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Rutherford Backscattering Spectrometry (RBS) Services

Rutherford Backscattering Spectrometry (RBS) is an ion scattering technique used for compositional thin film analysis.

Rutherford Backscattering Spectrometry (RBS) is a powerful technique for obtaining the composition of thin films with high accuracy. RBS is a first principles technique where the composition is directly obtained by solving the ion-atom scattering physics that take place when a projectile ion hits the sample with sufficient energy. RBS is unique in that it allows quantification without the use of reference standards and is frequently used to calibrate other analytical methods. It is typically the method of choice for quantitative compositional analysis of thin films used for semiconductors, optical coatings, and other applications where tight control of film composition is crucial.

During an RBS measurement, high-energy (MeV) He^{2+} ions (i.e., alpha particles) are directed onto a sample and the energy distribution and yield of the backscattered He^{2+} ions at a given angle are recorded. The energies of the backscattered particles depend both upon the mass of atoms from which they scatter (the kinematic factor) as well as the depth at which a collision occurs (the energy loss factor). The number of backscattered ions is directly proportional to the concentration of a given element. Since the likelihood of a backscattering event is known for all elements (known as the backscattering cross section), it is possible to derive quantitative depth profile models from the RBS spectra for thin films that are less than 1µm thick.

RBS determines areal densities (atoms/cm^2) of the constituent elements as a fundamental solution from first principles.

Areal density (N·t) calculation of RBS for element i.

$$(N \cdot t)_i = \frac{A_i \cos\theta}{Q\Omega\sigma_i(E,\theta)}$$

Where N = atomic density (atoms/cm^3), t = film thickness (cm), A = peak integration of the i_{th} element, θ = scattering angle, Q = total number of incident ions, Ω = solid angle of the detector (mSr), σ = scattering cross section, and E = energy of scattered ions.

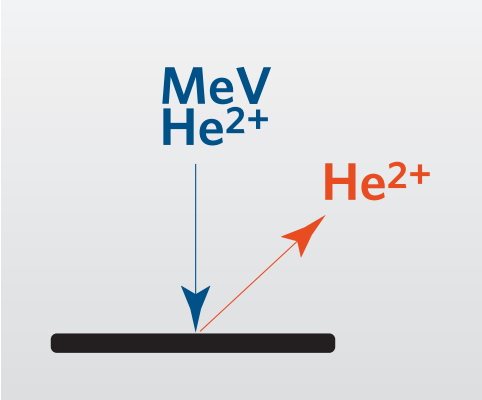

Figure 1: General schematic of how RBS works

Sub-Techniques

While RBS uses elastic scattering physics to determine the chemical composition of a thin film, MeV ion-atom interaction during RBS analysis produces a wealth of information in the form of elastic recoils, X-rays, Gamma rays and nuclear reactions. Each of these phenomena gives rise to additional signals that supplement the overall data analysis.

- Particle induced X-ray emission (PIXE)
- Proton induced Gamma emission (PIGE)
- Elastic recoil detection analysis (ERDA) or Hydrogen forward scattering (HFS)
- Nuclear Reaction analysis (NRA)
- Ion channeling
- Nuclear Reaction analysis (NRA)

Strengths

- Quantitative without the need for reference standards
- Depth profiles of top ~1 µm
- Determines approximate film thickness
- Can measure density of the film when physical thickness is provided
- Can analyze insulating and conductive samples
- Very sensitive for high-z elements. (ppm level)
- Can measure H, and all other elements except He, Li, Be
- Can analyze full wafers up to 300 mm
- Nondestructive

Limitations

- Typically, poor detection limits for B, C, N, O (3-5 at-%)
- Smallest analytical area ~2 mm diameter
- Sample must be vacuum compatible
- Limited depth resolution

Common Applications

The ability of RBS to deliver highly accurate film composition without the use of standards makes it ideal for the compositional analysis of semiconductor and other thin films.

- Thin film compositional depth profiling:
  - Metal silicides: WSi, FeSi, CoSi, TiSi, etc.
  - Nitrides: TiN, TaN, TaAlN
  - Dielectrics: SiN, SiO_2
  - High K Dielectrics: HfSiO, HfO_2
  - Low K Dielectrics: SiOCH
  - Hard mask: DLC, WC, WBC, BCH, BC
- Compound Semiconductor Layer composition: SiGe, AlGaAs, InGaAs, etc.
- Optical Coating compositional depth profiling: TiO_2, HfO_2, ZrO_2, WO_3
- Hydrogen in thin films: SiN, SiO_2, SiOCH, DLC, etc.
- Ion Implant Dosimetry (high Z elements): As, Sb, In dose
- Damage profiling in single crystal samples: Ion implant, polishing, annealing

Industry Sectors and Technologies

- Semiconductors
- Semiconductor capital equipment manufacturers
- High tech and next generation computing
- Aerospace and defense

Case Study: Composition of WSi_x films

In figure 2 below are overlaid RBS spectra from WSi_x films with three different Si/W ratios. The peak at high energy (high channel number) corresponds to scattering from the W in the film while the step at lower energy corresponds to scattering from Si. By measuring the intensities (yield) of the W and Si signals and correcting for the scattering cross sections of W and Si the exact ratio of Si/W can be determined within 1-2%. The width of the W peak is directly proportional to the thickness of the WSi_x layer. Using known values for the stopping powers of He in W and Si it is possible to calculate the thickness of the WSi_x layer.

