Rutherford Backscattering Spectrometry

Timothy P. Spila, Ph.D.
Materials Research Laboratory
University of Illinois

amc.mrl.Illinois.edu
Geiger-Marsden Experiment

*Top*: Expected results: alpha particles passing through the plum pudding model of the atom undisturbed.

*Bottom*: Observed results: a small portion of the particles were deflected, indicating a small, concentrated positive charge.
Rutherford Backscattering Spectrometry

RBS is an analytical technique where high energy ions (~2 MeV) are scattered from atomic nuclei in a sample. The energy of the back-scattered ions can be measured to give information on sample composition as a function of depth.
Van de Graaff accelerator


http://cnx.org
Rutherford Backscattering Spectrometry

3 MeV Van de Graaff accelerator

beam size $\Phi$1-3 mm
flat sample
can be rotated
Rutherford Backscattering Spectrometry

3 MeV Pelletron accelerator

beam size $\Phi 1$-3 mm flat sample can be rotated
Pelletron system consists of

- **Ionization chamber**
- Acceleration tube
- Focusing quadrupole
- Steering magnet
- RBS end station
Pelletron system consists of
- Ionization chamber
- Acceleration tube
- Focusing quadrupole
- Steering magnet
- RBS end station
Pelletron system consists of
• Ionization chamber
• Acceleration tube
• Focusing quadrupole
• Steering magnet
• RBS end station
Pelletron system consists of

- Ionization chamber
- Acceleration tube
- **Focusing quadrupole**
- **Steering magnet**
- RBS end station
Pelletron system consists of
- Ionization chamber
- Acceleration tube
- Focusing quadrupole
- Steering magnet
- **RBS end station**
Primary Beam Energy

Thin film projected on to a plane: \( \text{atoms/cm}^2 \)

\[
(N_t)[\text{at/cm}^2] = N[\text{at/cm}^3] \times t[\text{cm}]
\]

Elastic Two-Body Collision

\[ E_1 = KE_0 \]

\[ K = \left( \frac{\sqrt{M_2^2 - M_i^2 \sin^2 \theta + M_i \cos \theta}}{M_i + M_i} \right)^2 \]

Elastic Scattering

\[ M_1 v_0^2 = M_1 v_1^2 + M_2 v_2^2 \]

\[ M_1 \vec{v}_0 = M_1 \vec{v}_1 + M_2 \vec{v}_2 \]

\[ M_1 < M_2, \ 0 \leq \theta \leq 180^\circ \]

\[ 0 \leq \Phi \leq 90^\circ \]

RBS: He backscatters from \( M_2 > 4 \)
Rutherford Scattering Cross Section

Coulomb interaction between the nuclei: exact expression -> quantitative method

\[ \sigma_R(E, \theta) \propto \left( \frac{Z_1 Z_2}{4E} \right)^2 \left[ \sin^{-4} \left( \frac{\theta}{2} \right) - 2\left( \frac{M_1}{M_2} \right) \right] \propto \left( \frac{Z_2}{E} \right)^2 \]
RBS – Simulated Spectra

hypothetical alloy $\text{Au}_{0.2}\text{In}_{0.2}\text{Ti}_{0.2}\text{Al}_{0.2}\text{O}_{0.2}/\text{C}$

Element ($Z,M$): $\text{O}(8,16)$, $\text{Al}(13,27)$, $\text{Ti}(22,48)$, $\text{In}(49,115)$, $\text{Au}(79,197)$

$$\sigma_R(E, \theta) \propto \left(\frac{Z^2}{E}\right)^2$$

Energy [keV]

Counts

Energy [keV]

Counts

Energy [keV]

Counts

Energy [keV]

Counts

Energy [keV]

Counts

$\theta = 150^\circ$

He$^4$

Target mass (amu)

Kinematic factor: $K$

© 2019 University of Illinois Board of Trustees. All rights reserved
SIMNRA Simulation Program for RBS and ERD

Energy [keV]

Counts

Channel

© 2019 University of Illinois Board of Trustees. All rights reserved.
Calibration Sample

\[ \alpha = 22.5^\circ \]
\[ \beta = 52.5^\circ \]
\[ \theta = 150.0^\circ \]
Cu-Nb-W Alloy on SiO$_2$/Si

© 2019 University of Illinois Board of Trustees. All rights reserved.
Thickness Effects

TiN/MgO

300 nm

400 nm

600 nm

N, O, Mg interface

Ti surface

Incident

D

N

Scattered

He^+

© 2019 University of Illinois Board of Trustees. All rights reserved.
Incident Angle Effects

**TiN/MgO**

Surface peaks do not change position with incident angle
Example: Average Composition

TiN/SiO$_2$

As-deposited

Annealed in atmosphere for 12 min at $T_a = 600$ °C

Experimental spectra and simulated spectra by RUMP
• Free-standing polyamide films are too thin to give sufficient signal in the RBS.

• Use the added stopping power of the polymer to split the Pt peak in the RBS spectrum.
Areal mass density by RBS

0.005 wt% TMC, 0.1 wt% MPD

Energy (keV) vs. Counts

Areal Mass Density (μg cm⁻²) vs. [MPD] (wt%) and [TMC] (wt%)

QCM, RBS
• Quantitative technique for elemental composition
• Requires flat samples; beam size $\Phi 1-3$ mm
• Non-destructive
• Detection limit varies from 0.1 to $10^{-6}$, depending on Z
  • optimum for heavy elements in/on light matrix, e.g. Ta/Si, Au/C...
• Depth information from monolayers to 1 $\mu$m
Optimizing Simultaneous PIXE and RBS Capabilities

Thomas J. Pollock\textsuperscript{1}, Robert White\textsuperscript{2}

\textsuperscript{1}National Electrostatics Corp., Middleton, Wisconsin, U. S. A. 53562-0310
Pollock@pelletron.com

\textsuperscript{2}National Renewable Energy Laboratory, Golden, Colorado, U. S. A. 80401
Robert.White@nrel.gov

Sponsor Presentation
Thanks to our sponsors!