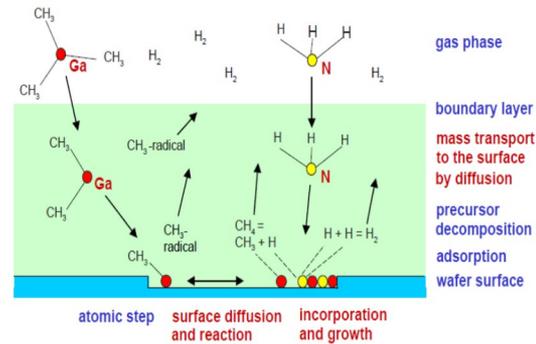
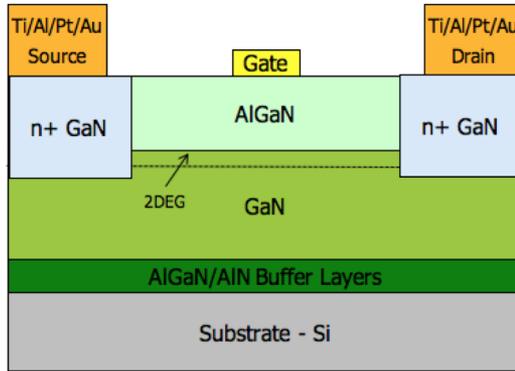


MOCVD Regrown Ohmic Contacts to AlGaIn/GaN Heterostructures



Team Members: Savannah Benbrook, Yanni Dahmani

SNF Staff Mentors: Dr. Xiaoqing Xu, Dr. Usha Raghuram

Group Mentor: Dr. Caitlin Chapin, Stanford Postdoc

External Mentors: Dr. Dong Lee, QMAT, Inc., Dr. Michael Grundmann



Outline

- **Motivation**
- **Process**
- **Sample Design**
- **Regrowth DOE**
- **Results**
 - ↳ SEMs of Regrowths #1-4
 - ↳ Optical Microscope Images
 - ↳ Possible Causes
 - ↳ TLM Data
 - ↳ Hall Data
- **Future Work**
- **Acknowledgements**

Motivation

- GaN-heterostructure device reliability is currently limited by the contact metallization schemes
- Ohmic contact formation via MOCVD “regrowth” of an n+ GaN layer to side contact 2DEG has been demonstrated to reduce R_c
- Project Goals:
 1. Develop an ohmic contact regrowth technique for AlGaN/GaN devices
 2. Bring MOCVD regrowth capability to the SNF

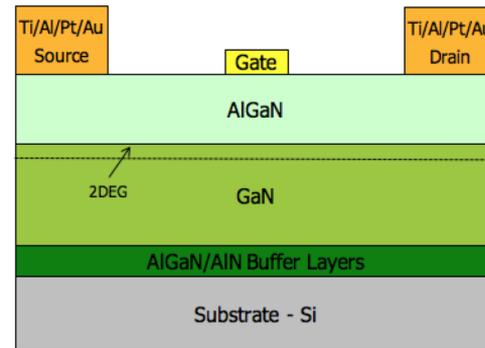


Figure 1: Cross section of a typical AlGaN/GaN HEMT without regrown contacts

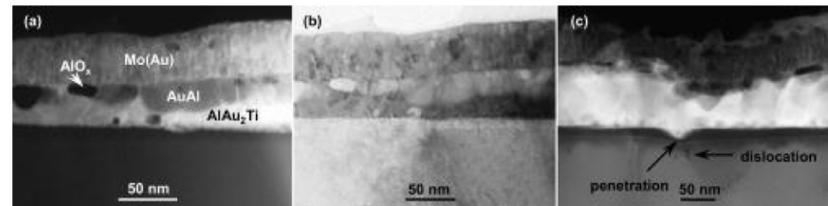
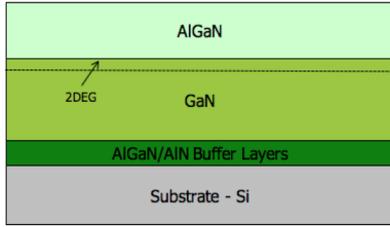


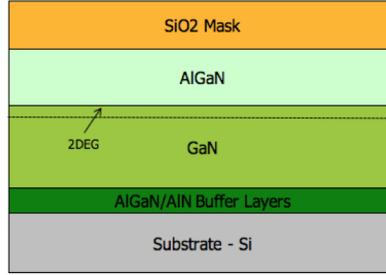
Figure 2: Ti/Al/Mo/Au Ohmic contact stack on AlGaN showing the undesirable interdiffusion of Au and the formation of intermetallics after a 600°C anneal

