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MUSIC to Reduce Defects and Improve Throughput on Implants for SiC MOSFETs

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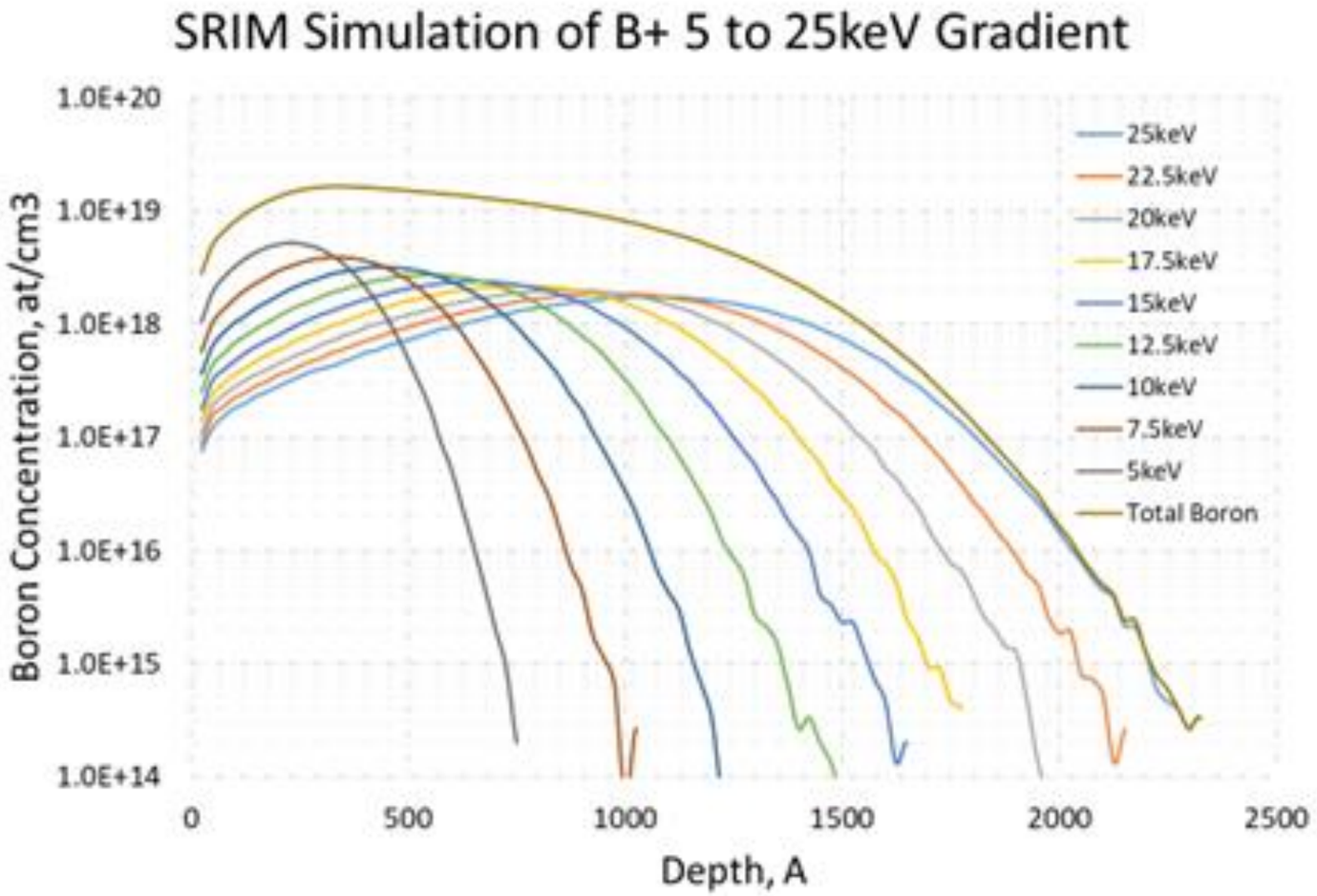
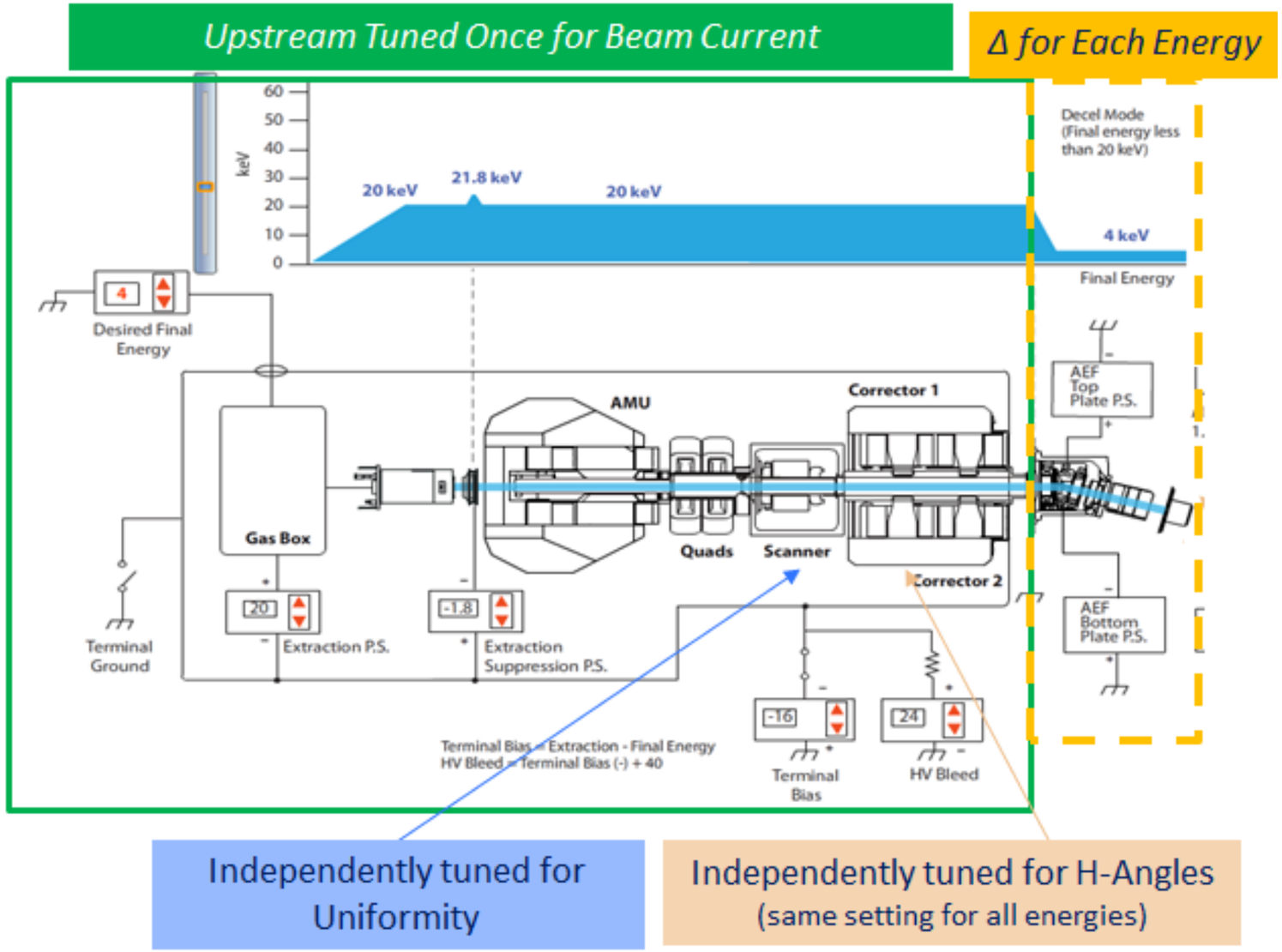
Introduction

