# ECE 4813

# Semiconductor Device and Material Characterization

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As with all of these lecture slides, I am indebted to Dr. Dieter Schroder from Arizona State University for his generous contributions and freely given resources. Most of (>80%) the figures/slides in this lecture came from Dieter. Some of these figures are copyrighted and can be found within the class text, *Semiconductor Device and Materials Characterization*. ***Every serious microelectronics student should have a copy of this book!***

# Ion Beam Characterization

## Secondary Ion Mass Spectrometry
## Rutherford Backscattering

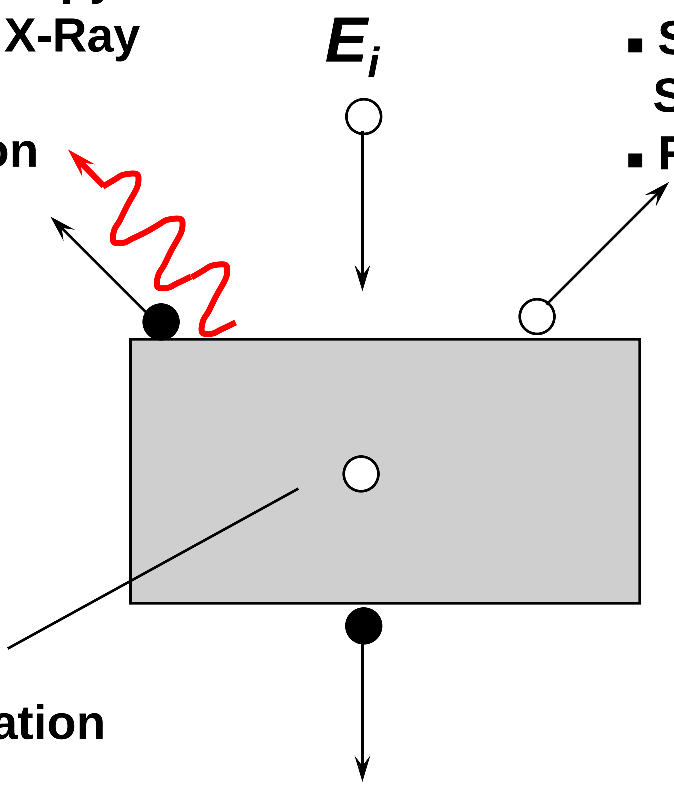
# Ion Beam Characterization

***Emission***

- **Photon Spectroscopy**
- **Particle Induced X-Ray Emission**
- **Electron Emission**

***Reflection***

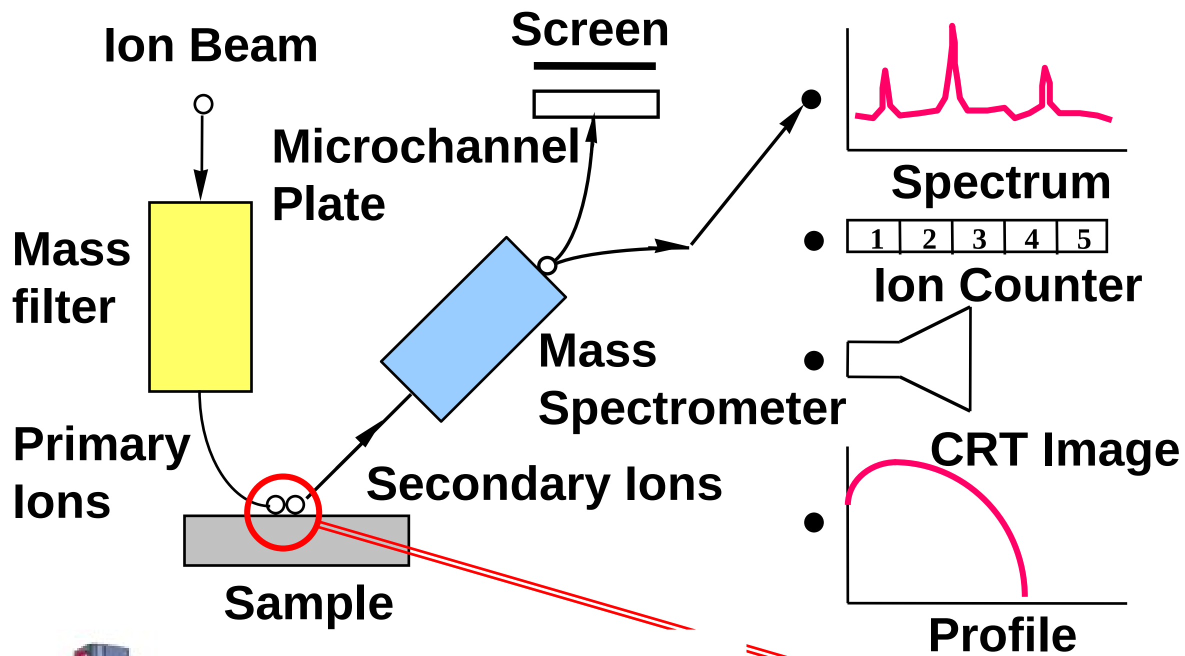
- **Sputtering**
- **Secondary Ion Mass Spectrometry**
- **Rutherford Backscattering**

