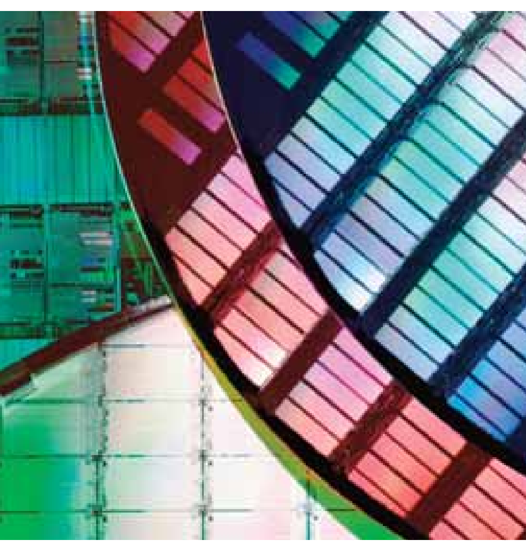
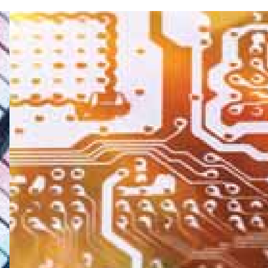
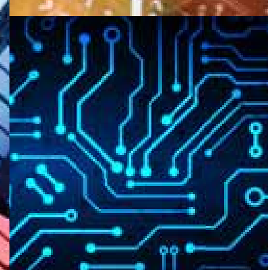
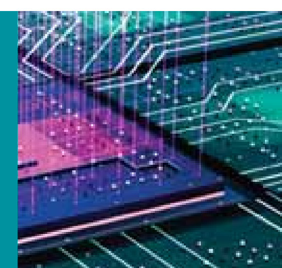
CAMECA
SCIENCE & METROLOGY SOLUTIONS

Semiconductors

ANALYZE
CONTROL
OPTIMIZE




AMETEK
MATERIALS ANALYSIS DIVISION

Nanoscale Compositional Analysis and Metrology for Semiconductors

Semiconductor devices pervade our daily lives with more interconnected, portable electronics, booming high speed mobile communication, and the Internet of Things, requiring ever greater amounts of data storage, exchange, and processing.

After doubling transistor density every 18 months, Moore's law has been superseded by the "More than Moore" approach, leading to the integration of compound semiconductors into mainstream device architectures, in parallel to the integration of analog aspects of the device onto the package or chip.

To meet surging demand, semiconductor device manufacturers and designers need to analyze materials for performance enhancement and device reliability while containing costs. Semiconductor characterization instrumentation must meet conflicting requirements: it must enable research and process development in the early stage of innovation and be usable for high volume manufacturing (HVM) ensuring low cost of ownership and high uptime.

Designed with the above challenges in mind, the CAMECA instruments have been widely used to support R&D and HVM of semiconductor devices. The required technological capabilities are implemented on suitable platforms allowing the greatest benefits to the semiconductor market.

Addressing “More Than Moore” Characterization Challenges Using SIMS & APT

Pioneer and world leader in Secondary Ion Mass Spectrometry (SIMS) since the 1960s, CAMECA has also perfected Atom Probe Tomography (APT) over two decades. Both techniques deliver micron to nanometer level material composition for a wide array of use cases.

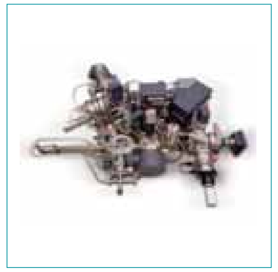
SIMS provides quantitative data about contamination levels, in-depth dopant profiles and precise compositional information. It supports new product development as well as in-fab process control. SIMS is uniquely positioned to meet the requirements of future device processes due to its high sensitivity, excellent depth resolution, wide range of detectable species and high repeatability.

APT’s ability to generate atomic-scale chemical analysis of complex 3D structures with buried interfaces makes it the best suited tool for characterizing advanced devices and supporting R&D of next generation semiconductors.

CAMECA’s portfolio of high productivity, high precision analytical instruments can accelerate the development of new materials and devices and maximize manufacturing yields. Whether measuring low-level dopant implants, nanoscale transistors, or memory devices, CAMECA has a solution tailored to address each of your needs.

Review the examples in the following pages to find out how SIMS and APT can support your research and production.

SIMS



IMS 7f-Auto

- Magnetic sector SIMS
- Monocollection detection
- High versatility with high throughput
- Deep implants & light elements

AKONIS

- Fully automated magnetic sector SIMS
- Full wafer analysis
- < 1 nm depth resolution
- SiGe & SiP in-line Epi monitoring

IMS Wf / SC Ultra

- Extreme Low Impact Energy magnetic SIMS
- < 1 nm depth resolution
- Dual ion source
- Ultra thin films, SiGe & implants

SIMS 4550

- Ultra low energy quadrupole SIMS
- 2 nm depth resolution
- SiGe depth profiling

