Title: Surface Morphology of GaAs and GaSb (111)A Grown by Molecular Beam Epitaxy

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For equivalent oxide thicknesses (EOTs) below 1 nm, the higher density of states of Si will provide more drive current per gate width than higher injection velocity III–V materials, e.g., $In_xGa_{1-x}As$, InP, etc. By utilizing the effective mass anisotropy of the satellite X– and L–valleys of III–V materials, it may be possible to have simultaneously large density of states and high injection velocities. Rotating the wafer to the (111) orientation, the maximum anisotropy between the longitudinal and transvers effective mass of one of the L–valleys can be harnessed to either allow for several L–states or a γ– and an L– state to be aligned.[1] Atomically smooth heterointerfaces grown on the (111) are required as the quantum–well thicknesses required to align the first γ– and L–eigenstate are approximately 1–2 nm.[2] The extremely low–energy of formation of inverted domains or stacking faults due to the 60° rotational symmetry of the (111) plane hinders the growth of atomically flat, defect–free crystals and heterojunctions. Particular care must be taken to encourage bonding and/or growth along step edges in order to preclude the formation of stacking faults.[3] We have used previously reported growth conditions[4] for smoothing of GaAs grown on GaAs (111)A to improve surface morphology of GaAs growth on vicinal GaAs (111)A substrates and heteroepitaxial GaSb on on–axis GaAs (111)A.

Samples were grown on semi–insulating GaAs (111)A substrates. Substrates were nominally on–axis (± 0.2 °), 2°±0.5° off–axis towards $\left(100\right)$, and 2°±0.5 off–axis towards $\left(\bar{1}\bar{1}2\right)$. All GaAs samples were grown at ~ 600 °C (temperature measured by pyrometer) while all GaSb samples were grown at ~ 535 °C. Increasing the V:III beam equivalent pressure (BEP) ratio during growth helped improve the surface morphology of both the GaAs and GaSb. Optimized GaAs and GaSb samples were grown with V:III BEP ratios of ~70 and 15, respectively. Increasing the ratio of As_4 to As_2 and Sb_4 to Sb_2 by decreasing the As and Sb cracking zones from 850 to 600 °C and 900 °C to 760 °C, respectively, improved surface morphology of both on–axis GaAs and on–axis GaSb. In the case of on–axis GaAs, decreasing the cracking zone temperature decreased stacking fault densities from 1.24 to 0.78×10^{8} cm^{-2}, as evidenced by the reduction of hexagonal or triangular surface features in AFM images. Surface terminations of stacking faults, as seen by AFM, were eliminated entirely by introducing a 15 min. 640 °C post–growth anneal. Surface morphologies from optimized growths showed 0.5–1 μm wide steps with RMS roughnesses of 0.054 nm (~0.5 μm^2). GaAs grown on vicinal substrates showed stacking–fault–free morphologies without post–growth annealing. Samples off–cut to $\left(100\right)$ showed bowed and/or kinked step edges with large surface mounds at the apex of the kinks. These samples had 5×5 μm^2 RMS roughnesses of ~ 0.63 nm; samples off–cut to $\left(\bar{1}\bar{1}2\right)$ showed kink–free step edges with surface roughness of ~ 0.24 nm. Increasing the Sb_4 to Sb_2 ratio and post–growth annealing improved the morphology of GaSb grown on optimized on–axis GaAs (111)A; however, while the density of stacking faults decreased, the triangular surface features indicative of stacking faults were not entirely eliminated. Additionally, large and ~ 50 nm deep surface pits were reduced in lateral (~ from 1–2 to 0.5–1 μm) dimension, but they were not entirely eliminated using these techniques.

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