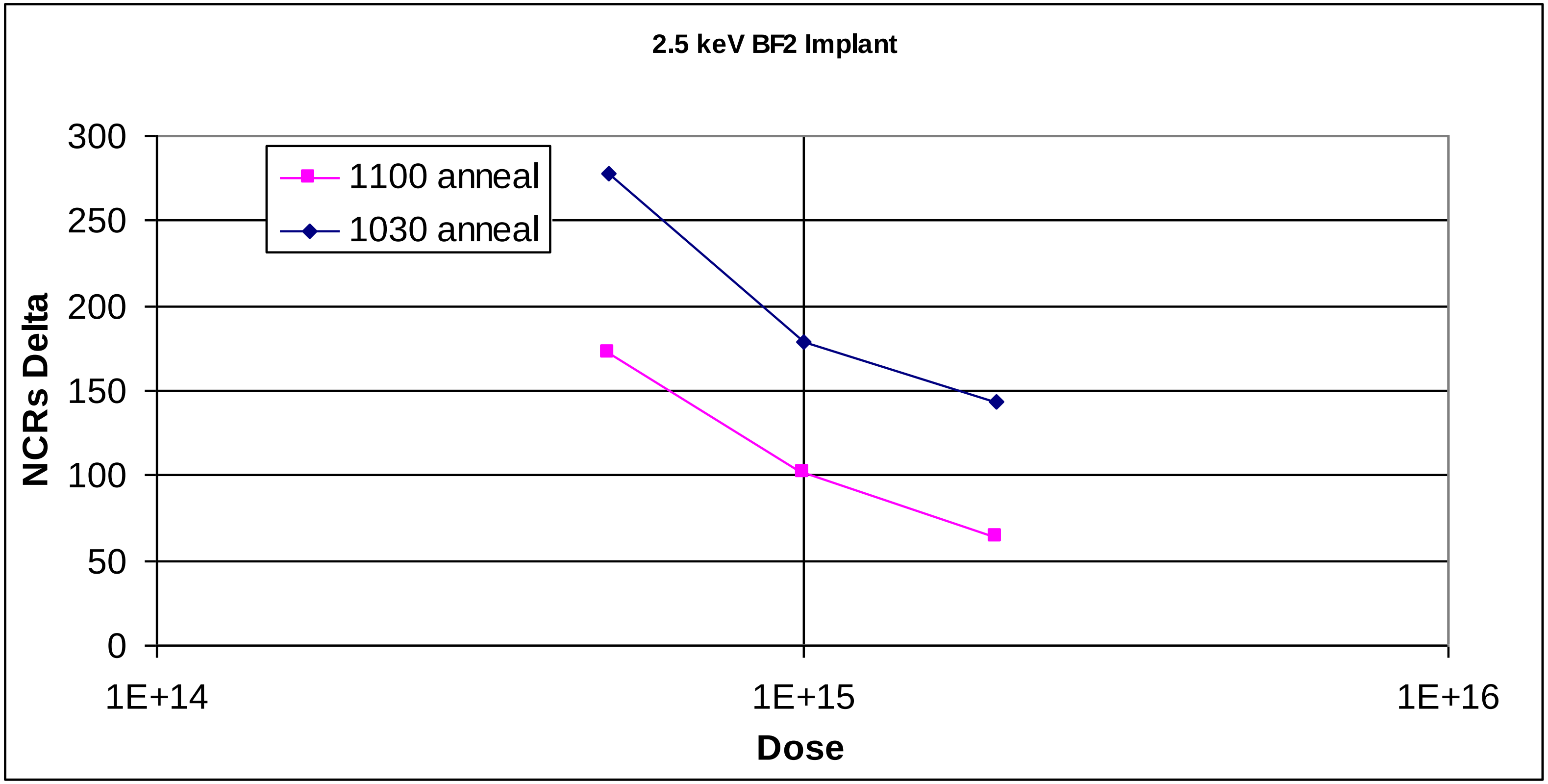


Slot 17 F 10KeV Q1 2E15, B 0.5KeV Q1 7E14 + 850 Spike

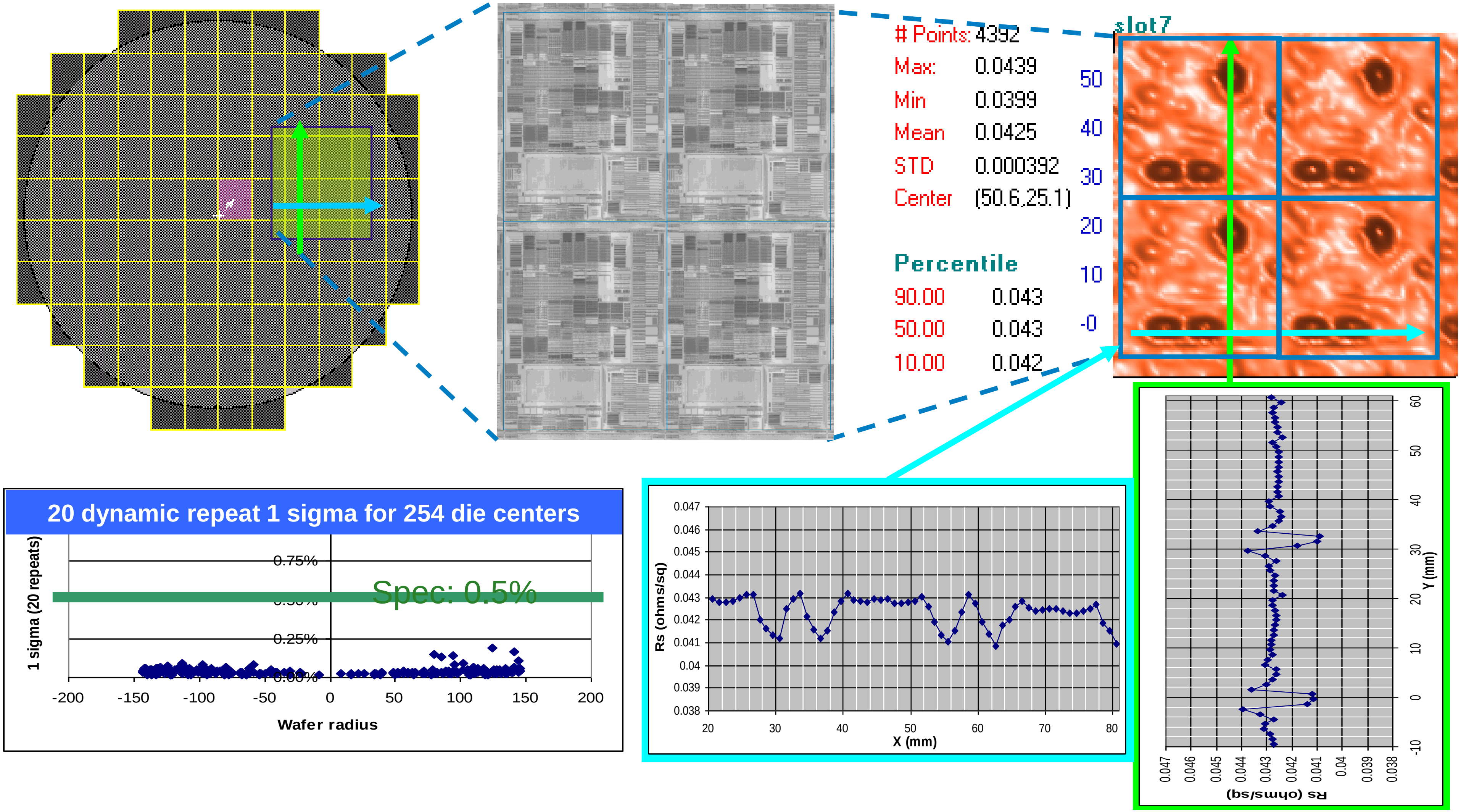


Slot 18 F 10KeV Q1 2E15, B 0.5KeV Q1 7E14, + 950 Spike

