Analysis of Hydrogen in Semiconductor Materials

Depth profiling in ^{1}H ion-implanted Si and GaAs samples

Hydrogen is the most abundant chemical element in our environment. It can be introduced into materials either intentionally during manufacturing processes (e.g. epitaxy, annealing, ion implantation, photolithography) or unintentionally through environmental effects such as corrosion or hydration. Understanding hydrogen distribution is essential for designing materials with tailored properties and for elucidating the mechanisms that govern their behavior.

Dynamic Secondary Ion Mass Spectrometry (SIMS) is a highly sensitive technique for analyzing hydrogen concentration and its distribution in solids. CAMECA's IMS 7f-Auto is a versatile SIMS instrument that delivers superior depth profiling capabilities, with H detection limits (DLs) down to sub-ppm level.

This study investigates the in-depth distribution of hydrogen in ion-implanted silicon and gallium arsenide samples (courtesy of Ion Beam Services). Analyses were performed using the IMS 7f-Auto at the CAMECA factory.

Samples were mounted in the same holder together with a "clean" silicon sample. The pre-sputtering method was applied overnight on the "clean" sample to minimize the contribution of residual gases to background signals[1]. The SIMS analyses were then carried out using optimized analytical conditions:

- Cs^{+} ion bombardment at 15keV impact energy
- Collection of negative $^{1}H^{-}$ secondary ions
- Small raster and high primary current → high sputtering rate
- Analyzed area adjusted to raster size → avoid crater edge effects
- Vacuum level in the analysis chamber → ~4×10^{-10} mbar
- Liquid nitrogen cold trap → minimize background

Data quantification was performed using standard samples provided by EAG. The detailed primary current (Ip), raster conditions, and sputtering rate (SR) are indicated in the figures.

For Si samples, a hydrogen DL ~1E16 at/cm^3 (~0.2 ppm) was obtained on the reference implant (Fig. 1 top), whereas a DL ~3E16 at/cm^3 (~0.6 ppm) was obtained on the very deep implant (Fig. 1 bottom). The DL is slightly higher for the very deep implant, as analysis on this type of sample (total analyzed depth of ~7 µm) requires a larger raster to minimize topographic effects. This leads to a lower sputtering rate and consequently a higher detection limit.

Since GaAs is softer than silicon, a comparable SR can be achieved using a larger raster. (Fig. 1 top & Fig. 2). An excellent hydrogen DL of ~5E15 at/cm^3 (~0.1 ppm) could be reached on GaAs.

The data show excellent detection limits and highly reproducible measurements, along with high throughput (30 minutes to analyze down to ~7 µm).

The CAMECA IMS 7f-Auto enables hydrogen depth profiling in various materials from tens of nanometers to tens of microns. Thanks to SIMS high sensitivity and low background, optimized detection limits are achieved, which depend on matrix composition and analytical conditions. The IMS 7f-Auto is a benchmark tool for light element analysis in semiconductors.

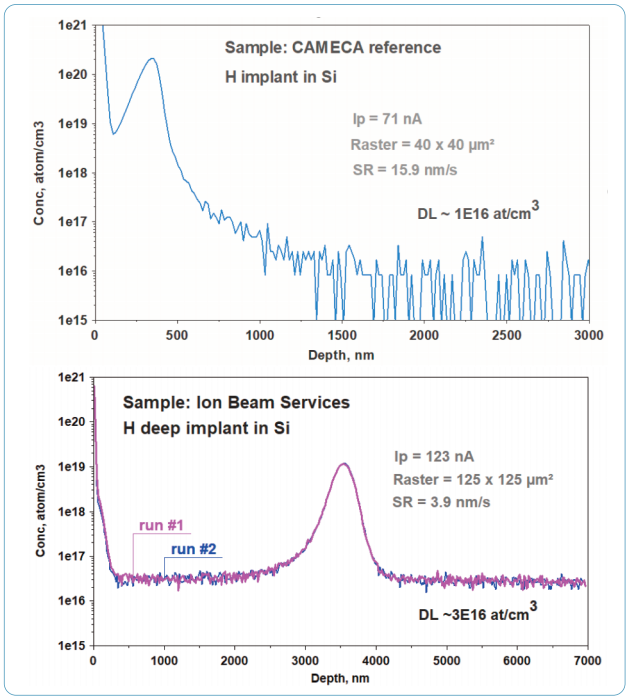


Fig. 1: Hydrogen SIMS depth profiles obtained in ^{1}H implanted Si samples. Top: CAMECA internal reference sample. Deep implant: ^{1}H implantation at 30 keV energy (Rp ~313 nm) and dose ~3E15 at/cm². Analysis time: 6 min. Bottom: Sample provided by Ion Beam Services. Very deep implant: ^{1}H implantation at very high energy (Rp ~3.7 µm) and maximum concentration ~1E19 at/cm³. Overlay of two runs. Analysis time: 30 min / run.