- Many implanted structures require multiple implants at different energies to form a proper junction depth profile
- For example, multiple implants are required to form a nearly constant doping level in the vertical direction
- This is especially true for silicon carbide devices, because implanted dopants do not diffuse during activation annealing



Multi-Step Implant Chain (MUSIC)

- MUSIC is a technique to complete multiple implants without removing the wafer from the chuck by rapidly retuning the beam in between implants
- Only the downstream beamline components are retuned in the MUSIC protocol (source retuning is not fast enough)
- MUSIC protocol is limited to recipes of the same species and charge state and within a limited energy range



MUSIC is a unique capability for multiple chain implants that minimizes beam retuning while the wafer remains on the electrostatic chuck (ESC).

- Potential benefits of MUSIC:
  - Productivity: Reduced number of beam tunes increases tool efficiency
  - Yield: Reduced wafer handling steps reduces particle defects
  - Multiple implant steps increase control over the final dopant profile
  - Fewer implant steps means less native oxide growth, reduced oxygen knock-in by the implants
  - Reduced temperature non-uniformity for heated implants

Traditional Energy Chain	Multi-Step Implant Chain
Autotune Recipe 1	Autotune All Recipes
Implant Wafer 1	Implant Wafer 1 with all
Implant Wafer 2	Implant Wafer 2 with all
…	…
Implant Wafer 25	Implant Wafer 25 with all
Autotune Recipe 2	
Implant Wafer 1	
Implant Wafer 2	
…	
Implant Wafer 25	
Autotune Recipe 3	
Implant Wafer 1	
Implant Wafer 2	
…	
Implant Wafer 25	

