Secondary Ion Mass Spectrometer

HOW DID WE GET HERE?

Discovery of Emission of Secondary Ions

J.J. Thomson, born in England in 1856, observed at the Cavendish lab, the emission of positive ions from a metal surface induced by primary ions bombardment.

First Commercial SIMS

From the early 60's, R.F.K. Herzog (center) had moved to US and teamed up with Helmut Liebl (left), born in Germany in 1927. Together they produced the IMS1101 at UCA Corporation in Massachusetts.

1852 — 1910 — 1949 — 1967 — 1968

Discovery of Sputtering

In 1852, William Robert Grove, born in Wales in 1811, was studying the electrical conductivity of gases when he noticed the deposition of metallic particles on a glass tube.

First SIMS Prototype

Richard Franz Karl Herzog, born in Austria in 1911, published an article based on the thesis of his student F.P. Viebock at the University of Vienna describing the first SIMS prototype.

SMI300

In parallel, in France, licensing the work of Raimond Castaing, born in Monaco in 1921, and several of his students including Georges Slodzian initially at the University of Toulouse and then Paris, Orsay, CAMECA released its first SIMS equipment.

HOW DOES IT WORK?

Principles of Secondary Ion Mass Spectrometer (SIMS):

Unlike neutral particles (atoms, molecules, or clusters), ions (charged particles) can be spatially controlled to form a beam (called ion beam) with controlled kinetic energy, flux density, and spot size.

When a solid sample is irradiated by an ion beam with keV energy, fragments of surface material are ejected. Those fragments include: electrons, neutral atoms or clusters, ions or charged clusters. Only 1 – 5% of the ejected particles are ions. SIMS analyzes the charged particles (atomic or cluster ions) in the ejected materials.

There is a general correlation between the primary ion beam type and the ions ejected: Positively charged primary ions will favor the production of negative ions and negatively charged primary ions will favor the production of positive ions. In SIMS, these ions are then accelerated, focused, and analyzed by a mass spectrometer.

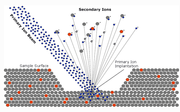

Figure 1. Ion beam and surface interaction (www.cameca.com/products/sims/technique)

A high energy ion beam is focused on to the target sample surface and ejects: neutral or ionized particles and electrons. These ejected ions are called secondary ions and are collected by ion lenses and filtered according to each particle's mass to charge ratio (mass analyzer), then projected to detectors such as electron multiplier, Faraday cup, or CCD.

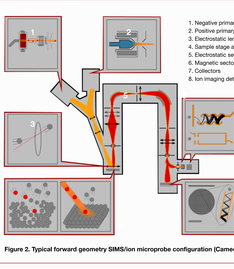

Figure 2. Typical forward geometry SIMS/ion microprobe configuration (Cameca IM 6f) showing

Operation Modes:

There are two types of SIMS operation depending on the area of interest – Static SIMS and Dynamic SIMS.

1. Static SIMS is highly surface sensitive technique for molecular characterization of surfaces. Relatively low flux (< 1E12 atoms/cm2) ion beam may either defocus or raster scan across the sample for analysis. To avoid artifacts, the analysis beam should be a different element from those in the sample. Higher-level analysis can reveal significant groups of higher masses.

2. Dynamic SIMS is used to study thin films along a depth. It is usually equipped with oxygen (O) and cesium (Cs) sputtering ion beams to enhance, respectively, positive and negative secondary ion intensities. The ejected ionic species are continuously analyzed while the surface is sputtered by the ion beams. The detection limit of SIMS is very low (typically ppm or ppb level), that is why SIMS is often used to understand the in-depth distribution of trace elements like dopants or contaminants in semiconductor applications.

Analyzer Types:

SIMS equipment is usually defined by its analyzer type – magnetic, quadrupole, and time-of-flight (ToF) analyzers.

