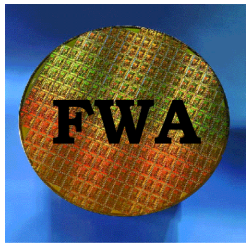

Full Wafer Analysis of Ion Implanted Wafers and Thin Films by Low Energy X-Ray Emission Spectrometry (LEXES)

Charles J. Hitzman and Charles A. Evans, Jr.
Full Wafer Analysis
2326 Walsh Avenue, Bldg. H, Santa Clara, CA 95051
Phone (408) 986-9200 Fax (408) 986-8500
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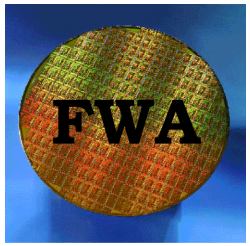
http://www.fullwaferanalysis.com



Full Wafer Analysis
What is LEXES?

Technique

Low

Energy

X-ray

Emission

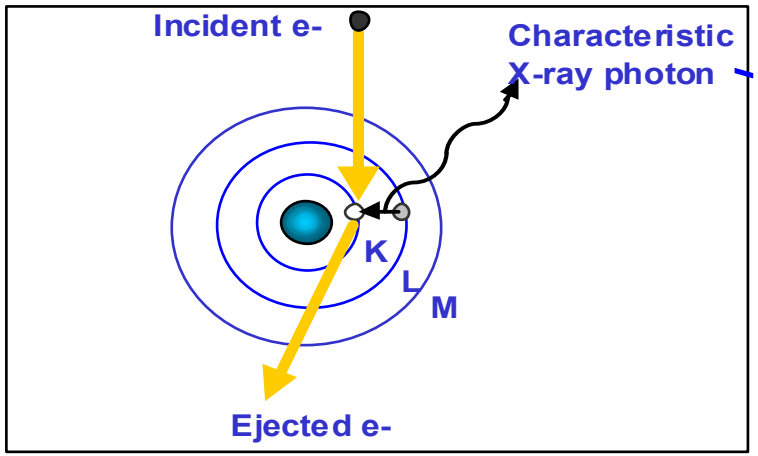
Spectrometry

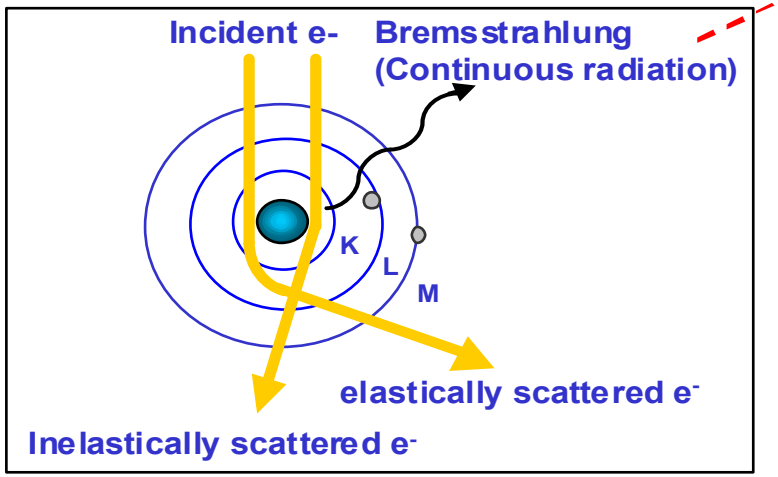
Instrument

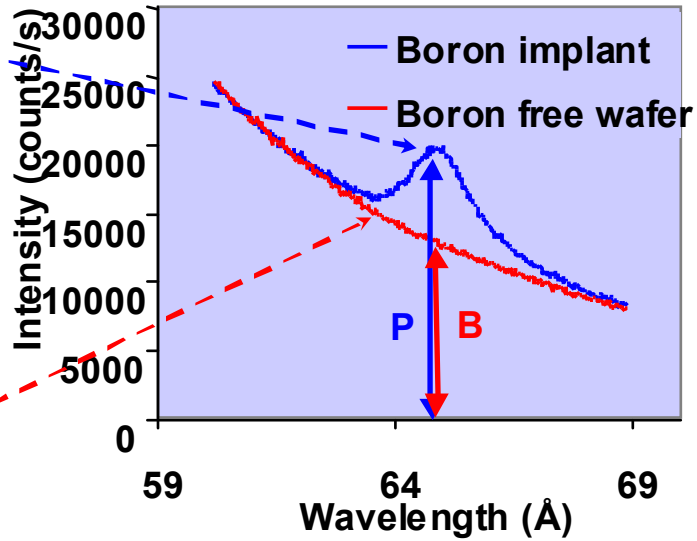
Shallow Probe 300 (SP300)
by CAMECA Instruments

Theory of the Analytical Method

Atomic Processes Involved in LEXES



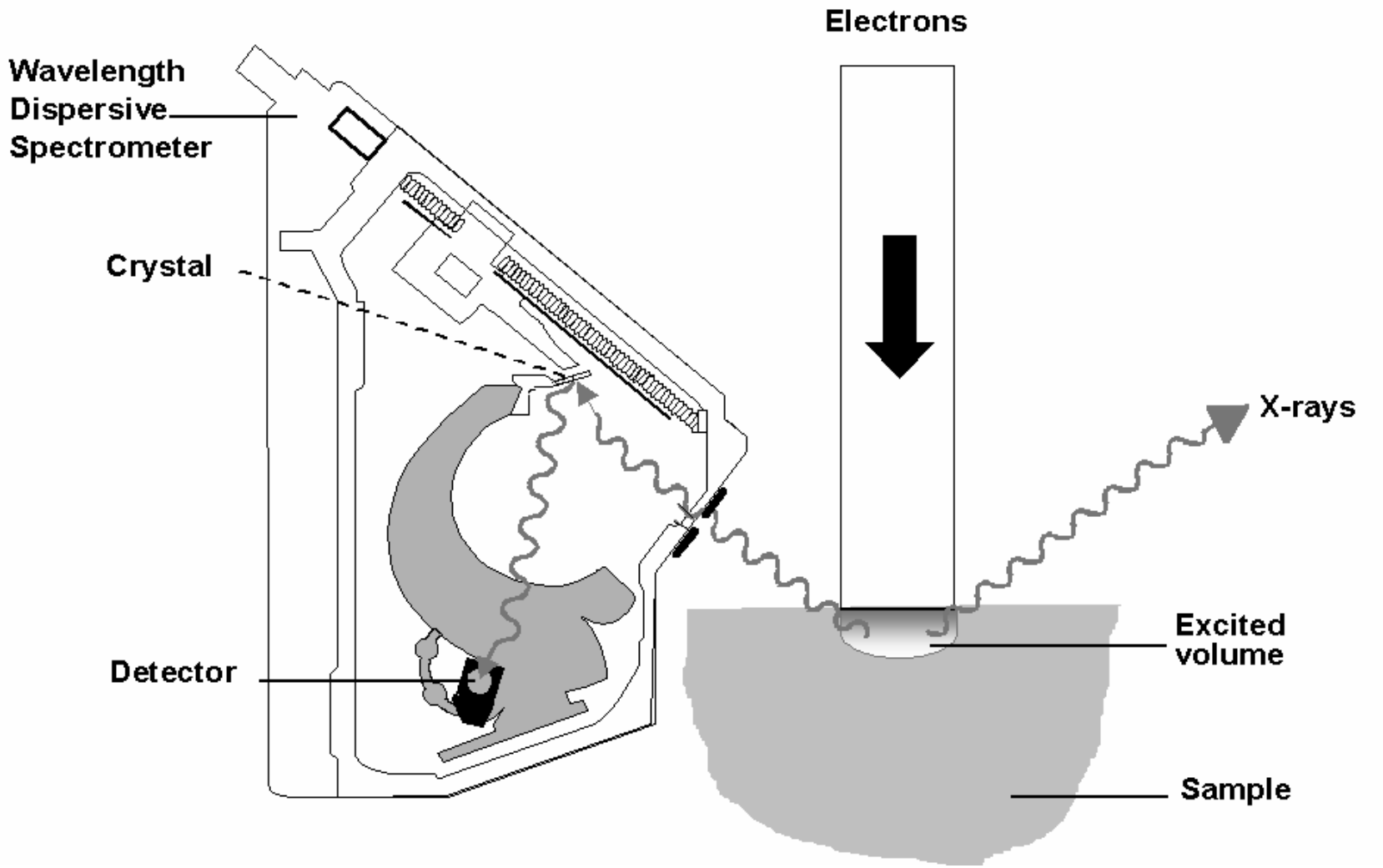




IElement (cps) **= P - B**

Intensity at Element X-ray position is proportional to dose or film thickness.

