Secondary Ion-Mass Spectroscopy (SIMS)

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Outline

- Introduction to SIMS
- Instruments of SIMS
- Analysis conditions
- Quantification
- Specific Applications
- Profiling Issues
## Analytical Beam Techniques

*Source: R1*

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Principle of SIMS Analysis

- Bombardment of a sample surface with a primary ion beam ($I_p$) followed by mass spectrometry of the emitted secondary ions ($I_s$) constitutes secondary ion mass spectrometry.

- SIMS is a surface analysis technique used to characterize the surface and sub-surface region of materials and based on m/e ratio measurement of ejected particles under ion bombardment.

Source: R2
History of SIMS

- J. J. Thomson built MS prototype to measure m/z of electron, awarded Nobel Prize in 1906.
- MS concept first put into practice by Francis Aston, a physicist working in Cambridge England in 1919 and awarded Nobel Prize in 1922.
- Improved vacuum pump technology in the 1940s enabled the first prototype experiments on SIMS at the University of Vienna, Austria.
- 1948-52 - Time of Flight (TOF) mass analyzers introduced.
- 1955 - Quadrupole ion filters introduced by W. Paul, who also invents the ion trap in 1983 (wins 1989 Nobel Prize)
  - In the early 1960s two SIMS instruments were developed. One was an American project for analyzing the spatial and isotopic distribution of all the elements from hydrogen to uranium present in samples of moon rock brought back to earth.
  - The other at the University of Paris.
- Mass spectrometers are now one of the MOST POWERFUL ANALYTIC TOOLS IN CHEMISTRY
Applications - 1

Source: R1

- **Surface analysis (Static SIMS)**
  - Low sputtering rate ~ 1 A/hr
  - Depth ~ 0.5 nm
  - Typical spatial resolution ~ 100 μm
  - Optimal spatial resolution ~ 10 nm ~ 1 μm
  - Element >= H
  - Detection limit ~ $1 \times 10^{10} \sim 1 \times 10^{11}$ cm$^{-2}$

- **Ion mapping**
Applications - 2

- Depth profiling of elements (Dynamic SIMS)
  - Sputter rate \( \sim 10 \ \mu m/hr \)
  - Typical depth resolution : 10 ~ 20 nm
  - Optimal depth resolution : 2 ~ 5 nm
  - Detectable elements >= H
  - Detection limit : ppm-ppb
  - Typical beam diameter : 1 ~ 100 \( \mu m \)
  - Extreme beam diameter ~ 100 nm

- Image depth profile

Source: R1

Source: R2
Instrumentation

Source: R1

- **Primary beam**
  - $O_2^+$, $O^-$, $Cs^+$, $Ar^+$, $Xe^+$, $Ga^+$, etc.
    - $O_2^+$ for electropositive species (B, Al, etc)
    - $Cs^+$ for electronegative species (N, P, As, etc)
    - $Ga^+$ for improved lateral resolution
  - Primary beam angle: 0 - 60 deg. (high sputter rate => low secondary ion yield)
  - Beam energy: 0.5 - 20 keV
  - Beam diameter: typical 10 ~ 100 $\mu$m, extreme 0.1 $\mu$m
  - Mass analyzers: magnetic sector (precision mass analysis), quadrupole (depth profiling), time of flight (TOF, organic materials)
    - Magnetic sector: mass/charge ratio, good transmission, very high mass resolution ($^{28}$Si and $^{12}$C$^{16}$O, ie. 27.976 and 27.995). High extraction energy results in surface roughness and charging.
    - Quadrupole: low transmission, low mass resolution, very fast peak switching
    - TOF: time taken to travel a drift space, high mass resolution, very high mass range
Advantages and Disadvantages

Advantages

- All elements detectable and isotopes can be distinguished.
- Detection limits of ppm for most elements and ppb for favorable elements.
- Good depth resolution (2~5 nm) and lateral resolution (20 nm ~ 1 µm)
- Insulator analyzable
- Chemical information obtained from relative molecular ion abundances.

