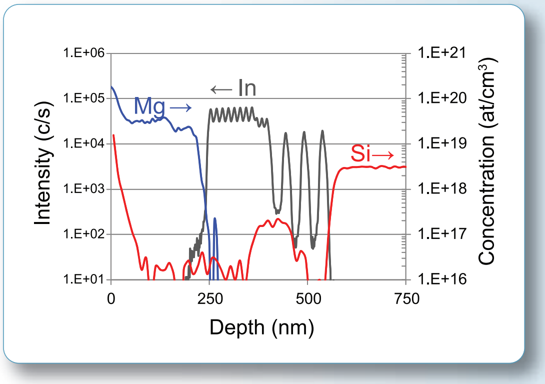
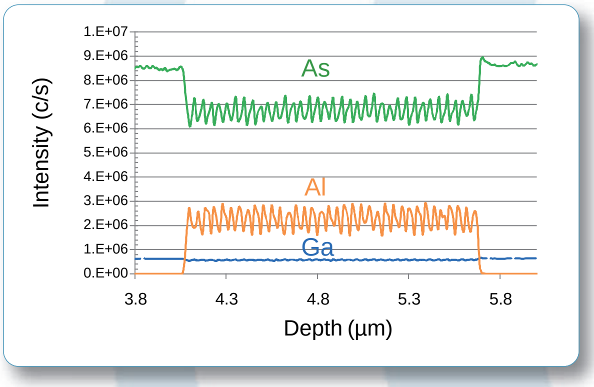
CAMECA®
SCIENCE & METROLOGY SOLUTIONS

SIMS for LEDs

Application note

SIMS Analytical Technique for R&D and Process Control of Novel LED Devices





Doping & impurity control
Multilayer structure analysis
Layer interface quality

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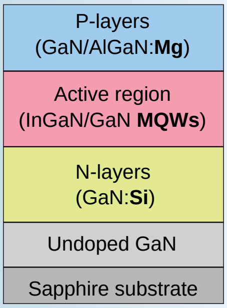
MATERIALS ANALYSIS DIVISION

SIMS technique is a key tool for R&D of future LED devices

A light emitting diode (LED) is a semiconductor device that emits narrow-spectrum light when forward biased. LEDs are seeing a tremendous development, but several challenges still remain. Notably the brightness of the LEDs must be increased.



Schematic structure of a III-nitride compound used for the fabrication of high-power LEDs.

LED technology is based on multilayer structures grown by means of EPI tools (MOCVD), and using semiconductor doping techniques. LED technology uses a large number of materials (GaAs, GaN,...), doped with species like Mg, Si, Zn (charge carriers),... and with electrical properties suffering from contamination such as H, C, O.

Like for Si technology development for ICs, **Secondary Ion Mass Spectrometry (SIMS)** is a key tool for R&D of LED devices, as it provides **depth profiles with excellent detection sensitivity for dopants and impurities**, while keeping **high analysis throughput**. Therefore, the SIMS technique proves extremely useful to solve various problems:

- Doping concentration and distribution (Si, Mg, Zn)
- Impurity control (H, C, O, metals,...)
- Layer structure control
- Layer interface quality (junction impurities, diffusion of contaminants,...)

thus reducing R&D cycle times and enhancing production yields.

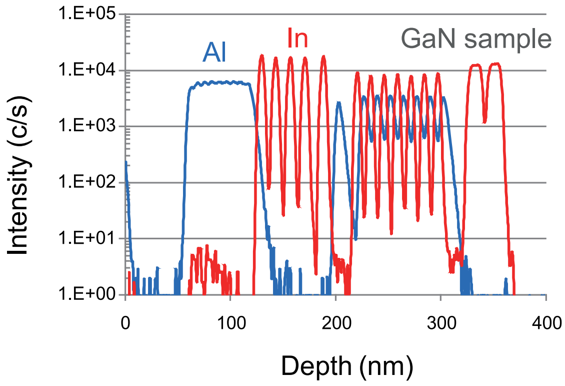
Doping and structure composition monitoring with SIMS

Data obtained using the CAMECA **IMS 7f-Auto** are shown here for both matrix and dopant species. Based on a magnetic sector mass spectrometer, the **IMS 7f-Auto** achieves **benchmark performance in terms of sensitivity, depth resolution and mass resolution**.

