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Use of Secondary Ion Mass Spectrometry as a thin film characterization tool

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Eurofins EAG

EAG background

- EAG founded by Charles Evans 42 years ago
- Purchased by Eurofins almost 2 years ago
- Eurofins
  - Started in 1987 with four people testing wine
  - 45,000 staff and 800 laboratories
  - Eurofins EAG

Overview of talk

- Introduction to Secondary Ion Mass Spectroscopy (SIMS)
  - Instrumentation
  - Fundamental physics
- Introduction to thin film characterization
  - SiON gate oxide
  - ALD thin films
- Why does SIMS characterization add value
- What are the requirements for analysis
- External calibration possibilities

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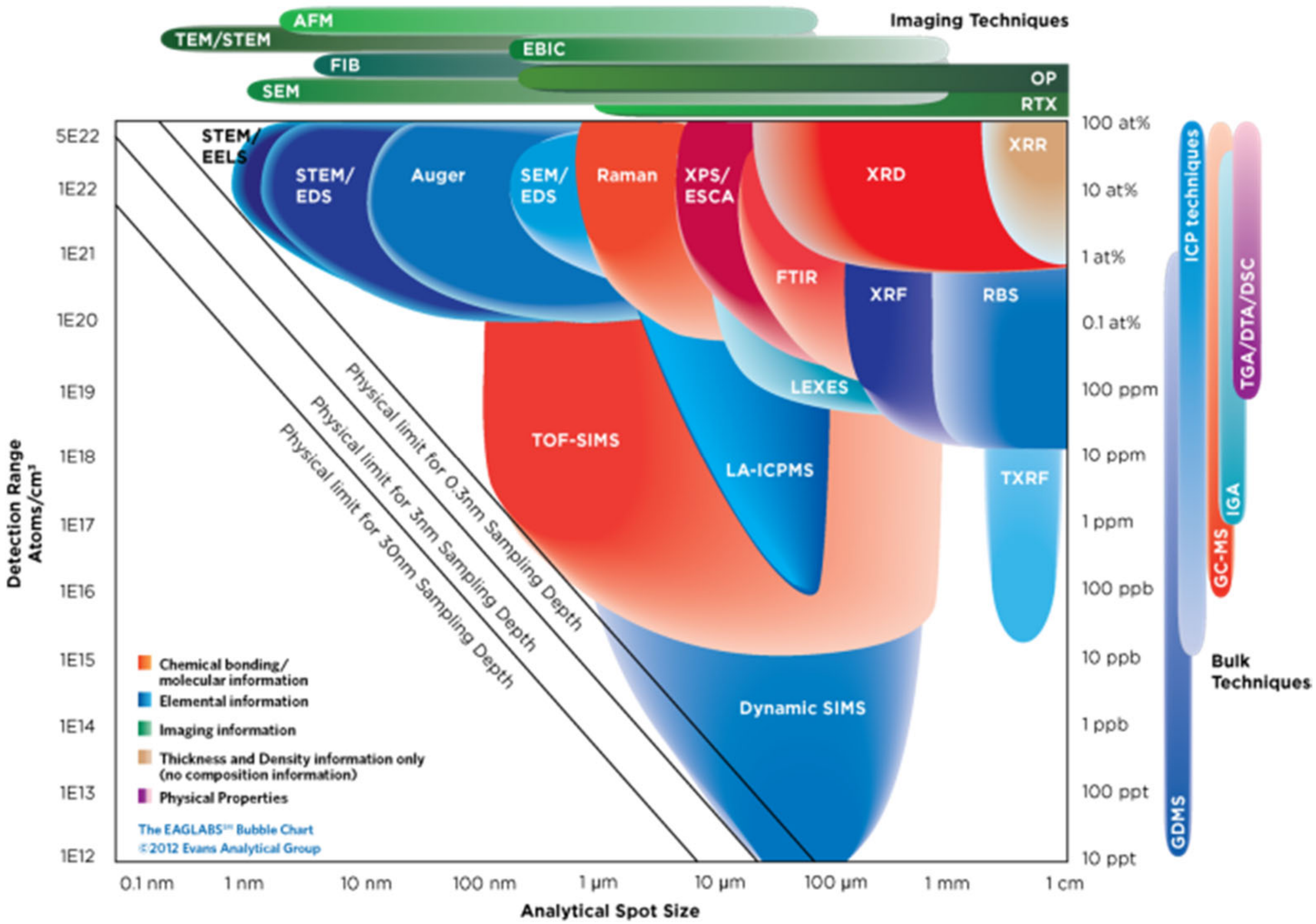
EAG Bubble Chart

Analytical Resolution vs. Detection Limit



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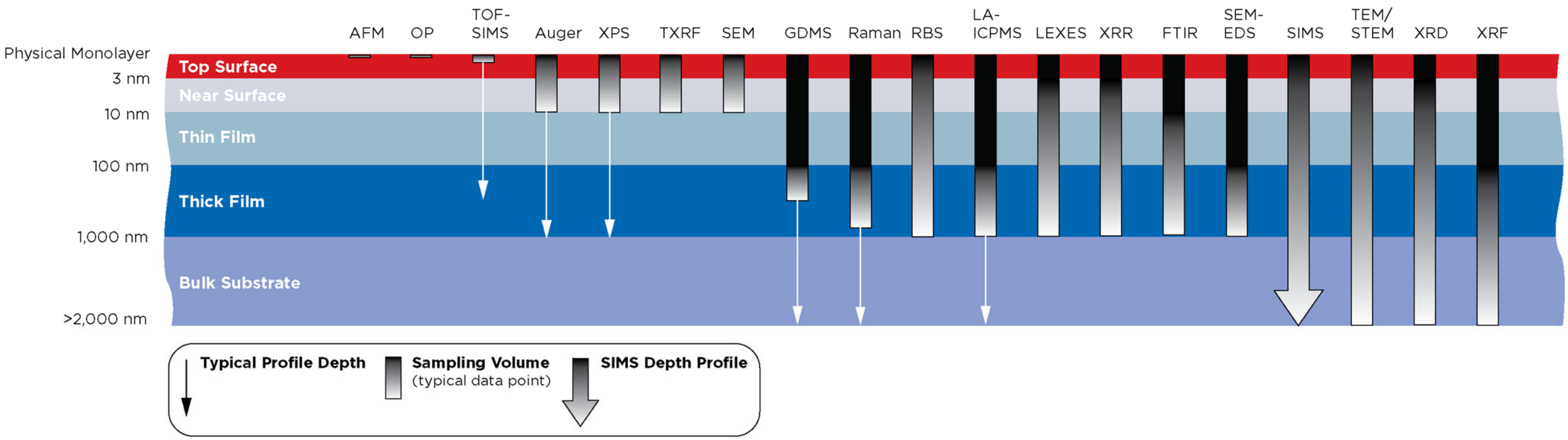
Comparing Analytical Techniques

