APPLICATION NOTE #SIMS-012

Investigating Magnesium Diffusion in GaN:

Insights from Dynamic SIMS Analysis

Advancements in energy conversion offer a viable pathway to significantly reduce carbon footprints. Gallium nitride (GaN) stands out among materials for power electronics due to its exceptional properties, enabling high breakdown voltage and low turn-on resistance in devices. This study delves into the diffusion behavior of magnesium within GaN. To ensure structural integrity and material purity, bulk crystals grown via Halide Vapor Phase Epitaxy on ammonothermal native seeds were utilized. Samples of various polarities (0001), (10-10), and (11–20) were prepared and implanted with magnesium ions at a fluence of 1 × 10^{16} at/cm^2 and 230 keV energy. Ultra-high-pressure annealing, ranging from 1250–1450°C, was conducted to activate the dopant and mitigate post-implantation damage, leading to species diffusion during the annealing process.

Dynamic Secondary Ion Mass Spectrometry (D-SIMS), a powerful analytical technique known for its excellent detection limits even for challenging light elements, its high sensitivity and throughput, was employed to measure impurities through depth profiling of various species including Mg and H. The obtained Mg depth profiles, as shown in Fig.1, revealed a Mg peak of 4.5 × 10^{20} at/cm^3 at ~200 nm, consistent with simulations by SRIM. Despite post-implantation profiles showing no disparities across different sample polarizations, diffusion depth significantly varied with annealing temperature and polarity. Notably, the [10-10] direction exhibited the shallowest profile, while the [000–1] direction showed the greatest depth.

D-SIMS results underscored significant diffusion anisotropy, with the [000–1] direction characterized by the deepest and [10-10] by the shallowest diffusion depth. Numerical analysis indicated a one order of magnitude difference in the D0 factor between these directions, suggesting dominant substitutional diffusion with gallium vacancies for Mg concentrations above 10^{17} at/cm^3. Although post-implantation damage significantly influenced the diffusion process, diffusion depths extended beyond the implantation zone. Lower Mg concentrations witnessed a diffusion mechanism shift, potentially involving Mg–H complex diffusion.

Ion implantation stands as a crucial semiconductor device preparation technology. While prevalent in the silicon industry and expanding in silicon carbide, its development in GaN remains ongoing. The challenges of deep species diffusion within the implanted layer pose significant hurdles, addressed effectively by the superior depth profiling capabilities of D-SIMS, its high dynamic range and excellent detection limits, making it the most suitable analytical technique for studying these processes.

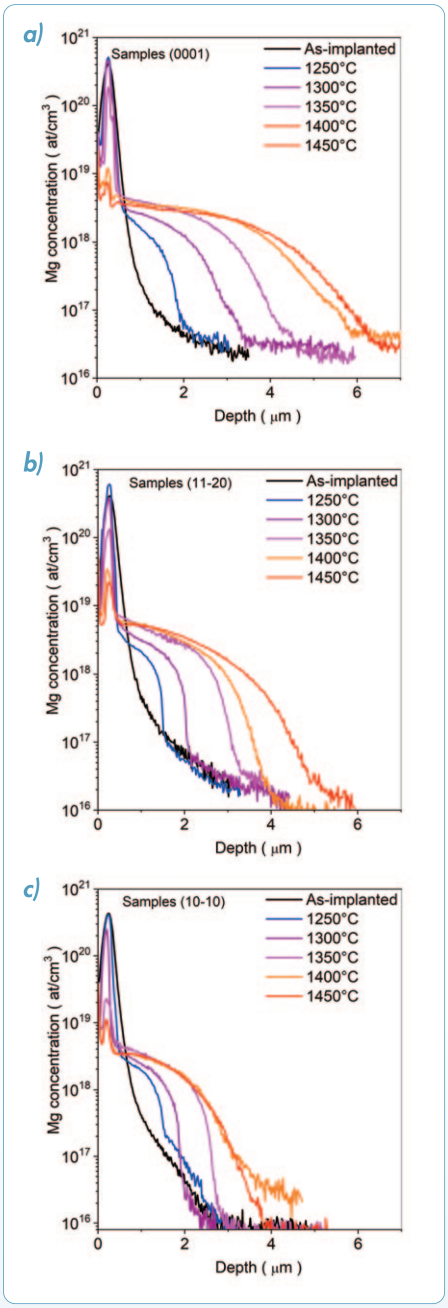


***Figure 1:** Magnesium was measured after Ultra High Pressure Assisted treatment using D-SIMS.*

Mg depth profiles were assessed along the following crystallographic orientations:

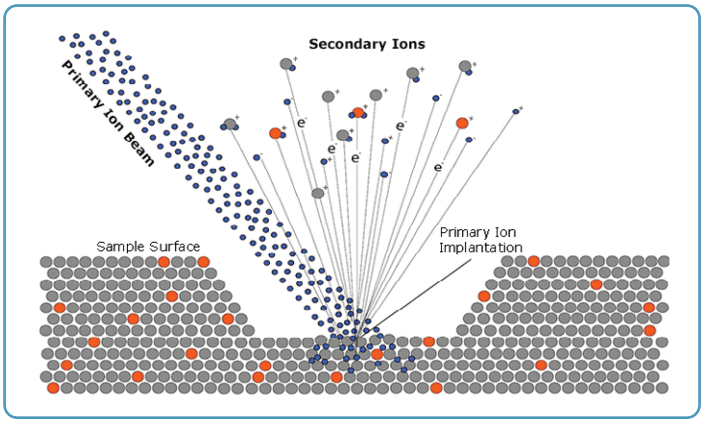
a) [0001]

b) [11-20]

c) [10-10].

