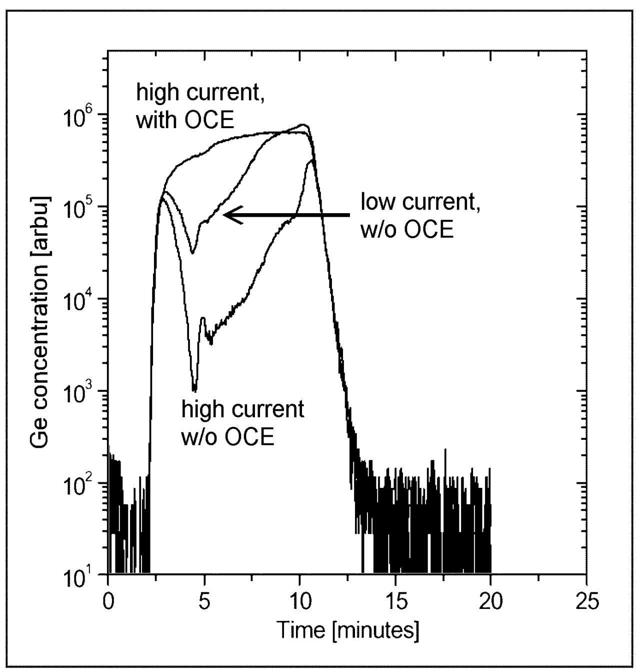
QUANTIFICATION OF Ge AND B IN SiGe USING SECONDARY ION MASS SPECTROMETRY

H.-Ulrich Ehrke, Hans Maul
Cameca GmbH
Bruckmannring 40, D-85764 Oberschleissheim / Munich, Germany

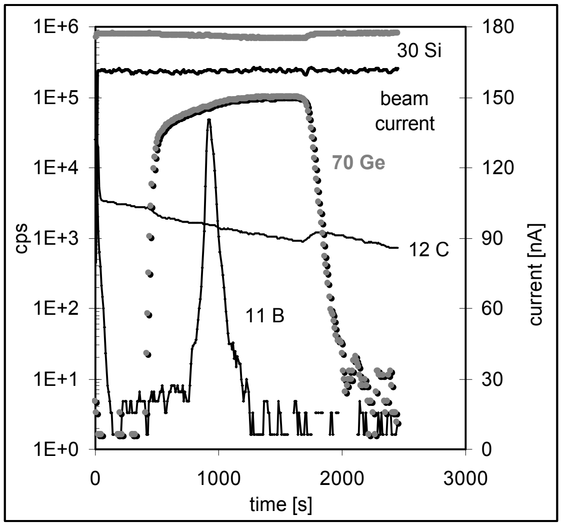
Abstract. This paper reports on routine secondary ion mass spectrometry (SIMS) applications in SiGe EPI process control. Subjects, among others, are quantitative Ge and B co-dopant depth profiles because of their correlation to the bipolar performance figures such as Ft (cut-off frequency), Fmax (maximum oscillation frequency at unity gain) and BVceo (collector-emitter break down voltage) (1).