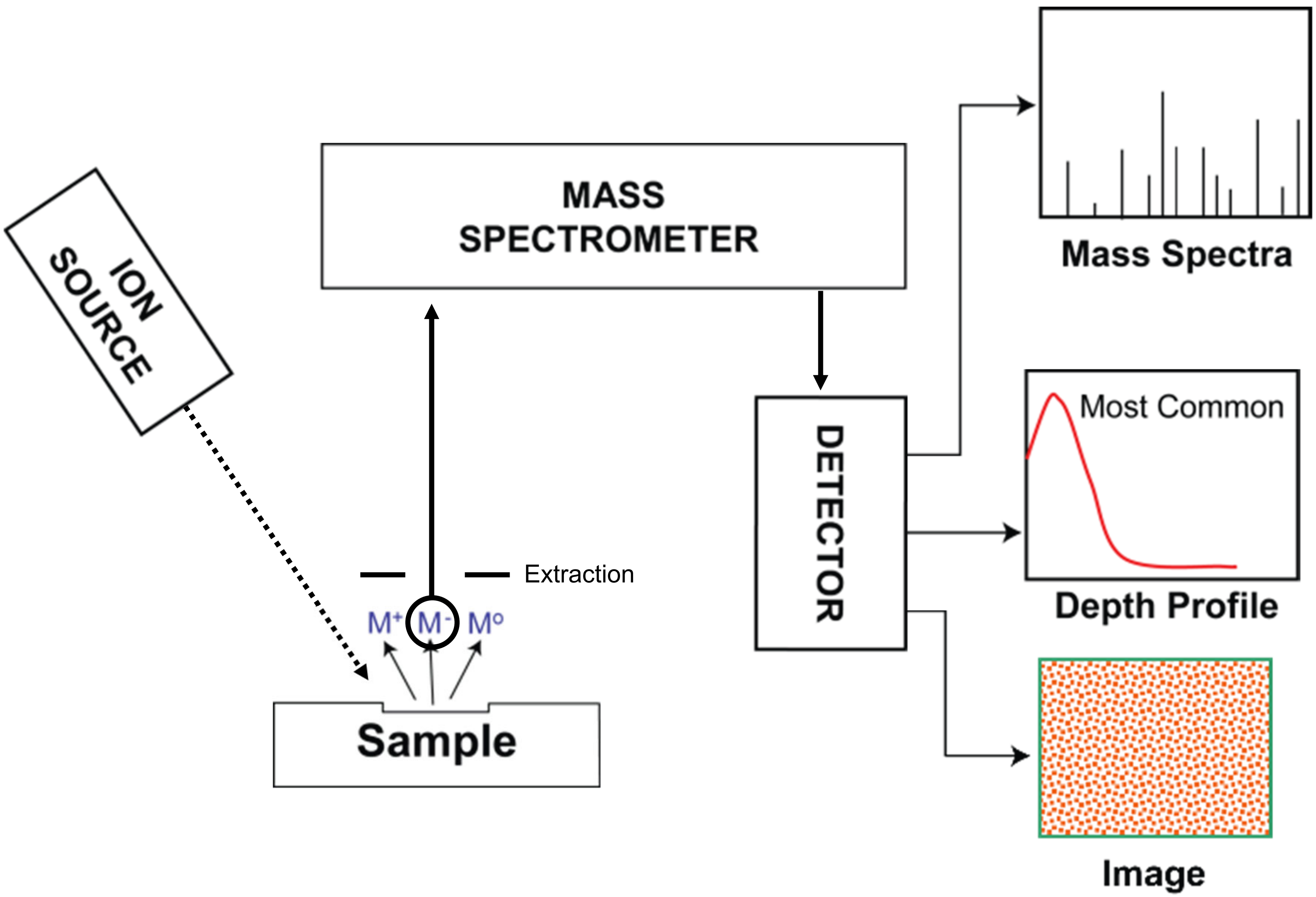
Depth of Analysis



SIMS Key Applications

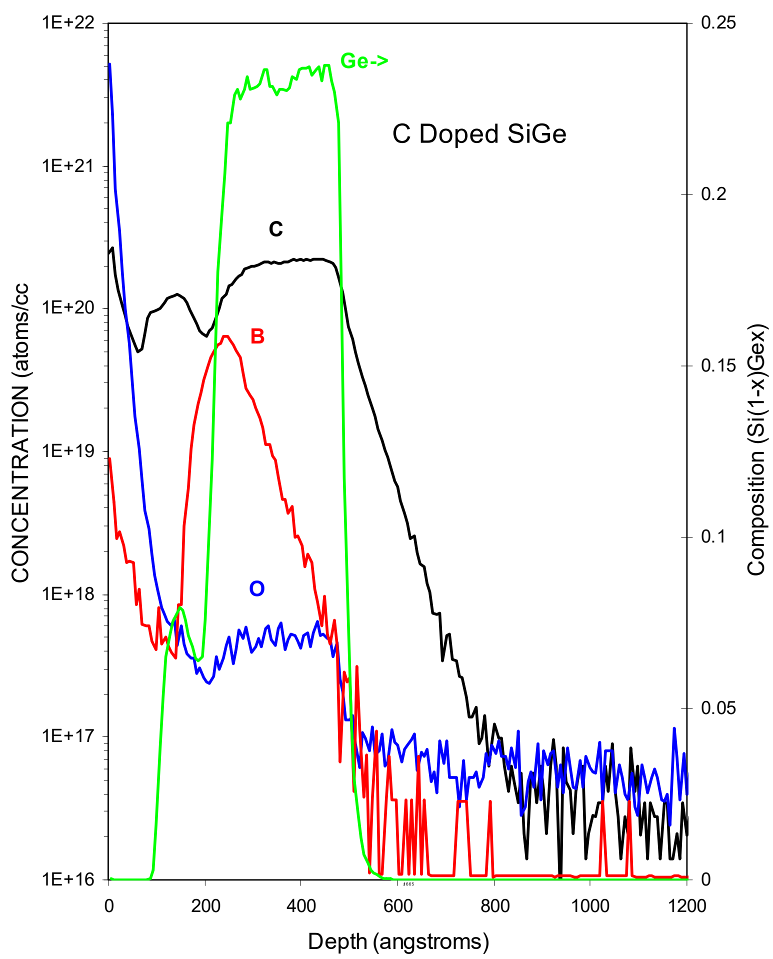
- Typical applications include
  - Trace element profiles
  - Major element profiles
  - Survey element profiles
  - Layer structure
- Typical Materials analyzed
  - Semiconductors
  - Dielectrics
  - Metals
  - Polymers