Adapted from: Sierakowski et al. Lateral and vertical diffusion of magnesium in ion-implanted Halide Vapor Phase Epitaxy gallium nitride. Mater. Sci. Semicond. Process., Vol. 171, 108022 (2024)

The Technique Behind

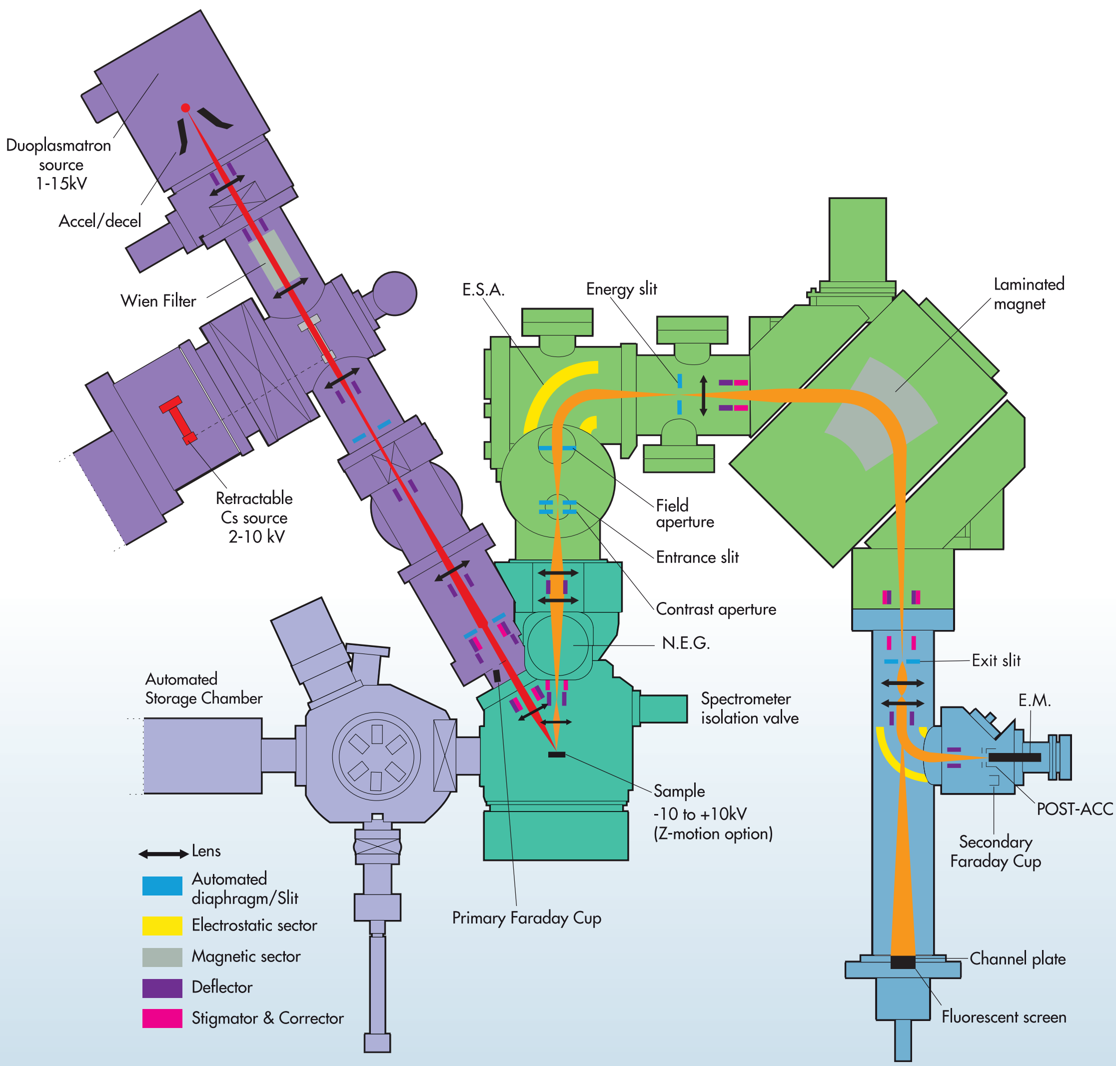


Dynamic SIMS

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.

March 2024. Ref. AP SIMS-012_GaN

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

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