# Compositional Measurement of Confined SiGe Devices with Self Focusing SIMS

## *A novel method for probing nm-sized structures*

The continued downscaling of semiconductor transistors, both laterally and in depth, results in acute characterization challenges. Metrology tools must ensure lateral resolution of a few nanometers as well as high depth resolution while retaining high sensitivity. Dynamic Secondary Ion Mass Spectrometry (SIMS) enables access to high depth resolution at low primary impact energies (≤500 eV). However, it still utilizes a micron sized beam to probe nanometer sized structures. In order to overcome the beam size limitation when analyzing small features, one can seek to localize (laterally and in depth) the signal emitted by the device by specifically tracking the molecular secondary ions emitted from the 3D area of interest.

This novel method is referred to as Self-Focusing SIMS[1,2,3]. In the case of a SiGe device, one looks for the $Ge_2^+$ signal while taking all Ge containing molecular ions in the mass spectra into account.

### Methodology

One of the main advantages of dynamic SIMS is its ability to produce unfragmented mass spectra. For SiGe analysis, the number of mass peaks to be analyzed is limited to monoatomic and diatomic germanium, e.g. $Ge^+$ , $Ge_2^+$ and $SiGe^+$ secondary ions enabling high duty cycles for improved data density. Ge relative concentration is obtained using the below formulas derived from the fact that $C_{Si} + C_{Ge} = 1$:

Formula 1 $$C_{Ge} = \frac{\alpha I_{Ge}}{\alpha I_{Ge} + I_{Si}\gamma}$$ Formula 2 $$C_{Ge} = \frac{\beta I_{Ge_2}}{\beta I_{Ge_2} + I_{SiGe}}$$

In the case of confined SiGe structures, the formula for compositional analysis in blanket structures is modified using a geometric factor γ in order to reflect a variable surface coverage of Ge over the total SIMS analysis area at crater bottom. Knowledge of this geometric factor at every point of a depth profile enables compositional analysis in confined structures[4]. Conventionally, such a geometric factor γ is determined by transmission electron microscopy. However, we demonstrate determining this using the self-focusing SIMS approach.

The parametric scaling factor α in the above formula is proportional to the ratio between ion yields of $Ge^+$ and $Si^+$. The parametric scaling factor β is proportional to the ratio between ion yields of $Ge_2^+$ and $SiGe^+$. α is obtained by measuring a known reference sample and applying the above formulas to solve for β.

### Analysis validation

When non-confined SiGe (blanket wafer or plain pads larger than beam) analysis is performed, the geometric factor γ is 1. Thus, the Ge concentration given by formula 1 is equal to the one given by formula 2. SIMS results obtained using this approach have been validated using RBS.

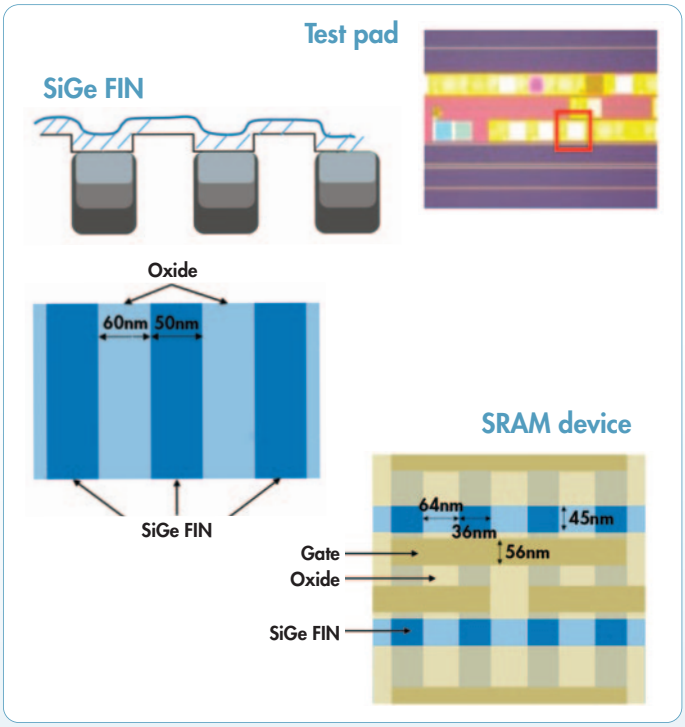
### Nanometre sized structure dimensional information

When analysis is run on confined SiGe structures, the formulas can be solved to extract the γ coefficient. This coefficient is representative of the portion of the total analysis area occupied by the confined SiGe region. Dynamic SIMS is thus able to provide dimensional information without need of TEM analysis.