Wang, et al. 2007

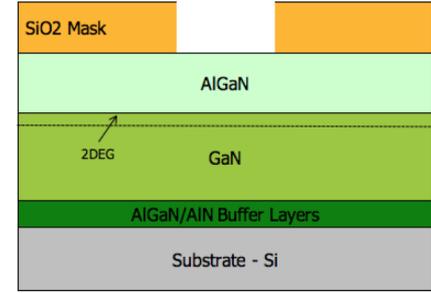
Process



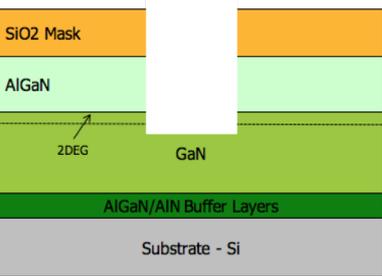
1. MOCVD Growth



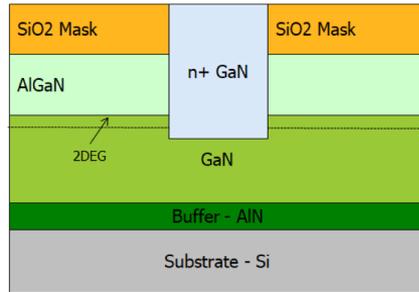
2. Oxide Mask



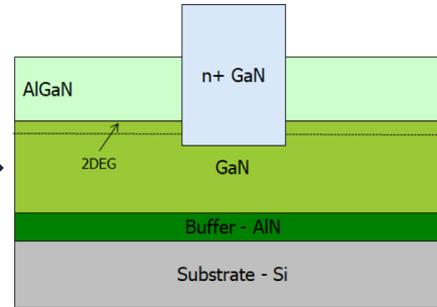
3. Oxide Etch



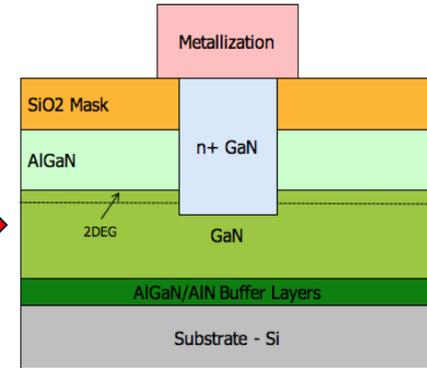
4. III-V Etch



5. MOCVD Regrowth



6. Oxide Mask Removal



7. Metallization

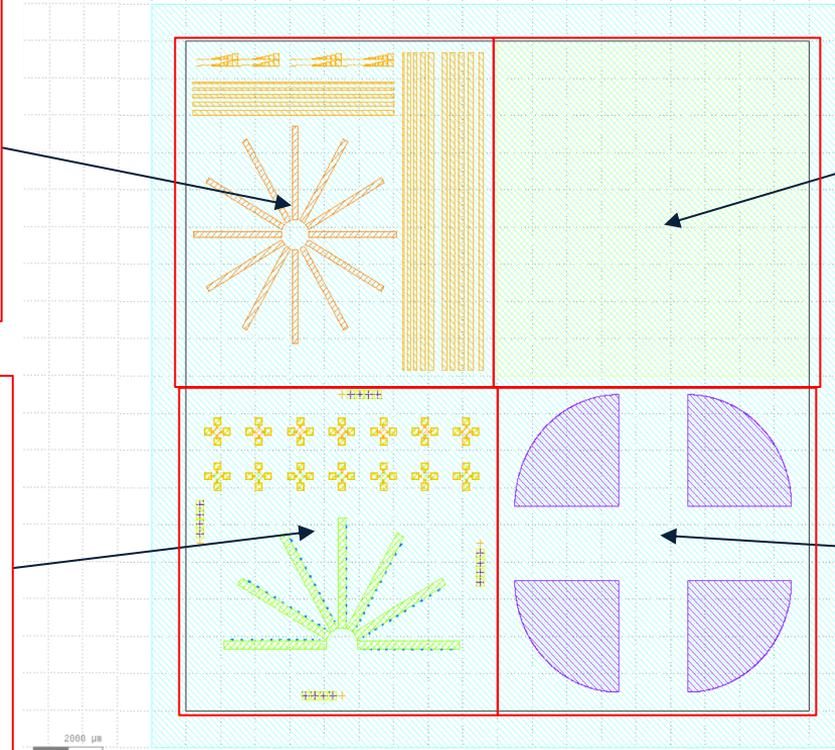
Sample Design

Purpose: Explore impact of trench size and orientation on regrowth quality

- Regrown trenches
- Starburst pattern
 - Vertical
 - Horizontal
- Regrown squares
- Lengths 1-150 μ m

Purpose: Extract 2DEG mobility, doping concentration, and contact resistivity

- Hall devices
- Regrown contacts
 - Regrown contacts & centers
- Transfer line method (TLM)
- Distances between regrown contacts 5-100 μ m



Purpose: Extract regrowth mobility and doping concentration

- Large 1 cm x 1 cm Hall device
- Entirely regrown

Purpose: Extract AlGa/GaN mobility and doping concentration

- Large 1 cm x 1 cm Hall device
- Purple contact regions are regrown
 - AlGa/GaN elsewhere

Regrowth Design of Experiments

Regrowth #	Sample Size	Bake	Anneal	Growth Temp - H ₂ and NH ₃ ambient
1	2 cm x 2 cm	840°C H ₂ ambient;	930°C N ₂ ambient;	885°C
2	2 cm x 2 cm	3 SLM NH ₃ ambient for	5 SLM NH ₃ for 30min	1090°C
3	Cleaved piece	5min		1050°C;
4	2 cm x 2 cm			*TMGa, NH ₃ , SiH ₄ flow rates doubled to counteract decomposition rate

Regrown Sample #1

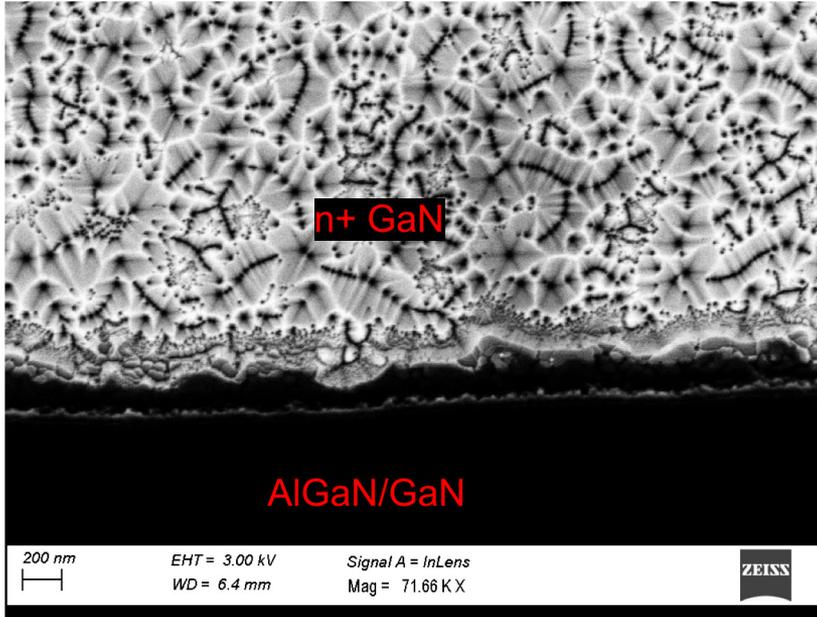


Figure 3: Top view of regrowth sample #1 edge of 150um square.

