Title: Selective Area Regrowth of Self-Aligned, Low-Resistance Ohmic Contacts on InGaAs

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With each technology node, transistor device active areas decrease by approximately 1:4; to increase device performance by maintaining absolute resistance, contact resistivities must decrease by 1:4. The high dopant concentrations achievable by MBE provide a method for creating low-resistance ohmic contacts; however, line-of-sight deposition and low desorption of atomic species may hinder the self-alignment of regrowth. Precise control over growth conditions makes MBE a suitable technique for creating self-aligned, low resistance, regrown ohmic contacts to InGaAs. The addition of Sb as a surfactant helped smooth the otherwise large surface features believed to be the result of threading dislocations. However, the low V:III ratio during regrowth induces uncontrolled alloying of layers beneath the regrowth as evidenced by parallel and cross-sectional atom probe tomography (APT).

Samples were grown by solid source MBE lattice matched to semi-insulating InP with layer structure as follows from the substrate: 400 nm InAlAs, 3 nm of Si-doped 2 and 3×10^{19} cm^{-3} InAlAs, and 25 and 15 nm of InGaAs, respectively. 300 nm of SiO_2 and 20 nm of Cr were deposited by PECVD and e-beam evaporation. A combination of electron beam and photolithography followed by ICP dry etching was used to define dummy spacer pillars. Oxidation and oxide removal of exposed InGaAs was done with UV ozone and a 10 H_2O:1 HCL dip. Samples were heated to 420 °C and treated with thermally cracked hydrogen ($\approx 1\times10^{-6}$ Torr) for 40 minutes prior to regrowth. 70 nm of 5×10^{19} cm^{-3} Si-doped InAs was regrown on the exposed InGaAs regions with quasi-migration enhance epitaxy (MEE) at 500 °C with V:III beam equivalent pressure (BEP) ratios of approximately 4.0, 5.6, and 8.0. An additional InAsSb sample with an As:In BEP ratio of 3.94 was grown with an Sn:In BEP ratio of approximately 1.16. After regrowth, electrical shorts over the dummy pillar were removed, and samples were metalized with lifted-off e-beam evaporated Ti/Pd/Au and mesa isolated. Contact resistances were extracted by transmission line measurements (TLM).

RHEED images during regrowth showed 4x2 surface reconstructions for regrowths with V:III BEP ratios of 4.0 and 5.6 indicating an In-rich surface reconstruction. SEM of regrowths at V:III BEP ratios of 4.0 and 5.6 showed no faceting and fill-in to the dummy pillar edge. AFM showed roughened surfaces with large cat-eye features possibly due to high Si incorporation and lattice mismatch between InGaAs and InAs. The sample grown with Sb did not show evidence of any cat-eye features, and had an optically specular surface reflection; however, it did have a larger root mean square (RMS) roughness. Parallel and cross-sectional APT of an Sb-free sample revealed a position-dependent alloying of the InGaAs layer with the InAs regrowth carrying some of the Ga along with it normal to the regrowth interface. The effect was evident throughout the sample though less pronounced far from the masked regions. Of the samples regrown without Sb, V:III ratios during regrowth had no effect on contact resistance with the 25 and 15 nm thick-channel samples having contact resistances of 190 and 105 Ω μm, respectively. Metal-semiconductor contact resistances were 2.1 Ω μm.

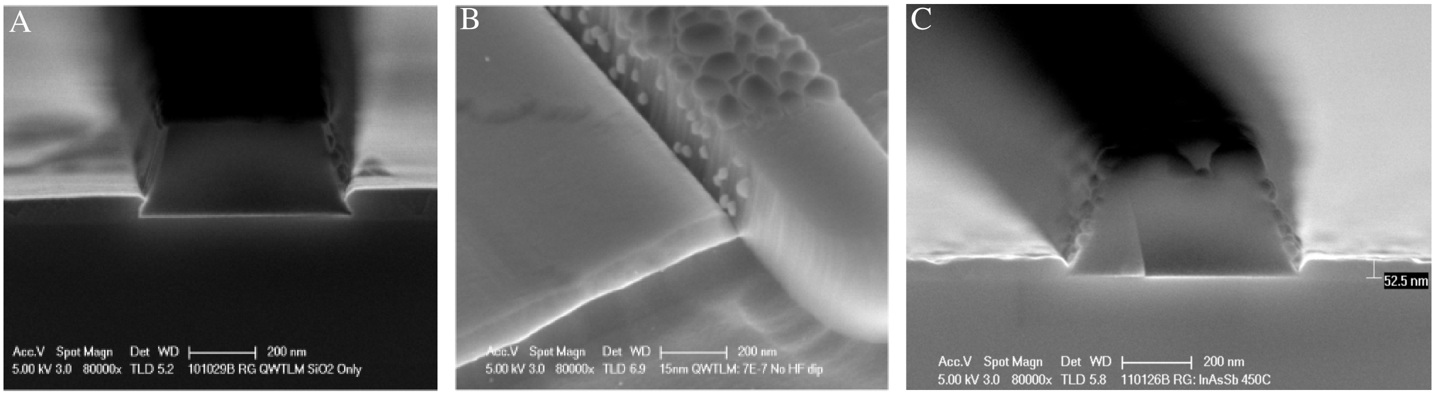

Figure 1: SEMs of regrowth with As:III ratio of 4.0 (A), 5.6 (B), and regrowth with Sb (C).