### Application to confined structures and results validation

Four test samples produced by the same SiGe growth recipe were employed to both investigate a micro-loading growth effect and validate the developed quantification model (Figure 1). The samples used were a SiGe blanket wafer, a SIMS pad in the scribe line (50x60 μm²) which is larger than the beam size, an equally spaced uniformly boron doped vertical SiGe FIN structure with evenly spaced SiGe and $Si_3N_4$, and an SRAM device with SiGe structure occupying 11% of the total analysis area.

*Figure 1: Three of the analyzed samples are shown schematically.*



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Both protocols, with monoatomic $Ge^+$ and molecular $Ge_2^+$ , were applied to the set of samples enumerated before. The results of Ge composition quantification are shown in Figure 2. The results of Ge compositional analysis obtained using the molecular ions (formula 2) are shown on the X-axis of the graph, while Ge concentration produced by monoatomic ions (formula 1) is shown on the Y-axis of the graph.

The solid black line shown on Figure 2 indicates the result of TEM measurements performed in the structures of interest. The microloading growth effect is clearly identified by using the self-focusing SIMS approach of examining the Ge clusters, as seen by the increasing Ge concentration with increasing confinement. The fraction of analyzed area occupied by the SiGe structures can be extracted from the ratio of Ge concentration obtained using formula 2 and formula 1.

When profiling small features such as a SiGe FIN structure, the Ge composition ratio produced by formula 2 and formula 1 is representative of the SiGe coverage in the area of interest and can be used to further quantify dopant depth profiles, such as boron doping, using a standard RSF based algorithm.

## The advantages of self-focusing SIMS

This approach to analyzing small features is about ten times faster than a direct study of the feature with say TEM or APT. In addition, as SIMS is averaging over many such structures, the signal-to-noise is high, resulting in more statistically reliable results compared to TEM or APT. On the other hand, no compositional variation within the confined area can be determined using this technique.

## AKONIS

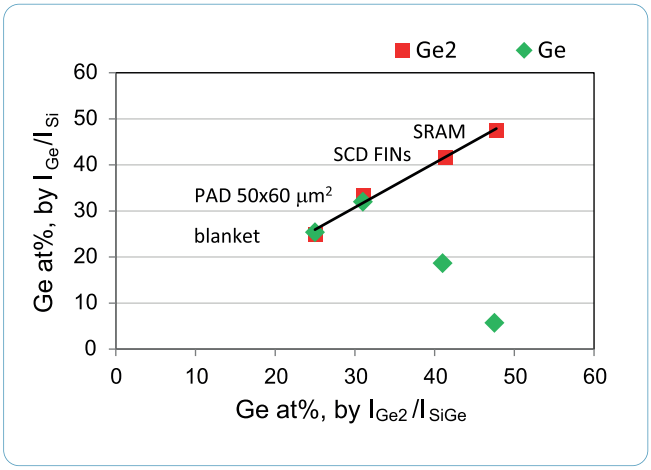
The new CAMECA AKONIS SIMS tool fills a critical gap in semiconductor fabrication processes by providing high throughput, high precision detection for implant profiles, composition analysis and interfacial data directly in the semiconductor manufacturing line. AKONIS provides a very high level of automation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

Complementing the IMS Wf/SC Ultra as well as the SIMS 4550 (quadrupole SIMS) used to support the semiconductor industry via characterization labs, AKONIS - with full automation of instrument set-up and acquisition routines - enables rapid, within-fab analysis without compromise in analytical sensitivity.

AKONIS benefits from recent development in EXtremely Low Impact Energy (EXLIE) ionic column technology (< 150 eV), coupled with a full wafer handling system including a high resolution stage enabling measurements on pads down to 20 µm.

*Figure 2:*

*A microloading growth effect is identified by using the Ge clusters in a self-focusing SIMS approach on the confined SiGe structures. In addition, the fraction of analyzed area occupied by the SiGe structures is represented by the degree of underestimation of Ge concentration obtained by conventional SIMS approach, instead of the self-focusing approach.*





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[3] *M. Py et al., Surf. Interface Anal., 43, 539-542 (2011)*
[4] *W. Vandervorst et al., Materials Science in Semiconductor Processing, 62, 31–48 (2017)*





***For more information please visit www.cameca.com/products/sims/akonis***


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