Photoluminescence metrology for global wafer and micro implant and anneal uniformity

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AVS Junction Technology Working Group
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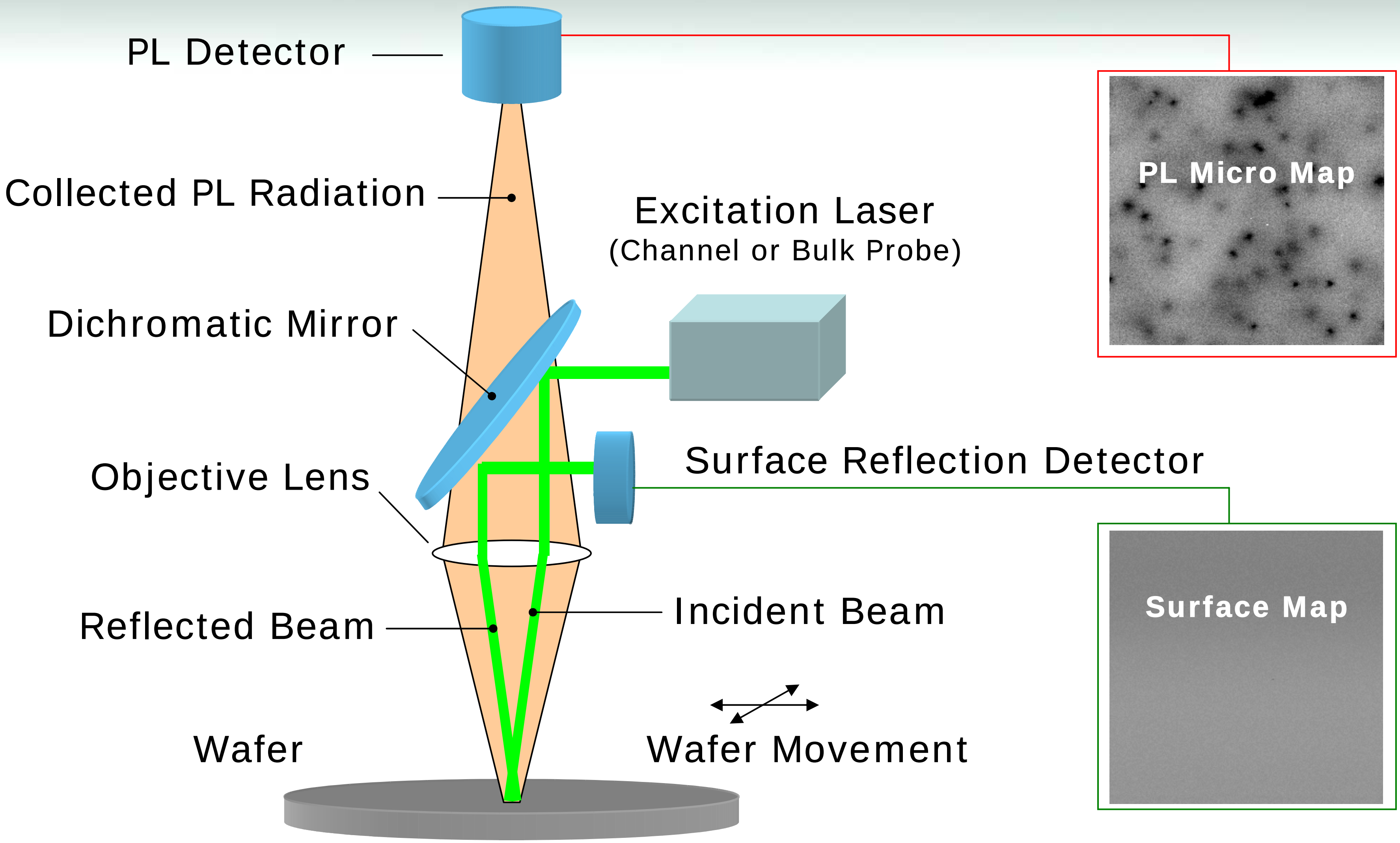
Outline

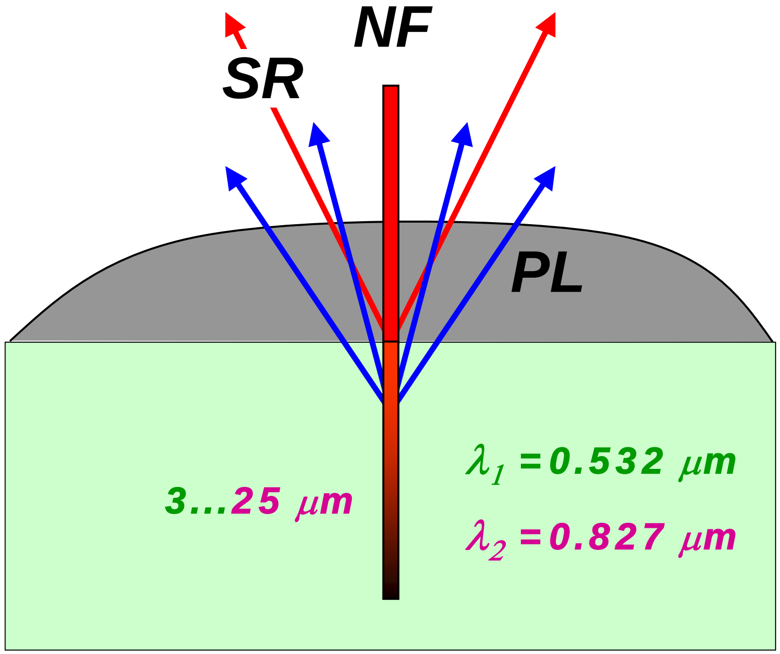
- Principle of Operation
- PLi Implant and Anneal Metrology
  - As implanted study – dose and energy
  - Anneal process studies
    - Species effects
    - Annealer signatures
  - Laser annealer
  - Measurement precision
- Summary

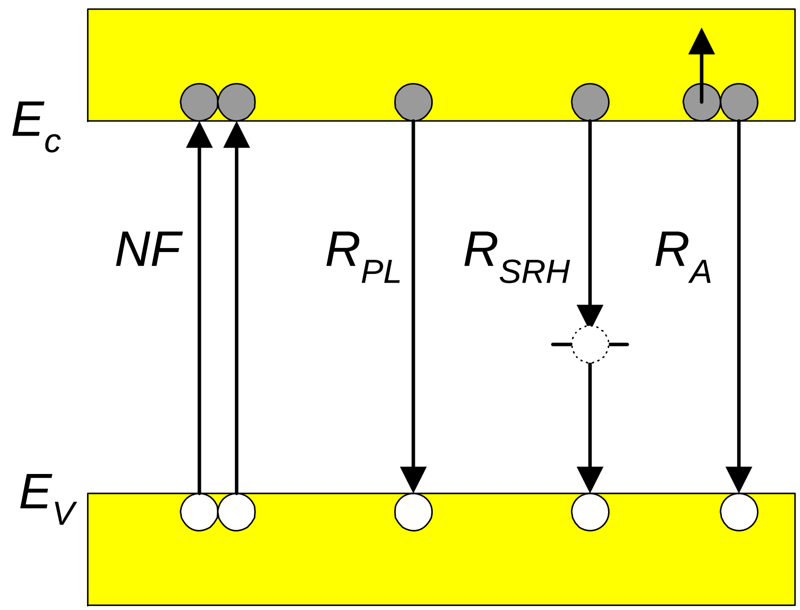
Experimental Setup - Simplified Optics Schematic



Principle of Operation

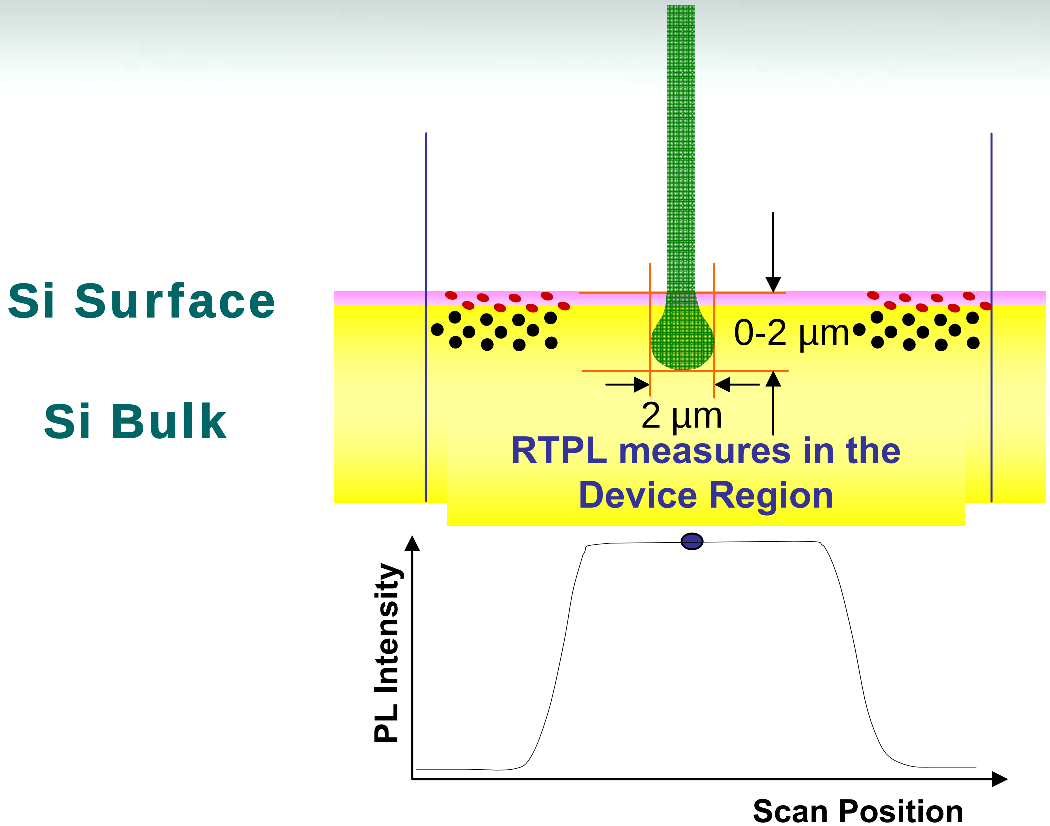
$P \approx 7\ mW$
$R \approx 1\ \mu m$
$NF = f\,(P, R, \lambda)$

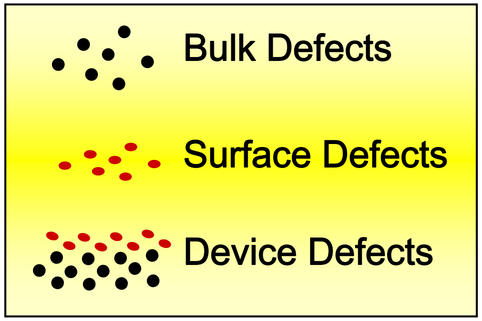




R_{PL} - radiative recombination rate
R_{SRH} - SRH recombination rate
R_A - Auger recombination rate

PL Imaging (PLi)

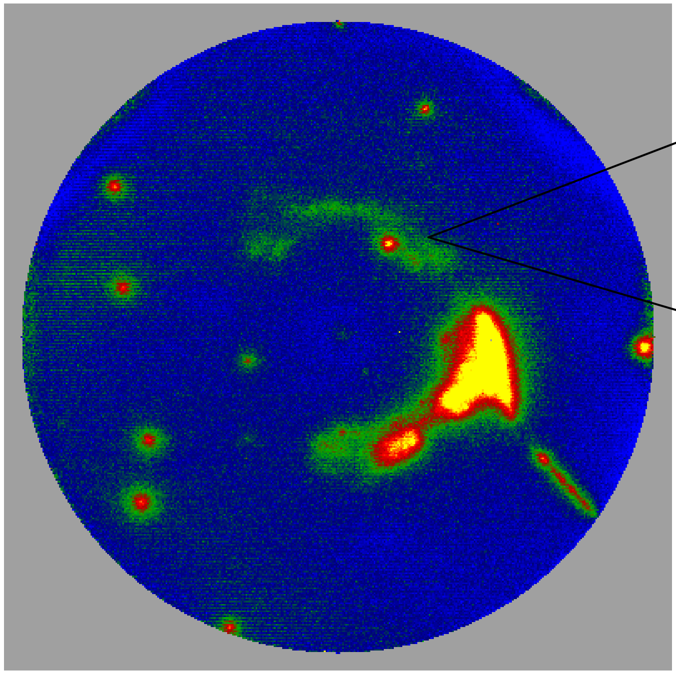




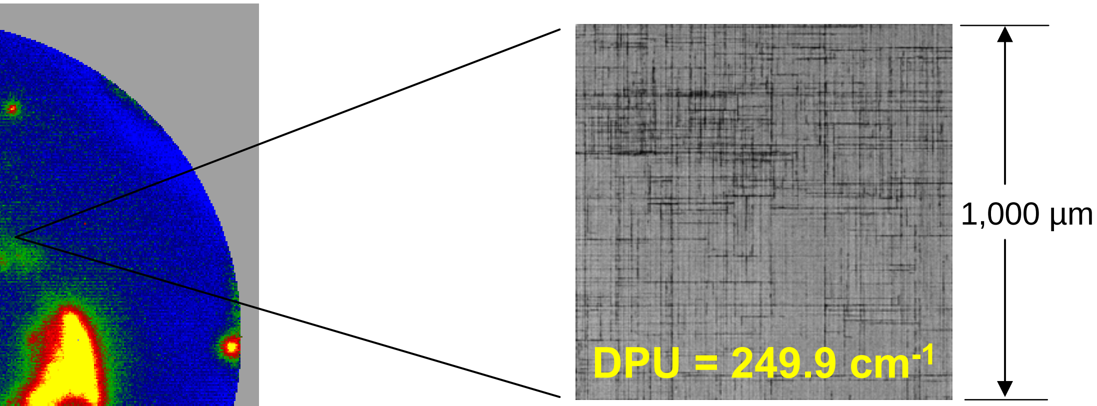
- Sub-micron-scale spatial resolution
- Rapid macro and micro scans
- Non-destructive and non-invasive