X-ray production and detection in LEXES

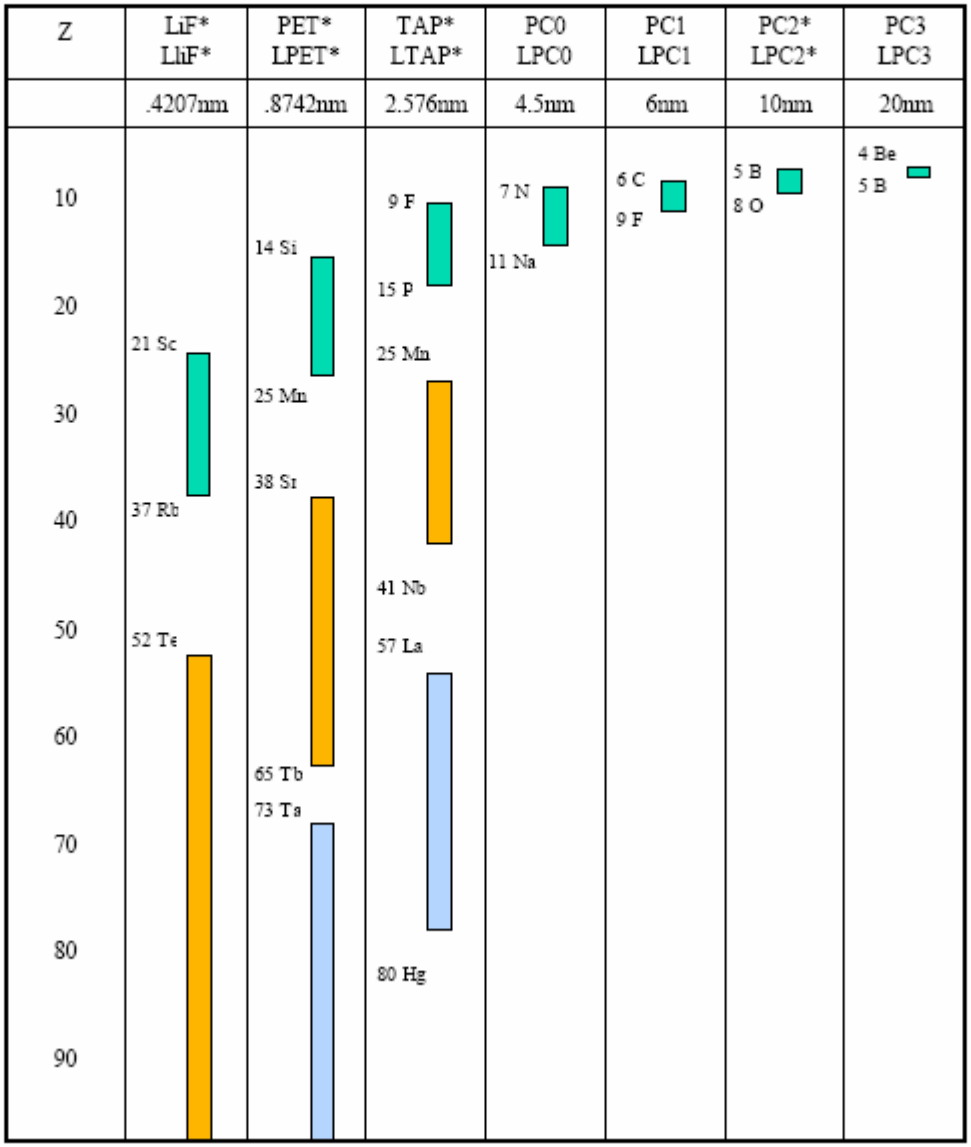


SX 100 Crystals and their wavelength coverage

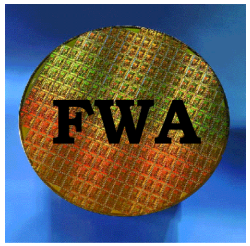
CAMECA

* Most commonly used crystals

K Lines
L Lines
M Lines

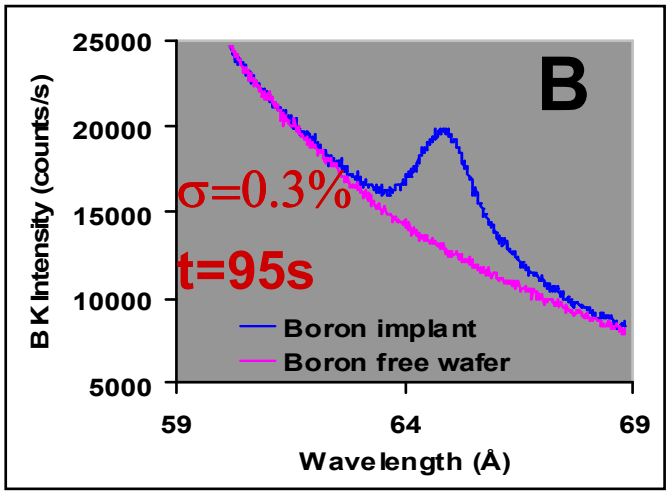


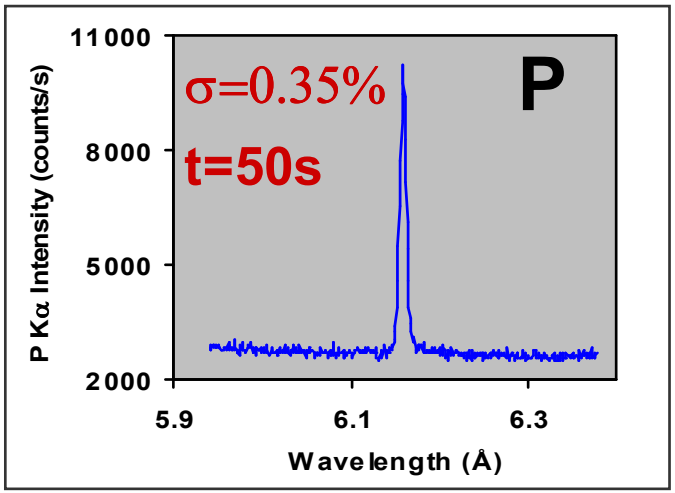
2002/53004/MO/CL January 2002

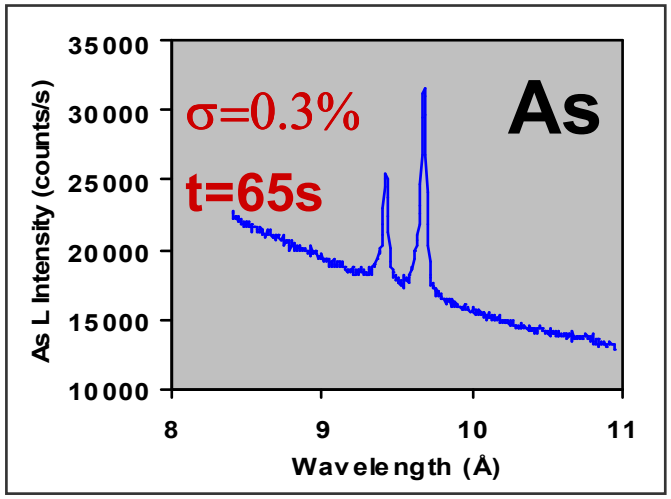


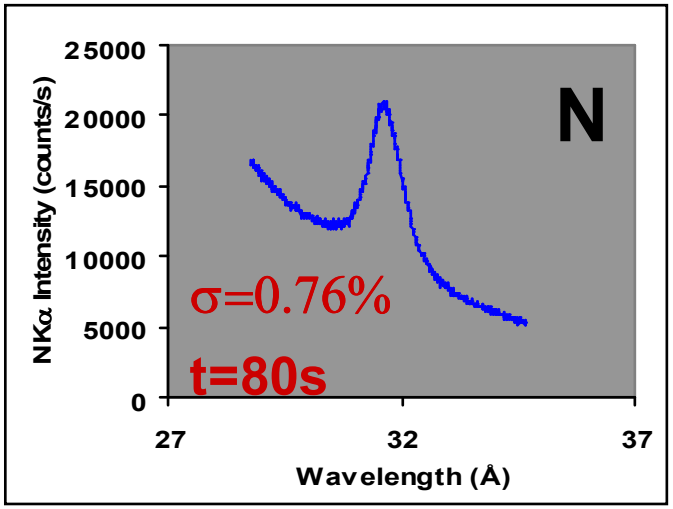
Qualitative Results

Examples of X-ray Spectra Acquired on 1E15 at/cm^2 Shallow Implant



