eurofins EAG Laboratories



Point-by-Point CORrected-SIMS (PCOR-SIMS℠) Services

PCOR-SIMS℠ is an EAG proprietary technique that can measure layer thickness, composition, and doping profiles more accurately than a regular SIMS analysis, where calibration with respect to alloy composition is not made at every data point.

The development of PCOR-SIMS℠ can be traced back to the late 1990s when then, Evans Analytical Group, was faced with the challenge of acquiring accurate profiles for both dopants and matrix elements in Silicon Germanium (SiGe) materials. Previous to this time, it was commonly assumed that the SIMS technique could not quantify matrix-level concentrations, and there was no way to calibrate ion intensities as a function of change in matrix composition for quantitative analysis of multi-layer semiconductor materials. For developing a method to address this challenge many test samples had to be fabricated and quantified using nuclear and high-resolution electron microscopy techniques. These samples formed the basis for the empirical relationships between SIMS intensity and concentration that are the underpinnings of the PCOR-SIMS℠ methodology. The same techniques were used to verify the accuracy of the final PCOR-SIMS℠ results in complex structures.

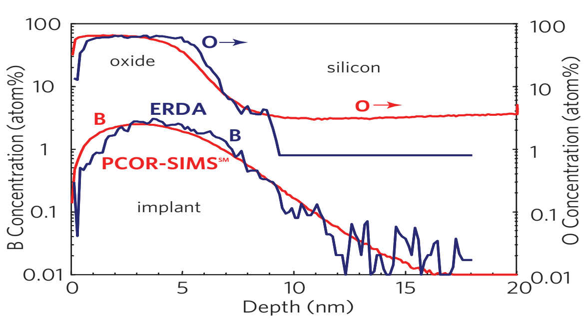

Figure 1: B High Dose Implant Through Surface Oxide
ERDA data courtesy of Dr. Wilfried Vandervorst

PCOR-SIMS℠ is needed to extend accurate dopant quantification into percent level. In Figure 1 above compare ERDA (elastic recoil detection analysis) with PCOR-SIMS℠. ERDA provides a quantitative depth profile in the high concentration portion of the profile that is not matrix dependent and does not need standards.

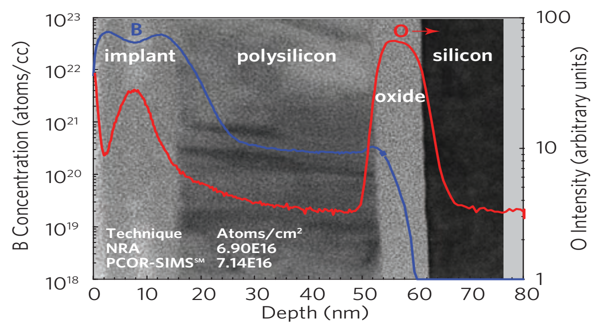

Figure 2: B Plasma Implant into Polysilicon

Figure 2 shows that PCOR-SIMS℠ is needed to accurately measure dopants in multiple layers and blended composition layers. In this chart we compare PCOR-SIMS℠ with TEM and NRA (nuclear reaction analysis). TEM confirms the location and thickness of layers and NRA confirms that total boron is correct.

After successful utilization for SiGe and shallow dopant profiles near surface oxide, PCOR-SIMS℠ has become an essential method for III-V compound semiconductors characterization.

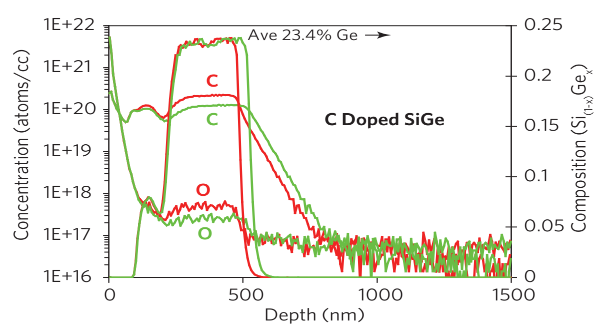

Figure 3: SiGe

PCOR-SIMS℠ plotted in green shows the correct SiGe composition profile, the correct carbon dopant and oxygen contaminant profiles, and the correct thickness at every data point in Figure 3. The red plot shows uncorrected composition, carbon, oxygen and layer thickness where carbon and oxygen are 2x too high and layers are 20% too thin.

The device which benefits from this the most is Vertical Cavity Surface Emitting Lasers (VCSELs). One of the biggest challenges associated with the application of SIMS to the analysis of AlGaAs/GaAs VCSELs is the range of variations in aluminum content which impacts the calibration accuracy for composition. Complicating matters further, changes in alloy composition affect the sensitivity of the dopant species measured in the depth profile.

PCOR-SIMS℠ addresses these issues by employing empirically derived analytical functions to correct for the well-known ‘SIMS matrix effect’.