Contamination and Defect Metrology

Macro-mapping + Micro-mapping



Example macro-map of 200mm blanket SiGe wafer showing metallic contamination from epitaxial process



Micro-map of same wafer showing dislocations

Spatial fingerprinting of electrically active defects from wafer-scale to micron-scale

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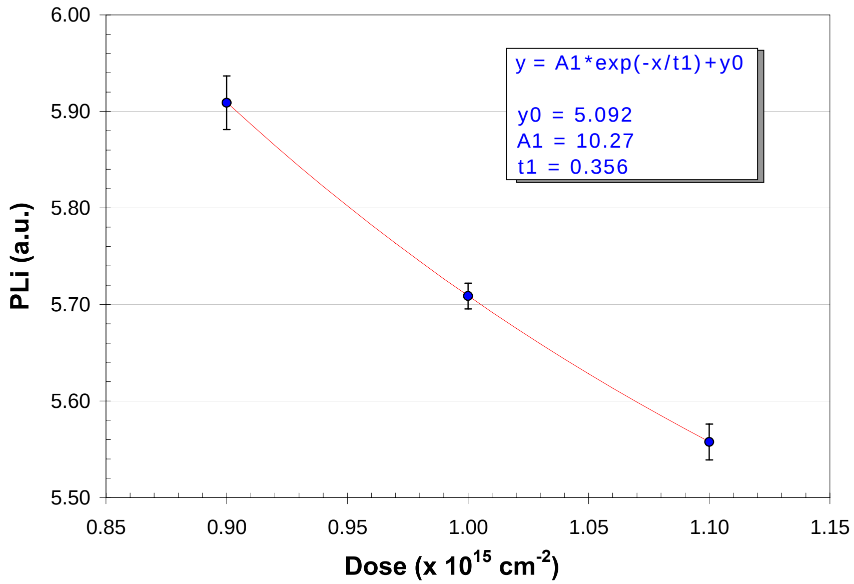
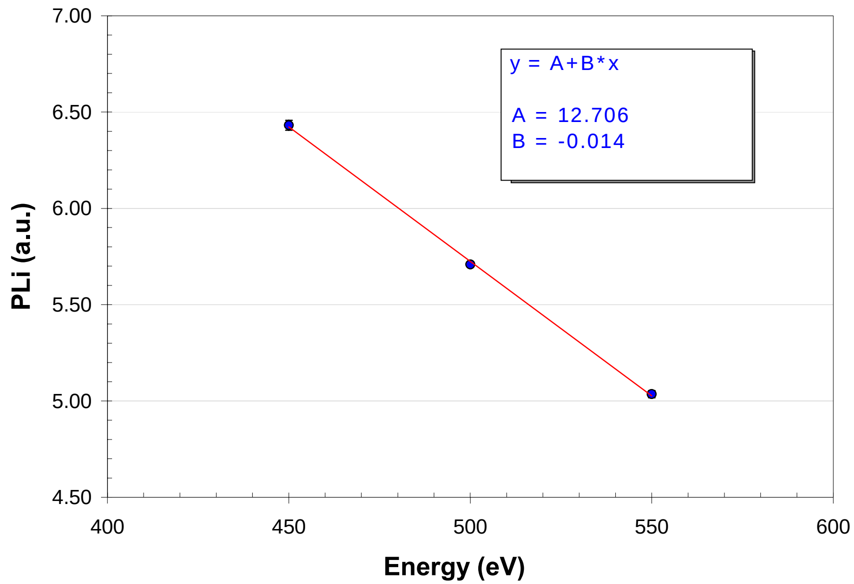
As-Implanted Capability – Dose and Energy Impact

USJ, $B_{10}H_{14}$, equiv. dose and energy – 0.9 to 1.1×10^{15} cm^{-3}, 450 to 550 eV

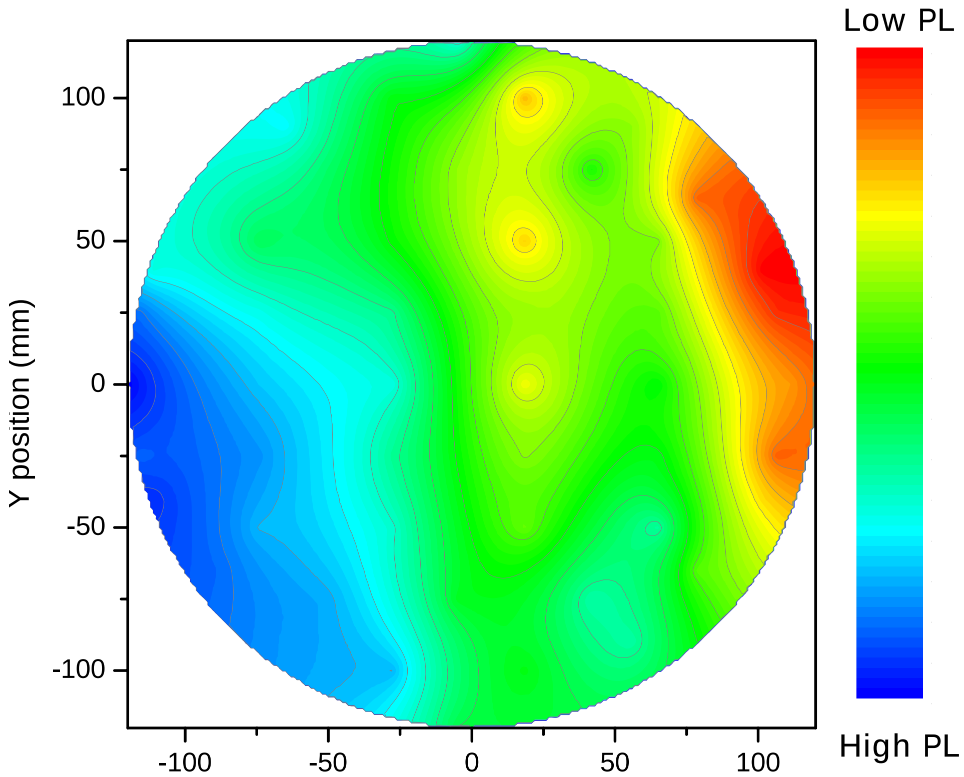




D = 3σ/S, σ = 0.1%	Dose (0.9 ~ 1.1 E15)	Energy (450 ~ 550 eV)
Sensitivity, S:	0.31	1.22
Detectability, D (%)	0.97	0.25

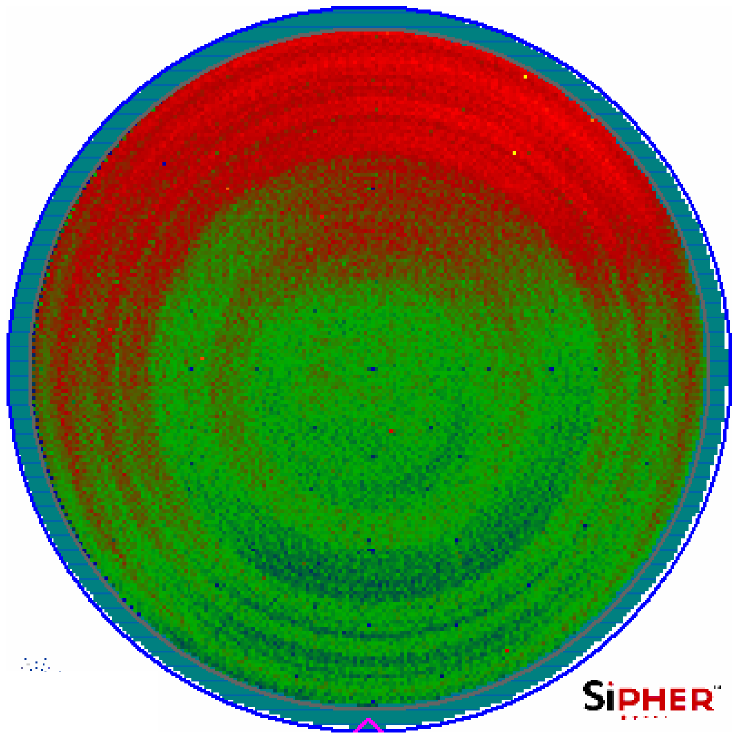
As-Implanted Capability: Implanter Signatures

^{11}B, 1×10^{15} cm^{-2}, 500 eV



Channel Probe: Contour maps reveal within wafer non-uniformity in the as-implanted USJ wafer from a beam-line system

$B_{10}H_{14}$, 1×10^{15} cm^{-2}, 500 eV



Bulk Probe: Full wafer maps reveal within wafer non-uniformity in the as-implanted USJ wafer. Substrate features are also exposed.

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Design of Experiment - Anneal

Box AA

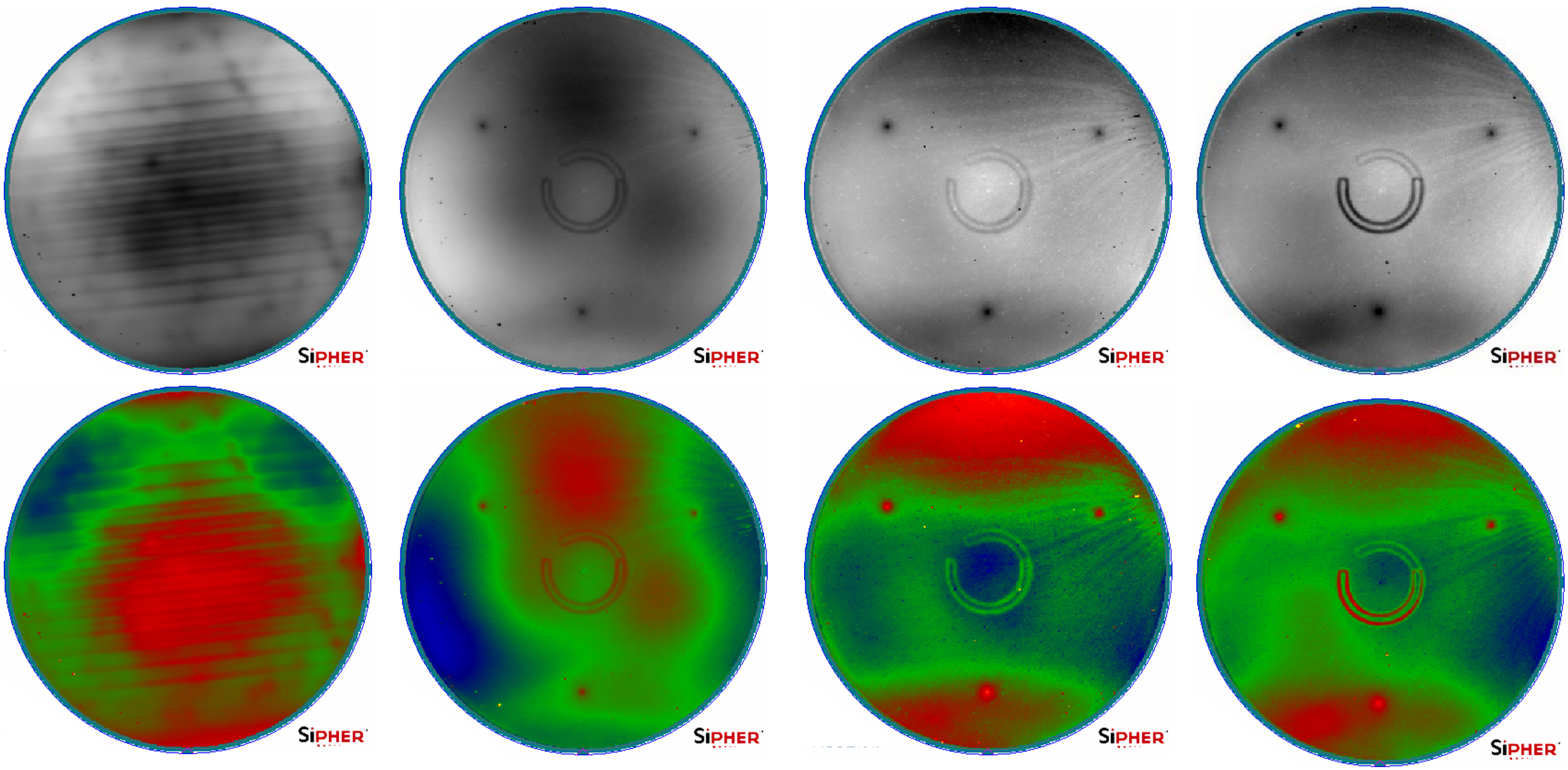
No.	Split		Wafer	
	I/I	Activation	Type	Wafer ID
13	Ge 10keV 5E14/cm2 + B 0.5keV 1E15/cm2	600C 1min (SPER)	P	23BKB272MM
12		1000C Spike only	P	23BKA092MM
11		1000C Spike + FLA	P	23BKB116MM
10		900C Spike + FLA	P	23BKB114MM
9		FLA	P	23BKB112MM
8	As 3keV 1e15/cm2	1000C Spike only	P	23BKB176MM
7		1000C Spike + FLA	P	23BKB108MM
6		900C Spike + FLA	P	23BKB173MM
5		FLA	P	23BKA066MM
4	B 0.5keV 1E15/cm2	1000C Spike only	P	23BKA067MM
3		1000C Spike + FLA	P	23BKB269MM
2		900C Spike + FLA	P	23BKB270MM
1		FLA	P	23BKB271MM

