EAG℠ Evans Analytical Group

AN 373

Process Control Using SIMS for Compound Semiconductors

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Discussion

The measurement of dopant and impurity concentrations as a function of depth in compound semiconductors is often accomplished using Secondary Ion Mass Spectrometry (SIMS), because of its very low detection limits and excellent depth resolution. SIMS is a key analytical technique for research and development of compound semiconductor epitaxy and devices, but does it have the capability for process control?

Process control, or monitoring, typically requires a tight precision over a long period of time. The required measurement precision is dictated by the required process tolerance, i.e., the measurement precision must obviously be tighter (or smaller) than the process tolerance. The ratio of the process tolerance (PT), in terms of a standard deviation, to the measurement precision (MP) is sometimes called the PT/MP ratio, and depending upon one's use of statistical control in manufacturing the desired PT/MP ratio varies from 3x to 10x. (For example, the International Technology Roadmap for Semiconductors, ITRS, targets metrology for a ratio of 3x minimum to a desired 10x if possible. However, there are some metrologies in use in the silicon semiconductor industry that do not meet even the 3x requirement.)

An indication of what is possible with SIMS for compound semiconductors is revealed in the following example. Figure 1 shows a SIMS depth profile of Si, C, O, H, In, Ga, and Al in a GaAs HBT wafer. This is a planar structure, i.e., not a device, so many "samples" can be taken from this wafer over time for SIMS measurements. This is important since SIMS is a destructive technique. The assumption is that the HBT structure is uniform across the wafer.

The important point is that this sample, a CONTROL SAMPLE, is measured after a reference material is analyzed to determine relative sensitivity factors. The CONTROL SAMPLE has been measured many times over a period of years, a longer period of time typically than the life of any one compound semiconductor process. The precision determined from these measurements include variations due to the measurement process plus any non-uniformity across the wafer.

Figures 2, 3 and 4 are long term charts of different parameters taken from the SIMS measurement of the CONTROL SAMPLE. For example, Figure 2 shows the Carbon Base Doping, the Silicon Top Contact Doping, and the Silicon Sub-Collector Doping versus time. The relative standard deviation (RSD), as defined by the ratio of the one standard deviation to the average value, is shown in the chart for these parameters. The RSD varies from 4.7% to 6.6%. Also shown in Figure 2 is the precision for measurement of the Al atom fraction. Even for a key matrix component, the RSD is 2.9%. Figure 3 shows the data for the Silicon Collector