SIMS Technique

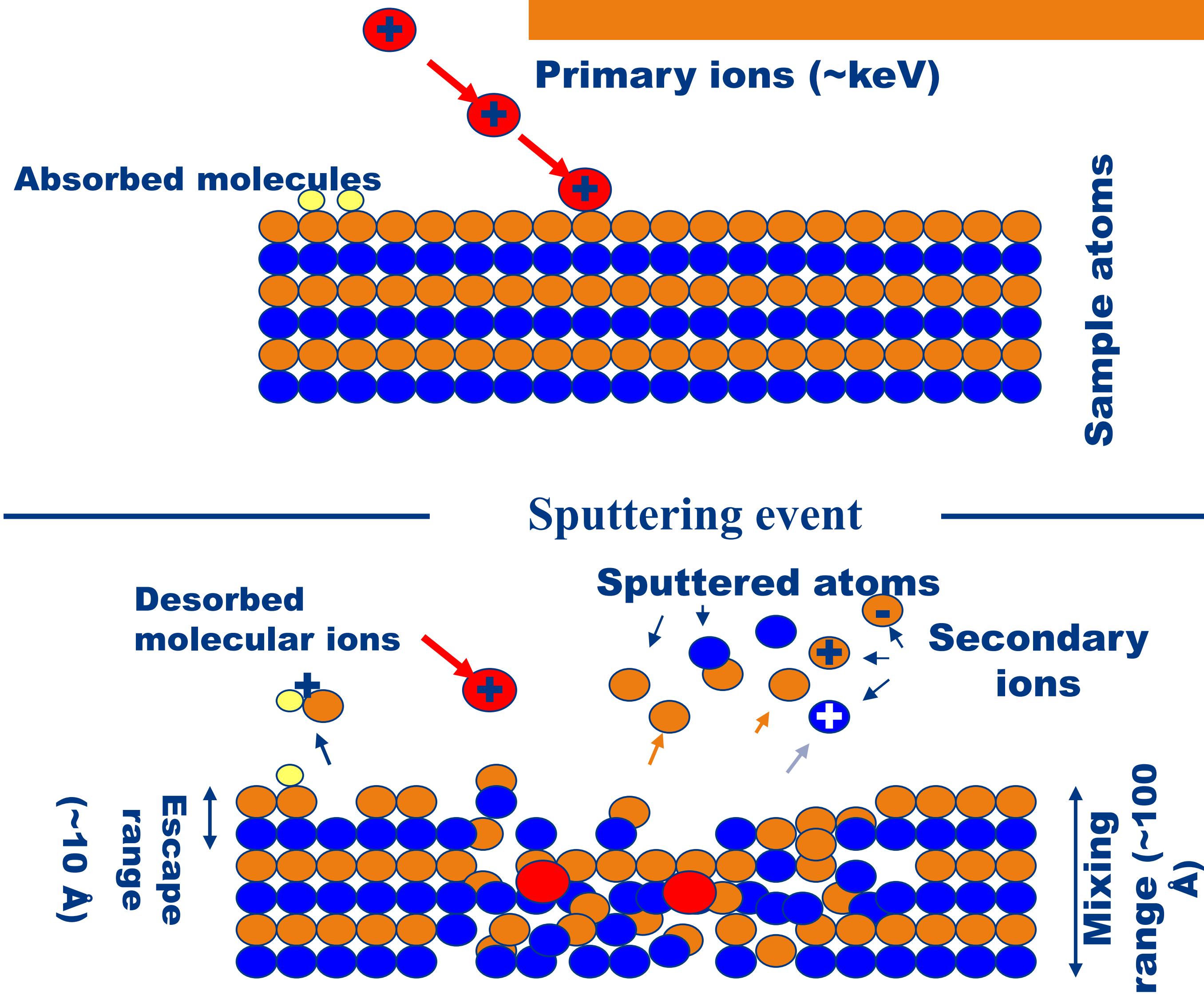


Typical Data

Si cap layer
SiGe ramp: B doped
SiGeC
Si Substrate

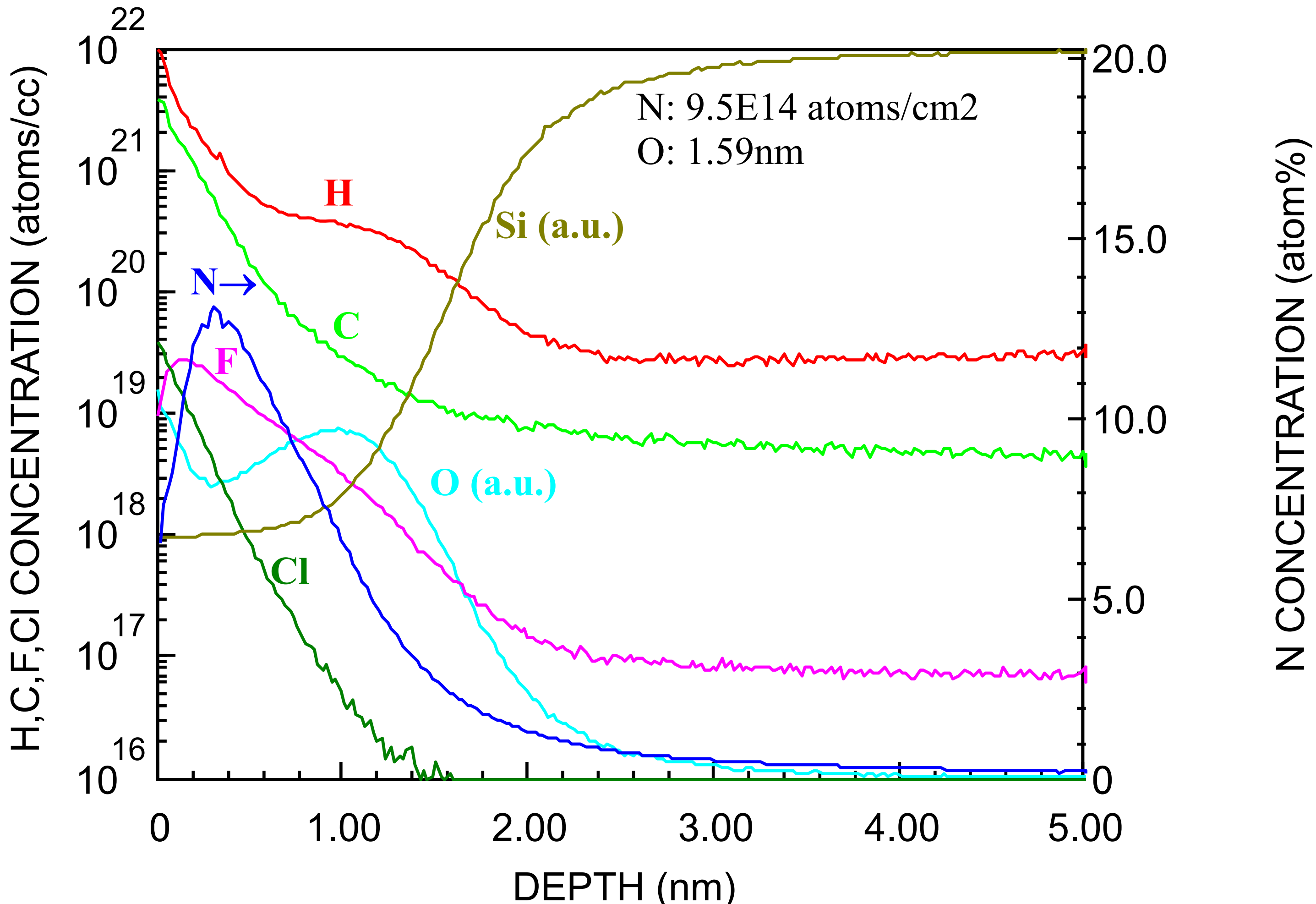


Basic Sputter Process in SIMS



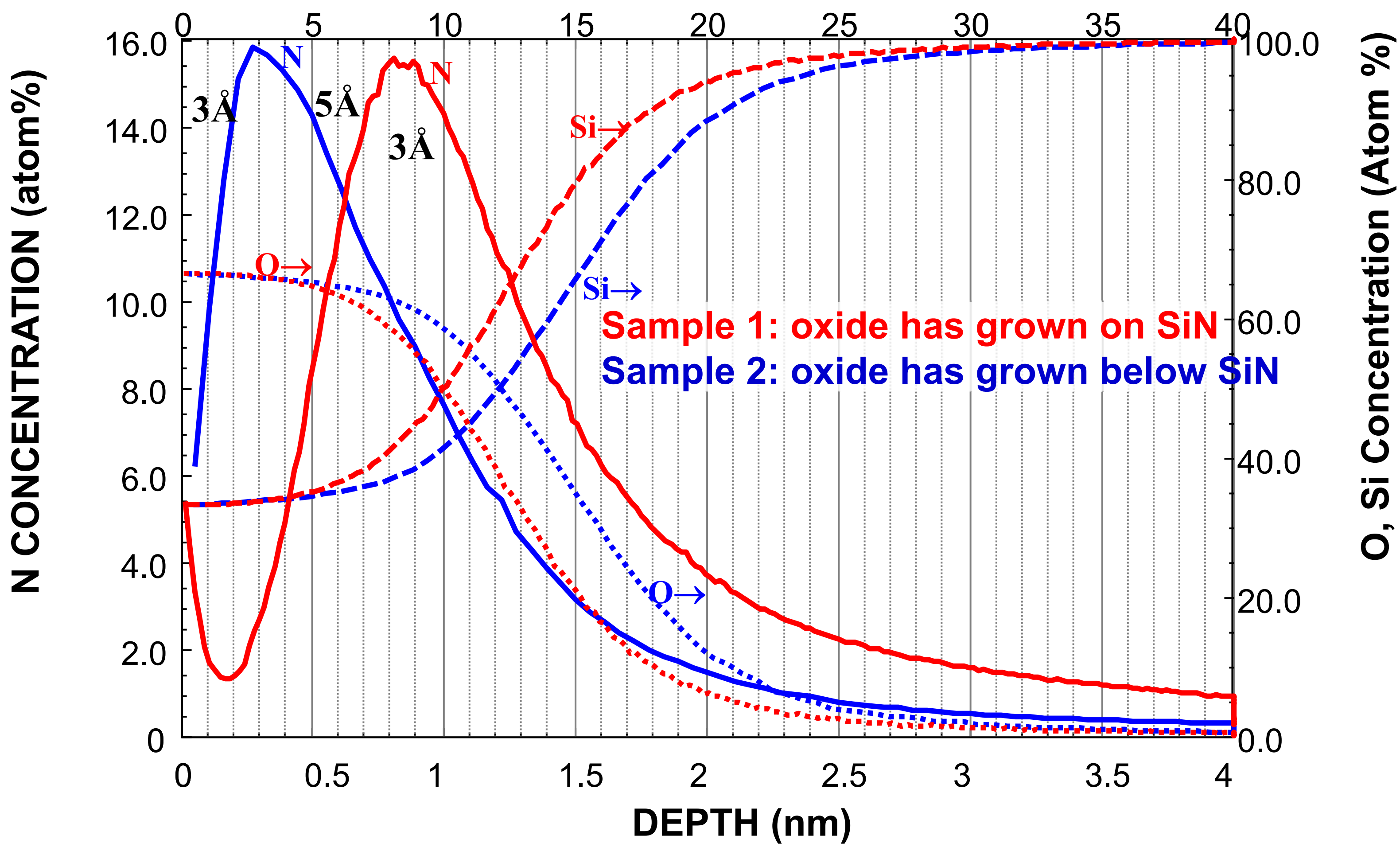
Gate oxide analysis

Oxide thickness, N areal density, F dopant



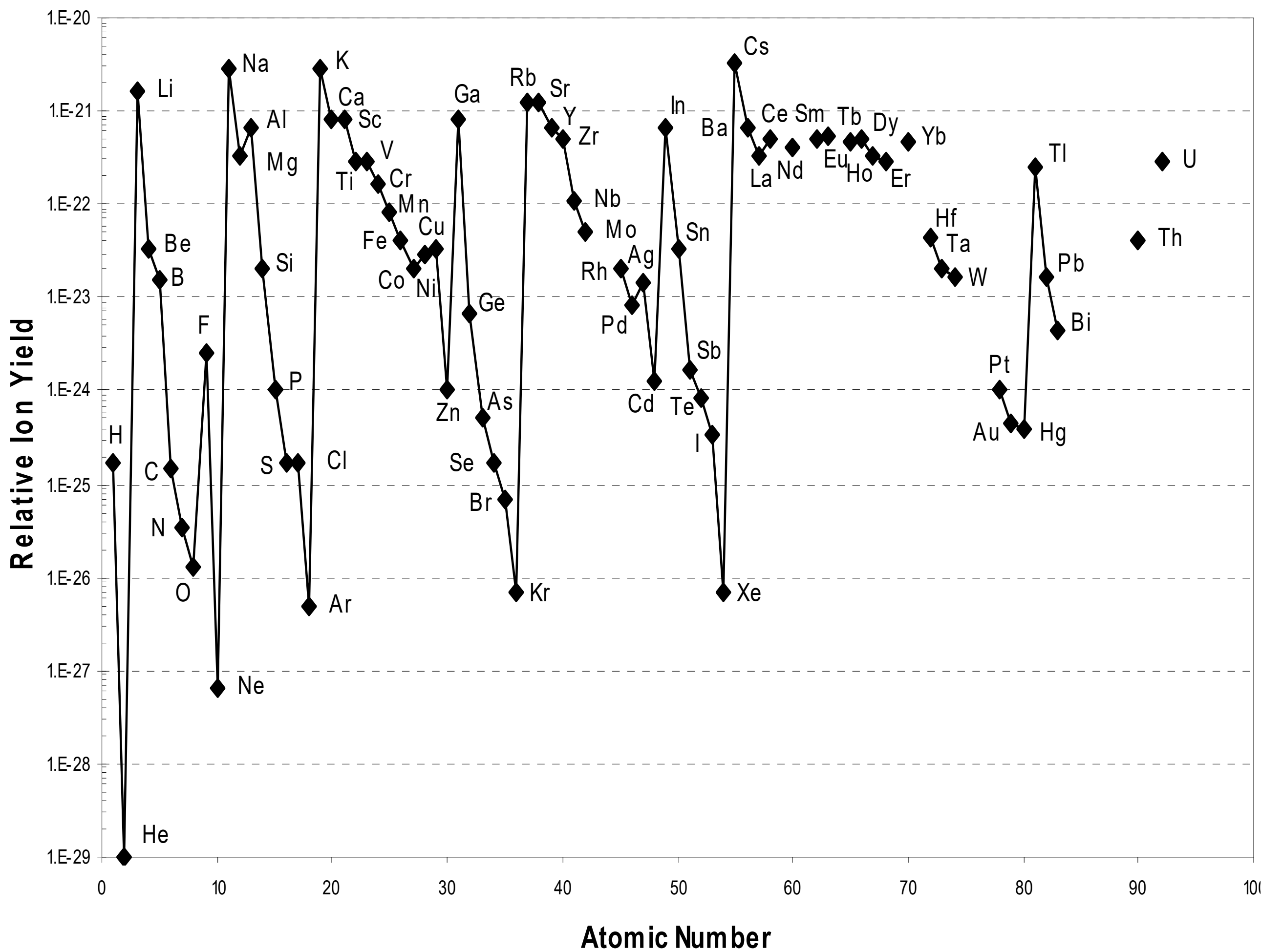
Thin film depth resolution

Difference between samples on the order of one atom layer



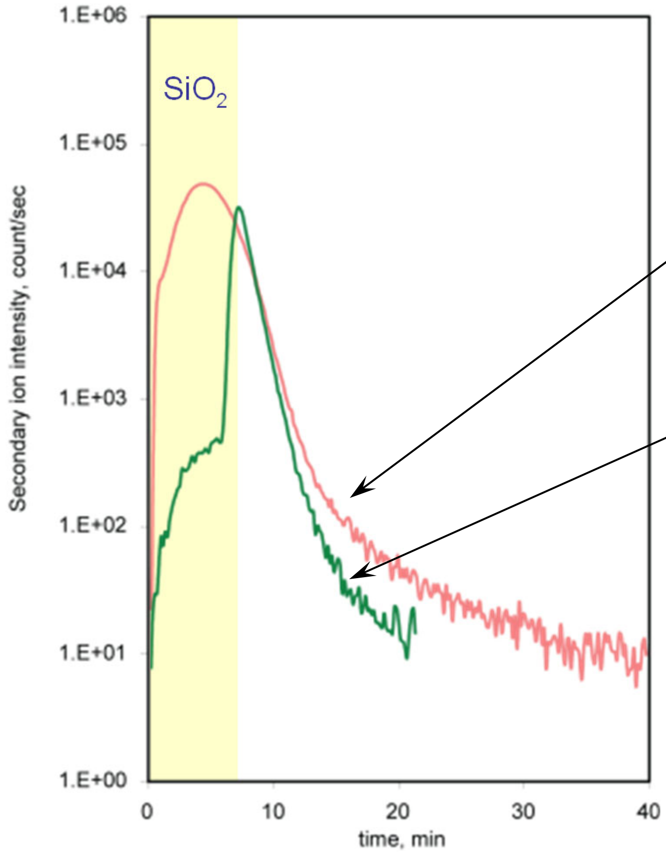
SIMS Quantification: Effect of Element

Positive Ion Yields in Silicon