RS300 Eddy Current Test on P/P Implant



Product Wafer NCRs Mapping & Line Scan



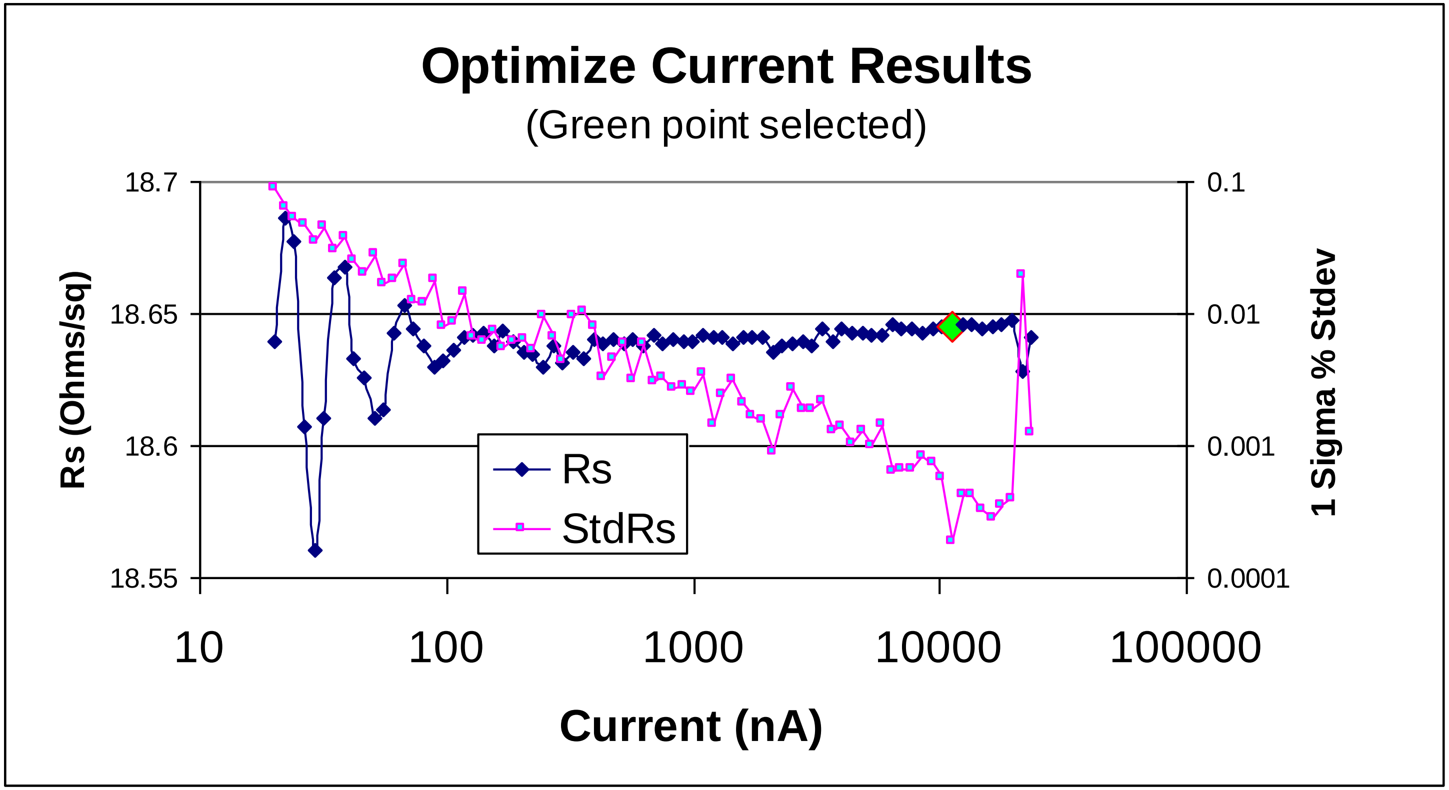
# Points:	4392
Max:	0.0439
Min	0.0399
Mean	0.0425
STD	0.000392
Center	(50.6,25.1)