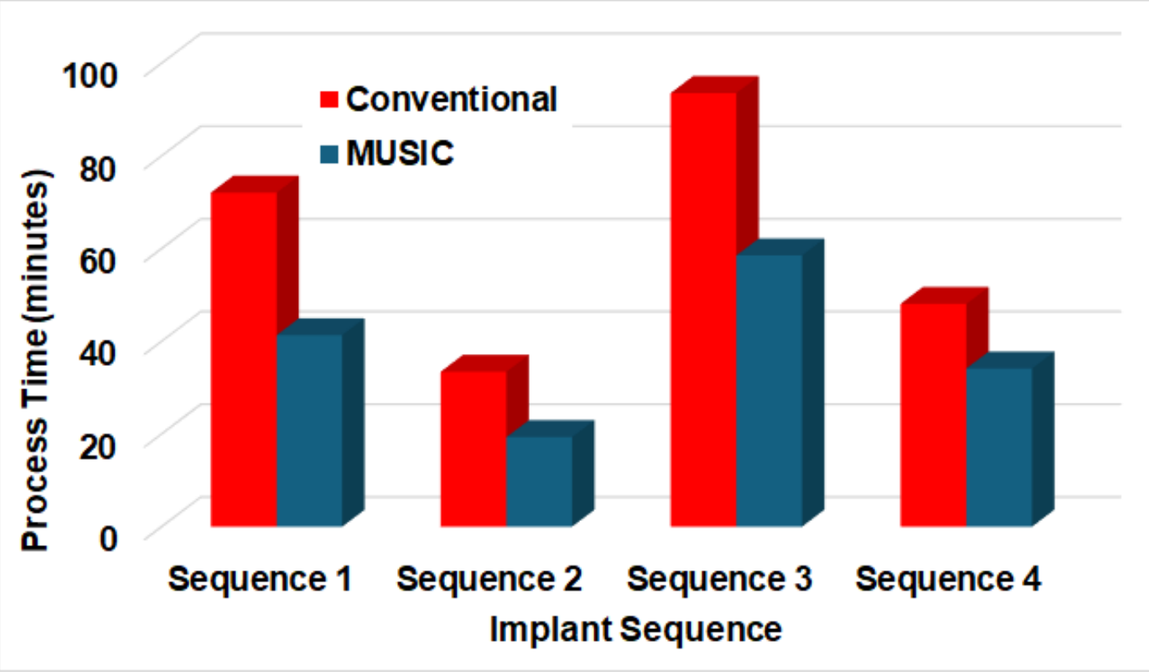
Experiment

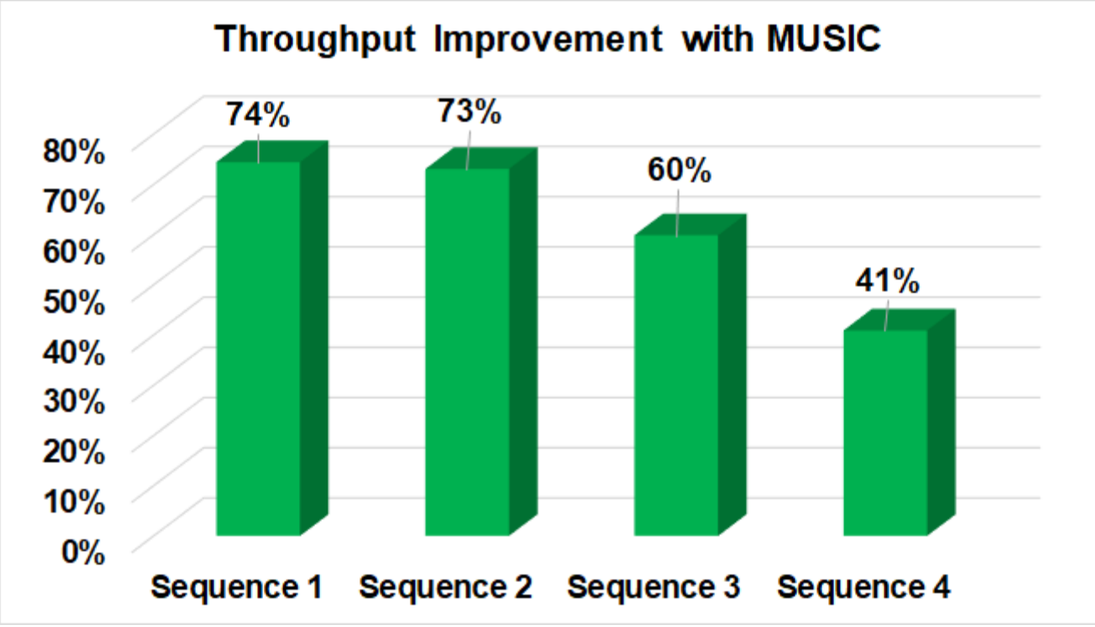
- SiC Power MOSFET device
- Compared conventional multiple implants with MUSIC for
  - 2 phosphorus sequences
  - 2 aluminum sequences
- 2 lots (25 wafers) for each sequence
- All implants done at 400°C
  - Significant time saved by minimizing the number of heat/cool cycles
- Non-channeling tilt/twist condition
- Total wafer handling and thermal cycling events reduced from 11 to 4

Sequence	Species	Energy (keV)	Dose (cm^{-2})
Sequence 1	P+	80	$2.5x10^{14}$
	P+	120	$5.0 x10^{14}$
	P+	150	$5.0 x10^{14}$
	P+	200	$5.0 x10^{14}$
Sequence 2	P+	30	$7.5 x10^{13}$
	P+	60	$7.5 x10^{13}$
Sequence 3	Al+	80	$1.0 x10^{15}$
	Al+	150	$1.0 x10^{15}$
	Al+	200	$1.0 x10^{15}$
Sequence 4	Al++	300	$5.0 x10^{13}$
	Al++	400	$3.0 x10^{13}$