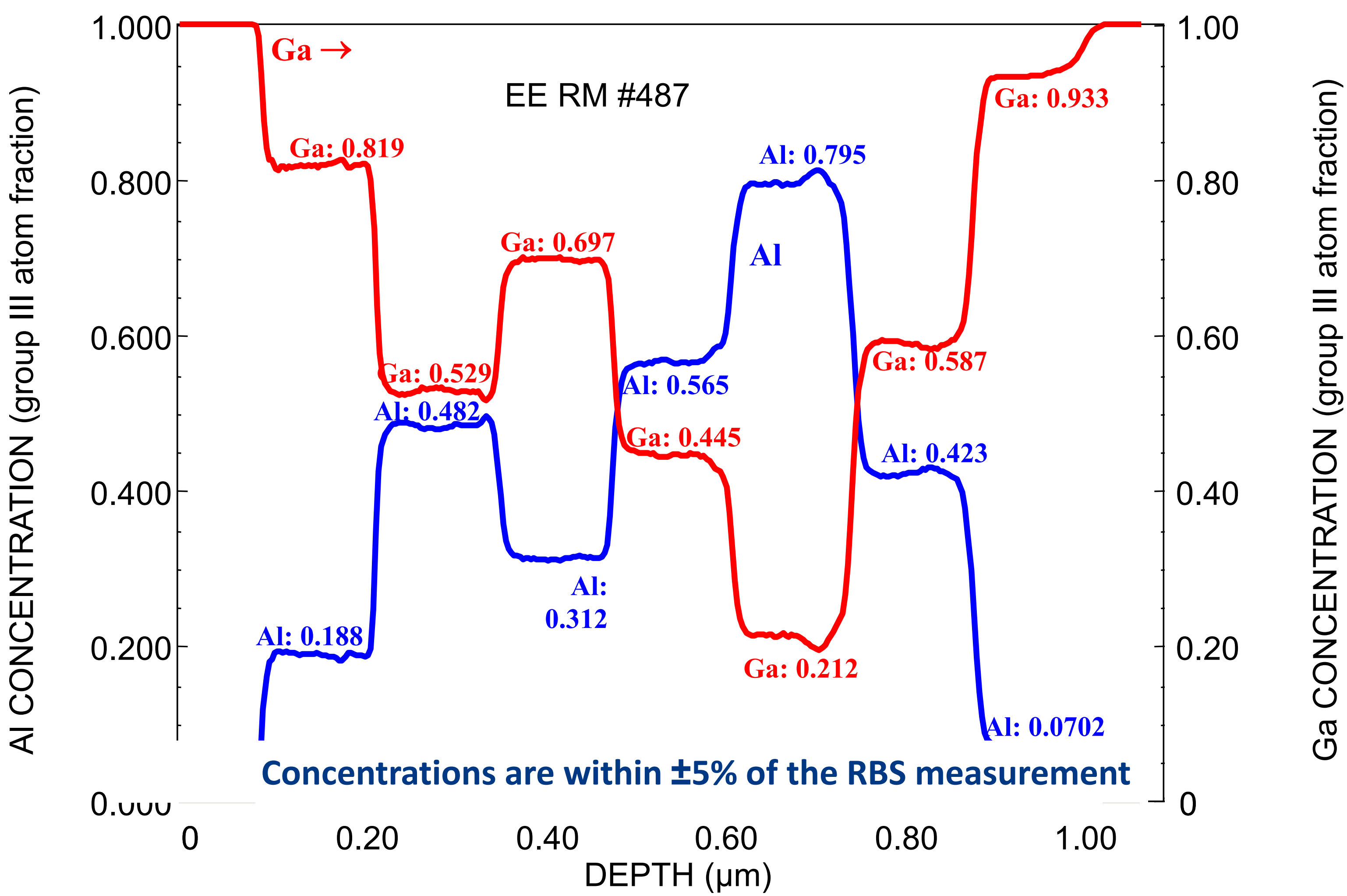
- Secondary ion yields can change by 6 orders of magnitude or more!
- We cannot calculate or predict ion yields (many have tried and failed)
- Ion yields depend strongly on the analysis **element**

SIMS Quantification: Effect of Matrix



- Ion yields depend just as strongly on the sample Matrix.
- Arsenic implanted into silicon shows the familiar implant profile shape.
- The same implant into SiO_2 on Si looks dramatically different.
- The reason? The ion yield for arsenic in oxide is MUCH different.