Percentile

90.00	0.043
50.00	0.043
10.00	0.042

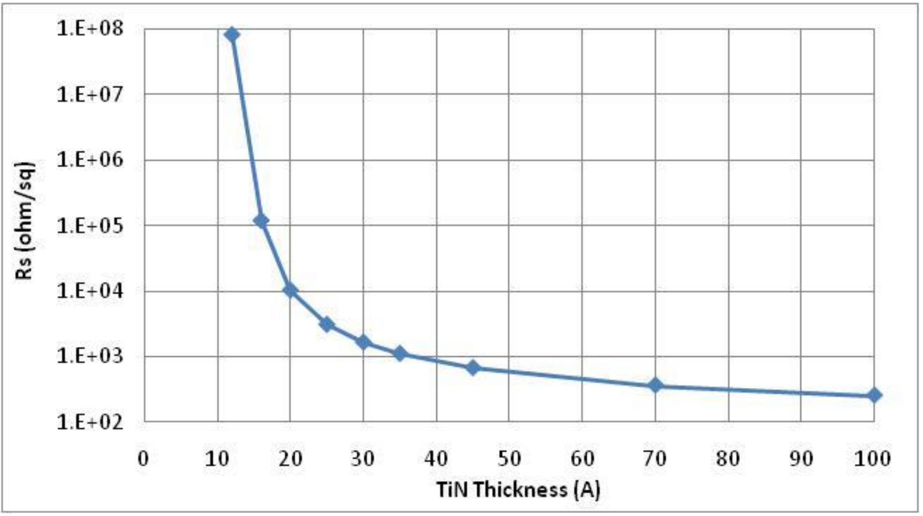
1 Sigma of dynamic 20 repeats <0.5%

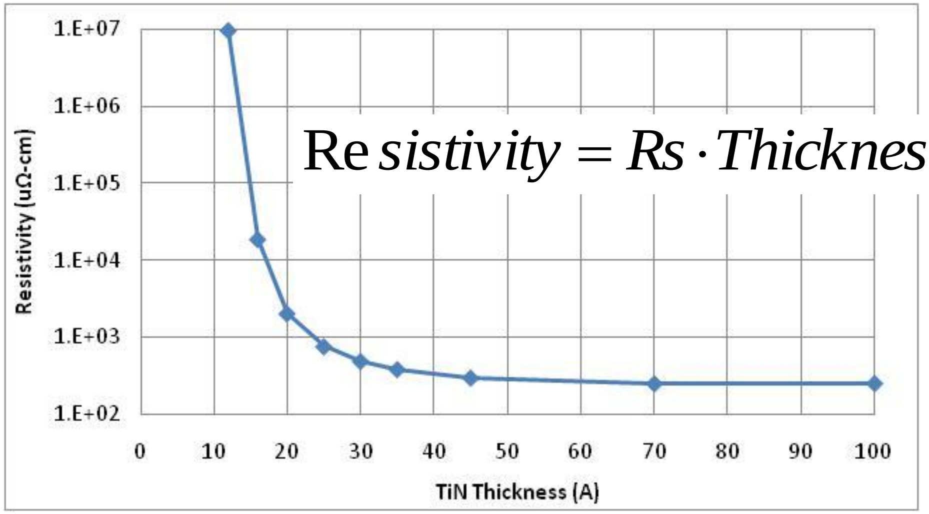
Optimize Current Example 1



OC routine picked a good current.