NanoSIMS 50L

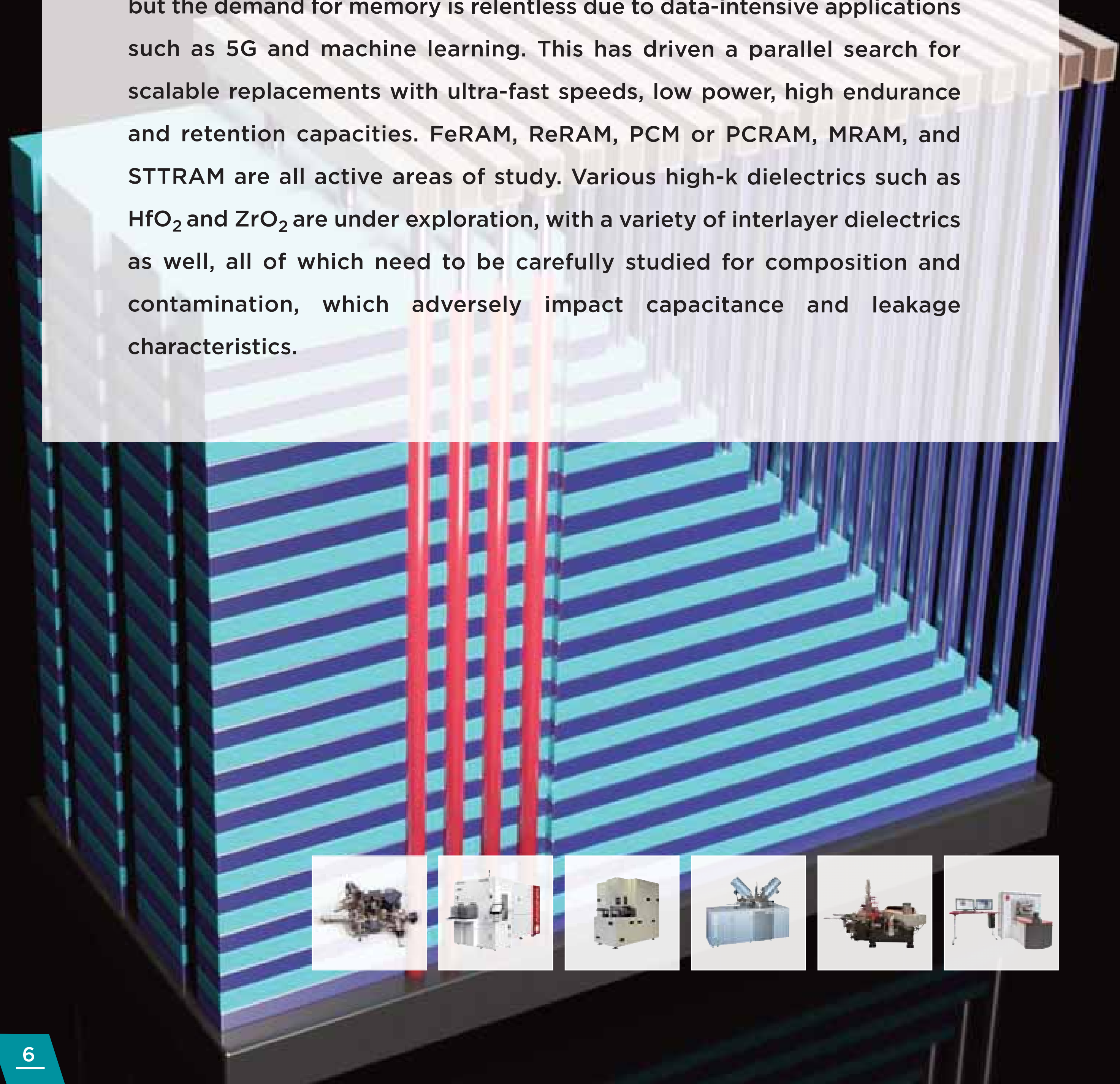
- 50 nm lateral resolution magnetic SIMS
- Multicollection detection system
- High sensitivity imaging
- Small area analysis

APT

LEAP®

- Local Electrode Atom Probe
- Nanoscale 3D quantitative analysis
- 3D device dopant distribution
- Near-line process monitoring