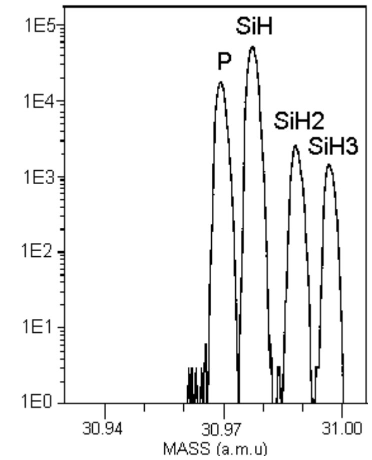


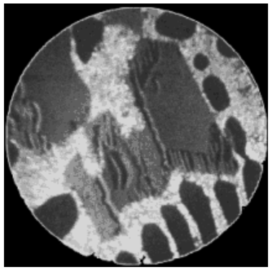

***Absorption***

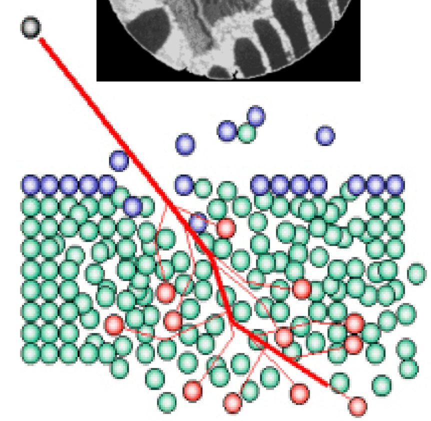
- **Ion Implantation**

# Secondary Ion Mass Spectrometry



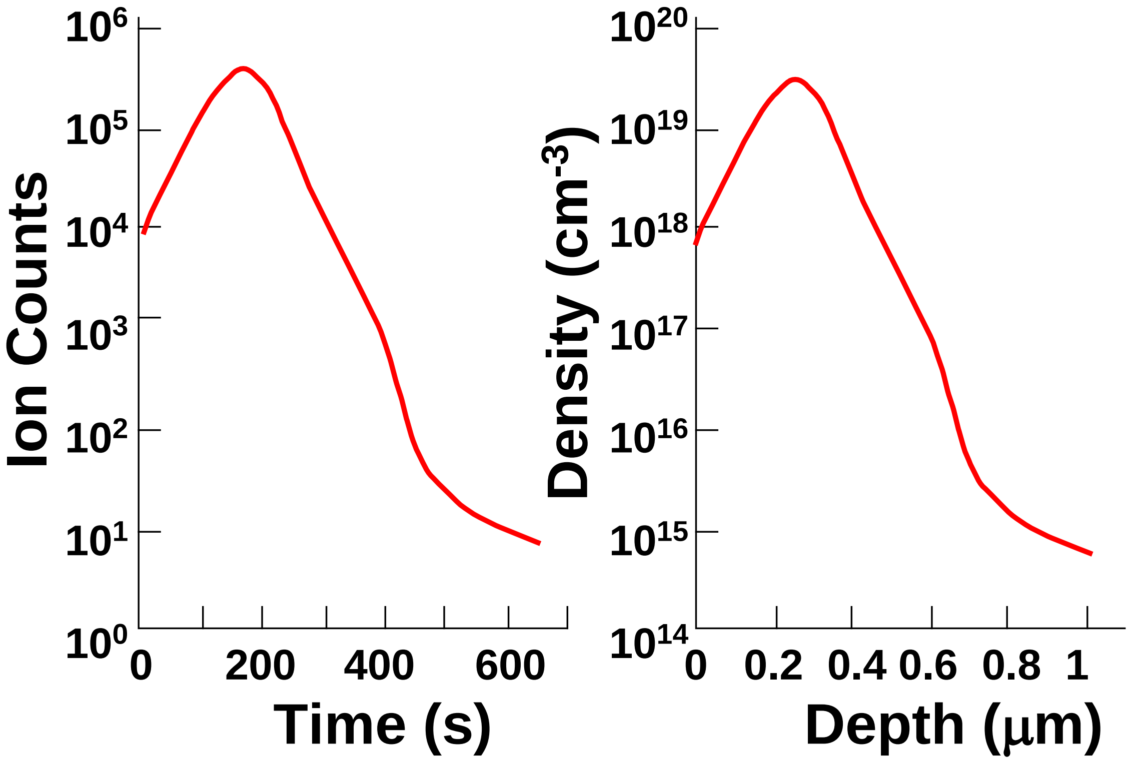


# Secondary Ion Mass Spectrometry

- **Secondary ion mass spectrometry (SIMS) is the most common doping profile method**
- ***Principle:* Atoms sputtered from the sample; mass of the ejected ions analyzed**
  - **Ion mass $\Rightarrow$ element identification; ion intensity $\Rightarrow$ element density**
- ***Advantages:* Gives depth profiles. Can analyze all elements; most sensitive of all analytical techniques. Can measure several impurities simultaneously**
- ***Limitations:* Destructive method. Subject to matrix effect: ion yields influenced by a change in surface composition. Need standards for concentration determination, independent depth measurement**
- ***Sensitivity:* Depends on impurity. Highest sensitivity is boron in Si at ~ $10^{14}$ $cm^{-3}$; all other elements less sensitive. Sensitivity limited by interference from ions of similar mass/charge**

# SIMS

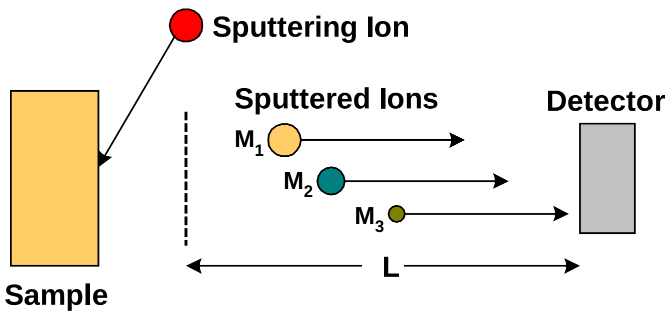
- Ion count ⇒ density: use calibrated standard
- Time ⇒ depth: measure depth of crater

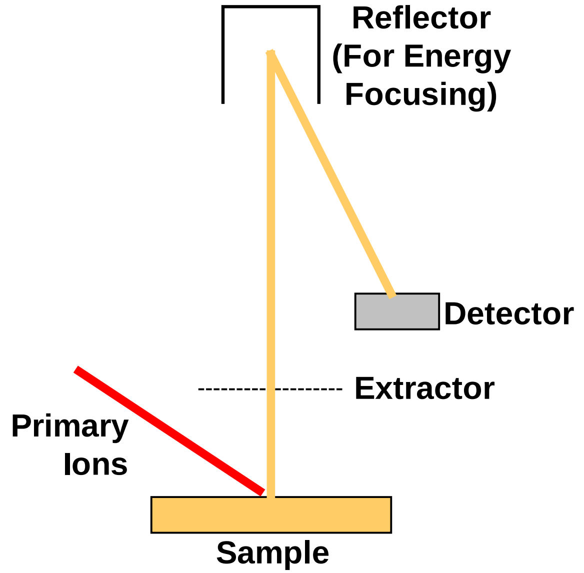


# Time-of-Flight SIMS (TOF-SIMS)

- Pulsed ion beam sputters the sample
- Ion time of flight is measured
- Measure transit time
  $\Rightarrow$ charge/mass ratio
- Low beam current $\Rightarrow$ low sputtering rate
- Suitable for organic surface contamination
- Sensitive for low metallic contamination (~ $10^8$ $cm^{-2}$)