Results – Productivity Improvement

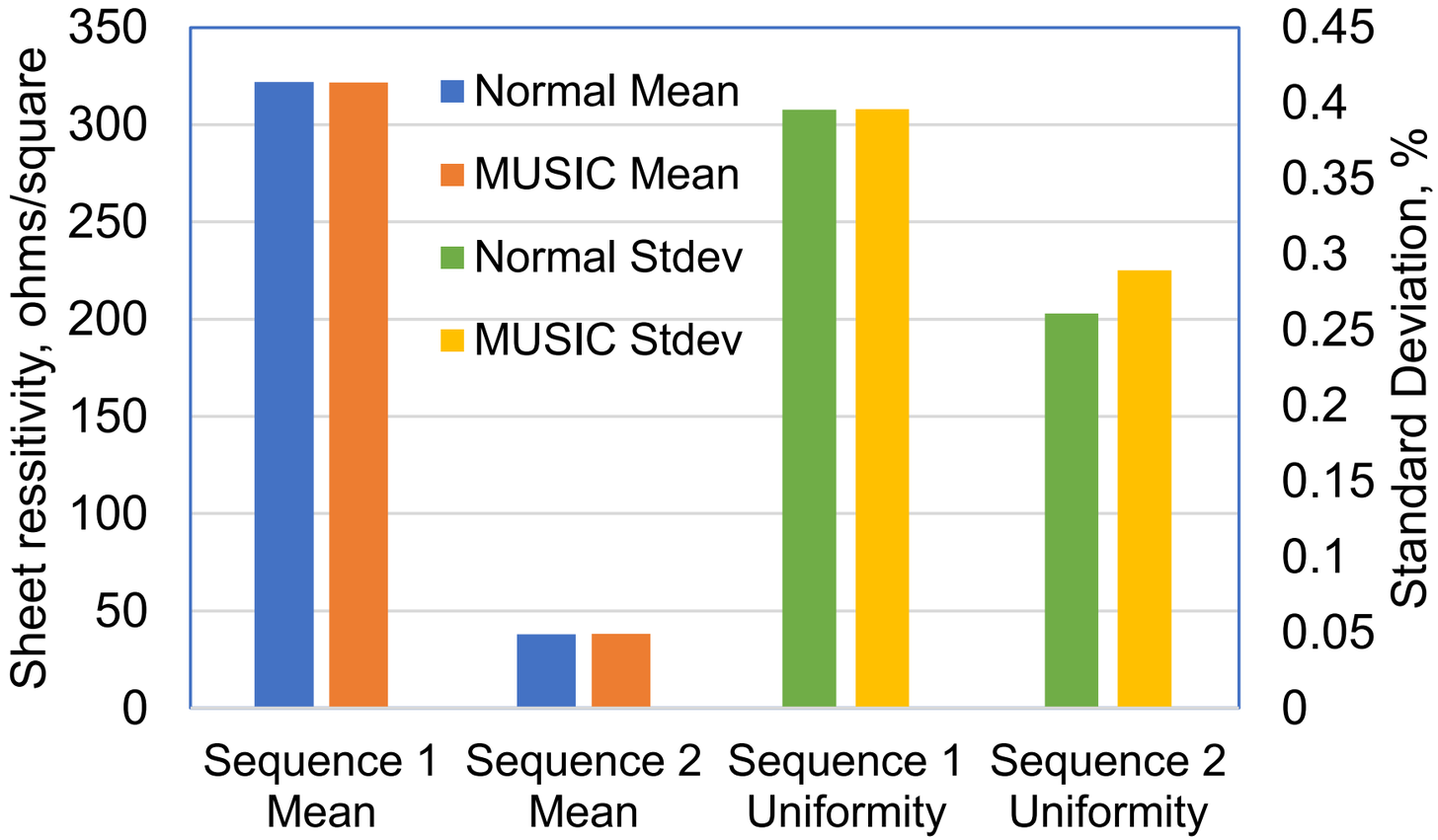
- Process time per lot decreased and net throughput increased significantly for all implant sequences measured





Results – Bare Wafer Sheet Resistivity

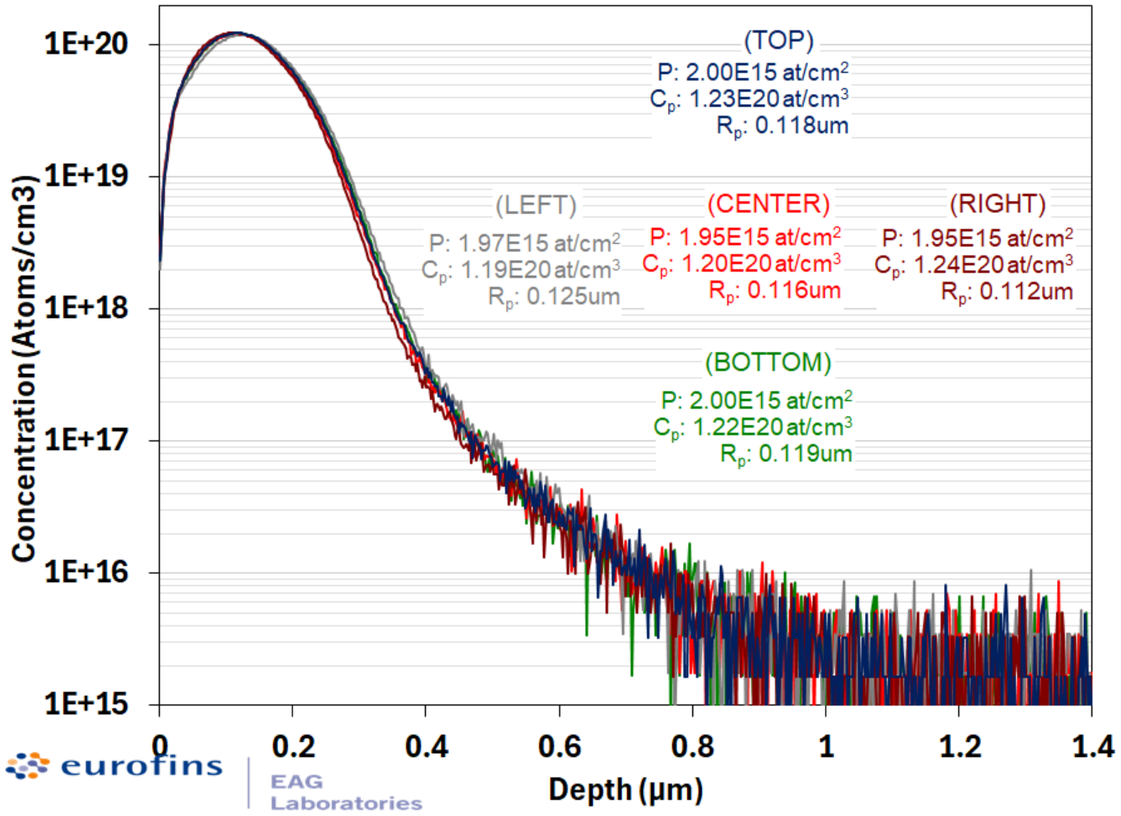
- No meaningful change in average sheet resistance or across wafer uniformity for either of sequences 1 and 2



