Title: Contact Resistance Limits of Ohmic Contacts to Thin Semiconductor Channels
Authors: Law, J. J. M.; Carter, A. D.; Lee, S.; Gossard, A. C., Rodwell, M. J. W.
ECE and Materials Departments, University of California, Santa Barbara, CA 93106

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. Extraction of contact resistance from a TLM-geometry on a transistor-like layer structure will be hindered by the 2-D state density limited conductance that imposes a maximum conductivity on any gateless transistor structure. A homoepitaxial regrowth of n^+ InAs on a 15 nm InAs channel gives a single-sided contact resistance of 65 $\Omega\,\mu$m while a graded regrowth from n^+ InGaAs to n^+ InAs on a thick n^+ InGaAs channel gives low contact resistance of 12 $\Omega\,\mu$m.

Samples were grown by solid source MBE metamorphic on GaAs and lattice matched to semi-insulating InP with active layer structure of 15 nm of InAs and 150 nm n^+ InGaAs and barriers of $Al_{0.76}Ga_{0.24}Sb$ and InAlAs, respectively. 300 nm of SiO_2 was deposited by PECVD. 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. At base pressures of $< 1\times10^{-9}$, samples were heated to 420 °C and treated with thermally cracked hydrogen ($\approx 1\times10^{-6}$ Torr) for 40 minutes prior to regrowth. Approximately 50 nm of 5×10^{19} cm^{-3} Si-doped regrowth was deposited in the areas not covered by SiO_2. The regrowth was homoepitaxial InAs on the InAs channel material and a grade from InGaAs to InAs on the InGaAs channel, and was produced by employing quasi-migration enhance epitaxy (MEE) at 500 °C. 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 TLM.

RHEED during regrowth showed a 4x2 surface reconstruction for the InAs regrowth on InAs channel while the graded regrowth on InGaAs showed an alternating 4x2 (group III and V shutters open) to 2x4 (group V shutter open) transition. SEMs of all regrowths showed fill-in to the dummy pillar edge. The contact resistance between the InAs regrowth and InAs channel material was 65 $\Omega\,\mu$m (130 $\Omega\,\mu$m for the total contact resistance between both contacts) and the contact resistance between the InAs regrowth and metal was ~2.9 Ω μm. The contact resistance between the graded regrowth and the InGaAs channel was ~ 12.4 $\Omega\,\mu$m, and the contact resistance between the graded regrowth and the metal was ~ 3.0 $\Omega\,\mu$m. A 2-D generalization of Landauer's state limited conductance can be written as $G = \frac{q^2 2^{1/2}}{\hbar \pi^{3/2}} \sum_i n_{s,i}^{1/2}$, where $n_{s,I}$ is the sheet carrier density in each mode/valley.[1] The measured resistance between the two regrown contacts on a 15 nm InAs channel (130 Ω μm) was close to the two-dimensional state limited resistance for this structure of 80 Ω μm. All TLM measurements of contact resistance on thin channels regardless of material will be limited by the above expression, thus setting a lower bound on the measurable contact resistance of such a structure.

[1] Landauer, R. *IBM J. Res. Dev.* **1**, 223 (1957).

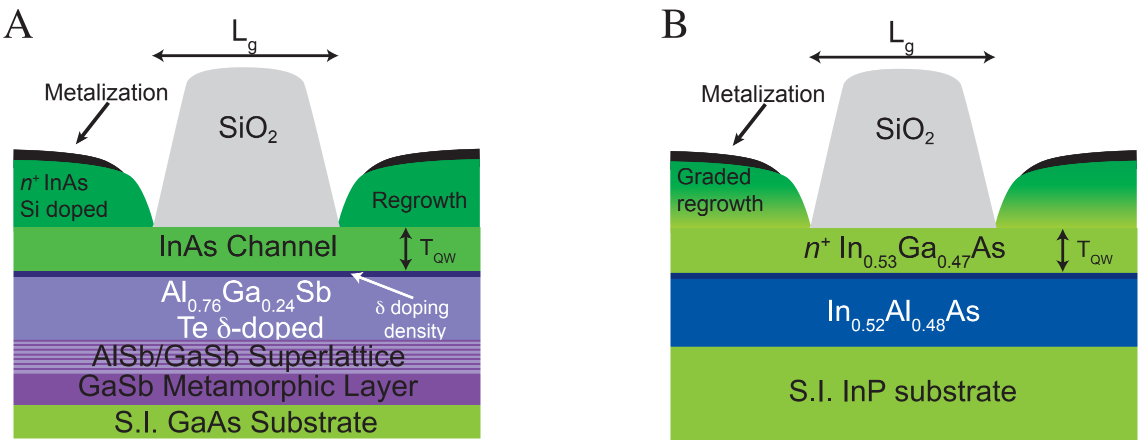

Figure 1: Illustration of (A) Homoepitaxial InAs regrowth on InAs channel and (B) graded InGaAs to InAs regrowth on InGaAs channel.