Sensitivity of TiN Film



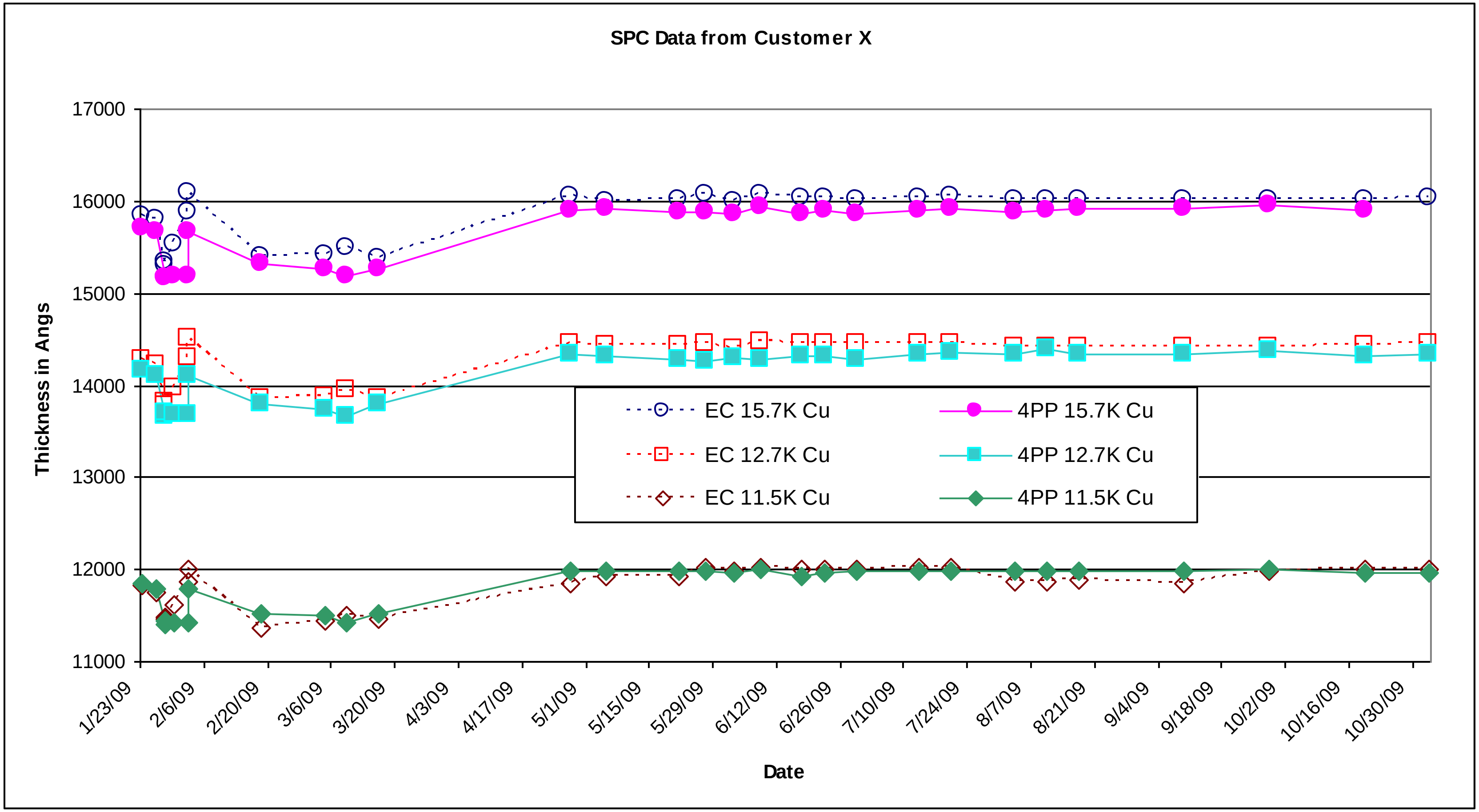


$$Resistivity = Rs \cdot Thickness$$

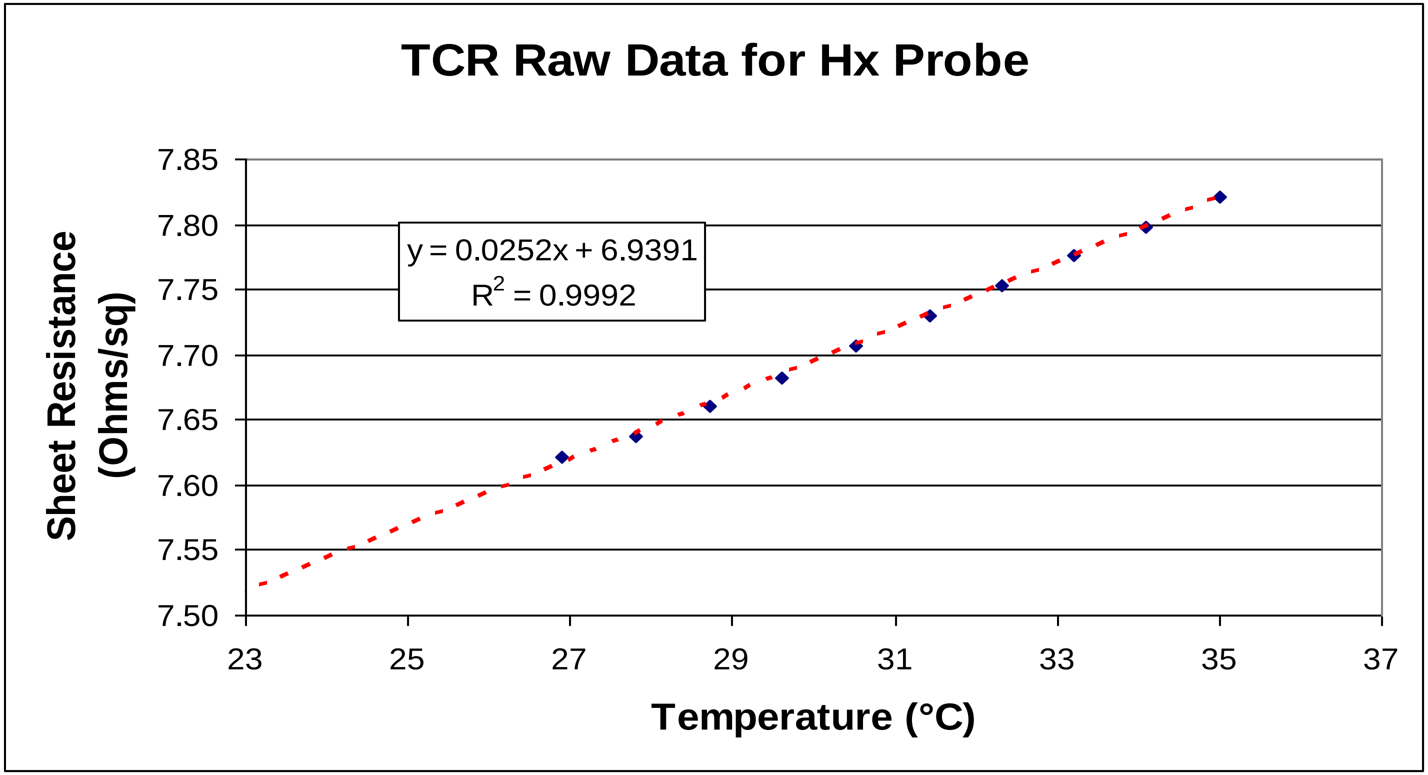
Wafer	slot10	slot12	slot14	slot16	slot18	slot20	slot22	slot24	slot8
TiN Thickness (A)	12	16	20	25	30	35	45	70	100
Rs (ohm/sq)	8.04E+07	1.18E+05	10201	3053	1637	1101	667	360	254
Resistivity (uΩ-cm)	9.65E+06	1.88E+04	2040	763	491	385	300	252	254