Disadvantages

- Mass interferences.
- Secondary ion yield vary by more than six orders of magnitude over the periodic table.
- Secondary ion yields are often matrix dependent.
- Numerous secondary standards are required to quantify data.
- Flat surface required for best depth resolution and for ion microscopy.
- Destructive analysis.
Outline

 Instruments of SIMS

 - Primary ion source
 - Ion Extraction
 - Mass Analysis
   - Quadrupole
   - Magnetic sector
   - Time-of-Flight
 - Ion Detector
 - Vacuum

Source: R3
Primary Ion Source - 1

Source: R3

- Ion sources
  - Ion sources with electron impact ionization - Duoplasmatron: $\text{Ar}^+$, $\text{O}_2^+$, $\text{O}^-$
  - Ion sources with surface ionization - $\text{Cs}^+$ ion sources
  - Ion sources with field emission - $\text{Ga}^+$ liquid metal ion sources

- Duoplasmatron
  - A cathode filament emits electrons into a vacuum chamber.
  - A gas such as argon is introduced in very small quantities into the chamber, where it becomes charged or ionized through interactions with the free electrons from the cathode, forming a plasma.
  - The plasma is then accelerated through a series of at least two highly charged grids, and becomes an ion beam, moving at fairly high speed from the aperture of the device.
Cs ion source

- Beams are generated by a surface ionization process. Cs vapor is produced by the heating of a solid Cs compound.
- The Cs vapor travels along the drift tube and strikes a W plate where it is thermally ionized.
- Any atom or molecule coming from the reservoir is forced to bounce between the W plate and the ionizer tip. This results in most atoms being ionized and escaping through the small hole in the cap.
- In general Cs beams are smaller than those generated by the duoplasmatron and sputter material more effectively due to their greater mass.
- However, the Cs gun is expensive to operate and is only routinely used for O, S or C isotopic analysis.
Primary Ion Source - 3

Liquid metal ion sources (LMIS)

- LMIS operates with metals or metallic alloys, which are liquid at room temperature or slightly above.
- The liquid metal covers a W tip and emits ions under influence of an intense electric field.
- It provides a tightly focused ion beam (<50 nm) with moderate intensity, i.e., high spatial resolution, which is important for mapping chemical elements over the specimen surface.

![Diagram of LMIS](image)
Secondary Ion Yield

- The variability in ionization efficiency leads to different analysis conditions for elements as indicated on the periodic table.

Source: R2
Electron Charge Neutralization

- Low-energy electron flood gun.
  - The electrons emitted from the W filament pass through deflectors and a quadrupole lens that is used to shape and focus the electron beam.
  - A magnetic prism (deflection coil) deflects the electrons by an angle of 90° towards the sample. After passing through the immersion lens the electrons arrive at the sample surface (also held at -4500 or -10,100 V) with zero energy.
  - Therefore when negative secondary ions are analyzed, a cloud of low energy electrons are formed just above the sample surface where they are available for charge compensation.
  - When positive ions are analyzed the sample is held at +4500 or 10,000 V and the electrons strike the sample at a voltage and current adjusted to give a stable signal.

Source: R3
Ion Extraction

Secondary ions are formed at the sample surface by the bombardment of the primary beam. These secondary ions are immediately removed by an extraction, or immersion lens.

The purpose of this transfer lens is to form a real magnified image of the sample surface at the position of the field aperture and to focus the secondary ion beam onto the entrance slit of the spectrometer.

Source: R3
Mass Analysis - 1

Magnetic Sector Analyzer

- Magnetic Sector Analyzer
- Electrostatic analyzer (ESA)
- Select the K.E. of ions
- Electrostatic Sector
- Source exit

Degree (r) of deflection of ions by the magnetic filed depends on m/q ratio.

\[ mv^2/r = qBv \]

Mass Analyzer (MA)
- Select the m/e
- Magnet Sector
- Point of double focus
- Energy Focal plane

High transmission efficiency
High mass resolution
Imaging capability

\[ R = \frac{1}{B} \left( \frac{2mV}{z} \right)^{\frac{1}{2}} \]

Capable: \( R \geq 2000 \)
Capable: \( R \sim 10^5 \)
Mass Analysis - 2
Source: R2

- Quadrupole Mass Filter

- The quadrupole consists of 4 circular rods with a direct current voltage and a superimposed radio-frequency (RF) potential.
- The A rods are connected and are at the same DC and superimposed RF voltages. The same is true of the B rods but in the opposite DC voltage with respect to the A rods, and RF field is phase shifted by 180°. Ions travel down the quadrupole between the rods.
- Only ions of a certain mass-to-charge ratio m/z will reach the detector for a given ratio of voltages: other ions have unstable trajectories and will collide with the rods.
- This permits selection of an ion with a particular m/z or allows the operator to scan for a range of m/z-values by continuously varying the applied voltage.
Mass Analysis - 3