Memory

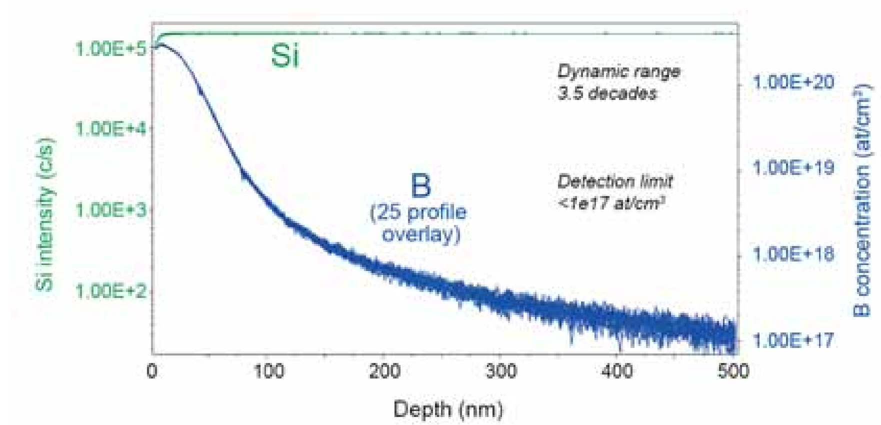


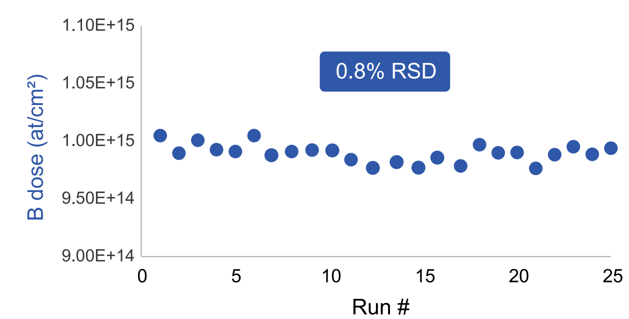
Scaling of DRAM and 3D NAND continues to push the limits of architecture, but the demand for memory is relentless due to data-intensive applications such as 5G and machine learning. This has driven a parallel search for scalable replacements with ultra-fast speeds, low power, high endurance and retention capacities. FeRAM, ReRAM, PCM or PCRAM, MRAM, and STTRAM are all active areas of study. Various high-k dielectrics such as HfO_2 and ZrO_2 are under exploration, with a variety of interlayer dielectrics as well, all of which need to be carefully studied for composition and contamination, which adversely impact capacitance and leakage characteristics.

Applications of Boron Implant in Silicon

In DRAM applications, boron is used for counter-doping to control the threshold voltage in n-channel device regions. It is essential to quantify the B implant for controlling the device characteristics on as-patterned wafers that run in short loops during technology development.

Scaling of such implant processes for high volume manufacturing of devices with repeatable electrical characteristics requires metrology on the B implant to enable statistical process control on the implanters. The AKONIS SIMS tool delivers highly repeatable analysis of B implant wafers on pad size craters with good detection limit and dynamic range.





Top: Overlay of 25 boron implant measurements in Si quantified profiles showing high repeatability with excellent detection limits and dynamic range for pad analysis.
Analysis conditions: O_2^+ 500 eV, raster 50 x 50 µm².
Bottom: Boron dose repeatability over 25 runs for statistical process control using test pads on patterned wafers.

SIMS

AKONIS

The AKONIS SIMS tool fills a critical gap in semiconductor fabrication processes by providing high throughput, high precision detection for implant profiles, composition analysis and interfacial data directly in semiconductor manufacturing lines. AKONIS offers a very high level of automation to ensure repeatability across tools for fab level process control and tool-to-tool matching.

Power Electronics

SiC wide bandgap power electronic devices are chosen today for high power applications such as solar inverters and off-board electric vehicles chargers due to their higher breakdown strength and thermal conductivity, while Al(Ga)N/GaN devices are preferred for high-frequency applications. Research conducted towards developing vertical devices in epi-GaN on heterogeneous substrates is increasing the current through each device. Efforts are also on-going for devices made from semiconductors with even larger bandgaps, such as diamond and GaO. However, accurate dopant profiling will be required to overcome the challenges.

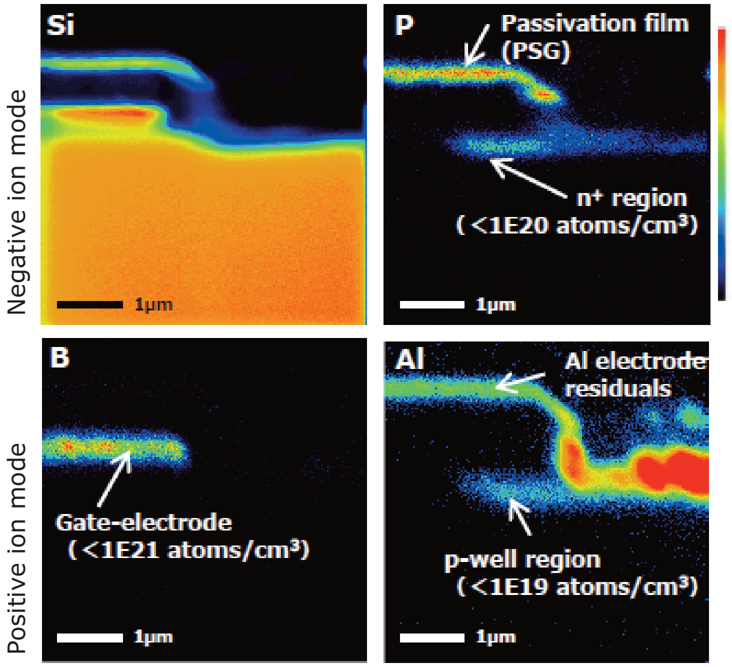
SiC Power Transistors

Quantitative dopant mapping in 2D and 3D is crucial information for the development of modern devices.

The NanoSIMS contributes to this task by mapping low concentration elements where (S)TEMs with EDS or EELS lack sensitivity. It offers a unique sweet spot of 50nm resolution together with high sensitivity for dopants and light elements (starting with H).

2D images can be recorded from a cross-section (example below). Alternatively, image stacks from the top surface can be processed to build 3D views, extract local diffusion profiles or reconstruct depth profiles from sub-µm regions of interest.

SiC power transistors can benefit from such NanoSIMS performance. In the example below, up to seven masses can be detected in multicollection mode, dopants (here B, P) and matrix elements (here Si, Al) at the same time, ensuring perfect normalization. High sensitivity and low background noise are the signature of CAMECA magnetic sector SIMS working in dynamic SIMS mode under ultra high vacuum.



