Selective Area Regrowth of Self-Algined, Low-Resistance, Ohmic Contact on $In_{0.53}Ga_{0.47}As$

J.J.M.Law[†,*], A.D.Carter[†], G.B.Burek[†], B.Thibeault[†], M.J.W.Rodwell[†], A.C.Gossard[†,*]

[*]Department of Electrical & Computer Engineering, [†]Materials Department, Univserity of California, Santa Barbara

Introduction

- III-V transistors are being developed for use in large scale integrated circuits[1]
- Scaling requirements dictate that as device areas scale by 1:4, absolute resistance must remain constant, requiring a 1:4 decrease in resistivities
- MBE can be used to regrow low-resistance, highly doped ohmic contact to InGaAs with careful control of growth conditions[2]

$$I_{D,v} = W_g C_{effective} v_{sat} \left(V_{gs} - V_{th}\right)$$

$$g_m = \frac{dI_{D,v}}{dV_{gs}} = W_g C_{effective} v_{sat}$$

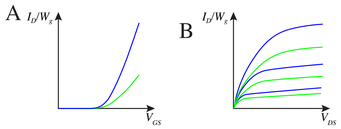

Figure 1: I_D vs (A) V_{GS} and (B) V_{DS} with varying V_{GS} and blue lines showing effect of larger v_{SAT}.

FET Parameters:	Change:
Gate length	1:2
Current density (mA/μm) and g_m (mS/μm)	2:1
Channel 2DEG electron density	2:1
Electron mass in transport direction	constant
Gate-channel capacitance density	2:1
Dielectric equivalent thickness	1:2
Channel thickness	1:2
Channel density of states	2:1
Source and drain contact resistivities	1:4

Table 1: Table of scaling laws for FETs under constant voltage requirements required to double transistor bandwidth.

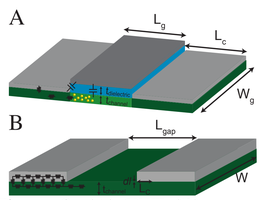

Figure 2: (A) FET (B) contact measurement structure.

- TLM measurements of total resistance versus gap spacing allow extraction of contact resistance from the formula below:

$$R = 2\frac{\rho_1 \cdot dl}{W \cdot L_c} + \frac{\rho_2 \cdot L_{gap}}{W \cdot t_{channel}} R = 2\frac{\rho_{contact}}{W} + \frac{R_{sheet} \cdot L_{gap}}{W} \text{ where } \rho_{contact} = \frac{\rho_1 \cdot dl}{L_c} \text{ and } R_{sheet} = \frac{\rho_2}{t_{channel}}$$

Experiment

- Samples were growth by solid source MBE lattice matched to semi-insulating InP
- Layer structure designed to give channel charge with pinning 0.2 eV below E_c:
  - 15 nm and 25 nm $In_{0.53}Ga_{0.47}As$, 3 nm $In_{0.52}Al_{0.48}As$ Si-doped 3×10^{19} and 2×10^{19} cm^{-3}, respectively, and 400 nm $In_{0.52}Al_{0.48}As$
- Dummy pillar definition:
  - 300 nm PECVD SiO_2, optical lithography, SF_6 and Ar ICP dry etch
- Regrowth Surface Preparation:
  - UV ozone oxidation, 10 H_2O:1 HCL dip, 3 hour 200 °C and 1 hour 325 °C, 40 min. H-clean at 420 °C at 1×10^{-6} Torr
- Quasi-migration enhanced epitaxy (MEE) regrowth
  - 500 °C, V:III BEP ratio of 4.0, 5.6, and 8.0
  - Additional regrowth (As:In BEP of 3.94) with Sb:In BEP ratio of 1.16
- Mesa isolation and Ti/Pd/Au metalization

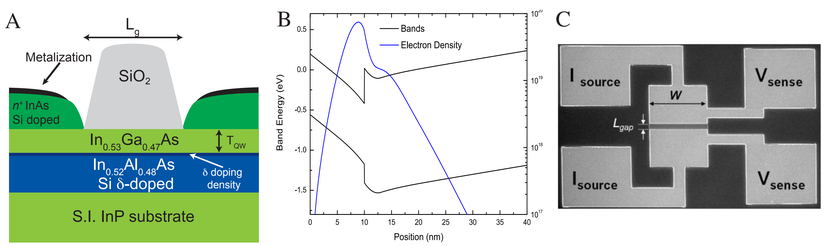

Figure 3: Sample structure (A), band structure of 25 nm thick InGaAs channel (B), TLM measurement structure (C).

Results

- Good regrowth morphology (faceting and fill-in near dielectric mask) is dependent on V:III ratio (Figure 4 and 5)
- Larger V:III ratios show more faceting and poor gate-edge fill-in (not shown)
- Addition of Sb helps smooth large surface terminations of line defects (Figure 4 (C) and Figure 5 (B))

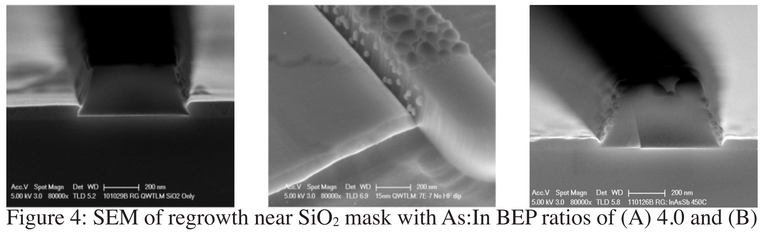

Figure 4: SEM of regrowth near SiO_2 mask with As:In BEP ratios of (A) 4.0 and (B) 5.6. Addition of Sb (C) helps smooth large surface features and does not affect fill-in with As:In BEP ratio of 3.94 and Sb:In BEP ratio of 1.16.