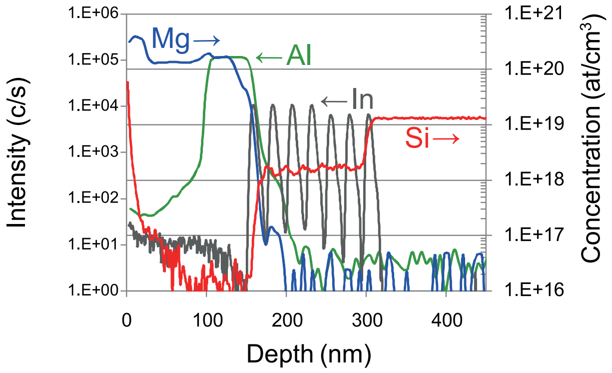
SIMS depth profiling measurements are typically performed using the following experimental conditions:

- MCs$^+$ mode [1] for both matrix species and P-type dopants (Mg, Zn).
- Cs$^+$ primary ions and negative secondary ion detection for N-type dopants. In particular, the ^{28}Si signal is analyzed using high mass resolution to eliminate the interferences between ^{28}Si and ^{27}Al^{1}H or ^{14}N$_2$ in GaN based LEDs.

These conditions provide the required detection limits for both P- and N-type dopants. Moreover, they offer **optimized throughput** and **ease of use**, as only one primary ion source is used for analyzing all species.



Layer composition in AlGaN/InGaN LED.
SIMS depth profiling of matrix species using MCs$^+$ mode at 2keV impact energy.
Excellent depth resolution and dynamic range are achieved.



P- and N-type dopant profiles in AlGaN/InGaN LED.
SIMS depth profiling of Mg, Si dopants, and Al, In matrix species.
• Mg was measured together with the matrix elements using MCs$^+$ mode at 2keV impact energy.
• Si was analyzed using Cs$^+$ at 3keV impact energy, negative secondary mode, and under high mass resolution conditions (~2500) to avoid mass interferences.
A detection limit better than 1E16 at/cm^3 was achieved for both Mg and Si.

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[1] *Characterization of III-nitride materials and devices by Secondary Ion Mass Spectrometry. P.K. Chu, Y. Gao, J.W. Erickson, J. Vac. Sci. Technol. B 16, 197 (1998).*

Impurity control and failure analysis with SIMS

In LED compounds, undesirable contamination of H, C and O into defects of GaN crystalline structure affect the electrical properties and shift the intended emission wavelength.

The **detection limits of dynamic SIMS** surpass the capabilities of competing techniques, therefore, SIMS is a particularly attractive technique for the analysis of light elements. Typical detection limits with the CAMECA dynamic SIMS instruments are ~5E17 at/cm^3 for Hydrogen, ~1E17at/cm^3 for Carbon and Oxygen.

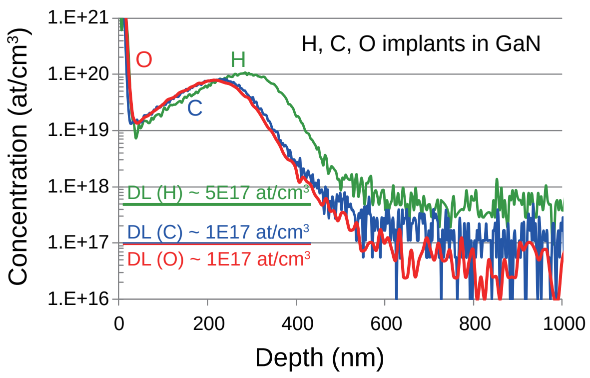
For analyses of Carbon and for vacuum contaminant species like Oxygen and Hydrogen, a Cs$^+$ primary beam must be used while collecting negative secondary ions. The **best detection limits** for those elements require **optimized vacuum** in the analysis chamber and a **high sputter rate** in order to minimize the contribution from the residual gas present in the analysis chamber. The CAMECA **IMS 7f-Auto** offers such conditions, and thus guarantees **best detection limits**.

The figures below show some examples of data obtained in GaN samples.