Cross-section analysis of SiC-MOSFET.
The NanoSIMS obtains 2D & 3D dopant distribution of the gate-electrode, p-well and n+ regions with combined high spatial resolution, high mass resolution and high sensitivity.

SIMS

NanoSIMS

The CAMECA NanoSIMS 50L is a dynamic SIMS using a small spot size (down to 50 nm) for both negative and positive secondary ions to produce high spatial resolution imaging capability. It has parallel detection of up to seven masses and ultra-high sensitivity, combined with high mass resolving power and excellent lateral imaging resolution.

Sensors

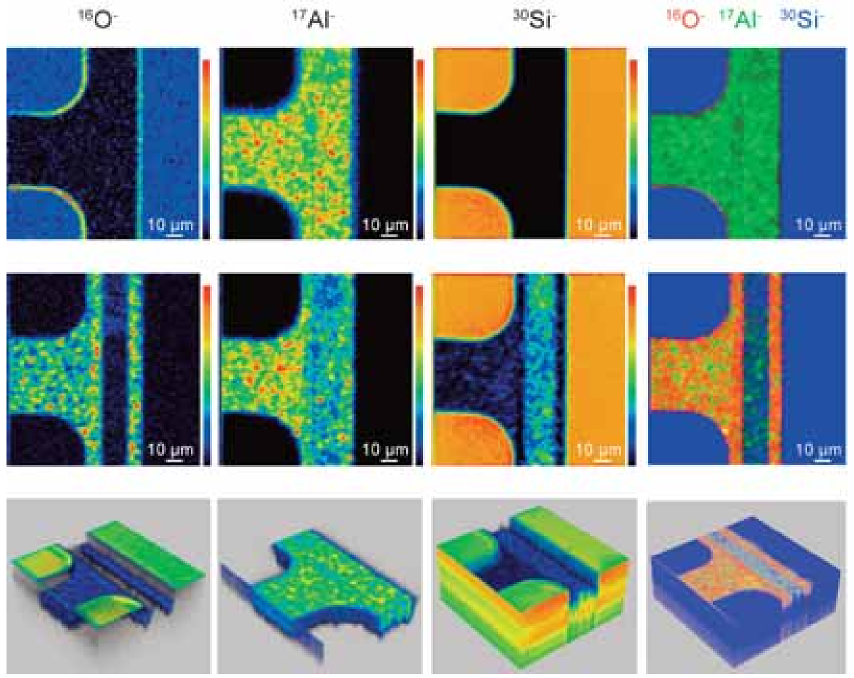
Micro Electro Mechanical Systems (MEMS) and sensors are in growing demand due to their increased use for Advanced Driver Assistance Systems, autonomous vehicles, smartphones, radio frequency and infra red sensing. This is turning them into micro-systems that are self-contained hubs and nodes with the goal of achieving low power, high repeatability and reliability.

Their design optimization requires precise and accurate mapping of dopants and impurities embedded under thick layers, which limits the number of techniques able to characterize them.

Applications in MEMS Piezosensor

Dynamic SIMS allows optimization of ultra-compact device design by monitoring the incorporation of dopants and impurities.

In particular, the IMS 7f-Auto scanning ion imaging capabilities can be used to investigate the local distribution of different species (including light elements) at the sub-micrometer scale. Powerful tools are available for image data processing: 3D volume reconstruction as well as retrospective depth profiling from the ion image stacks recorded sequentially while sputtering in-depth.



In-depth scanning ion imaging showing the presence of oxygen impurities at the interface of alumina over silicon structure in a Si-MEMS piezoresistive pressure sensor.

Top row: depth ~ 300 nm
Middle row: depth ~700 nm
Bottom row: 3D view
Field of view: 120 x 120 μm^2
Lateral resolution: ~3 µm
Total depth: ~2.3 µm

SIMS

IMS 7f-Auto

The IMS 7f-Auto delivers high precision elemental and isotopic analyses with high ease-of-use and productivity. It has been optimized for challenging applications such as Si-based, III-V and II-VI devices, bulk materials, and thin films, fulfilling industry requirements for efficient device development and process control.

Logic

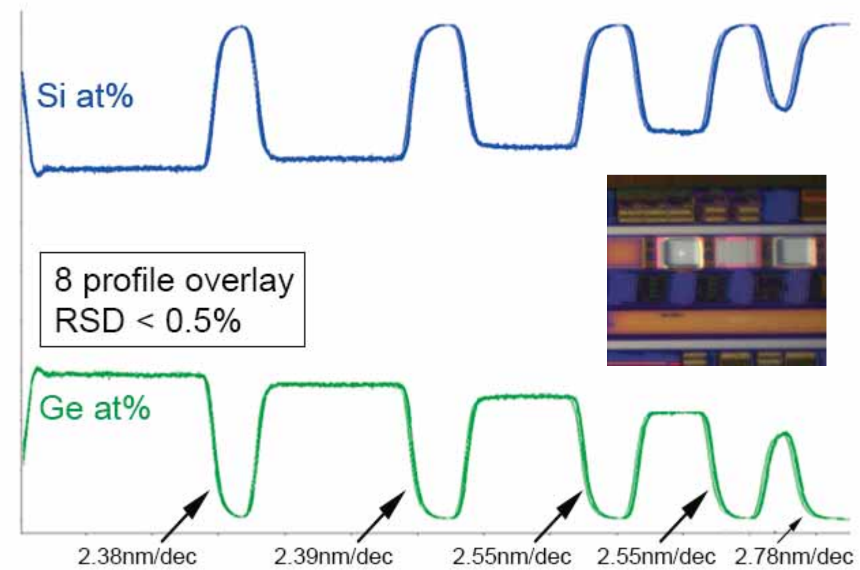
SiGe FinFETs are the mainstream in high end transistor technology. The natural next step is gate all around transistors, but further scaling is envisioned using a plethora of new materials and architectures including III-V FinFETs, complementary FETs, Tunnel FETs and vertical nanowires.

