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TEM characterization of GaSb grown on single crystal offcut Silicon (001)

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Compound III-V semiconductors have received much attention in recent years for photonic applications. One such III-V semiconductor system of current interest is GaSb in heterostructures with GaAs and InSb: this has potential applications in infrared detectors [1]. Growing these materials epitaxially on silicon promises to enable single chip integration of photonic devices with logic devices. For this study, epitaxial GaSb films were grown on offcut single crystal Si substrates using Molecular Beam Epitaxy (MBE). Details of the growth are described elsewhere [2].

Samples were prepared for electron microscopy using an FEI Nova 200 Dual Beam FIB. The sample was held at liquid nitrogen temperature during final thinning to reduce bending, crystal damage, and chemical reaction with the Ga ions. This was found to dramatically increase the quality of thin sections as compared to final thinning at room temperature. Scanning transmission electron microscopy (STEM) was carried out using a probe-corrected JEOL ARM200F STEM equipped with a cold field emission gun operated at 200 kV, equipped with a Gatan GIF Quantum ER spectrometer. Spectrum images were acquired in DualEELS mode with a 300 V offset between the low loss and high loss regions and with a probe convergence semiangle of 29 mrad and a spectrometer acceptance semiangle of 36 mrad.

Figure 1a is a low magnification TEM image of the GaSb/AlSb/Si interface. Whilst there is a high density of dislocations at the AlSb/Si interface and within the AlSb layer, most are confined within this layer and do not propagate into the GaSb. The result is that low defect density GaSb is readily produced. Figure 1c is a graph showing defect density as a function of film thickness, showing a close agreement between measurements by diffraction contrast TEM and MAADF STEM. This shows an effective buffer layer growth strategy reducing defect density by at least two orders of magnitude in the first micron of growth; further reductions could be achieved by the use of further superlattice structures.

Figure 1b is a HAADF-STEM image of the interface taken in the [110] direction. This clearly shows the 5° miscut of the Si-AlSb interface from (001). There is also a slight rotation of $< 1^{\circ}$ between the [001] directions in the Si and the AlSb. The use of offcut (001) silicon has been shown to be an effective growth strategy for reducing the presence of antiphase domains (APDs) during the growth of III-V crystals on Si and Ge [4]. This systematic rotation of the AlSb film suggests some of the misfit dislocations at the interface to the offcut silicon may have some out of plane components in their Burgers vectors. There are also indications in some HAADF images that the AlSb forms via an island growth mechanism, which then gradually coalesce, but leave the AlSb-GaSb interface a little rough

DualEELS spectrum images were then recorded across this interface. These were then pre-processed for quantification by energy alignment, and principal component analysis as described elsewhere [3]. The spectrum images were then quantified using the “Elemental Analysis” plugin in Digital Micrograph with some renormalisation of the data based on using the Al content as a proxy for the AlSb content and the Ga content as a proxy for the GaSb content. Figure 1d shows a line profile through the interface area. It is noticeable that the AlSb/GaSb interface is significantly less sharp than the Si/AlSb interface. The apparent non-sharpness on the Si/AlSb interface is probably mainly from beam broadening inside the specimen. The additional width of the AlSb/GaSb interface is probably from roughness of the top of the AlSb islands, but the GaSb still approaches a stoichiometric composition within a few nm. It is thus demonstrated that high quality epitaxial GaSb can be grown on Si using this new method.

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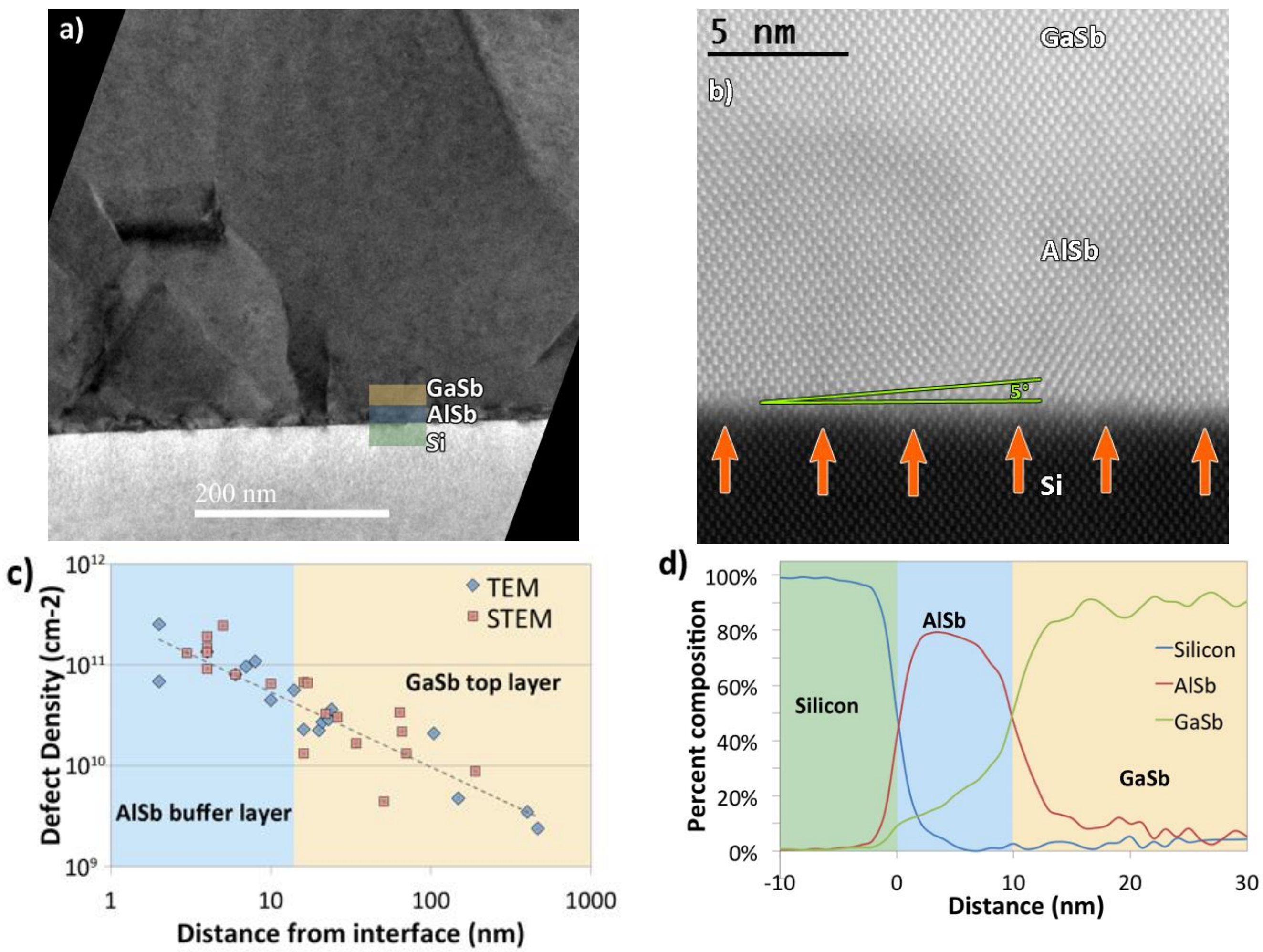

Figure 1. a) Low magnification BF-TEM image of the GaSb/AlSb/Si interface showing dislocations. b) Atomic resolution HAADF STEM image of the interface region showing the miscut and the misfit dislocations. c) Defect density as a function of distance from interface, for both TEM and STEM measurements. d) Chemical composition line profile across the GaSb/AlSb/Si heterostructure.

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