Structural characterisation of ion-implanted strained silicon

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The production of low resistance ultra-shallow junctions for e.g. source/drain extensions using low energy ion-implantation will be required for future CMOS devices. This architecture will require implants which demonstrate high electrical activation and nm range depth profiles. We investigate the properties of Sb implants in tensile strained silicon due to their potential to satisfy these criteria and the mobility enhancements associated with tensile strained silicon. Low energy (in this case 2keV) implants coupled with Sb’s large atomic radius are capable of providing 10 nm implant depths. In addition to this, Sb demonstrates higher electrical activation in the presence of tensile strain, when compared with the more traditional n-type dopant, As. Graded Si₁₋ₓGeₓ virtual substrates (VS) with 0.1≤x≤0.3 were used as template substrates upon which tensile Si layers were grown.

Prior to implantation the quality of the strained layer and SiGe buffer is assessed using synchrotron X-ray topography (SXRT) and high-resolution X-ray diffraction (HR-XRD). By way of example Fig. 1 shows a 117 large area back reflection topograph of the strained silicon sample grown on the Si₀.₇₇Ge₀.₂₃ substrate. The entire SiGe buffer layer (~3 µm) is imaged here as the X-ray penetration depth (tₚ) for this 117 reflection is 15.8 µm. Two major features of note are observed in the topograph. Firstly, the cross-hatched pattern running along two perpendicular 110 directions. This is an image of the array of misfit dislocations (MD) common in strained silicon samples [1]. These MDs provide strain relaxation in the VS, necessary for stable strained silicon epilayer growth. This strain relaxation is further confirmed by HR-XRD reciprocal space map (RSM) data (not shown). These misfit dislocations are observed in all samples. The second feature in the topograph is the presence of a lighter intensity, overlapping diffraction image, labelled “S” in Fig. 1. This displaced image indicates that a region of the SiGe buffer is tilted with respect to the substrate, this tilting results in a different Bragg angle for this region and therefore a slight displacement on the recording film. This tilt is also confirmed by HR-XRD RSM data.
Fig. 2 shows a large area transmission topograph of the strained silicon sample grown on a 30% Ge virtual substrate. The large “box-like” structures bounded by misfit dislocations are indicative of stacking faults (SF) [2]. The clarity of these X-ray topographic SF images suggests that the crossing stacking faults are not interfering with each other. We speculate that this may be a result of the graded nature of the SiGe buffer, which can confine MD arrays and SFs to individually grown terraces and this can allow SFs to pass under and over each other. The white “boxes” which can be seen in Fig. 2 may be a result of an even number of SFs with symmetrically opposite Burgers vectors passing through the imaged region. In this case the two diffracted X-ray wave-fronts could undergo phase-shifts in opposite directions resulting in no net change. For example, four stacking faults on top of each other, bordered by 60° misfit dislocations having the same Burgers vectors, may produce a white contrast similar to that imaged in Fig. 2.

In conclusion, SXRT topographs reveal the presence of misfit dislocations in all samples confirming the presence of a relaxed VS for all Ge concentrations. The emergence of lattice tilts at VS Ge contents above ~23% have been detected in both SXRT and HR-XRD measurements, and this may be of technological concern as this tilt continues into the strained silicon layer (based on HR-XRD evidence). At a VS Ge content of ~30%, stacking faults have been imaged using SXRT. These appear to be confined by the misfit dislocations in the SiGe VS. However, if these were to reach the strained silicon layer they could cause major problems for any device structure built on this material and future studies will focus on their thermal stability.

References