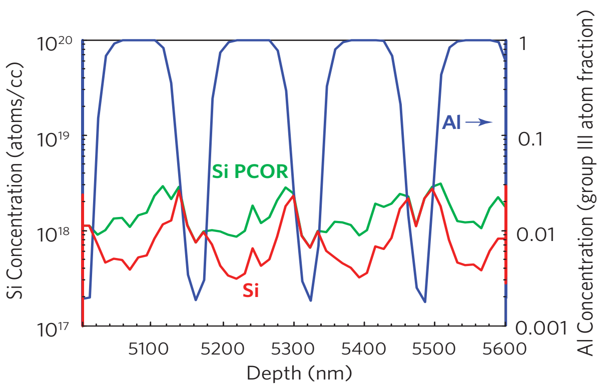

Figure 4: III-V Layers

Figure 4 shows that PCOR-SIMS℠ can determine the layer composition at every data point. In the figure above GaAs/AlGaAs is shown as a multi-layer structure. We can then plot a silicon dopant profile using the correct silicon sensitivity factor for the composition at every data point (shown in green). Silicon plotted using a single GaAs sensitivity factor is shown in red.

The agreement between the RBS and PCOR-SIMS℠ analyses of a multi-layer AlGaAs epi film with %Al varying from 7% to 80% is confirmation of the PCOR-SIMS℠ algorithm to quantify %Al in AlGaAs.

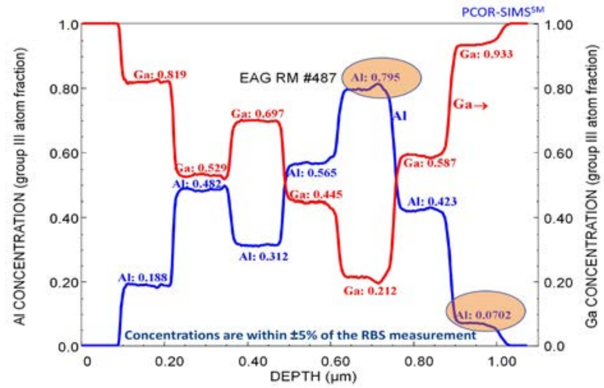

Figure 5: GaAs/AlGaAs Layers

Measurement of composition is the first step in PCOR-SIMS℠. In Figure 5 we compared PCOR-SIMS℠ to [RBS (Rutherford Backscattering Spectrometry)](), a technique that is not matrix dependent and does not need standards. The results agree to within 5%.

This confirmation made variable calibration of SIMS intensities as a function of %Al a possibility. Building a formulation using a series of AlGaAs reference materials led to more accurate characterization of complex VCSEL layers

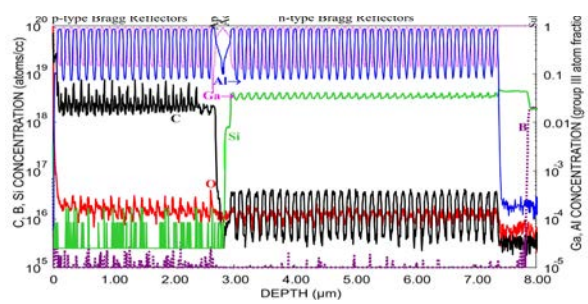

Figure 6: Depth Profile of a Full VCSEL Structure.

The PCOR-SIMS℠ technique pioneered by EAG Laboratories can provide a depth profile of a full VCSEL structure as seen in Figure 6. All of the profiles were acquired in a single analysis. Boron profile marks the beginning of the substrate.

Strengths

- The most accurate characterization of multi-compositional semiconductor layer structures
- Layer thicknesses in complex thin film structures

are more accurately evaluated

- Provides alloy composition analysis with nm layer resolution and <1% precision for sophisticated R&D and FA support
- Accurate placement and quantification of dopants or impurities in the layer structure allows faster epi growth process parameter development or source identification of contamination

Limitations

- Destructive
- Very specific standards required
- Elemental data - no chemical information

Common Applications

- VCSELs used in high-speed data communications, 3D sensing and facial recognition, LIDAR
- HBTs and pHEMTs used in wireless communications
- HEMTs used in power electronics and electrical vehicles
- Ultra-thin layers used in memory and logic applications in handheld devices

Case Study: Optimizing 2-D Electron Density in pHEMTs

The high electron mobility transistors, pHEMT, used in high frequency wireless communication antennas have intricately grown epitaxial layer structures. One of the most critical regions is around the InGaAs channel layer. The 1-5nm Si- δ layers on each side of this InGaAs channel need to be perfectly designed in concentrations, width, and distance from the InGaAs channel for optimum performance. The accurate PCOR-SIMS^{SM} assessment of these layers provides an easier device optimization development.

Many pHEMT structures benefit from PCOR-SIMS^{SM} depth profiling. Figure 7 shows that the composition for the GaAs, AlGaAs, and InGaAs layer structure is determined at every data point. Accurate layer thickness is shown at every data point since sputter rate variations for each composition is taken into account. Silicon spike concentration and spacer thickness can be accurately measured. Comparison with TEM shows the alignment of the dopant spikes with the sample structure.