The complexity of these architectures and hence the number of processing steps will drive the demand for analysis not only of the dopants controlling the drive current, but also to study contamination between the layers for leakage losses. Moreover, multi-element compositional analysis is critical due to the increased number of materials used in the active device region.

Applications in SiGe

Strain engineering of SiGe transistors requires metrology equipment that can access and reliably characterize SiGe layers with thicknesses of only a few nanometers. Quantification of the dopant is important to precisely engineer the strain. Another challenge for logic device manufacturers resides in obtaining high throughput quantification of boron and other light element dopants on multiple patterned wafer pads.

Shown below: repeatable quantification of SiGe:B heterostructures for pad analysis.



Depth profiling of a graded SiGe heterostructure on a pad by the AKONIS in-line SIMS demonstrating high interfacial resolution and precise quantification of elements.

(Axis units and elements removed for confidentiality.)

Automated data processing routines of the AKONIS in-line SIMS allow the operator to load jobs in a batch mode and to output the quantified profile and parameters of interest (dose, peak depth...) for different process recipe splits without need for SIMS expertise.

SIMS

AKONIS

The AKONIS SIMS tool fills a critical gap in semiconductor fabrication processes by providing high throughput, high precision detection for implant profiles, composition analysis and interfacial data directly in semiconductor manufacturing lines. AKONIS offers a very high level of automation to ensure repeatability across tools for fab-level process control and tool-to-tool matching.

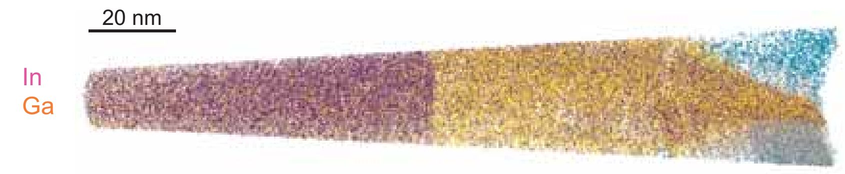
Logic

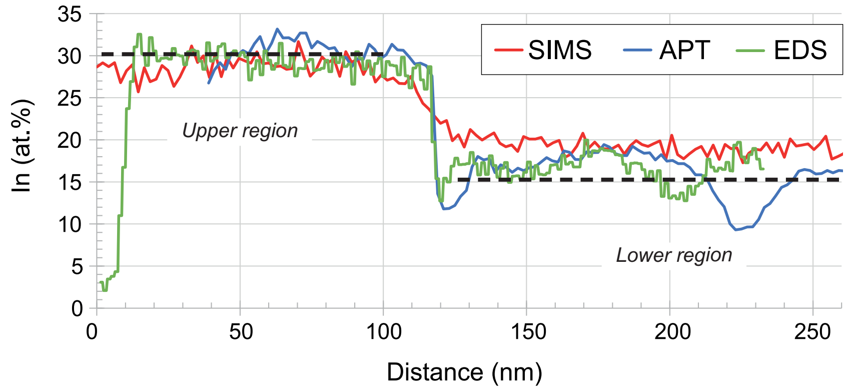
In the transistor business, III-V materials have conventionally been used for applications such as high-electron-mobility transistors and heterojunction bipolar transistors. The demonstrated mobility, however, has generated research for insertion into the core of advanced logic devices.

Applications in InGaAs FinFETs

III-V materials are being considered for use in FinFETs due to their higher mobility compared to SiGe.

In the framework of the recent 3DAM European ECSEL consortium study, correlative microanalytical techniques were used to characterize next generation logic device test structures. Shown below is a comparison of SIMS, EDS, and APT data in a fin region containing differing levels of indium.





The indium content measured is in good agreement across the varying techniques (the SIMS data show a slight elongation of the transition from the upper to lower regions since it is averaged over many fins).

The Atom Probe Tomography data not only confirms the interface sharpness between the two regions, but also shows the additional fine-scale variation of In which can be present within each region.

TEM data from N. Bernier, Z. Sagh, and V. Delaye (CEA Leti)
SIMS data by A. Franquet, V. Spampinato, P. van der Heyde (IMEC).
Acquired on CAMECA SC Ultra
APT data acquired on CAMECA LEAP 5000X

APT

LEAP®

Local Electrode Atom Probes (LEAP®) are the only instruments delivering quantitative compositional analysis in three dimensions with sub-nanometer spatial resolution, ppm sensitivity and high throughput. Atom Probe analyses of particular interest include dopant distribution in the source/drain, extension, interfacial and channel regions of devices where other common analysis techniques lack sufficient spatial or compositional resolution.