GaAs HBT Control Sample

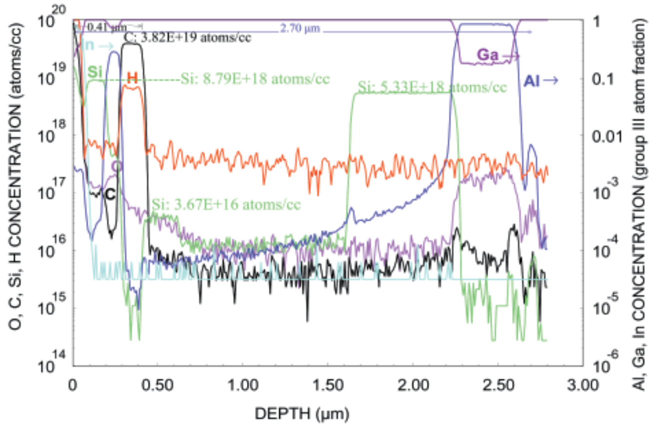

Figure 1. Control Sample for Long-Term Precision Check

High C and Si Concentrations

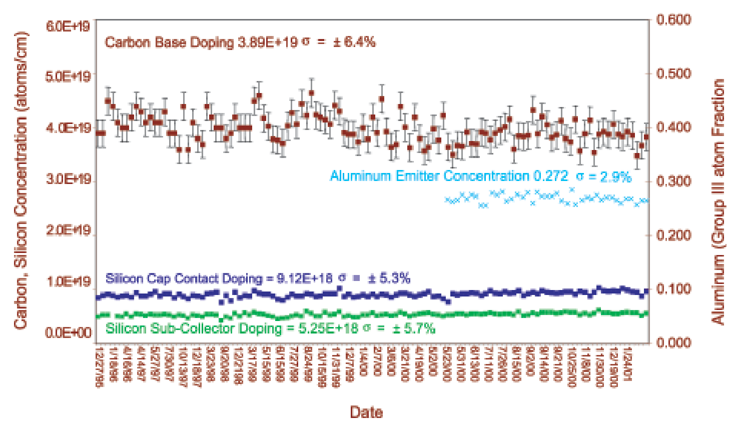

Figure 2. Long-Term Precision Statistics

Doping, and this has an RSD of 8.2%. Note that the higher RSD corresponds to a much lower doping level ($4x10^{16}$ atoms/cm^3) than the parameters in Figure 2 (>10^{18} atoms/cm^3). This illustrates a key point that the SIMS precision varies with concentration level.

Because of the excellent depth resolution of SIMS profiles it is also possible to accurately monitor layer thickness or junction depth. This is shown in Figure 4 for the epi thickness and Base/Collector Junction Depth. The RSDs of these parameters are 1.2% and 1.5% respectively.

In summary, SIMS can be used for long-term process control or monitoring of compound semiconductors. Whether SIMS is the measurement of choice for a particular application will depend upon a determination of the SIMS precision and upon the process tolerance of the manufacturing process.

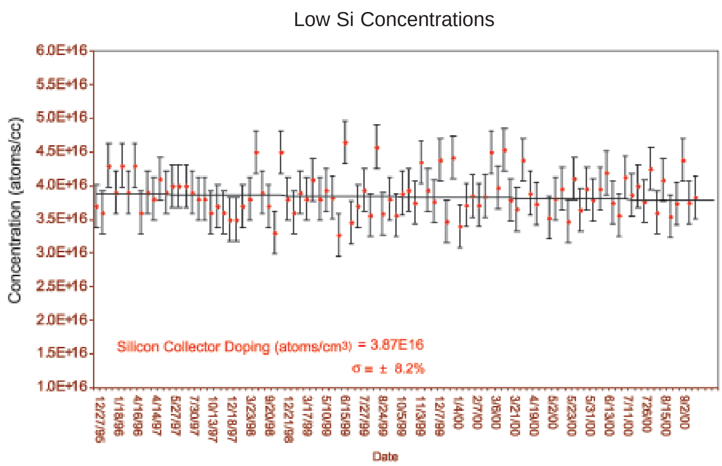

Figure 3. Long-Term Precsion Statistics

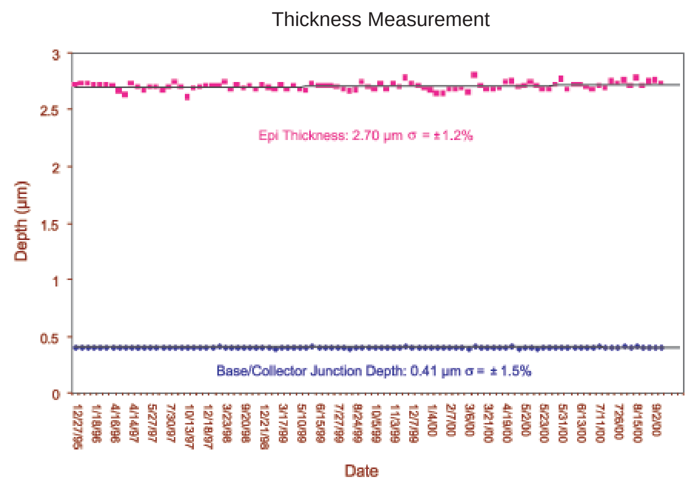

Figure 4. Long-Term Precision Statistics

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