Box AB

10	B18Hx (B equiv. 0.5kev, 1e15/cm2, tilt =0, twist =0)	600C 60sec SPE
9		1000C spike only
8		1000C spike + FLA
7		900C spike + FLA
6		FLA only

Bulk Probe Results

B, 0.5 keV, 1.0×10^{15} cm^{-2}



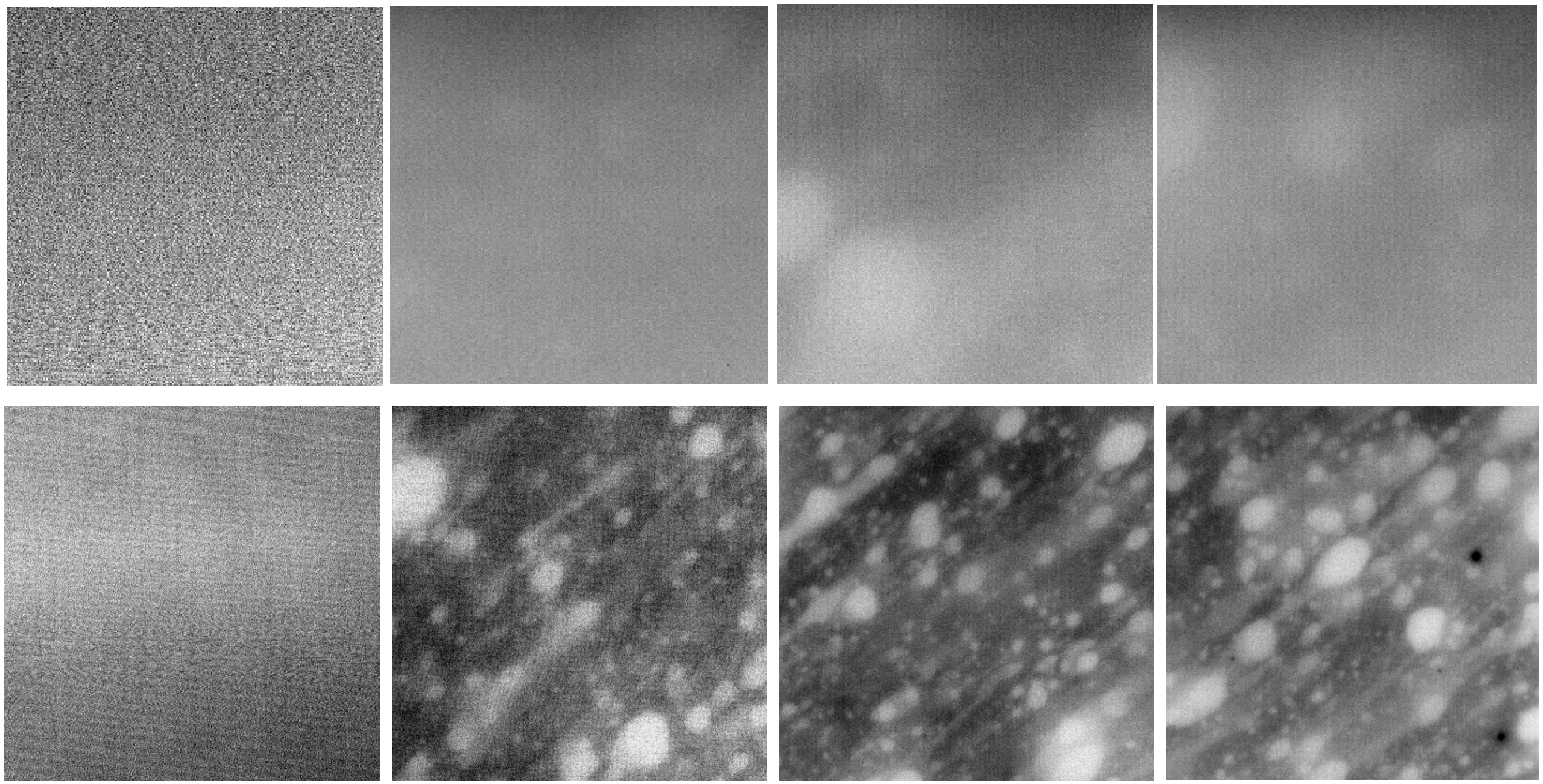
Flash	900°C Spike + Flash	1000°C Spike + Flash	1000°C Spike

