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# Dose Quantification for Low & Ultra Low Energy (ULE) Shallow Implants by SARIS™ Laser Ablation ICP-MS

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# Outline

- Overview of Laser Ablation ICP MS
- Calibration and Quantification
- Accuracy and Precision
- Current Projects
- Summary

# Various LA ICP MS Applications to Date:



## Quantitative Analysis

- **Total dose measurement for ULE ion implants (B, As, P, and Sb)**
- Surface and Bulk analyses of solids (silicon, quartz, SiC, Ceramics ...)
- Determination of TM in thin metal films (Al, Au, Cu, W, HfSiO ...)
- Microscopic/local analysis (solder bumps, Cu interconnect ...)

## Qualitative Analysis

- Particle identification (on wafers, chips, filters, and finished chips)
- Unknowns Identification (defects, discolored components, powders, films, polymeric materials, bonding wires, refractory crystals, residues)

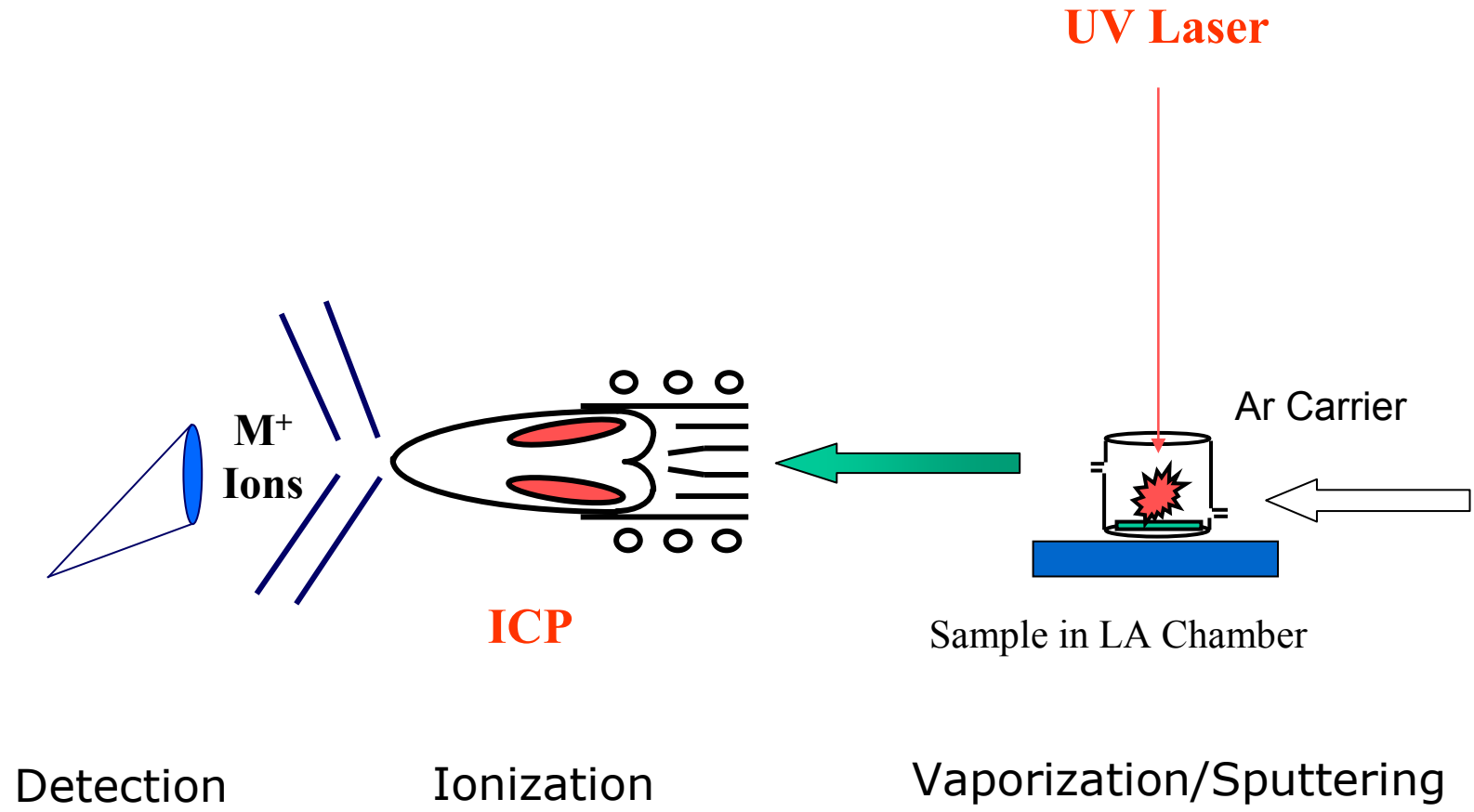
## Lateral Distribution Study

- Line scans (Memory, superconductors ...)
- Mapping around focused ion beam (FIB) cuts to study thermal diffusion

## Depth Profiling

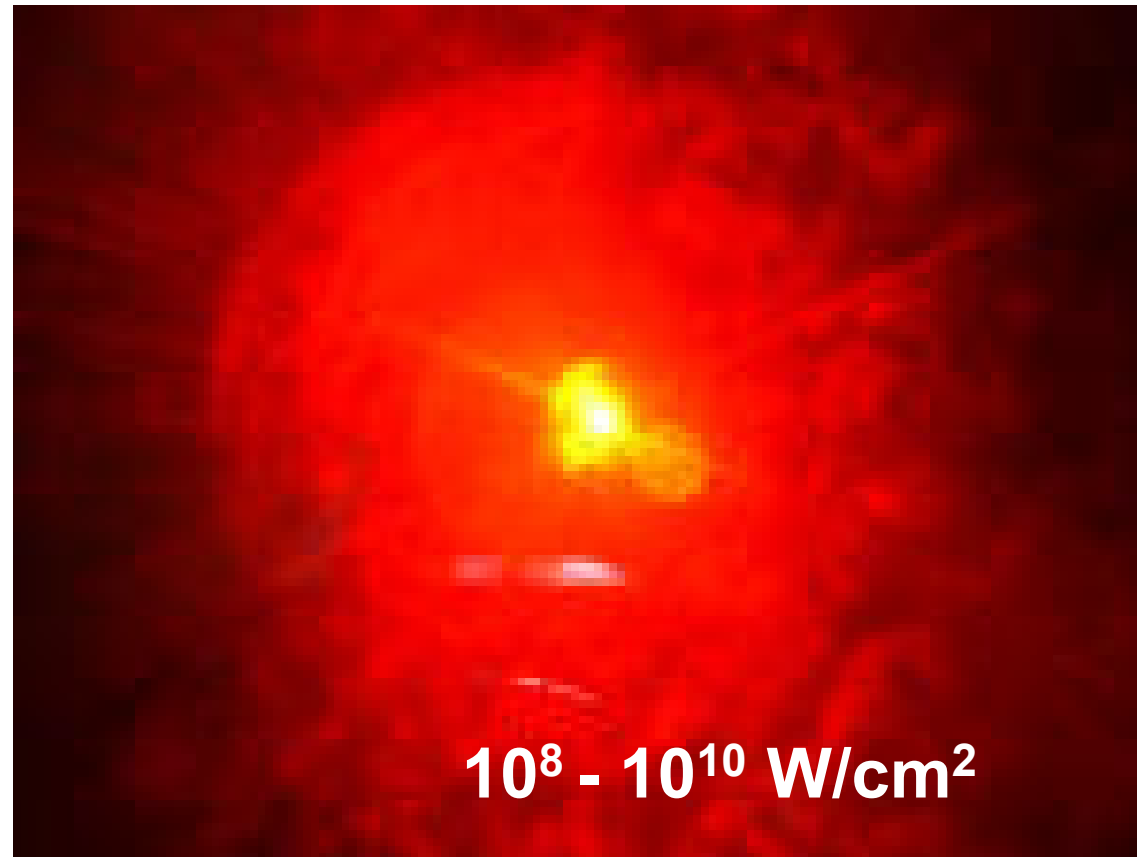
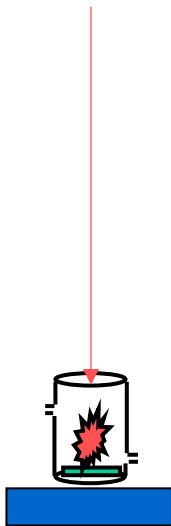
- Metal films, magnetic media, polymeric materials, ceramic insulators ...