$$t_t = \frac{L}{\sqrt{2V_{tof}}}\sqrt{\frac{m}{q}}$$

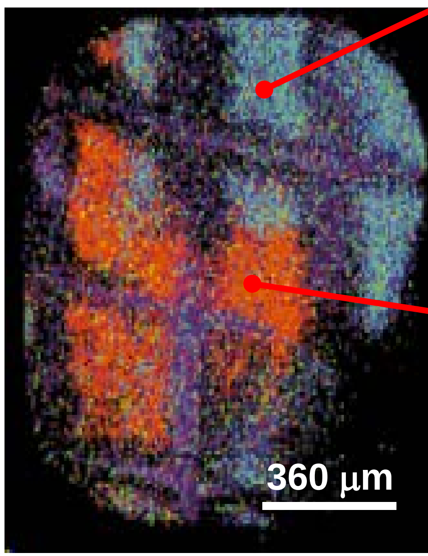


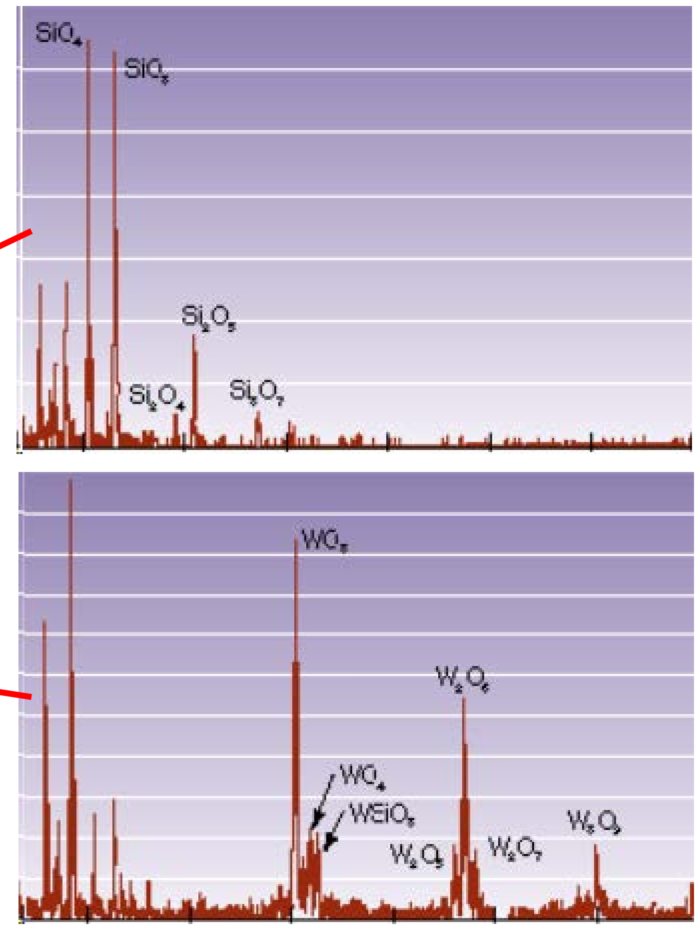

M.A. Douglas and P.J. Chen, "Quantitative Trace Metal Analysis of Si Surfaces by TOF-SIMS," *Surf. Interface Anal*. **26**, 984-994, Dec. 1998.

# TOF-SIMS Example

- 70 Line Cu grid on Si wafer
  - Blue/green: $SiO_2$ features
  - Red/orange: tungsten features
  - Purple: chlorine and carbon contamination




TOF Image

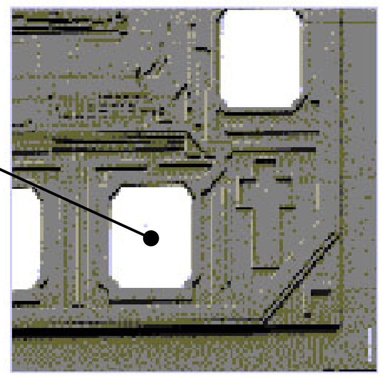


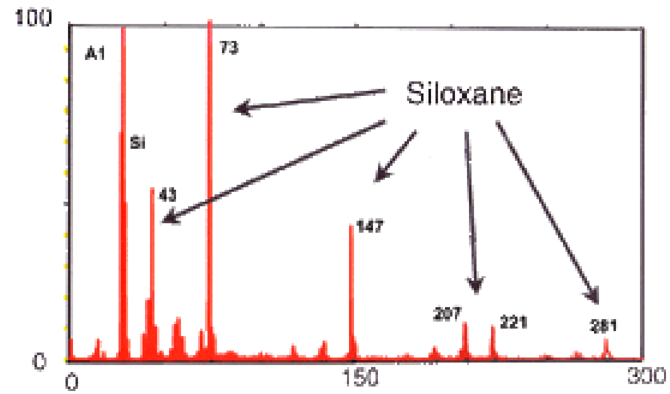

www.llnl.gov/str/Hamza.html

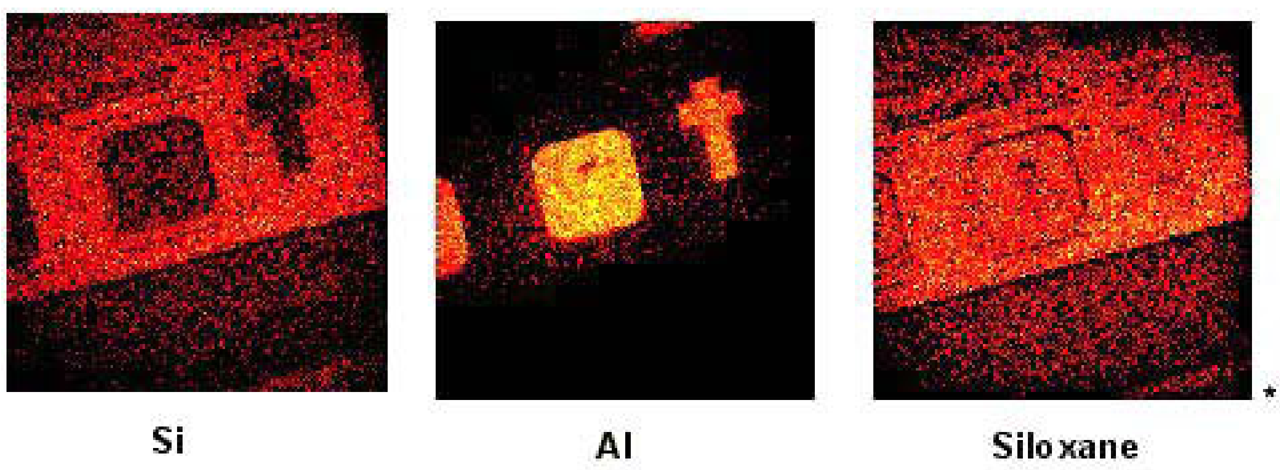
# TOF-SIMS Example

- Bond pad failure; covered with siloxane
- Siloxane mapped distinctly from elemental Si