- Rs trending up quickly with TiN film thickness decrease
  - Metal resistivity will become big with thickness decrease

Long Term SPC Data for Non Contact Rs

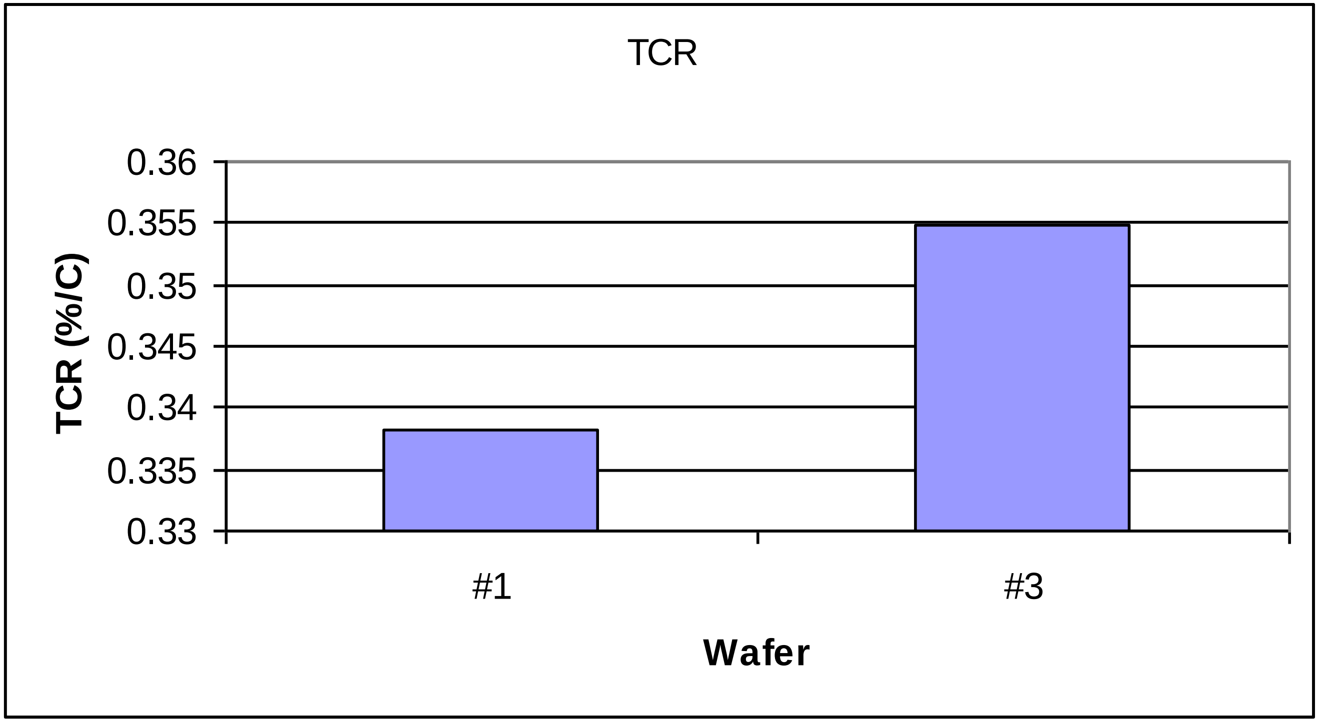


Example TCR Curve



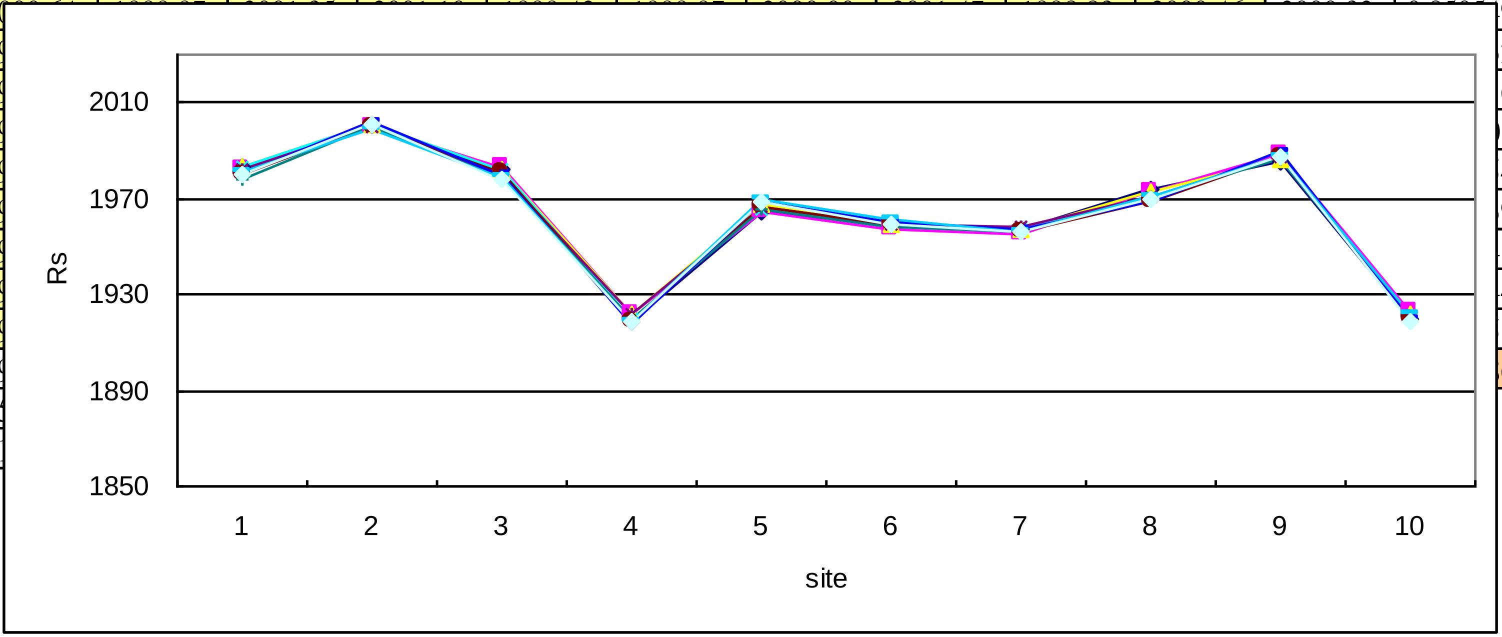
The maximum temperature which can be set in the system is 35 degrees C

RS200 TCR Values of NF19 and NF50 films



GRR Test Results

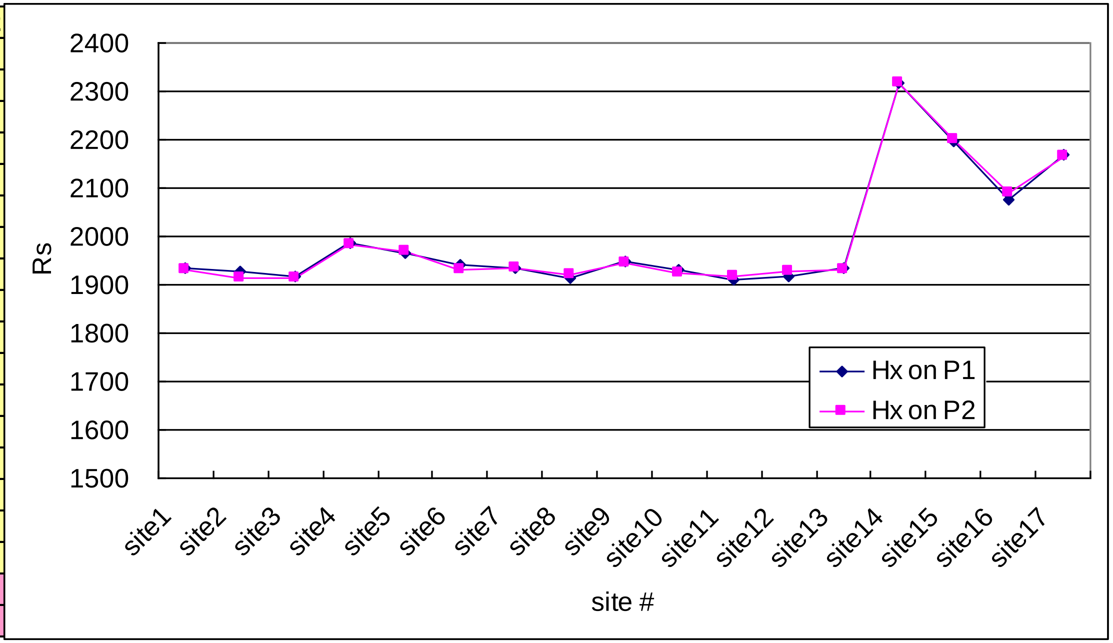
QC_SiH4	Rep1	Rep2	Rep3	Rep4	Rep5	Rep6	Rep7	Rep8	Rep9	Rep10	Average	std	std%
SIte1	1982.85	1982.41	1982.67	1983.46	1981.72	1980.32	1977.59	1980.19	1981.35	1980.43	1981.30	1.733735	0.09%
Site2													0.04%
SIte3													0.09%
SIte4													0.08%
SIte5													0.09%
SIte6													0.06%
SIte7													0.05%
SIte8													0.09%
SIte9													0.05%
SIte10													0.06%
Mean													0.03%
1sigma													
1sigma%													



- 10 reps of 10 pts map recipe on QC_SiH4 wafer;
- The std% of 10 reps for all 10 sites is smaller that 0.1%;
- Hx stability test meet TSMC GRR requests

