Applications

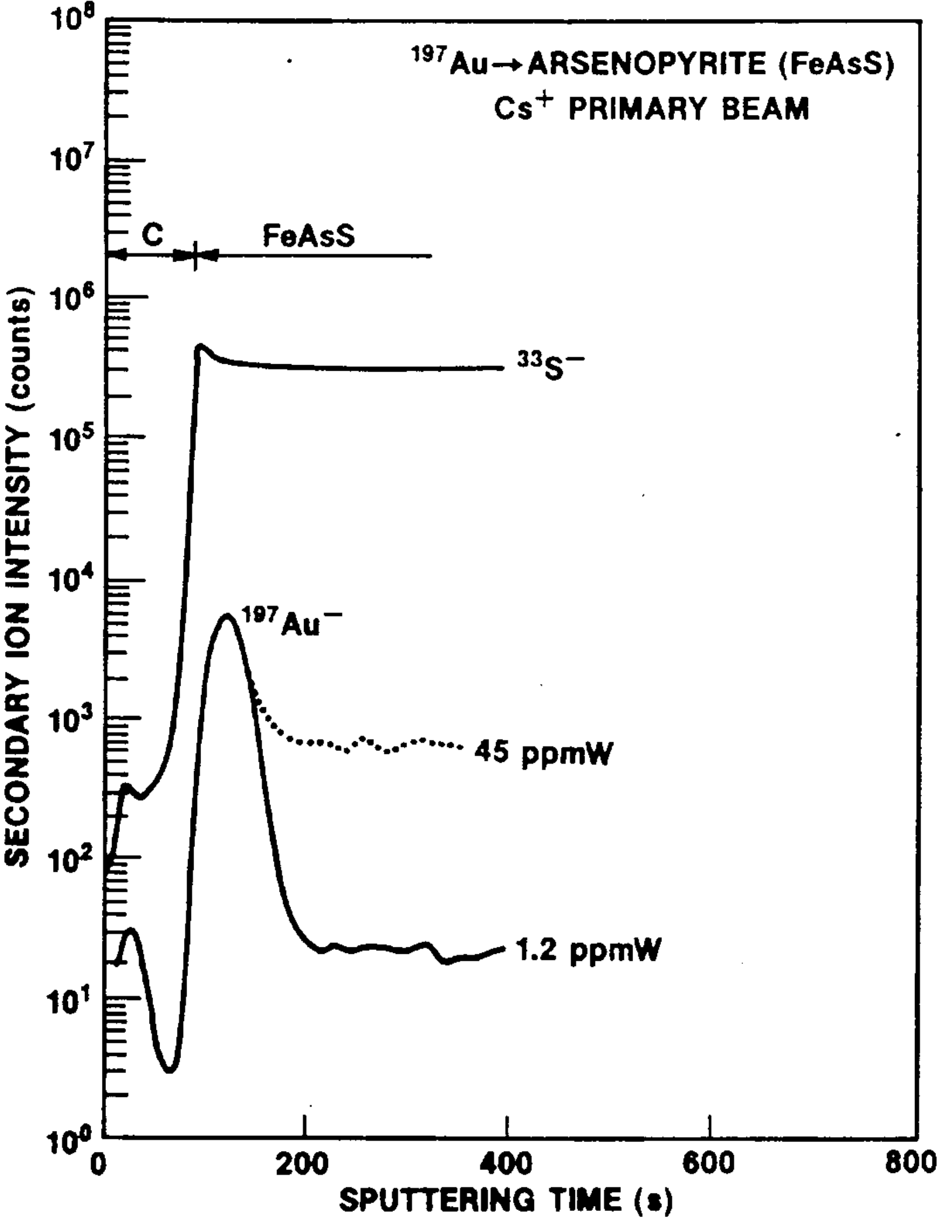
- SIMS successfully applied to many fields

- Catalysts, metals, ceramics, minerals may primarily use imaging

- Semiconductors extensively use depth profiling

  Si, GaAs, GaN, ZnO

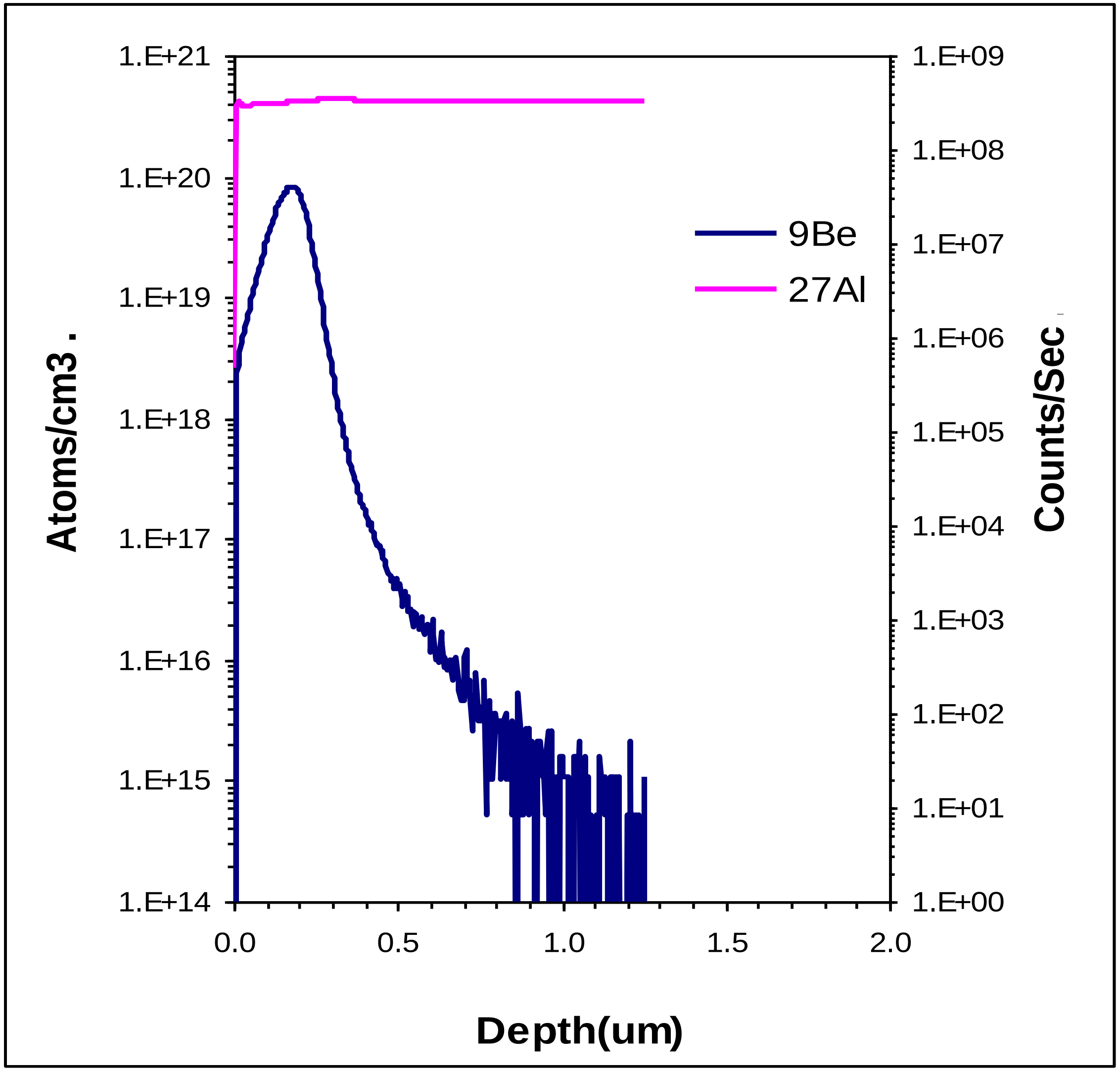
Minerals Analysis



Calibration of Au in minerals using ion implantation. Samples were carbon coated and then analyzed using Cs$^+$ at a sputtering rate of about 2 nm/s. The baseline Au level in the two samples of Arsenopyrite is different by almost a factor of 40.

S. Chryssoulis, Surface Science Western

Al_2O_3

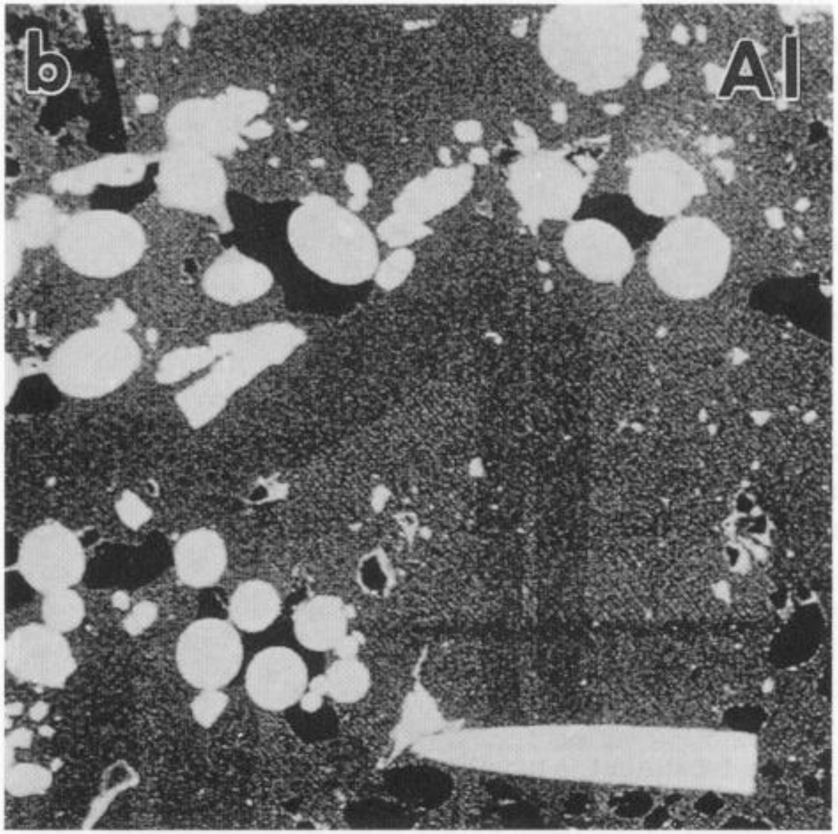


Be in Crystalline Al_2O_3
50keV
$1E15/cm^2$
Mass Res. 750

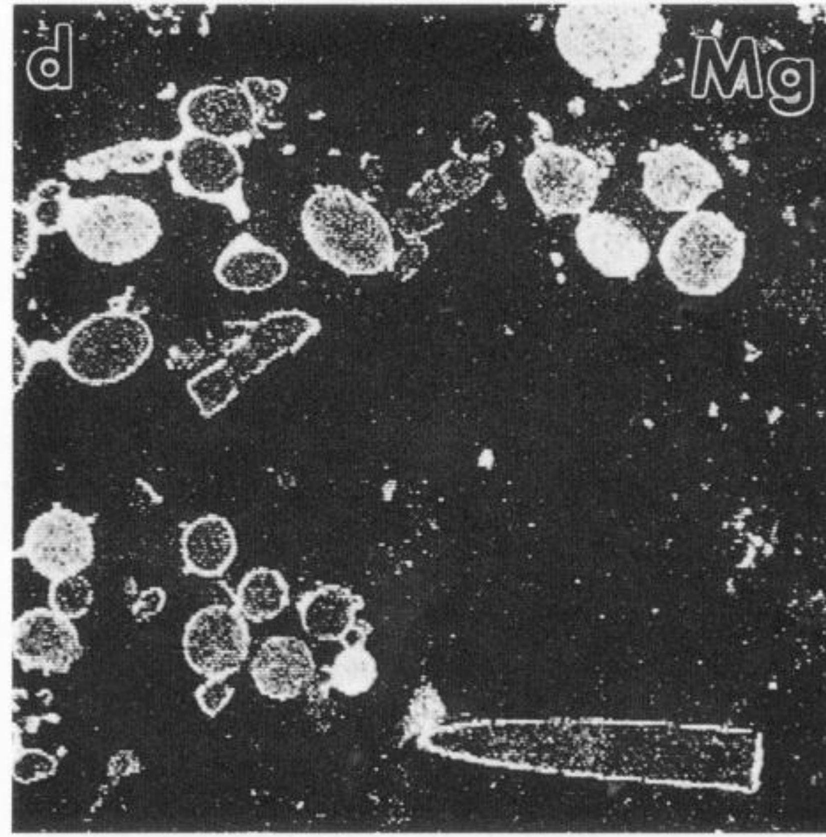
Detection Limit
$<1E15/cm^3$ (20ppba)

NCSU-AIF Sample from S. Novak, EAG

FIB-SIMS Images of Alloy



Al^+



Mg^+

Ga^+ SIMS images of a polished section of Al-Si-Mg-Cu alloy reinforced with Saffil fibers.