Bonding pad with poor wire bond



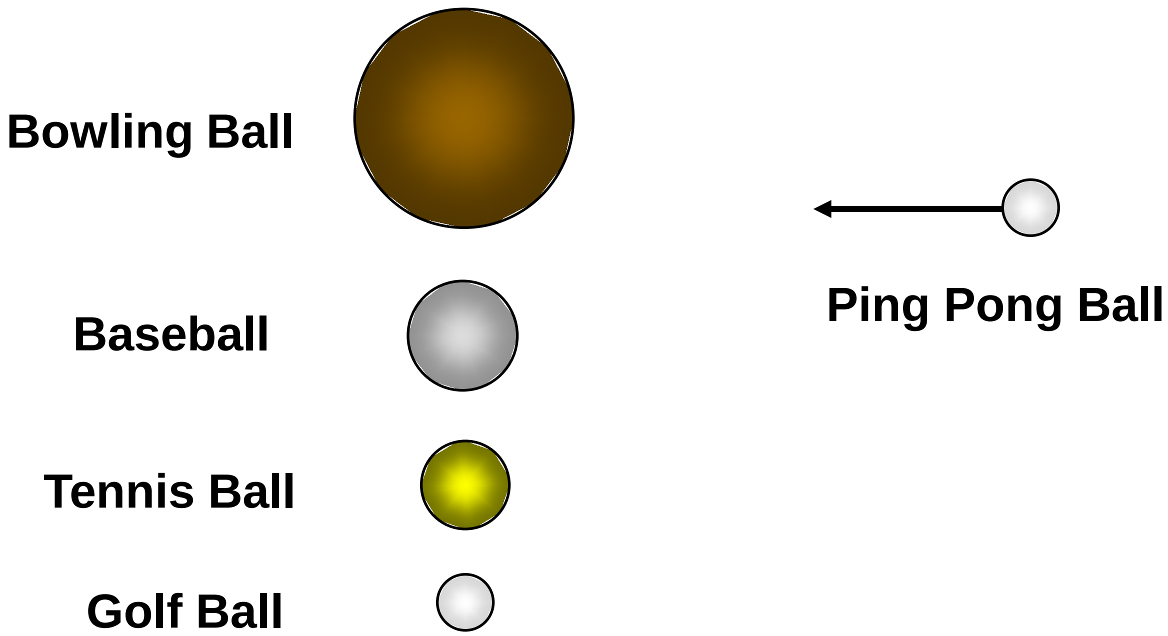



www.materialinterface.com/surface5.html

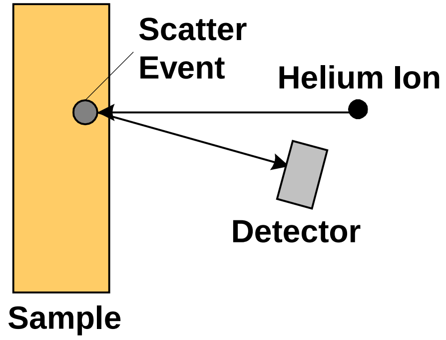
# Rutherford Backscattering (RBS)

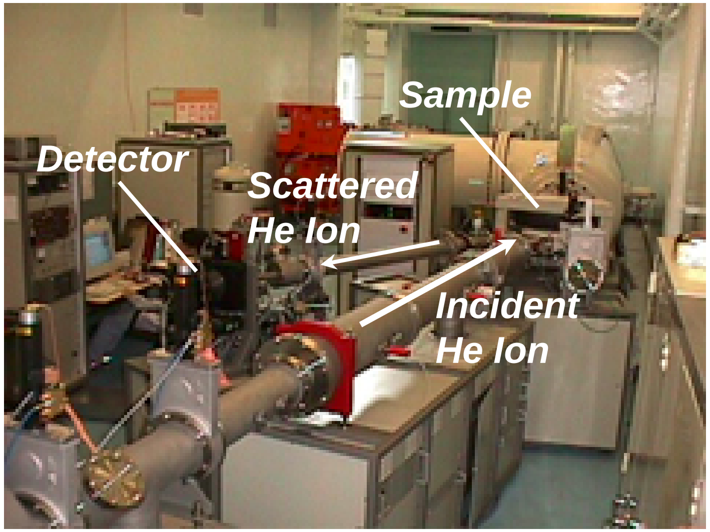
- **The incoming ping pong ball loses the *most* energy when it is scattered from which of the four balls?**



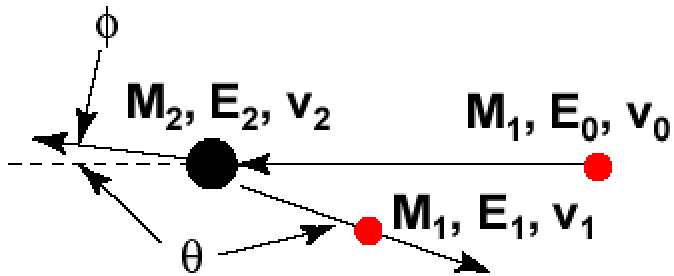
# Rutherford Backscattering

- He ions with several MeV energy are scattered by the sample atoms
- The mass of the sample atom is determined from the energy of the scattered ions