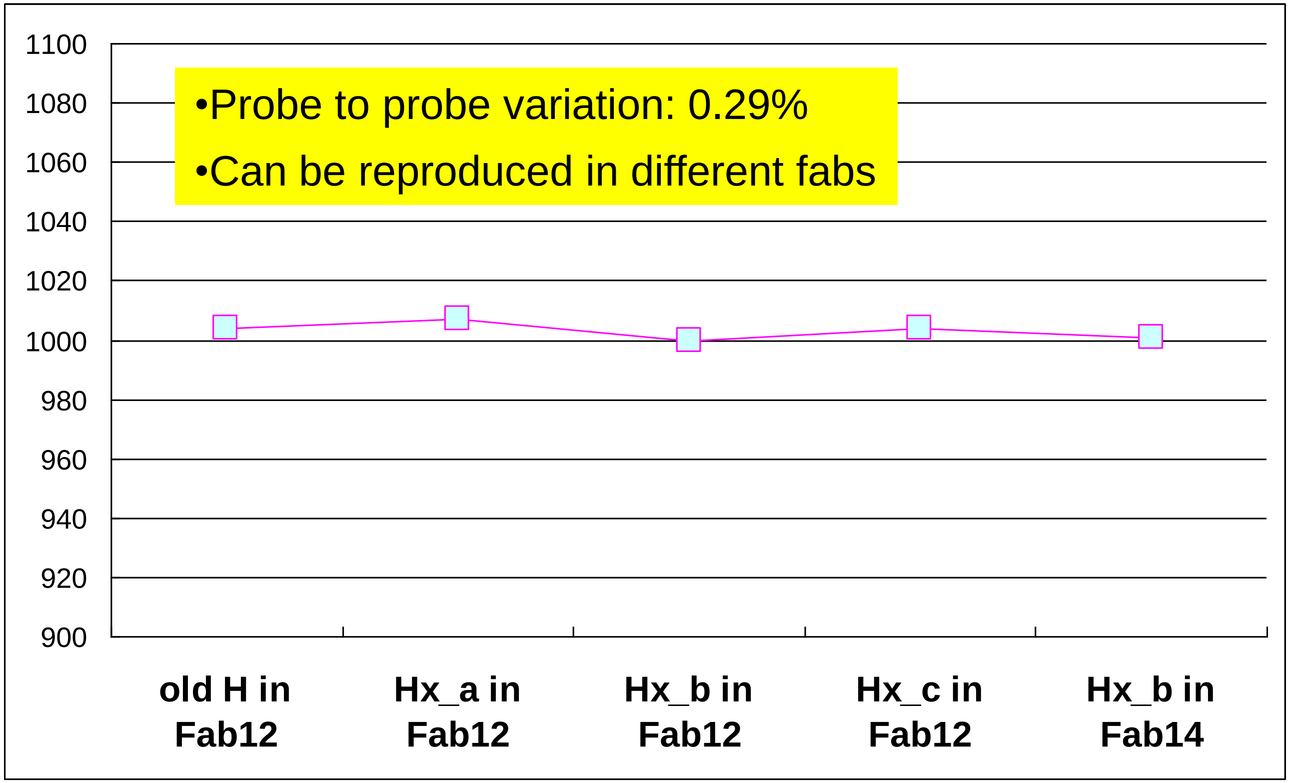
Dual Probe Arm Position Accuracy

	Hx on P1	**Hx on P2**
site1	1933.50	1932.01
site2	1929.21	1914.58
site3	1916.26	1912.22
site4	1985.49	1981.96
site5	1966.43	1968.13
site6	1941.53	1931.98
site7	1936.14	1935.46
site8	1914.17	1921.43
site9	1949.93	1945.59
site10	1930.27	1923.80
site11	1911.92	1917.17
site12	1918.45	1927.70
site13	1936.14	1932.21
site14	2315.84	2318.39
site15	2197.71	2201.04
site16	2074.62	2090.35
site17	2169.71	2164.09
Mean	**1995.7**	**1995.2**
std%	**6.0%**	**6.1%**



- Hx/H located on P1/P2, tested on same QC_SiH4 wafer with 17pts map recipe;
- No obvious deviation between two results;