Time-of-Flight (ToF)

- ToF SIMS is based on the fact that ions with the same energy but different masses travel with different velocities.
- Basically, ions formed by a short ionization event are accelerated by an electrostatic field to a common energy and travel over a drift path to the detector.
- The lighter ones arrive before the heavier ones and a mass spectrum is recorded.
- Measuring the flight time for each ion allows the determination of its mass.
- It enables the analysis of an unlimited mass range with high sensitivity and quasi-simultaneous detection of all secondary ions collected by the mass spectrometer.

\[ t = L\left(\frac{m}{2zV}\right)^{\frac{1}{2}} \]

1. Ion source with a pulsed a 90° deflector
2. Liquid metal ion source
3. Target
4. Single stage reflector
5. Detector
A Faraday cup measures the ion current hitting a metal cup, and is sometimes used for high current secondary ion signals.

With an electron multiplier an impact of a single ion starts off an electron cascade, resulting in a pulse of $10^8$ electrons which is recorded directly.

Usually it is combined with a fluorescent screen, and signals are recorded either with a CCD-camera or with a fluorescence detector.
Ion Detector - 2

Micro-Channel Plate (MCP) consists of an array of miniature electron multipliers.

- The channels are about 10 μm in diameter, 400 μm long and about 7° from the perpendicular to the plate face. They are located about 12 μm pitch and number up to 2000 in a 25 mm array. The front face of the plate is held at ground potential, while the back plate may be between +1000 to +2000 V.
- An ion passing down a channel hits the inner channel wall and produces secondary electrons.
- The channels are designed so that these secondary electrons initiate an electron cascade down the channel.
- The pulse of electrons from the back of the detector may either be passed to a second micro channel plate for further gain, or accelerated towards a phosphor screen, where their impact may be viewed directly.

Source: R3
An essential requirement for the operation and analysis is that the instrument is kept under Ultra High Vacuum (UHV).

- The level of vacuum required is one of the highest of all analytical instruments and requires extreme care with sample preparation and maintenance.
- The vacuum in the analysis chamber can get down to $5 \times 10^{-10}$ Torr. This is equivalent to approximately $10^{10}$ molecules/L while air has $2.7 \times 10^{22}$ molecules/L. Under these vacuum conditions the probability of a secondary ion hitting a gas molecule within the instrument is almost zero.
Outline

- Analysis conditions
  - Primary beam
  - Primary beam energy
  - Angle of incidence
  - Sputtering rate
  - Detected area
  - Species monitored
  - Energy distribution
  - Insulator effects
The selection of primary species depends on many factors:
- Secondary ion yield, detection limit, depth resolution, lateral resolution, charge neutralization, availability, microtopography formation, and sputtering rate.

Many primary beam species have been employed. $O_2^+$, Cs$^+$, O$^-$, Ar$^+$, Xe$^+$, and Ga$^+$ are commonly used.

Because of positive or negative secondary ion yield enhancement that results from the use of $O_2^+$ and Cs$^+$, respectively, they are usually employed.

To operate efficiently, one may need to sacrifice some sensitivity or detectability. For example, Cs$^+$ is often used for deep profiles when the secondary ion yield and detection limit are sufficient, such as for B in Si.
Beam Energy

The choice of beam energy affects depth resolution (ion beam mixing), secondary ion yield, and sputtering yield.

Ion beam mixing is the churning effect of the primary beam in the sample.
- This process includes a reversal of momentum back toward the surface.
- Recoil mixing is the forward momentum component of sputtering and accounts for the pushing of some atoms deeper into the sample.

Primary ion current and focusing are usually improved with higher ion energy.
The beam angle of incidence affects sputtering rate, secondary ion yield, and depth resolution.

- The sputtering yield increases with angle of incidence up to a certain angle and then decreases.
- For some multilayer structures, a 60 degree angle of incidence provides nearly equal sputtering yield, i.e. sputtering rate, for different materials.
- Secondary ion yields decrease as angle of incidence is increased until grazing incidence is approached.
- The optimum depth resolution is expected at off normal incidence because the collision cascade in the sputtering process occurs closer to the surface than at near normal incidence.

