SIMS Applications to Nuclear Science: Fission Products Behavior

In-depth and lateral distribution of high fission yield species

To ensure longevity of nuclear materials, it is of paramount importance to understand the diffusion and migration mechanisms of fission products in nuclear fuel and structural materials. This study focuses on applications of dynamic SIMS to the measurement of trace elements which are of interest for nuclear reactor operation.

Xenon in CeO_2

Fission noble gases such as xenon can be either "dissolved" in the UO_2 matrix at the position where they were created, in bubbles within the UO_2 ceramic, or released in the gap between the fuel pellet and the cladding. The formation of bubbles (e.g. xenon) induces swelling of the pellet and increases the stress on the inner part of the cladding, potentially creating safety issues.

The first example shows how SIMS can be applied to characterize the xenon in-depth distribution in an ion-implanted Cerium dioxide sample (Figure 1). CeO_2 is considered as a non-radioactive surrogate of UO_2 ceramics to simulate the properties of nuclear fuels during irradiation processes or long-term storage. Surface mapping of cerium and contaminant species was obtained with lateral resolution of ~1 µm (Figure 2).

Iodine in SiC

Iodine is a halogen with volatile and corrosive properties likely to induce stress corrosion cracking during pellet to cladding interactions. It is thus considered as a key element to be taken into account for safety assessment of nuclear materials. Low detection limits are needed because of the low content level in real samples.

The second example focuses on SIMS measurements of iodine in a SiC sample. Analysis of ^{127}I in SiC is challenging because of the several mass interferences that require very high mass resolving power, not achievable on the instrument. Data in Figure 3 show that the energy filtering technique can be a powerful method for removal of polyatomic interferences when analyzing high mass species such as ^{127}I. This results in a significant improvement of the depth profile dynamic range and thus of the detection limits.

Instrumentation

These data illustrate some of the unique analytical advantages of the CAMECA IMS 7f series magnetic sector ion mass spectrometer design for the study of nuclear materials: high sensitivity (low detection limits) for several elements of interest, depth profiling with high dynamic range, ion imaging with sub-µm resolution, and true band-pass energy filtering for removal of mass interferences.

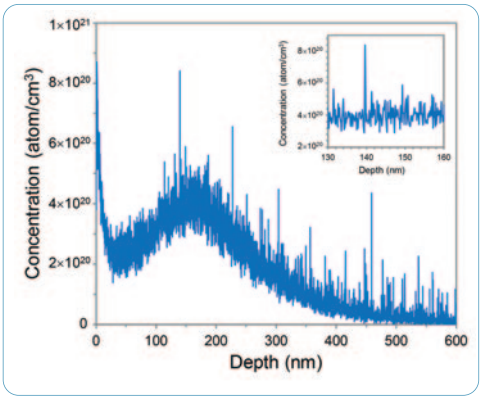


Figure 1: SIMS quantified Xe depth profile obtained in ^{129}Xe implanted CeO_2 sample. The baseline signal corresponds to dissolved Xe, whereas the signal spikes indicate the presence of gas bubbles.

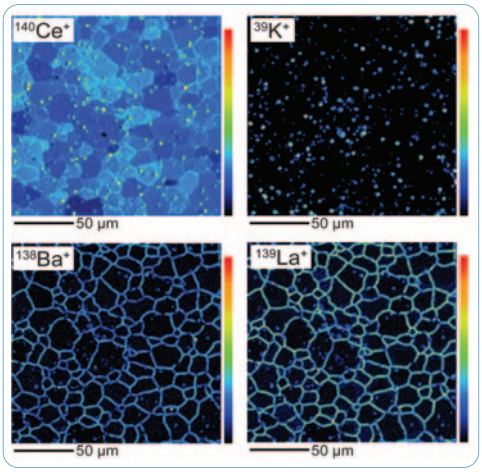


Figure 2: SIMS ion imaging data obtained in CeO_2 sample for Ce matrix species and K, Ba, La contaminants. Lateral resolution: ~1 µm. Field of view: 175 x 175 µm².

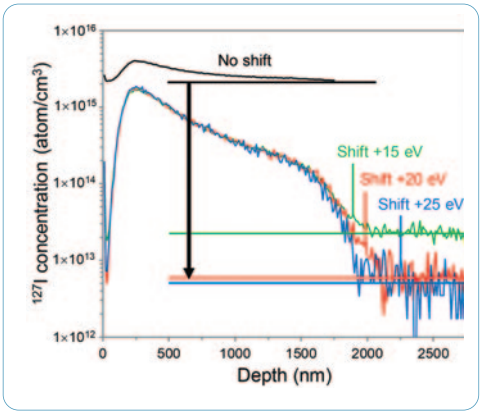


Figure 3: SIMS iodine quantified data obtained in SiC sample for different energy band-pass. The black arrow indicates the improvement of detection limit with a +20 eV shift in energy band-pass.