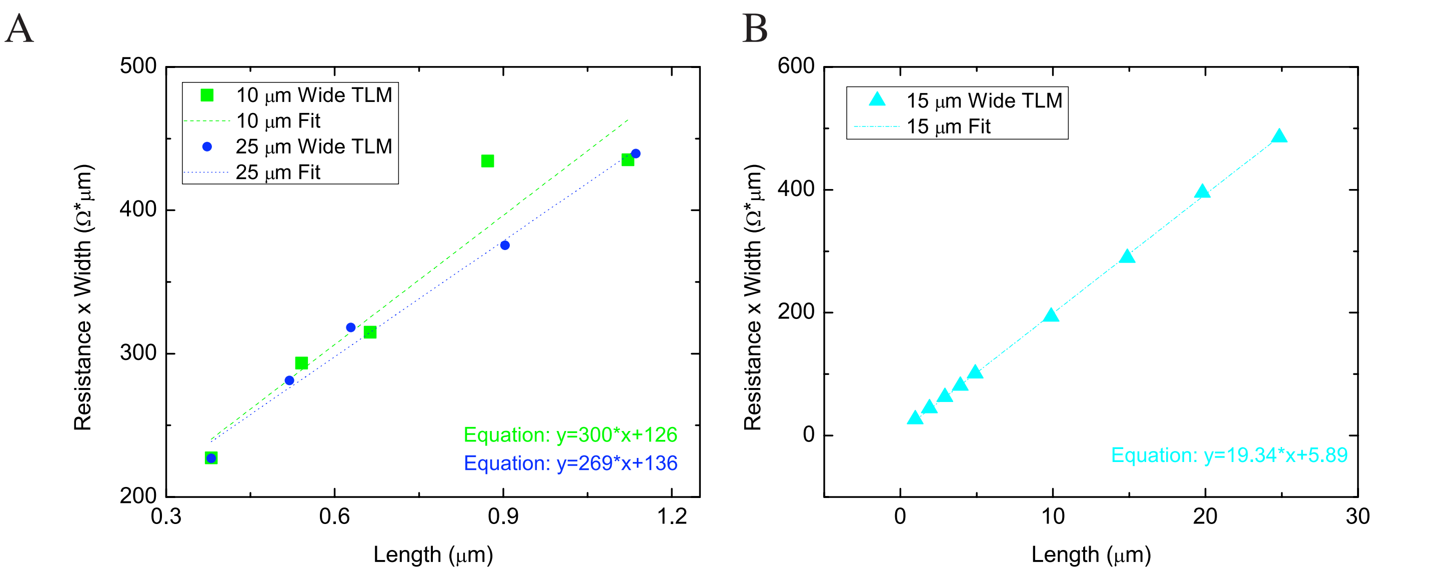

Figure 2: Resistance versus gap spacing for (A) 10 and 25 μm wide TLMs of InAs regrowth to InAs channel and (B) 15 μm wide TLM of metal to InAs regrowth.

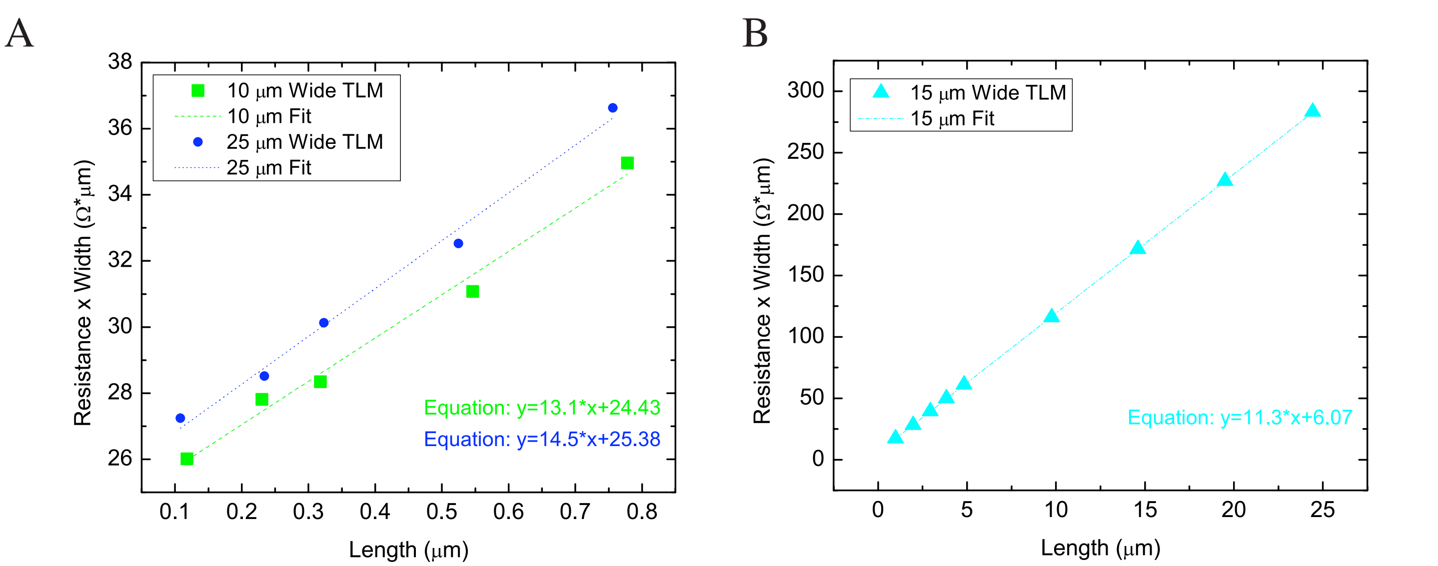

Figure 3: Resistance versus gap spacing for (A) 10 and 25 μm wide TLMs of graded regrowth to InGaAs channel and (B) 15 μm wide TLM of metal to graded regrowth.