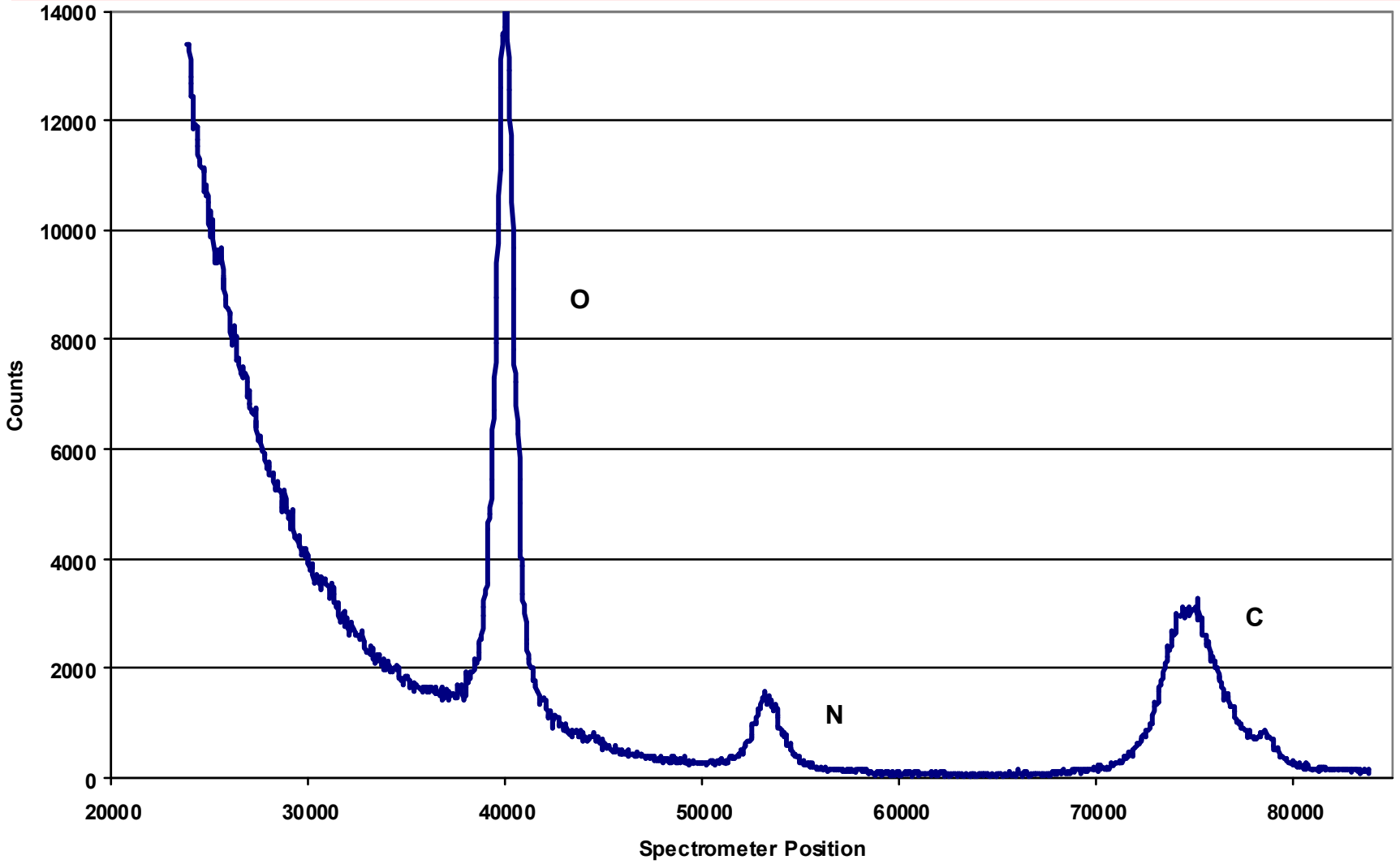


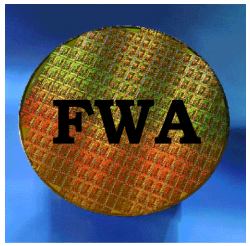




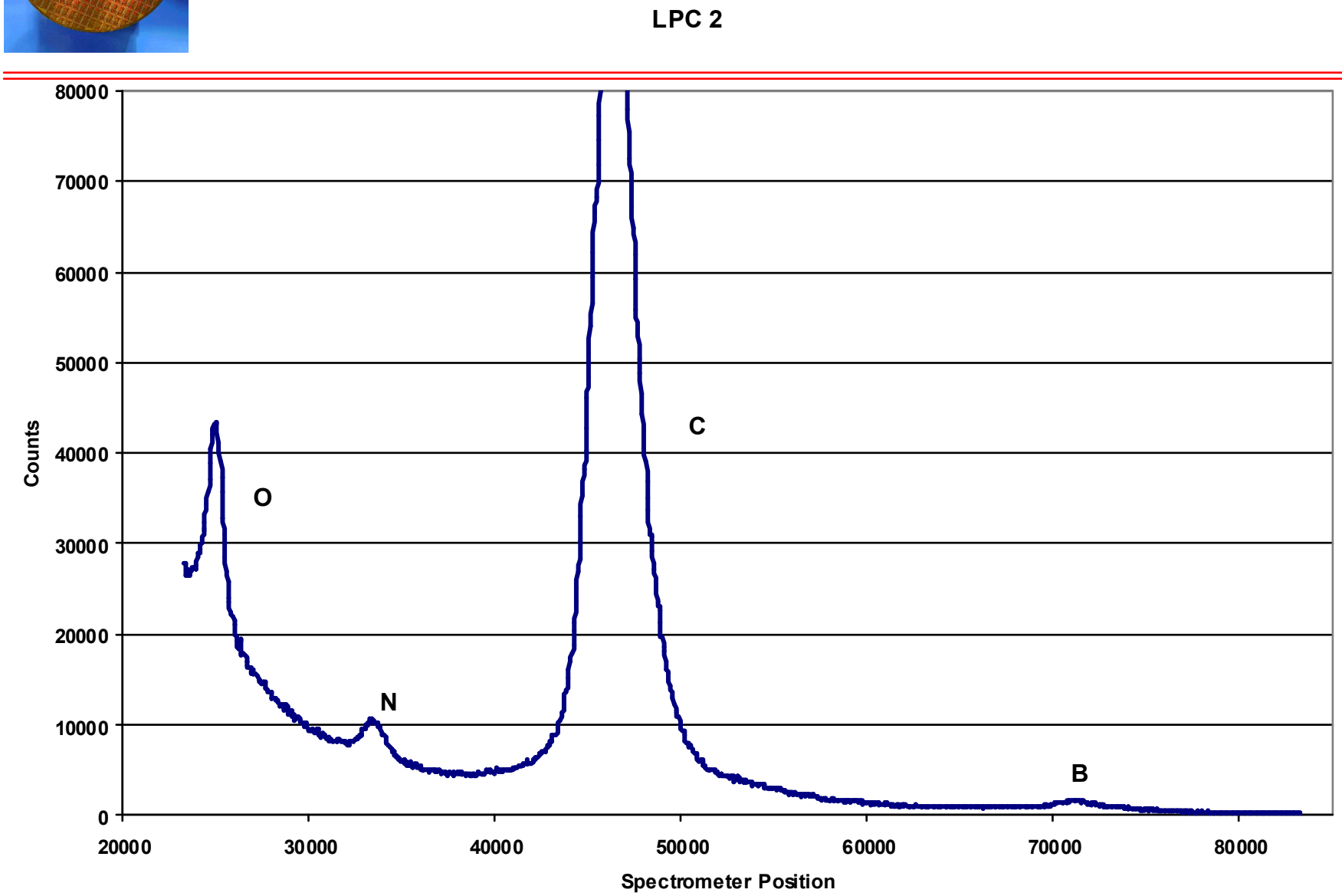
Examples of X-ray Spectra

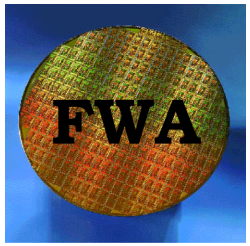
LPC 1





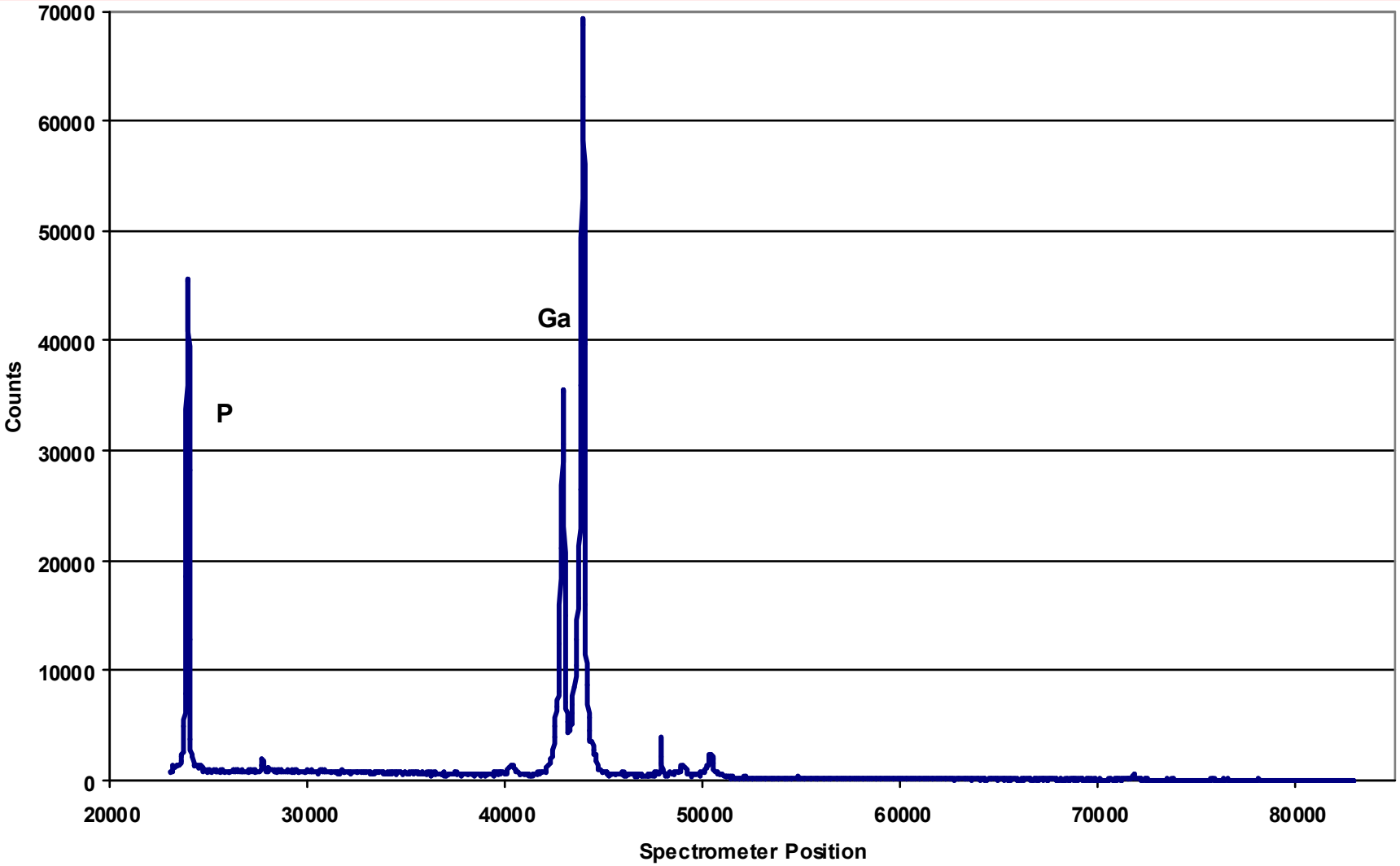
Examples of X-ray Spectra





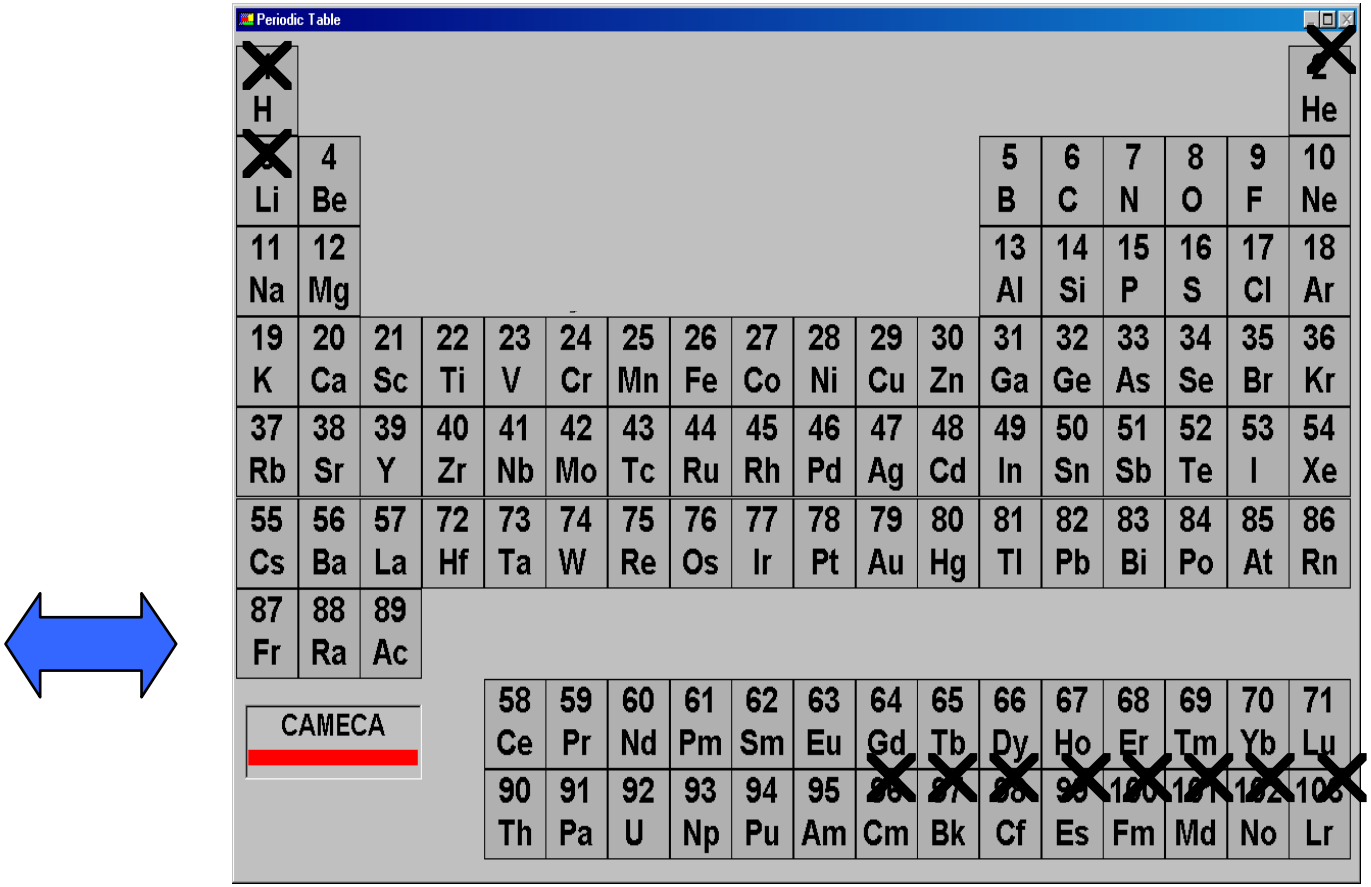
Examples of X-ray Spectra

LTAP

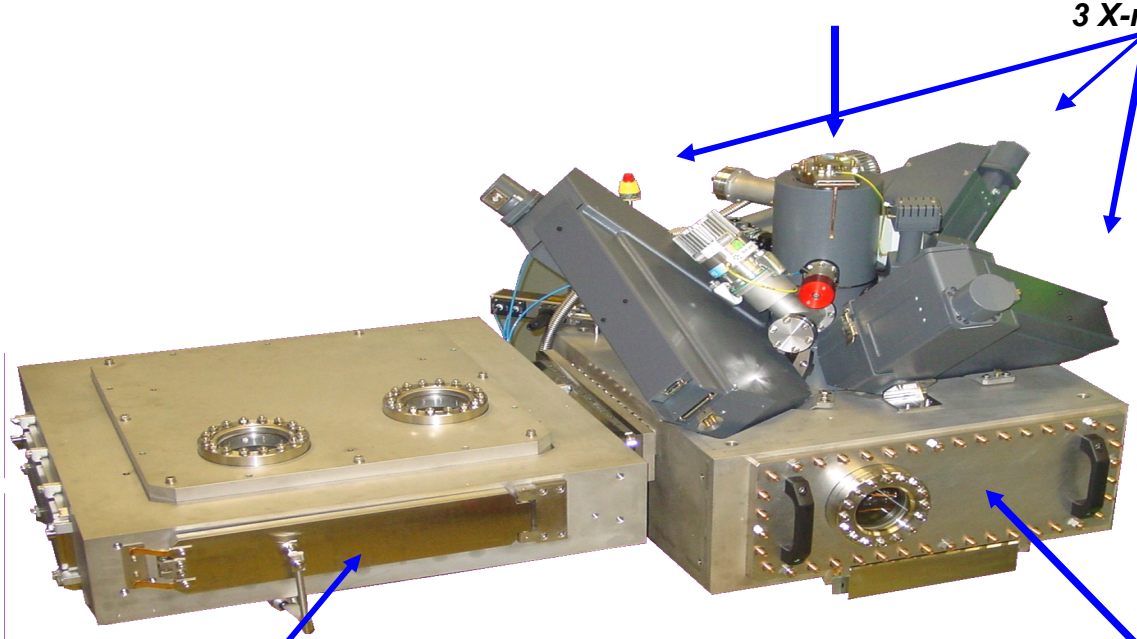


CAMECA Shallow Probe Range Element

Almost all of the periodic table can be analyzed.

