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Quantitative considerations in medium energy ion scattering
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Introduction

Due to its unique capability of providing near-quantitative compositional and layer structure information during depth profiling analysis, MEIS is a valuable tool for many research areas, such as nanostructure resolution. Medium energy ion scattering (MEIS) is becoming increasingly important to the characterization of microscale devices in structures in which scaling laws have determined the growth and design layers of nanometer thickness. Here we assess the quantitative accuracy in terms of both depth and concentration, that can be achieved in MEIS depth profiling.

Inelastic energy loss to depth scale conversion

Depth scales in MEIS are derived from the inelastic energy loss of the scattered projectiles on the way in and out.

The energy loss rate $dE/dx$ is dependent on the energy of the projectile and can be calculated from SRIM simulations, shown for $50 \text{ keV}$ and $200 \text{ keV}$.

For the energies used in MEIS the electronic energy losses can be well approximated by a power law:

$$\frac{dE}{dx} \approx kE^{\alpha} \text{ (V/m)}$$

where $k$ is the energy at the detector after scattering off a target atom at depth $x$, $E$ is the energy immediately before scattering at that depth, $E_0$ is the incident energy, and $x$ is the stopping cross section, and $\alpha$ is the kinematic factor for the scattering geometry adopted.

$$D \approx \frac{k}{E^{\alpha-1}}$$

The term $D$ is given as:

$$D = \frac{k}{E^{\alpha-1}}$$

The change in yield due to scattering off atoms at depth $x$ as a ratio to scattering off atoms at the surface directly as:

$$H(E_x) = \frac{\sigma(E_x)}{\sigma(0)}$$

where $\sigma$ is the scattering yield according to the Rutherford prediction ($\sigma = \frac{1}{8\pi} \frac{Z^2}{E}$), $E$ is the energy of the projectile, and $x$ is the atomic density and $\alpha$ the thickness of the surface layer across which an ion will see the energy equivalent to the width of a single bin within the detection system.

For scattering on the top surface $E_0 = E$ and $k = E_x$, so that the term in eq. (3) disappears; the yield off the surface is then:

$$H(E_0) = \frac{\sigma(E_0)}{\sigma(0)}$$

The change in yield due to scattering off atoms at depth $x$ as a ratio to scattering off atoms at the surface directly as:

$$\frac{H(E_x)}{H(E_0)} = \left(\frac{k}{E^{\alpha-1}}\right)^{1/2}$$

As long as the detector channel width $D$ is independent of energy (as in RBS - surface barrier detectors), factors like $D$ and $\sigma(0)$, have cancelled in eq. (7). The Rutherford cross section is $\frac{1}{8\pi}$, the electronic energy loss depending stopping cross section factors are defined in eq. (8), again constants such as the atomic density are ignored in this analysis which is permissible since only ratios of $\sigma(E_x)$ or $\sigma(E_0)$ are considered here. The benefit of the power law eq. (1) is now clear since:

$$\frac{\sigma(E_x)}{\sigma(0)} = \left(\frac{k}{E^{\alpha-1}}\right)^{1/2}$$

so that eq. (7) reduces to:

$$H(E_x) = \frac{\sigma(E_x)}{\sigma(0)}$$

i.e. deviations from the energy dependence of the yield according to the Rutherford prediction ($\sigma = \frac{1}{8\pi} \frac{Z^2}{E}$) with the inverse of the energy of the atom at the detector ($\frac{1}{8\pi} \frac{Z^2}{E}$) to a power $\alpha - 1$ ($\sigma(E_x)$ vs. $\sigma(E_0)$).

Extraction of depth profiles from Scattering Yield (cts)

The elastic energy loss (Scattering Yield, $\sigma(E_x)$) is given by:

$$\sigma(E_x) = \frac{A}{t}$$

where $A$ is the atom density and $t$ the thickness of the surface layer.

$\sigma(E_x)$ is therefore the yield off the surface, that is, the yield for $x = 0$ in eq. (10).

In experimentally measured data, the Scattering Yield (cts) is given by:

$$\sigma(E_x) = \frac{I}{t}$$

where $I$ is the intensity.

Experimental validation

The difference between the two expressions is that $A$ and $t$ are known, while $I$ and $t$ are experimentally measured.

|| Depth (nm) | Scattering Yield (cts) |
|-----------------|----------------------|
| 0               | 5,000                |
| 2               | 2,500                |
| 4               | 1,250                |
| 6               | 625                  |
| 8               | 312.5                 |

Spectrum simulation & Experimental confirmation

More complex layer systems can only be effectively interpreted using computer simulation of spectra. The simulation model used at SIAF, based on the SRIM software incorporates the corrections considered above. Its outputs are the fitted spectra and best fit depth profiles of species in a layer. In all cases depth scales have been used which require assumptions on the exact densities of atoms species, layer thickness and composition well compare with reference data, as shown.

Conclusions

- The MEIS yield ratio of particles scattered off surface atoms to those at depth is given by the Rutherford $\sigma(E_x)$ prediction + the inverse ratio of the particle exit energies to a power $\alpha - 1$.
- The impact of screening the potential on the backscattering yield in MEIS has been evaluated for He and $\alpha$ of different elements using the Andersen approach. For a fixed beam energy the screening correction depends mainly and almost linearly on $\alpha$.
- The experimental measurement data consistent with the screening correction leads to a correction factor to the Rutherford backscattering cross section ratio. Its dependence on beam energy and the electronic stopping power of the MEIS projectile is presented.
- This approach has been validated for a number of representative examples that yield substantial depth protons in different MEIS spectral analysis.
- The impact of the screening the potential on the backscattering yield in MEIS has been evaluated for He and $\alpha$ of different elements using the Andersen approach. For a fixed beam energy the screening correction depends mainly and almost linearly on $\alpha$. The experimental measurement data consistent with the screening correction leads to a correction factor to the Rutherford backscattering cross section ratio. Its dependence on beam energy and the electronic stopping power of the MEIS projectile is presented.