

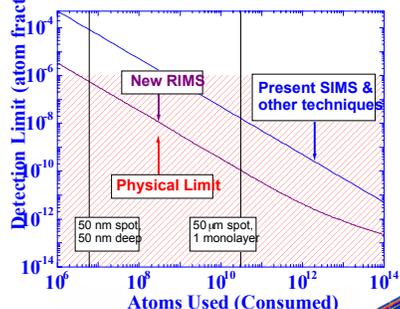
Detecting an Atom of One Element in a Trillion Other Atoms

Igor V. Veryovkin, Wallis F. Calaway, and Michael J. Pellin
Surface Chemistry, Materials Science Division

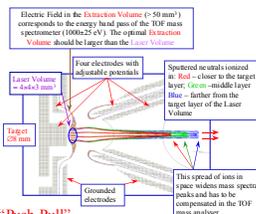
Researchers in the Surface Chemistry group of the Materials Science Division have developed a new time-of-flight (TOF) mass spectrometer for use in resonance ionization mass spectrometry (RIMS). In this technique, atoms in a solid are dislodged from its surface by laser light or energetic ions. Once in the gas phase, the element of interest is selectively photo-ionized by one or more lasers using resonantly enhanced multiphoton ionization (REMPI). The photo-ions are extracted, from the overwhelming number of neutral atoms of other elements that are not ionized, by an electrostatic field that directs them into the mass spectrometer for detection. Since only atoms of the selected element are photo-ionized, the separation of one element from all others is relatively easy, leading to the high discrimination required for trace analysis measurements.

The key to the latest breakthrough is the efficient extraction of photo-ions. Atoms ejected from the surface are distributed in time and space over a large volume, making it difficult to collect all of them. Through BES/MS Materials Chemistry funded research, a soon to be patented electrostatic optics design for ion extraction from a large volume was developed by modeling the sputtering process and the photo-ion flight path. To develop the new RIMS instrument (SARISA - Surface Analysis by Resonance Ionization of Sputtered Atoms) with improved photo-ion extraction efficiency and transmission, a three-dimensional computer model has been developed that calculates ion trajectories through time-of-flight mass spectrometers.

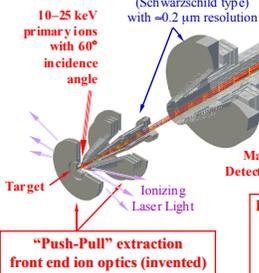
The newly invented extraction optics design permits nearly all of the ions in a laser ionization volume as large as 50 mm³ to be guided through the mass spectrometer, yielding an overall detection efficiency (atoms detected/atoms removed) that exceeds 30% for the new instrument. Thus, about one atom in three will be detected, making it possible, for the first time, to detect a few atoms of a particular element in a solid sample. The combination of sensitivity and selectivity permits detection of most elements at concentrations unparalleled by any other instrument in the world. As shown in the graph, the new instrument has improved sensitivity over other techniques, such as Secondary Ion Mass Spectrometry (SIMS), and approaches the physical limit below which there is insufficient material for making statistically significant measurements.



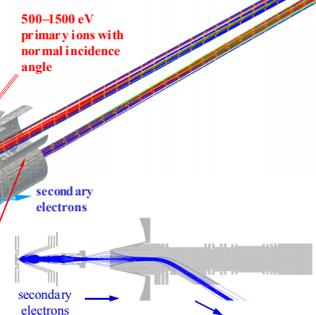
The new instrument will be used for trace analysis applications on samples with limited dimensions, such as micrometer- and nanometer-size devices and surfaces.



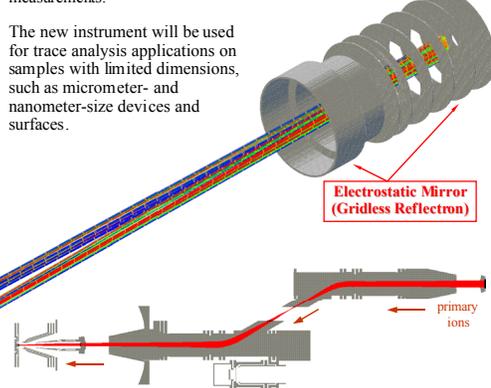
"Push-Pull" extraction system



"Push-Pull" extraction front end ion optics (invented)



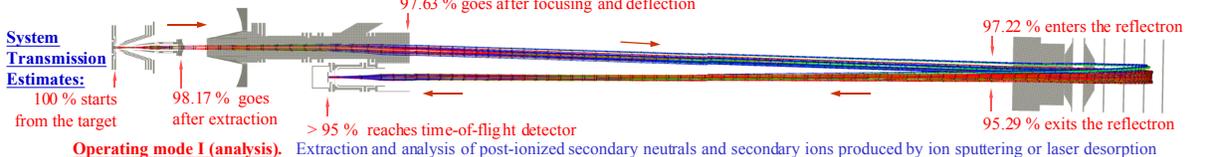
Operating mode II (imaging).
Extraction of secondary electrons for target imaging and primary ion pulse shape control



Operating mode III (sputtering).
Ion milling / target cleaning by normally incident primary ions with low energies (500 eV - 1.5 keV)

Extensive computer simulations helped to perfect the ion optical design and to estimate instrument efficiency. Shown in the table below is efficiency of SARISA instruments directly measured and simulated for the current instrument and estimated by computer simulations for the new instrument.

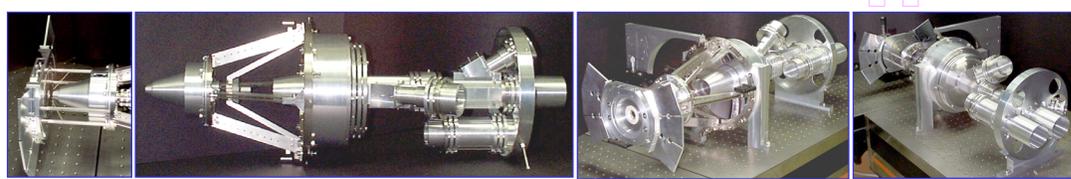
Instruments	Sputtered Fraction in Ionization Volume	Ionization Efficiency	Spectrometer Transmission	Detector Efficiency	Useful Yield (detected / consumed)
Present SARISA (experiment and simulations)	0.22	0.95	0.78	0.25	4 %
New SARISA (simulations)	0.43	0.95	>0.95	0.75	>30 %



Operating mode I (analysis). Extraction and analysis of post-ionized secondary neutrals and secondary ions produced by ion sputtering or laser desorption



Instrument mechanical drawing.



Photographs of the extraction and main ion optics portion of the instrument prior to installation in a vacuum chamber.