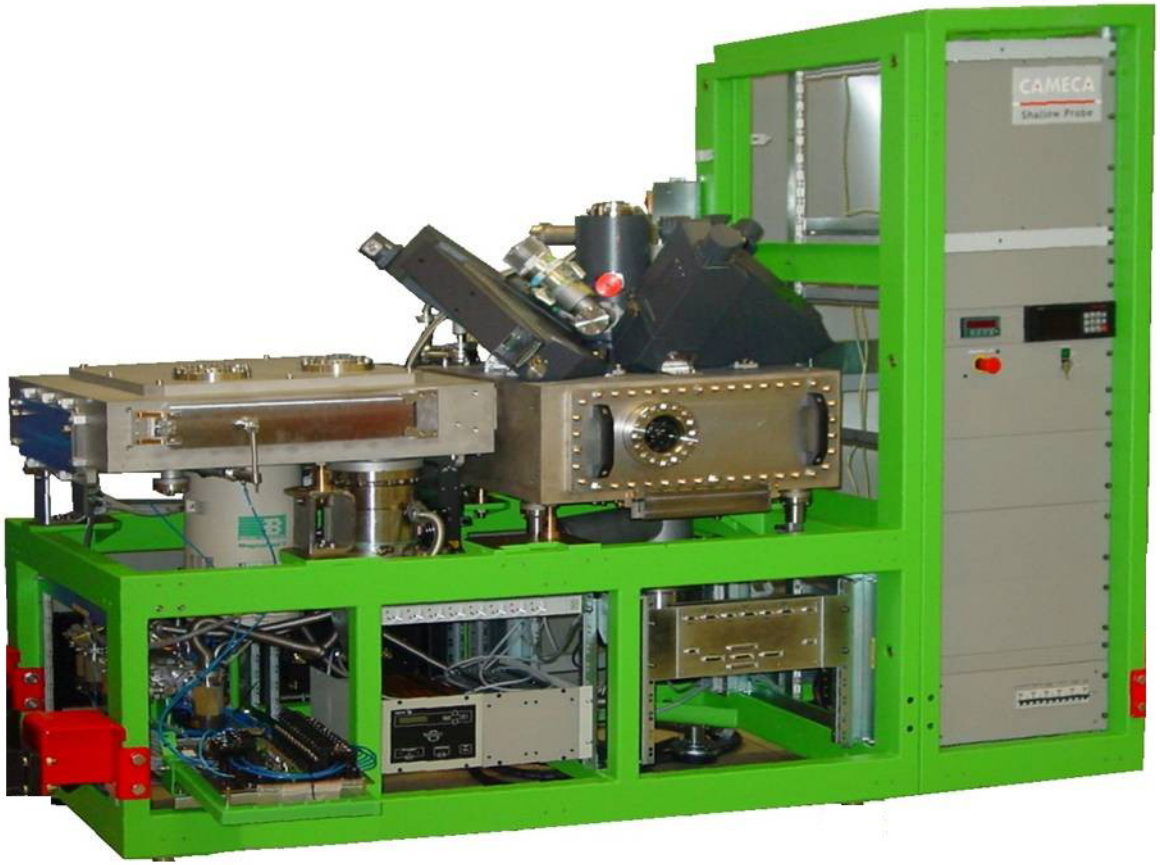


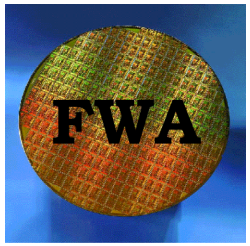
CAMECA Shallow Probe 300
Instrument Body



CAMECA Shallow Probe 300

Quantitative Metrology Tool for Thin Films and Shallow Implants

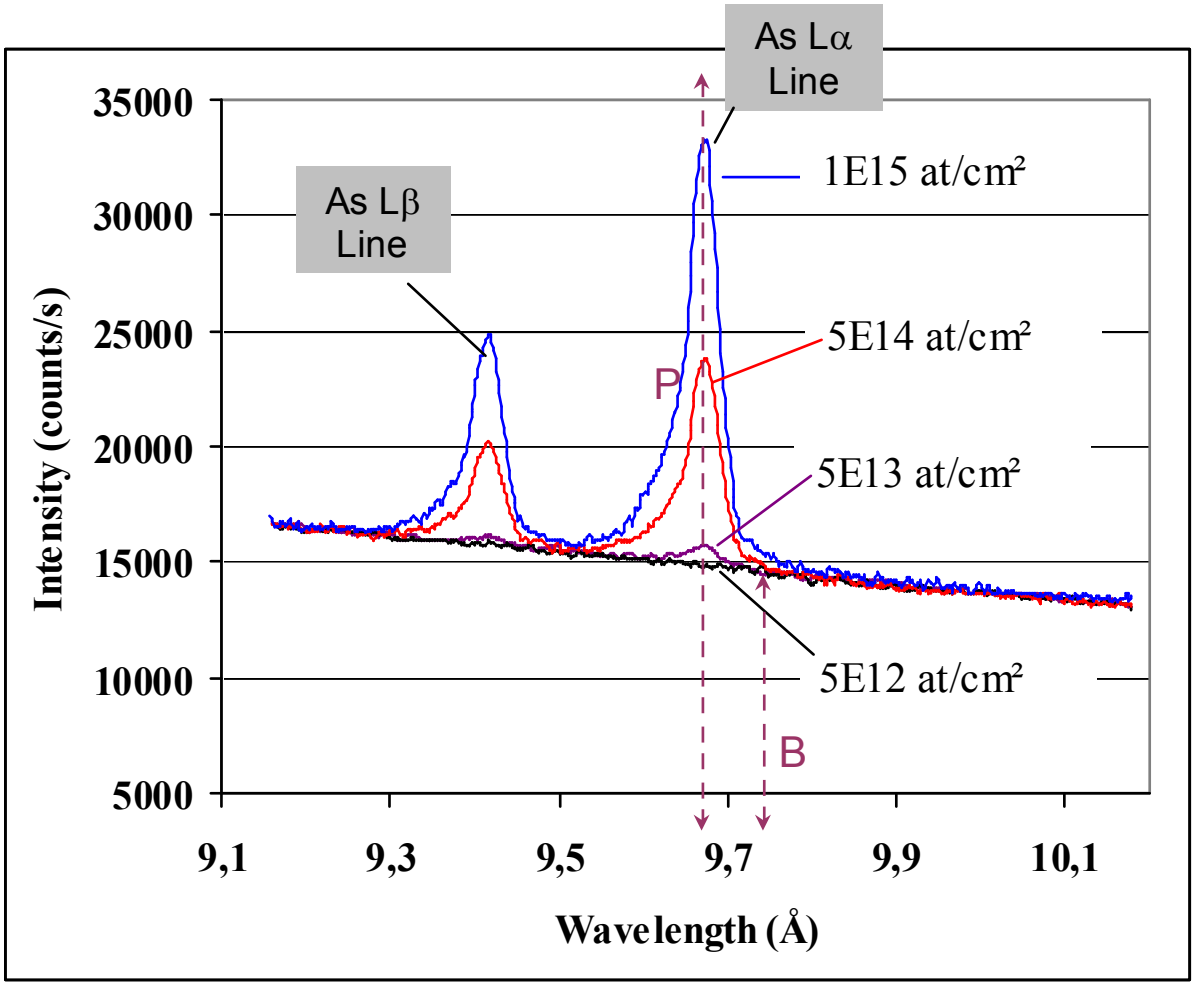




The LEXES Technique

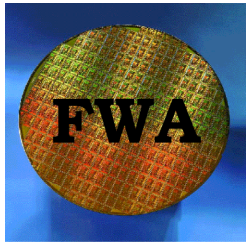
CAMECA Shallow Probe 300 applied to the dosimetry of ULE to medium energy implant

Signal Variation with Dose, and Illustration of Detection Limit Issues 5keV As Implants in Si



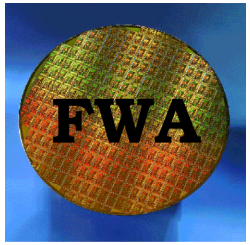
Uncertainty on dopant signal

$$\sigma_I(cps) = \sqrt{\frac{P}{t_P} + \frac{B}{t_B}}$$



Quantitation of X-ray Intensity (Peak – Background)

- How reliable is the X-ray intensity for determining relative concentration for similar samples?-EXCELLENT
- Are there matrix effects? Yes, but small
- Can the matrix effects be reduced or corrected? Yes
- Must a standard/reference sample be identical to the unknown sample? No
- The proof of these claims follows !!!



Conversion of LEXES X-ray Intensity Into Quantitative Concentrations

To Convert the X-ray Intensity (P-B) into Absolute Concentration or Dose, We Must Correct for the Following:

-

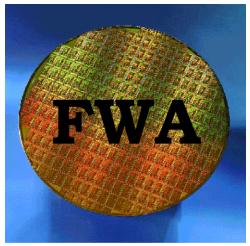
- **Energy loss** by the electrons as they penetrate the matrix,

- **Efficiency of X-ray production** at each depth, i.e. electron energy, and

- **Probability of the X-ray escaping** the matrix from the depth of its production.

The Mathematical Correction for the Above Effects Is

The IntriX Model



Test of The IntriX Model

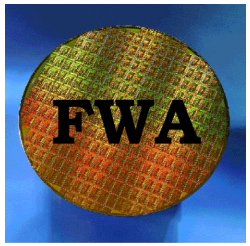
To test the **IntriX Model:**

1. As was implanted into Si and SiO2 to the same nominal dose, 1 E 15 at/cm. sq. (Sample 1).

2. P was implanted into Si, SiO2, TiSi2 and TaSi2 to the same nominal dose, 1 E 15 at/cm. sq. (Sample 2).

The **IntriX Model** was then used to quantify the results assuming that:

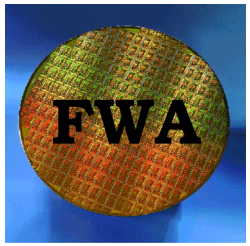
- The implants were all made into the same matrix, and, then calculated as
- They were made into the correct matrix.