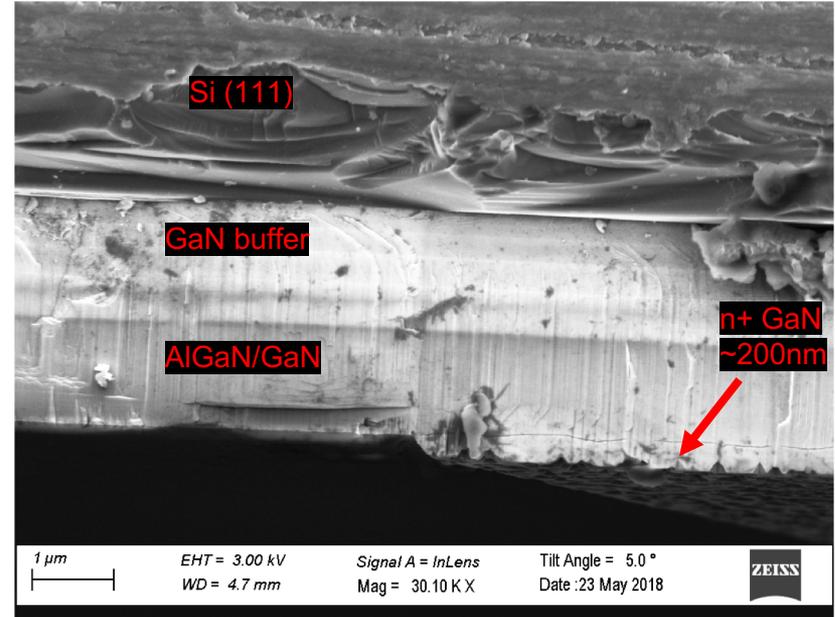


Figure 4: Cross section of regrowth sample #1.

Regrown Sample #2

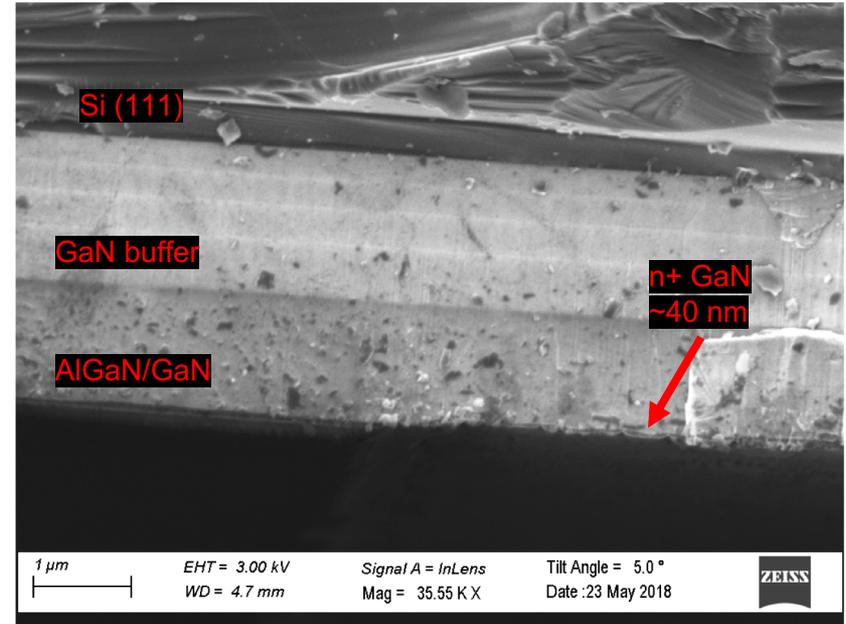
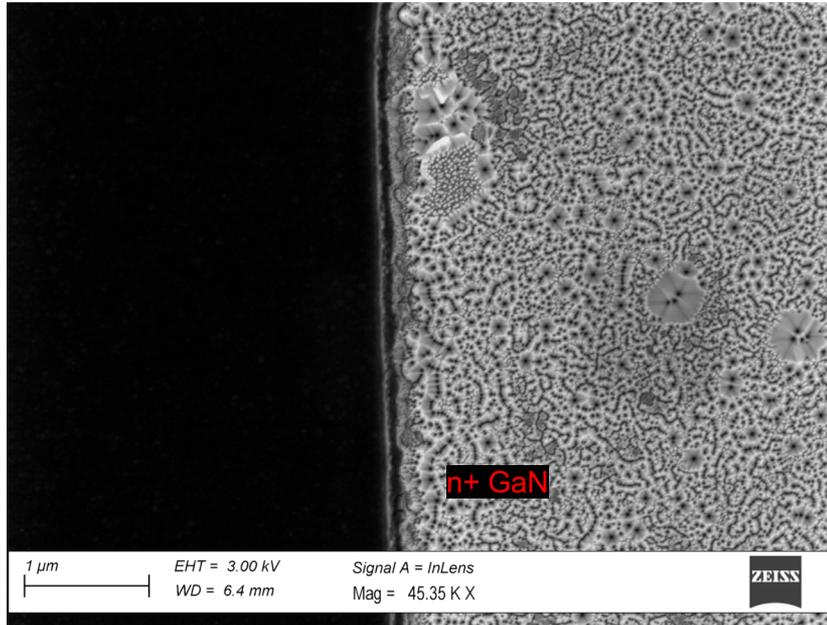
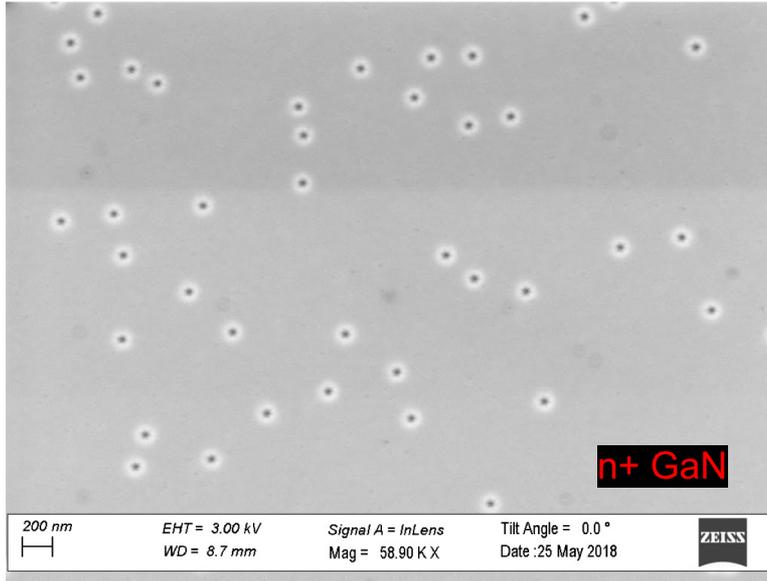
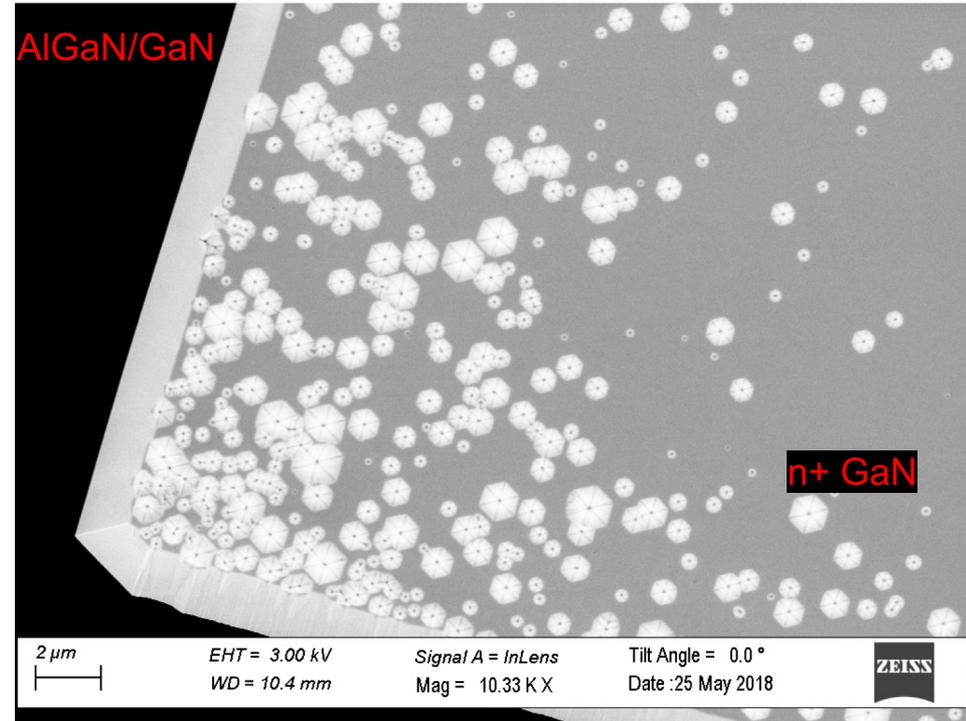