Data collected on IMS 7f-Auto, courtesy CEA Cadarache, France
From P. Peres et al, JVST B 36, 03F117 (2018)

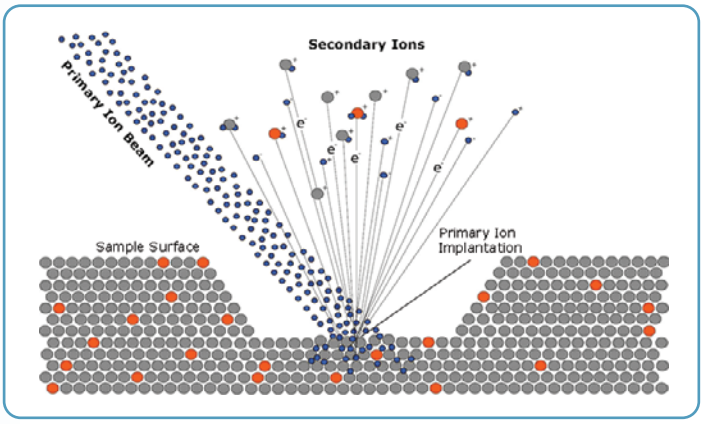
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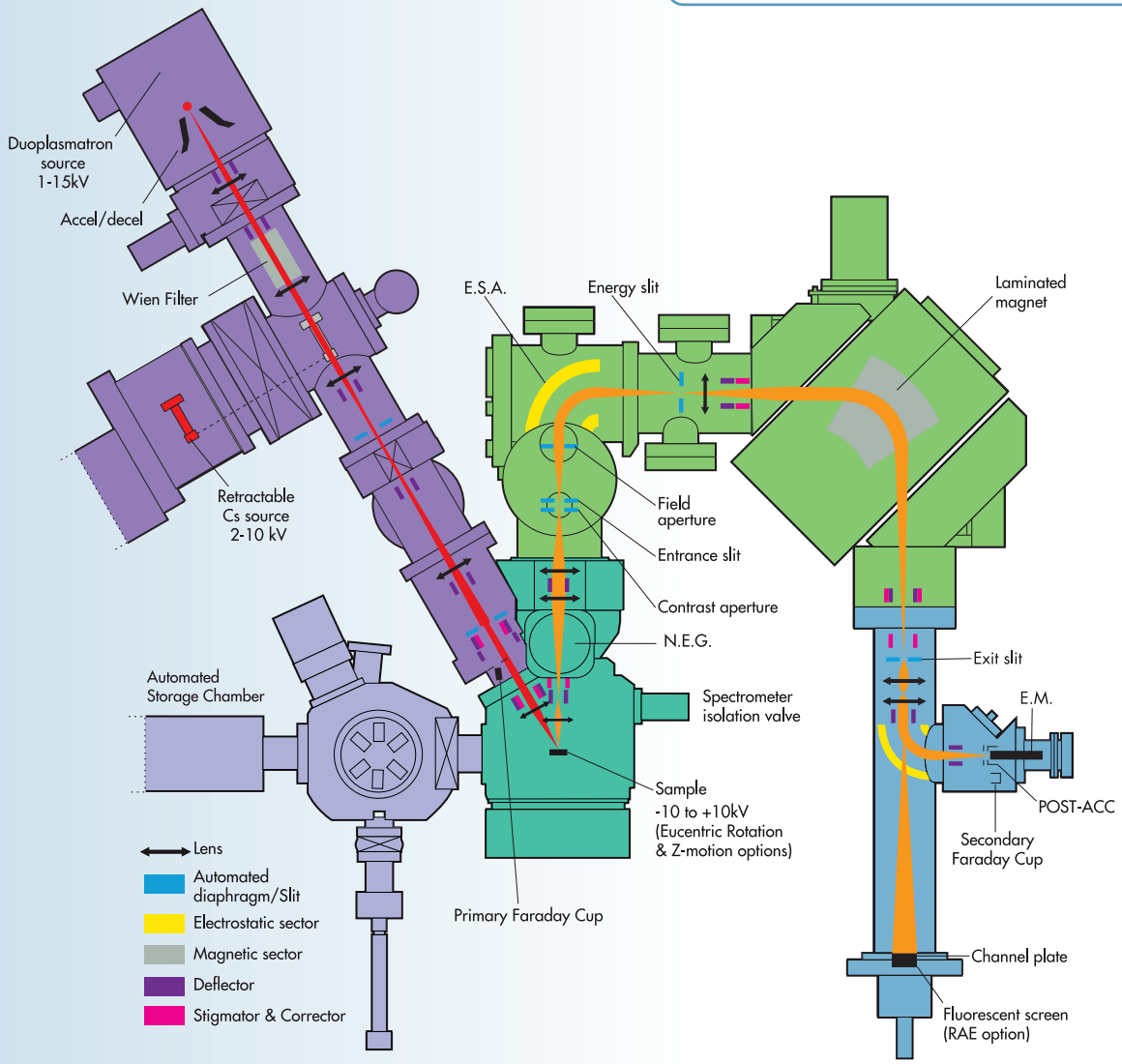
Dynamic SIMS

When a solid sample is sputtered by primary ions of few keV energy, a fraction of the particles emitted from the target is ionized. Secondary Ion Mass Spectrometry consists of analyzing these secondary ions with a mass spectrometer.

The SIMS technique is "destructive" by its nature (sputtering of material). It can be applied to any type of flat, solid material that can be kept under vacuum.

In dynamic SIMS, bulk composition and in-depth distribution of trace elements are investigated with a depth resolution ranging from sub-nm to tens of nm. SIMS is recognized as the most sensitive elemental and isotopic surface analysis technique.





CAMECA IMS 7f-Auto

The IMS 7f-Auto is a versatile SIMS tool offering reference detection sensitivity with high throughput and full automation. Its motorized storage chamber and sample transfer allows the analysis of multiple samples in chained or remote mode.

For more information please visit www.cameca.com/products/sims/ims7f-auto

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