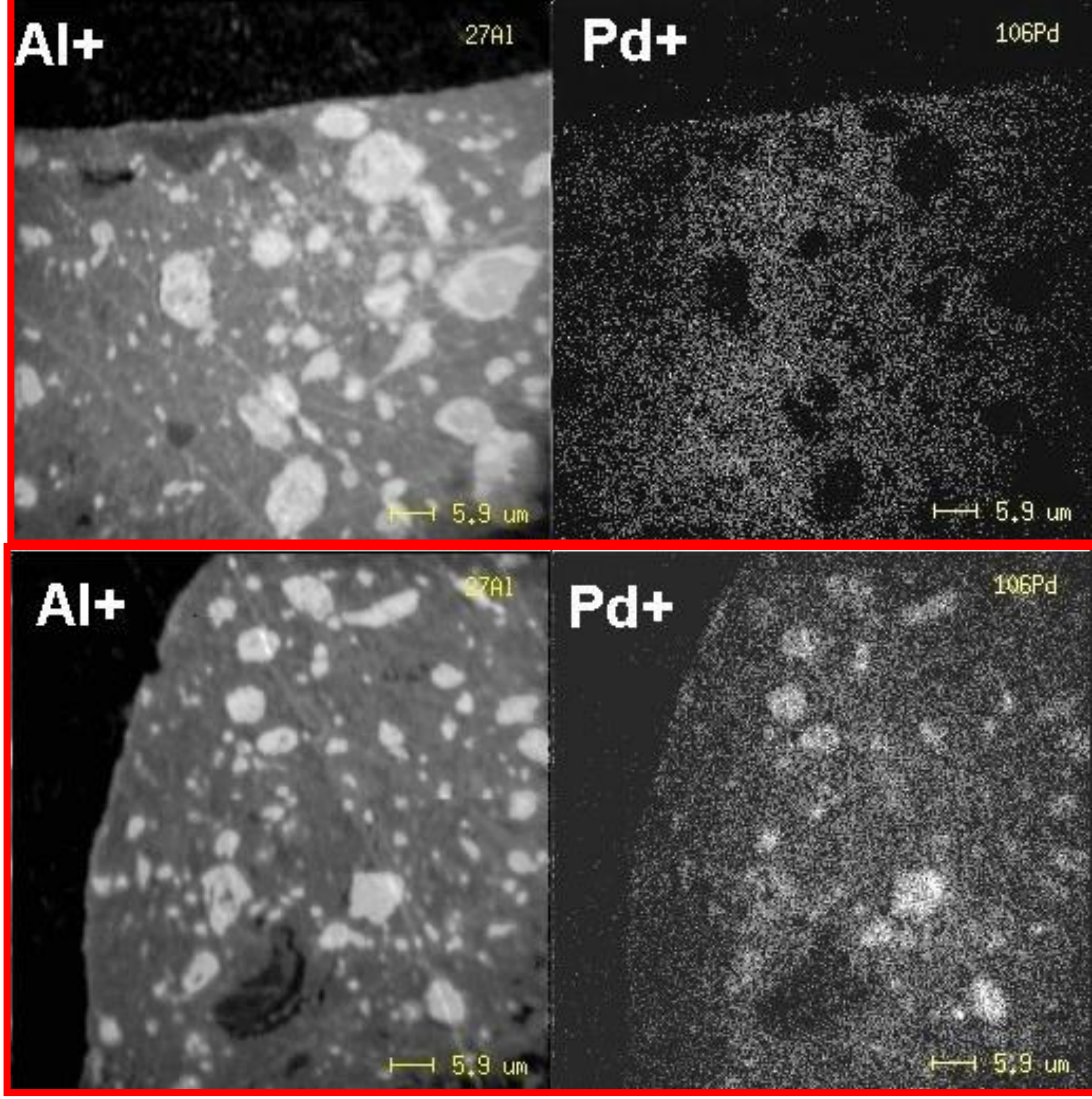
R. Levi-Setti, et al., Scanning Microscopy 7,1161 (1993)

Large Catalyst Extrudate Study

Bad

Edge of zeolite/Alumina extrudates (0.18wt% Pd)

Good



Pd-Al correlation evident in “good” catalyst

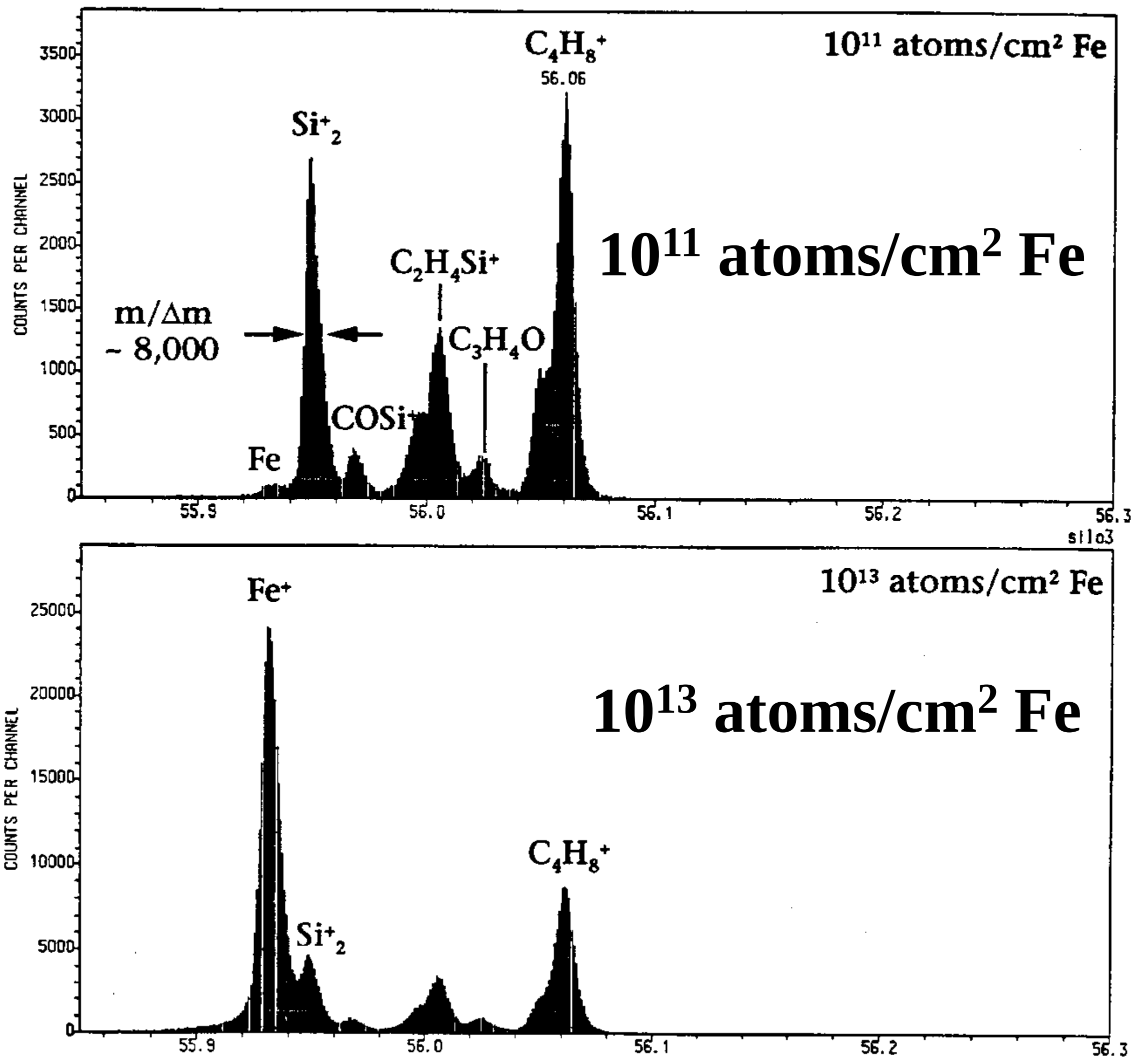
W.A. Lamberti, W.C. Horn, ExxonMobil Research & Engineering Co.

Semiconductor Applications

SIMS can be applied to almost every silicon processing step

- Crystal growth - O, C contamination
- Epitaxy - B, P, As dopants, O, C contamination, thickness
- Surface cleans - contaminants
- Oxidation - Li, Na, K, Cl
- Inter Level Dielectric deposition – e.g.,Tetraethyoxysilane (TEOS)
  H, Li, Na, K, C
- Polysilicon deposition - O, C contamination, P level ~10^{20} cm^{-3}
- Ion implantation - B, P, As, F, Al, Cr, Fe, Cu
- Diffusion - B, P, As
- Lithography - B, P, As penetration, Na contamination
- Dry etch - O, C, F, Cl, Al, Cr, Fe, Cu
- Metallization - Al, Si, Cu, Ti, W, N, and O and C contamination
- Process Simulation - B, P, As
- Process integration and failure analysis - SIMS patterns
- Packaging - Au, Ni, Cu, Tl

Time-of-Flight Surface Metals Analysis



Evans Analytical Group

High mass resolution required to separate Fe contamination from other ions

Presputter: Ga^+ 15 keV
300 µm x 300 µm
1 min to remove organics

Analysis: Ga^+ 15 keV
20 nA 40 µm x 40 µm
10 min

Time of Flight Detection Limits

Metal impurities on Si wafer

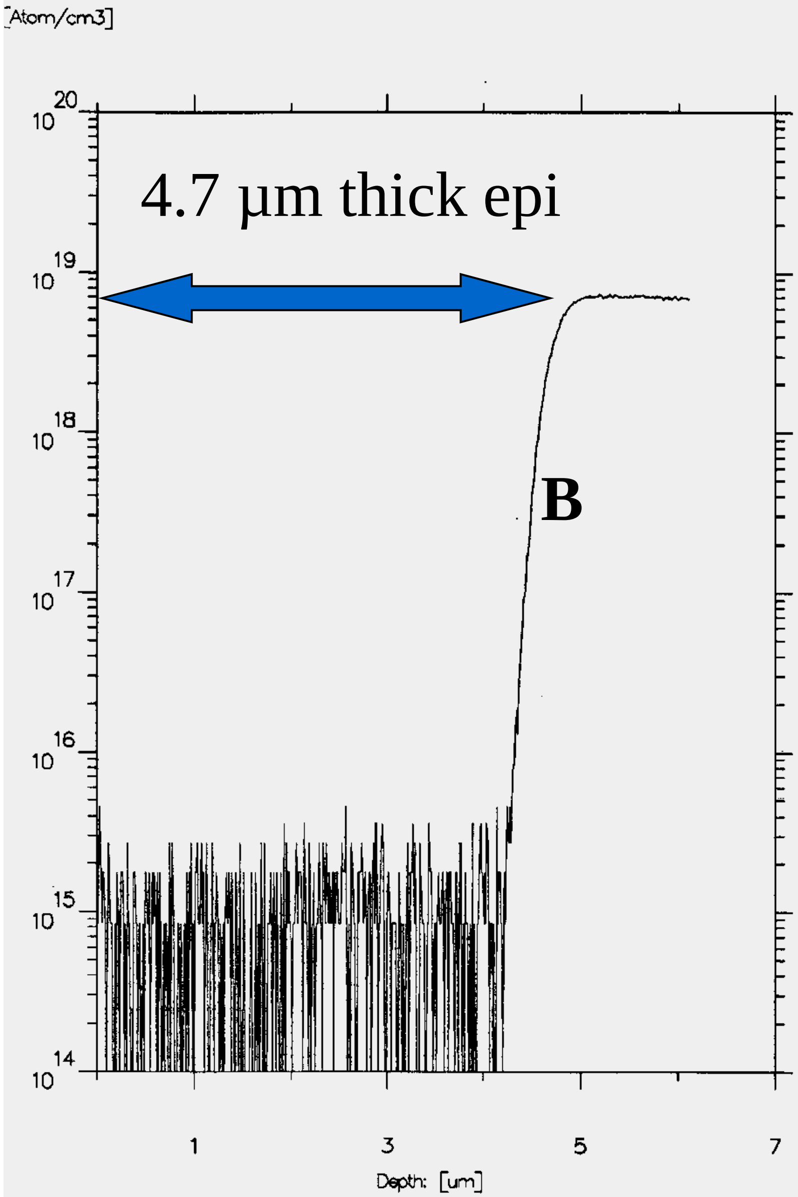
Element	Detection Limit (atoms/cm^2)
Li	2E8
B	2E8
Na	2E8
Mg	3E8
Al	3E8
K	5E8
Ca	3E9
Cr	1E9
Mn	4E9
Fe	2E9
Ni	1E10
Cu	1E10

100 µm x 100 µm area

one monolayer:
1E15 atoms/cm^2

CAMECA Instruments

Analysis of Epitaxial Si Layer



SIMS depth profile

200 mm diameter (100) Si wafer thickness 735 ± 20 µm

P^+ epitaxial Si on P type substrate (10-20 ohm-cm)

Measure epitaxial thickness and dopant concentration using SIMS. Avoid use of O_2^+ primary beam because of topography formation during sputtering.