Figure 6: Cross section of regrowth sample #2.

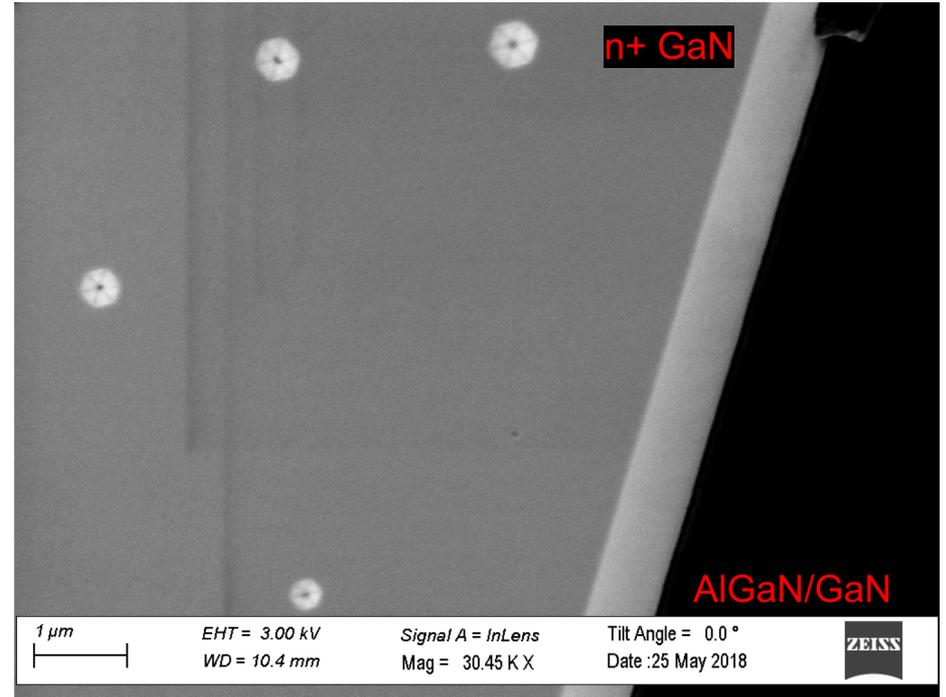
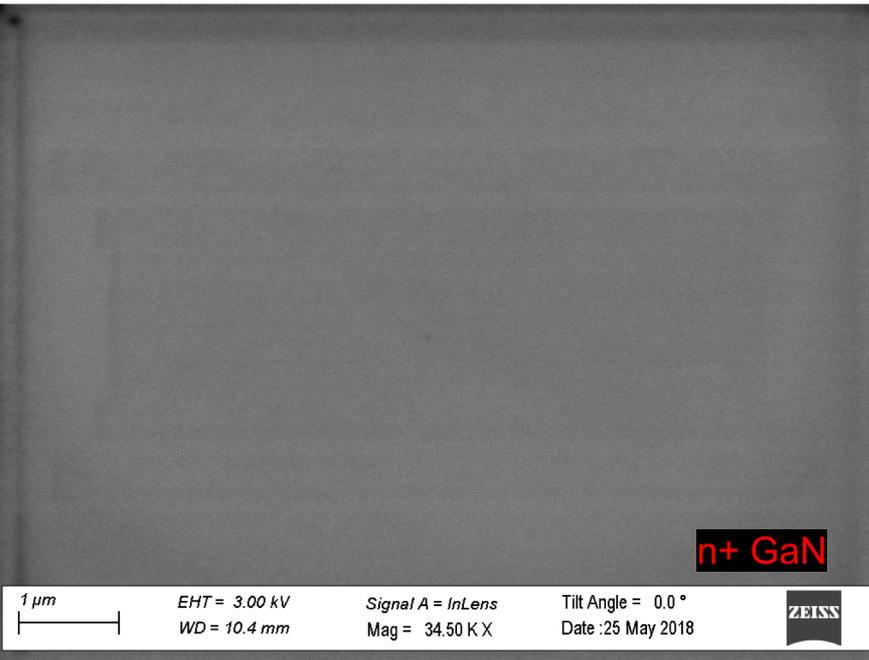
Regrowth Samples #3



