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A Comparative Analysis of a Si/SiGe Heterojunction-Bipolar Transistors: APT, STEM-EDX and ToF-SIMS

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Due to the complexity of characterising compound semiconductors, including dopant distribution, multiple characterisation techniques are needed. Traditionally time-of-flight secondary ion mass spectroscopy (SIMS) has been the tool of choice for chemical profiling of semiconductor systems. Although it affords a lower limit of detection, it is constrained by a low lateral resolution, making large test zones necessary (several hundred microns). More recently, energy dispersive X-ray - scanning transmission electron microscopy (STEM-EDX) allows local specimen preparation and can generate 2D concentration maps. But due to low sensitivity it cannot quantify light elements (i.e. boron). Because of size effects, large test zones are not always representative of the local chemistry in the device and a complete picture is therefore unavailable. Atom probe tomography (APT) is an analytical 3D microscopy technique which maps the position of atoms in a material allowing composition measurements of a small selected volume. With a sub-nanometre spatial resolution, analysis of localised structures is possible and all elements are detected with the same probability. Initially dedicated to metals, semiconductor applications have escalated in recent years [1].

In this work a Si/SiGe heterojunction bipolar transistor for 55nm BiCMOS (bipolar – complementary metal oxide semiconductor) technology development has been studied. The basic structure is made up of a silicon emitter, silicon-germanium base and silicon collector [Fig. 1(a)]. The base follows a germanium concentration gradient. Both emitter and collector are arsenic doped, the base containing boron. The stack was submitted to a spike anneal and preparation halted at the silicide step. The wafer was then analysed using the three techniques cited above. APT and EDX measurements specimens were prepared by focused ion beam (FIB). For the APT, backside preparation was privileged, due to a low analysis yield when using standard preparation geometry.

In the case of APT and STEM-EDX, measurements were made on both the test zone [Fig. 1(b)] and the final device [Fig.1(c)], whereas ToF-SIMS measurements have been made only in the test zones. By using APT is has been possible to validate the information from the other techniques. Moreover it gives the 3D distribution of boron atoms in the device. Due to the feeble concentration ($5{\cdot}10E^{19}$ at/cm^3) in the silicon-germanium base, although the boron signals are visible, the dopant distribution is not clear due to back-ground noise. To increase the signal-to-noise ratio, multiple event analysis of the APT data has been used [2]. Previously used for carbon detection, here we show it is also possible to apply this method to boron [Fig.2]. Once the data has been processed the dopant position in the structure is made clear. A slight shift in the position of the boron peak is noted relative to the test structure.

Comparison of the three techniques shows a similar shape. Comparison of STEM-EDX and APT shows a good agreement in the shape of the germanium profile, with a higher concentration and sharper profile in the device noted in both cases [Fig.3(a-b)]. Also, a small segregation of arsenic at the interface between the emitter and the base only in the device is made apparent. This is attributed to an incomplete cleaning of the interface before deposition of the emitter, resulting in a small oxide layer and accumulation of dopant [3] that must be avoided.

In conclusion, APT has allowed a direct comparison between test zones and real device. It is the only technique which allows direct detection of boron distribution in the later. Due to the low dopant concentration multiple-event analysis was used to increase the signal-to-noise ratio. Several substantial differences were noted between the test zones and device.

References

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[4] This study has been performed at the nanocharacterisation platform (PFNC) of the Minatec Campus and ST Microelectonics, Crolles. The author would like to acknowledge a CIFRE (ANRT) scholarship

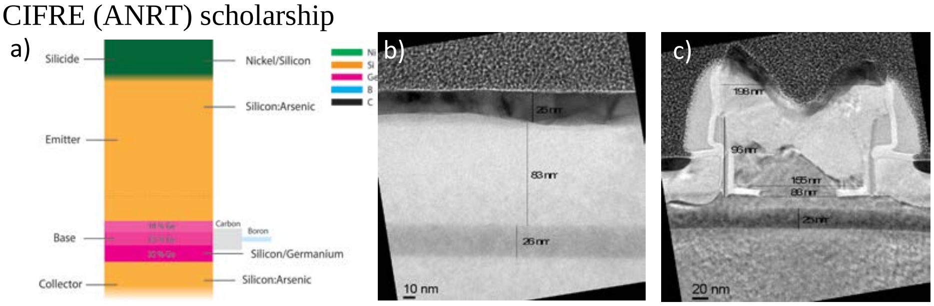

Figure1. Schematic representation of the gate stack analysed (a) and TEM images of both test zone (b) and device (c).

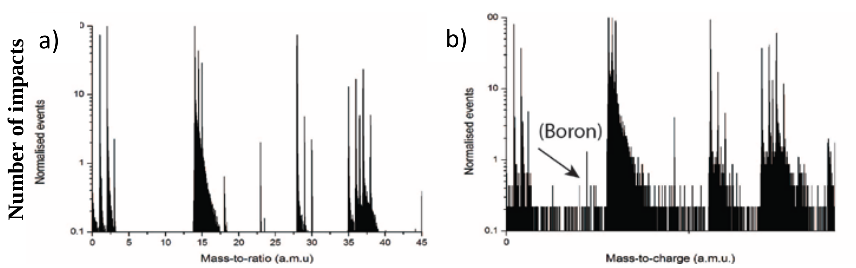

Figure2. Normalised mass-to-charge spectrum with all impacts (a) and only multiples (b).

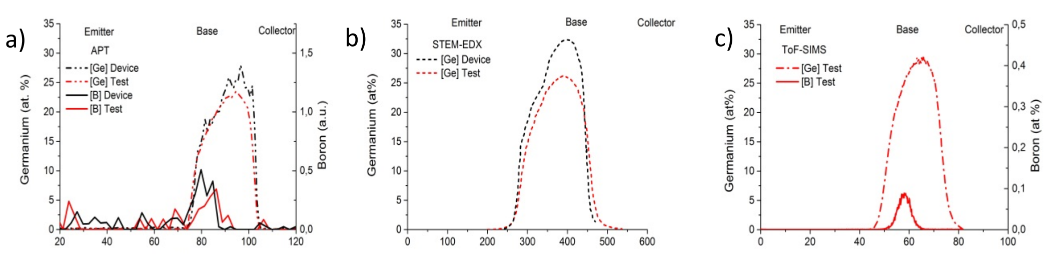

Figure3. Comparison of germanium (dashed lines) and boron (solid) in device (black) and test zones (red) by APT (a), STEM-EDX (b) and ToF-SIMS (c).