IntriX Model Applied to As Ion Implants

As Ion Implants

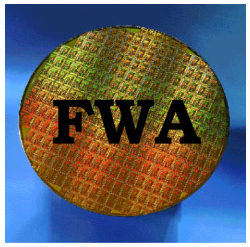
Nominal Dose	Matrix		LEXES Model Assuming Si Matrix	LEXES Model Assuming Correct Matrix
1.00E+15	Si		7.31E+14	7.31E+14
1.00E+15	SiO2		6.39E+14	7.28E+14
		Average	6.85E+14	7.30E+14
		SD	6.51E+13	2.12E+12
		RSD	9.50%	**0.29%**



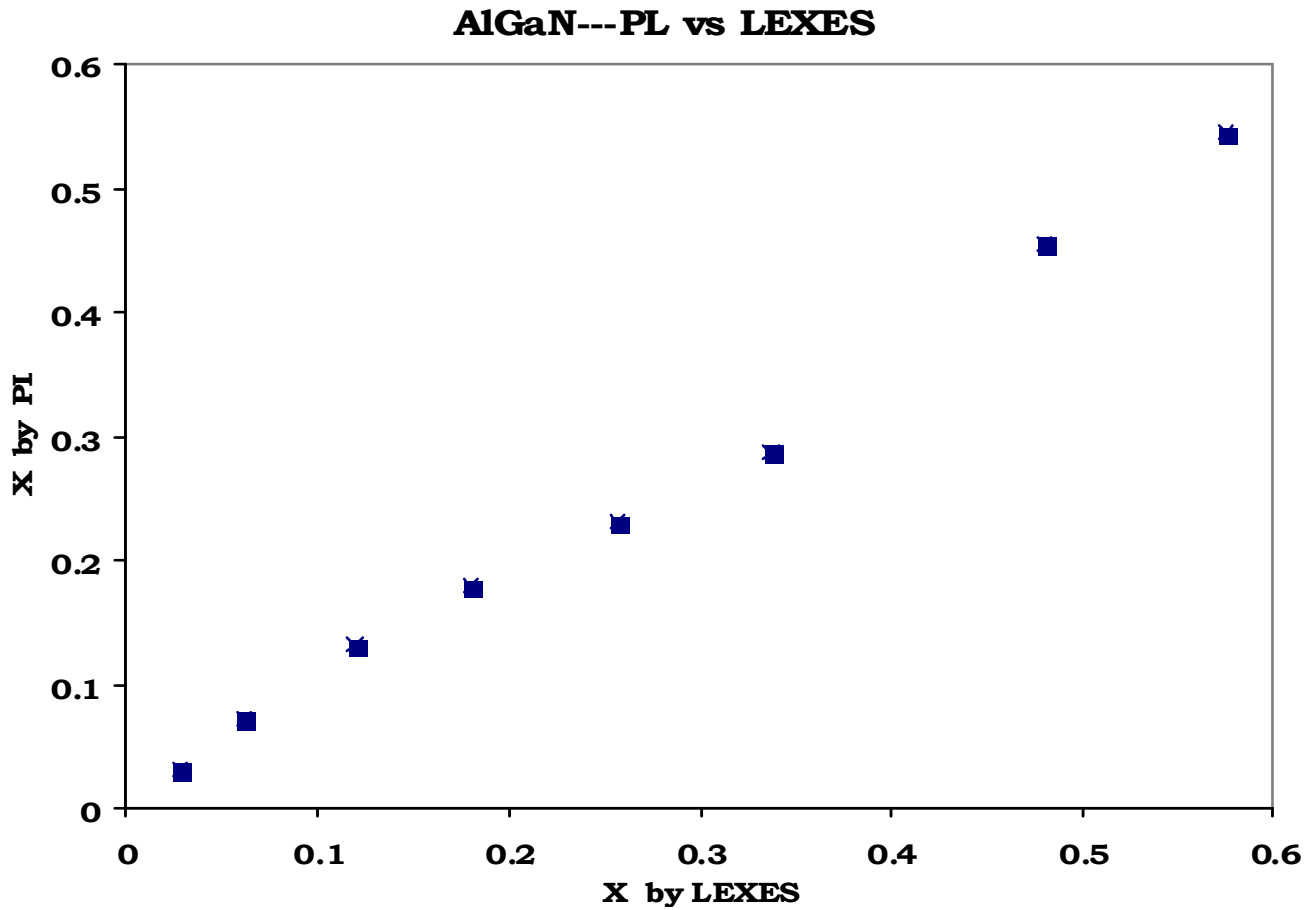
IntriX Model Applied to P Ion Implants

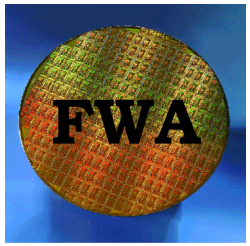
P Ion Implants

Nominal Dose	Matrix		LEXES Model Assuming Si Matrix	LEXES Model Assuming Correct Matrix
1.00E+15	Si		9.61E+14	9.61E+14
1.00E+15	SiO2		8.19E+14	9.50E+14
1.00E+15	TiSi2		1.19E+15	1.01E+15
1.00E+15	TaSi2		7.73E+14	9.65E+14
		Average	9.36E+14	9.72E+14
		SD	1.87E+14	2.64E+13
		RSD	20.03%	**2.72%**



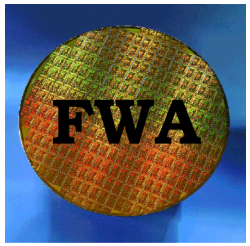
LEXES Analysis Quantified For Major Constituents





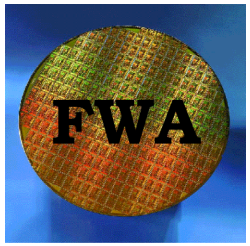
Conclusions--I

- Relative X-ray intensities, without correction for the specific/exact matrix, can provide relative quantitation within +/- 20%.
- The element of interest can be quantified by using a reference material containing the element of interest in a matrix of another material.
- With IntriX correction of the effects of the element in a known/defined matrix, quantitation of a few percent can be achieved.



Conclusions--II

The IntriX Model Is Highly Effective For Calculating Dose or Concentration from X-ray Intensities Produced by the Same Element in Different Matrices

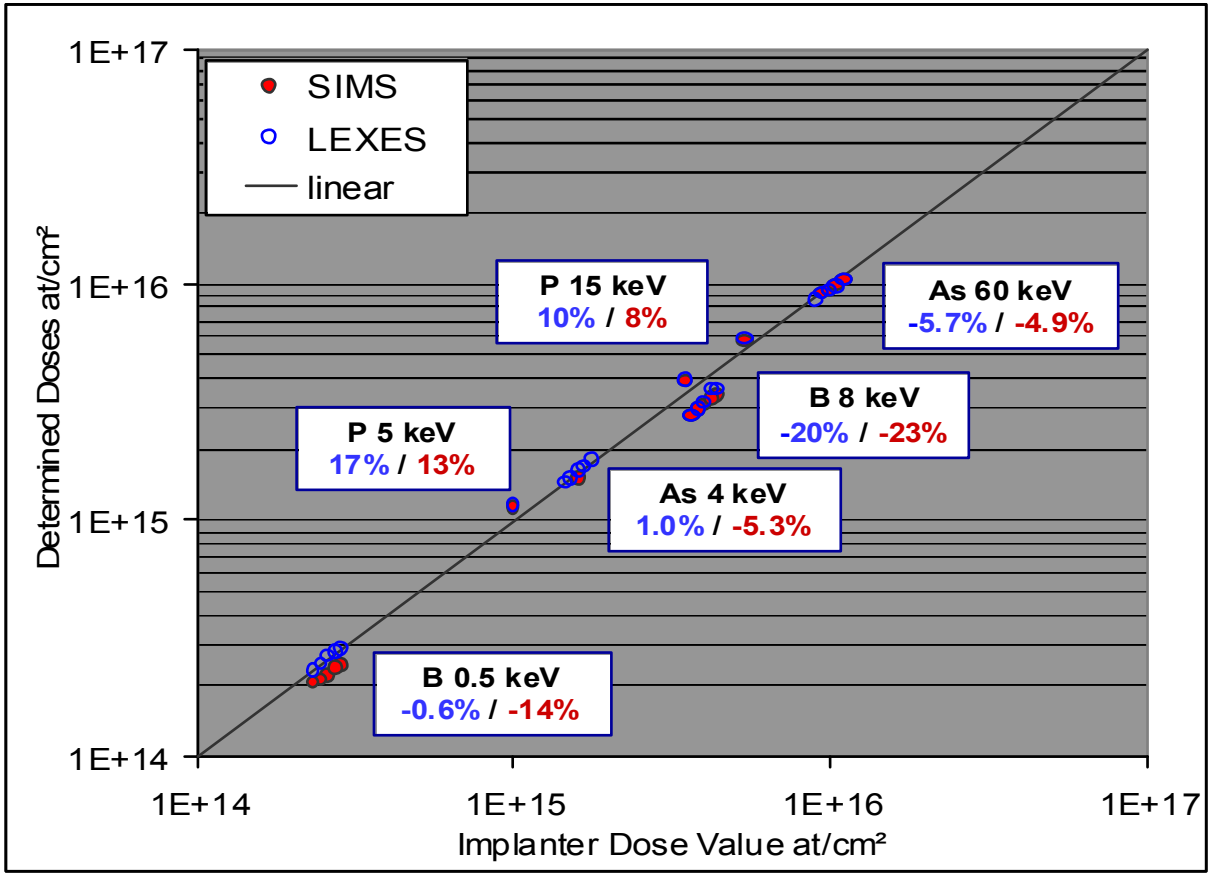


Accuracy of Dose Determination

Comparison with SIMS Values

- Although completely independent, SIMS and LEXES typically agrees **within 5%,** whatever the dopant type and dose.
- Deviation between Implanter tool values and both techniques is about 5-20%.

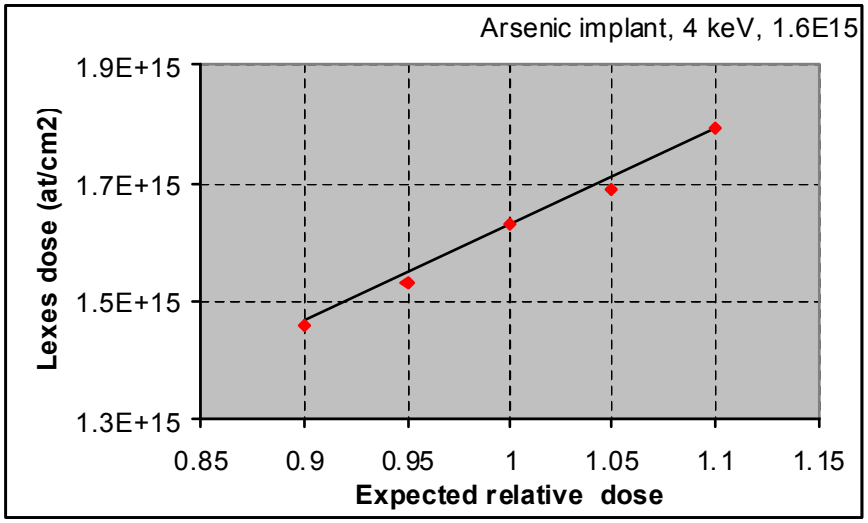
SIMS data were recorded with CAMECA IMS 6f equipped with Accel-Decel option.



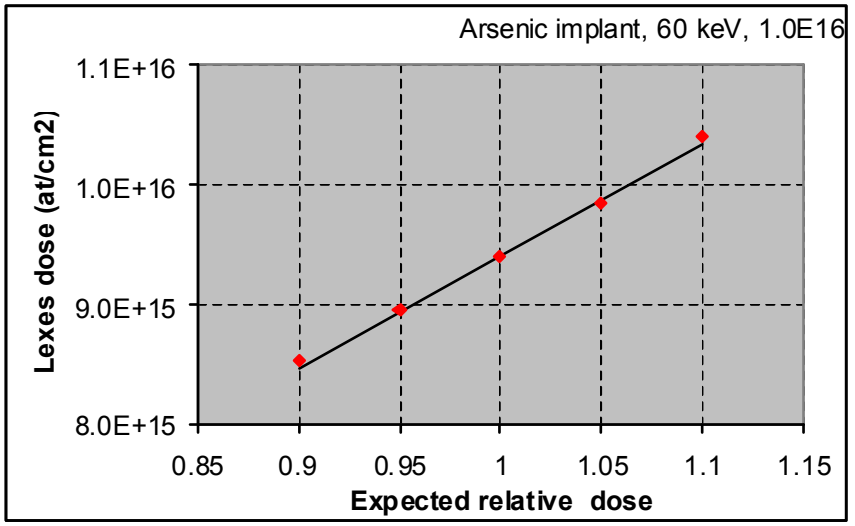
Samples provided by S. Corcoran from Intel Inc. and P. Ronsheim from IBM