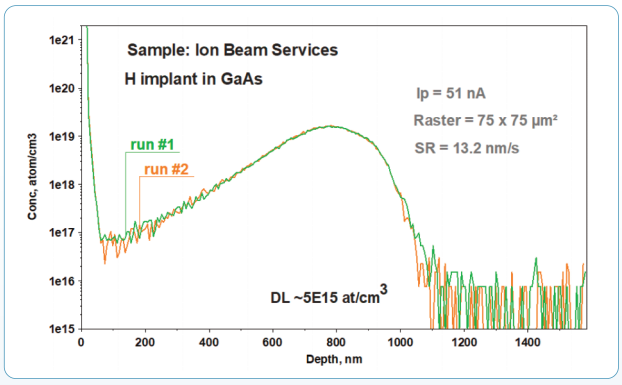
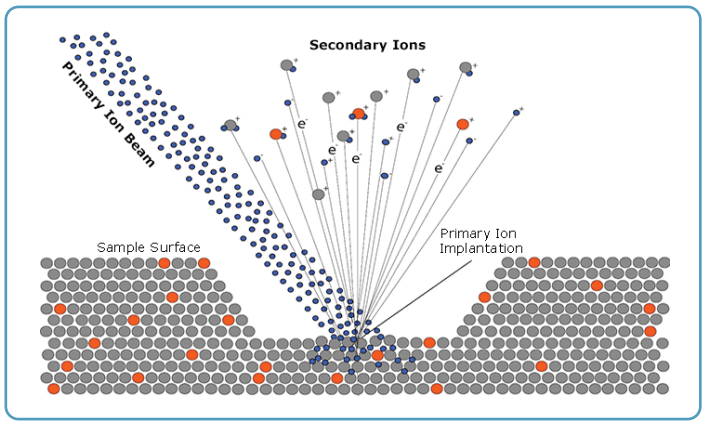


Fig. 2: Hydrogen SIMS depth profiles obtained in ^{1}H implanted GaAs. Sample provided by Ion Beam Services. ^{1}H implantation at high energy (Rp ~780 nm) and max. concentration ~1E19 at/cm³. Overlay of two runs. Analysis time: 2 min / run.

[1] *CAMECA Application note 15: Dynamic SIMS Application in Silicon Carbide: Pre-sputtering Protocol for Optimized N Detection Limit.*

The Technique Behind

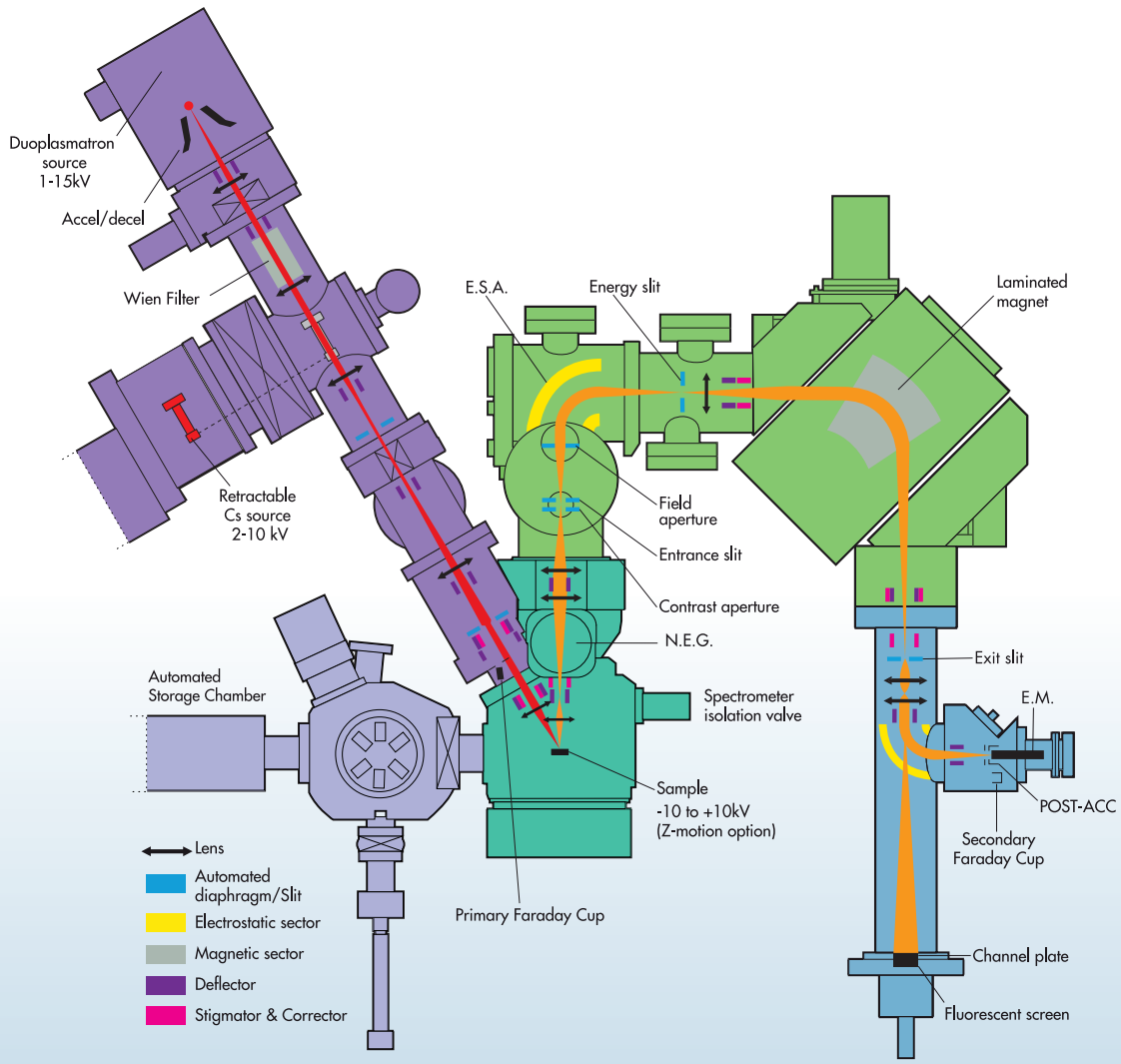


Dynamic SIMS

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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