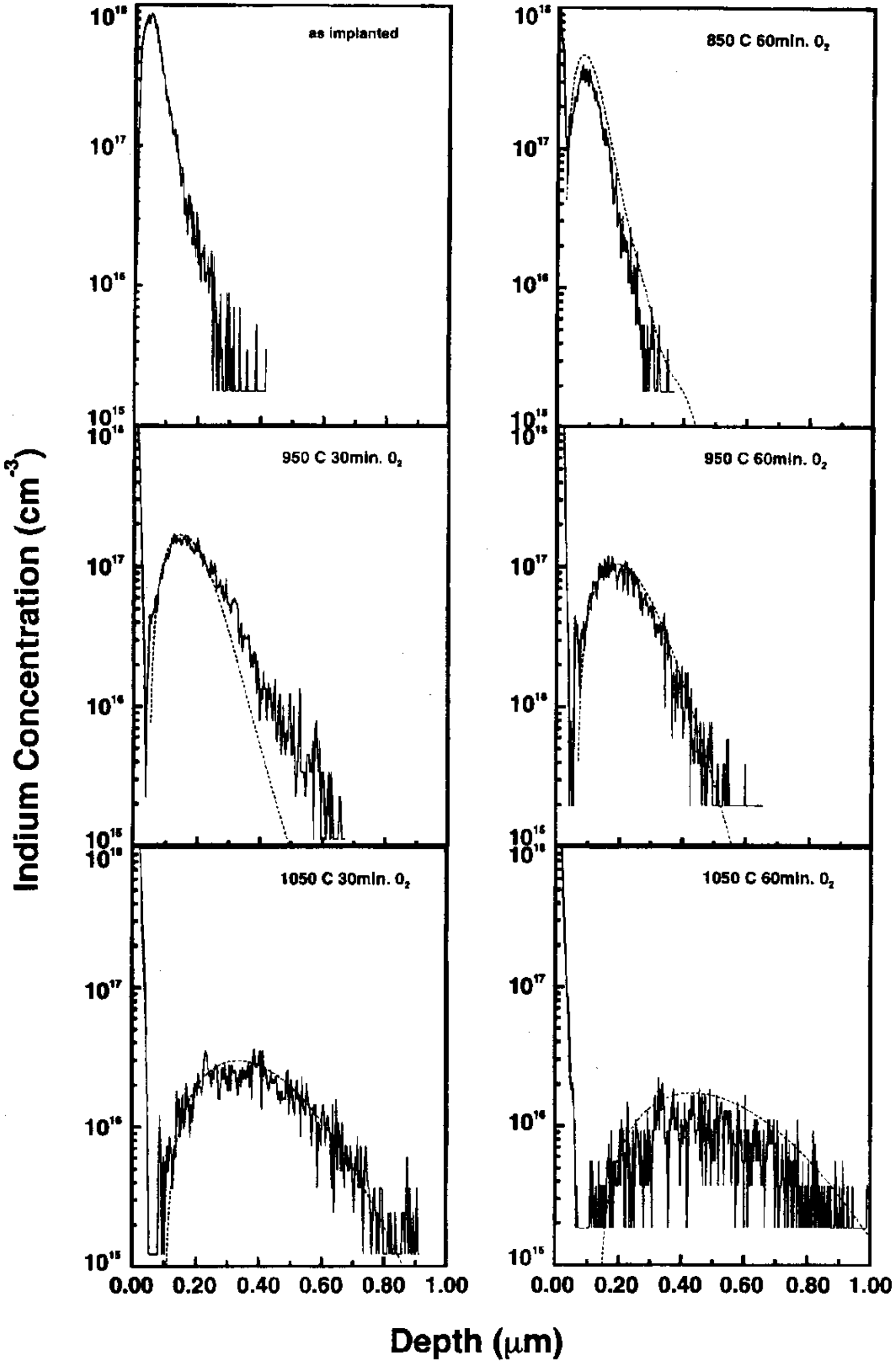
Ion Implantation

- SIMS and ion implantation are closely related
  (SIMS instrument is an ion implanter + mass analyzer)

- Absolute dose measurement
  Can distinguish dose differences of less than 5%

- Cross contamination
  P in As implants is significant concern because P diffuses faster than As. B is also a fast diffuser.
  Presence of P, As, or Sb at 1% of B dose can cause as much as 5% shift in sheet resistance

- Metallic contaminants
  Fe, Cu, Na, Al, Mo, W among those checked frequently



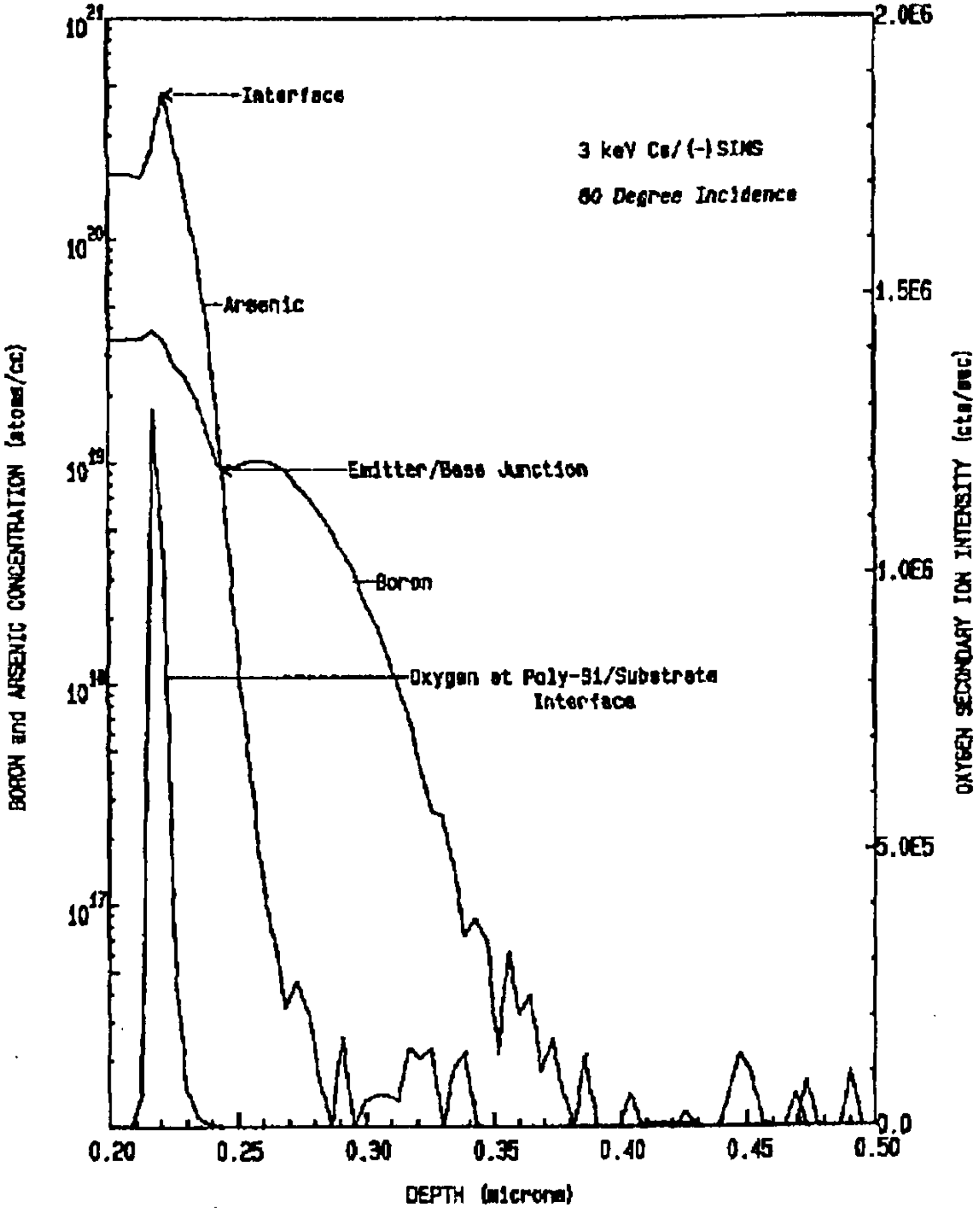
Indium Diffusion

SIMS Depth Profile

SIMS profiles and simulations for In 60 keV 8E12 atoms/cm^2 as implanted and after 850ºC - 1050°C anneals in O_2

I. C. Kizilyalli, et al., J. Appl. Phys. 80, 4944 (1996)

Dopant Profiles

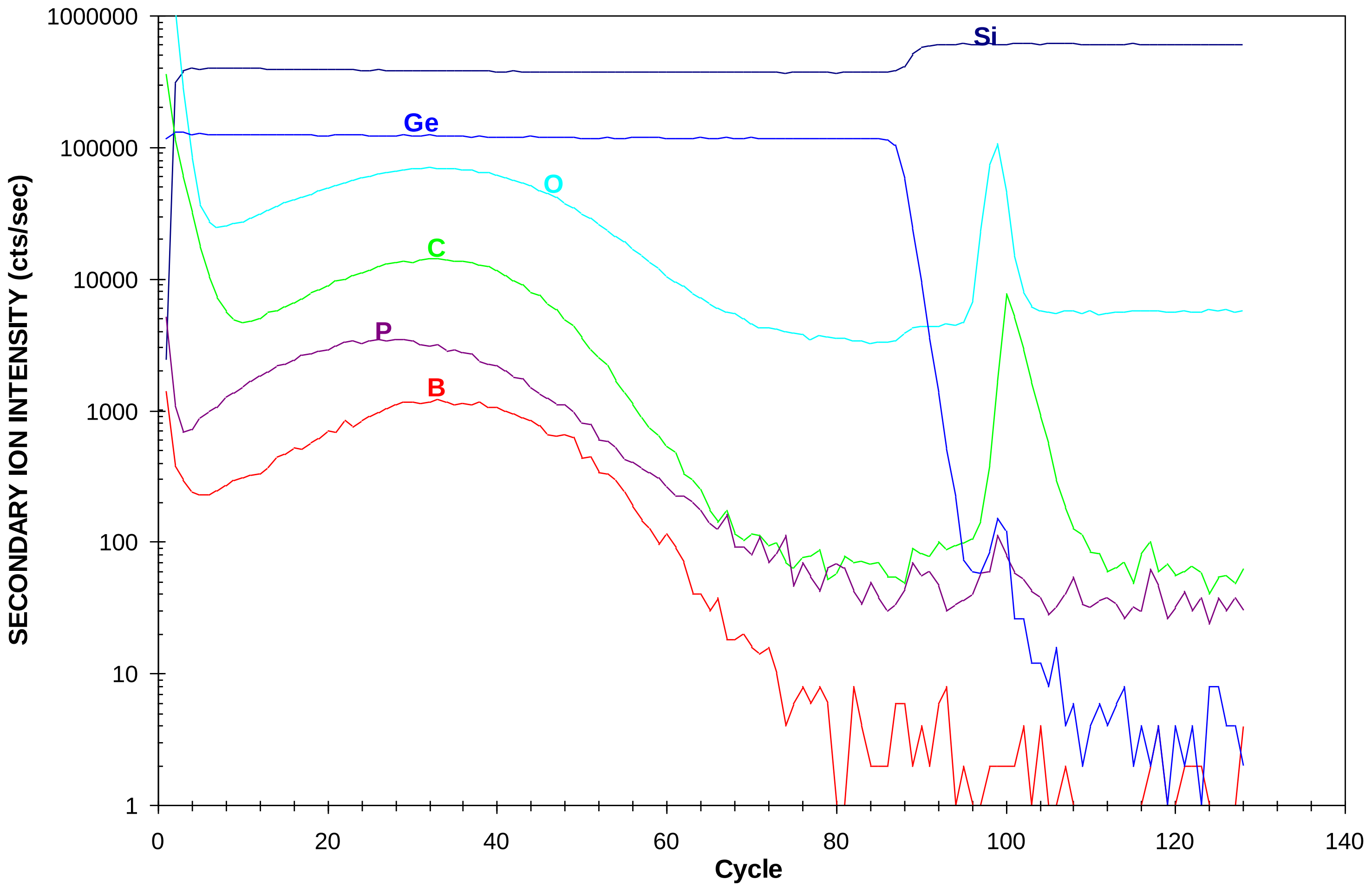


Quantitative SIMS depth profiles of As and B in bipolar transistor structure showing shallow emitter/base junction.