Source: R1
Effect of sample potential

- Magnetic sector instruments hold the sample at several kV. The nominal angle of incidence will be affected by the potential.

\[
\sin \theta = \frac{\sin \theta'}{\sqrt{1 - \frac{E_s}{E_p}}}
\]

where \( \theta \) is the actual angle of incidence
\( \theta' \) is the nominal angle of incidence
\( E_s \) is the sample bias
\( E_p \) is the primary voltage
\( E_p - E_s \) is the impact voltage

Source: R1
The sputtering rate is determined by the following factors:

- The mass, energy, and angle of incidence of the primary angle.
- The mass of the sample atoms. A weak dependence on crystal orientation, crystal type, and sample temperature.
- The surface binding energy of the sample.
- The current density of the primary beam, which is the beam current divided by the rastered area.
Detected Area

Source: R1

- In a depth profile, the total rastered area cannot be used for detection of secondary ions because of contributions from the crater walls.
  - A large raster-to-detected area ratio is generally required for the microprobe mode where secondary ions from sidewalls are excluded with electronic gating ON of the detector only when the primary beam is in the center of the crater.
Species Monitored - 1

Source: R1

- Detection limit (DL) is affected by the following factors:
  - Low count rate, causing the DL to be limited by the minimum reliable measurable count rate, rather than by the true detection limit of the mass in the matrix.
  - High implant standard dose, causing the DL to be limited by the instrument dynamic range, caused by resputtering.
  - Contaminated instrument, causing a background signal not originating from the sample.
  - Poor vacuum for H, C, O, N, or molecules formed from vacuum species.
  - Contaminated primary ion beam, caused by lack of primary ion beam mass filtering.
Sensitivity versus Dynamic Range

- Achieving maximum dynamic range often requires a trade off or optimization between sensitivity and detection limit.
- An element that has good sensitivity (low RSF) may have a poor detection limit (background). For example, PSi\(^{-}\) in a Si matrix has a lower RSF than P\(^{-}\) but exhibits a poor detection limit because of mass interference from abundant Si\(_2\)\(^{2-}\).
- Dynamic range is also influenced by count rate saturation for the detector used for the secondary ion signal. Count rate loss often begins at about 3x10\(^5\) counts/sec. If a reliable background count rate is 3 counts/sec, then a maximum accurate dynamic range of 5 orders of magnitude is defined.

<table>
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<tr>
<th>Primary Ion Beam (O_2^+) or (Cs^+)</th>
<th>Element</th>
<th>Detected Ion</th>
<th>Detection Limit ppm</th>
<th>Detection Limit atom/cm(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>(^{11}B^+)</td>
<td>0.002</td>
<td>&lt;10(^{14})</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>(^{31}P/31P^+)</td>
<td>0.1</td>
<td>&lt;5 \times 10(^{15})</td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>(^{75}As^+)</td>
<td>0.2</td>
<td>&lt;10(^{16})</td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>(^{121}Sb^+)</td>
<td>1.0</td>
<td>5\times 10(^{16})</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>(^{12}C^+)</td>
<td>1.0</td>
<td>5\times 10(^{16})</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>(^{16}O^+)</td>
<td>10</td>
<td>5\times 10(^{17})</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>(^{28}Si_2N^+)</td>
<td>10</td>
<td>5\times 10(^{17})</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>(H^+)</td>
<td>100</td>
<td>5\times 10(^{18})</td>
<td></td>
</tr>
</tbody>
</table>

Source: R1

Source: R2
Species Monitored - 4

Source: R1
Energy Distribution

Source: R1

- The secondary ion energy distribution from a sample varies with ion species.
  - Molecular ions in general have a narrower energy distribution than atomic ions, an high pass energy window can be chosen to select atomic ions.

![Graph showing energy distribution of secondary ions for different species.](image)
Insulator Effects

- When charging occurs during analysis of insulator, the energy distribution can be shifted.
  - This issue can be relaxed by electron flood.

Source: R1
Outline

- Quantification
  - Procedure
  - Quantification by Ion Implantation
  - Calibration Using Ion Implantation
Procedure

Source: R1

There are two principal methods of elemental sensitivity quantification for SIMS.

- The use of ion implanted standards with accurately known fluences.
- The use of bulk samples doped to accurately known trace element concentrations or atom densities.