# Ion Scattering




- Conservation of *energy*

$$E_0 = M_1 v_0^2 / 2 = E_1 + E_2 = M_1 v_1^2 / 2 + M_2 v_2^2 / 2$$

- Conservation of *momentum*

$$\textit{Parallel}: M_1 v_0 = M_1 v_1 \cos\theta + M_2 v_2 \cos\phi$$

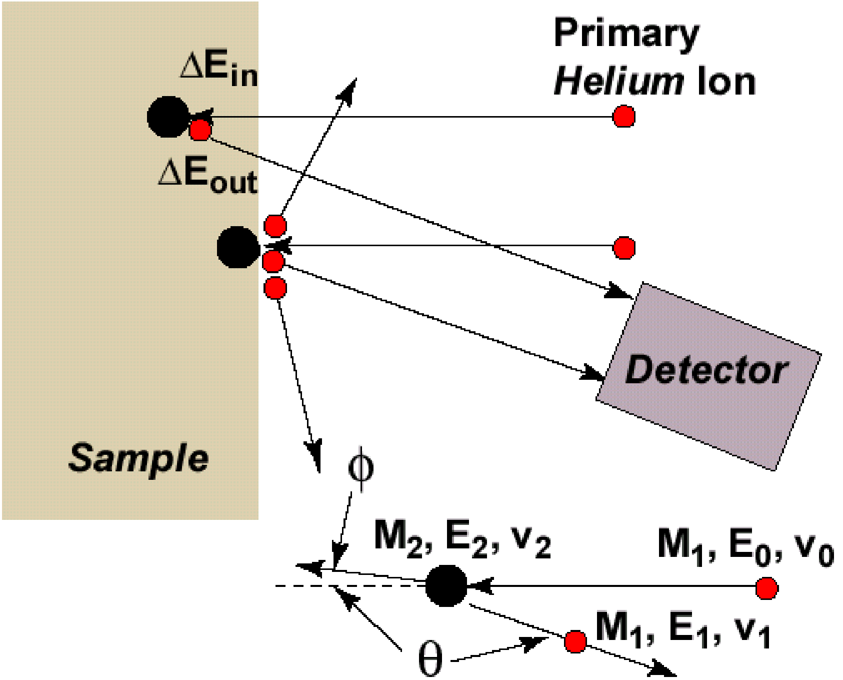
$$\textit{Perpendicular}: 0 = M_1 v_1 \sin\theta - M_2 v_2 \sin\phi$$

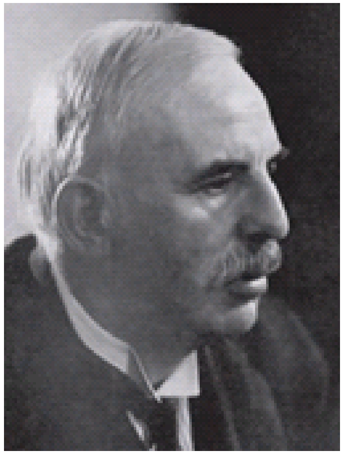
- Eliminating ϕ and $v_2$ $\quad \frac{v_1}{v_0} = \frac{\pm\sqrt{M_2^2 - M_1^2 \sin^2\theta} + M_1 \cos\theta}{M_1 + M_2}$

- For $M_1 < M_2$, use "+" $\quad \frac{E_1}{E_0} = \left( \frac{\sqrt{M_2^2 - M_1^2 \sin^2\theta} + M_1 \cos\theta}{M_1 + M_2} \right)^2$

# Rutherford Backscattering

- He ions of 2-3 MeV are scattered; energy loss gives information
- Nondestructive
- Good for heavy elements on light substrate, *e.g*., silicides
- Sensitivity ~ $10^{18}$ - $10^{19}$ $cm^{-3}$
- *K*: kinematic factor
- $R = M_1/M_2$



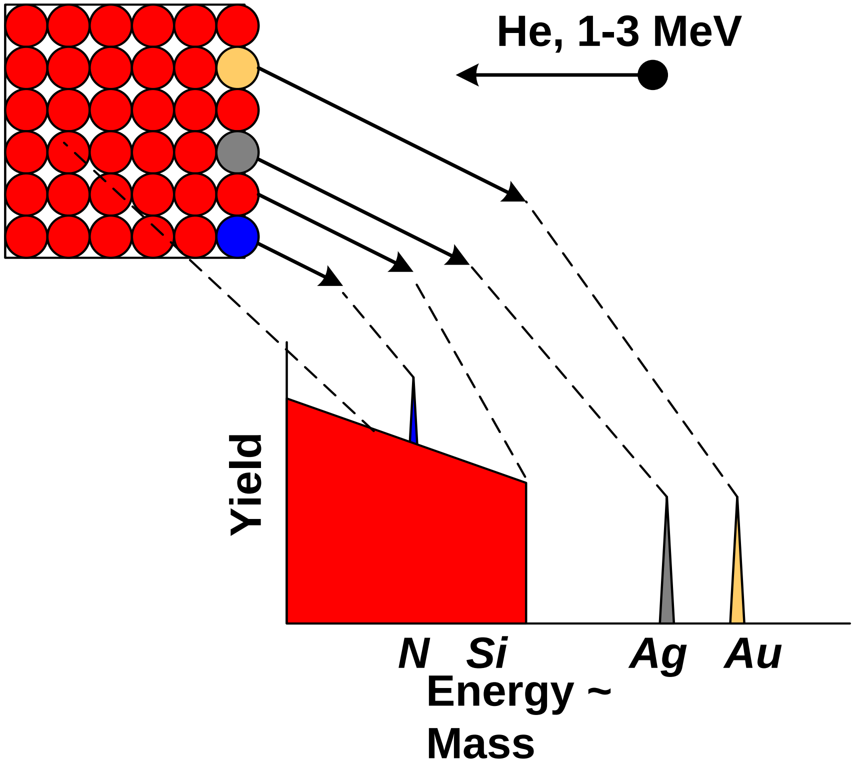



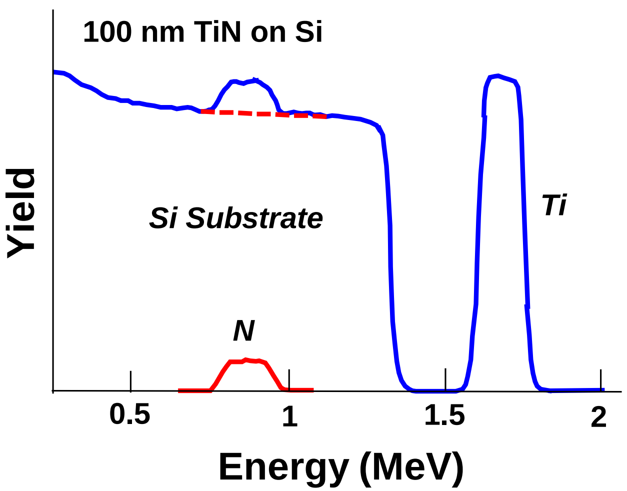
E. Rutherford

$$K = \frac{E_1}{E_0} = \frac{\left[\sqrt{1-(R\sin(\theta))^2} + R\cos(\theta)\right]^2}{(1+R)^2}$$

# Rutherford Backscattering

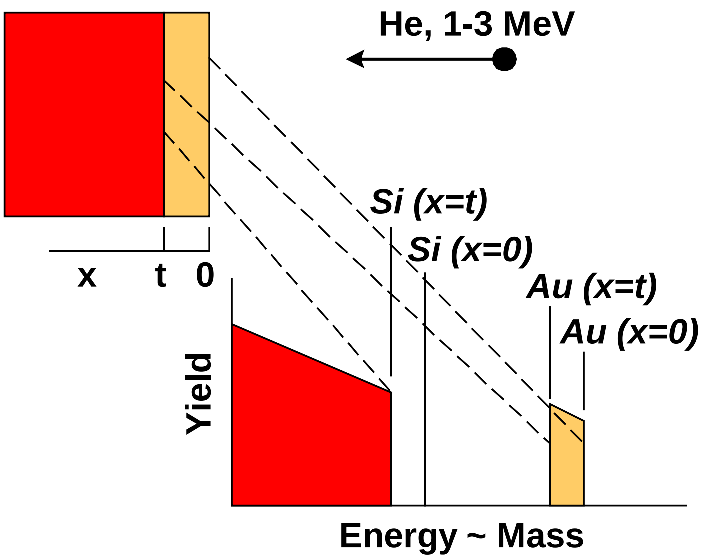
- **RBS works best for heavy elements on light substrates**