Resolving Small Dose Variations in Arsenic

Shallow Implants



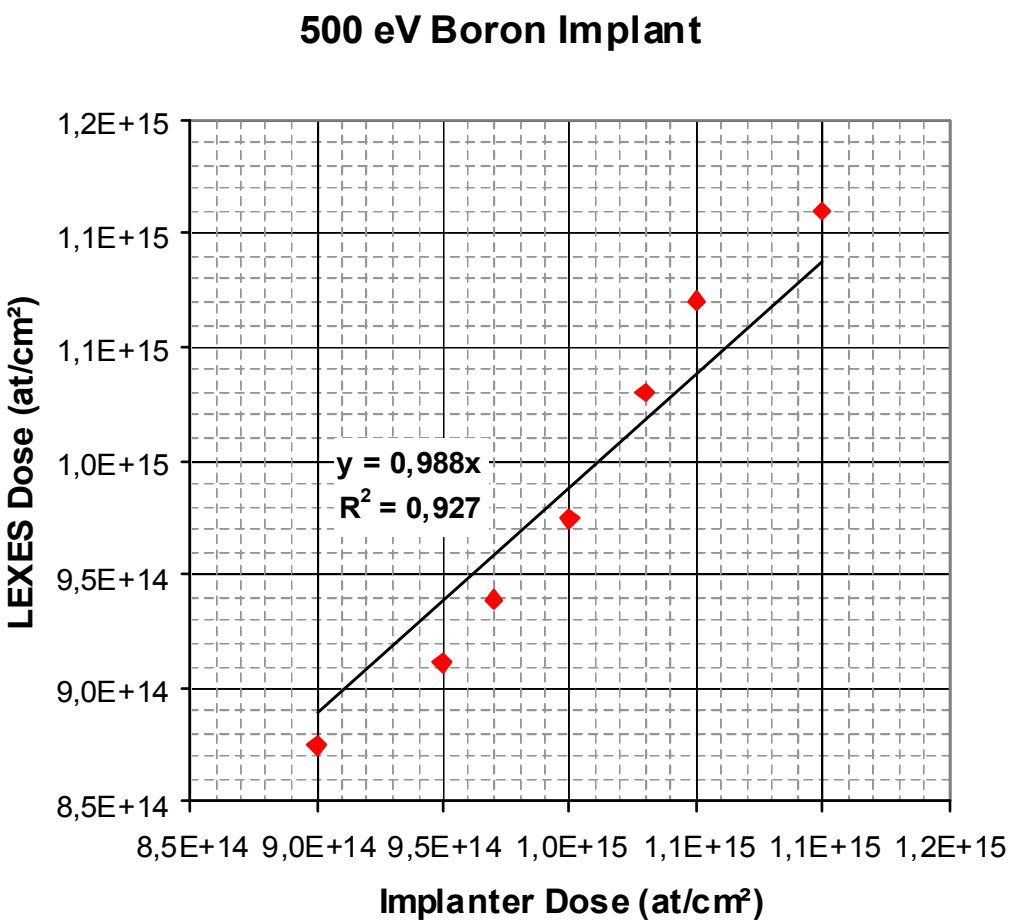
Medium Energy Implants



Shallow Probe easily discriminates dose gradations of 5%. Linearity is maintained even for very shallow implants or highly doped implants (E16 at/cm²).

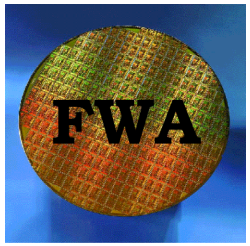
Uncertainty bars are smaller than the dots (1s <0.5%).

Resolving Small Dose Variations
ULE Boron Implants



Shallow Probe clearly discriminates dose gradations of 2% in the 1E15 range.

LEXES absolute dose values matches implanter nominal values typically within 3%.



Statistical Process Control for LEXES ULE As Implanted into 300mm Si Wafer

Purpose of study

- To determine the long term reproducibility of the LEXES instrument.
- Value of daily reference sample over the use of an archival sensitivity factor.

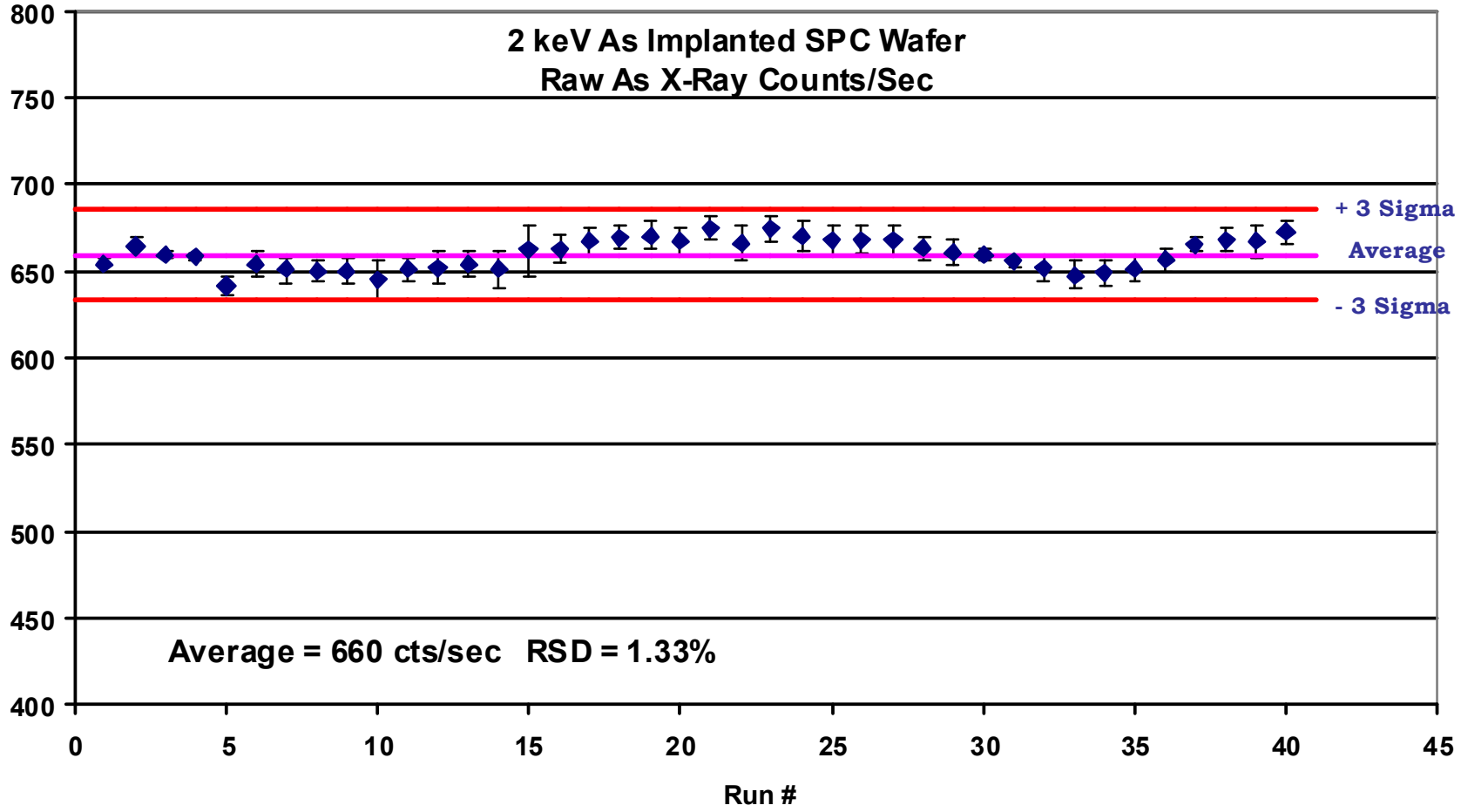
Sample

- **300mm As ion implant at 2keV, nominal dose of 1.00E+15 at/cm2.**

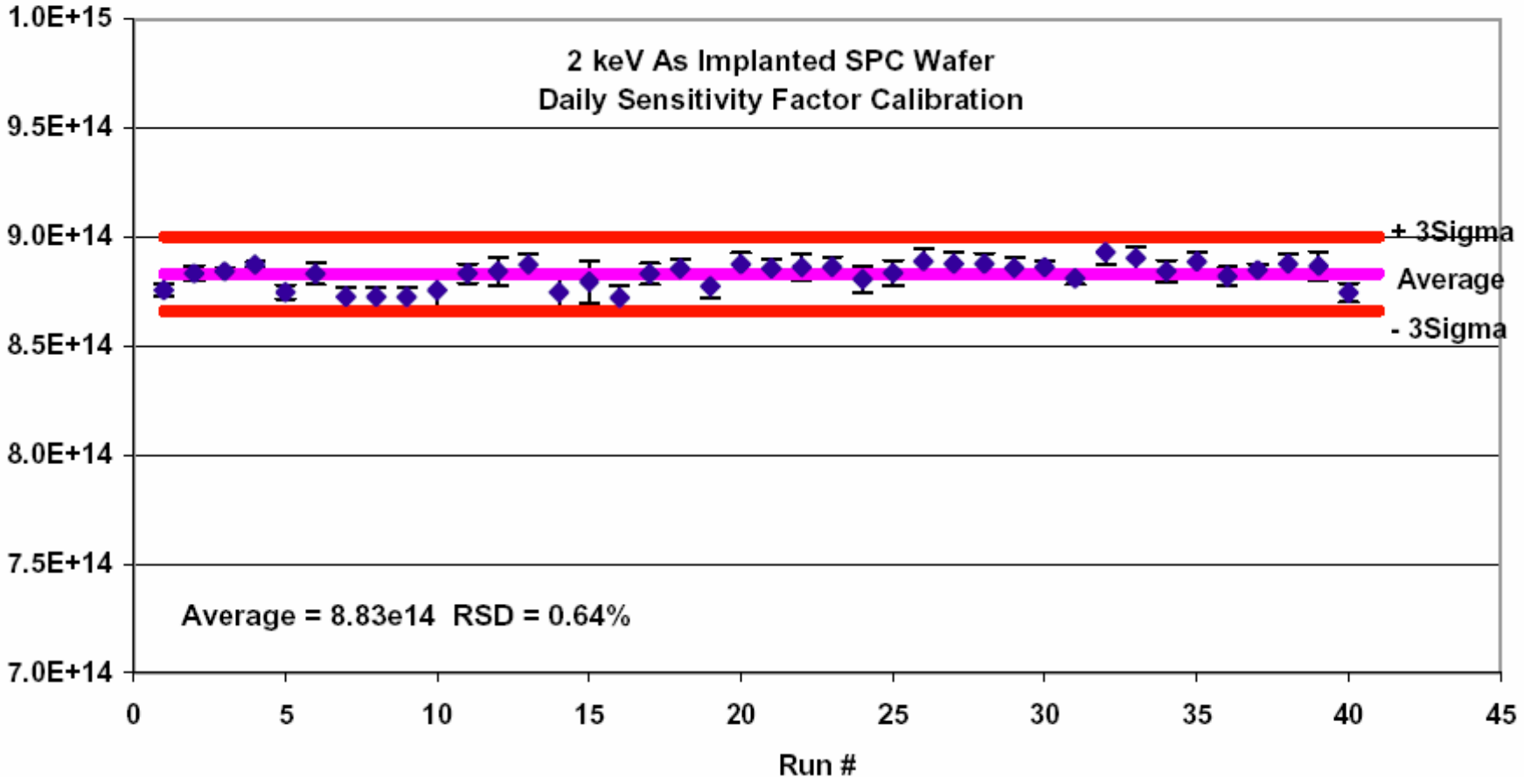
Analysis

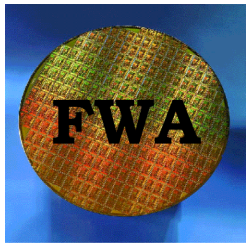
- 25 points around the wafer with five (5) replicate analyses per point.
- 40 analyses over three (3) month period with the wafer removed and reloaded approximately 10 times with three (3) to four (4) analytical cycles per loading.