# Laser Ablation ICP-MS



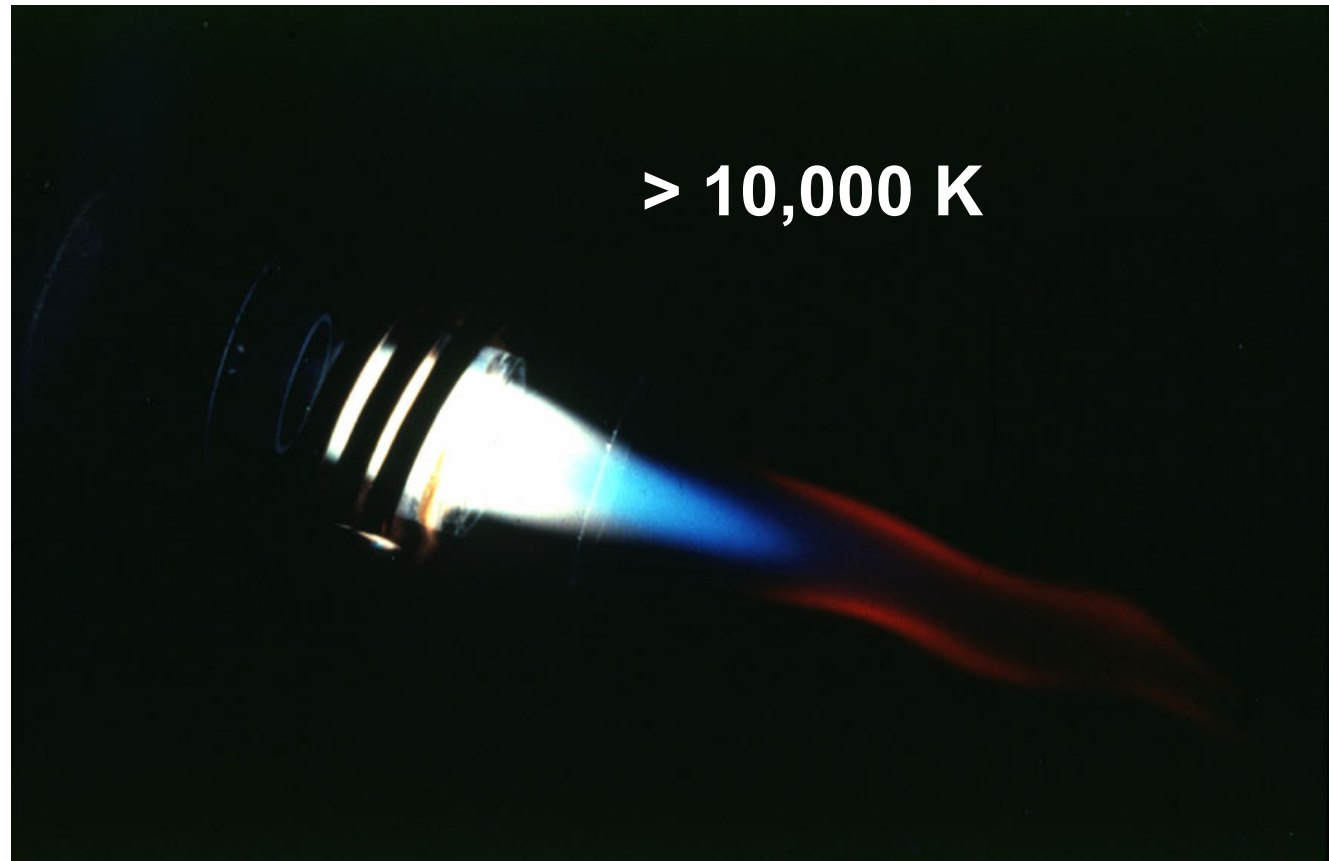
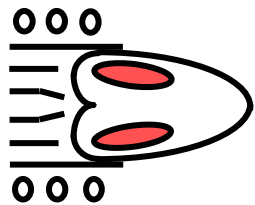
# Laser Induced Plasma

UV Laser



$10^8 - 10^{10} \text{ W/cm}^2$

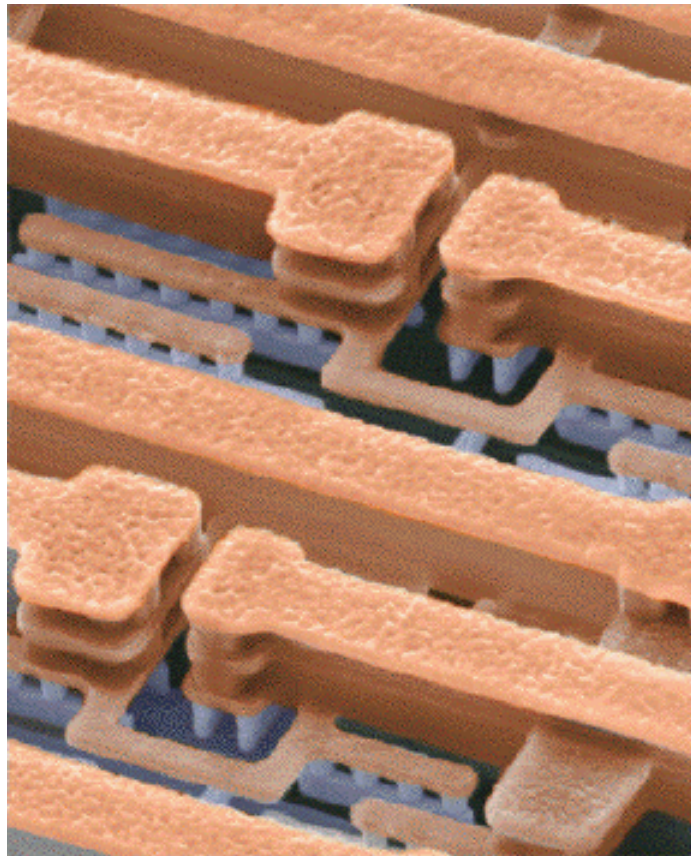
# Inductively Coupled Argon Plasma (ICP)



# Laser Ablation Figures of Merit

- Minimum sampling size 4  $\mu\text{m}$ , can sample 1  $\text{cm}^2$  area
- Laser is only responsible for sampling, the ICP plasma takes care of ionization resulting in less matrix effects and more quantitative signals
- Signal intensities are directly proportional to total dose of implanted ions. Simple and linear calibration curves can be constructed for analysis
- LA ICP-MS dose results are not affected by:
  - ✓ implantation energy used
  - ✓ annealing condition of wafers, and
  - ✓ presence of high concentration fluorine in silicon
  - ✓ Depth resolution of the technique