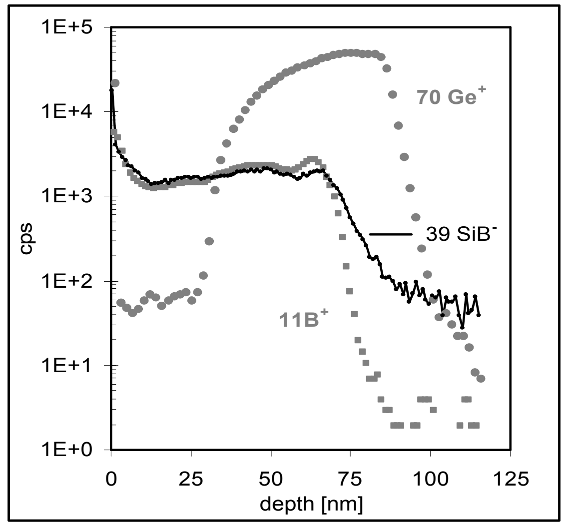
SIMS ANALYSIS OF SiGe WITH A LOW ENERGY NORMAL INCIDENCE OXYGEN BEAM

Quantitative Ge and B depth profiling is best done with a beam of low energy oxygen primary ions at normal incidence (2). These conditions are superior for high depth resolution profiling of the B co-doping. Easy quantification of boron is supported because the RSF (Relative Sensitivity Factor) is independent of the Ge concentration. In addition, under these conditions, the Ge concentration is directly proportional to the Ge secondary ion intensity over the entire concentration range of interest. No Ge concentration dependent calibration factors need to be applied to convert the measured Ge intensity to a Ge fraction, as is required when using Cs primary ions. According to the above it is sufficient for the concentration calibration to determine the amount of Ge at a single point of the depth profile. This is usually done at the top of the profile (Ge-plateau). Typically a RSF (Relative Sensitivity Factor) generated from a single concentration Ge standard is used (by ratioing the Ge signal to the bulk Si signal for concentration calibration).

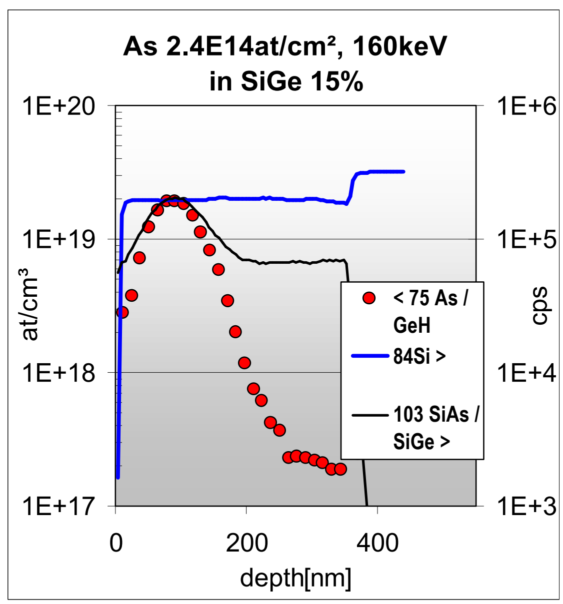


Under these analysis conditions the sample surface is fully oxidized and a surface potential change may occur during the course of depth profiling. This would make accurate and precise measurements impossible (fig. 1). To avoid such artefacts entirely an OCE (Optical





Conductivity Enhancement) device has been developed by Atomika (2). Absence of charging can easily be verified by monitoring the primary ion beam current measured directly at the sample. The linear scale of sample current in fig. 2 demonstrates the efficiency of charge compensation obtained.



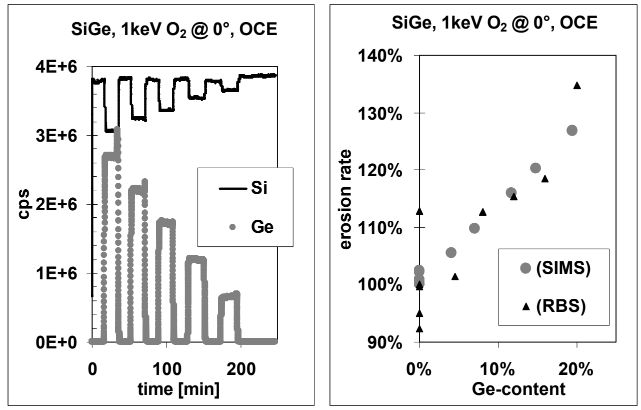
<u>Comparison with Cs protocol</u>

In contrast to Cs, the low energy oxygen protocol exhibits superior depth resolution and dynamic range (limit of detection) for B profiles, whereas the performance for germanium is very similar (fig. 3). On the other hand, Cs-primary ions are mandatory for the analysis of oxygen or arsenic.

Although a mass interference occurs between As^{75} and $Ge^{74}H$ it is possible to monitor the arsenic profile (fig. 4) with the Atomika quadrupole SIMS 4550. With Cs-bombardment the RSF values follow the Ge-concentration in a linear fashion (3), whereas the oxygen protocol at normal incidence shows constant RSF`s over a wide range of Ge-concentration (2).