Composition of AlGaAs



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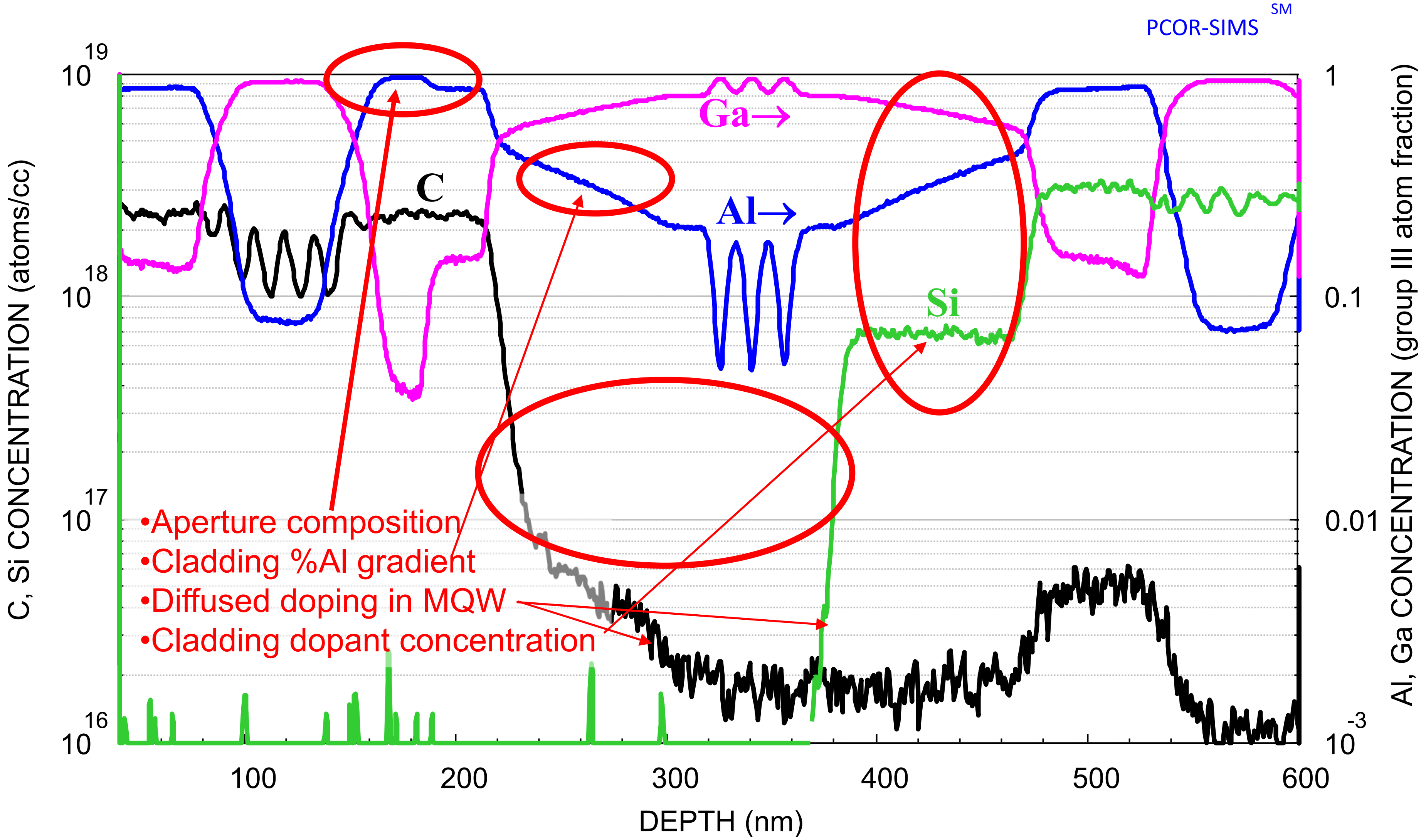
VCSEL active region



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Accuracy in Multi-layer Stack

- Case of dopants in semiconductor we use PCOR-SIMS to calibrate in layers of varying composition. Examples include SiGe, AlGaAs, InGaAs.
- Case of contaminants in metal or dielectric stacks – ion yield changes may not be corrected.

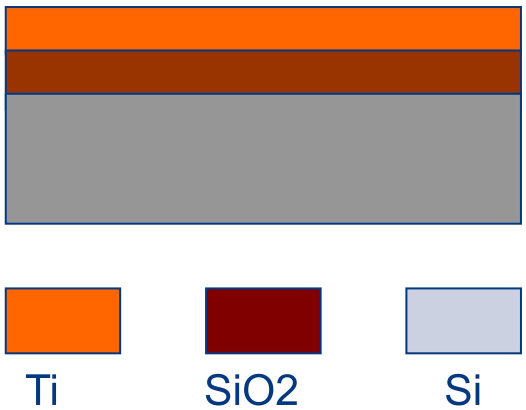
1. *Calibrated using XXX standards, calibration in other layers may have 2x error*
2. *No sputter rate change with composition applied*
3. *Profile tails may be compromised by morphology / roughness*

Advanced SIMS Sample Preparation

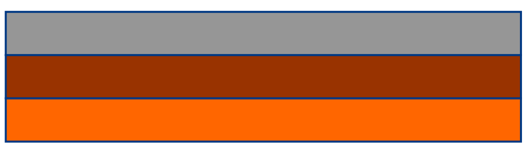
- Common ALD metallization stack consists of a conductor and barrier layer
- SIMS can measure the composition and distribution within the stack - interdiffusion
- Requirement for SIMS is to measure the effectiveness of barrier layer
- Front-side SIMS can result in artifacts which distort the real profile
- Analysis from back-side can yield improved depth resolution