Emitter/base junction depth
Below polySi/Si interface
is 27 nm

C. W. Magee and M. R. Frost
Int. J. Mass Spectrometry Ion Processes 143, 29 (1995)

Analysis of SiGe Matrix and Impurity Species: Impurity Elements

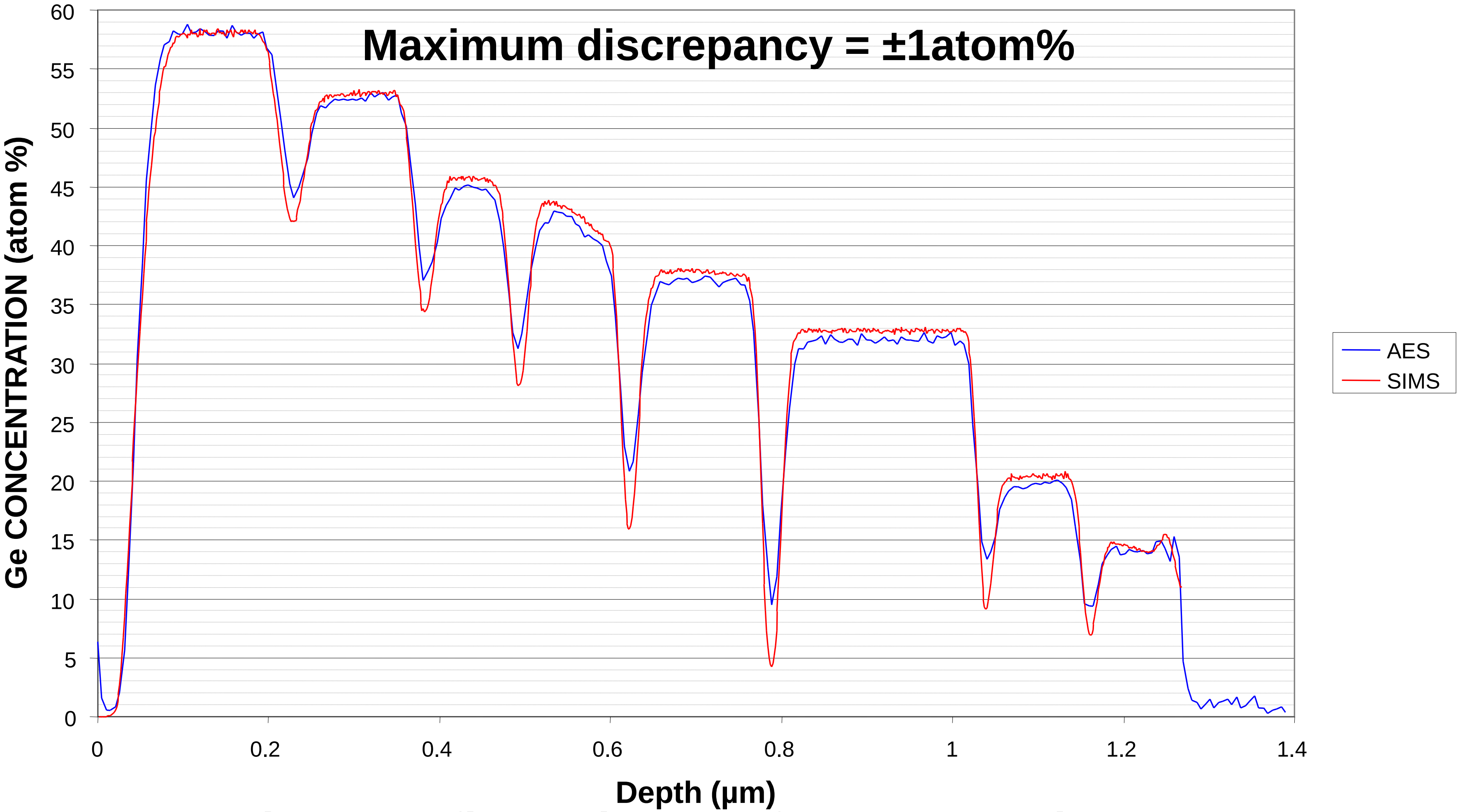


$Si_{0.85}$ $Ge_{0.15}$ Implanted with B, P, C and O

C. Magee, Evans Analytical Group

Analysis of SiGe Matrix and Impurity Species: Matrix Elements

AES & SIMS Analysis Comparison of a Multi-layered SiGe Sample

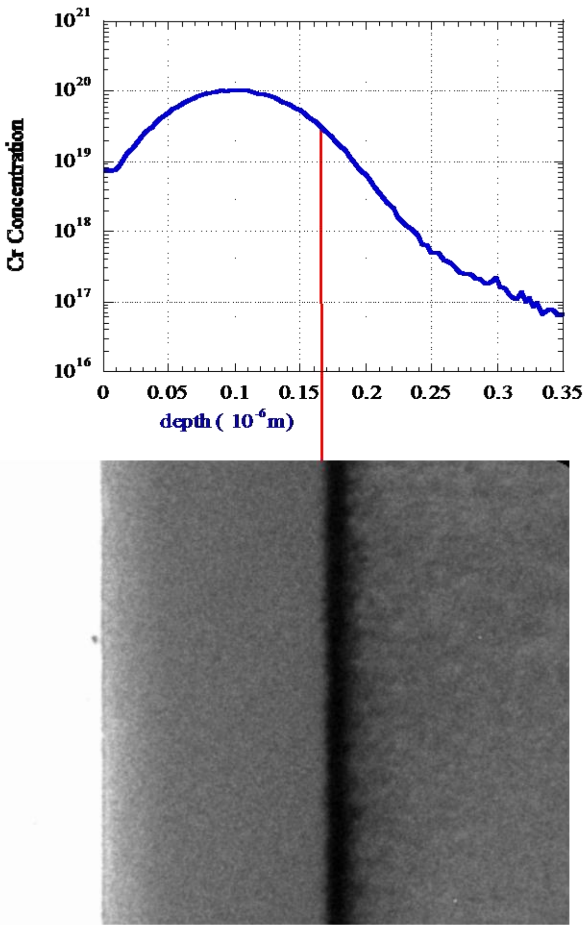


Single Profile & Single Reference Material

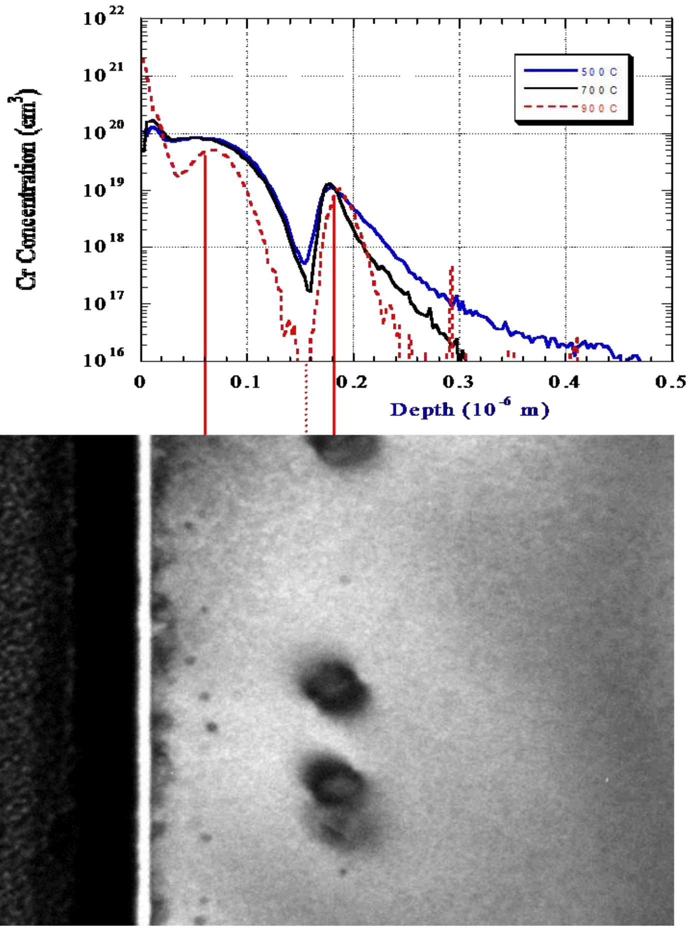
C. Magee, Evans Analytical Group

Diffusion of Implanted Cr in Si

as-implanted | after anneal



a) Cr as implanted in Si



b) SIMS depth profiles [top] and associated bright field TEM image of 900°C-anneal of Cr-implanted Si. [bottom]

SIMS

TEM

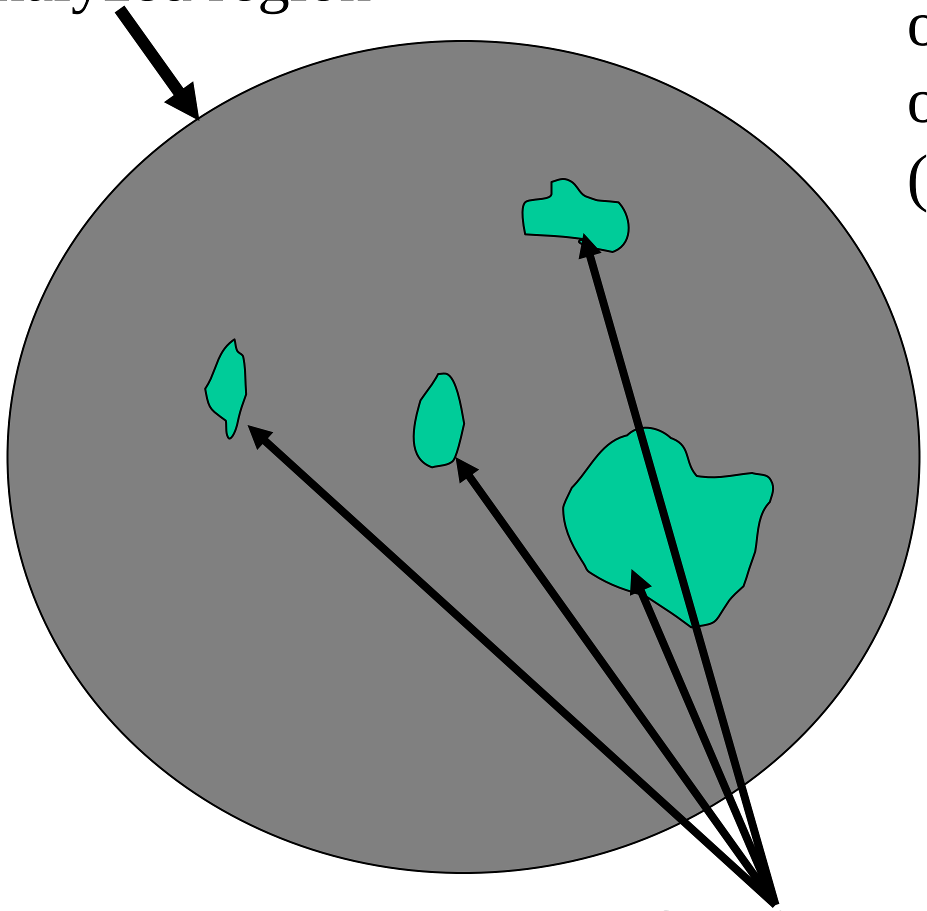
H. Francois St. Cyr, et al. Univ. Central Florida

CAMECA IMS-3f (60µm analyzed diameter)

Non-uniform Distribution

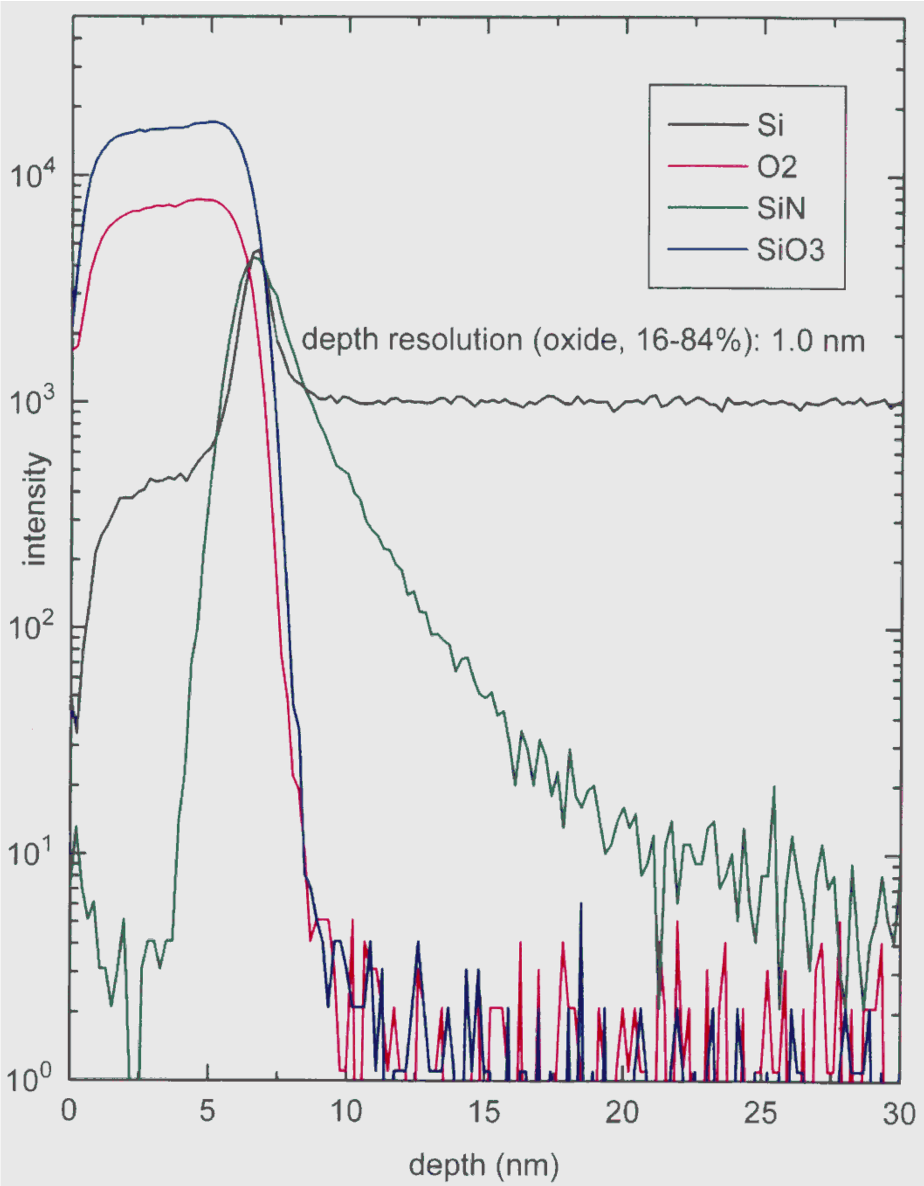
Cr after anneal at 0.2μm on previous slide is uniform on 60μm scale (variations <1μm)