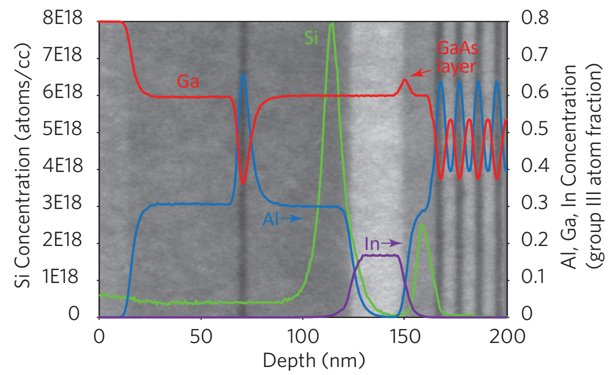

Figure 7: pHEMT

For more information please see our White Paper on [Optimizing 2-D Electron Density in pHEMTs Using Secondary Ion Mass Spectrometry]

Case Study: Near-Surface Analyses of Plasma-Based B Ion Implants in Si

Current electronic devices pack a lot of memory, have fast processing power, consume very little power, and fit into small handheld devices. To make this possible, the doping of Si must be very high and thin i.e., shallow from the surface. The proximity to surface oxide and doping concentrations approaching atom% levels pose a characterization challenge which can only be overcome by using PCOR-SIMS^{SM}. With accurate quantification of these Ultra-Shallow element distribution device engineers can develop optimum process parameters for best performance.

Figure 8 shows very shallow–high dose implantation results in a significant portion of the dopant residing with a surface modified layer. This dopant is not available for activation. PCOR-SIMS^{SM} shows the thickness of the surface modified layer, measures oxygen content, and determines the correct sensitivity factor at each data point for the dopant. The result is accurate dopant profile shape and dose, and a more realistic measure of junction depth, defined by the distance from the oxide/Si interface to the point where the boron profile crosses 5E18 at/cc.

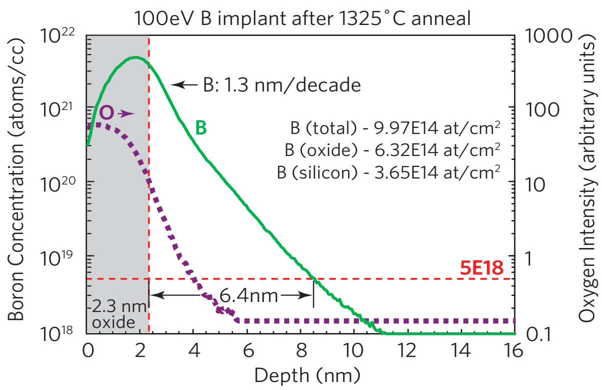

Figure 8: Ultra-Shallow Implants

J. Vac. Sci. Technol. B, Vol. 24, No. 1, Jan/Feb 2006, page 408.

For more information see the Application Note entitled [Characterizing Annealed ULE B Implants using PCOR-SIMS^SM].

Case Study: High Resolution Characterization of p-DBRs in VCSEL

Sensors with 3-D rendering capability are becoming a part of our daily life in face recognition, automobile accident-avoidance devices and self-driving in the future. These devices became affordable with improved efficiency in VCSEL modules which are made from epitaxial films containing 100+ elaborate, very thin layers. The location and concentrations of dopants around rapidly changing composition requires PCOR-SIMS^SM algorithm for accurate analysis of these important transitions. With the aid of this unique characterization, physicists and epi engineers can design and grow the most sophisticated VCSEL materials.

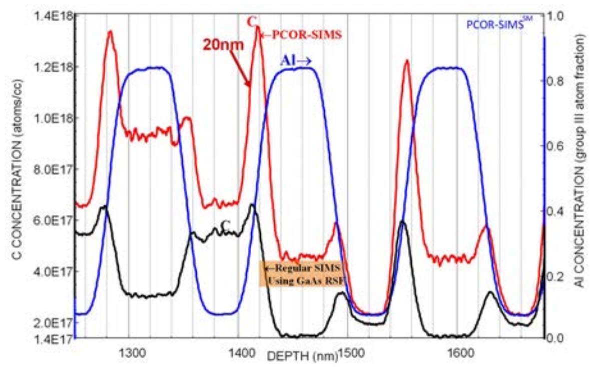

Figure 9: Accurate carbon concentration and depth placement in AlGaAs layers with a graded composition

For more information see the White Paper entitled [Scrutinizing VCSELs by SIMS]

PCOR-SIMS^SM at EAG

PCOR-SIMS^SM continues to be a valuable resource for EAG Laboratories customers to achieve a more accurate analysis and to provide the data they need to create sophisticated products efficiently.

EAG is the industry standard for SIMS analysis, offering the best detection sensitivity along with accurate concentration and layer structure identification. No other analytical laboratory can match EAG's depth of experience, as well as dedication to research and development in the SIMS field. We have the highest number of SIMS instruments worldwide (more than 50 SIMS instruments), highly qualified scientists, and the world's largest reference material library of over 8,000 ion-implanted and bulk-doped standards for accurate SIMS quantification. EAG has been doing SIMS analyses for over 40 years; longer than any other commercial laboratory.