GaAsGe Ternary Alloys Studied by Cross-sectional Scanning Tunneling Microscopy

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Similarly to Si, Ge exhibit an amphoteric behavior when used as dopant in GaAs, i.e. it can substitute both Ga and As atoms [1]. In molecular-beam-epitaxy-(MBE)-grown GaAsGe, at low doping concentration, Ge preferentially substitute either Ga or As atoms depending on the growth condition, i.e. the As_2 to Ga ratio in the molecular beams [2]. However, at high doping concentration, Ge is expected to substitute Ga and As atom to the same extent [1],[3]. A GaAs/GaAs:Ge structure comprising of seven 50 nm-thick GaAs:Ge layers with decreasing Ge concentration (5% - 0.01% Ge) grown by MBE was analyzed by cross-sectional scanning tunneling microscopy (X-STM). All the layers aside the 5% Ge one were imaged by X-STM. In filled-states X-STM images, the Ge atoms appear as bright features with different shapes depending on where they are located in the GaAs lattice, i.e. whether they are sitting on a Ga or As site and at what depth below the cleaved surface (0th layer).
Several features are identified in the layer at lower Ge concentration (0.01% Ge, L7). Of these features we assume that some correspond to a Ge atom sitting on a Ga-site located at different depth below the cleaved surface. Similarly, some other features are related Ge atoms on As-sites located at different depth below the surface. These different features have been classified and related to the Ge position below the cleaved surface through symmetry considerations taking into account the contribution of the different surface states to the X-STM images, namely the A_4 and A_5 state located in the valence band and the C_3 and C_4 located in the conduction band [4], [5]. Other observed features are given by Ge located deeper below the cleaved surface (5th layer or lower), interstitial atoms and vacancies that can be either intrinsic or caused by the cleave of the sample.
Additionally, we calculated the Ge concentration in the measured layers and we compared it to the nominal concentration. We found that for most the layers, the experimental concentration is comparable to the nominal one.
With this study, we aim to gain further insight into the preferential incorporation of Ge in GaAs, which is difficult to determine with other techniques.

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Supplementary Pages

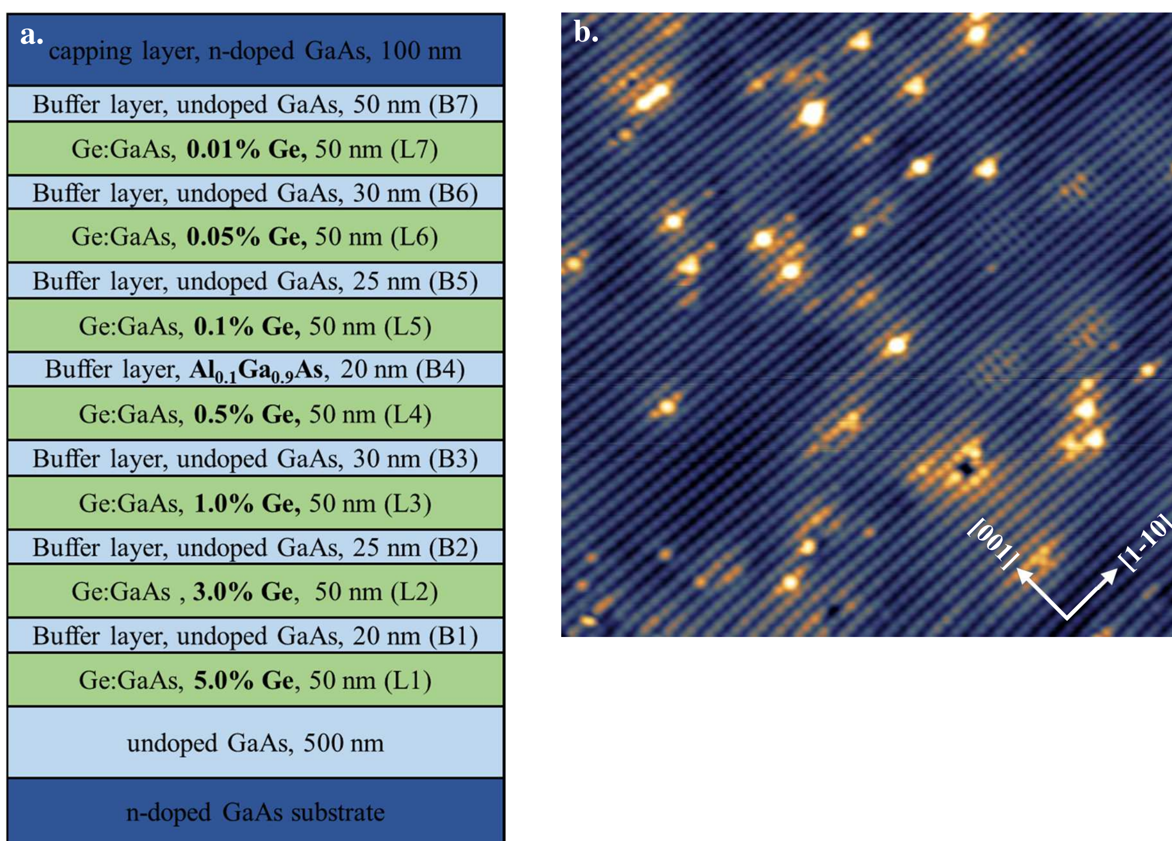

Figure 1. **a.** Schematic structure of the sample. **b.** 25.0 × 25.0 nm^2 high resolution filled-state X-STM image of L4 (0.5% Ge), V_b = −3.24 V, I_t = 50 pA, 77K.

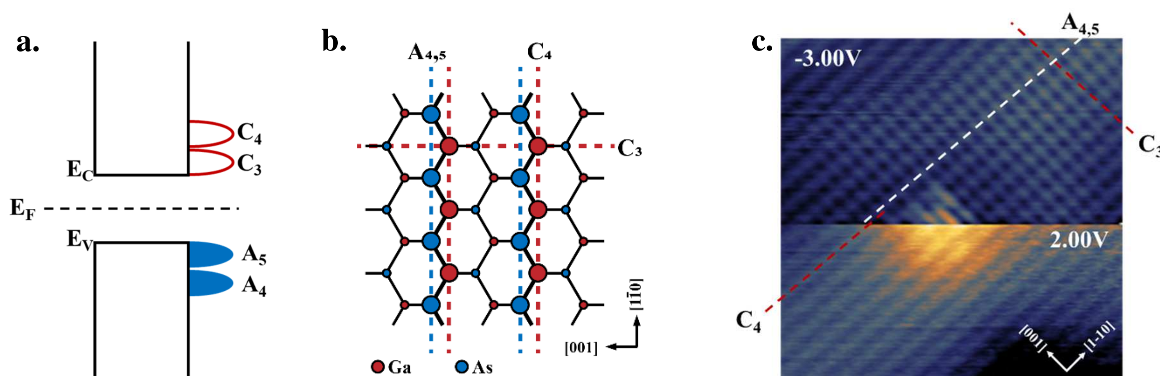

Figure 2. **a.** Schematic energy diagram of the surface states of an undoped III-V semiconductor with no band bending; E_c and E_v indicate the conduction band and the valence band energies, respectively, while E_F indicates the Fermi level. **b.** Schematic top view of the (110) GaAs surface. **c.** 10.0 × 10.0 nm^2 high resolution X-STM image of one of the Ge-related features identified, V_b = 2.00 V (bottom) and V_b = -3.00 V (top), I_t = 50 pA, 77K. The dashed lines indicate the contribution of the different surface states to the corrugation in the X-STM image.