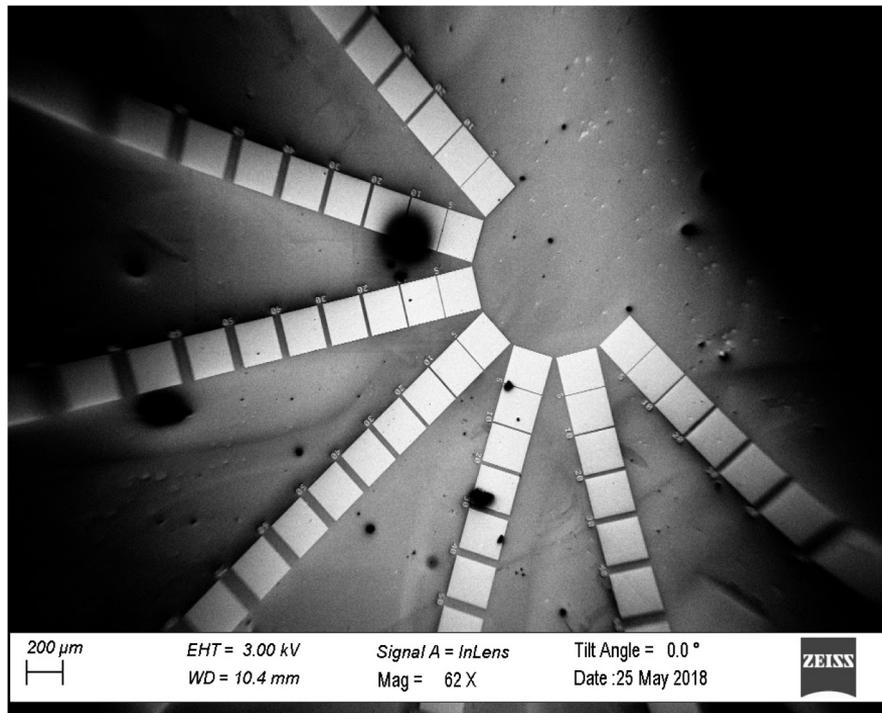
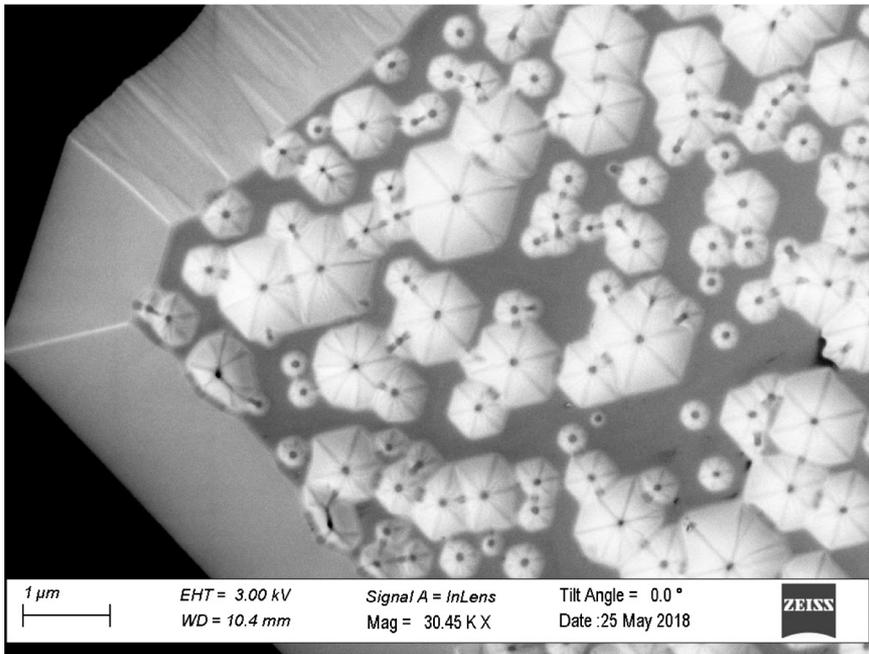
Control Sample



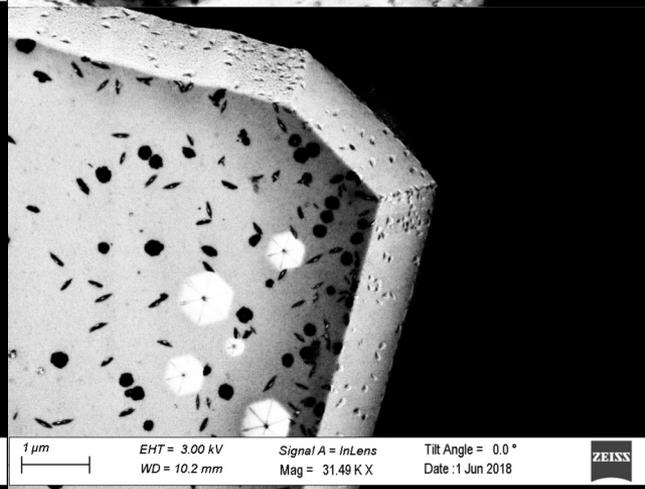
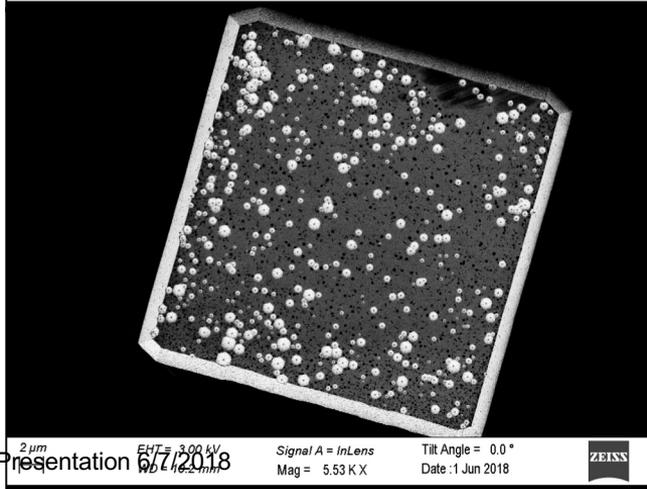
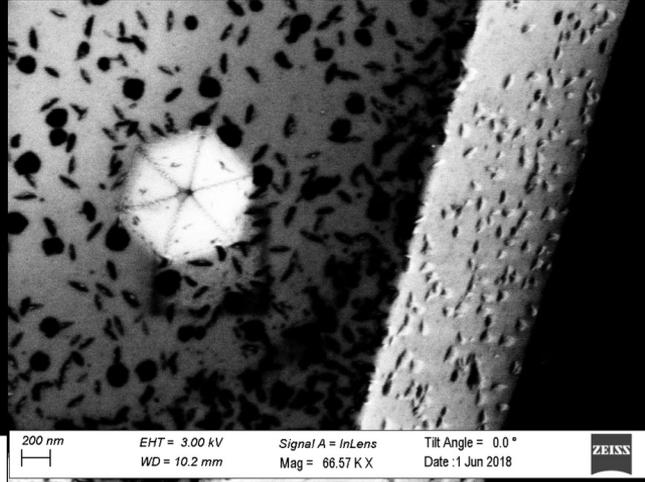
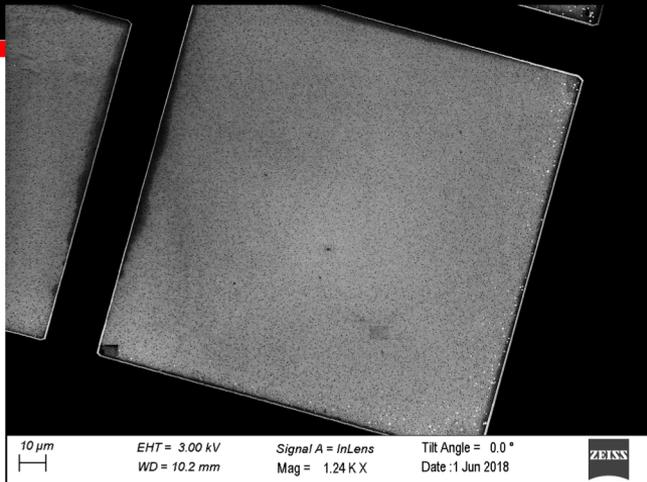
Regrowth #3- Edge vs Center