Bulk Probe Results

Micromapping at X=0 and Y=75 mm; B, 0.5 keV, 1.0×10^{15} cm^{-2}

250x250 μm²

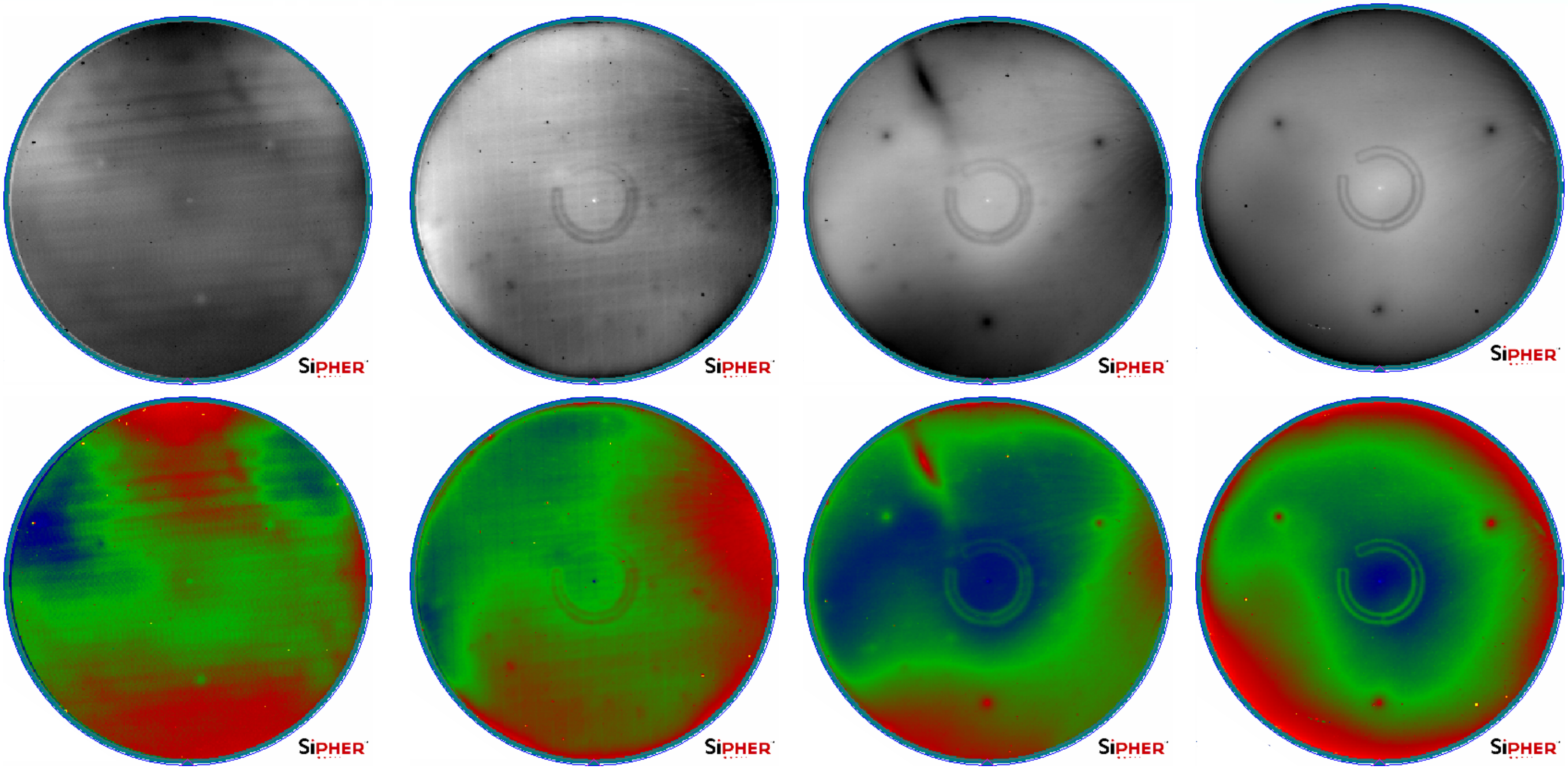
2000x2000 μm²



Flash | 900°C Spike + Flash | 1000°C Spike + Flash | 1000°C Spike

Bulk Probe Results

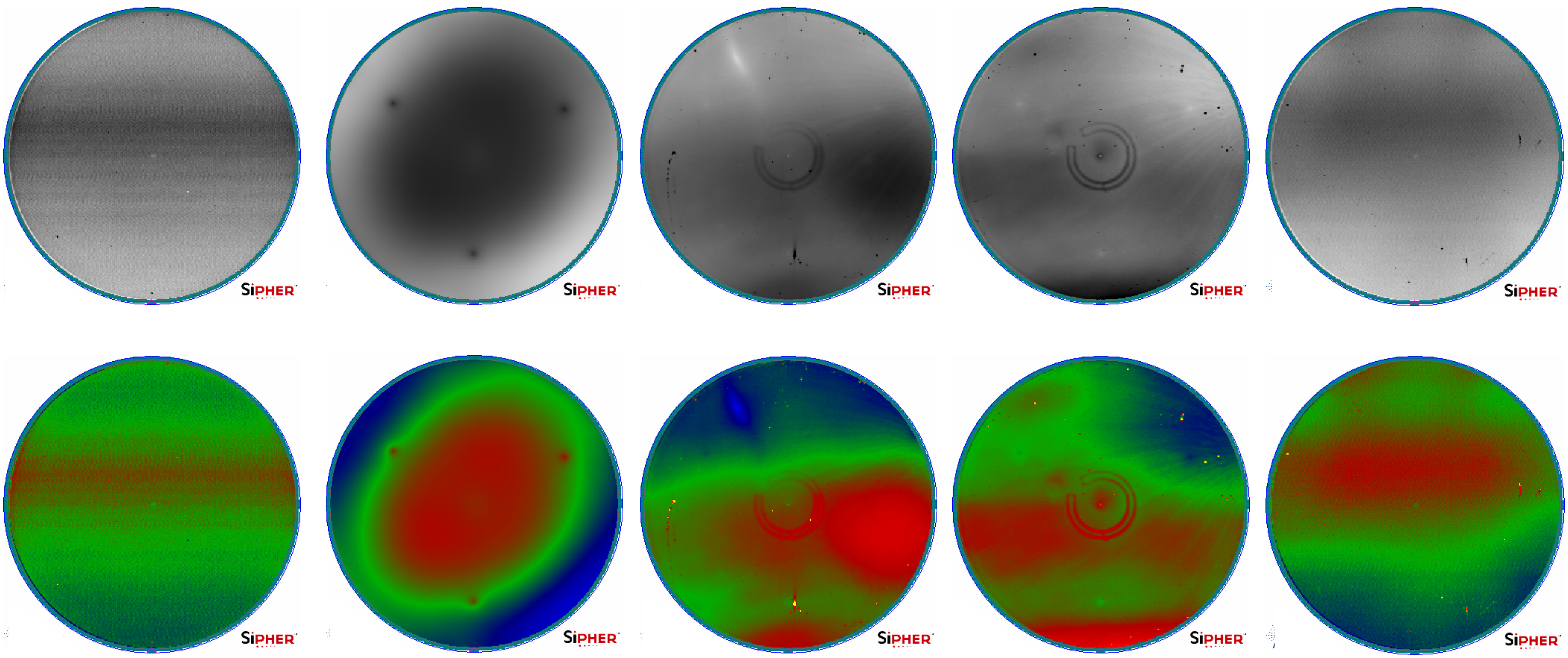
As, 3.0 keV, 1.0×10^{15} cm^{-2}



Flash | **900°C Spike + Flash** | **1000°C Spike + Flash** | **1000°C Spike**

Bulk Probe Results

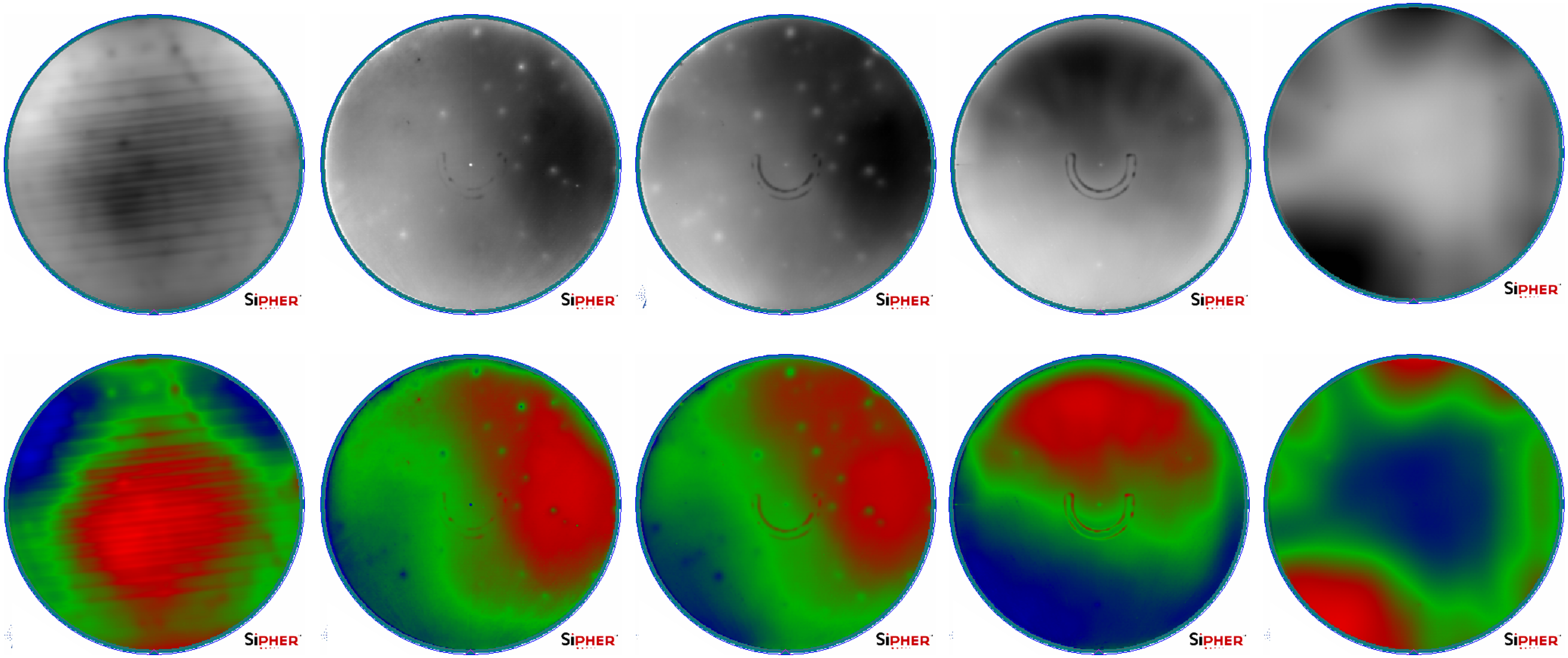
Ge , 10.0 keV, 5.0×10^{14} cm^{-2} + B, 0.5 keV, 1.0×10^{15} cm^{-2}



Flash | **900°C Spike + Flash** | **1000°C Spike + Flash** | **1000°C Spike** | **600°C SPE**

Bulk Probe Results

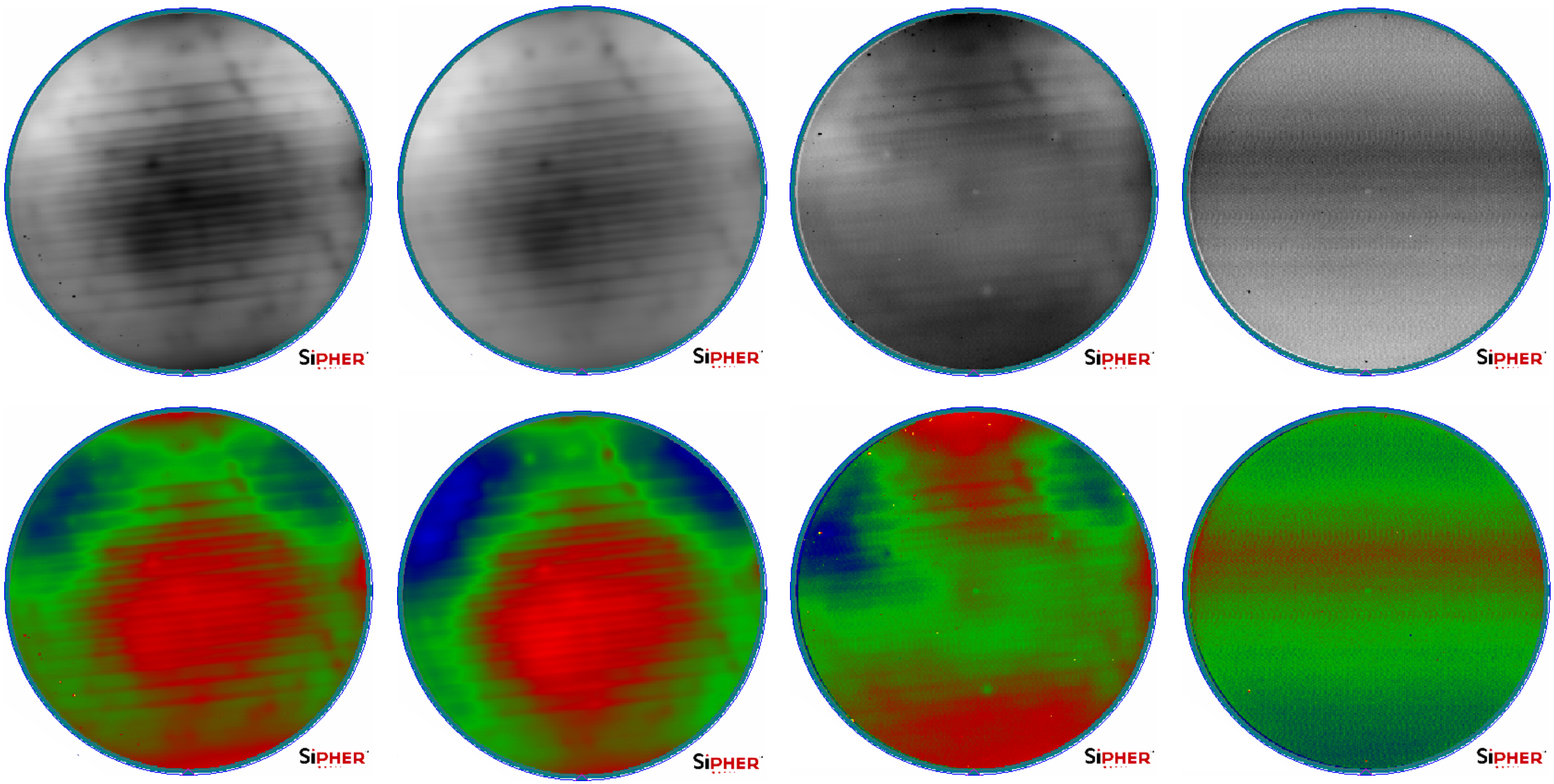
$B_{18}H_x$, 0.5 keV, 1.0×10^{15} cm^{-2} (equivalent)



Flash | **900°C Spike + Flash** | **1000°C Spike + Flash** | **1000°C Spike** | **600°C SPE**

Bulk Probe Results

Impact of implanted specie; Flash annealing



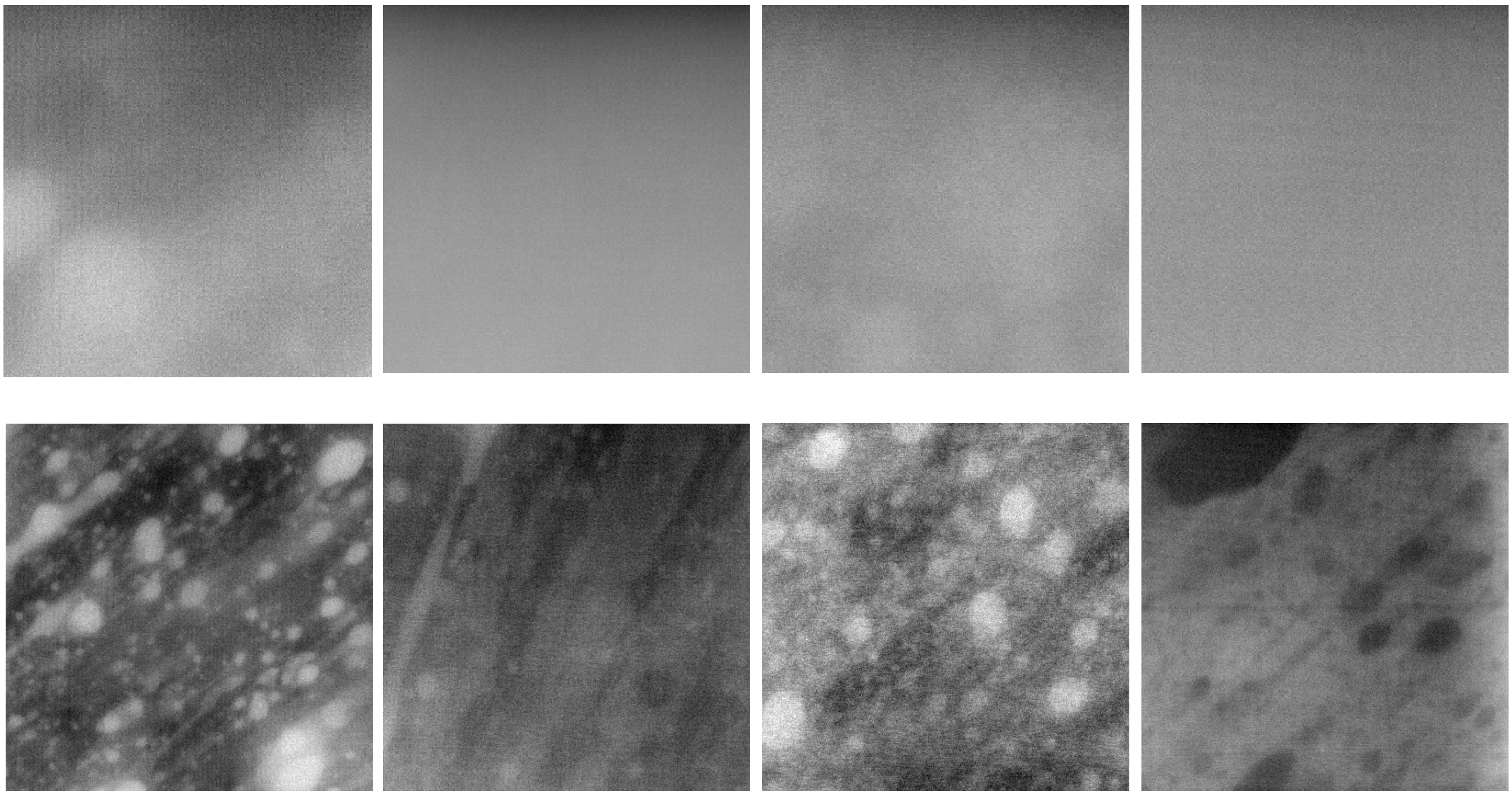
Boron | $B_{18}H_x$ | Arsenic | Ge + Boron

Bulk Probe Results

Micromapping at X=0 and Y=75 mm; Different species; 1000ºC Spike + Flash annealing