Statistical Process Control for LEXES ULE As Implanted into 300mm Si Wafer



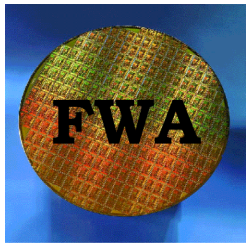
Statistical Process Control for LEXES ULE As Implanted into 300mm Si Wafer





Statistical Process Control for LEXES ULE As Implanted into 300mm Si Wafer

2keV As Implanted SPC Wafer	Average	RDS
Single Archival Sensitivity Factor Calibration	8.77e14	1.33%
Daily Sensitivity Factor Calibration	8.83e14	0.64%



Dose and Energy Study of ULE As Ion Implants

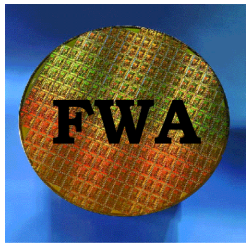
Purpose of study

Across wafer implant uniformity.

- Wafer-to-wafer implant reproducibility.
- Precision of the LEXES technique.

Wafers studied

- Implants by AMAT Quantum III.
- Analyses by CAMECA Shallow Probe 300.
- Seven wafers were implanted with energies of 1.8keV to 2.2keV to a nominal dose of 1.0E+15.
- Each wafer was analyzed at center – 0.5r – 0.98r.
- Five analyses per position.

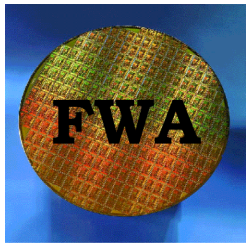


Dose and Energy Study of ULE As Ion Implants

Representative LEXES data for Arsenic as-implanted wafer

Measurement	0.98R	2000 eV R/2	Center	Across Wafer
1	8.62E+14	8.70E+14	8.74E+14	
2	8.68E+14	8.74E+14	8.61E+14	
3	8.66E+14	8.75E+14	8.73E+14	
4	8.65E+14	8.72E+14	8.79E+14	
5	8.61E+14	8.74E+14	8.65E+14	
Ave	8.64E+14	8.73E+14	8.70E+14	8.69E+14
SD	2.77E+12	2.20E+12	7.14E+12	5.48E+12
RSD %	0.32%	0.25%	0.82%	**0.63%**

For the **seven** wafers, the data was as below:
Average: 8.69E+14
SD: 9.10E+12
RSD: 1.05%



Dose and Energy Study of ULE As Ion Implants

It is important to note that the global precision of **1.05% RSD** represents:

- the **within wafer uniformity** of the implanter
- the **wafer-to-wafer repeatability** of the implanter, and
- the **precision of the LEXES measurement**.

Dose and Energy Study of ULE As Ion Implants

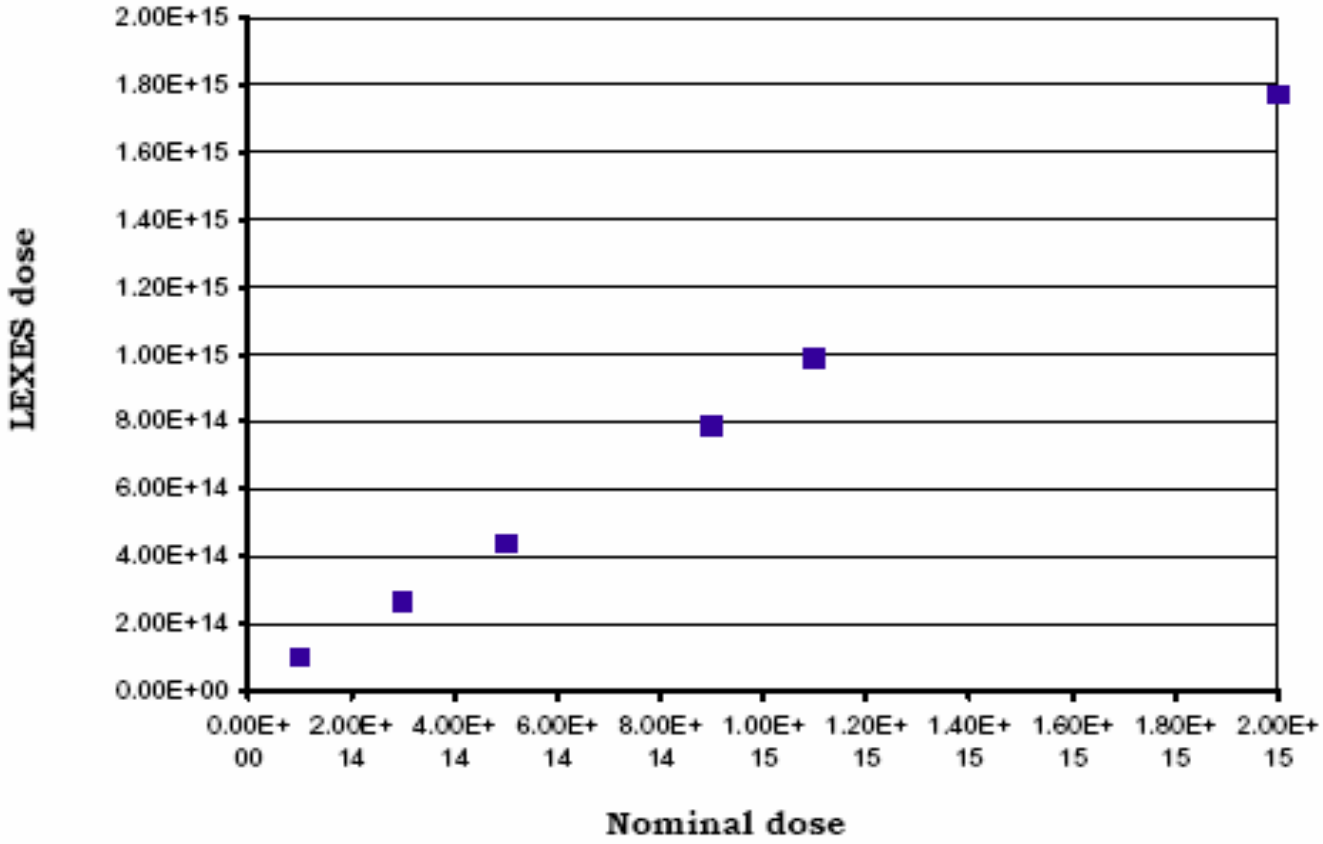
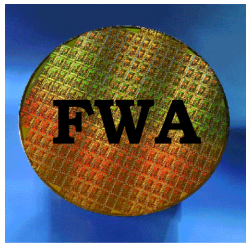


Figure 1. Dose by LEXES vs. Nominal Dose



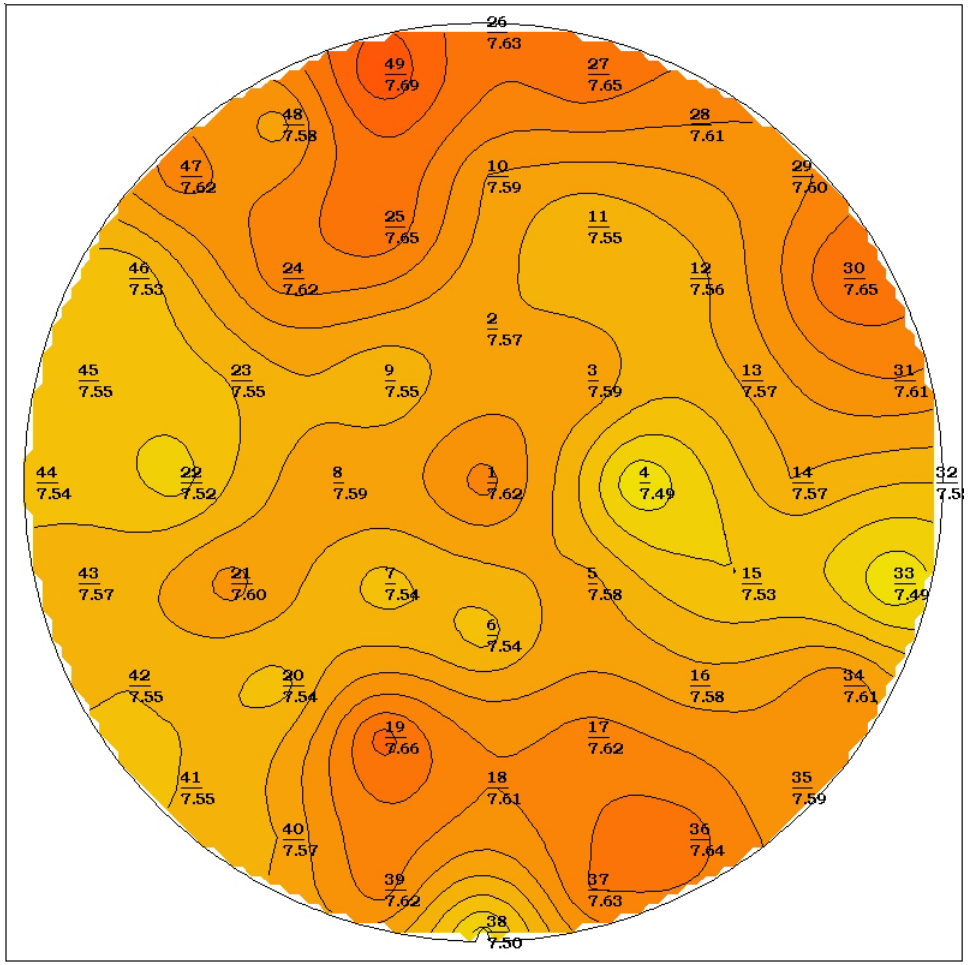
New SPC Wafer

300 mm Wafer

Co-Implanted with

- As 2 keV 1E 15
- Ge 1 keV 1E 15
- F 20 keV 2E 15
- C 5 keV 3E 15
- B 0.5 keV 1E 15