Relative Sensitivity Factor (RSF)

- An RSF is a conversion factor from secondary ion intensity to atom density.

\[
\rho_i = \frac{I_i}{I_m} \times RSF \text{ atoms/cm}^3
\]

\[
RSF = \frac{Dose \times (Cycle \ number \times cycle \ time) \times I_m}{Depth \times (\Sigma I_i - I_b \times Cycle \ number)}
\]

where \(\rho_i\) is the impurity atom density in atoms/cm\(^3\)
\(I_i\) is the impurity isotope secondary ion intensity in counts/sec
\(I_m\) is the matrix isotope secondary ion intensity in counts/sec
\(I_b\) is the background ion intensity of \(I_i\) in counts/data cycle.
Quantification by Ion Implantation

- Ion implantation

Raw data

Corrected data

Isotopes corrected data
In making an ion implantation standard, several factors must be considered.

- Only one isotope should be implanted. choice, dose, energy, and mass interference. Otherwise, all implanted isotopes must be monitored.
- Impurities in the ion implant beam at masses to be implanted must be avoided.
- The dose implanted must be accurately measured. The typical dose accuracy is within 10%. Charge compensation can be used to remove the effect of conductivity change due to high dose implantation.
- The energy must be high enough to place the implant peak deeper than the equilibrium depth. The intensity drop from the peak of the implant to the level at the surface should be at least a factor of 3.
Outline

 Specific Applications
  • Bulk Analysis
  • Organic Materials
  • Chemical Mapping
  • 3D Analysis
Bulk Analysis - 1

There are two major modes of bulk impurity analysis.
- High sputtering rate and low detection limit depth profiling of selected elements.
- Element mass scan.

Depth profiling
- Masses are generally analyzed in groups.
- Reaching the equilibrium signal associated with each mass is required.

Mass scan
- For thin films, the sample thickness, the sputtering rate, and the time required to obtain the desired statistical information must be traded off.
- A depth profile of a mass that will indicate the interfaces and thickness of the desired layer is performed firstly.
- The time required to reach the layer and the time that will be available for subsequent analysis within the desired layer can be determined.
Bulk Analysis - 2

Source: R4

Ultra-shallow junction

- A beam of low energy oxygen ions is used for sample erosion, and a Liquid Metal Ion Gun is used in high current mode for the analysis of the eroded crater bottom.
- The parallel detection of all masses allows the measurement of the implanted F as well as metal surface contaminants, for example aluminum, at the same time.

- BF$_2^+$ implant
  - 2.3 keV to 1x10$^{16}$ cm$^{-3}$
- 500 eV O$_2^+$ sputtering
- Oxygen flooding
- 15 keV Ga analysis
- Repetition rate of 50 kHz
Operation conditions

- Depth profiling with SIMS presents serious problems in organic materials, because the primary keV atomic ion beams often damage.
- Irradiation with large Ar cluster ion beams rarely leads to damage accumulation on the surface of the films.
- Ar cluster ion beams:
  - Ar cluster size 650 ~ 700 atoms
  - Energy 5.5 keV/Current 4–8nA
  - Diameter 0.2 ~ 0.4mm
  - Incident angle 45°.
- Etching stage
  - Continuous Ar cluster ion beams.
  - Scan area 3mmx4.5mm
- Analysis stage
  - Size-selected Ar cluster ions
  - Scan area 0.6mmx1mm
  - Up to 2x10^{11} ions/cm^2 were irradiated during 10 s of SIMS analysis and the fluence was estimated to be much below the static SIMS limit.
Organic Materials - 2

Source: R5

AFM topography images (1μm x 1μm) of the PS surface (a) before and (b) after etching 20 nm.

Ra = 0.19 nm

Ra = 1.1 nm
Organic Materials - 3

- **OLED structure**
  
  - For this analysis in dual beam mode a 10 keV \( \text{Ar}_{2500}^+ \) sputter beam was used in combination with a 30 keV \( \text{Bi}_3^+ \) analysis beam.
Small area mapping

- ToF-SIMS elemental mapping of a garnet amphibolite (石榴角閃岩) from the KTB deep borehole, Germany. An anastomosing network of carbon can be seen on grain boundaries and cleavage traces. From Mogk and Mathez (2000).

Backscattered electron image of garnet amphibolite. Garnet is green; Hornblende is light blue.

Na map. Na in the crack in the garnet.