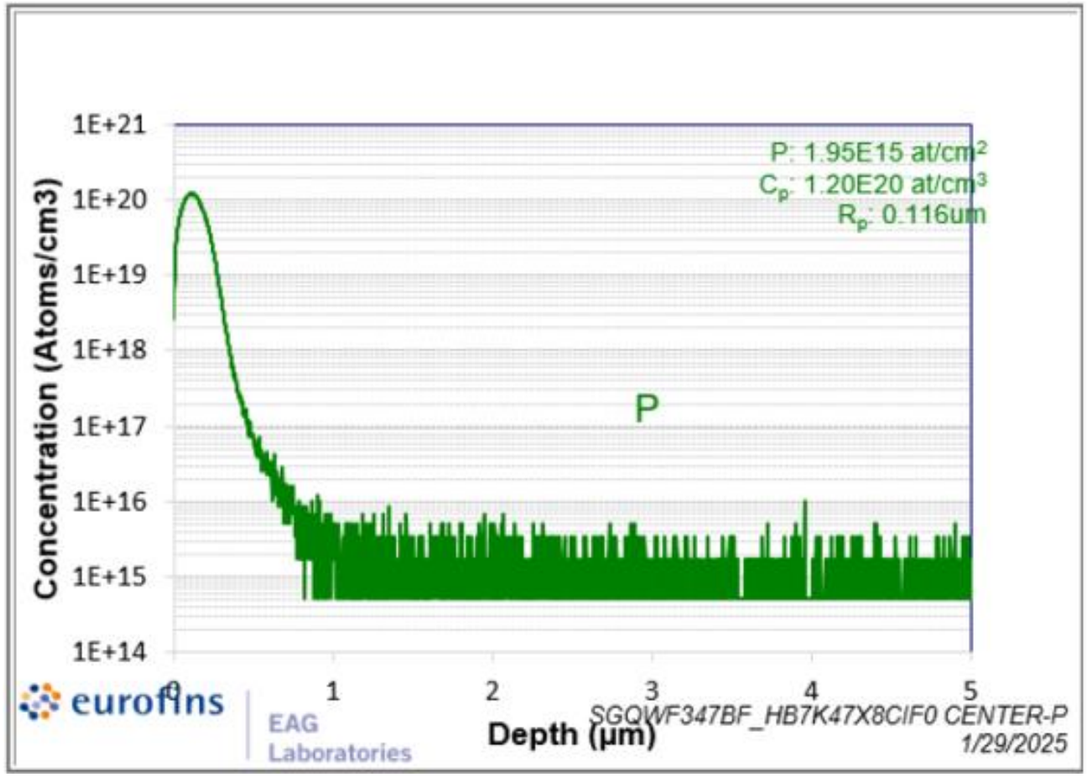
Results – Bare Wafer SIMS Results

- No across wafer difference in the combined profiles

Sequences 1 & 2 with MUSIC



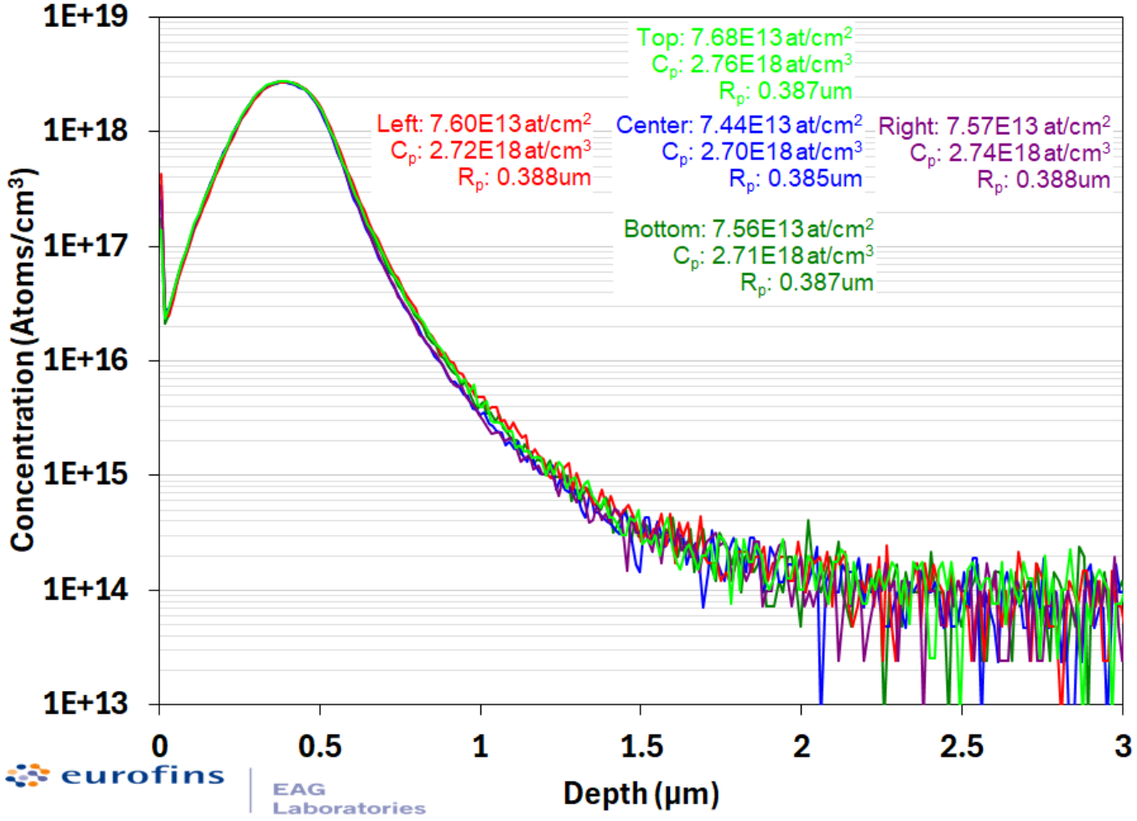