Optoelectronics

Driven by mobile 3D sensing, traditional high brightness LED and edge-emitting lasers are being replaced by vertical cavity surface emitting lasers (VCSELs) in growing demand. Other booming applications include automotive, medical, and AR/VR.

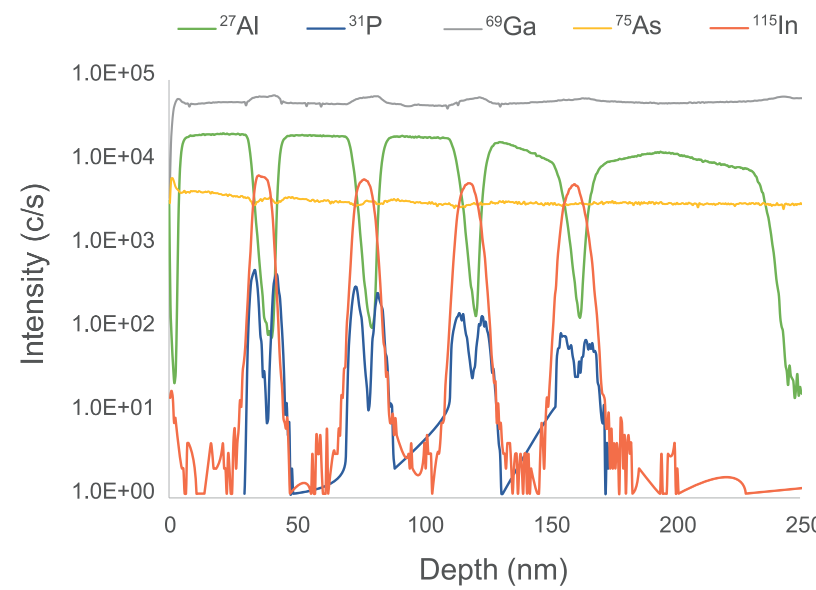
VCSELs are also evolving into quantum dot and quantum cascade lasers, often made of multiples layers of varying composition. A key region of interest is the active layers where the quantum confinement occurs to produce laser emission. The broad array of elements (GaAs/AlGaAs, InP) and the thin alternating layers make these structures difficult to analyze.

Applications in III-V VCSELs

The measurement of III-V elements in the active region of VCSEL devices requires ultra high resolution analytical capabilities.

The IMS Wf and the SC Ultra excel in this type of analysis. Equipped with oxygen and cesium sources to use the best conditions for each element of interest, they can operate at energies down to 150 eV with a high secondary extraction field to enable ultra high depth resolution. Below we show resolution even between the quantum well and barrier layers.

The SC Ultra can be used for coupon analysis while the IMS Wf provides identical capability to handle up to 300 mm wafers.



Overlay of raw profiles showing ultra high resolution to separate out the quantum well layers from the barrier layers.

SIMS

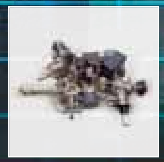
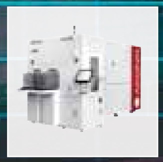
SC Ultra

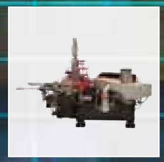
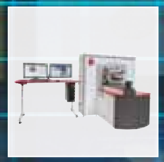
Offering a large range of impact energies (100 eV to 10 keV) with no compromise on mass resolution and primary beam density, the IMS Wf and the SC Ultra ensure unequaled analytical performance at high throughput for the most challenging semiconductor applications: implants (from extra shallow to high energy), ultra-thin nitride oxides, high-k metal gates, SiGe doped layers, Si:C:P, PV and LED devices, graphene, and more.

Display

Emerging technologies such as AR, VR, and wearables are pushing the future needs of display technology. This is on top of the needs of smartphones, and high-end TVs. This demand is driving research in micro-LEDs in parallel to the current back plane-TFT based displays. Multiple micro-LEDs can fit in one pixel, producing a much better picture than OLEDs while also being compatible with flexible substrates.

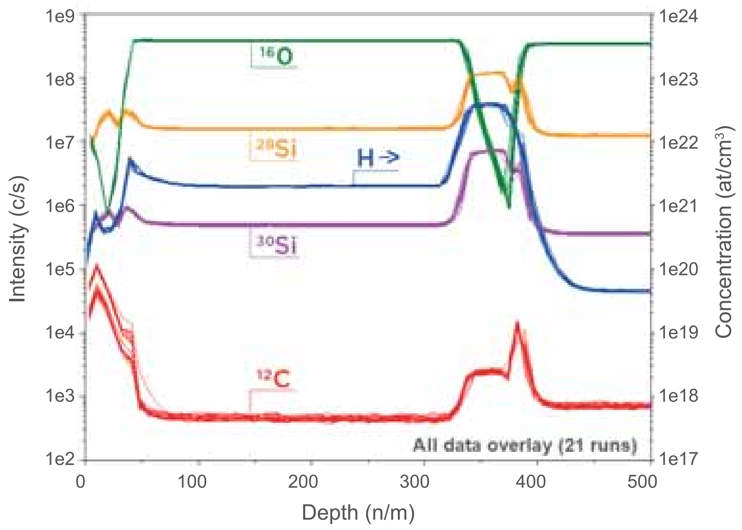
Alloys that can span the entire range of the visible spectrum, like InGaN, are generating interest to overcome challenges associated with manufacturing RGB mLEDs on a large scale. However, tuning these multi-element alloys requires precise compositional quantification.