Analyzed region



Species not uniformly distributed

Nitrided Gate Oxide



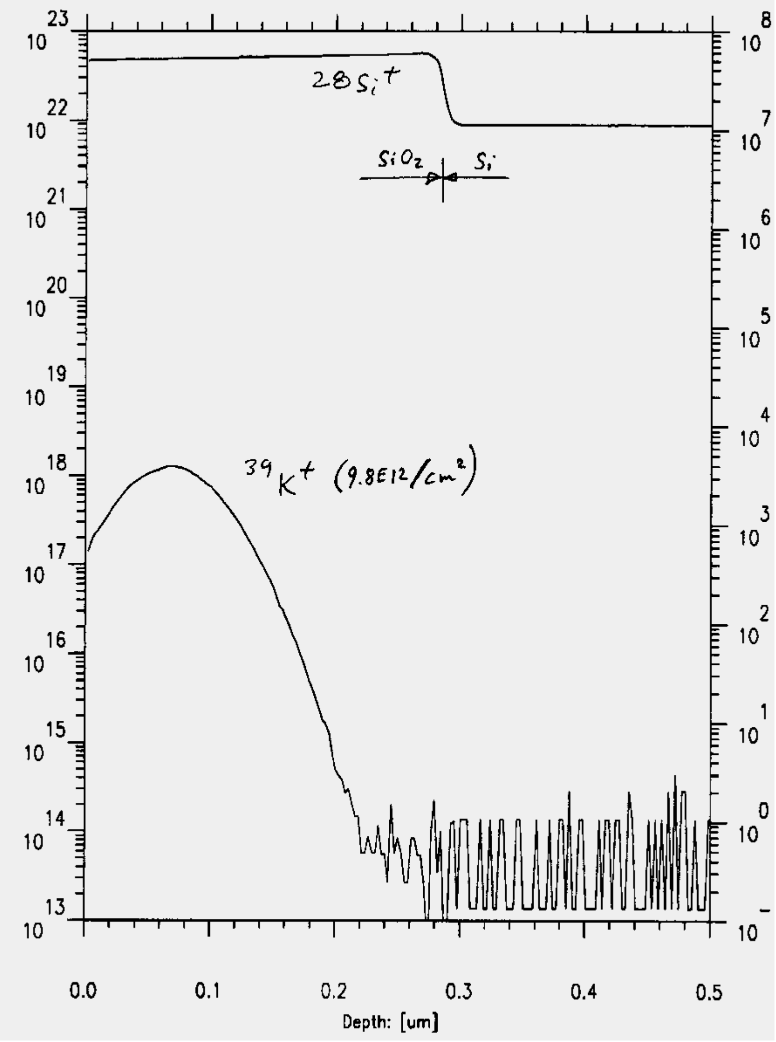
TOF-SIMS Depth Profile

7 nm oxide/Si with nitride at interface

Sputter:1 keV Cs^+, negative ions
250 µm x 250 µm
Analysis: 11 keV Ar^+
25 µm x 25 µm

TOF-SIMS IV

Gate Oxide



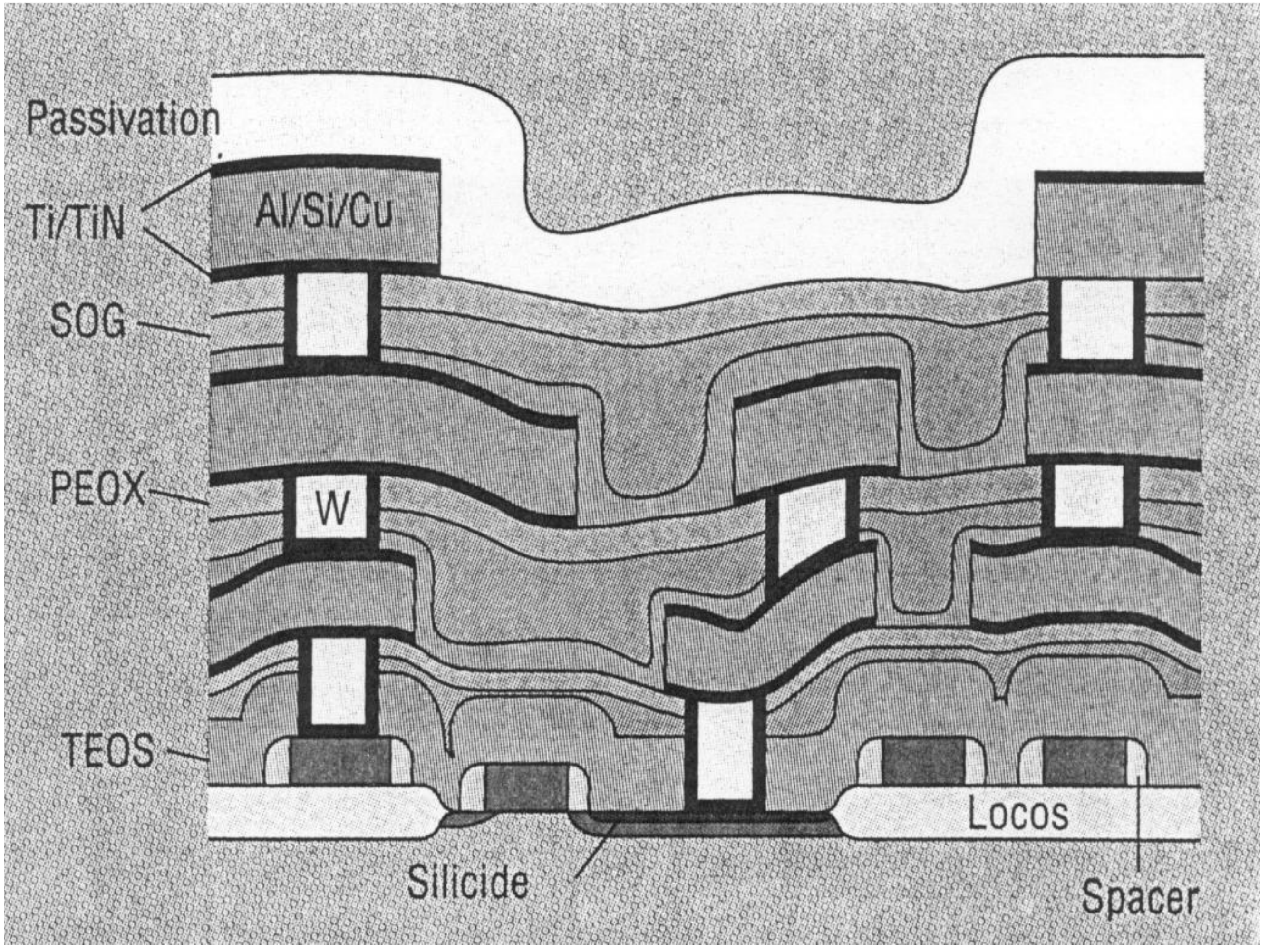
- Li, Na, K contaminants in oxide can be mobile when voltage is applied
- Need to monitor at high sensitivity

^{39}K in SiO_2 9.8E12/cm^2

Baseline at 7E13/cm^3 or 1.4 ppb (atomic)

CAMECA IMS-6f

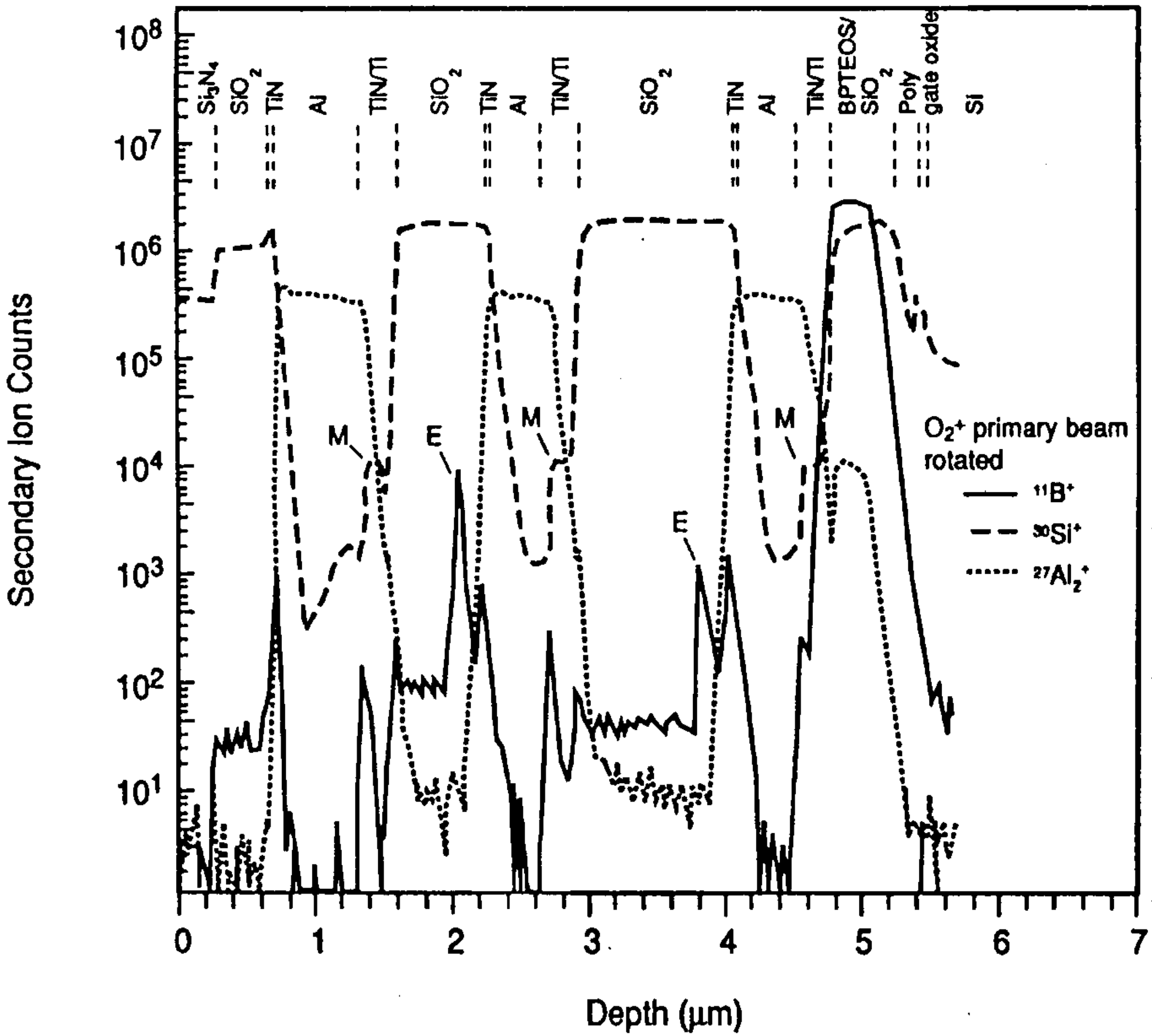
Schematic of 3-Level Interconnect Scheme



0.5 µm semiconductor device generation

B. Roberts, A. Harrus, R. L. Jackson, Solid State Technology (Feb. 1995) 69

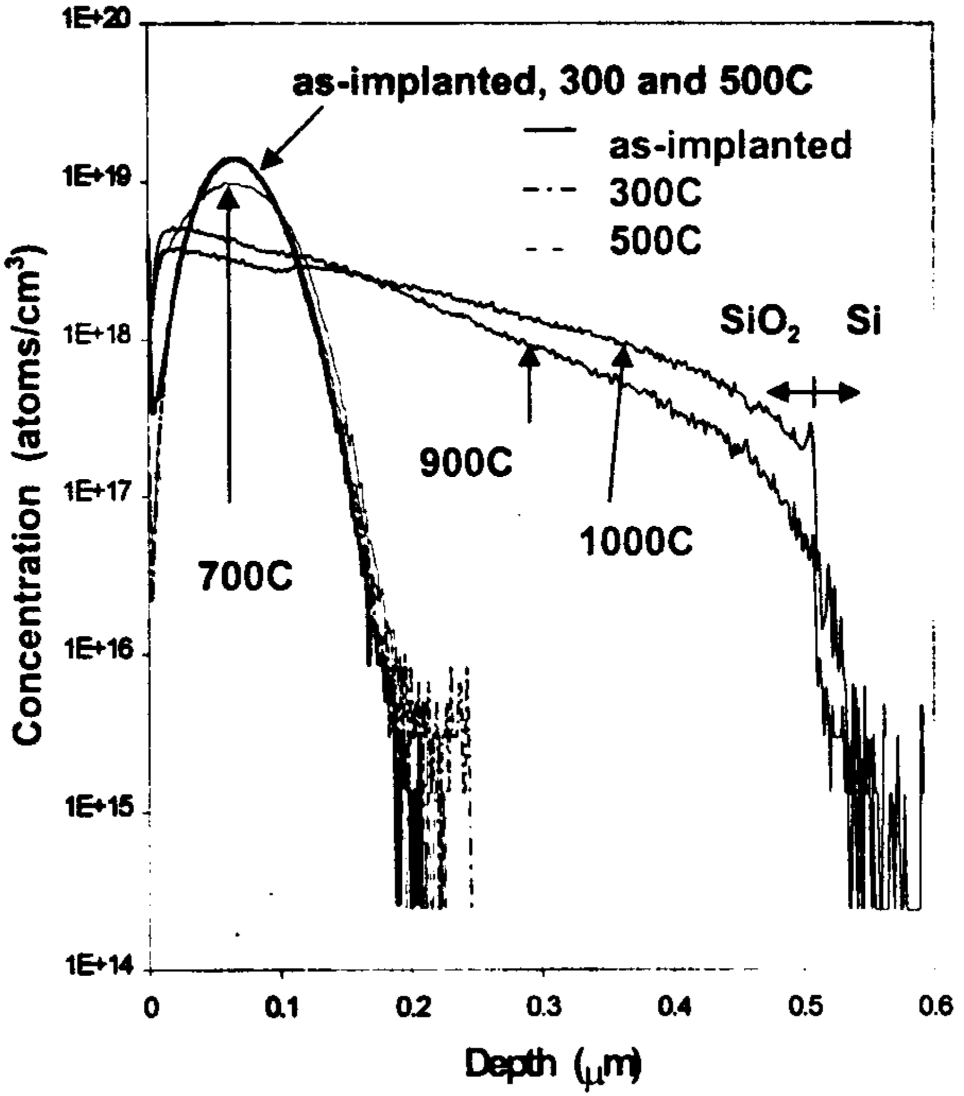
Sample Rotation for Metal Layers



O_2^+ primary beam SIMS depth profile of 3-level metal structure obtained using sample rotation. The B peaks marked E are the etch-back points for SiO_2 layers. The Si features marked M are due to a mass interference.