Sequence 1 & 2 without MUSIC



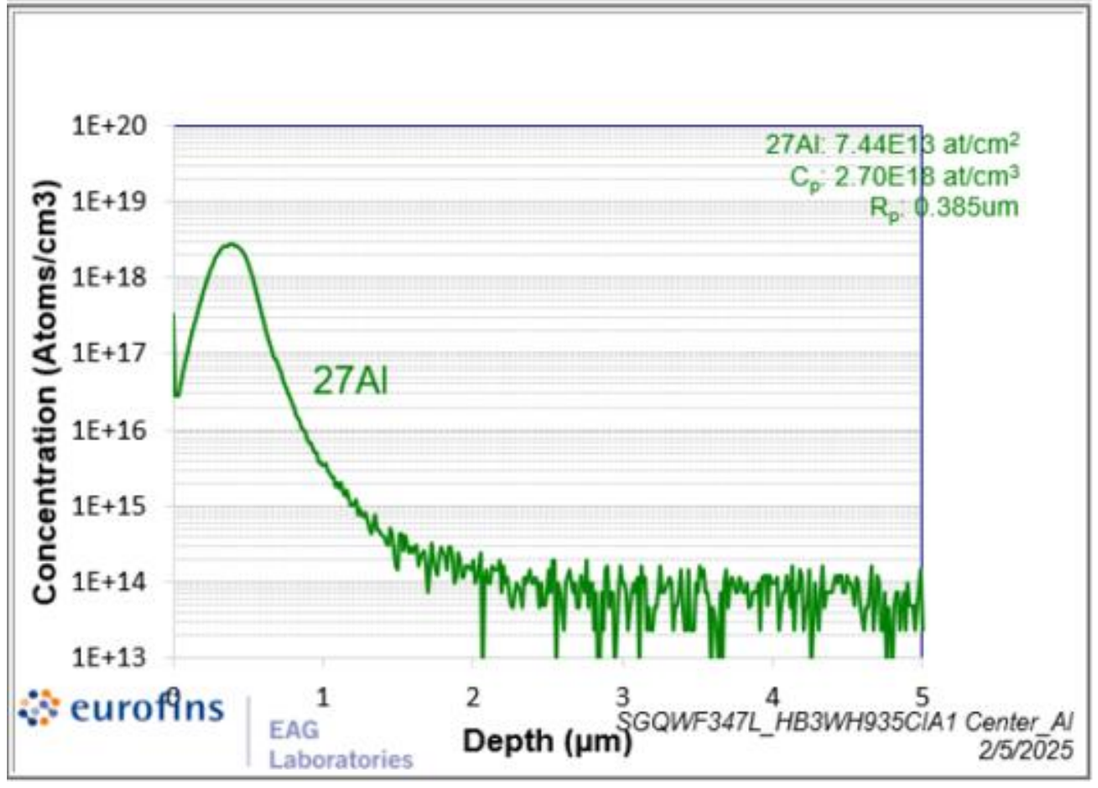
Results – Bare Wafer SIMS Results

- No across wafer difference in the combined profiles

Sequences 4 with MUSIC