# Quantitation with LA ICP-MS is very Good



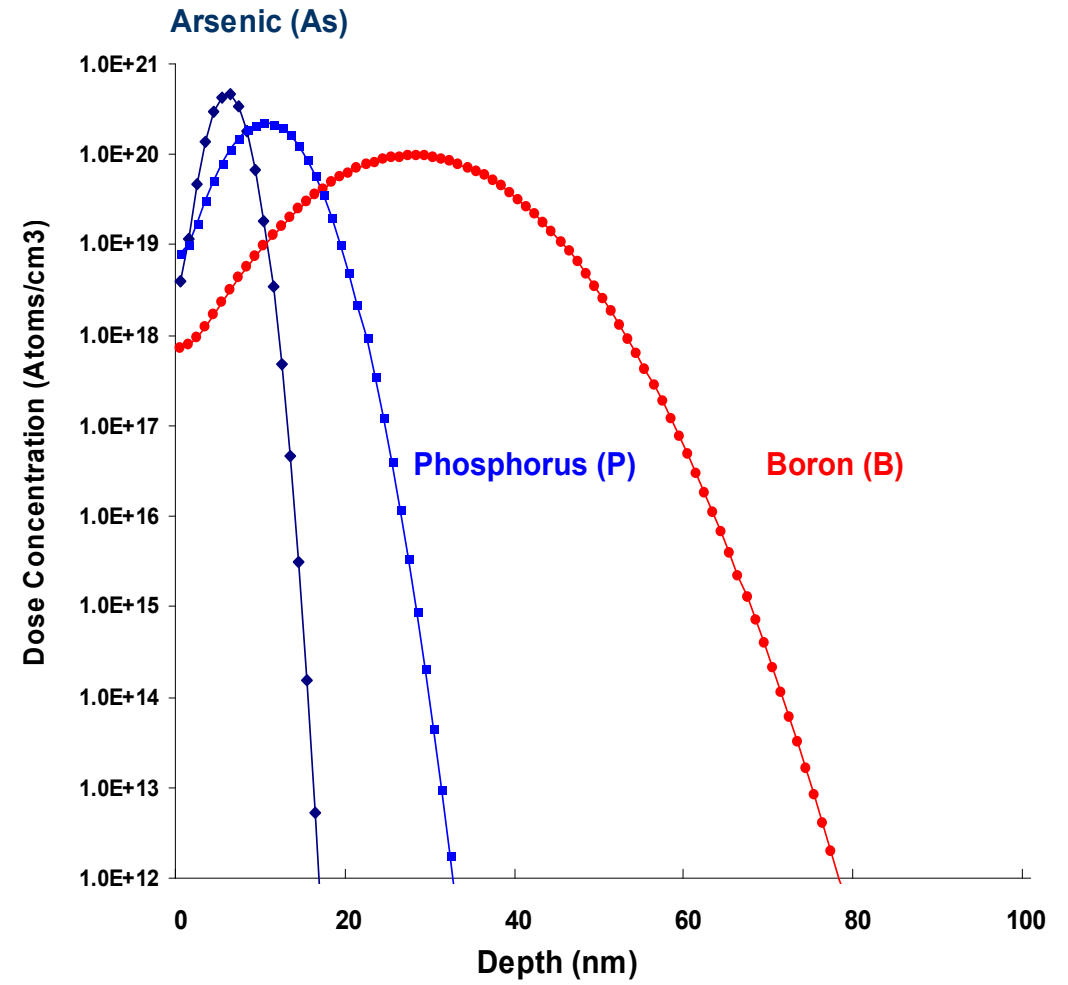
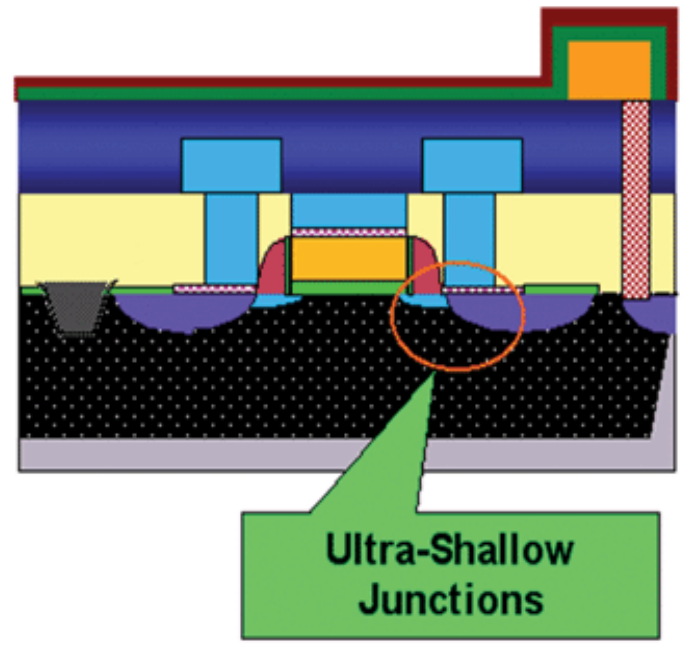
**Analysis of copper interconnect for metal additive by LA ICP-MS and wet method**

<b>Analysis Methods</b>	<b>Sample1</b>	<b>Sample2</b>
<b>LA ICP-MS</b>	<b>0.56%</b>	<b>0.44%</b>
<b>SD (n=2)</b>	<b>0.03%</b>	<b>0.03%</b>
<b>Wet Chemistry*</b>	<b>0.56%</b>	<b>0.45%</b>

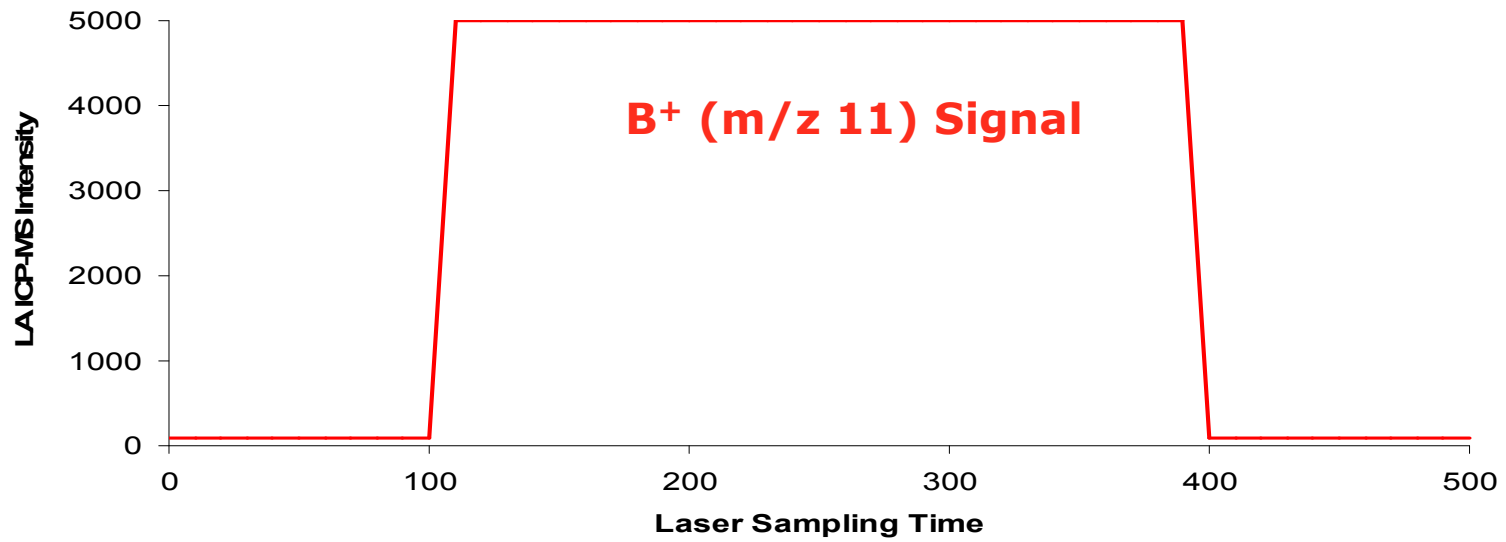
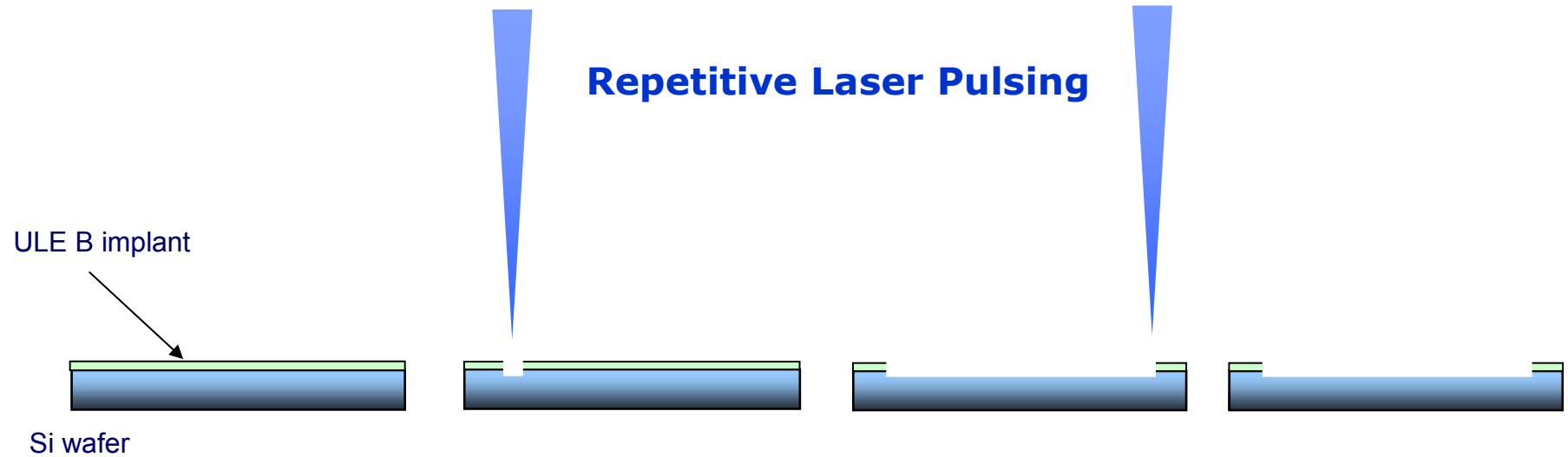
**\* Acid digestion followed by ICP-OES analysis**