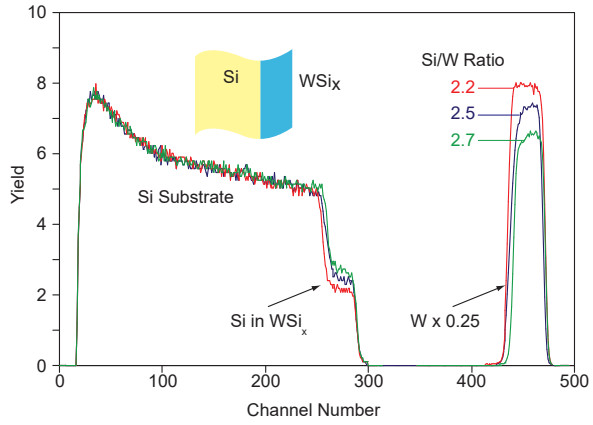

Figure 2: Highly accurate Si/W ratios can be determined by measuring the intensities of the W and Si scattering peaks and correcting for the scattering cross section for each element. Film thickness can also be determined.

Case Study: RBS/HFS Analysis of SiN Film

Hydrogen forward scattering is a sub-technique of RBS where the ~2MeV He^{2+} ion beam is directed onto the sample at a grazing incidence (75° to normal). Hydrogen atoms are ejected out of the sample as recoils and are recorded with a detection system. Figure 3 below shows the simultaneously recorded RBS + HFS spectra of a silicon nitride film. Both the RBS and HFS data are modeled simultaneously with the appropriate physics model to obtain the accurate composition of the H-containing SiN film.

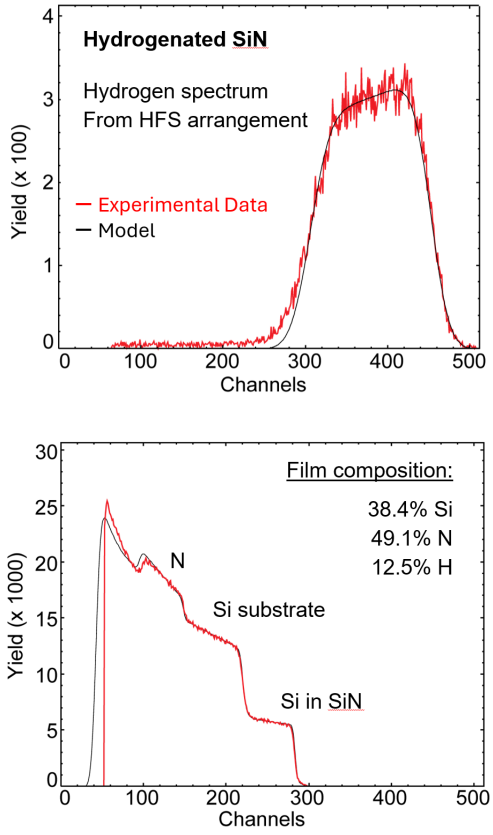

Figure 3: Simultaneously recorded RBS +HFS spectrum of SiN film.

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Complementary Techniques

The limitations of RBS can be easily overcome by pairing the technique with other complementary techniques or sub-techniques. Such techniques include SIMS, Auger Electron Spectroscopy (AES), X-ray Photoelectron Spectroscopy (XPS) and X-ray fluorescence spectroscopy (XRF).

RBS has higher detection limits for low-Z elements at trace concentrations, therefore, RBS can be paired with AES, XPS and SIMS to obtain information about trace contaminants in the film. Also, these techniques provide better depth resolution. Auger offers much better spatial resolution but can have problems with analyzing insulating samples. XPS can provide chemical state determination in addition to elemental quantification. Both Auger and XPS sample only the upper ~10nm of materials and use ion beam sputtering to remove material from the sample to obtain a depth profile. This sputtering process can modify the material being analyzed, resulting in less accurate quantitative results. RBS does not sputter the sample, so it is typically able to provide more accurate quantitative results. SIMS requires reference standards for accurate measurement.

RBS can also be used to nondestructively determine film thickness so it can be used instead of Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM) cross sectioning. However, to derive a film thickness from RBS data one must assume a density for the film, which leads to an additional potential source of error. Conversely, if one knows the physical film thickness from another technique such as TEM or SEM then the film density can be calculated accurately using the RBS data. RBS is complementary to X-ray reflectivity (XRR) analysis, which can also determine film density and film thickness but does not determine film composition.

RBS at EAG

EAG is a world leader in RBS analysis, having developed proprietary RBS analysis software and instrumentation used in other labs around the world. We have two RBS instruments located at our lab in Sunnyvale, CA and have been offering RBS analysis for over 30 years. EAG has unmatched RBS experience analyzing a wide range of materials and we are continually innovating to get the best out of our instruments and to understand new and novel materials. We serve both domestic and international clients from various facets of industry, academy, and government.