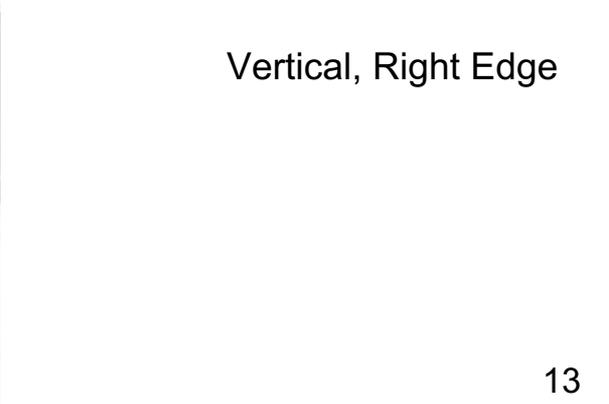
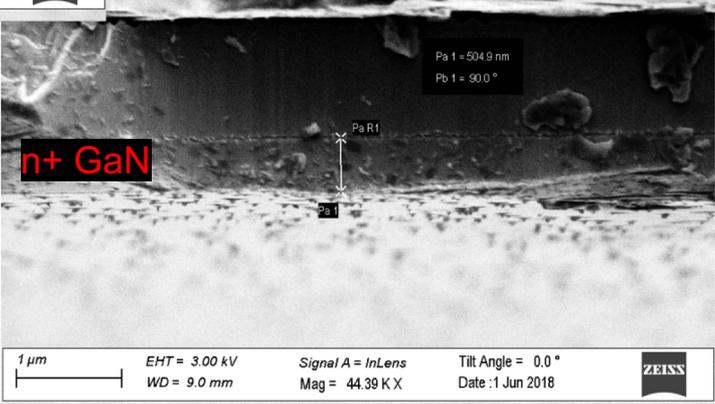
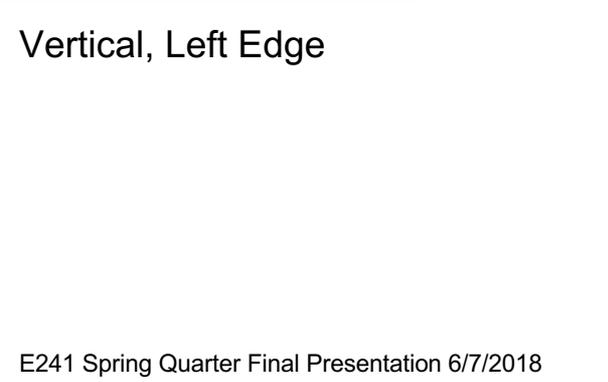
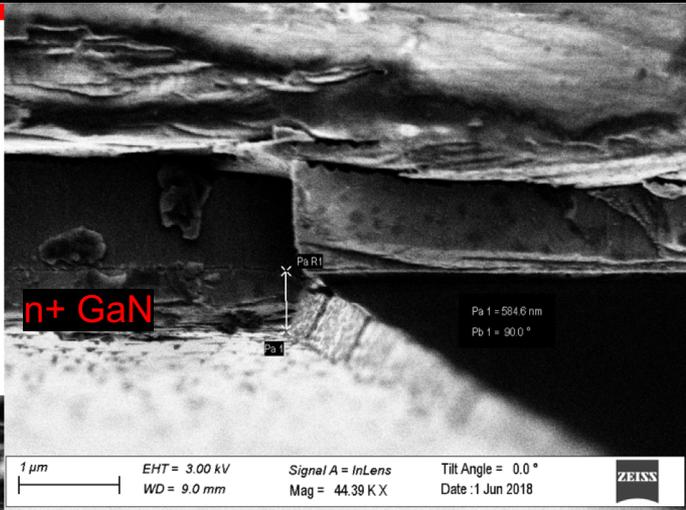
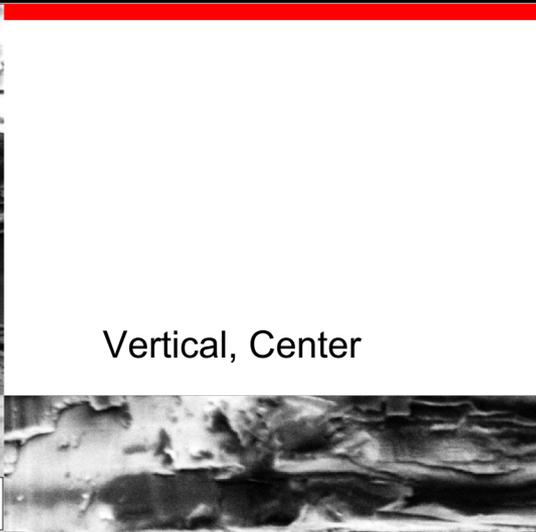
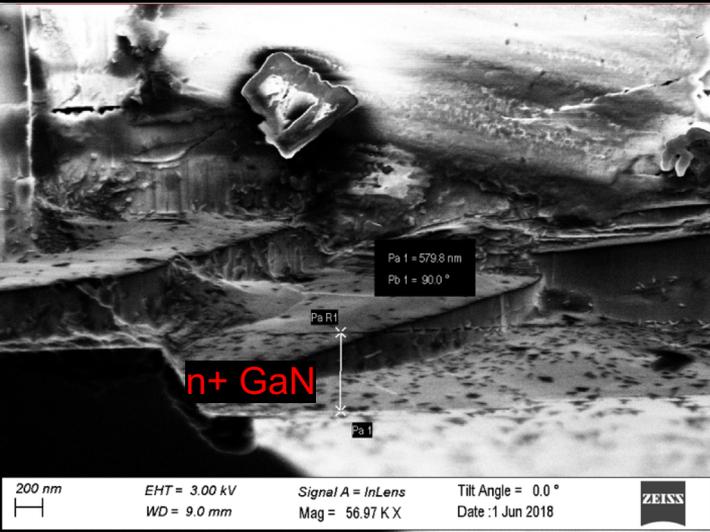
Regrowth #3



