# Dynamic SIMS Application in Power Electronics

## Accurate characterization of Si-doped β-$Ga_2O_3$ epitaxial films

β-$Ga_2O_3$ has emerged as a highly promising material for next-generation power electronics due to its exceptional properties, including an ultrawide bandgap (~4.8 eV) and high breakdown field (~8 MV/cm). Among the various dopants explored for β-$Ga_2O_3$, silicon stands out for its remarkable electrical properties, making it ideal for use in both lateral and vertical devices.

In this study, researchers focused on achieving continuous Si doping in β-$Ga_2O_3$ epitaxial films on (010) and (001) substrates. To accomplish this, they utilized a valved effusion cell and employed Dynamic Secondary Ion Mass Spectrometry (D-SIMS) to precisely determine Si concentrations within the epitaxial films.

D-SIMS measurements of Si-doped β-$Ga_2O_3$ layers on a (010) substrate reveal a spike in Si concentration at the film/substrate interface (Figure 1a). Continuous Si doping with flat profiles and sharp turn-on was achieved using a valved effusion cell, controlling doping concentration between ~$1.0 \times 10^{20}$ $cm^{-3}$ and ~$5 \times 10^{16}$ $cm^{-3}$. Additionally, a Si-doped (010) β-$Ga_2O_3$ sample was examined at temperatures >1000 °C, confirming stable Si doping during growth. Figure 1b demonstrates Si doping dependence on cell temperature, with flat profiles observed at 1200, 1100, and 1000 °C, along with distinct doping regions within single Si-doped layers. Excessive gas species accumulated in the effusion cell during growth, suggesting gas species facilitate continuous Si doping.

The D-SIMS depth profiling of a 100-nm-thick Si-doped β-$Ga_2O_3$ epitaxial film on the (001) substrate reveals a flat Si doping of $8.3 \times 10^{18}$ $cm^{-3}$ with sharp turn-on characteristics across the entire film (Fig. 2). This demonstrates the high ionization efficiency of doped Si, consistent with previous studies suggesting Si as a shallow donor in β-$Ga_2O_3$. Continuous Si doping capability on (001) substrates spans from below the background impurity level to approximately $1.0 \times 10^{20}$ $cm^{-3}$.

The achievement of continuous Si doping in β-$Ga_2O_3$ epitaxial films on both (010) and (001) substrates, along with the use of D-SIMS analysis for accurate characterization, marks a significant breakthrough in the field of power electronics material science. The D-SIMS technique stands out for its superior depth profiling capabilities, which combine excellent depth resolution with high sensitivity. D-SIMS proves essential for precisely controlling doping concentrations within complex epitaxial nanostructures. Consequently, it plays a vital role in improving the performance and reliability of devices in various electronic applications, particularly those involving vertical configurations.

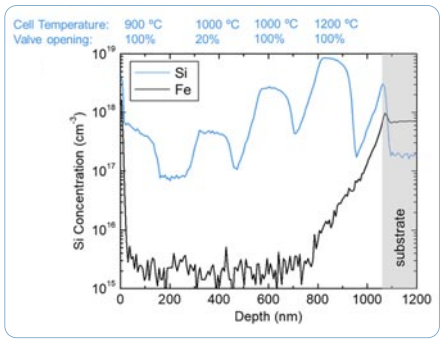
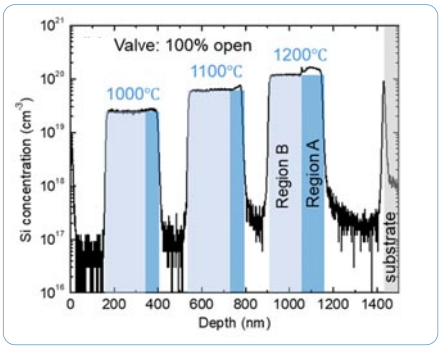



*Figure 1a: D-SIMS profile of Si-doped β-Ga2O3 (010) film with varied doping levels achieved by adjusting effusion cell temperatures and needle valve apertures during MOCATAXY growth at 800°C substrate temperature. Fe profile indicates film-substrate interface.*

*Figure 1b: D-SIMS profile of a Si-doped β-Ga2O3 (010) SIMS-stack sample with 240 nm Si-doped layers grown at different Si cell temperatures, separated by UID spacer layers.*



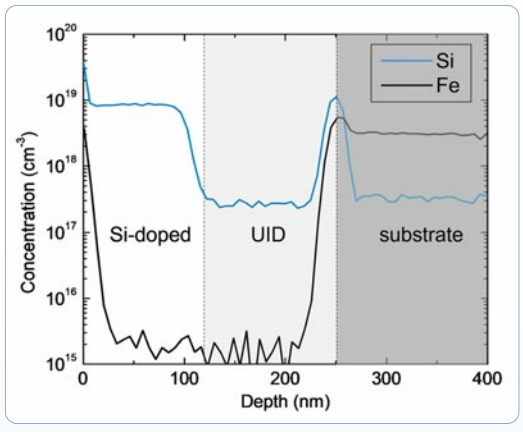
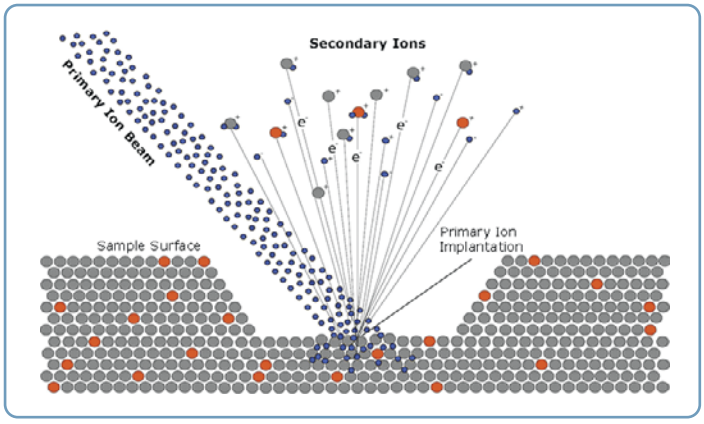