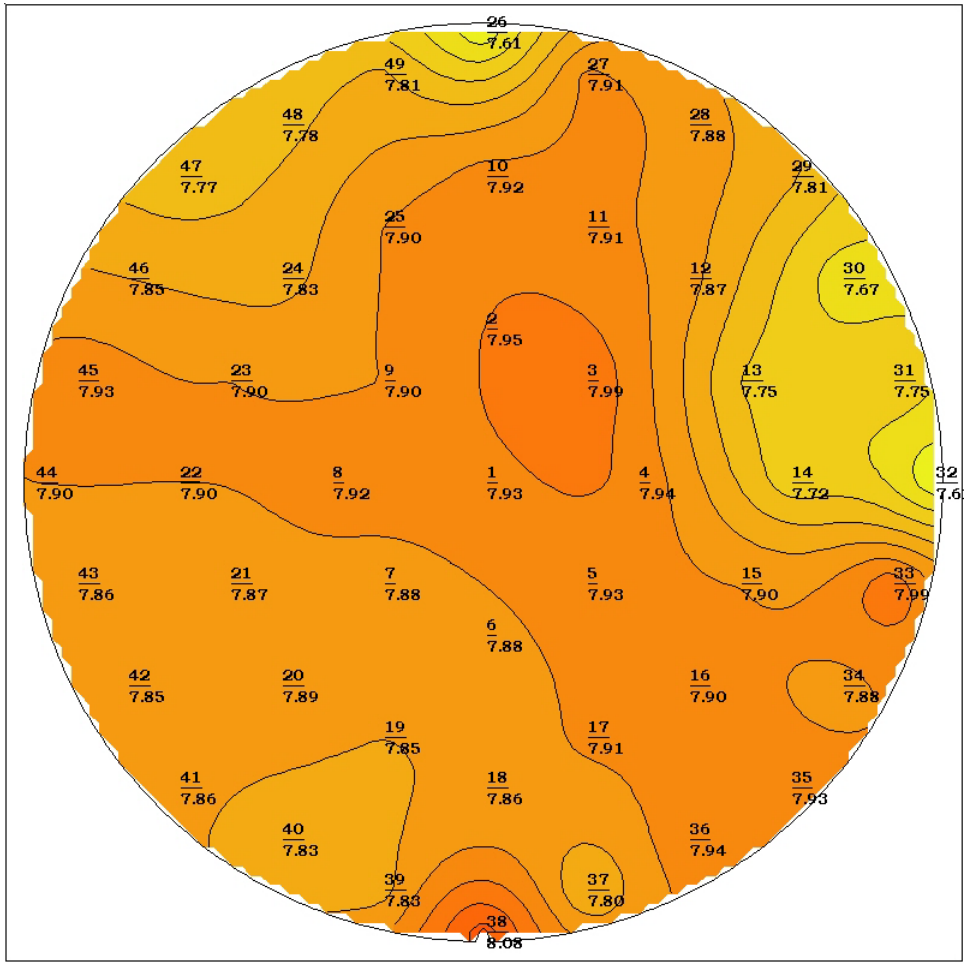
As Implant in SPC Wafer



Ave Dose = 7.58e14 atoms/cm2

% RSD = 0.60% Across Wafer

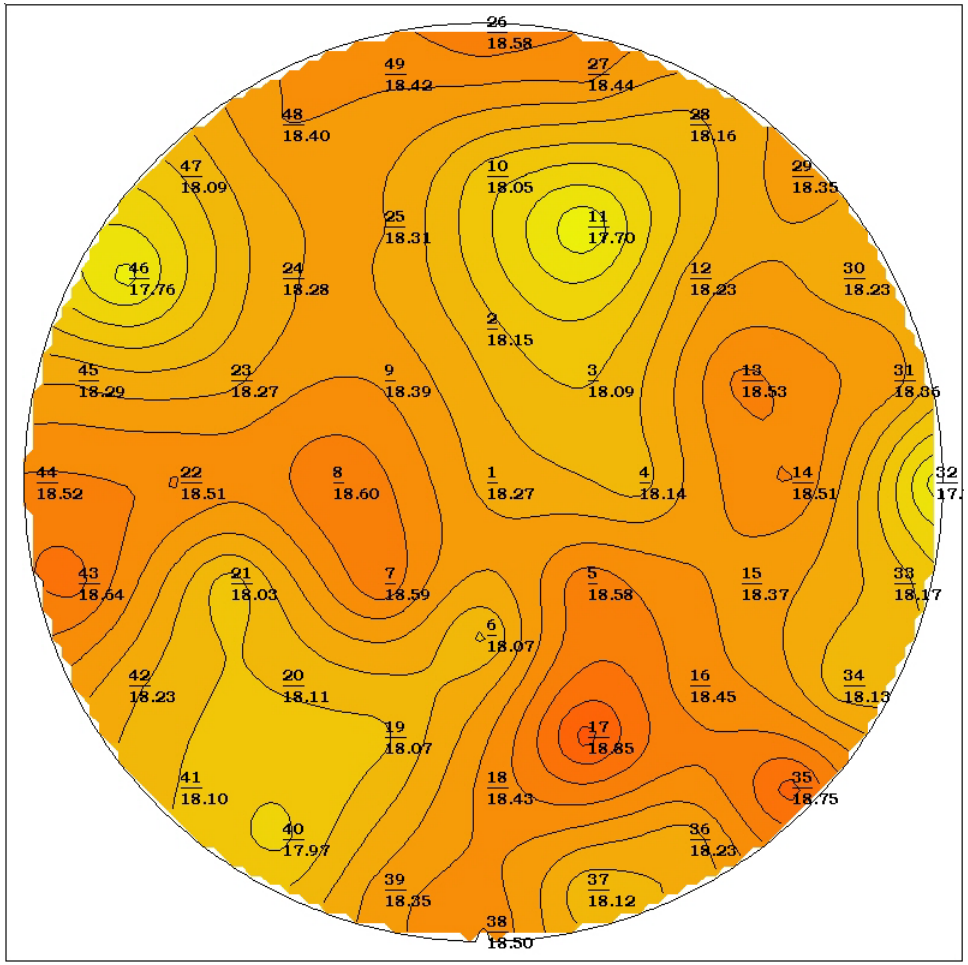
Ge Implant in SPC Wafer



Ave Dose = 7.86e14 atoms/cm2

% RSD = 1.13% Across Wafer

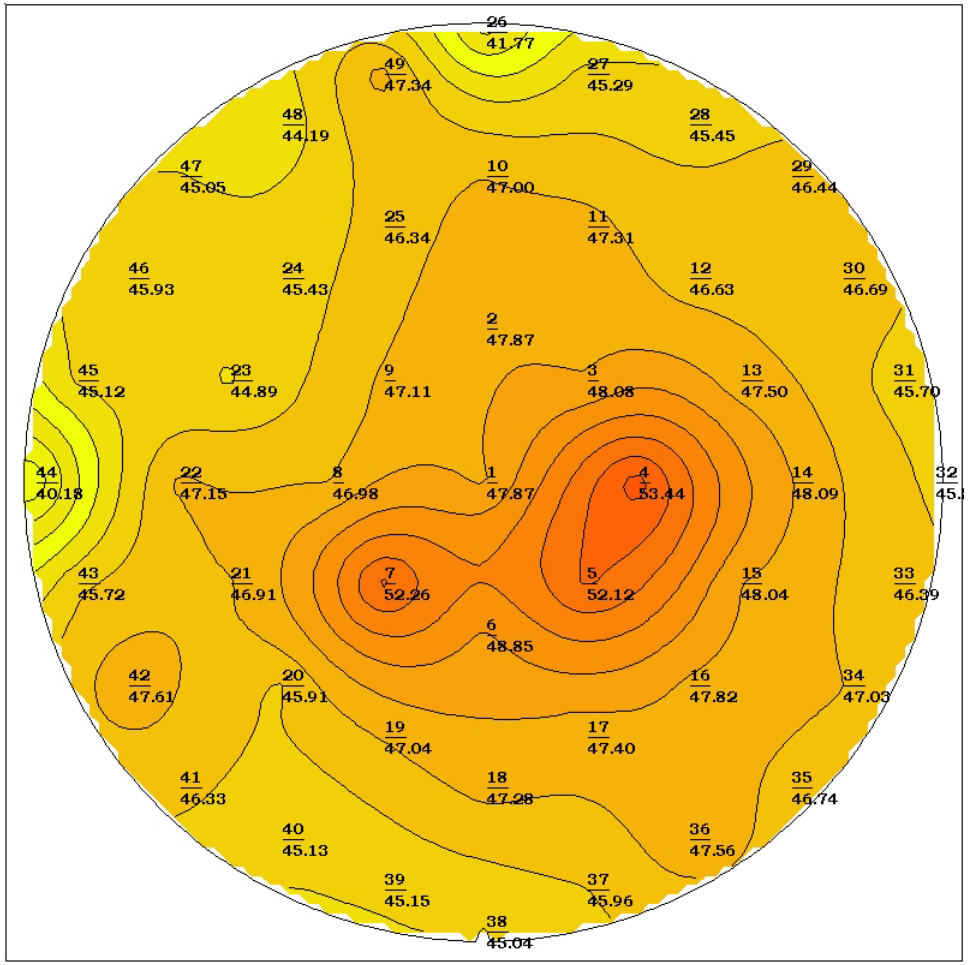
F Implant in SPC Wafer



Ave Dose = 1.83e15 atoms/cm2

% RSD = 1.35% Across Wafer

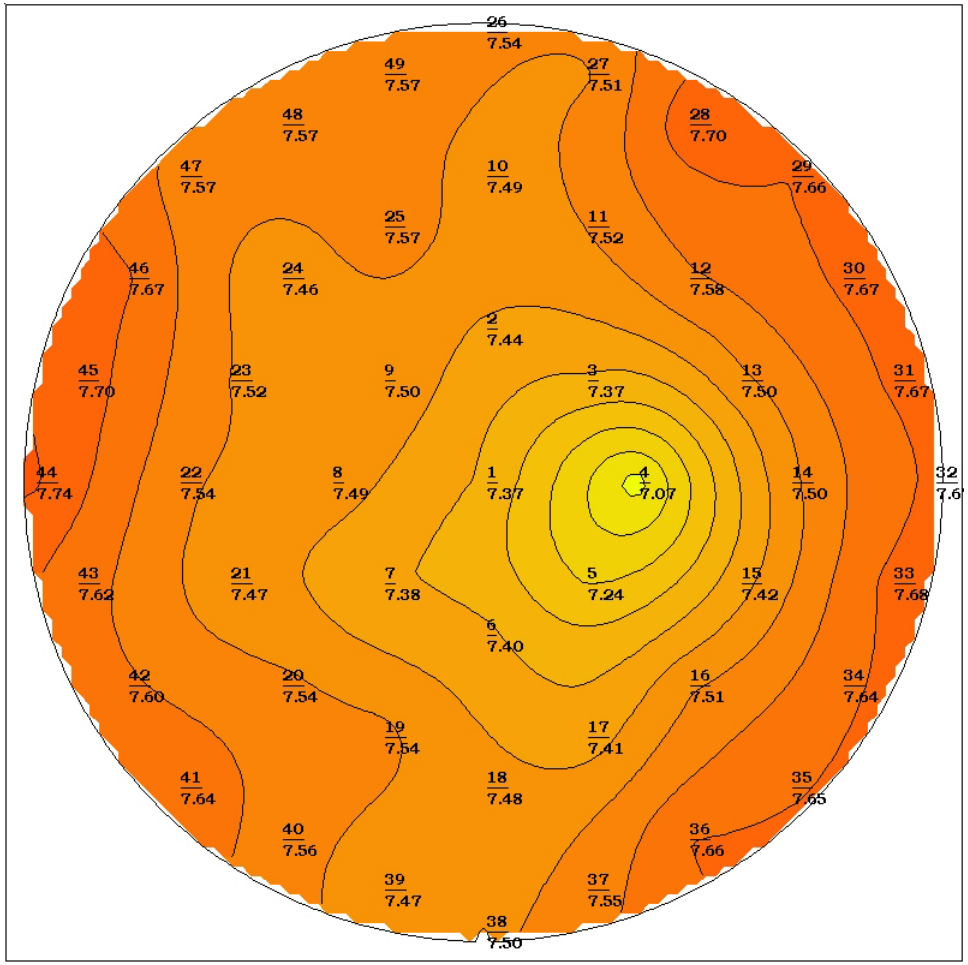
C Implant in SPC Wafer



Ave Dose = 4.67e15 atoms/cm2

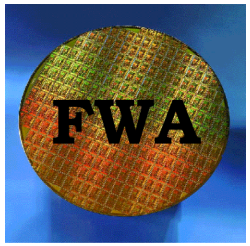
% RSD = 4.62% Across Wafer

B Implant in SPC Wafer



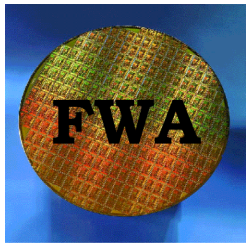
Ave Dose = 7.53e14 atoms/cm2

% RSD = 1.64% Across Wafer



Application of LEXES to Thin Films

- Silicon Oxynitrides
- SiGe Layers
- Atomic Layer Deposition
- CoWP cap layers on Cu interconnects
- Cu/Ta/TaN stacks

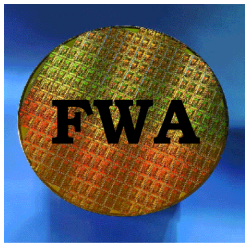


LEXES Analysis

SUMMARY

- **Excellent precision within an analysis**
- **Excellent precision over the long term**
- **Small matrix effects**
- **Matrix effects well corrected by IntriX model**
- **Final analysis is highly quantitative**
- **Full Wafer Mapping gives visual insight into within wafer and wafer-to-wafer variations**

Some data courtesy of CAMECA and their colleagues.



10 points Line Scans, 15sec/point