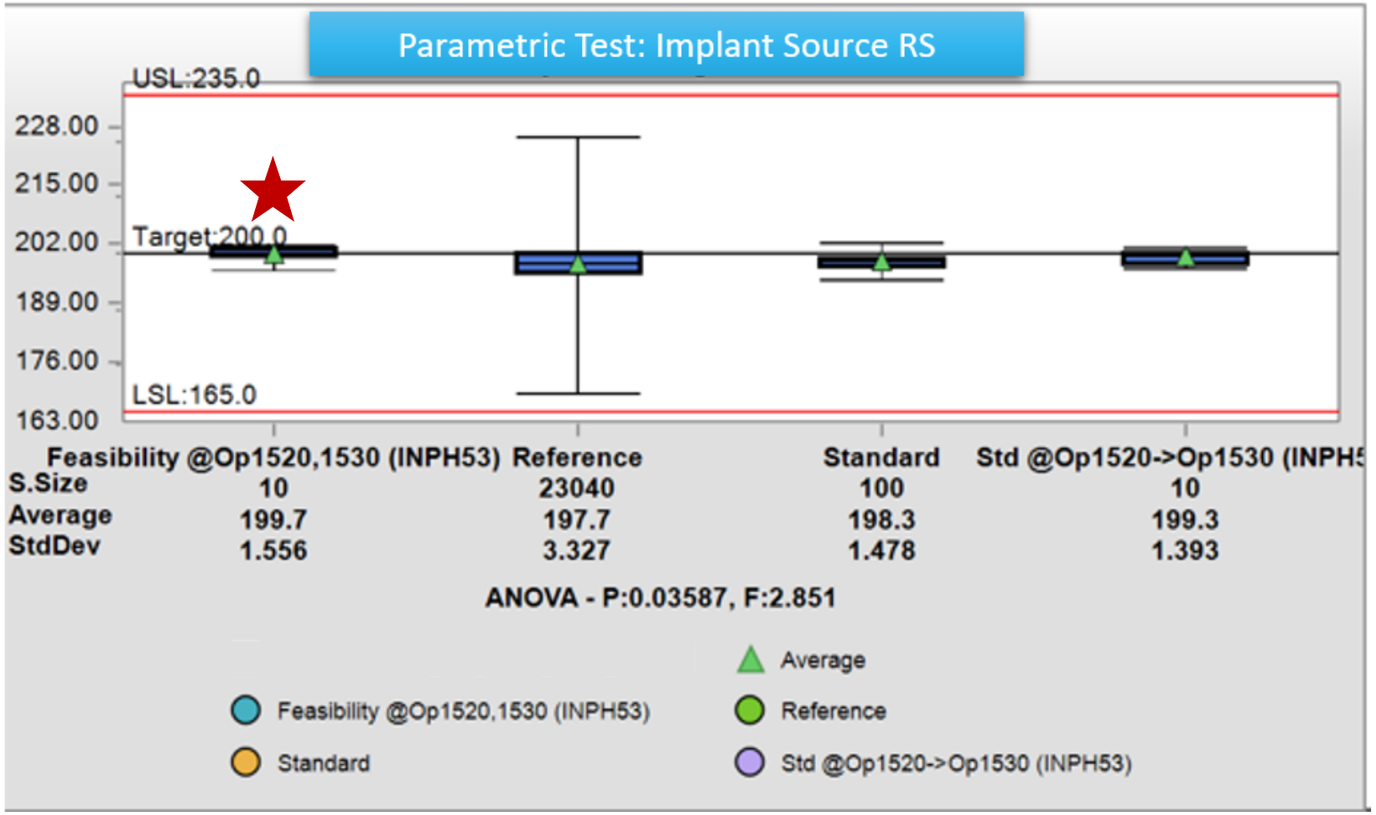


Sequence 4 without MUSIC



Results – Device Wafer Electrical Test

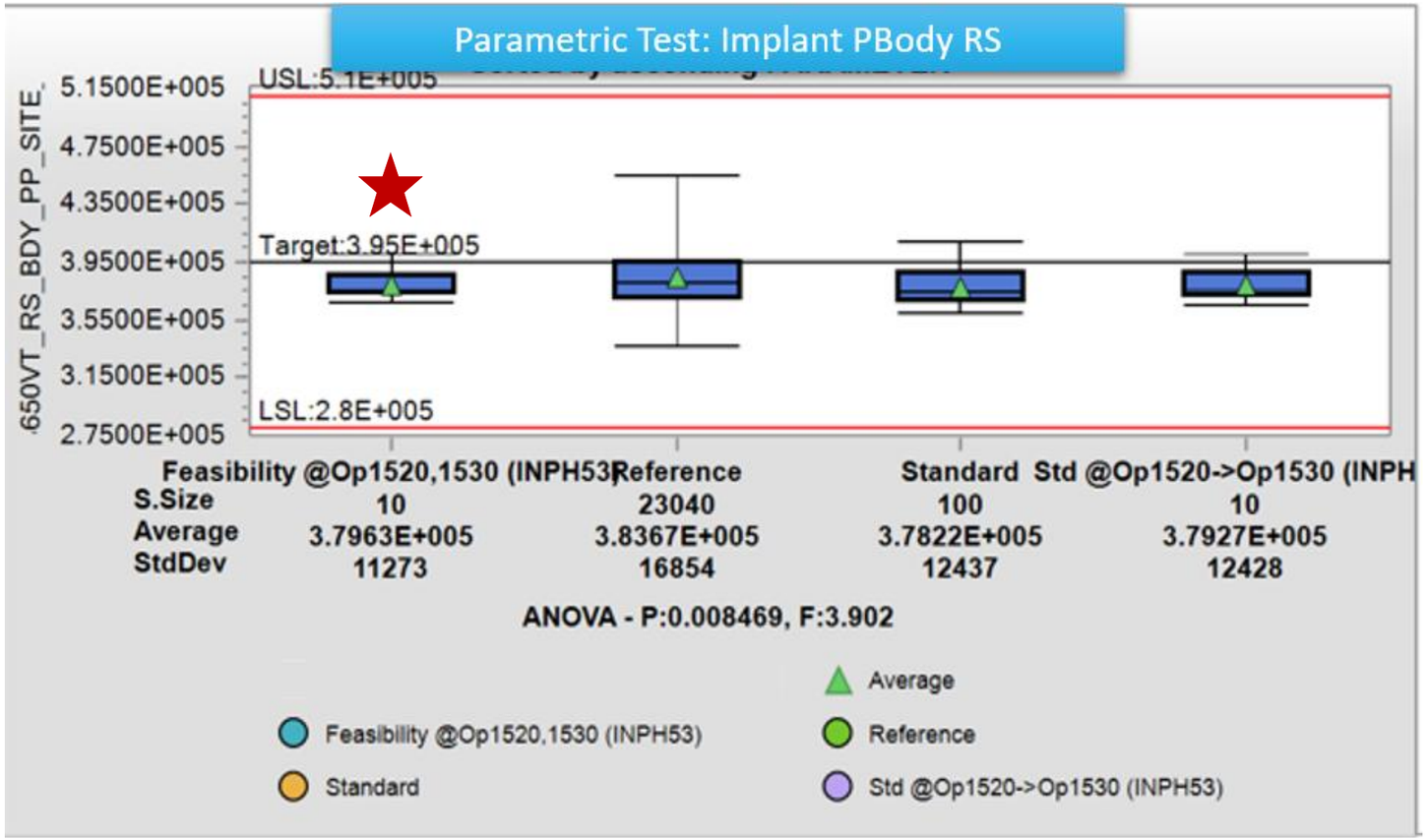
- No change in the trend for N+ Source resistance