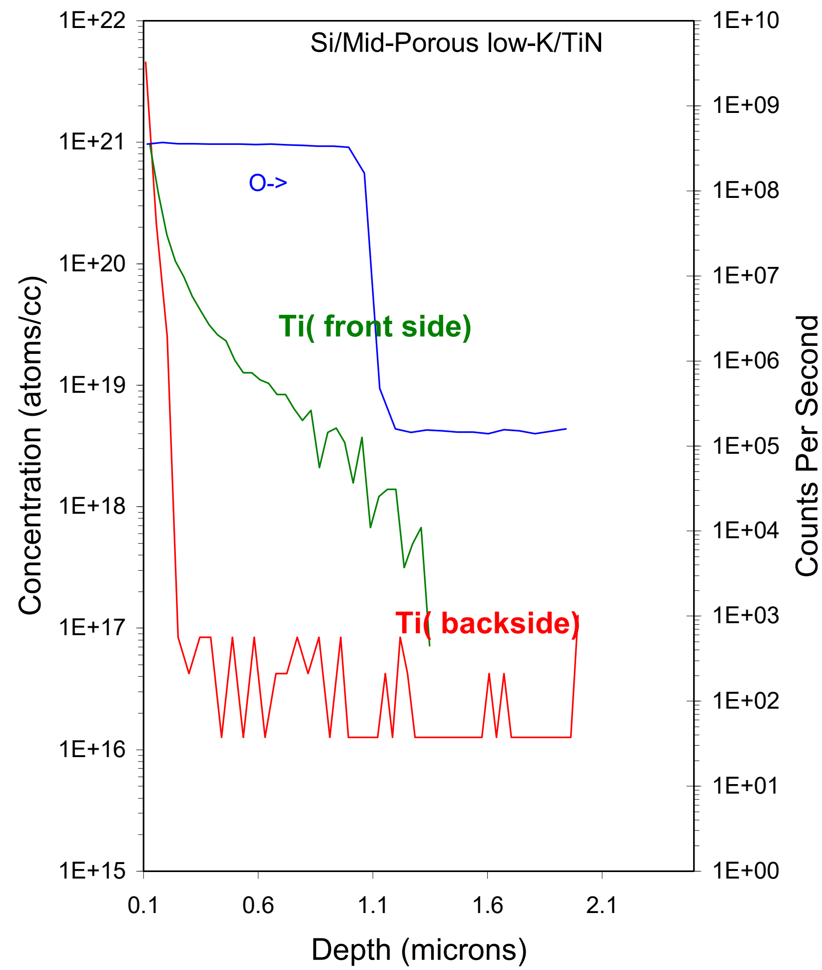
Backside SIMS

Sample structure



Backside thinning





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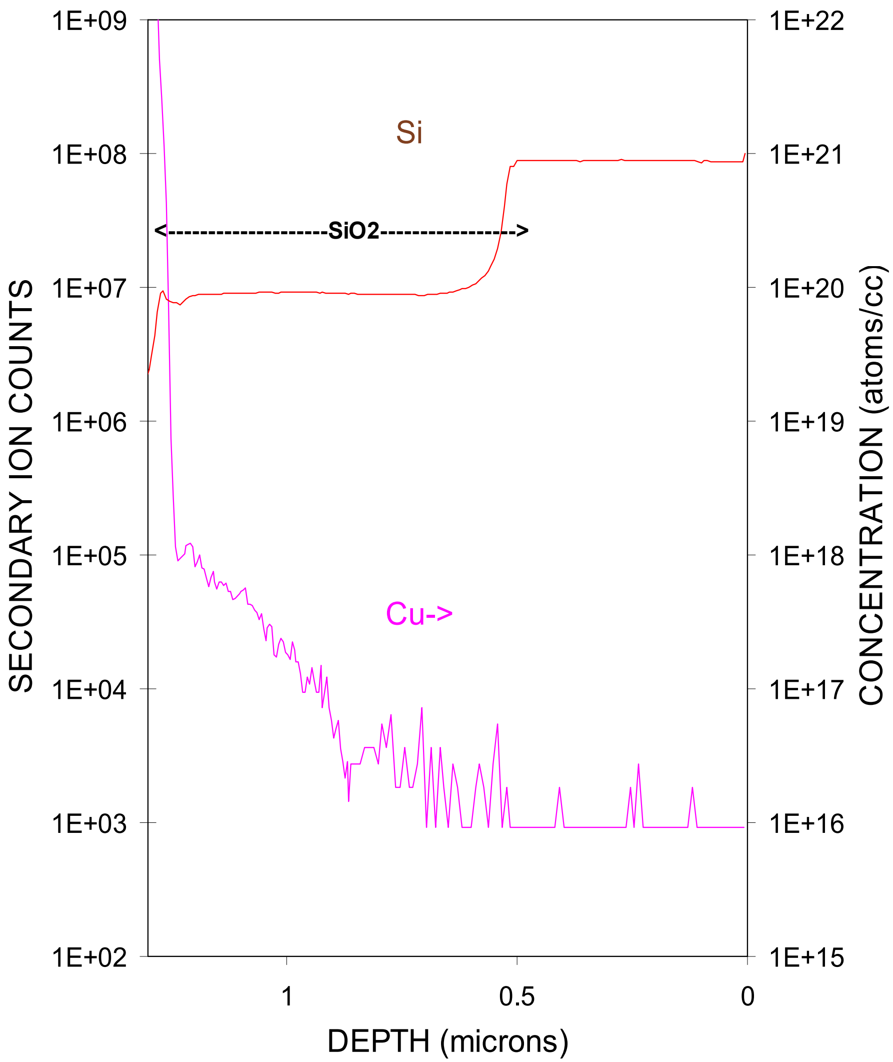
Backside SIMS

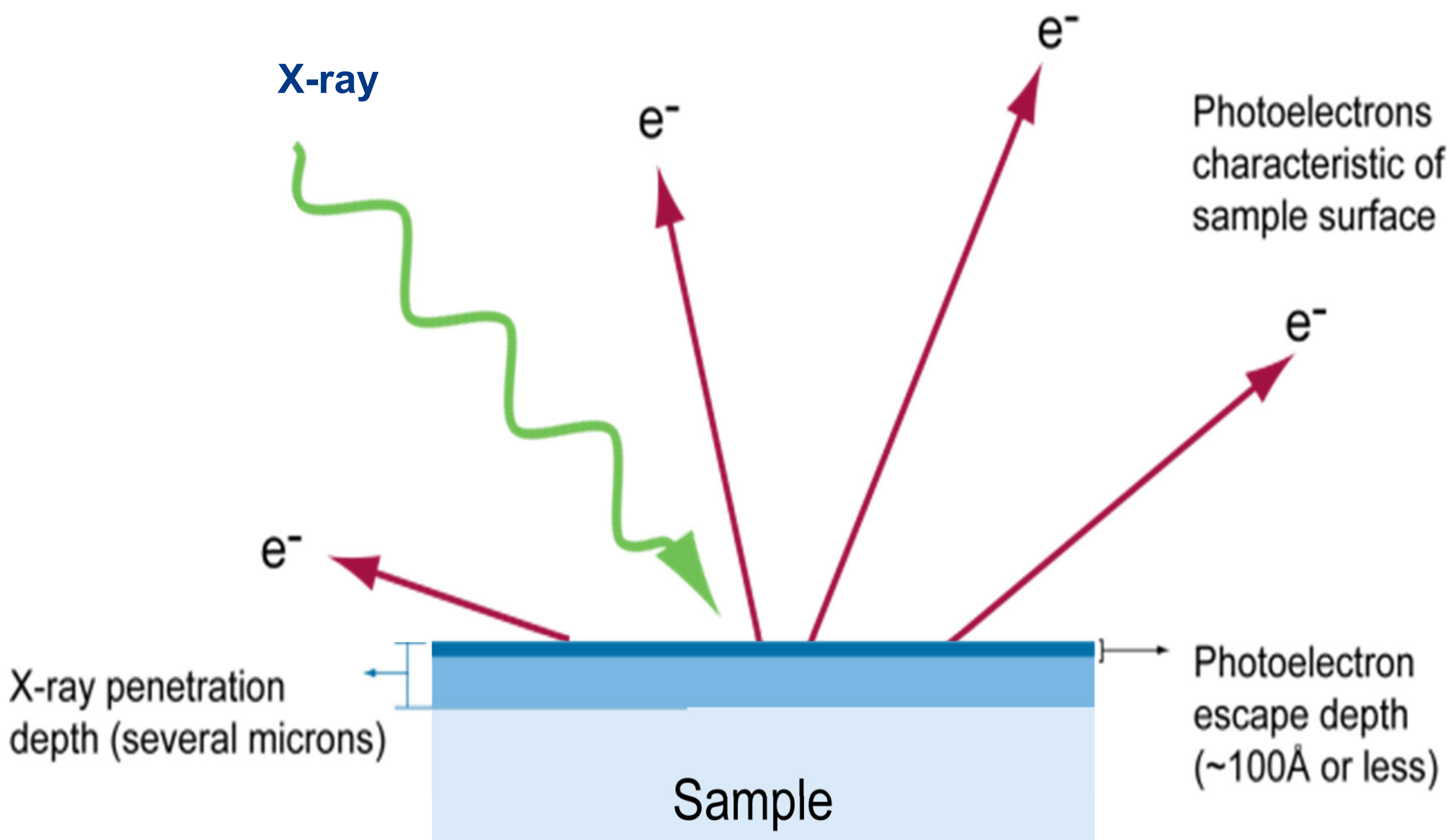


- Cu in SiO_2:
  - Diffusion of copper into dielectric (SiO_2) can be seen in this backside profile and we know it is real
  - No evidence of copper diffusion into the silicon substrate is seen
  - A barrier layer is required to prevent copper diffusion into SiO_2

Additional Thin Film Characterization

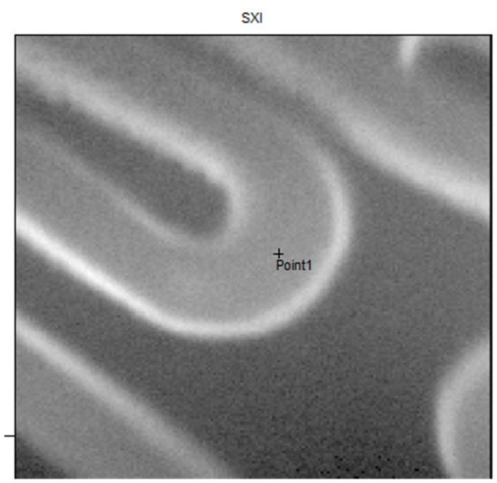
- Compare and contrast XPS and SIMS
- Strength and weakness of XPS
- Introduce RBS and an supporting partner to SIMS