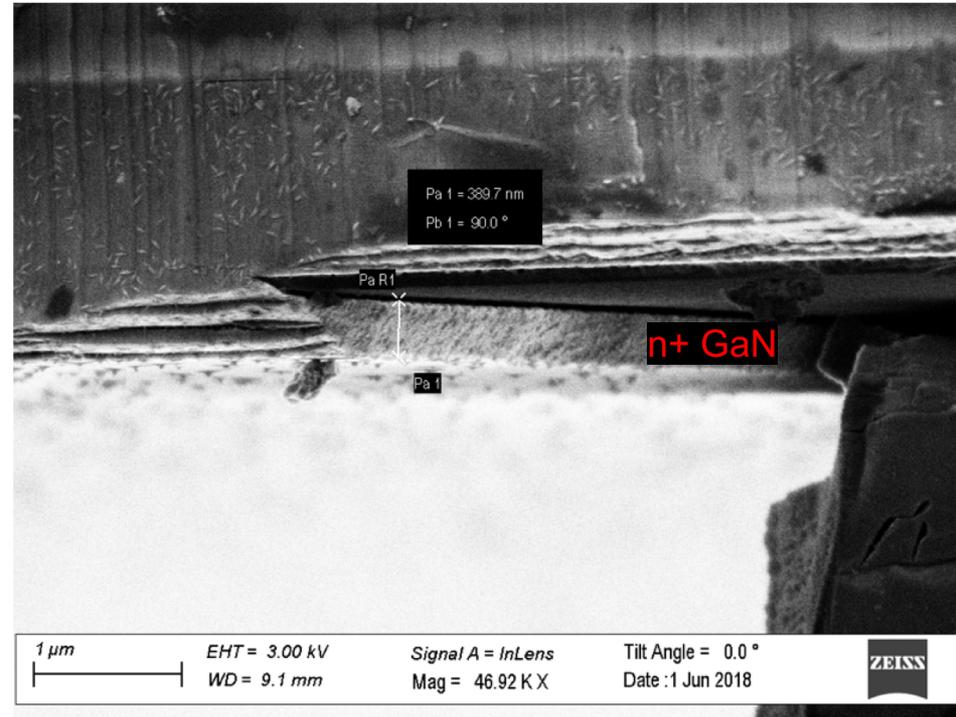
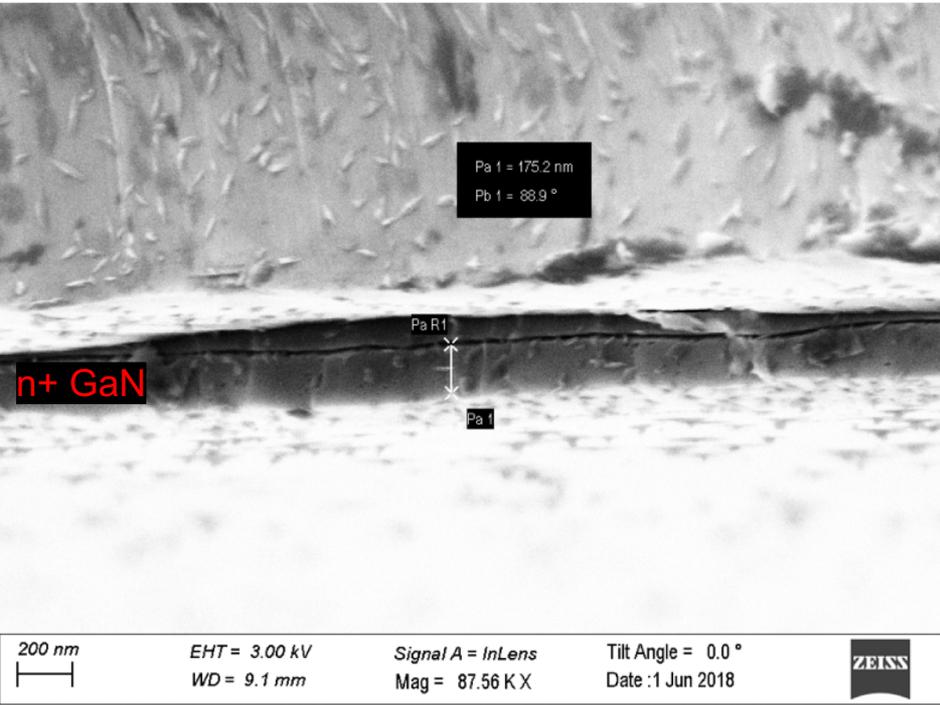
SEM Data - Regrowth 4 - Top