# Ultra Low Energy (ULE) Dose Measurement for Ultra Shallow Junction Ion Implantation

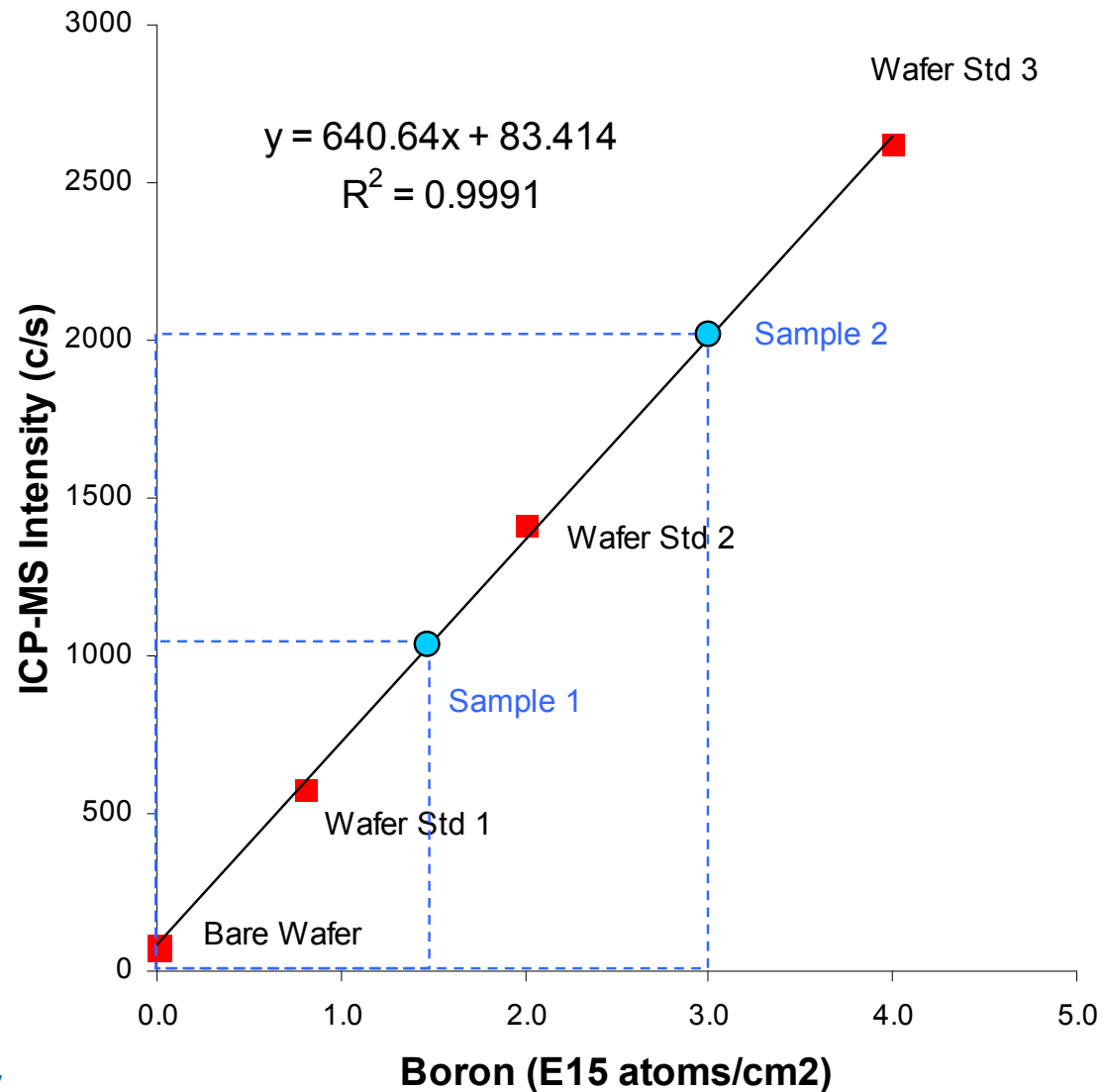


# How is Laser Ablation Sampling Performed?



# Calibration & Analysis for ULE B<sup>+</sup> Implants

## Laser Ablation Provides $Y = aX + b$ (EASY)



# ULE Boron Dose Measurements

Wafer No.	Expected (ions/cm <sup>2</sup> )	Found (ions/cm <sup>2</sup> )
1	8 E14	8.3 E14
2	2 E15	2.1 E15
3-1	4 E15	4.2 E15
3-1	4 E15	4.4 E15
3-3	4 E15	4.3 E15
3-4	4 E15	4.2 E15
3-5	4 E15	4.3 E15
	<b>Average</b>	<b>4.3 E15</b>
	<b>S.D.</b>	<b>8.9 E13</b>
	<b>R.S.D.</b>	<b>2.1 %</b>