XPS Process



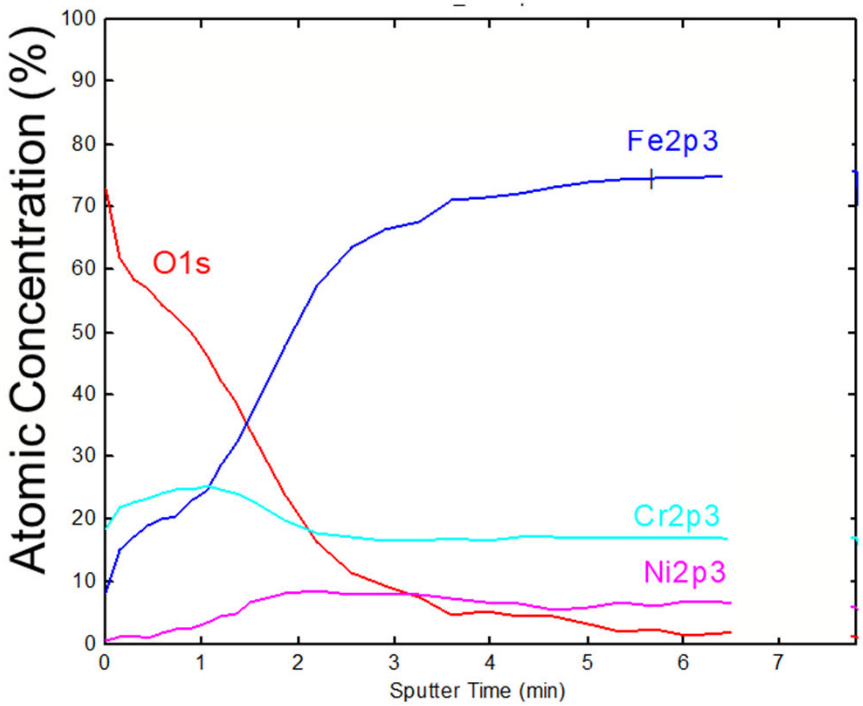
X-ray
e-
e-
e-
e-
Photoelectrons characteristic of sample surface
X-ray penetration depth (several microns)
Sample
Photoelectron escape depth (~100Å or less)

XPS depth profile

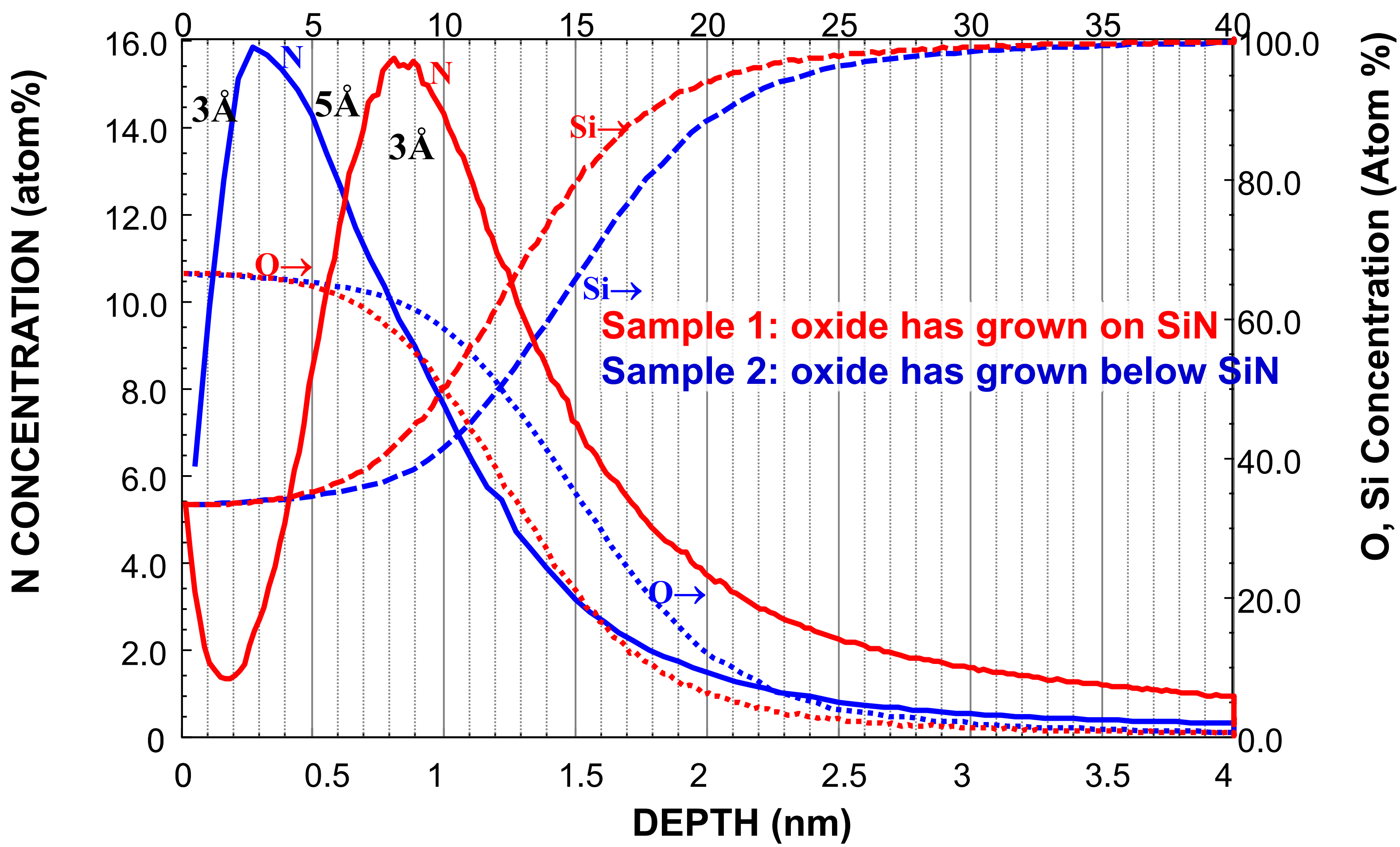


X-ray Induced Secondary Electron Image

Sputter rate ~20Å/min



SIMS Profile of Thin Oxide Film



Limitations of XPS Depth Profile

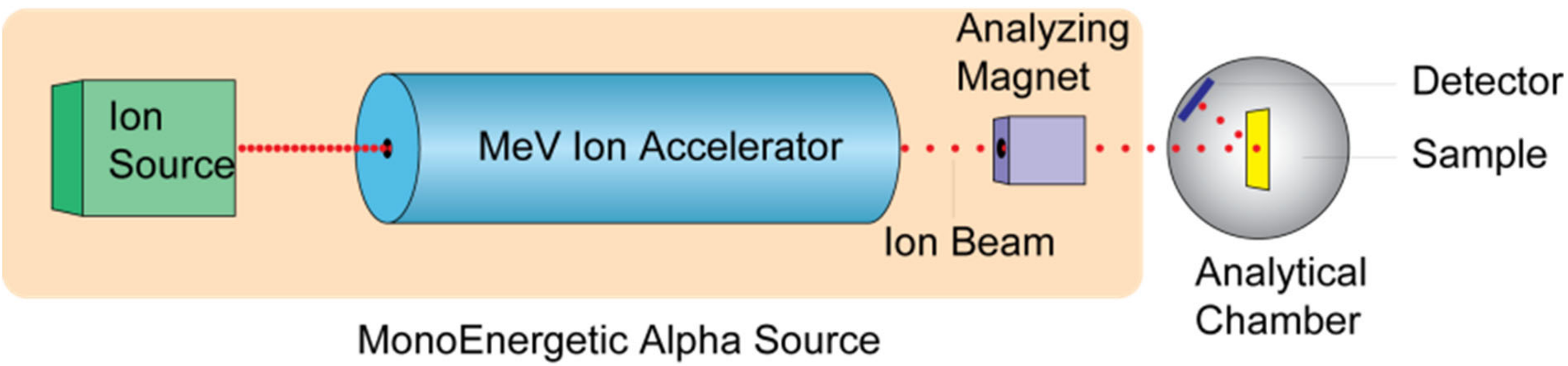
- Cannot quantify hydrogen
- Depth resolution is not as good as SIMS, 3nm versus 0.5nm
- Detection limit is not as good SIMS, 1000ppm versus 1ppm
- Dynamic range is not as good as SIMS, 2 decades versus 5
- Preferential sputtering introduces calibration error