★ MUSIC Wafers

Results – Device Wafer Electrical Test

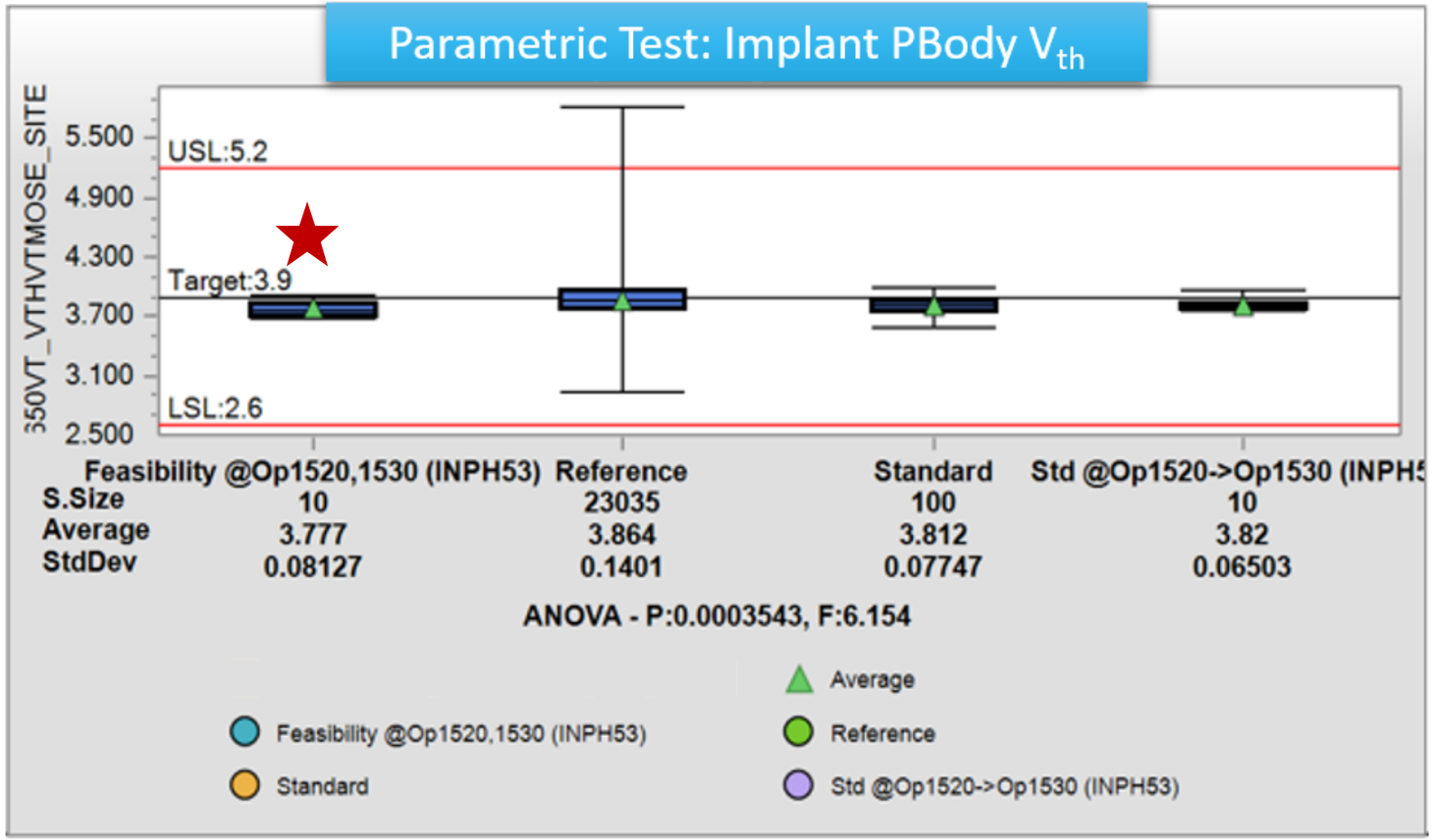
- No change in the trend for body resistance



★ MUSIC Wafers

Results – Device Wafer Electrical Test

- No change in the trend for body threshold voltage



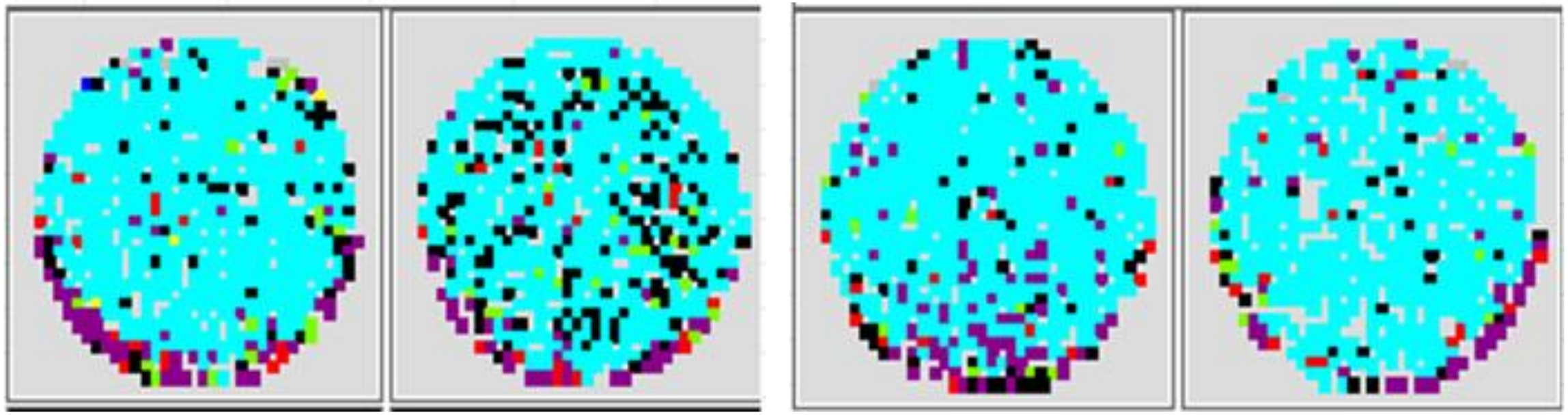
★ MUSIC Wafers

Results – Wafer Yield

- No change in the yield map resulting from the MUSIC protocol
- Light blue = good die

Conventional

MUSIC



Conclusions

- MUSIC is a new technique to complete multiple implants of the same species at different energies, doses, and tilts without removing the wafer from the chuck
- Achieved by varying the voltages in the downstream portion of a high current or medium current beamline, while keeping source, analyzer magnet, quadrupoles, and beam focus parameters constant
- The MUSIC protocol improved throughput of 4 implant sequences by 41-74%, resulting in significantly higher implant capacity
- No effect on bare wafer parameters, electrical test data, or wafer yield was observed
- We conclude that the MUSIC approach is practical for high volume manufacturing