Excellent Accuracy

Good Precision

# How do we measure precision?

Loading and Analysis

Loading and Analysis

Loading and Analysis

Loading and Analysis

Loading and Analysis

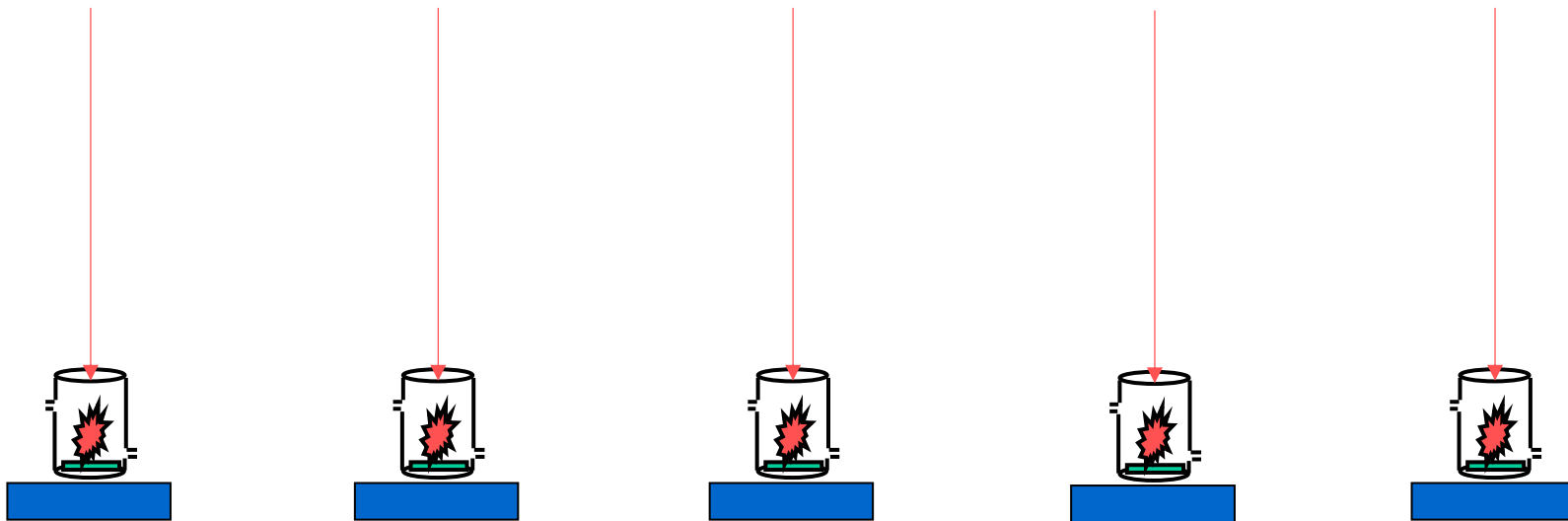
**UV Laser**

**UV Laser**

**UV Laser**

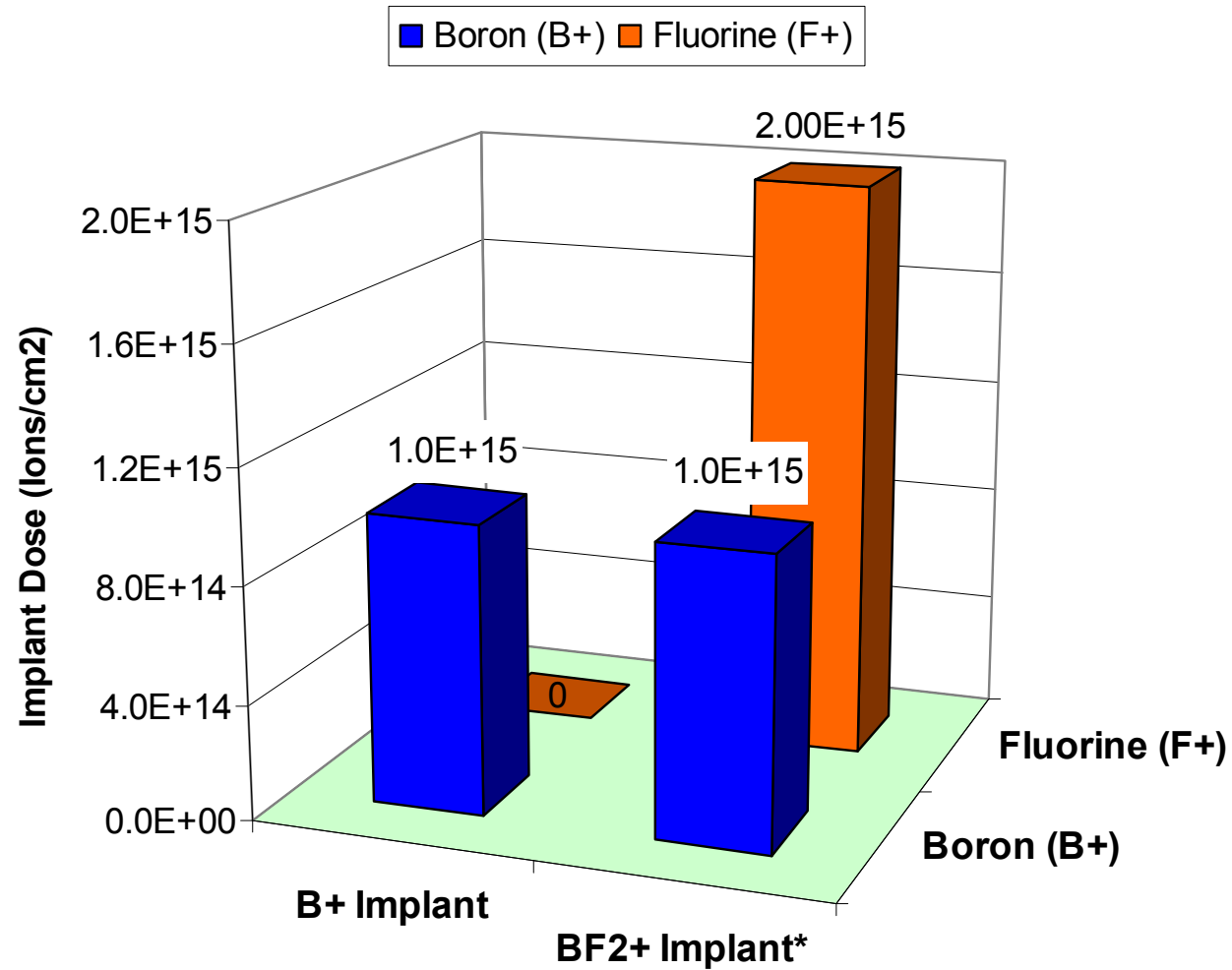
**UV Laser**

**UV Laser**



5 separate Loadings and Analyses

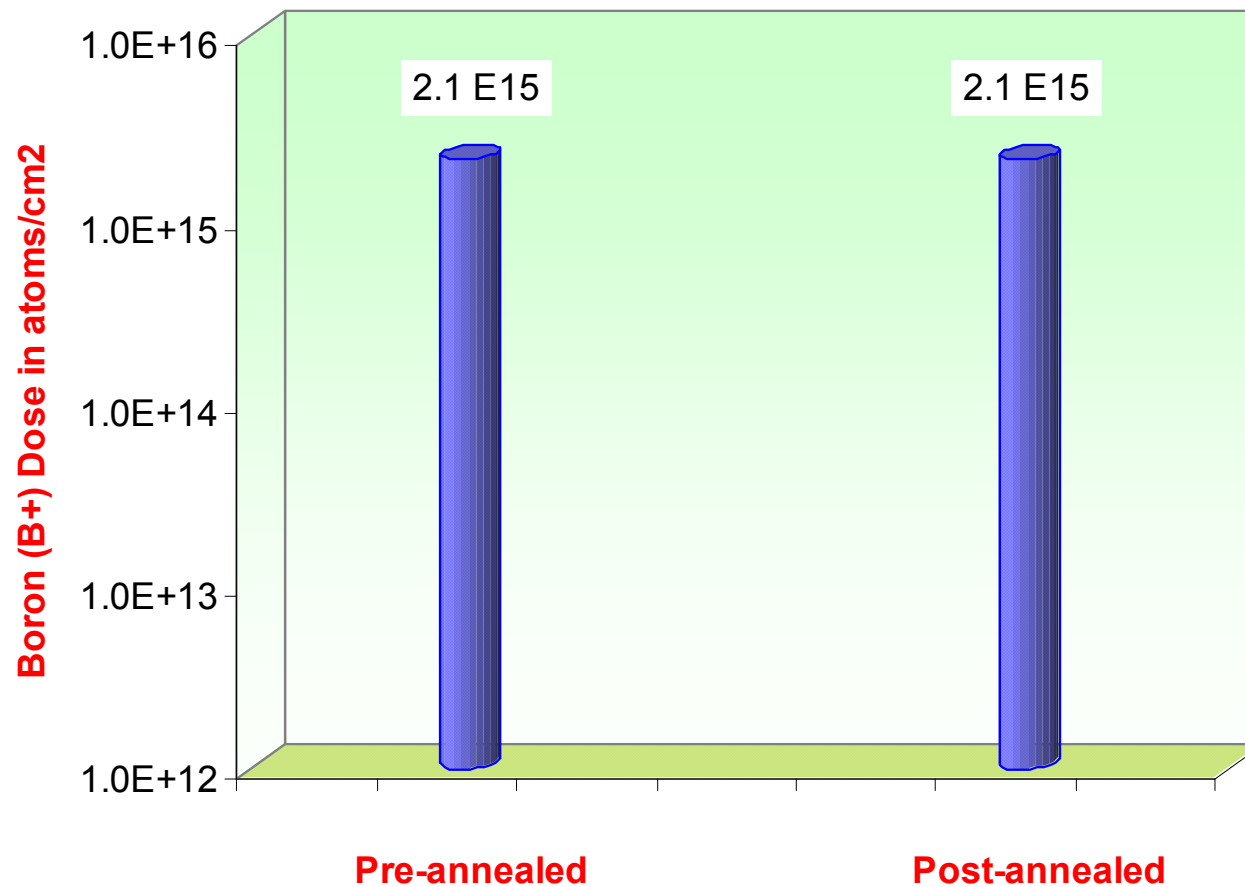
# High-Dose BF<sub>2</sub> Implants: No problem!



