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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 of thin, nanometre resolution, medium energy ion scattering (MEIS) is becoming increasingly important to the characterisation of microelectronic device structures in which scaling laws have determined the growth and design layers of nanometre thickness. Here we assess the quantitative accuracy in terms of both depth and concentration, that can be achieved in MEIS depth profiling.

Peak-to-peak ratios

The absolute backscattering yield of target atoms at a depth \( x \) in a homogeneous target is according to Zhu et al. (Backscattering Spectroscopy, 1984)

\[
\frac{H(E_x)}{H(E_0)} = \frac{1}{1 + \frac{x}{\lambda}}
\]

where \( E_0 \) is the energy at the detector after backscattering off a target atom at depth \( x \) is the energy immediately before backscattering at that atom. \( \lambda \) the energy-dependent Rutherford scattering cross section, \( 0 \) the detector acceptance angle, \( D \) the total number of incident particles, \( D_0 \) the detector energy bin or channel width, \( i \) the stopping section, and \( K \) the kinematic factor for the geometry adopted. 

\[
\frac{H(E_x)}{H(E_0)} = \frac{\frac{1}{1 + \frac{x}{\lambda}}}{\frac{1}{1 + \frac{x}{\lambda_i}}}
\]

where \( x_i \) is the depth of the target atom.

\[
D = \frac{1}{1 + \frac{x}{\lambda_i}}
\]

The term \( D \) is given as:

\[
D = \frac{1}{1 + \frac{x}{\lambda_i}}
\]

\[
\frac{H(E_x)}{H(E_0)} \propto \frac{1}{1 + \frac{x}{\lambda_i}}
\]

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.

\[
\text{pathlength} = \int \frac{dE}{dσ/dE} \text{dE}
\]

Eq. (1) enables a fully analytical conversion of inelastic energy loss to path length:

\[
\text{pathlength} = \int \frac{\text{dE}}{\text{d}E} \text{dE} = \frac{1}{K} \left[ 1 - \text{e}^{-x/K} \right] = -\frac{x}{K}
\]

Example: 100 keV He ions on Au: 100 keV (100% surface, containing O and Au), \( x = 50 \) nm, \( \lambda = 25.8 \text{ nm} \), \( \lambda_i = 20.4 \text{ nm} \). Apply \( x = 10 \) (in the in, then \( x_i = 25 \)) the kinematic factor \( K \) (49°)

\[
K = \frac{M_{H}+M_{O}}{M_{O}} = 1.08
\]

and finally II. eq. (2) on the way out. This gives \( \text{pathlength} = -\frac{x}{K} = -\frac{50}{1.08} \text{ nm} = 46.3 \text{ nm} \)

II. The near-linear relationship between \( \text{pathlength} = -\frac{x}{K} \) and \( \lambda_i \) is seen in the Appendix (Figure A1). 

\[
\text{pathlength} = \int \frac{\text{dE}}{\text{d}E} \text{dE} = \frac{1}{K} \left[ 1 - \text{e}^{-x/K} \right] = -\frac{x}{K}
\]

Experimental validation

Outlook

Conclusion

Turning to the Screening correction

The MEIS energy regime of the \( \text{He} \) and \( \text{He}^+ \) ions are moderated and a fraction of the scattered projectiles leave the surface neutralised. When using electrostatic analysers (unlike for TOF ones) these particles are not counted, but cannot be ignored in quantitative analysis. Fractions of particles leaving ionised are generally accurately known. Shown below are data measured by various groups for H and the projectiles as a function of energy.

FOM group data library of 50 sets at 5 different energies (Leverkusen & Ziegler) (no clear dependence on target atom)

Kido group (Kido et al. Nucl 267, 2000) (566) (some dependence on target atom and exit angle)

Rutgers group (Busch, Doctor thesis)

Alko & Marjan & Young; calculations

General formula for effective ion survival probability as function of energy \( E \) based on available data (lines, Bailey):

\[
\begin{align*}
\text{P}_{\text{mean}} &= 1 - e^{-E/\text{in}} \\
\text{P}_{\text{H}} &= 0.0045 \text{ keV}^{-1} \\
\text{P}_{\text{He}} &= 0.0022 \text{ keV}^{-1}
\end{align*}
\]

Combined Screening & Neutralisation correction

Combining the screening and neutralisation corrections gives correction curves for the backscattered x-sectional as a function of target atom number, normalised to 1 for Si atoms.

Correction curves for Si, 100 and 200 keV He ions scattered through 90° at the surface) as function of target atom number, \( Z_t \) from 50 to 1000 keV for 400 keV.

Overall correction is mass and energy dependent and needs to be included to yield quantitative data.