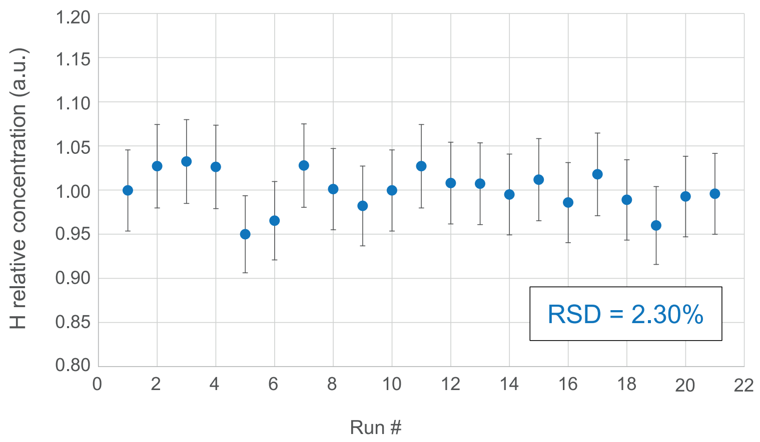



Applications in Si:H on TFT

Hydrogen acts as an electron donor and shifts threshold voltage making it an undesired impurity in display TFT devices. Manufacturers must carefully monitor its distribution in the oxide layers. Dynamic SIMS instruments are best fit for measuring hydrogen due to superior depth profiling capabilities combining benchmark sensitivity, depth resolution and throughput. With a high density Cs primary ion beam allowing high sputtering rates, an optimized UHV analysis chamber, and a nitrogen trap minimizing background levels, the IMS 7f-Auto ensures best-in-class detection limits for hydrogen and other light elements.





Measurement of hydrogen in SiO_2 based sample structure.

Top: Overlay of H quantified profiles and C, O, Si depth profiles, total of 21 measurements (three sample holders, seven samples in each holder). Measurements performed in fully unattended mode.

Bottom: H average concentration in SiO_2 for the 21 depth profile measurements. Excellent reproducibility is obtained.

SIMS

IMS 7f-Auto

The IMS 7f-Auto delivers high precision elemental and isotopic analyses with high ease-of-use and productivity. It has been optimized for challenging applications such as Si-based, III-V and II-VI devices, bulk materials, and thin films, fulfilling industry requirements for efficient device development and process control.

Overview of applications & capabilities

	IMS 7f-Auto	AKONIS	IMS Wf/SC Ultra	SIMS 4550	NanoSIMS 50L	LEAP®
Dopant process control: dose, depth profiling, diffusion & annealing, trace element quantification	Excellent performance	Excellent performance	Excellent performance	Good capabilities	Can be addressed	Good capabilities
Failure analysis: contamination, diffusion	Excellent performance	Good capabilities	Good capabilities	Good capabilities	Excellent performance	Can be addressed
High resolution 2D & 3D imaging: traces, dopant, single transistor	Good capabilities			Can be addressed	Excellent performance	Good capabilities
300 mm wafer handling		Excellent performance	Good capabilities			
FOUP handling (SECS/GEM)		Excellent performance				
Ultra thin structures ULE implant dose, SiGe	Can be addressed	Excellent performance	Excellent performance	Good capabilities	Can be addressed	Can be addressed
Light elements H, C, O, N, trace analysis	Excellent performance		Can be addressed	Can be addressed	Good capabilities	Can be addressed
LED, optoelectronics, III-V compounds GaAs, GaN, InP	Excellent performance	Can be addressed	Excellent performance	Good capabilities	Can be addressed	Excellent performance
IR detectors, II-VI compounds HgCdTe	Excellent performance		Good capabilities		Can be addressed	Can be addressed
Oxynitrides & high-k gate dielectrics	Can be addressed		Excellent performance	Good capabilities	Can be addressed	Can be addressed
Photovoltaics	Excellent performance		Can be addressed		Can be addressed	Good capabilities

Excellent performance Good capabilities Can be addressed

Time buyers, money savers

Whether directly in-fab, near or off-line, a CAMECA SIMS or APT microanalytical instrument implemented within your fabrication process will deliver key return on investment.

Reduce analysis costs
No longer outsourcing analyses to third-party labs will dramatically reduce your costs.

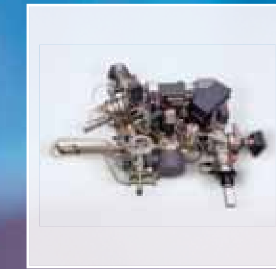
Enhance yields
Running your analyses in-house facilitates uniformity control, you will analyze more samples and improve yields significantly.

Minimize production losses & improve quality
Regular and fast monitoring eliminates the risk of having to stop production while waiting for results. You will avoid wasting money on non-detected off-spec products and improve quality.

Accelerate new equipment & process ramp-up
In-house metrology will enable better and faster implementation of new production processes or tools, reducing qualification time and improving quality.