1. Magnetic sector SIMS uses a magnetic sector field to separate the secondary ions by their mass-to-charge ratio. It is usually used in high speed dynamic mode for selected species. Non selected elements are not analyzed since they do not reach the detector.

2. Quadrupole mass analyzer separates the masses by resonant electric fields which allow only the selected masses to pass through the quadrupole. Again, only the chosen species will be measured.

3. Time-of-Flight (ToF) SIMS separates the ions in a field-free drift path according to their velocity. Since all ions possess the same kinetic energy, the velocity and therefore time-of-flight varies according to the mass of each ionic species. This measurement is achieved by using pulsed ion beams. As it is the only analyzer type that can detect all generated secondary ionic species simultaneously, ToF SIMS is used for applications that require thorough analysis. It is the standard analyzer for static SIMS.

Strength and Limitations:

1. Strength:
   a. Strong lateral and vertical sensitivity.
   b. Very low detection limit which can go down to ppb level and allows the analysis of isotopic ratios
   c. In-situ analysis that eliminates the need for complex sample preparation
   d. One of the few metrologies that can analyze hydrogen

2. Limitations: As SIMS only analyzes ion species from the ejected particles, which depends on many parameters such as primary beam type, ionization probability of components, and surface's electronic states, the elemental ratio detected doesn't reflect the actual composition of the sample. Therefore, SIMS results can't be quantitative and can only be used for the relative comparison of samples within a batch or for the trace element profile analysis.

APPLICATIONS

SIMS is widely used in most of materials science and engineering including biotechnology areas.

1. Application areas:
   a. Semiconductor: dopant species and profiles, diffusion profiles, and trace element analysis
   b. Light Emitting Diode (LED): Compositional and structural analysis of p-n layer stack, analysis of interface and polymer contaminant identification in packaging
   c. Geoscience: Mainly to analyze trace elements and isotopes with high mass resolution analyzer
   d. Bioscience: Analysis of hydrogen (H) and physiologically important elements such as Na, K, Mg, and Ca. Ion imaging of elements in areas as large as 250 micrometers in diameters with a lateral resolution of 0.5 micrometers. Three-dimensional analysis of sequential layers.

Example Data from Various Applications:

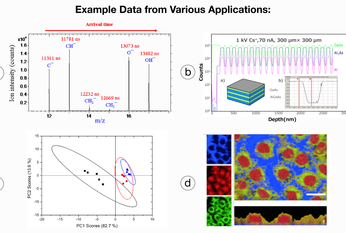

Figure 3. Various examples of data from SIMS technology:
a. Example of static SIMS showing some of components on sample surface (http://publish.uwo.ca/~hnie/tof-sims.htm)
b. Example of dynamic-SIMS analysis of GaAs/AlGaAs superlattice (https://www.vivac-phi.com/en/products/tof-sims/nanotof2/)
c. PC1 vs. PC2 scores plot generated using Principal Component Analysis (PCA)-Assisted ToF-SIMS, which is based on static SIMS data. PCA assisted ToF-SIMS is used to identify large molecules. (Analytical chemistry 2014, DOI: 10.1021/ac500059a)
d. Example of 3D ToF-SIMS bio-imaging – Rat kidney cells generated based on PCA assisted ToF-SIMS (Biointerphases 10, 018902 (2015))

CUSTOMER SERVICE WORKFLOW

STEP 1 — Consult with Our Technologists

STEP 2 — Provide Your Samples

STEP 3 — Receive In-Depth Report

STEP 4 — Debrief with Our Technologists

WHY CHOOSE OUTERMOST TECHNOLOGY FOR SIMS?

1. State-of-the-art equipment: Both magnetic sector and ToF-SIMS
2. Advanced analysis including organic molecule identification and 3D SIMS
3. Integrated reports with analysis of measured data
4. Seamlessly combined with other metrology such as Auger/XPS, RBS, nano-FTIR, and others
5. Industry's most affordable pricing

CAMECA IMS 7f-Auto