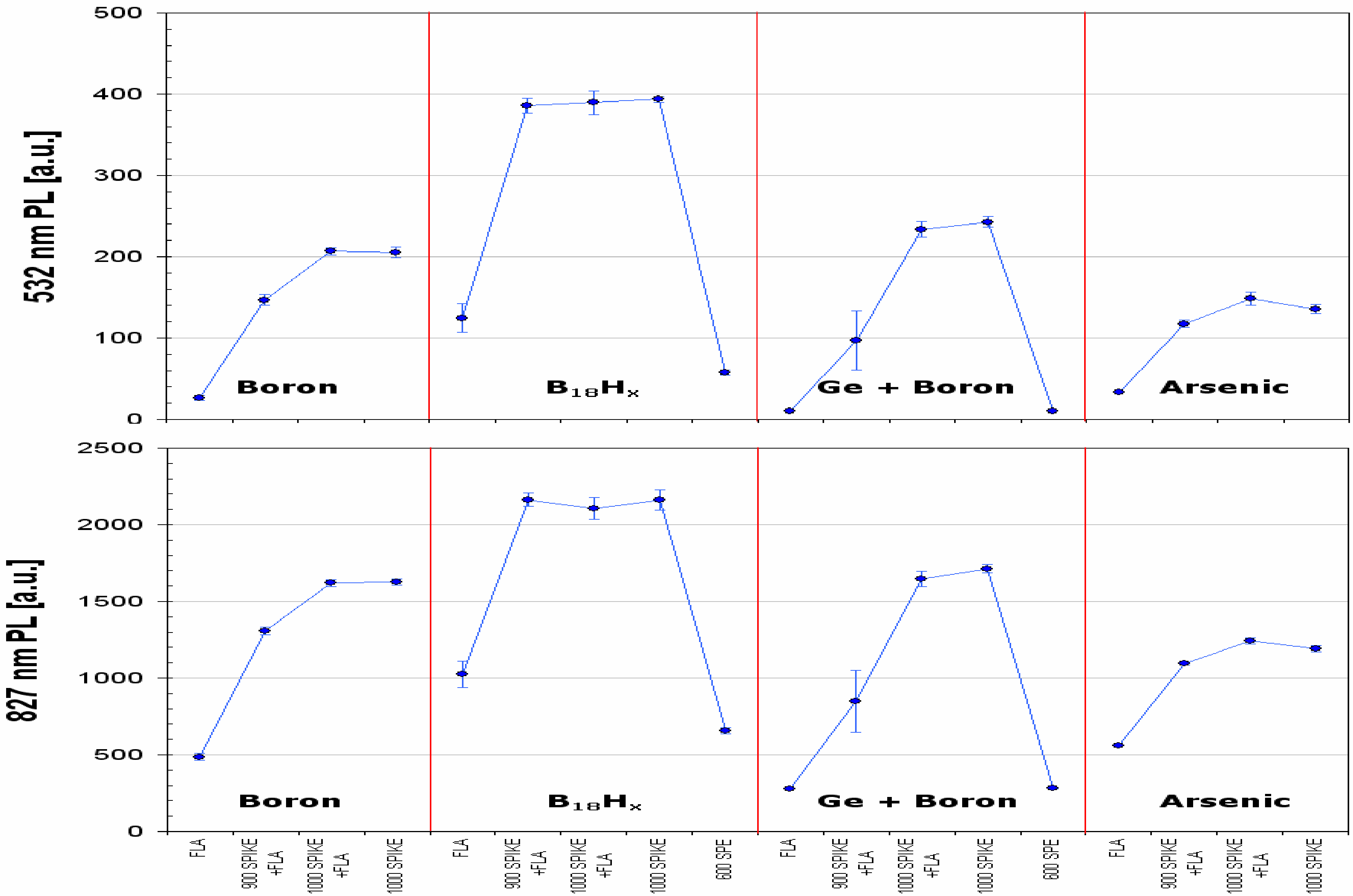
250x250 μm^2

2000x2000 μm^2



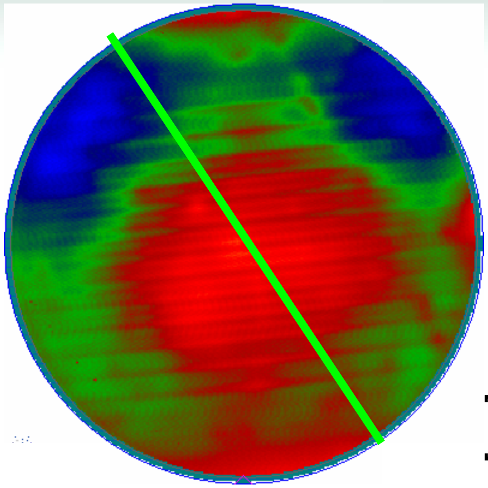
Boron | $B_{18}H_x$ | Ge + Boron | Arsenic

Numerical Data

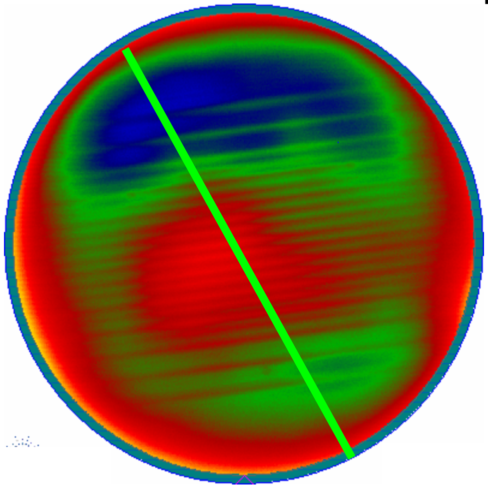


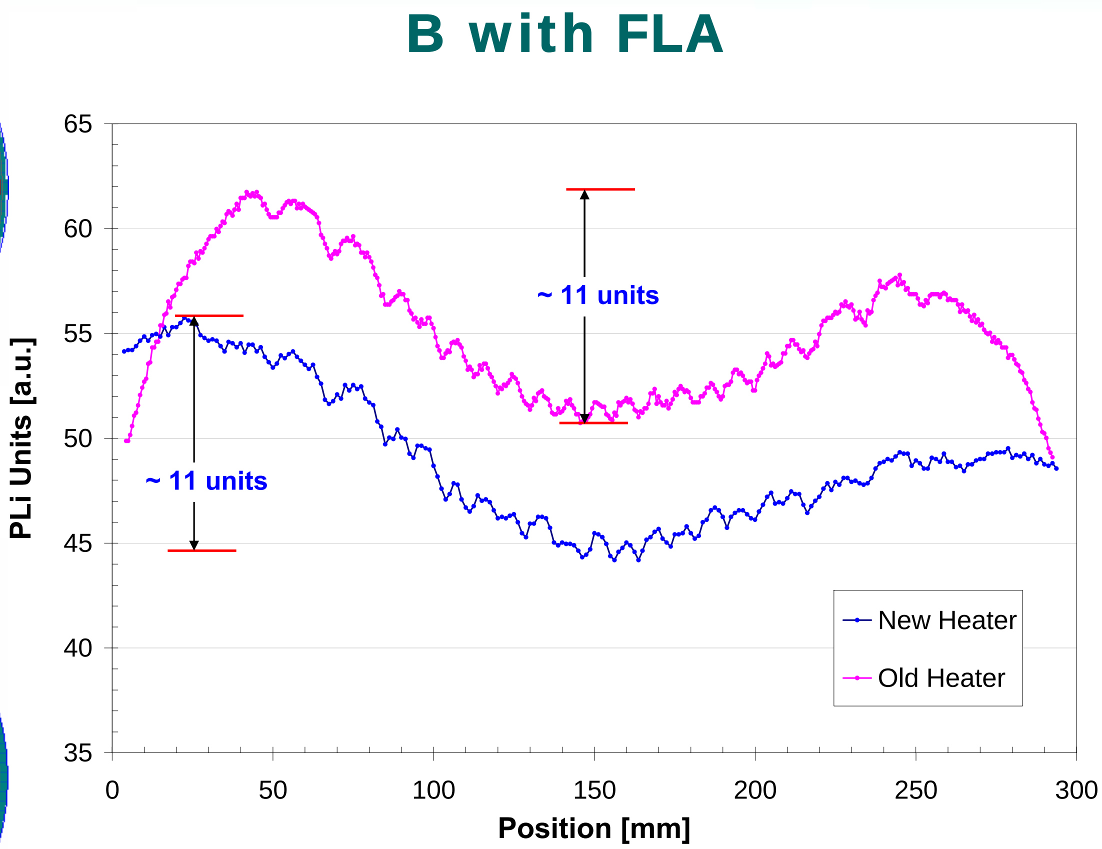
New vs. Old Heater Design Effects

New



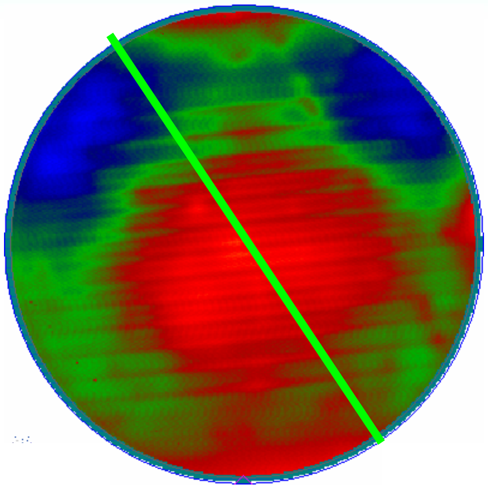
Old



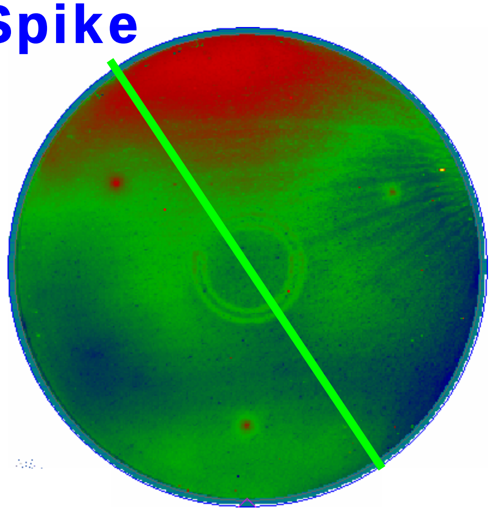


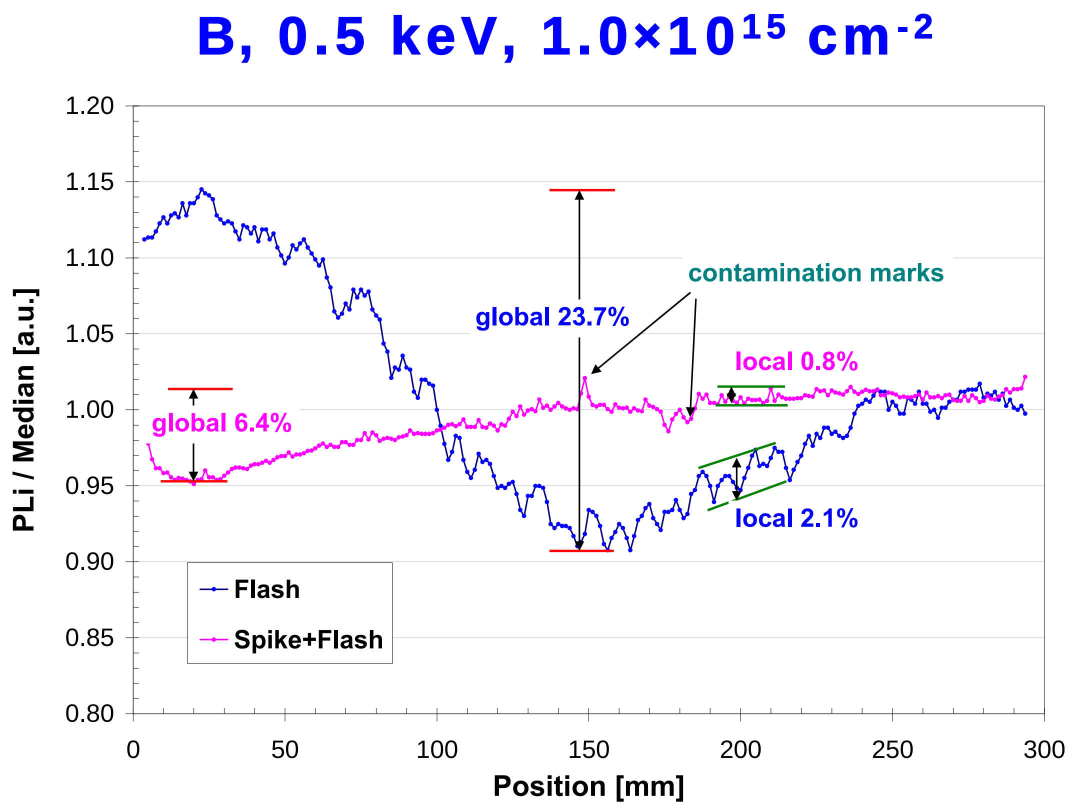
Suppression of Flash Lamp Variation Effects by Spike Annealing

Flash



Flash + Spike





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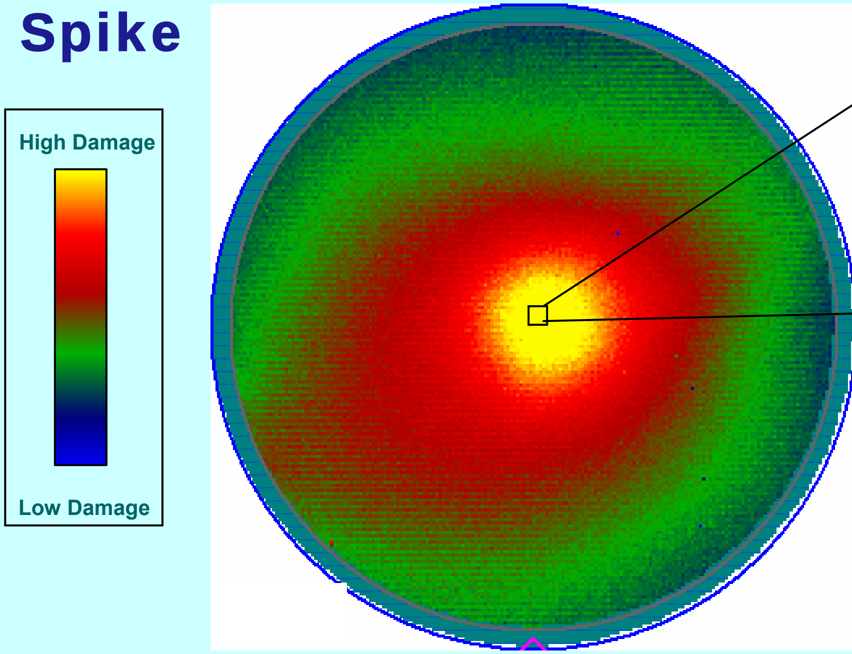
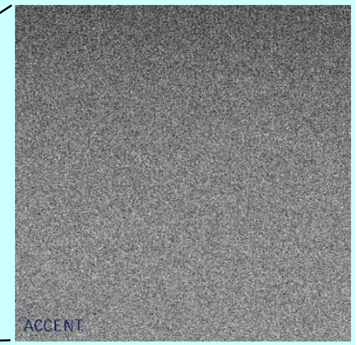
PLi Inspection - Damage Recovery