# Rutherford Backscattering

- RBS works best for heavy elements on light substrates

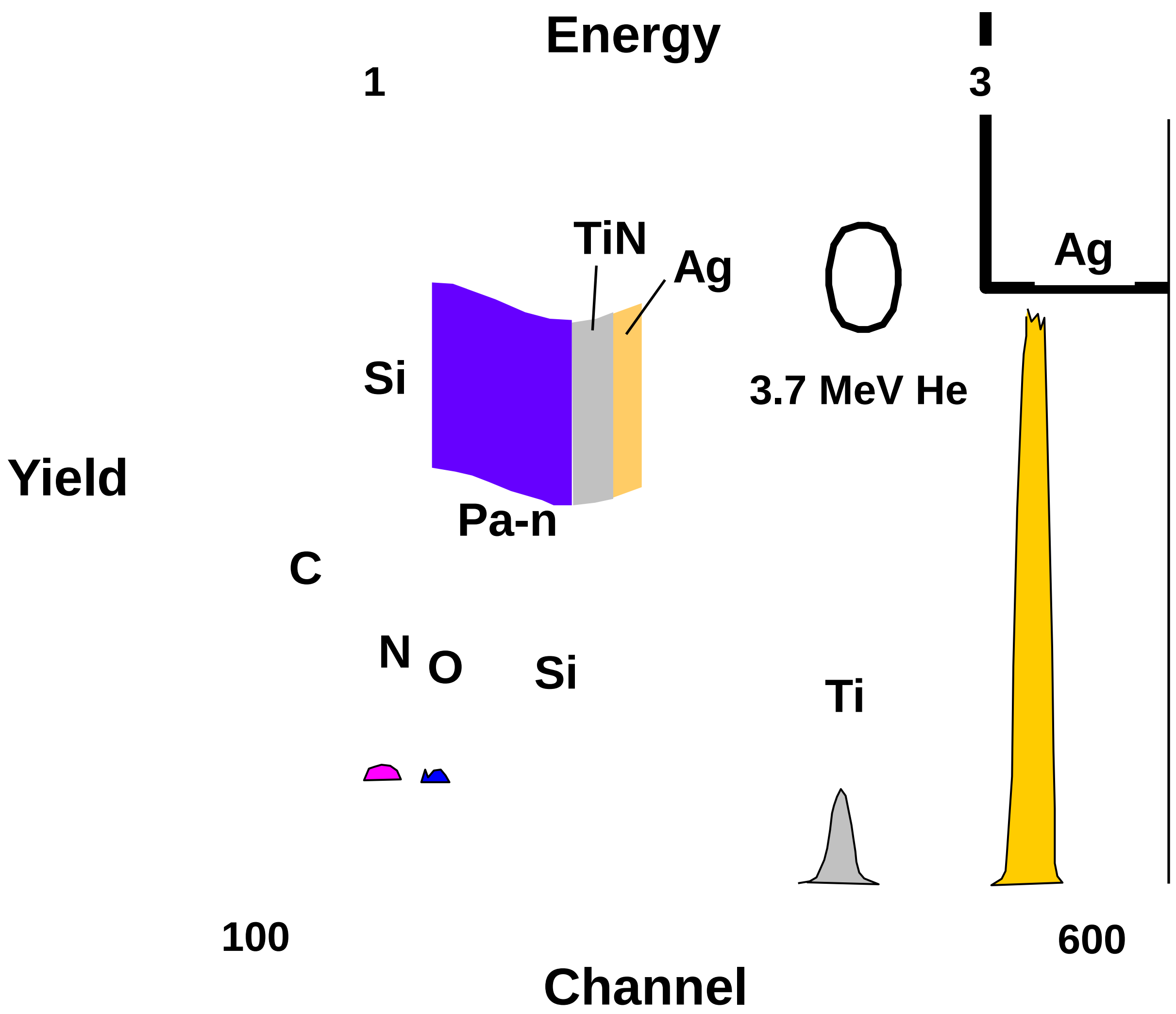



$$Yield = \sigma \Omega Q N t$$

$$\sigma = \frac{q^2 Z_1 Z_2}{4E} \frac{4}{\sin^4\theta} \frac{\left(\sqrt{1-(R\sin\theta)^2}+\cos\theta\right)^2}{\sqrt{1-(R\sin\theta)^2}}$$

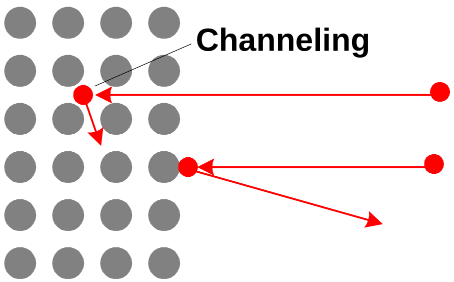
σ: scattering cross section
Ω: solid detector angle
*Q*: no. of incident ions
*N*: target atom density
*t*: thickness

