Detailed analysis of opacity foils areal density uncertainties determined by Rutherford Backscattering Spectrometry

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Introduction

Comprehensive characterization of materials and components used in the building of High Energy Density (HED) targets is crucial for collecting reliable and reproducible experimentally measured atom-specific datasets. Modern manufacturing and diagnostics instruments enable the production of complex targets with well-defined geometric dimensions. Whereas there has been a long-standing concern about poorly known accuracy of elemental areal density values of thin foils used for opacity measurements at Z- and NIF-facilities. Such foils typically consist of two atomically mixed elements (such as Fe and Mg) with a wide range of stoichiometric variations. Most of the quantitative analytical techniques suitable for thin film chemical composition analysis rely on calibration standards with a predetermined chemical composition, which in our case is essentially the object of the measurement. Consequently, Rutherford Backscattering Spectrometry (RBS), which does not require a material specific standard, has traditionally been used for opacity foils elemental areal density measurements. In this study, we present analysis of areal density measurements uncertainties obtained with the new Ion Beam Analysis (IBA) capability recently installed at the Ion Beam Materials Laboratory (IBML) at LANL.

RBS strengths and weaknesses pertaining to opacity foils characterization

Strengths	Weaknesses
Quantitative analysis without calibration standards;	May result in damage of free-standing opacity foil;
Chemical composition and impurity elements;	Witness sample on carbon substrate is preferred;
Stoichiometry and areal elemental density;	Discrepancies between data obtained at different IBA facilitates are possible;
Depth profiling and thickness;	

Rigorous RBS measurements of ion implanted dopants in Si wafers, developed to meet ever growing semiconductor industry standards, have approached accuracy and precision in the 1-2% range.

Parameters contributing to RBS measurements uncertainties

1. RBS experimental details

- High vacuum (<10^{-6} Torr)
- Monogenetic He^+ ion beam
- Regular He^+ ion energy calibration
- Accurate ion beam current integration
- Secondary electron suppression
- Sample and detector orientation
- Acquisition system electronics calibration
- Detector solid angle value
- Pile up correction
- Selection of optimal conditions

2. RBS fundamental equation

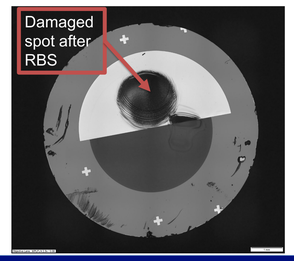
Backscattered particles yield ($H_{A,0}$) at the sample surface for the component A of a compound A_mB_n:

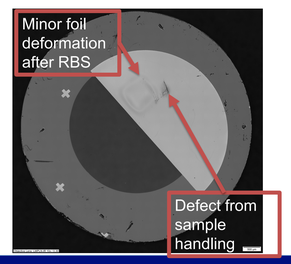
$$H_{A,0} = \sigma_A(E_0, \theta)\Omega Q m \Delta / ([\varepsilon_0]_A^{AB})$$

$\sigma_A(E_0, \theta)$ – differential Rutherford scattering cross-section
E_0 – beam energy
Θ – scattering angle
Ω - detector solid angle
Q - number of incident ions
m - atomic fraction of element A in matrix A_mB_n
Δ - electronics gain
$[\varepsilon_0]_A^{AB}$ – stopping cross-section for element A in A_mB_n

3. Sample quality

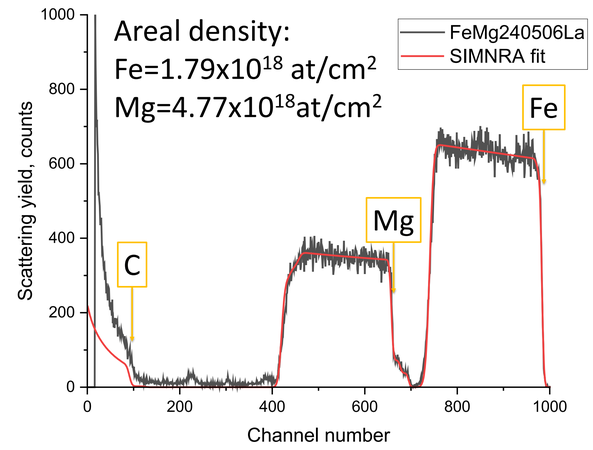
- Microstructural defects:
  - pores, cracks, grain boundaries
- Chemical composition:
  - variation with depth and nonuniform areal distribution
  - impurities (O and cross contamination)
- Sample degradation induced by the He^+ ion beam





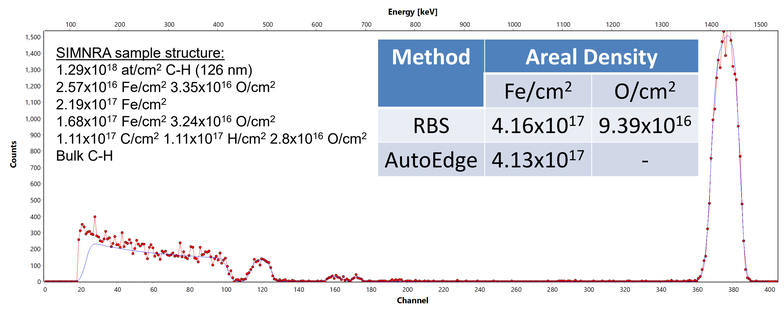
RBS measurements and uncertainties estimates

1. RBS spectrum (He^+, E_0=3.1MeV,θ=174°) from a uniform Fe-Mg film deposited on Carbon substrate



Parameter	Uncertainty, %
Counting statistics ($H_{Mg,0}$)	5.3
Counting statistics ($H_{Fe,0}$)	4.0
Scattering angle (Θ)	0.2
Electronics gain (Δ)	0.13
Beam energy (E_0)	0.3
Rutherford cross section for Mg (σ_{Mg})	0.1
Rutherford cross section for Fe (σ_{Fe})	0.1
Stopping cross-section for Mg ($[\varepsilon_0]_{Mg}^{MgFe}$)	3.5
Stopping cross-section for Fe ($[\varepsilon_0]_{Fe}^{MgFe}$)	3.5
Ω x Q	2.0
Total uncertainty	8.52

2. Areal density measurements of Fe/Parylene-N foil by RBS (He^+, E_0=2.0MeV,θ=165°)and AutoEdge



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