Macro-mapping + Micro-mapping

Spike

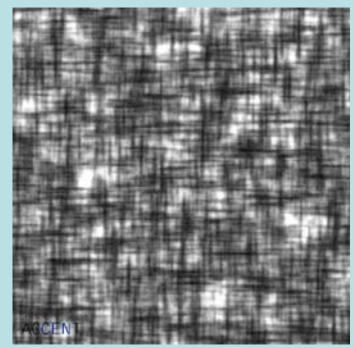




500 x 500 µm²

Macro-map of 200 mm USJ-implanted wafer showing large scale non-uniformity from spike anneal

Flash



Micro-map showing massive dislocation density from high temperature (1300°C) flash anneal

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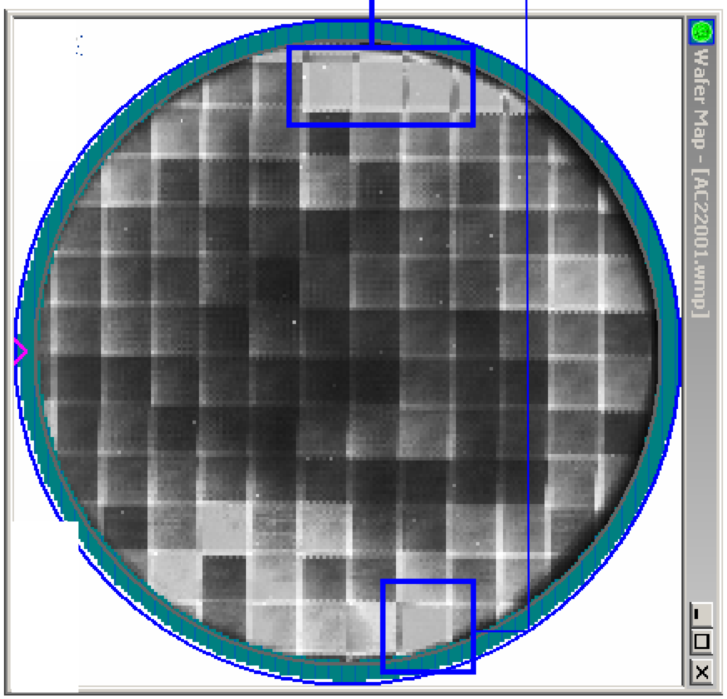
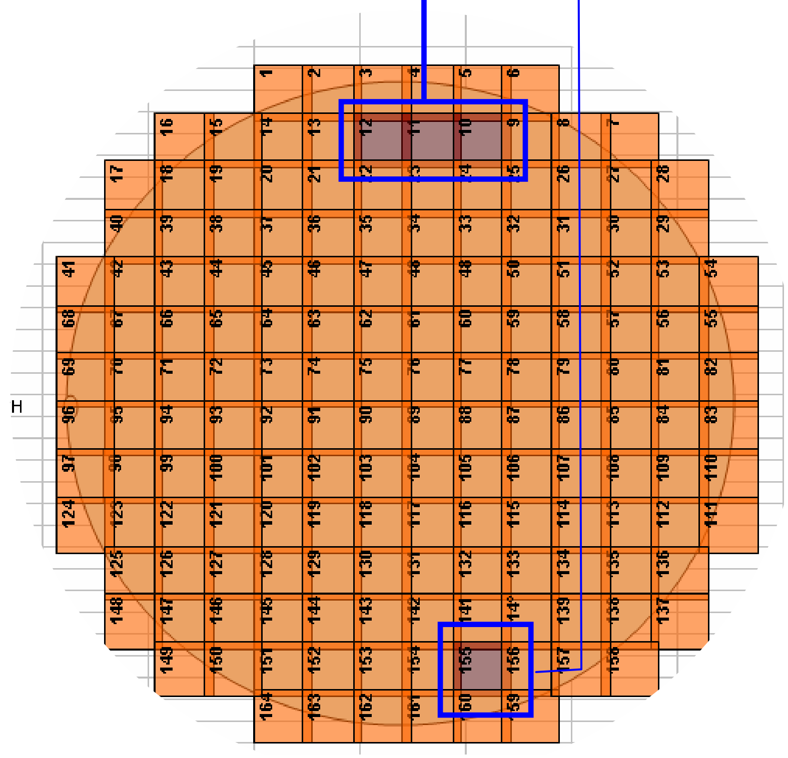
PLi Inspection: Laser 1 Anneal Signature

Laser Anneal Type 1: Correlation Between PLi and Laser Melt

High PLi Regions

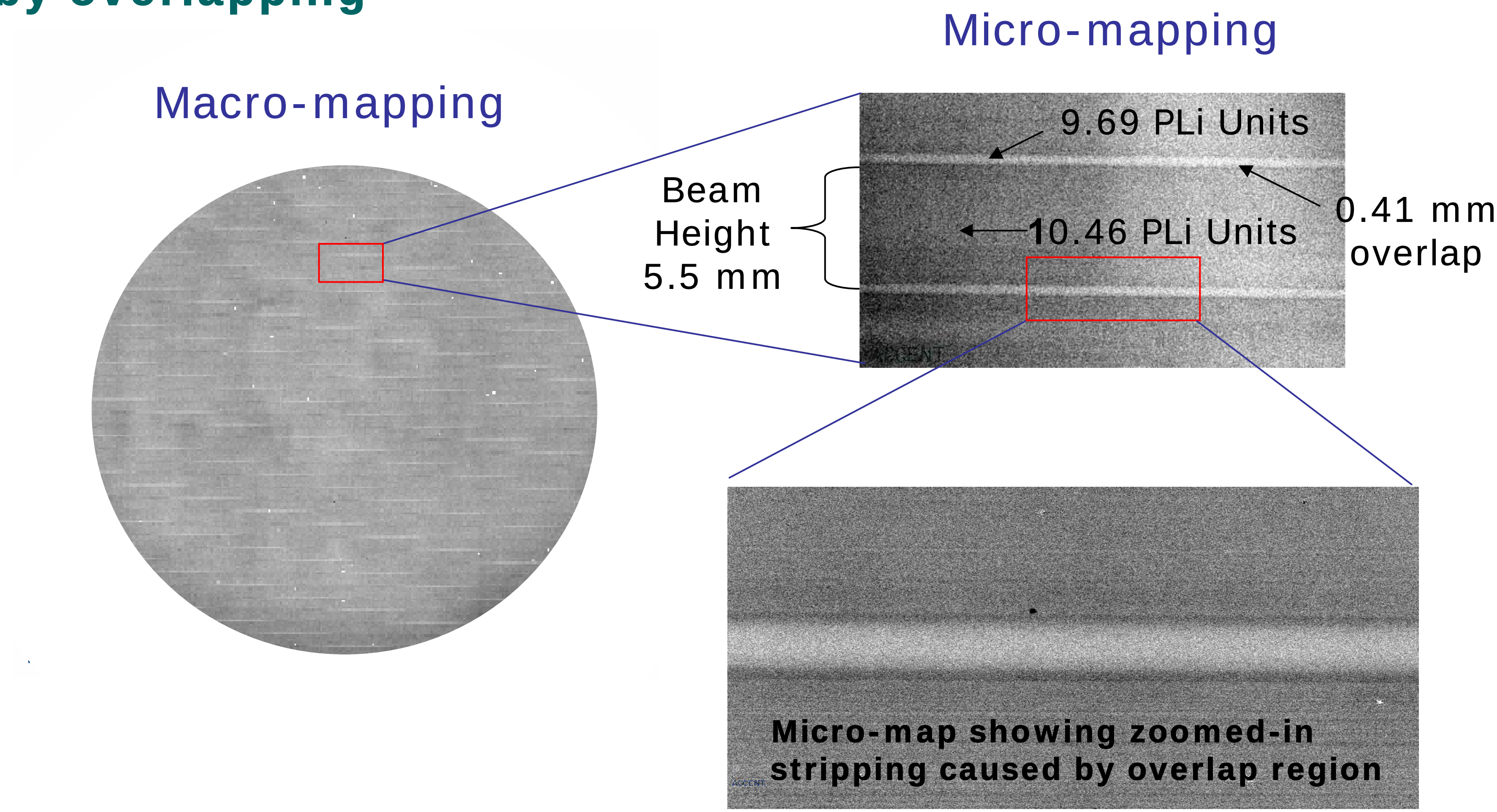


Laser Melt Regions

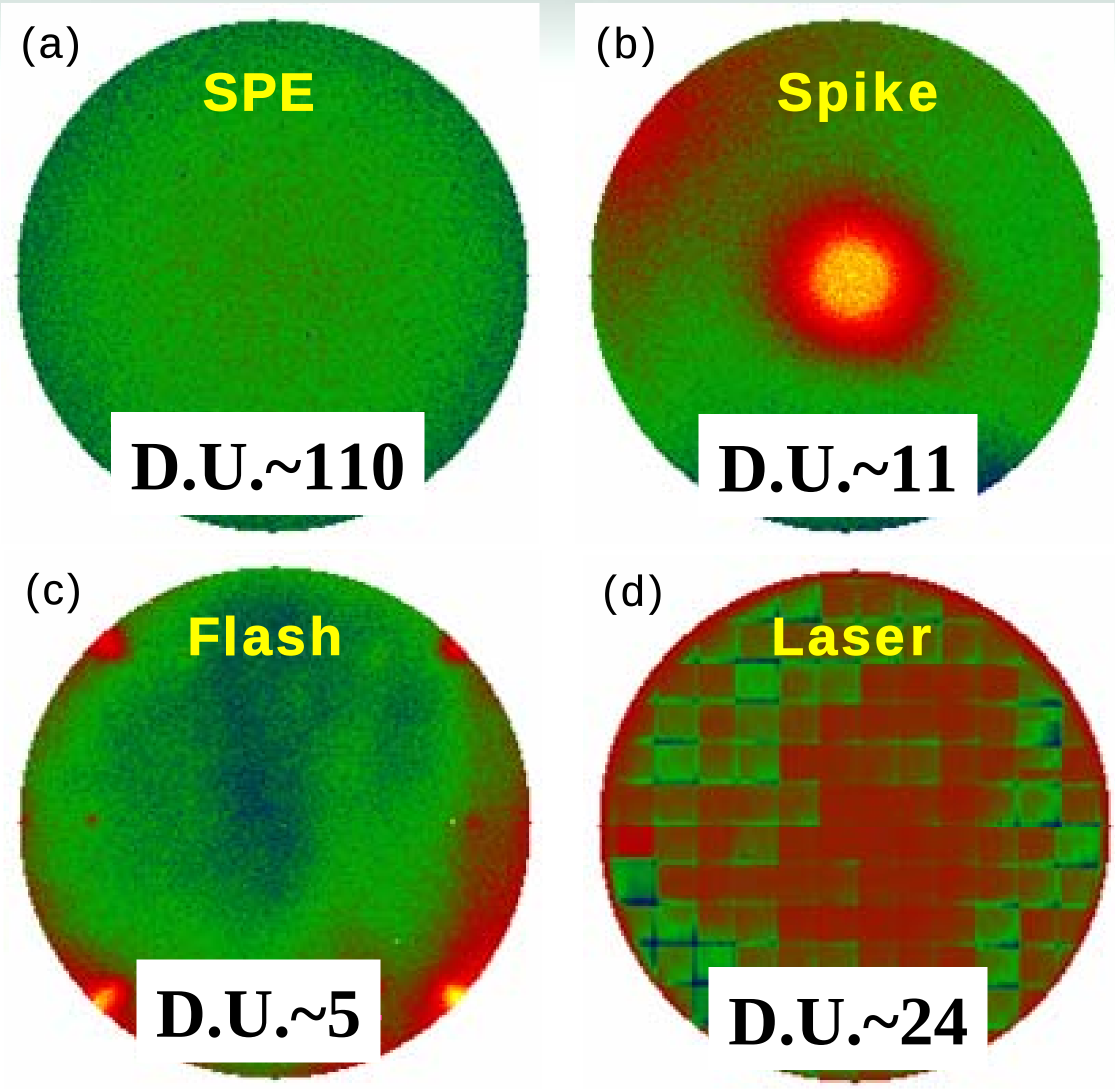


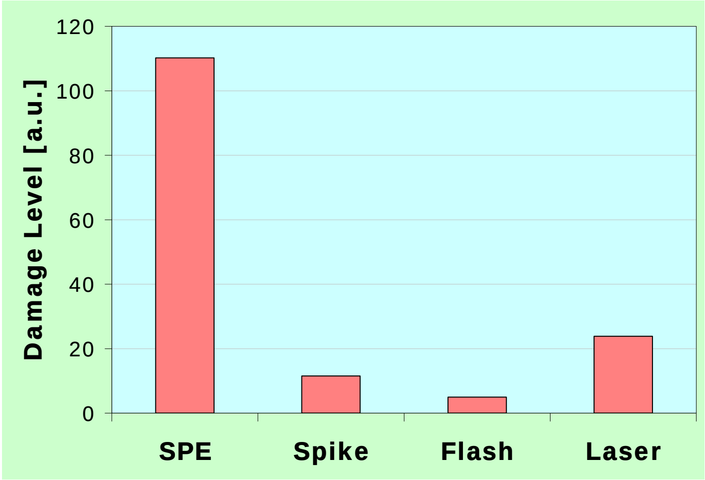
PLi Inspection: Laser 2 Anneal Signature

Laser Anneal Type 2: stripping caused by overlapping



Annealing Uniformity and Residual Damage





SPE anneal is uniform but it does not remove completely the damage. Spike, flash and laser anneals remove more damage, but exhibit higher non-uniformity than SPE.