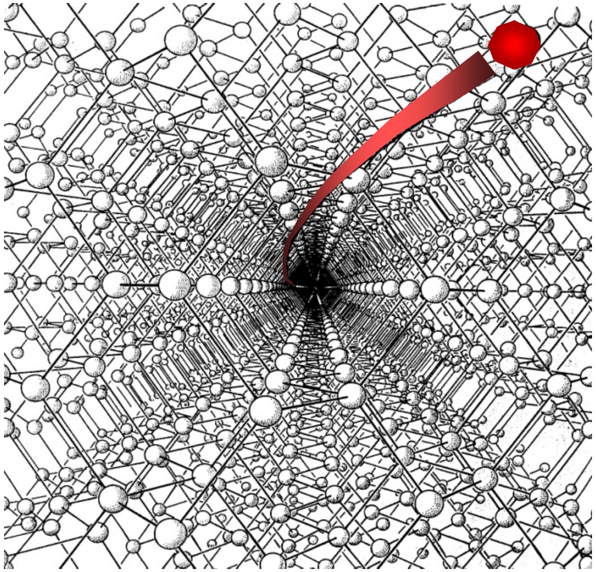
# Rutherford Backscattering



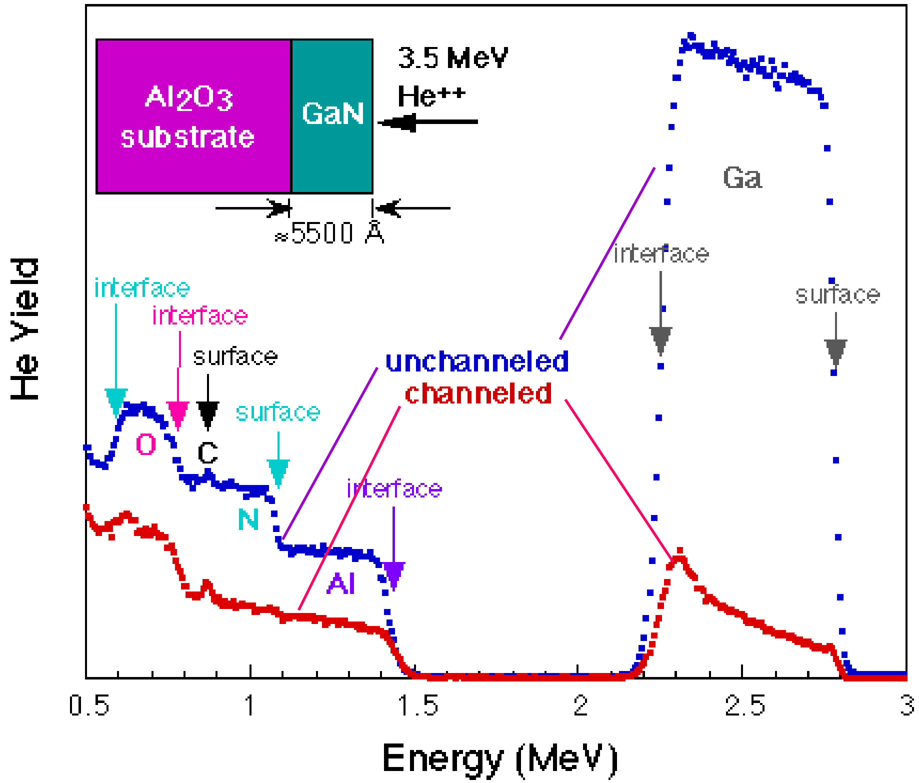
# Channeling

- He ions are scattered more when they are not channeled



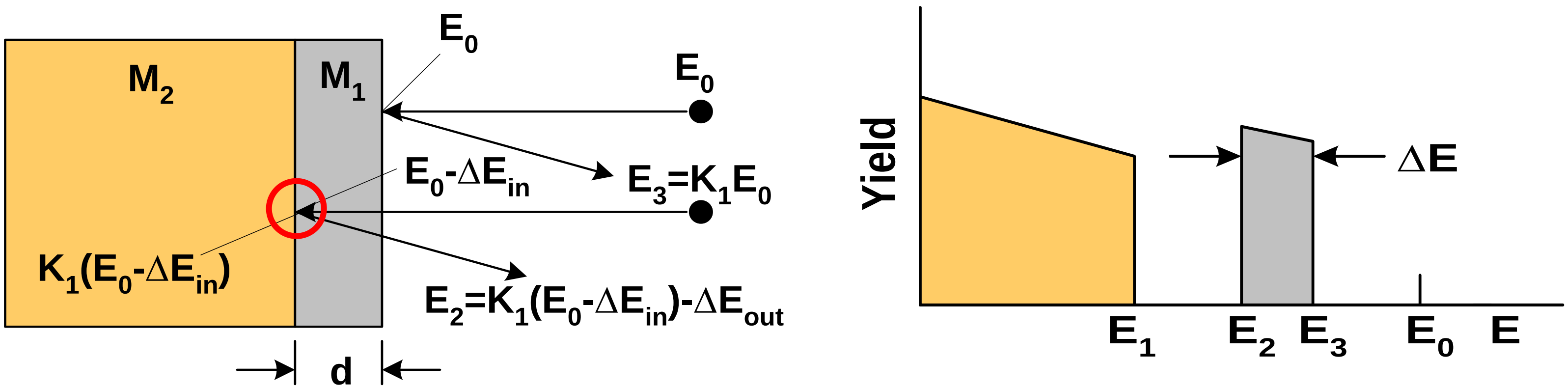



*Scient. Am.* **218**, 90 (March 1968)



# Thickness Measurements

- Thickness determined by measuring the various energies




$$E_3 = K_1 E_0;\ E_2 = K_1(E_0 - \Delta E_{in}) - \Delta E_{out}$$

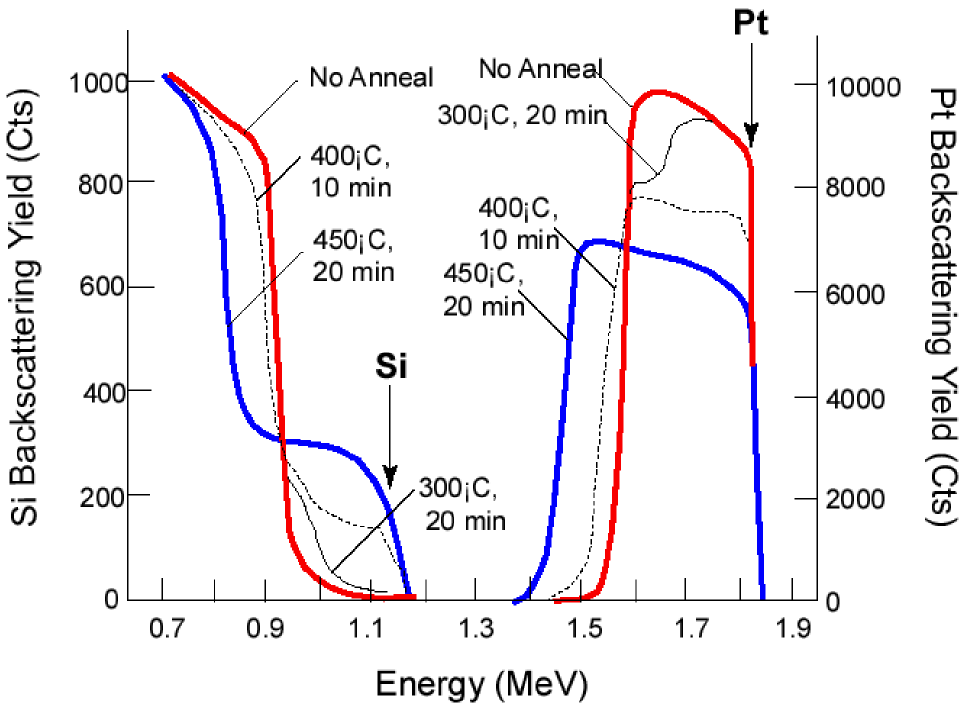
$$\Delta E = E_3 - E_2 = K_1 \Delta E_{in} + \Delta E_{out} = [S_0]d$$