Depth calibration

The erosion rate in strained silicon is linear with the Ge-content over a wide concentration range (fig. 5) (3, 4). As already demonstrated (5), this allows an easy and precise compensation and exact determination of the depth scale.
The actual depth z_i (at every point i of the profile) is simply the product of time t_i and relative erosion rate $v_{Ge}(F_{Ge\ i})$, $F_{Ge\ i}$: average Ge-content between surface and actual depth.



$$z_i = t_i \cdot v_{Ge}(F_{Ge\ i}) \cdot v_{bulk\ Si} \quad [1]$$

APPLICATION OF SIMS MEASUREMENTS IN PRODUCTION CONTROL

Process control data of both blank and patterned B doped SiGe wafers are presented in table 1. LP-CVD (low pressure chemical vapour deposition) has been used to grow the SiGe EPI on Si substrates. The layer structure consists of a near 12% SiGe layer deposited on the Si substrate, followed by a B doped, graded SiGe layer topped by a B doped Si cap. The wafers were analysed using an Atomika SIMS 4500, installed at TSMC using a 1keV oxygen beam at normal incidence.
The results in table I show that in this process control application the Ge concentration is measured with a precision of better than 0.5% atom. The repeatability of the B peak concentration is better than 5%. The B peak depth position precision is 0.2 nm.

same day relative Ge concentration		day to day		
test 1	test 2	relative Ge conc. (plateau)	relative B conc. (peak)	B-peak position [arbu]
96.65%	97.03%	95.5%	105.2%	14.31
101.35%		95.5%	102.4%	14.07
101.35%		91.0%	102.4%	14.17
101.35%		96.6%	95.8%	14.17
101.35%	97.03%	102.1%	102.4%	14.17
101.35%		102.1%	102.4%	14.17
101.35%		102.1%	102.4%	14.17
102.57%		102.1%	102.4%	14.17
102.57%	102.97%	108.8%	99.1%	14.17
101.35%		102.1%	89.6%	14.17
96.65%		102.1%	95.8%	14.17
101.35%				
101.35%	102.97%			
101.35%				
94.78%				
94.78%				
RSD 2.75%		RSD 4.87%	RSD 4.55%	RSD 0.38%

It is fair to conclude that SIMS, especially SIMS with normal incidence oxygen low energy primary ion beam in combination with OCE can reliably monitor an important step in the SiGe production process.

SUMMARY

SiGe quantification is a routine task for SIMS analysis. Normal incidence sputtering with Oxygen offers in combination with OCE a reliable, stable and precise protocol for the measurement of absolute Ge and B concentration in ultra thin layers of strained silicon.

The main advantages in contrast to Cs primary ions are better depth resolution and Ge-concentration independent RSF`s for B and Ge, which allows quantification for a wide range of Ge-concentration from a single reference standard.

Cs primary ions are required for oxygen or arsenic analysis.

ACKNOWLEDGEMENTS

The authors would like to thank Marc Dowsett, Univ. of Warwick for providing SiGe SIMS data. We would like to thank P.F. Chou, TSMC for providing SiGe SIMS data. We also thank Sanjay Patel, Material Analytical Service Inc, Phoenix for providing the arsenic implant in SiGe. We would also like to thank Norbert Loibl for SIMS measurements and Keith Baxter for carefully reviewing the manuscript.

REFERENCES

1. B.S. Meyerson, IBM J. Res. Develop. Vol. 44 No. 3 May 2000
2. M.Dowsett et al., Proceed. SIMS XIII, Applied Surface Science 203-204 (2003) 500
3. S Patel and J. Hunter, Proceed. SIMS IVX
4. U. Zastrow, J. Fölsch, A. Mück, K. Schmidt and L. Vescan, Proceed. SIMS X
5. H.-Ulrich Ehrke, Hans Maul, Proceed. SIMS IVX

This paper was published in Mater Sci in Semicond Proc 8 (2005) 111-114