Dynamic SIMS Applications in Silicon Carbide

Pre-sputtering Protocol for Optimized N Detection Limit

Introduction

Silicon carbide (SiC) is a wide bandgap semiconductor that has emerged with the development of high-power electronic devices. Its superior properties, including larger critical electric field, higher thermal conductivity, and greater breakdown voltage, enable devices to operate at higher current densities, temperatures, and blocking voltages [1]. Nitrogen is a key dopant for producing n-type semiconductor materials in SiC [2].

Dynamic secondary ion mass spectrometry (SIMS) is crucial for evaluating nitrogen concentration in SiC, and the CAMECA IMS 7f-Auto is renowned for its unmatched depth profiling performance and low detection limits (DLs). Traditionally, a pre-sputtering protocol is employed before SIMS analysis to enhance the DLs of light elements such as H, C, and O in silicon [3]. Building on this established method, our study applies the pre-sputtering protocol to the analysis of nitrogen in SiC, aiming to assess performance improvement.

Protocol

SIMS analyses were performed on two SiC samples: a ^{14}N implant in SiC (EAG standard) and a N doped thick (~10 µm) epi SiC, courtesy of Korea Basic Science Institute (KBSI). Samples were mounted on the same holder together with a silicon sample used for pre-sputtering*.

Two analytical protocols were tested on the standard sample:

Protocol A: overnight outgassing in analysis chamber,

Protocol B: overnight pre-sputtering (~ 20 hours) in analysis chamber and cold trap filled with liquid nitrogen (LN2) one hour prior to analysis.

For the epi SiC sample, only one profile was acquired using protocol B.

The detailed analytical conditions are described on the right-side**.

Results

Applying protocol B, a nitrogen DL of 1.4×10^{15} at/cm^3 could be reached in the standard, which is more than one order lower than the DL of 3.1×10^{16} at/cm^3 obtained with protocol A, see Figure 1. A DL of 1.4×10^{15} at/cm^3 is appropriate for SiC samples with nitrogen content around 1×10^{16} at/cm^3 or higher.

Protocol B was used to depth profile nitrogen in the N doped thick epi SiC sample (Figure 2) with enough depth resolution to observe the concentration drop at ~ 9.8 µm depth. The sputter rate was 110 nm/min, enabling to profile over ~12 µm in less than two hours.

Conclusions

The CAMECA IMS 7f-Auto enables precise nitrogen depth profiling in SiC, with significantly enhanced DL using the pre-sputtering protocol, a method that can be applied routinely. Thick SiC structures can also be analyzed within a reasonable analysis duration. The IMS 7f-Auto is a reference tool for light element analysis in semiconductor materials.

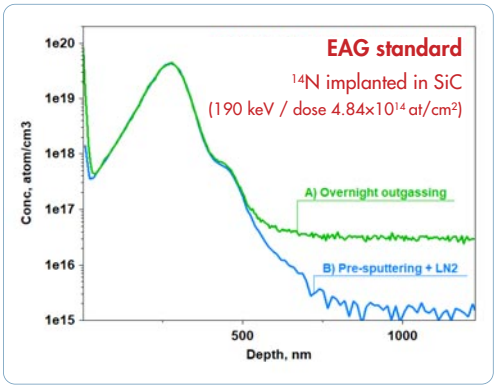


Figure 1: Nitrogen depth profiles in SiC standard obtained using protocols A and B.

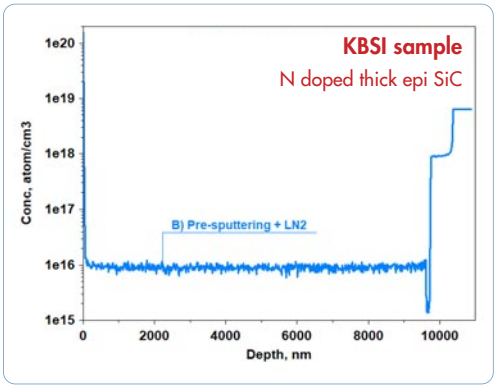


Figure 2: Nitrogen depth profile in N doped thick epi SiC obtained using protocol B.

Pre-sputtering method:

Bombardment of a clean Si sample with a high current primary ion beam and over a large raster for a long duration (few hours up to overnight depending on required DLs). A thin silicon layer is deposited within the analysis chamber, particularly on the immersion lens front plate, acting as a clean coating. This layer enhances vacuum quality by adsorbing impurities, reducing their contribution to the SIMS analytical background and thus improving the DLs [3].