F. A. Stevie, J. L. Moore, S. M. Merchant, C. A. Bollinger, and E. A. Dein
J. Vac. Sci. Technol. A12, 2363 (1994)

Diffusion in Barrier Layers



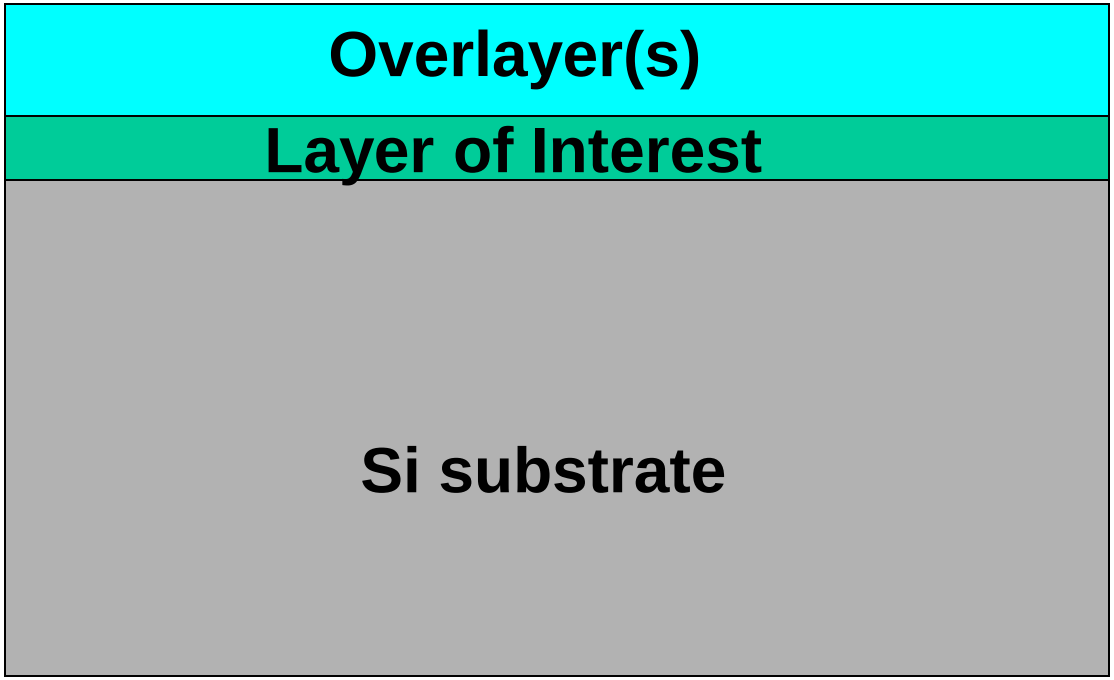
SIMS Depth Profiles

Cu in Si_3N_4 layer on Si
as implanted and after anneals

K. K. Harris, et al., Adv. Metallization Conf. Proc., Materials Res. Soc. (2000) 307

Back Side Analysis Method

- Avoid roughening from sputtering of metal layers
- Eliminate memory effect when sputtering through high concentration layer when low concentration is to be detected
- Material chemically etched or mechanically polished



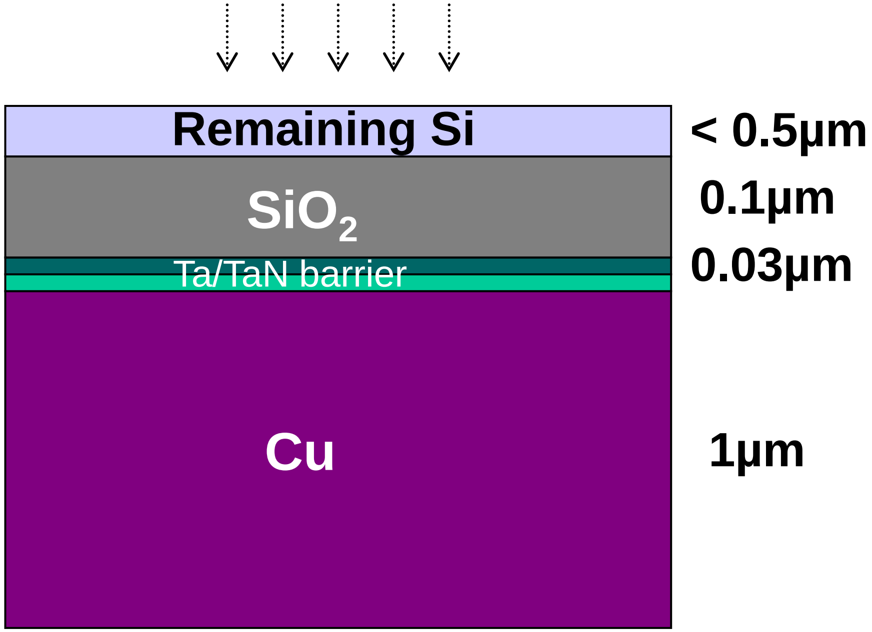
Back Side Polish Method

- **Mount sample in a way to provide conductive path from polished sample surface to sample holder**
- **Polish evenly to remove substrate**
- **Highly polished surface parallel to layer of interest**
  - **roughness less than few nm**
- **Successful polishing requires ability to:**
  - **Make angular adjustments to insure parallelism**
  - **Measure remaining thickness of material**

Back Side Analysis of Cu Barrier

Sample Structure
$Cu/Ta/TaN/SiO_2/Si$(substrate)

After removal of 750 μm Si



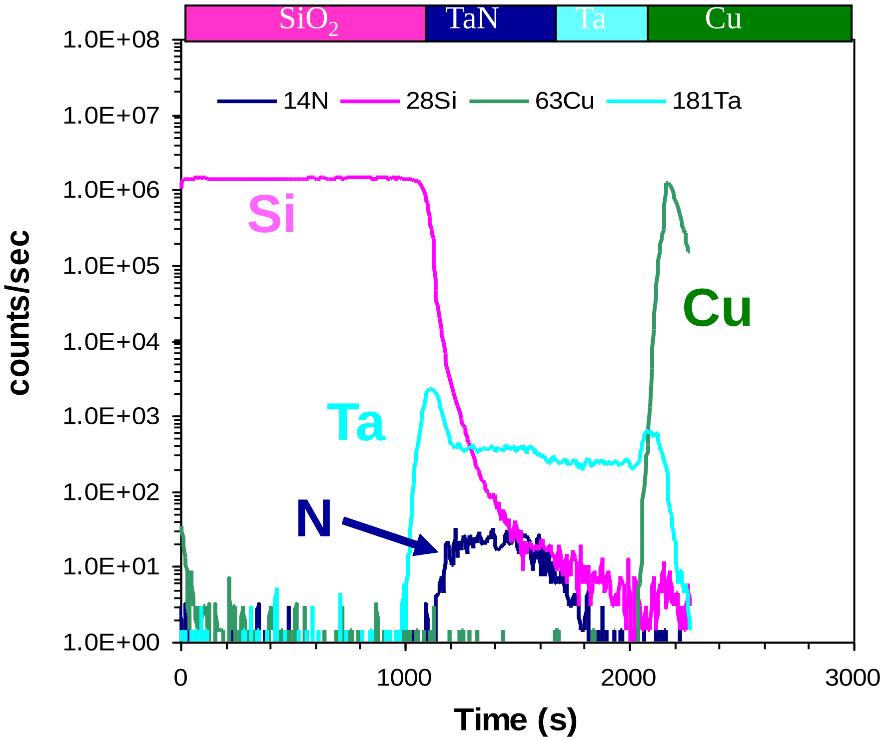
Front side

- Ta/TaN barrier used to prevent diffusion of Cu into SiO_2 or Si
- Use backside analysis to study trace Cu and avoid sputter through Cu layer
- Samples can be backside polished having only 2.5nm slope over 60μm in the SiO_2 layer

C. Gu et al., J. Vac. Sci. Technol. B22, 350 (2004)

Backside SIMS Analysis of Cu Barrier

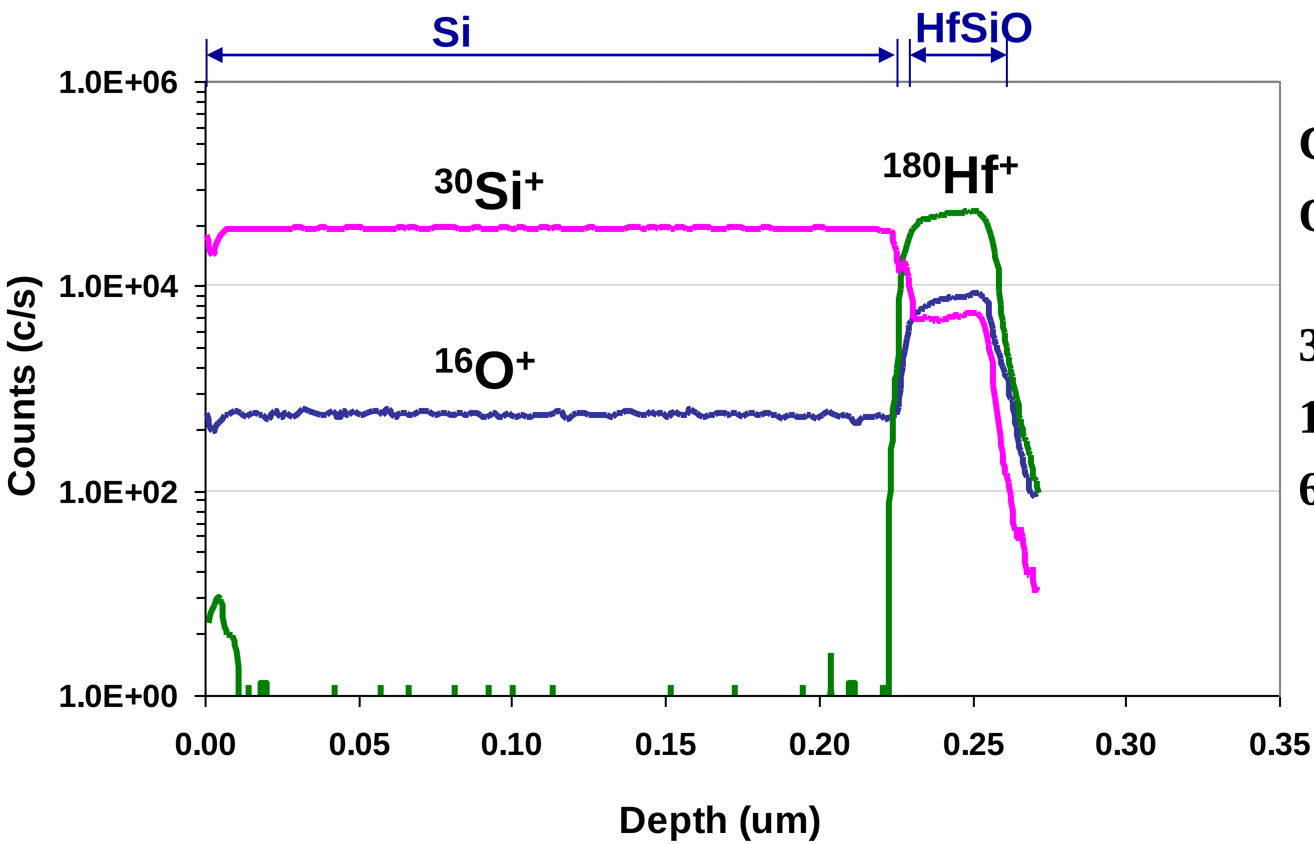
O_2^+, 1.2kV primary / 0.7kV sec e^- beam - 3.2 keV impact



- Low energy ion beam (500eV impact energy) provided well resolved SiO_2/TaN/Ta/Cu structure
- Electron beam charge neutralization needed due to charging of SiO_2
- TaN and Ta layers readily distinguished
- Cu not detected in barrier layers or SiO_2

C. Gu et al., J. Vac. Sci. Technol. B22, 350 (2004)

Back Side Analysis of 25nm $Hf_xSi_yO_2$



CAMECA IMS-6f

O_2^+ 1.25keV impact energy 48.5º

30nA beam current

190µm raster size

60µm detected dia.