**$[S_0]$: backscattering energy loss factor (eV/Å)**

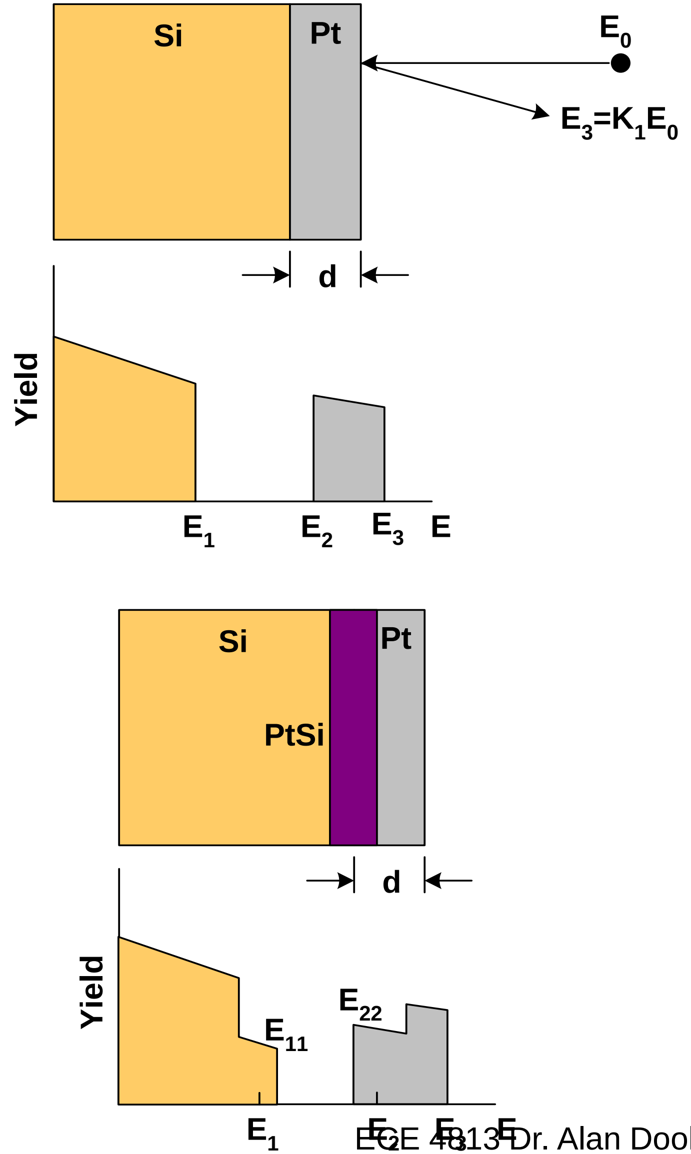
$$E_1 = K_2(E_0 - \Delta E_{in}) - \Delta E_{out}$$

# Silicide Formation

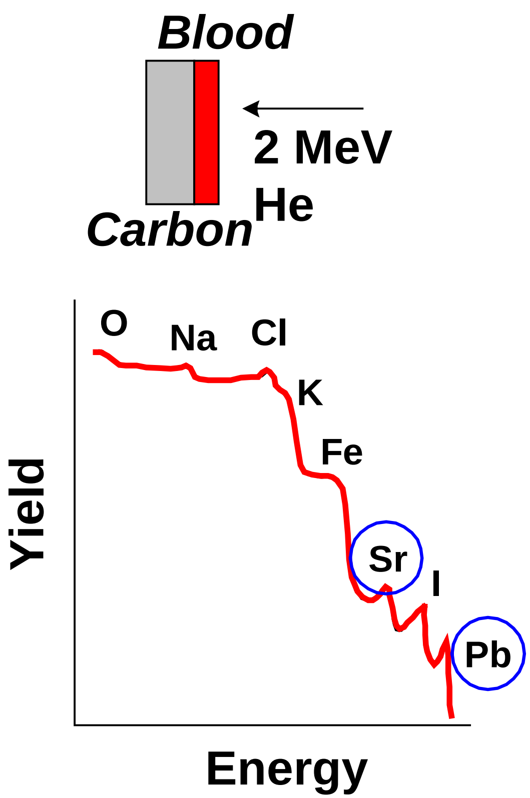
- **RBS is ideal for measuring the formation of silicides**

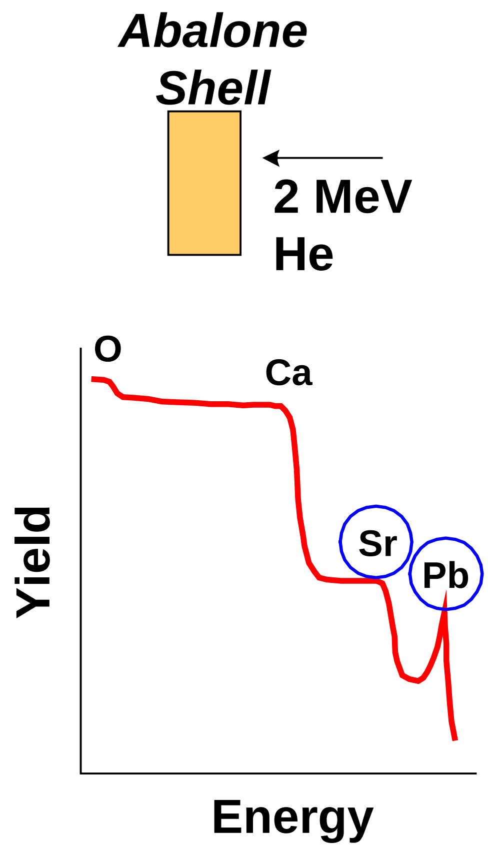



M.A. Nicolet et al. *Science*, **177**, 841 (1972)



# RBS Examples




M.A. Nicolet et al. *Science*, **177**, 841 (1972)

# Review Questions

- What is the main application for SIMS?
- What is the principle for RBS?
- What is TOF-SIMS?
- What is channeling?
- How are the SIMS vertical and horizontal data converted?