Light elements analysis (H, C, O) in GaN reference samples. Excellent dynamic SIMS detection limits:

~5E17 at/cm^3 for Hydrogen
~1E17 at/cm^3 for Carbon
~1E17 at/cm^3 for Oxygen

H, C, O were analyzed using Cs$^+$ 15keV impact energy, negative secondary mode.

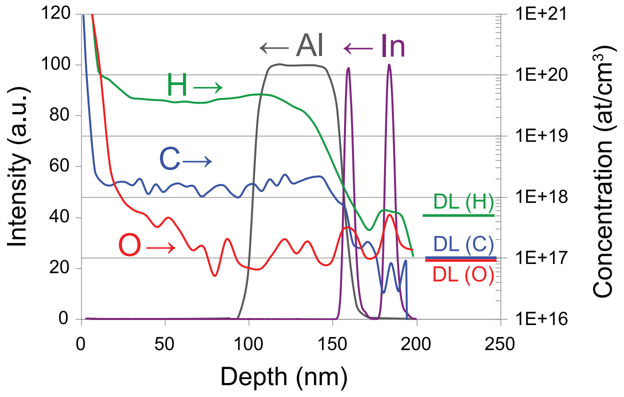


Impurities in AlGaN/InGaN LED. Light elements analysis (H, C, O) with best detection limits.

Results show Hydrogen and Carbon levels above the detection limit within the first GaN/AlGaN layer.

For H, C, O, same experimental conditions as above.

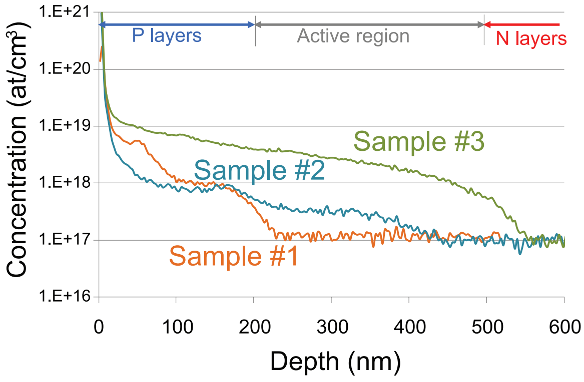
Matrix species Al and In were measured using MCs$^+$ mode at 2keV impact energy.



Failure analysis in AlGaN/InGaN LED samples.

SIMS results reveal the presence of a significant Oxygen contamination, the in-depth distribution being different for each sample. The contamination is particularly high for sample #3 (O level >1E18 at/cm^3 over the first 500nm).

Same experimental conditions as above.

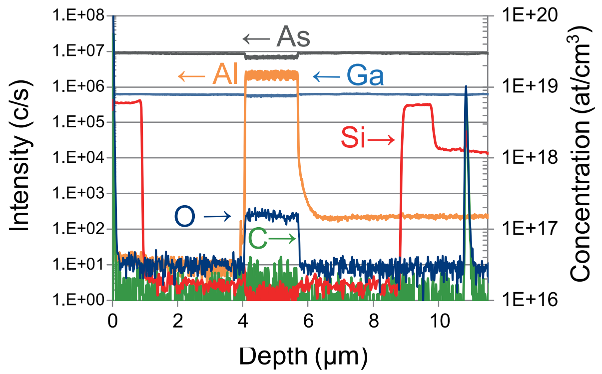


The CAMECA SIMS instruments are key tools for optimizing the performance of both GaN- and GaAs- based LED devices.

Optimized doping (Mg, Si, Zn,...) and reduced impurity incorporation (H, C, O, metals) are essential for high efficiency LED devices.

Using dynamic SIMS, depth profiles can be recorded up to several microns within minutes, with **detection limits from the ppm down to the ppb range** depending on the species to be analyzed. Dynamic SIMS also offers **high depth resolution**, which has been widely used for ultra shallow implant technology.

Therefore, the CAMECA SIMS instruments are extremely useful in investigating the composition and characterizing the **elemental distribution of dopants and impurities on different layers**, making them your best choice for R&D and process control of novel LED devices.



GaAs based LED compound.
SIMS depth profiling up to 12µm
for matrix species,
Si dopant and C, O impurities.

CAMECA is the world premier provider of microanalytical instrumentation.
We deliver cutting-edge science and metrology solutions, and offer our customers unparalleled support and maintenance service through the comprehensive AMECARE program.

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