*Figure 2: D-SIMS profile of 100-nm Si-doped β-Ga2O3 film on Fe-doped (001) substrate grown by MOCATAXY. A flat Si doping profile was achieved using a valved effusion cell. The spike in Si concentration at the UID-substrate interfaces due to residual impurities.*

*Adapted from: T. Itoh et al. $Ga_2O_3$ films by plasma-assisted molecular beam epitaxy. APL Mater. 11, 041108 (2023).*

# The Technique Behind

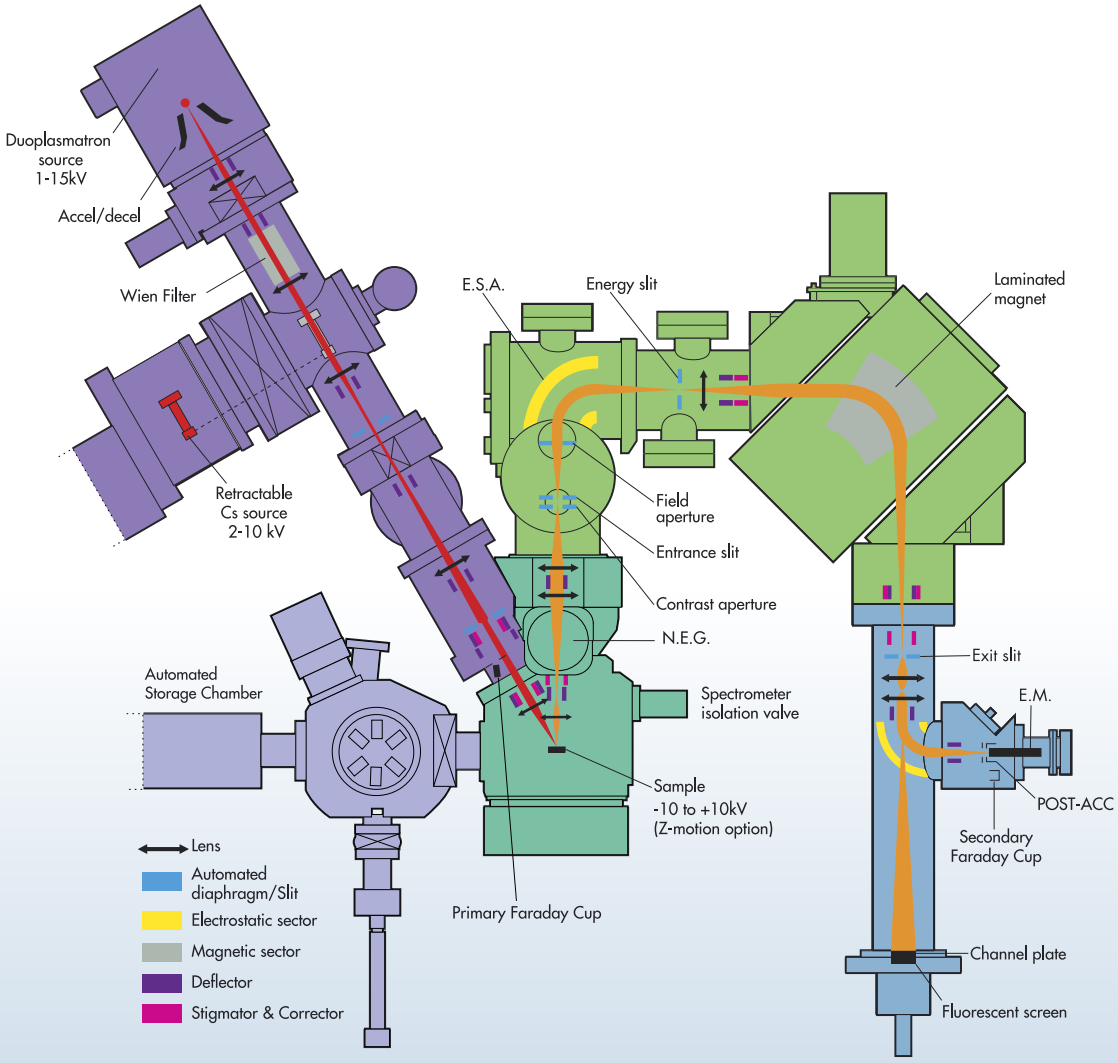



## Dynamic SIMS

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

June 2024. Ref. AP_SIMS-014_Power Electronics