Fe map. Fe enrichment in cleavages in the hornblende.

Carbon map. Interconnecting network of carbon along hornblende cleavages.
Large Area mapping

- If chemical mapping is required to analyze the distribution of a contamination of a large area, then the stage stepping acquisition mode can be used. In this mode a series of small images is sequentially acquired and stitched together automatically.

Source: R8
Chemical Mapping - 3

Source: R7

Distribution of materials

Drug Composition Analysis

Nylon mesh – 10 micron depth

Plasma cleaned scalpel blade
3D Chemical Mapping

By sputtering the sample surface simultaneously images from increasing depth are obtained and hence three dimensional data are collected.

- The raw data file contains each point of analysis of the digitally scanned beam with its X, Y, and Z coordinates and a mass spectrum,
Outline

- Profiling Issues
  - Ion beam mixing
  - Depth resolution
  - Segregation
  - Charge driven diffusion
  - Matrix Effects
  - Surface Effects
  - Crater shape
  - Microtopography
  - Memory Effects
  - Mass Interference
  - Count Rate Saturation
Ion Beam Mixing

Source: R1

Ion beam mixing is also known as knock-on effect

- Three different ion beam mixing processes can be identified: recoil mixing, cascade mixing, and radiation enhanced diffusion (RED).
  - Recoil mixing arises from direct collisions of the primary ions with sample atoms that are driven into sample. Anisotropic movement.
  - Cascade mixing results from the motion and collisions of sample atoms with each other in the collision cascade. Isotropic movement.
  - RED is thermally-activated diffusion, enhanced by the vacancies and defects produced by the bombardment.
- Interface width is defined as the depth interval over which the intensity drops from 84% to 16% of the maximum.
Segregation and Charge Driven Diffusion

Segregation

- Gibbsian segregation is the tendency of one species in a multi-element solid to increase its concentration at the surface because this constitutes a site of lower chemical potential than the bulk.
- Movement of an analyzed species, such as As in SiO$_2$, can occur during ion bombardment because of chemical gradients.

Charge driven diffusion

- Using oxygen primary ion beam at low incident angle, the sputtering rate is low so that a microscopic SiO$_2$ layer is formed.
- Charge-driven diffusion of some species, such as Na and Cu, may occur due to the charges accumulated on the oxide.
Matrix and Surface Effects

Matrix effects

- Secondary ion yields can vary with sample composition.
- The change of primary ion density at surface and interface of multilayer sample affect the secondary ion intensity.

Surface effect

- The native oxide, the equilibrium depth, and surface defects produce depth profile aberrations.
- Low energy and oxygen flooding can reduce equilibrium depth.
Crater Shape

Crater shape issue comes from nonuniform raster or asymmetric beam shape.
- Sputtered front is not at the same plane.
- Signal from various plane are mixed.

Source: R1
Microtopography

Source: R1

- Surface topography may be the property of the original sample surface or changed by ion bombardment.
  - Grains with different orientation have different sputtering rate.
  - Ripple topography is an instability of a plane surface to periodic disturbance.
  - Signal from various planes are mixed.
Memory Effect and Mass Interference

Memory effect
- Residual gas contamination or deposited atoms from previously sampled.
- Significant for magnetic sector mass analyzer.

Mass interference
- Variety and intensity of the molecular ions and the multiple charges species.

Count rate saturation
SIMS Decision Map
Source: R1
Summary

- SIMS can be used to analyze the composition of organic and inorganic solids.
- SIMS can generate spatial or depth profiles of elemental or molecular concentrations.
- To detect impurities or trace elements, especially in semiconductors and thin filaments.
- Secondary ion images have spatial resolution on the order of 0.5 to 5 μm. The depth resolution is around 2 to 5 nm.
- Detection limits for trace elements range between $10^{12}$ to $10^{16}$ atoms/cm$^3$. That is around ppb ~ ppm.
- SIMS is the most sensitive elemental and isotopic surface microanalysis technique. However, very expensive.
References

- R3: SECONDARY ION MASS SPECTROMETRY (SIMS), JAC C:\IP\DOC\SIMS4.DOC
- R4: iONTOF Application Note - Boron Ultra-Shallow Depth Profiling
- R6: iONTOF Application Note - Gas Cluster Ion Source
- R8: iONTOF Application Note - Large Area Mapping
- R9: iONTOF Application Note – 3D Analysis