- **Depth profile is sputter rate corrected**
- **Hf^+ leading edge: 1.3nm/decade**

F. A. Stevie, C. Gu, J. Bennett, R. Garcia, and D. P. Griffis SIMS XV, Appl. Surf. Sci. 252, 7179-7181 (2006)

Polymer Layers

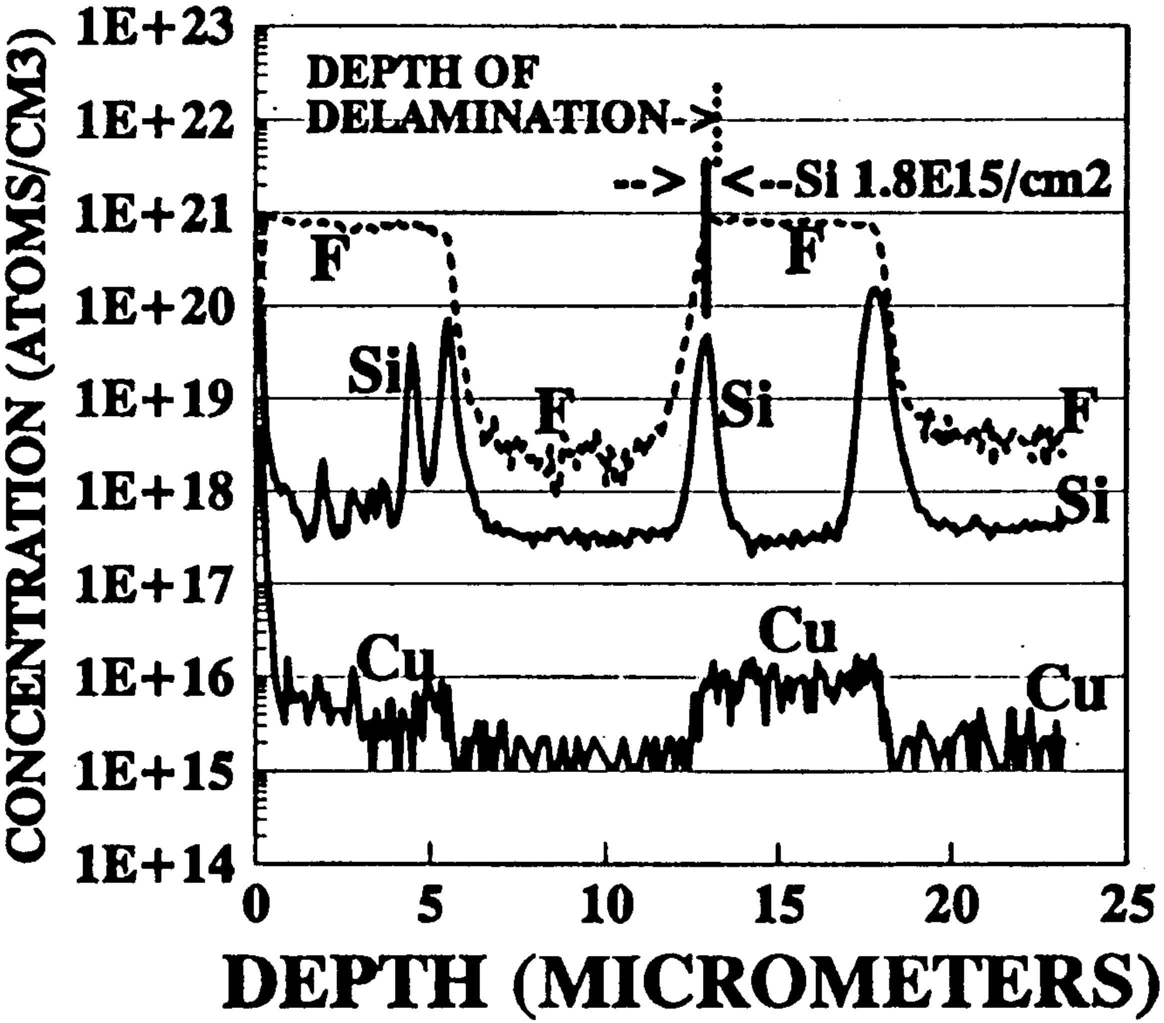
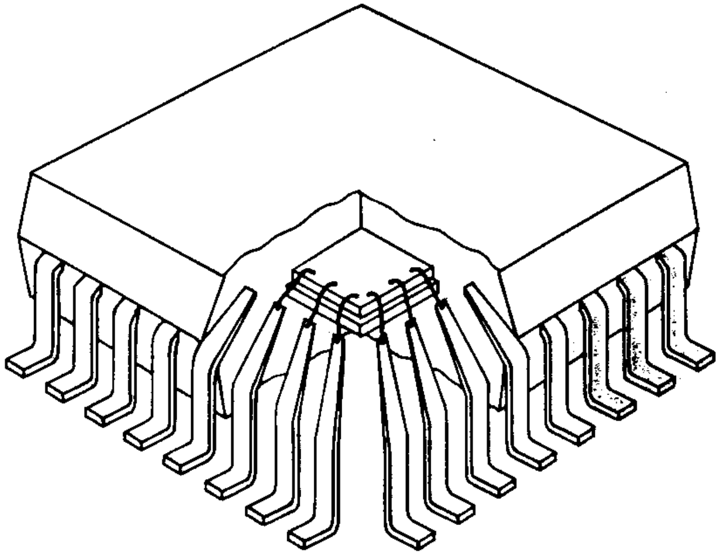
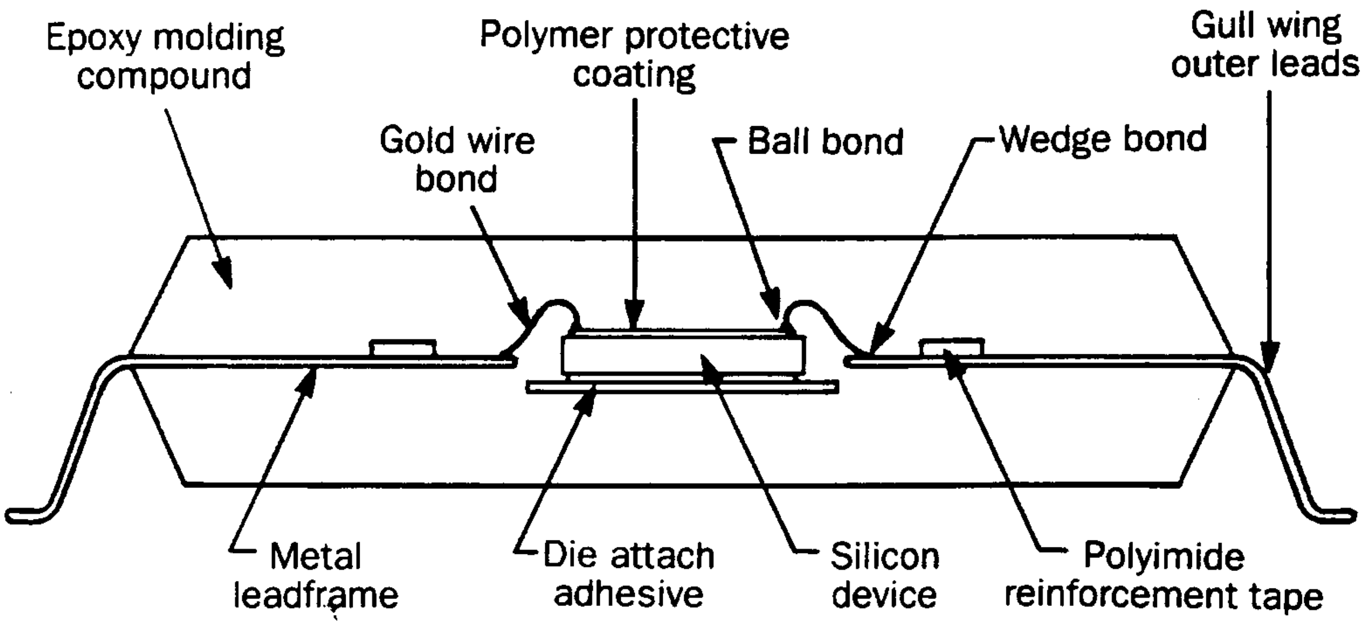


FIG. 3. SIMS depth profile of a polymer stack of alternate F-containing and standard polyimide. Immediately adjacent to this analysis area was a region where the top 13 μm of polyimide had delaminated.

C. C. Parks, J. Vac. Sci. Technol. A15, 1328 (1997)

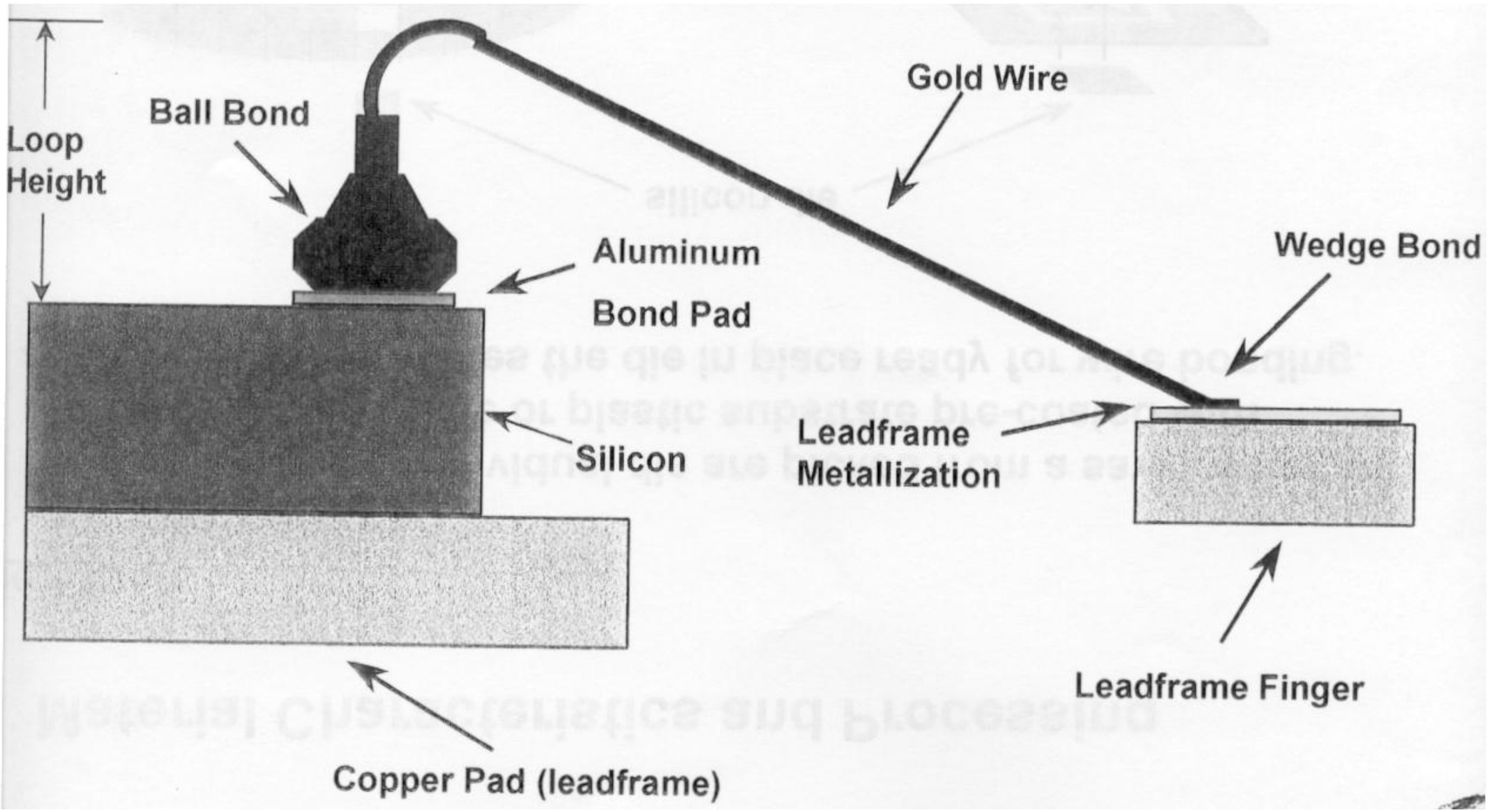
Packaging



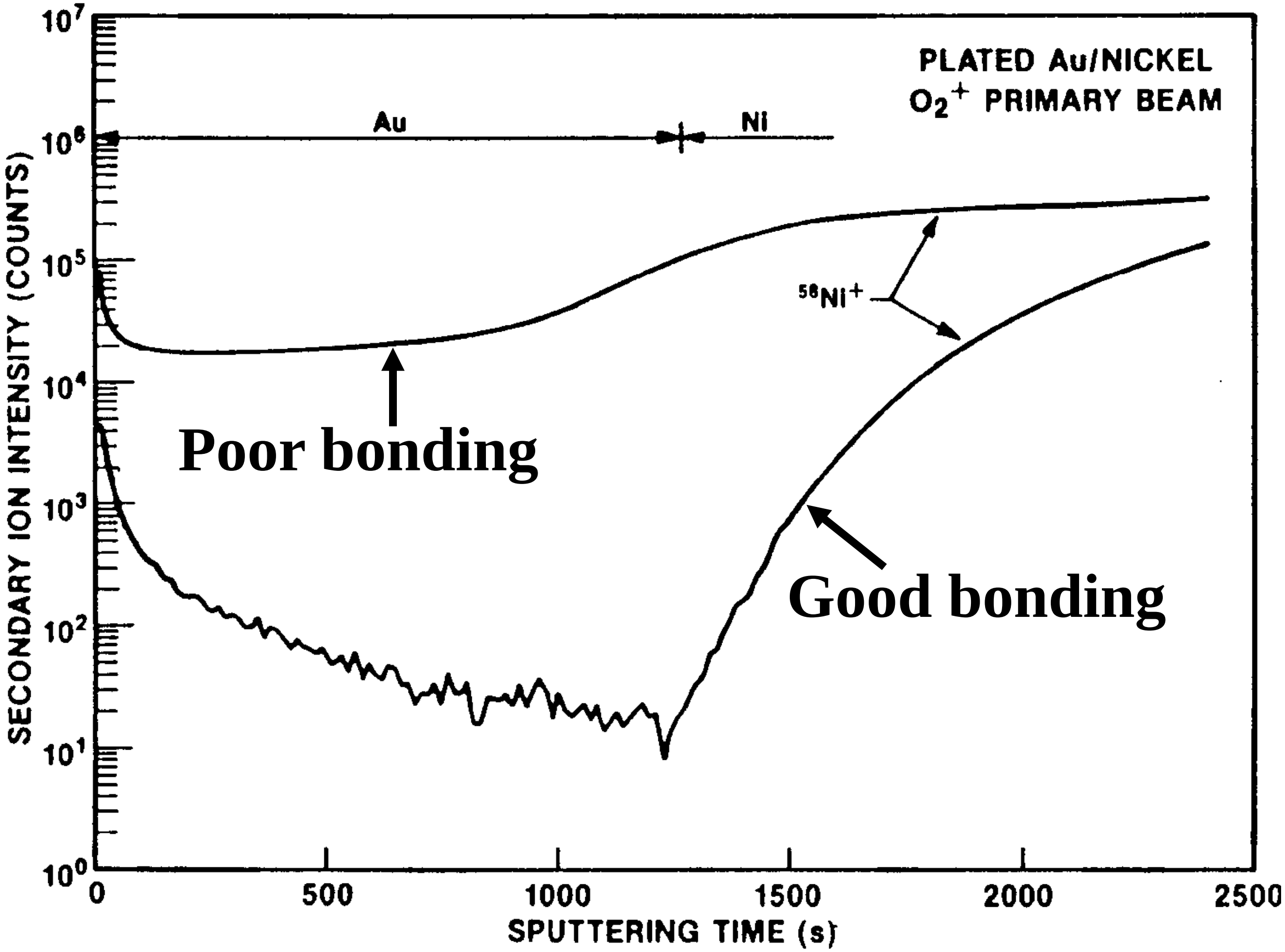

Epoxy molding compound
Polymer protective coating
Gull wing outer leads
Gold wire bond
Ball bond
Wedge bond
Metal leadframe
Die attach adhesive
Silicon device
Polyimide reinforcement tape