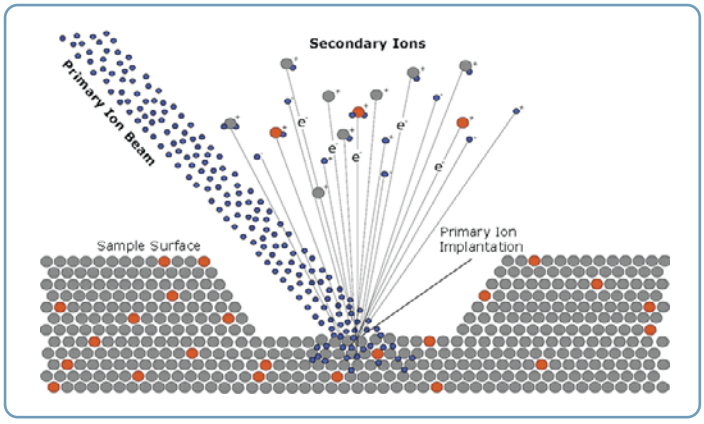
Analytical conditions:

- *Cs^+ ion bombardment at 15keV impact energy, 80 nA primary current, 90x90 µm² raster, and negative secondary ion collection from a 33 µm diameter area.*
- *Pre-sputtering conditions: > 400 nA primary current and 500x500 µm² raster.*
- *Vacuum level in the analytical chamber: ~4×10^{-10} mbar.*
- *Due to low ionization yield of nitrogen monoatomic species, $^{12}C^{14}N^-$ ion cluster was collected. Analyses were performed at high mass resolution (> 7200) to resolve the $^{12}C^{14}N^-$ / $^{13}C_2$ mass interference.*
- *SIMS crater depths were measured using a stylus profilometer and N concentration calibration was derived from the known dose value in the EAG standard sample.*

[1] Langpoklakpam et al., Crystals 12, 245 (2022). [2] Kudriavtsev et al., Surf. Interface Anal. 35, 491–495 (2003). [3] Miwa et al., Appl. Surf. Sci. 252, 7247 (2006).

IMS 7f-Auto analyses conducted at CAMECA Application Laboratory, France.

The Technique Behind

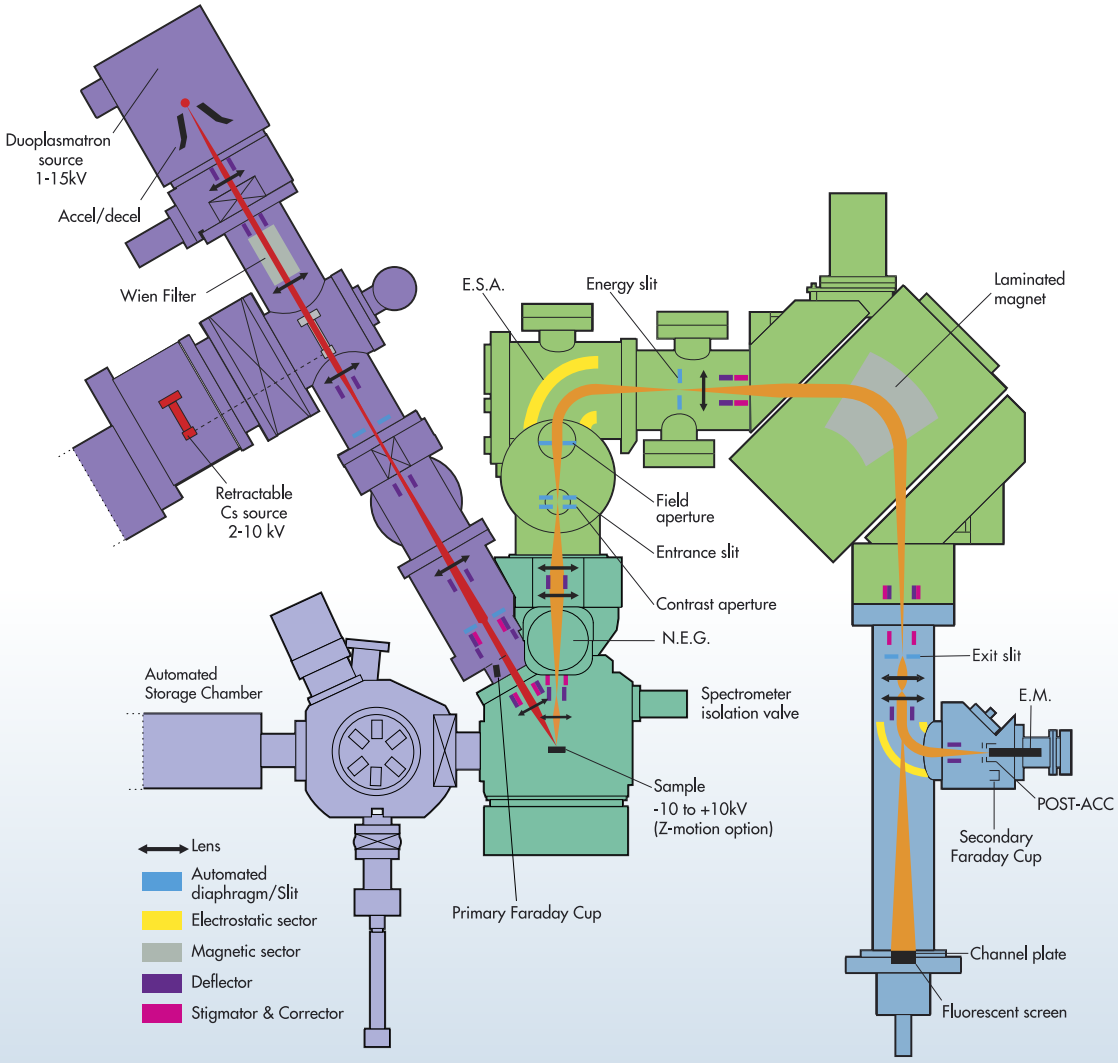


Dynamic SIMS

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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