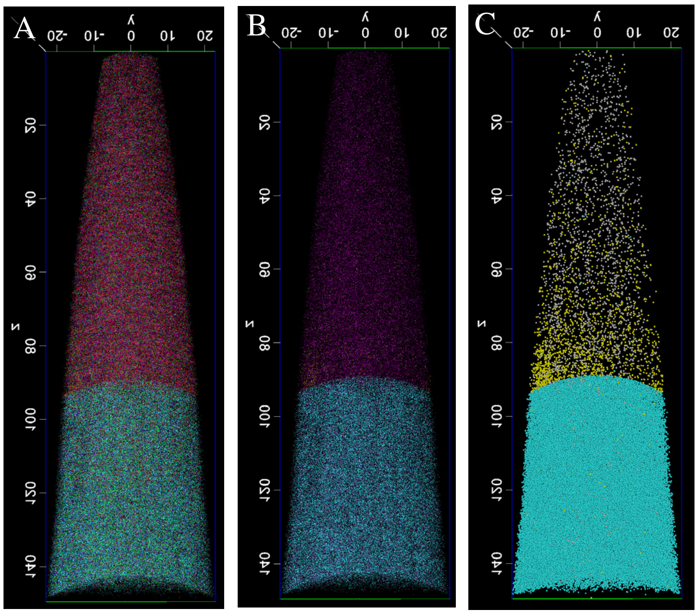

Figure 2: Parallel LEAP reconstructions of regrowth with As (pink), In (purple), Ga (yellow), Al (blue), and Si (grey). All atoms (A), As removed (B), and In and As removed (C).

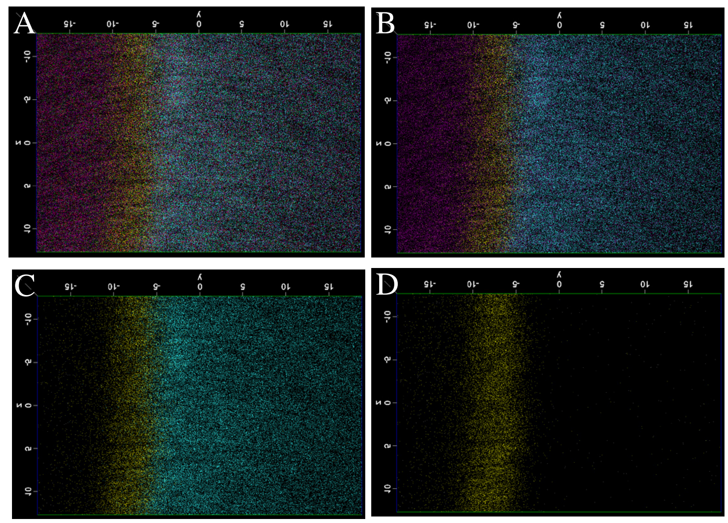

Figure 3: Cross-sectional LEAP reconstructions of regrowth with As (pink), In (purple), Ga (yellow), Al (blue), and Si (grey). All atoms (A), As removed (B), In and As removed (C), and Ga only (D).

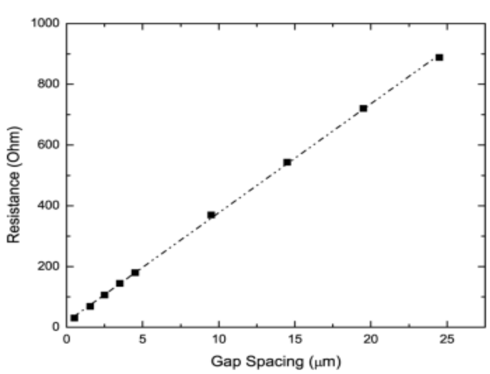

Figure 4: TLM measurements of 70 nm InAs regrowth on a 25 nm thick InGaAs channel, 25 μm wide regrowth grown with a V:III ratio of 4.0.

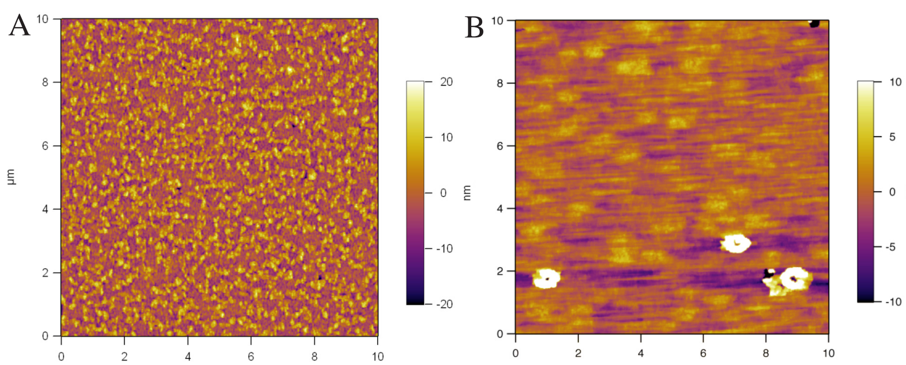

Figure 5: AFM topographs of (A) 50 nm of InAsSb regowth on InGaAs and (B) 20 nm of InAs regrowth on InGaAs.