Elements blue and yellow produce a compound green

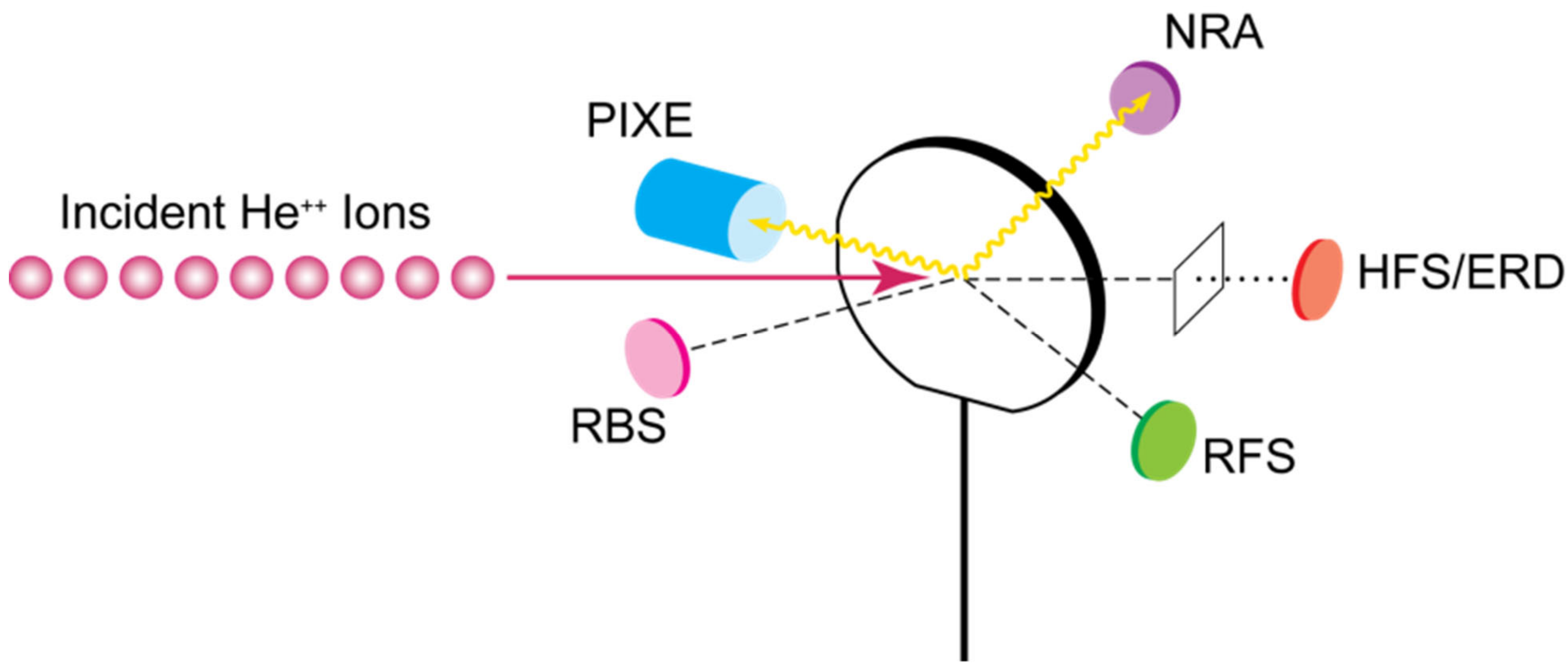
Ion bombardment produces an altered layer teal

RBS Instrument Configuration

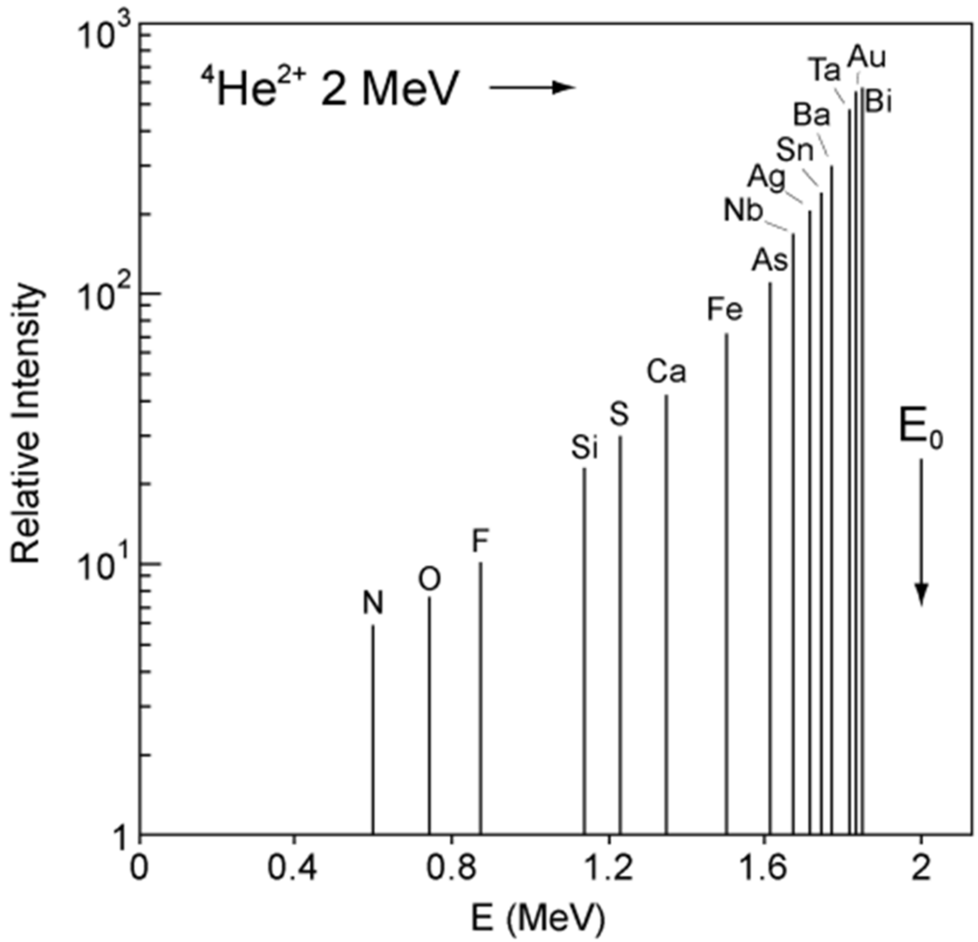
- MeV ions from an electrostatic accelerator are focused on a sample in a vacuum chamber for analysis
- Typically, 2.2 MeV He2+ ions are used (α particles)



Accelerator Based Techniques



Scattering Yields and Energies

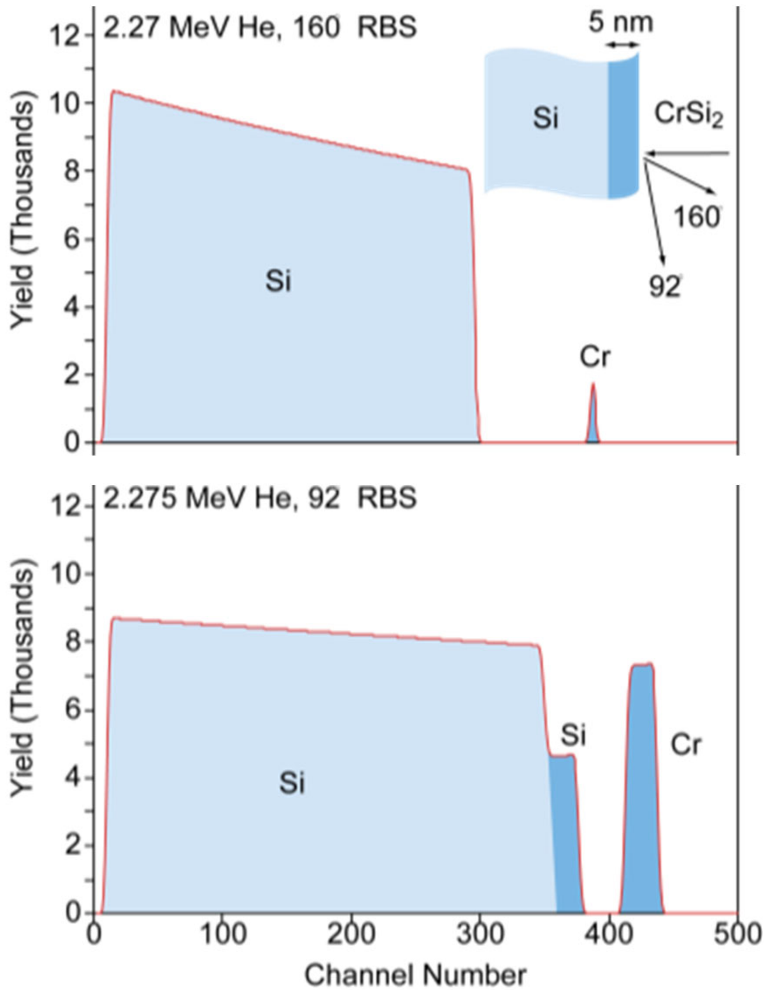


$$E = \left[\frac{m - 4}{m + 4} \right]^2 E_{in}$$

$$\sigma_{Rel} = \left[\frac{Z_x}{Z_{Bi}} \right]^2$$

σ = scattering cross section
Z = atomic number

Effects of RBS Scattering Geometry



- Atoms scattered directly backwards out of the sample undergo the minimum energy loss versus depth
- Atoms escaping nearly tangent to the sample surface undergo a much larger energy loss versus depth
- This difference can be used to optimize RBS depth resolution
- Can also be used to resolve ambiguities from data acquired at a single angle

Limitations of RBS

- Films should be greater than 10nm
- Elements with similar Z cannot be separated
- Stack structure should be modeled prior to analysis
- Low Z elements (C, N, O, F) may not be resolved
- Depth resolution not as good as SIMS
- Low Z elements better by SIMS

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Conclusion

- XPS analysis of thin films is easy, if not always accurate
- SIMS analysis of thin films is not easy, but adds value because:
  - better depth resolution than many techniques
  - dynamic range and detection sensitivity allow for measurement of composition and contamination
- Calibration from other techniques can enhance SIMS accuracy