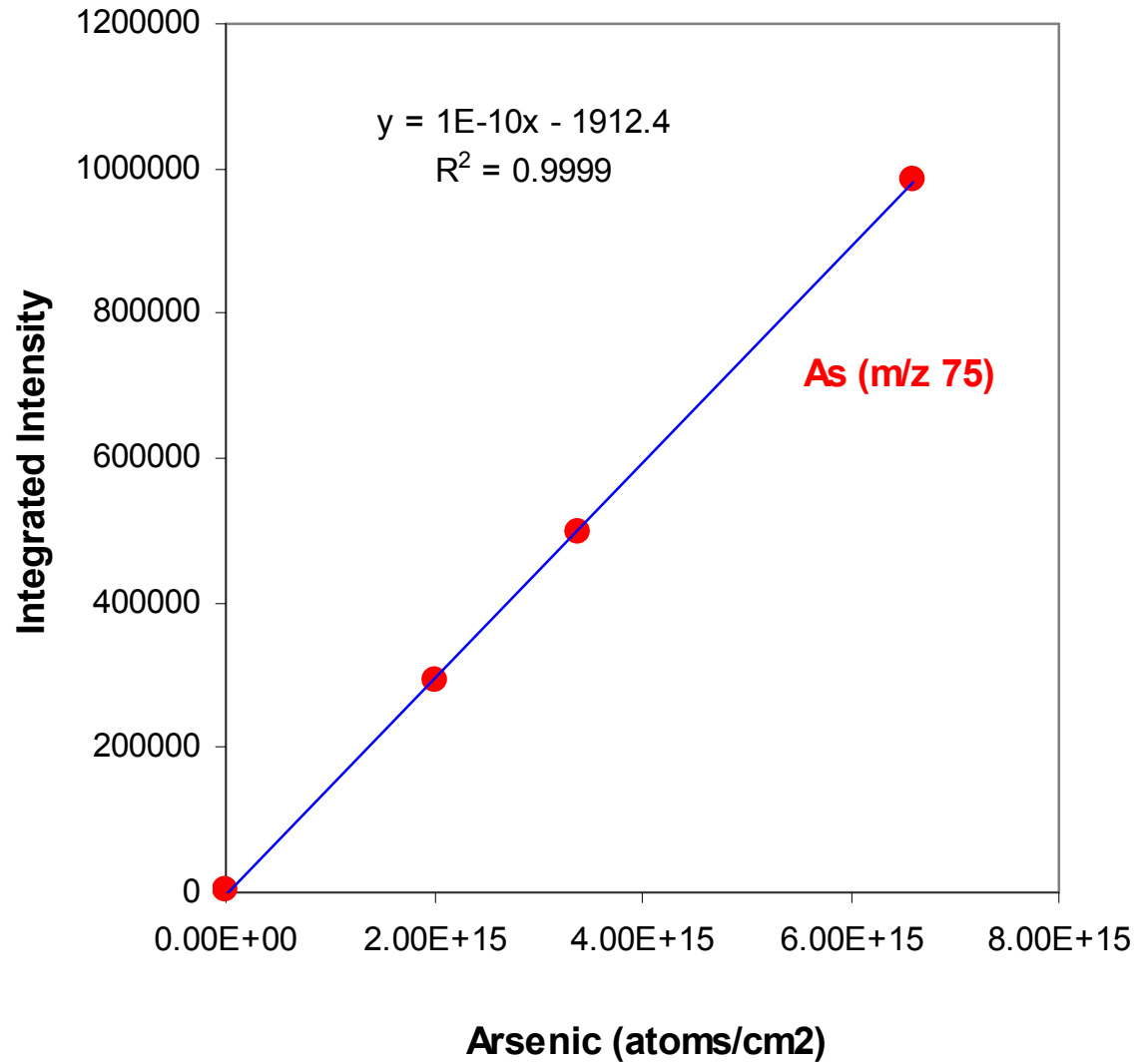
\* F+ doses were provided by ion implantation company