Packaging

Wire Bond



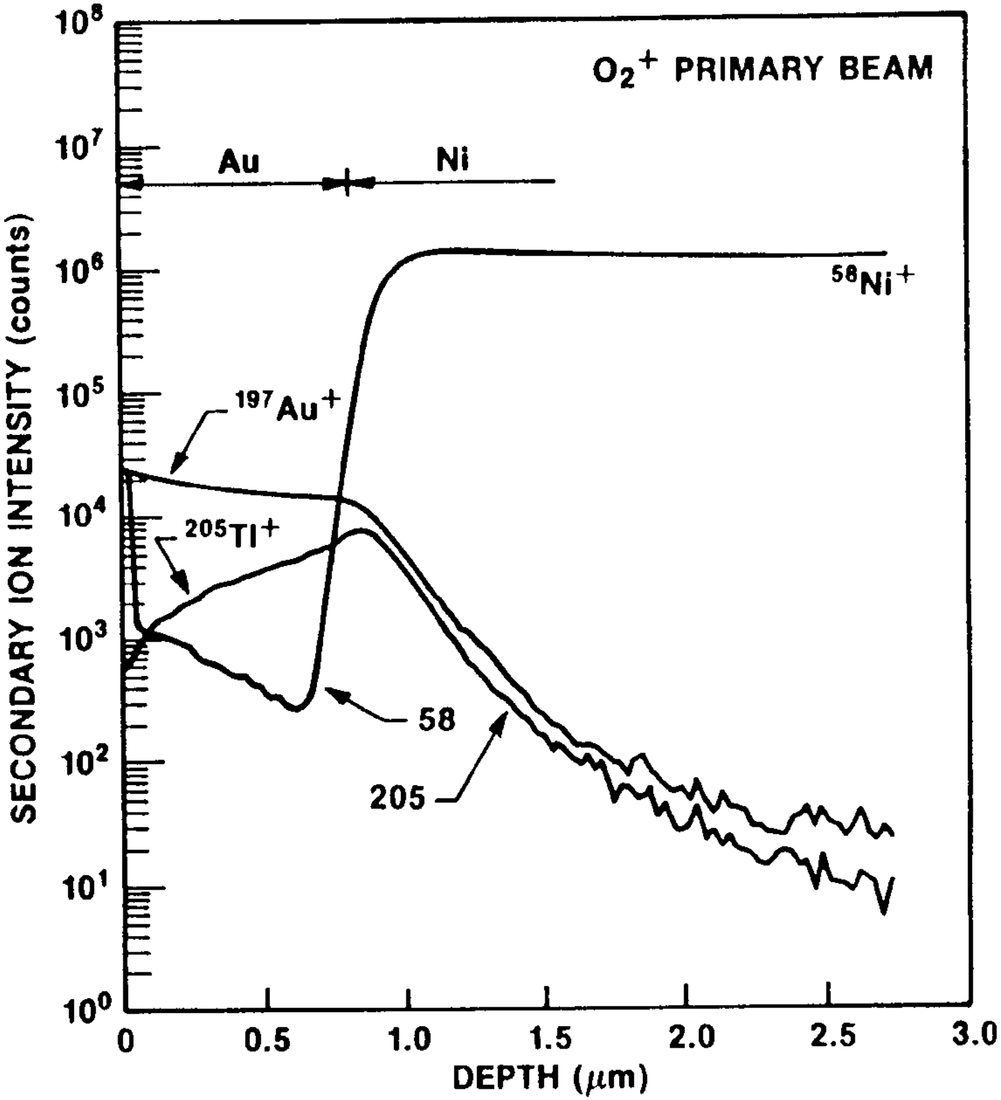
Au Plating : Ni Diffusion



Poor bonding shows Ni diffusion through Au layer

SIMS, R. G. Wilson, F. A. Stevie, and C. W. Magee
Wiley, New York (1989)

Au plating: Thallium Contamination

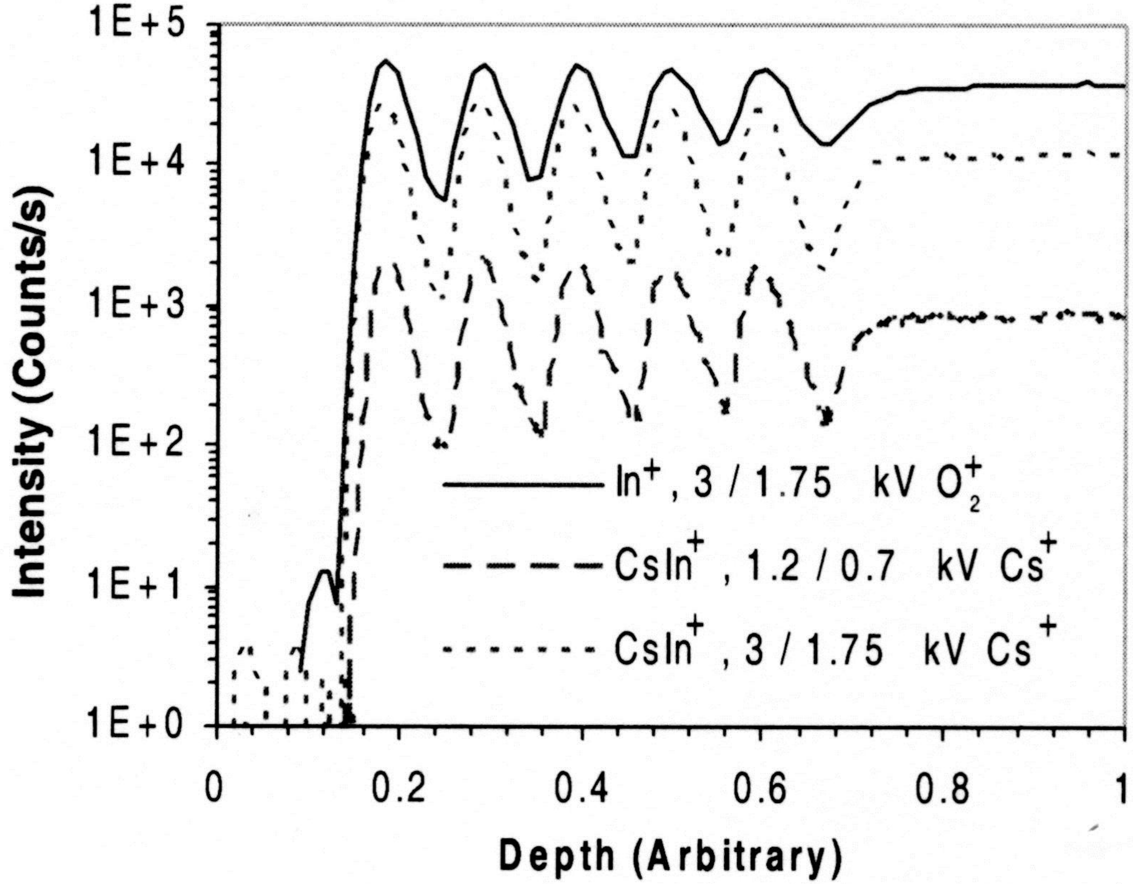


Thallium (Tl) used as hardener for Au films

Tl depth profile in a Au layer on Ni shows the Tl is nonuniformly distributed and gradually increases from the surface to the Au/Ni interface. From K. P. Moll, AT&T Bell Laboratories. Analyzed using a CAMECA IMS-3f.

SIMS, R. G. Wilson, F. A. Stevie, and C. W. Magee Wiley, New York (1989)

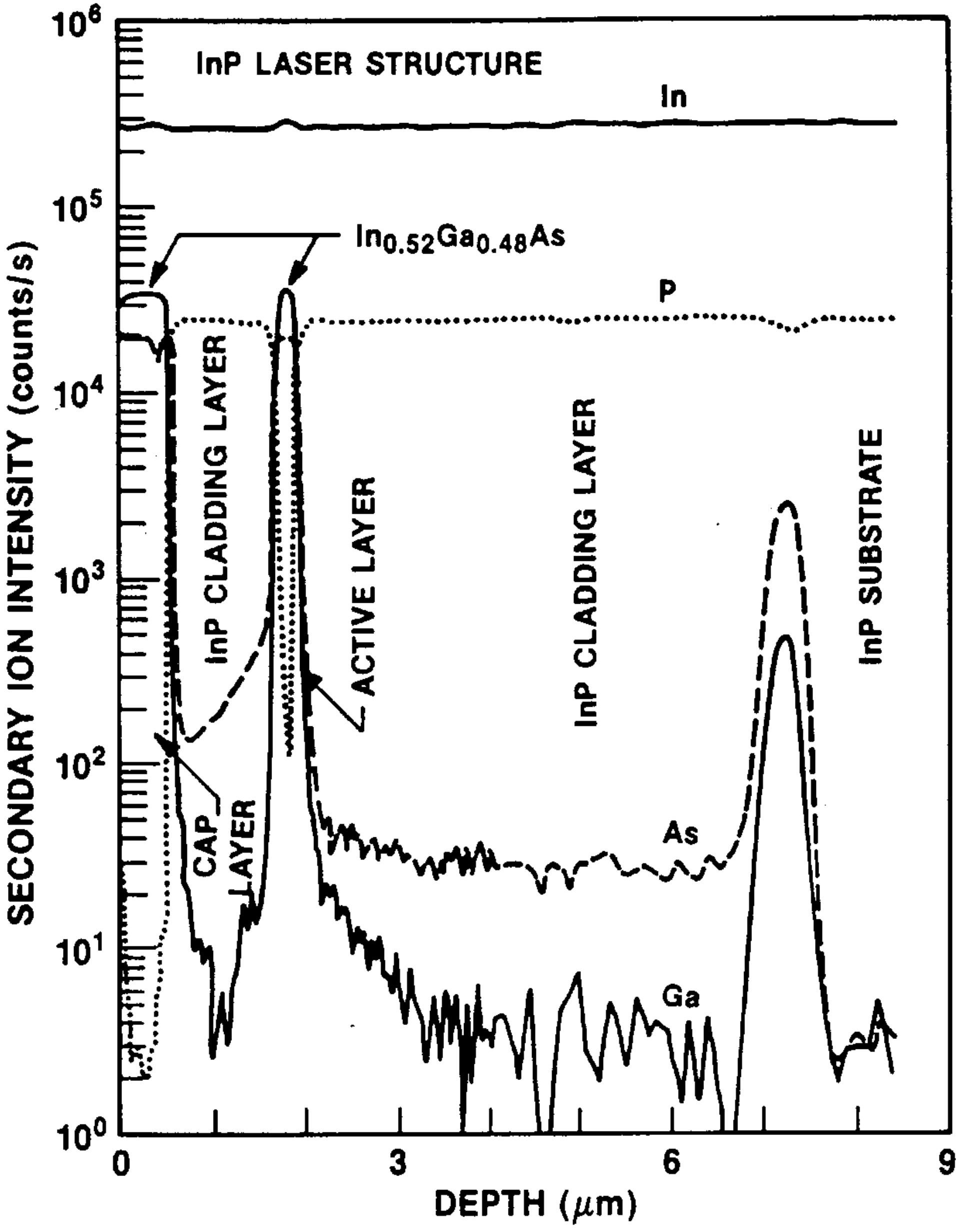
Depth Resolution in GaN Structure



InGaN/GaN layers in multi quantum well structure
at various source/sample potentials

M. Kachan, J. Hunter, D. Kouzminov, A. Pivovarov, J. Gu, F. Stevie, and D. Griffis
SIMS XIV Proceedings, Applied Surface Science 231-232, 684-687 (2004)

Lightwave: InP Laser Structure



Matrix and impurity ion species in same depth profile

SIMS, R. G. Wilson, F. A. Stevie, and C. W. Magee, Wiley, New York (1989)