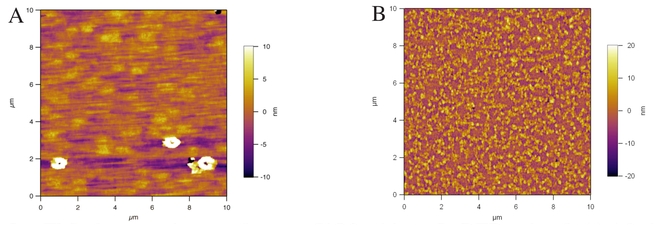

Figure 5: AFM of regrowth away from an SiO2 with As:In BEP ratio of (A) 4.0 showing large cat-eye defects and (B) InAsSb regrowth with As:In of 3.94 and Sb:In of 1.16 showing larger RMS surface roughness but with smoothed surface defects.

- Atom probe tomography (APT) performed on samples near an SiO_2 mask and heterointerfaces parallel to was the evaporation direction
- Ga from InGaAs layer has been dissolved and distributed throughout regrowth as seen in Figure 6

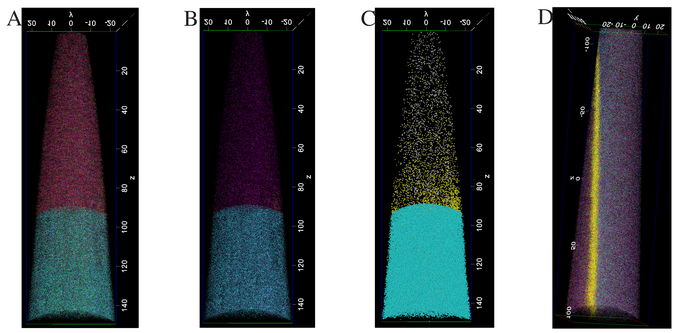

Figure 6: Reconstructions of atom probe tomography data collected in the parallel orientation near an SiO_2 mask with Al displayed in light blue, Ga in yellow, In in purple, and As in red (As), As_2 (pink), As_3 (green), and As_4 (dark blue). (A) all atoms displayed, (B) without any As, (C) without any As and In, and (D) cross-sectional APT far from dielectric mask.

- Cross-sectional APT far from an SiO_2 mask reveals similar but less extensive Ga allowing throughout regrowth.

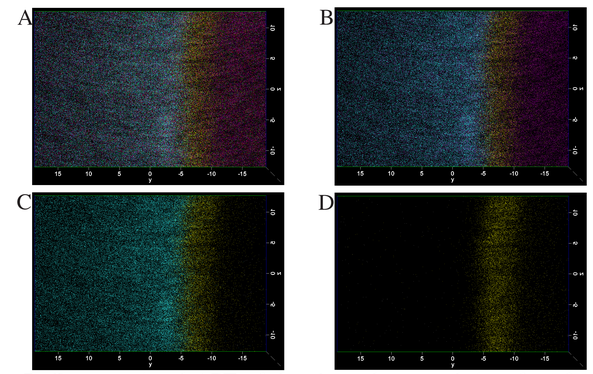

Figure 7: Cross-sectional APT of the channel-regrowth interface far from a masked region. (A) smaller region of Figure 6 (D) with all atoms displayed, (B) As removed, (C) In and As removed, and (D) only Ga.

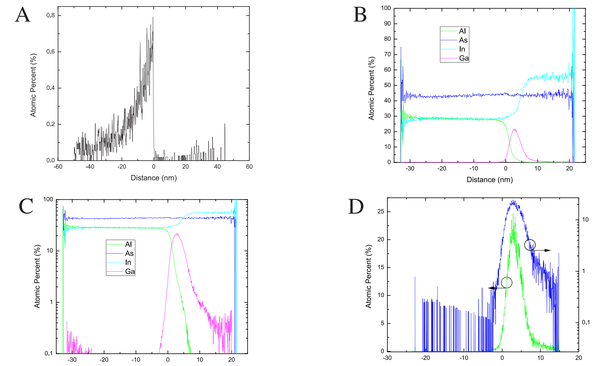

Figure 8: Proxigram of (A) parallel APT, and (B), (C), and (D) cross sectional APT showing Ga distribution at the regrowth interface.

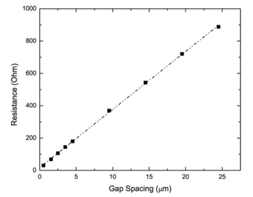

Figure 9: TLM of InAs regrowth on a 25 nm thick InGaAs, 25 μm wide regrowth grown with a V:III ratio of 4.0.

Quantum well thickness	As:In BEP ratio	Contact resistance
25 nm	5.6	135 Ω μm
25 nm	4.0	146 Ω μm
15 nm	4.0	105 Ω μm

Table 2: Contact resistance as a function of layer structure and As:In BEP ratio.

Conclusion

- Self-aligned, regrown, ohmic contacts on InGaAs with contact resistance as low as 100 Ω μm are formed by MEE
- APT shows poor InGaAs interfaces and position-sensitive Ga distributions throughout the regrowth

References

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2. M. A. Wistey, G. J. Burek, U. Singisetti, A. Nelson, B. J. Thibeault, S. R. Bank, M. J. W. Rodwell, and A. C. Gossard, "Regrowth of Self-Aligned, Ulta Low Resistance Ohmic Contact on InGaAs," **5th International Conference on Molecular Beam Epitaxy**, Vancouver, Canada, 2008.

MATERIALS
UC Santa Barbara

UNIVERSITY OF CALIFORNIA SANTA BARBARA
ELECTRICAL AND COMPUTER ENGINEERING

SRC Semiconductor Research Corporation