# Effect of Post-Annealing: No issue!

Identical doses for both pre and post annealed wafers



# Calibration for As<sup>+</sup> Implants

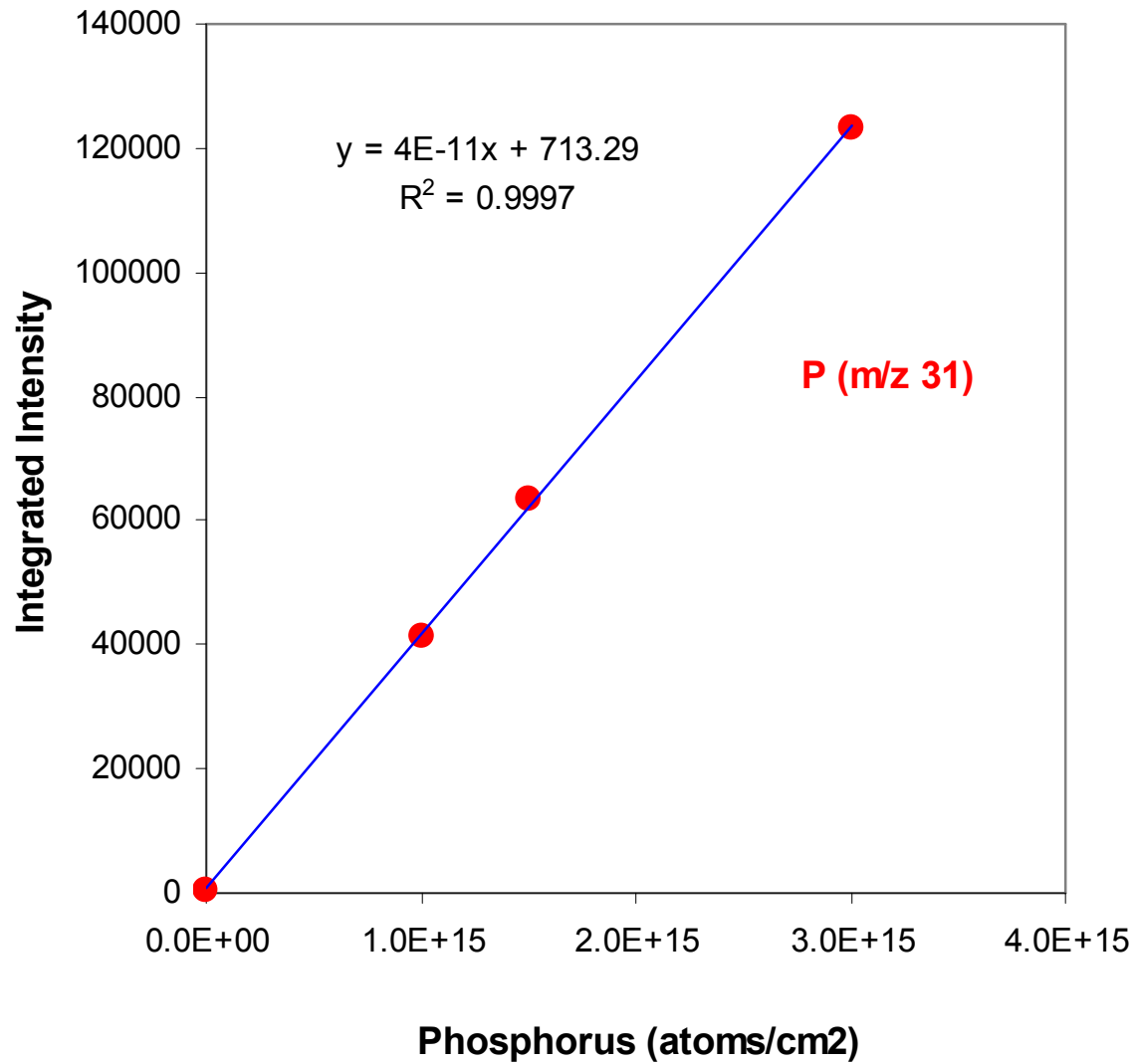




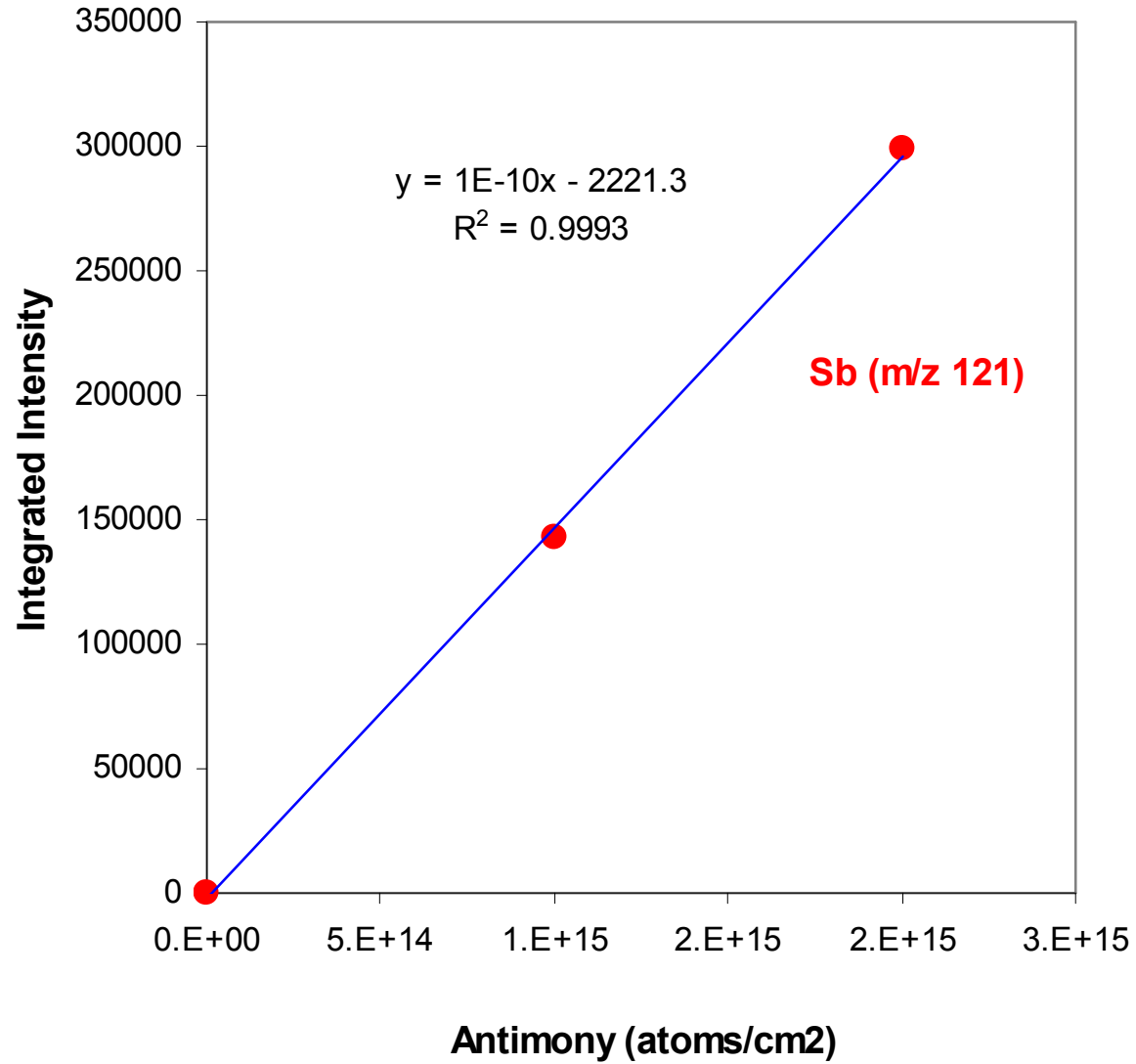
# Low Energy As<sup>+</sup> Dose Measurements

Wafer No.	Expected (ions/cm <sup>2</sup> )	Found (ions/cm <sup>2</sup> )
1	6.5 E15	6.5 E15
2	6.5 E15	6.8 E15
3	6.5 E15	6.3 E15
4	6.5 E15	6.6 E15
5	6.5 E15	6.9 E15
	<b>Average</b>	<b>6.6 E15</b>
	<b>S.D.</b>	<b>2.2 E14</b>
	<b>R.S.D.</b>	<b>3.4 %</b>