Increase deposition & implanter tools uptime
Running your analyses in-house enables you to obtain results in minutes instead of days, which significantly reduces the fab tool qualification time!

Protect your intellectual property
Not having to send high IP value samples outside the company eliminates the risk that competition could access your R&D.





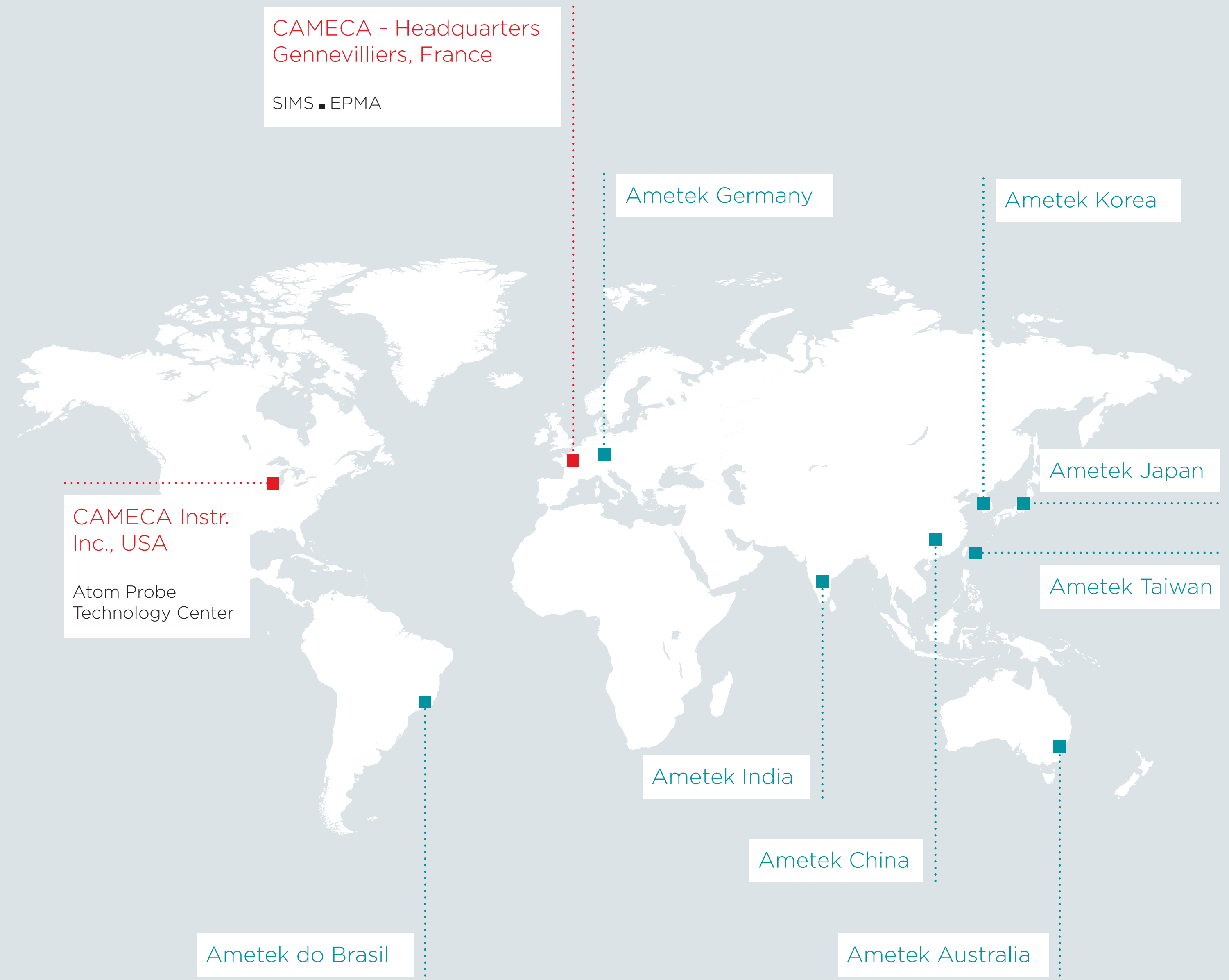

About CAMECA

CAMECA started in France in 1929 as a manufacturer of movie theater projectors, before rapidly evolving into a provider of scientific instrumentation for the international research community and in-fab / near-fab metrology solutions for the semiconductor manufacturing industry. From its inception, CAMECA has been renowned for its precision mechanics, optics and electronics.

Since pioneering Electron Probe MicroAnalysis (EPMA) in the 1950s and Secondary Ion Mass Spectrometry (SIMS) in the 1960s, CAMECA has remained the undisputed world leader in these techniques while achieving numerous breakthrough innovations in complementary techniques such as Atom Probe Tomography (APT).

Operating under ISO 9001 certification, CAMECA controls not only the technology, but all aspects in the design, manufacture, installation, and servicing of products. Located near Paris, France (CAMECA headquarters) as well as in Madison, Wisconsin, USA, our plants are state-of-the-art facilities, using best practices for clean room production, computer networking, electron and ion optics simulation, and advanced CAD.

CAMECA is a business unit of AMETEK, Inc., a leading global provider of electronic instruments and electromechanical devices, as part of the AMETEK Materials Analysis Division.



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Sales and service

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