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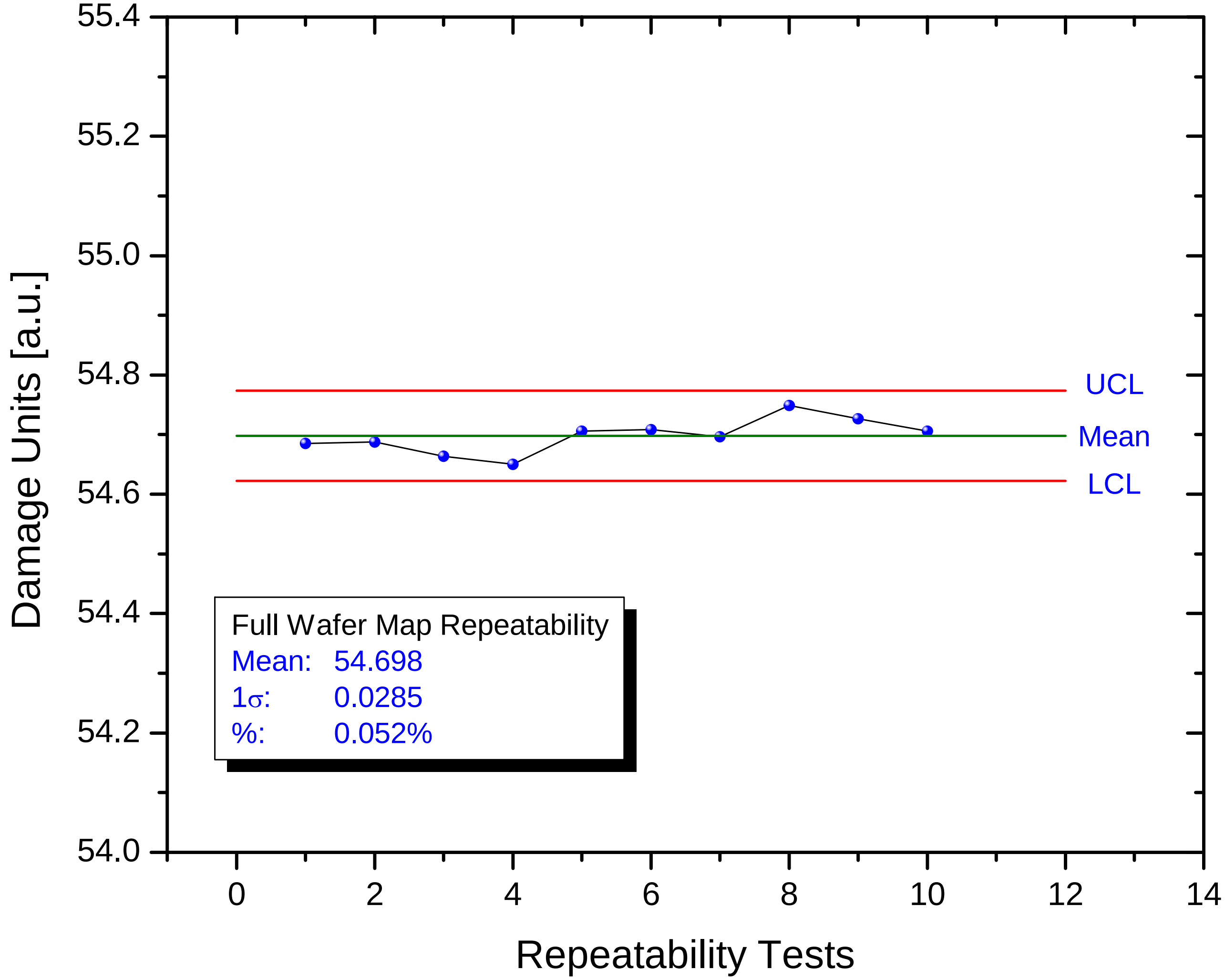
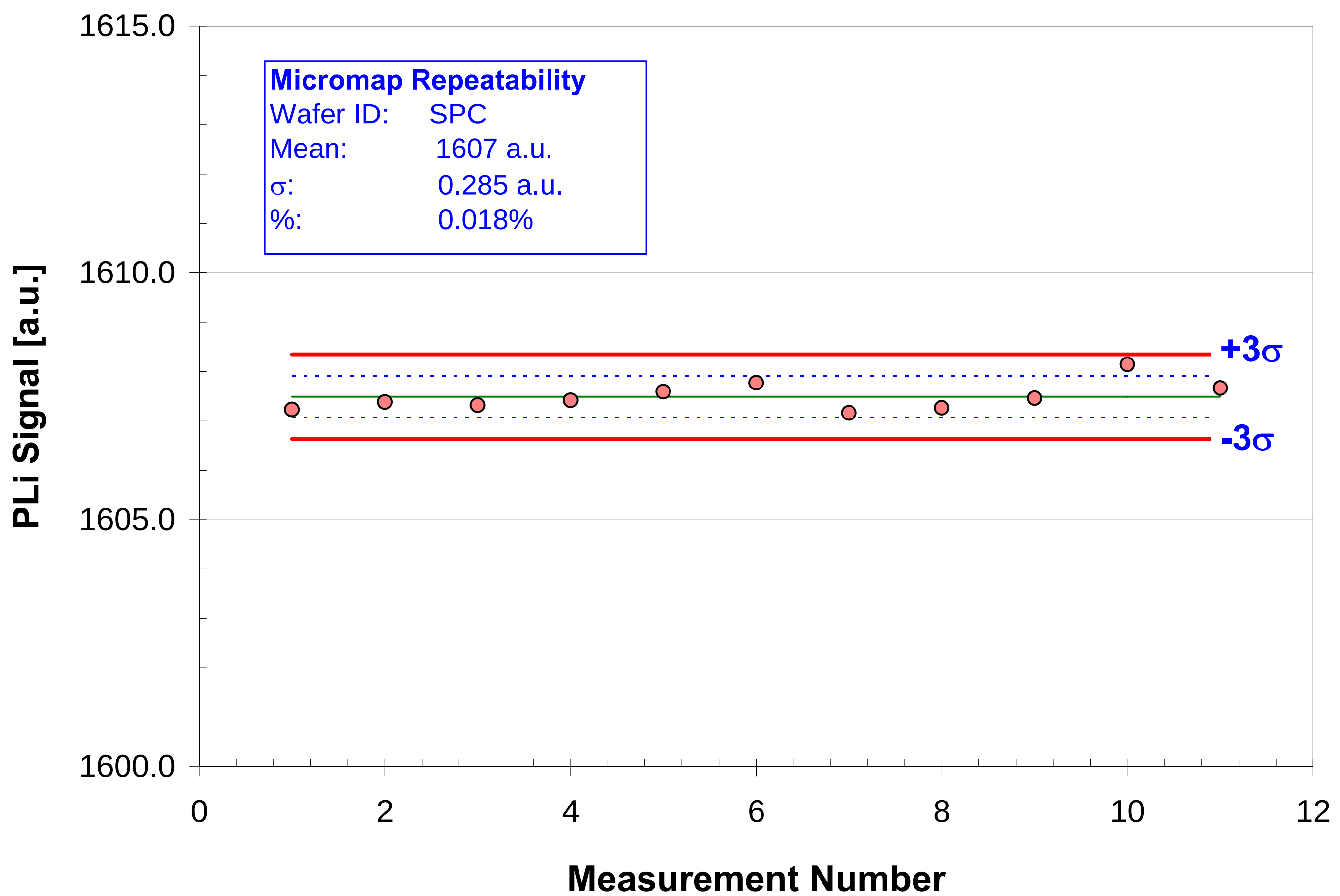
Damage Inspection - Full Wafer Map Repeatability

Boron, 1×10^{15} cm^{-2}, 500 eV, with FLASH annealing



PLi Inspection - Micro Map Repeatability

SPC sample, un-implanted, 10 nm oxide passivated



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Summary

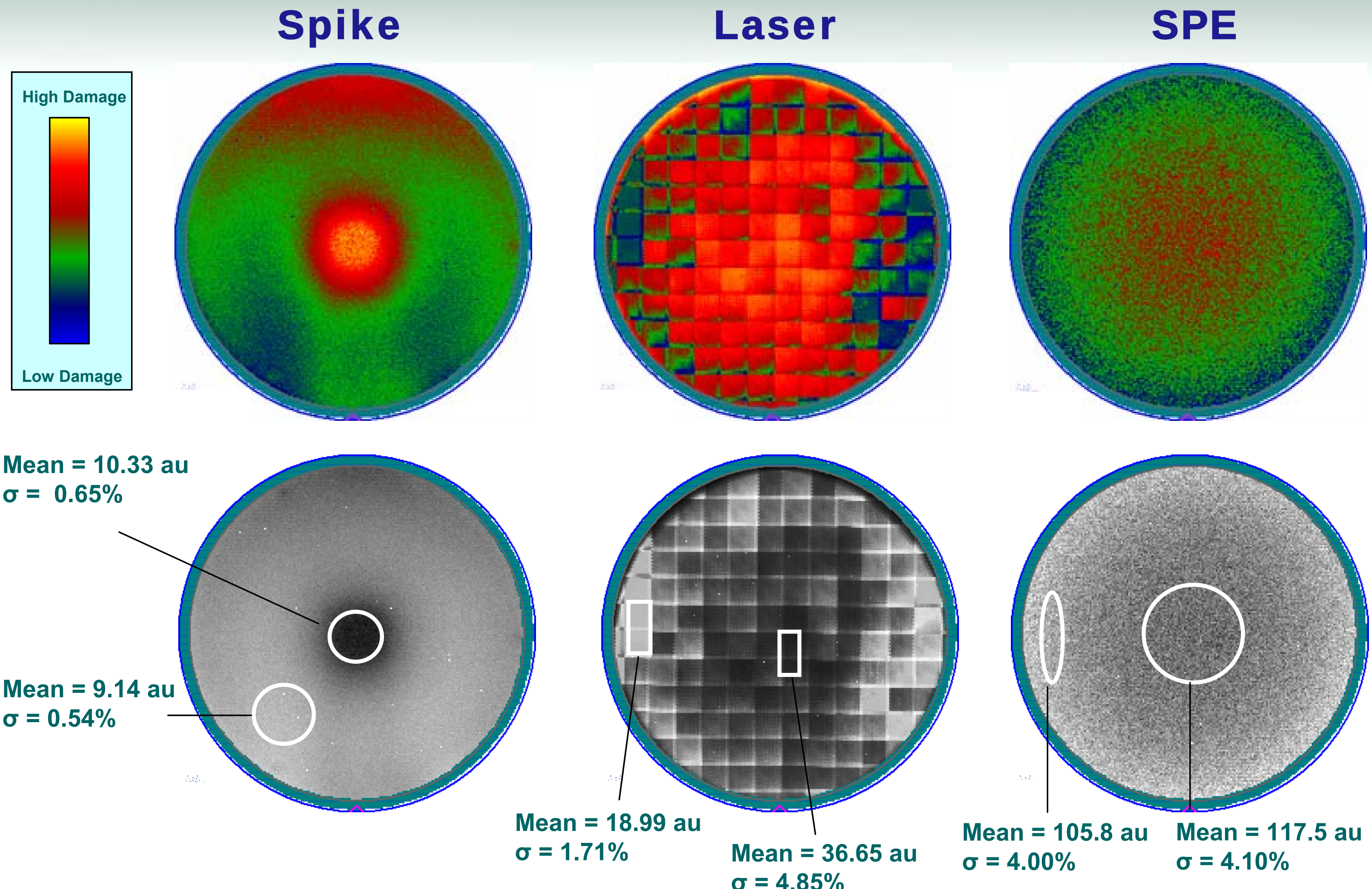
- Provided an overview of PLi technology
  - **Optical set-up and interaction physics**
- Demonstrated sensitivity of PLi to dose and energy variation
  - **Variety of process conditions**
- Data from several experiments indicates:
  - **High temperature (1000°C) Spike or high temperature Spike followed by Flash annealing are the most efficient ways of removing the post implantation damage**
  - **Flash annealing alone leads to relatively large global and local residual damage variation, while Spike combined with Flash effectively suppresses the variation**
  - **Flash signature clearly visible for all species studied**
  - **Annealer heater performance can be optimized with PLi technology**
  - **Of all species B18 shows best results for damage removal across all anneal methods, but the best removal is obtained with a 900°C Spike + Flash annealing**