# Calibration for P<sup>+</sup> Implants



# Calibration for Sb<sup>+</sup> Implants

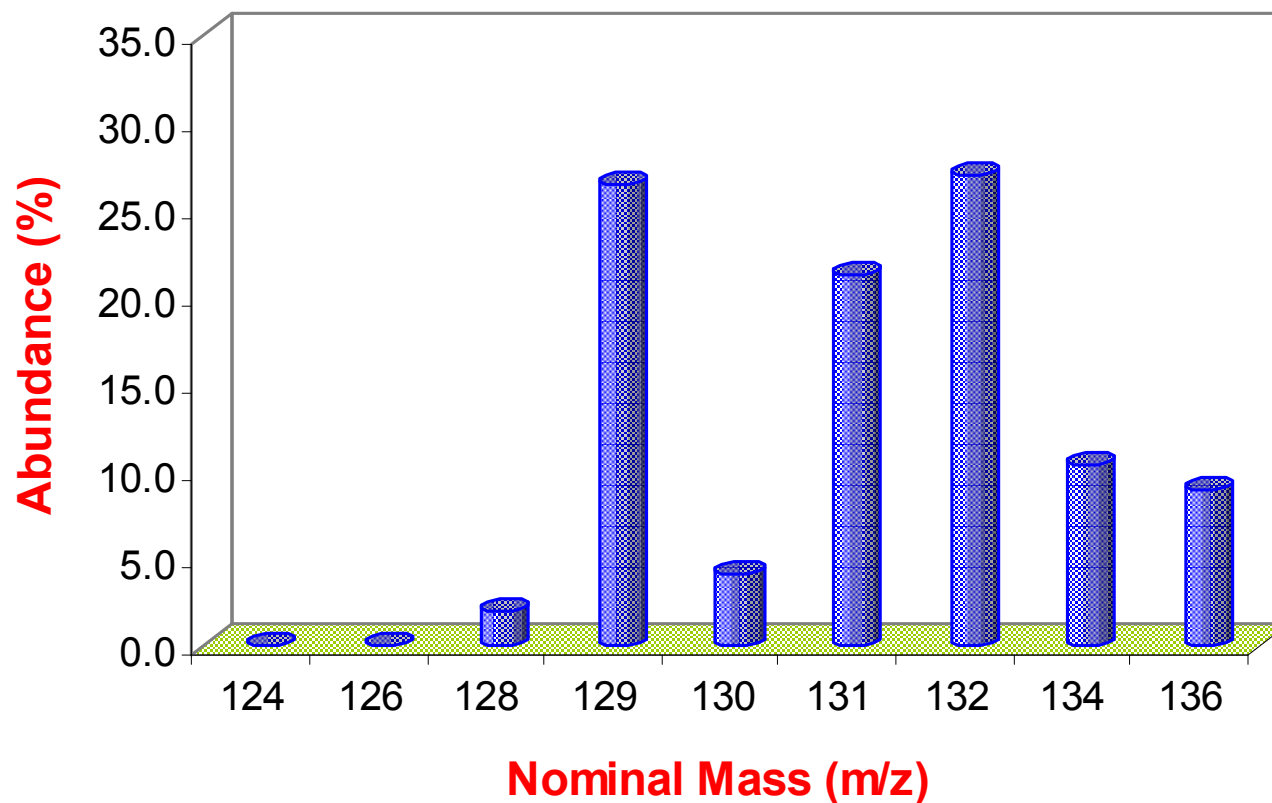


# Quantitative Analysis of Trace Elements on implanted Wafer Surfaces

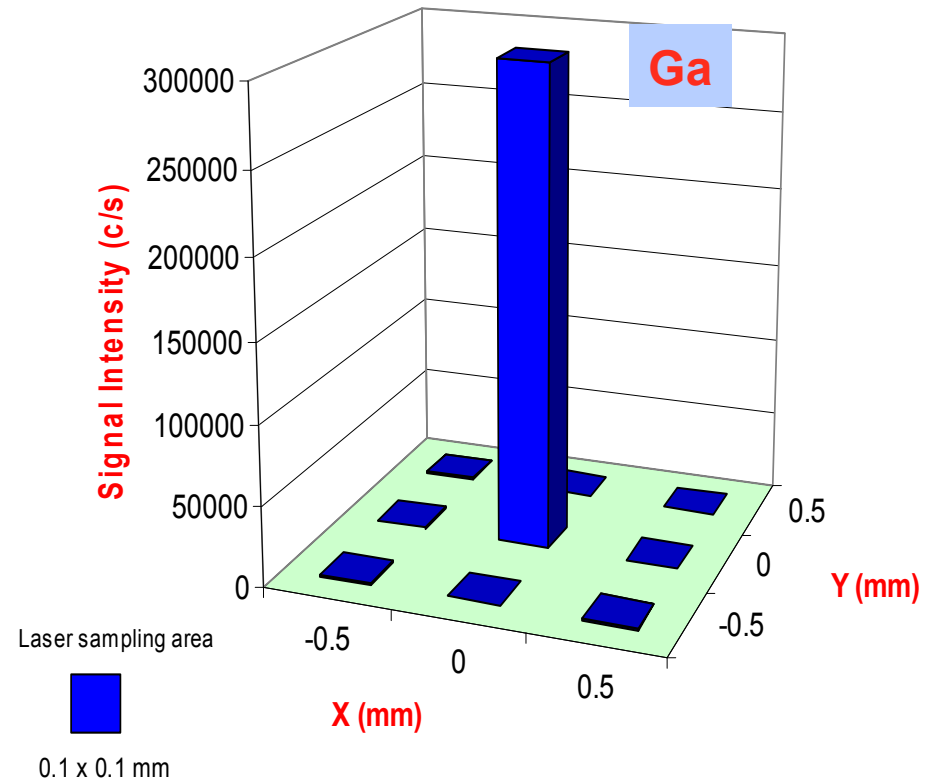
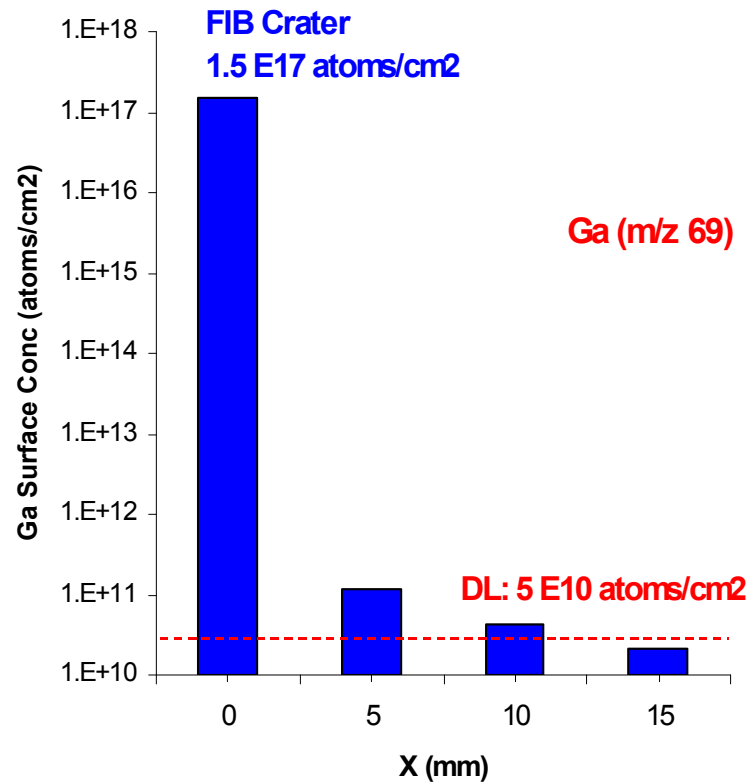
Element	DLs	Element	DLs
	atoms/cm <sup>2</sup>		atoms/cm <sup>2</sup>
<b>Ag</b>	5.0E+10	<b>La</b>	5.0E+09
<b>Al</b>	5.0E+12	<b>Li</b>	6.0E+12
<b>As</b>	5.0E+11	<b>Mg</b>	1.0E+12
<b>Au</b>	5.0E+10	<b>Mn</b>	2.0E+11
<b>B</b>	5.0E+13	<b>Mo</b>	2.0E+11
<b>Ba</b>	5.0E+09	<b>Na</b>	5.0E+11
<b>Be</b>	2.0E+13	<b>Ni</b>	7.0E+11
<b>Bi</b>	1.0E+10	<b>P</b>	5.0E+13
<b>Ca</b>	1.0E+14	<b>Pb</b>	1.0E+10
<b>Cd</b>	1.0E+11	<b>Sb</b>	5.0E+10
<b>Ce</b>	1.1E+10	<b>Sc</b>	1.0E+13
<b>Co</b>	1.0E+11	<b>Sn</b>	2.0E+11
<b>Cr</b>	5.0E+11	<b>Sr</b>	2.0E+10
<b>Cu</b>	5.0E+11	<b>Ta</b>	1.0E+10
<b>Fe</b>	5.0E+13	<b>Ti</b>	2.0E+12
<b>Ga</b>	5.0E+11	<b>Tl</b>	2.0E+10
<b>Ge</b>	2.0E+11	<b>V</b>	2.0E+11
<b>Hg</b>	5.0E+11	<b>W</b>	5.0E+10
<b>In</b>	2.0E+10	<b>Zn</b>	1.0E+12
<b>K</b>	2.0E+13	<b>Zr</b>	3.0E+10

# Dose measurement of Xenon Implants

## Natural Abundances of Xe Isotopes



# Dose Measurement of Gallium for Focused Ion Beam (FIB) Crater



# Summary

- LA ICP-MS signal intensity is directly proportional to total dose of an implanted ion in silicon.
  - ✓ Use of simple and linear calibration curves enhances analysis accuracy.
  
- Use of NIST traceable standards:
  - ✓ LA ICP-MS results can be used to calibrate ion implanters operated in different fabs & foundries, and
  - ✓ correlate total doses used in various processes.
  
- LA ICP-MS has been shown to be both a complementary and supplementary technique to SIMS, XRF and SEM-EDX analyses.