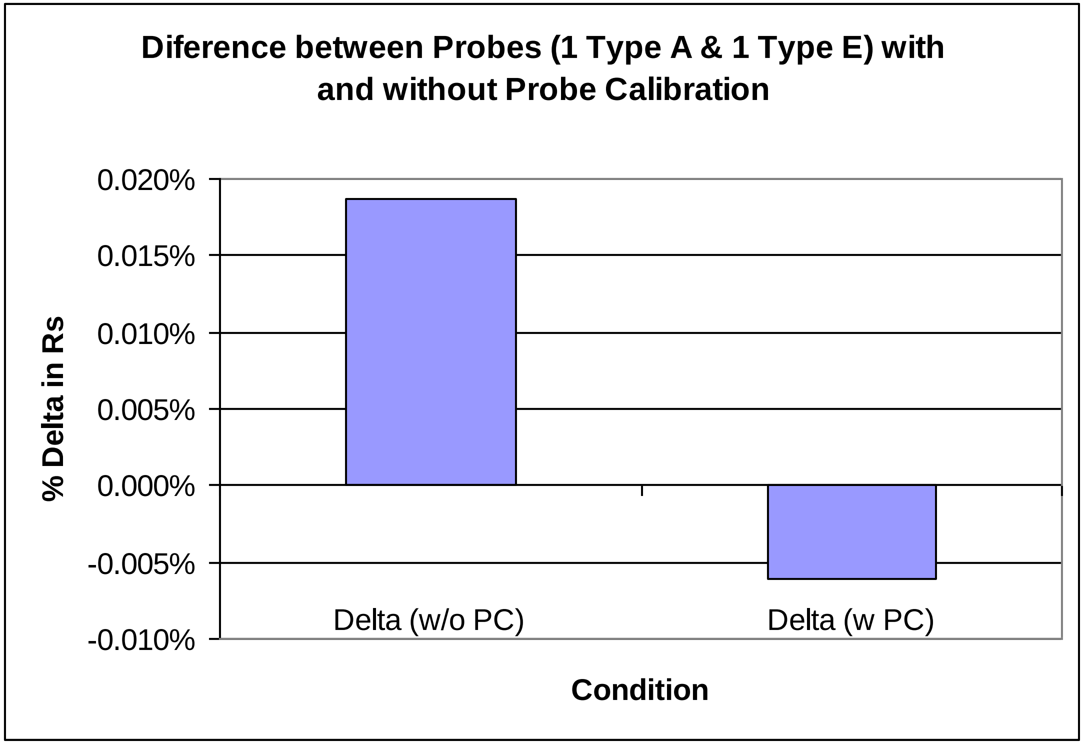
Hx Matching Performance



- Probe to probe variation: 0.29%
- Can be reproduced in different fabs

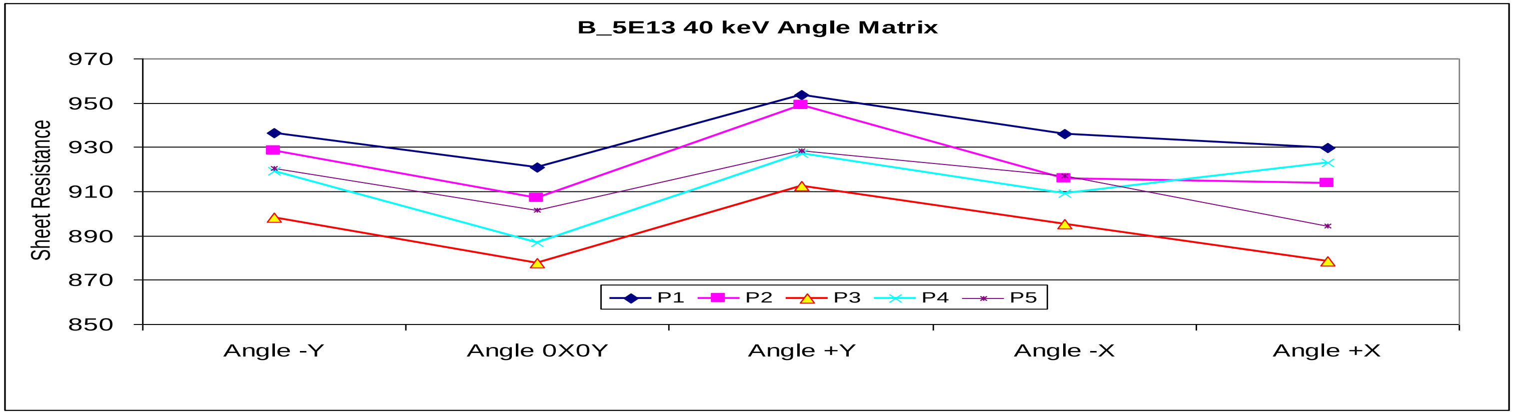
- Different Hx probes reported similar Rs values on QC wafers;
- One Hx probe reported similar Rs values on different tool site;
- Probe to probe variation is smaller than 0.3%.

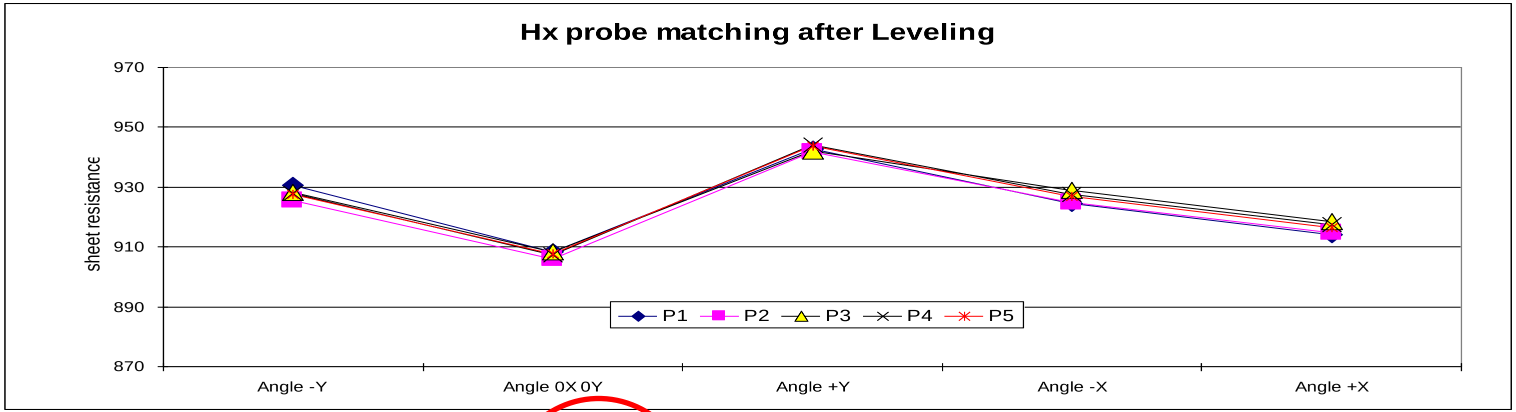
Probe Calibration



Using probe Calibration reduced the delta between two probes by a factor of 3.

Matching Before & After Leveling of Tips





Map average	Mean	927.88	907.62	942.88	926.58	916.27
	std%	0.19%	0.11%	0.11%	0.20%	0.20%
Map 1sigma	Mean	13.38	13.22	16.21	12.98	14.56
	std%	0.04%	0.05%	0.01%	0.09%	0.06%

Summary

- Improved signal to noise on provides clearer pictures of the process through the Micromap feature.
- Larger signal makes possible post anneal measurements on the TP680.
- In many cases a good correlation to 4PP Rs can be obtained with the TP680.
- The Hx probe for the RS200 systems minimizes leakage effects allows measurements of implants down to 5nm Xj.