Acknowledgements

- John Borland of JOB
- Andrzej Buczkowski, Zhiqiang Li, Dave Doyle of Nanometrics

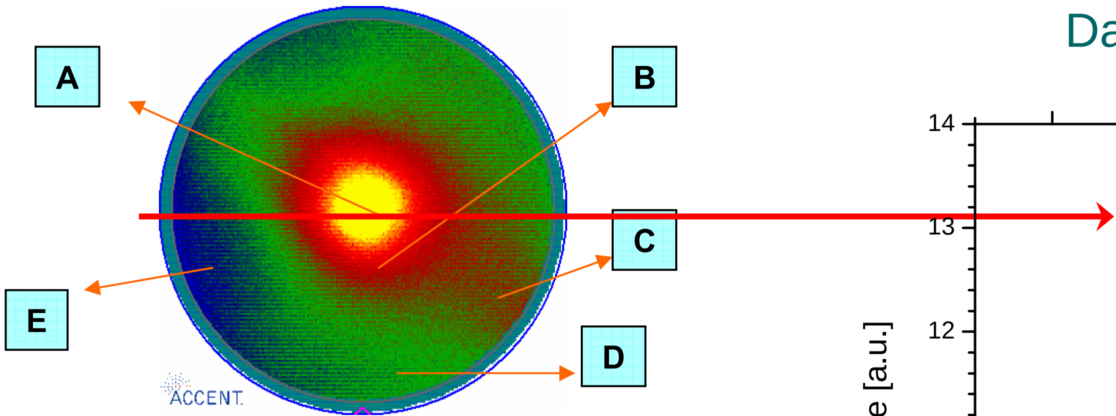
Additional Slides

Annealing Equipment Signatures

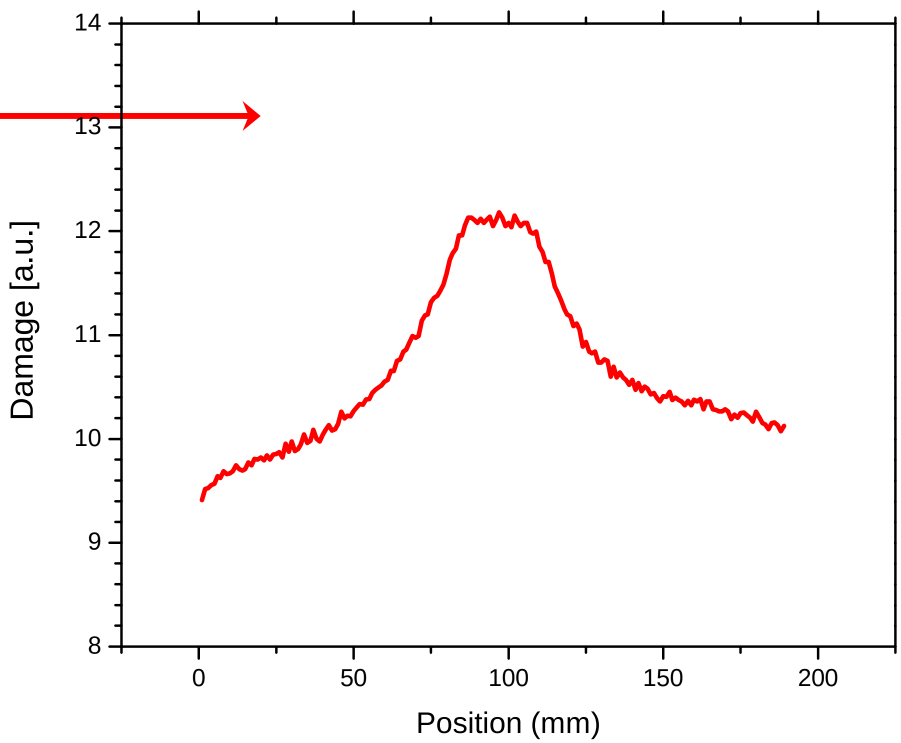


Residual Damage Uniformity Map

Spike Annealed

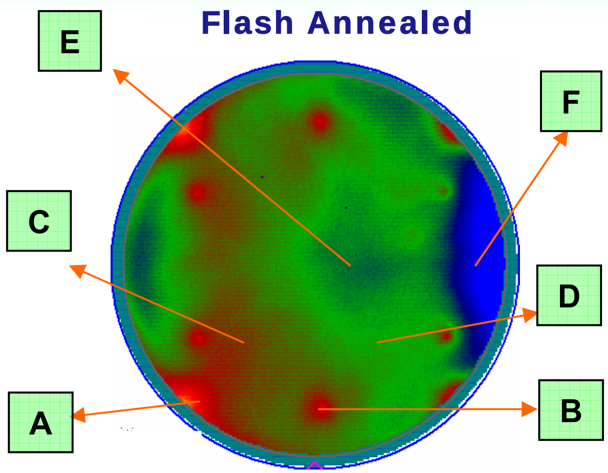


Damage Level: Line Profile:



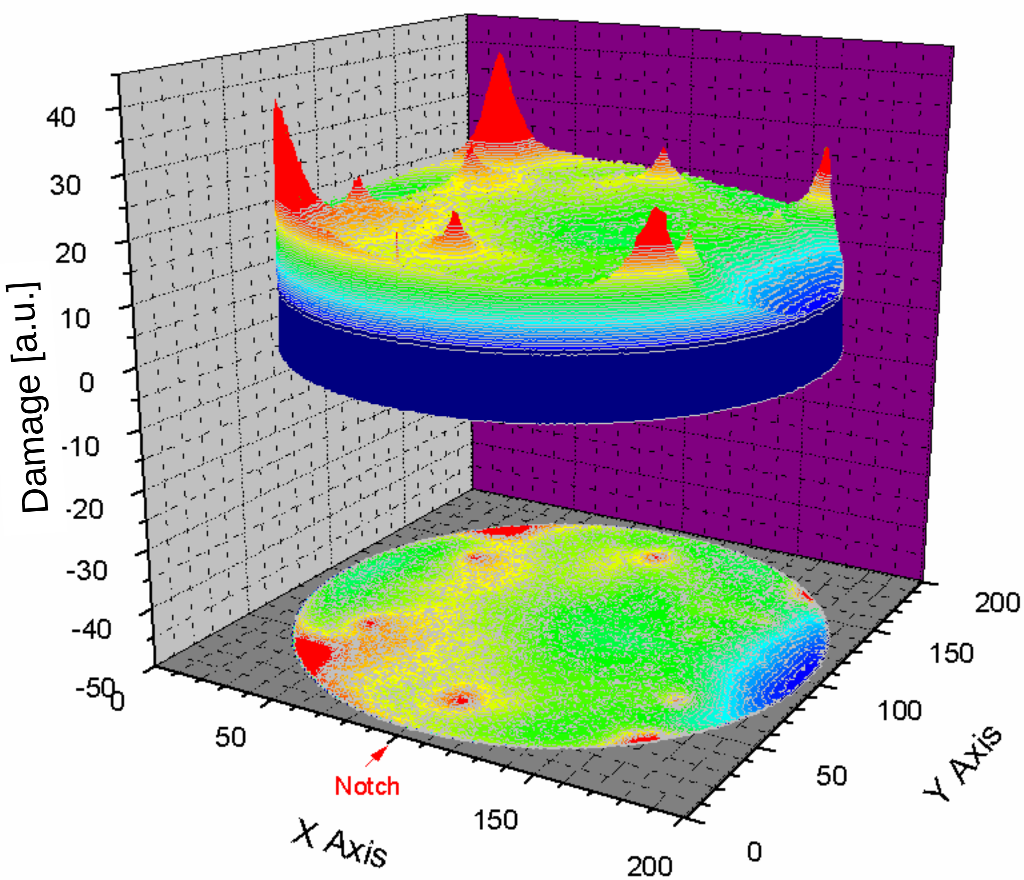
Sampling size: 6 × 6 mm²		
	Mean	StDev
A	12.11	0.69%
B	11.26	1.28%
C	10.40	0.65%
D	10.10	0.69%
E	9.43	2.025

Residual Damage Uniformity Map

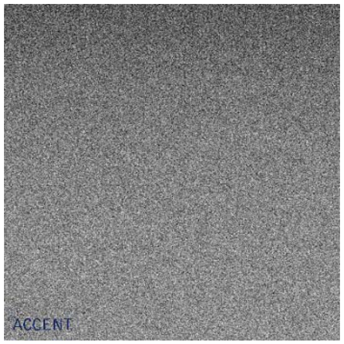
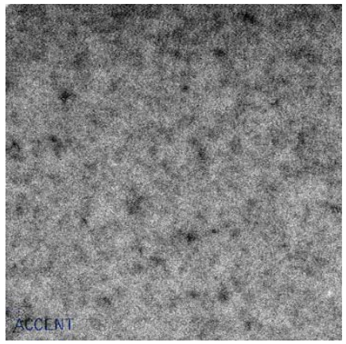
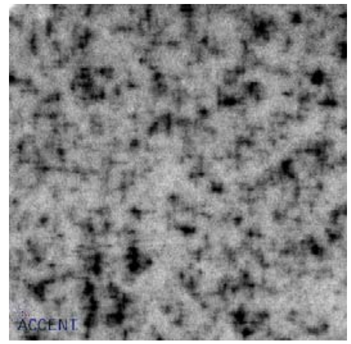
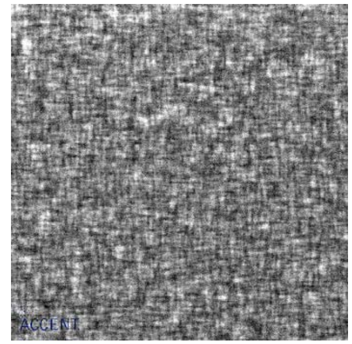
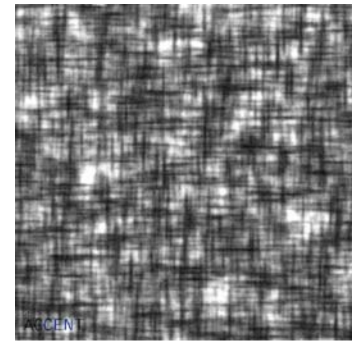
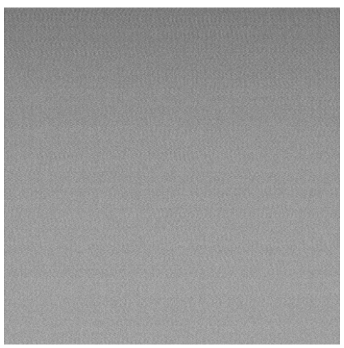
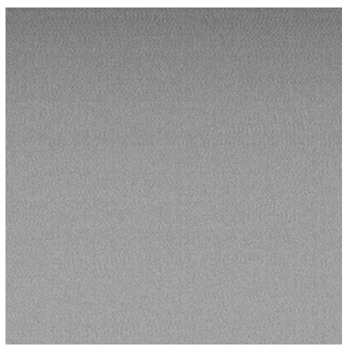
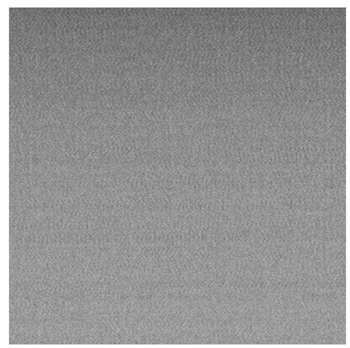
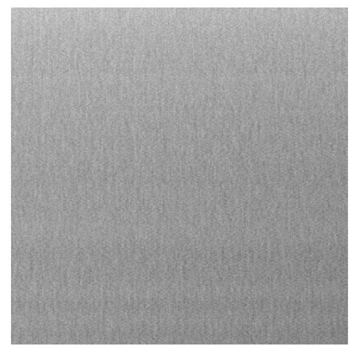
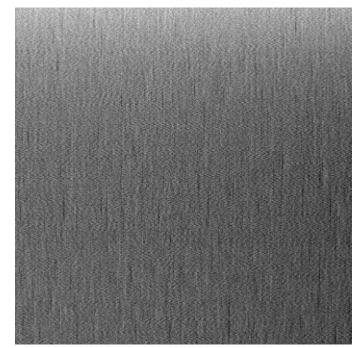


Sampling size: 6 × 6 mm²		
A	32.67	8.98%
B	24.70	5.03%
C	20.46	1.69%
D	18.86	1.07%
E	17.25	1.11%
F	8.09	3.66%

Damage Level: 3D



PLi of USJ Flash Anneal Residual Defectivity

	700 Pre : 1250 Peak	700 Pre : 1300 Peak	750 Pre : 1300 Peak	750 Pre : 1350 Peak	2 × (750 Pre : 1300 Peak)
PL					
	Mean: 28.53 δ : 4.69 %	Mean: 11.78 δ : 2.87 %	Mean: 9.01 δ : 4.85 %	Mean: 55.05 δ : 14.8 %	Mean: 36.63 δ : 26.6 %
SR					
	Mean: 2.427 δ : 0.401 %	Mean: 2.426 δ : 0.186 %	Mean: 2.426 δ : 0.158 %	Mean: 2.411 δ : 0.189 %	Mean: 2.402 δ : 0.251 %

PAI 1×10^{15} Ge @ 30 keV
Boron 1×10^{15} @ 5 keV

High Damage — Low Damage