SEM Data - Regrowth 4 - Cross Sections



SEM Data - Regrowth 4 - Cross Sections

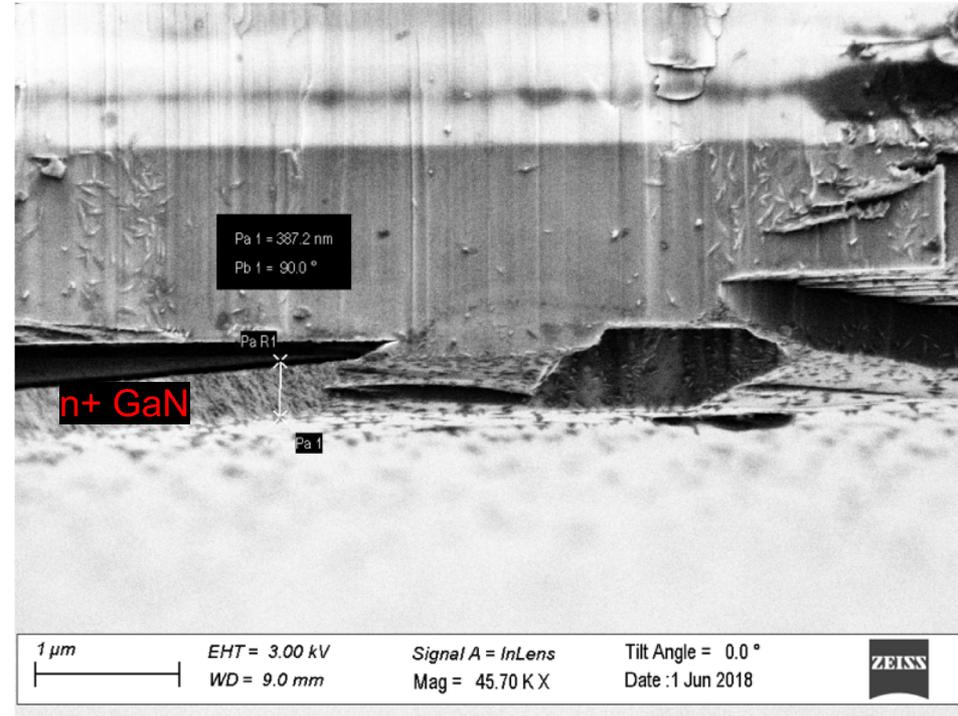
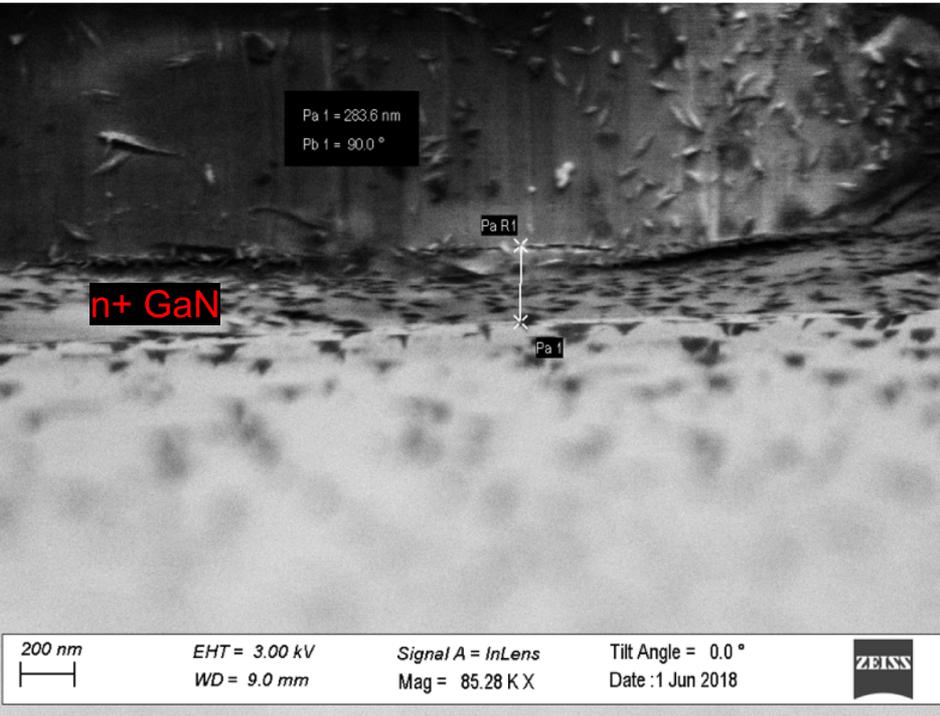


30 Degrees to Left, Center

E241 Spring Quarter Final Presentation 6/7/2018

30 Degrees to Left, Right Edge

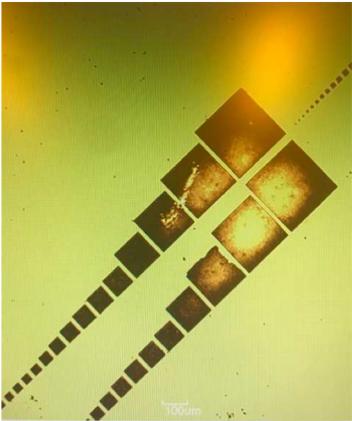
SEM Data - Regrowth 4 - Cross Sections



30 Degrees to right, Center
E241 Spring Quarter Final Presentation 6/7/2018

30 Degrees to Right, Left Edge

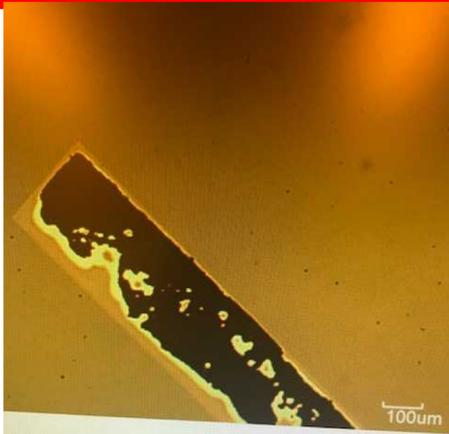
Optical Microscope Images



Regrowth #2 Square patterns



Regrowth #1 Square patterns



Regrowth #1 Spiral Trench



Regrowth #2 Trenches



Regrowth #1 Large Hall

Possible Causes

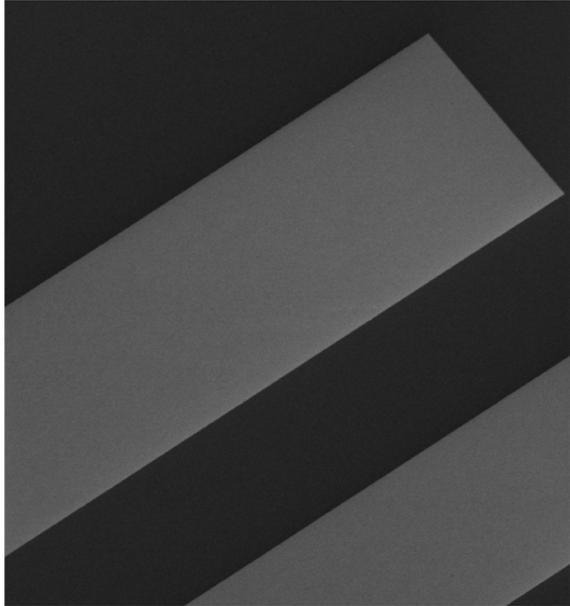
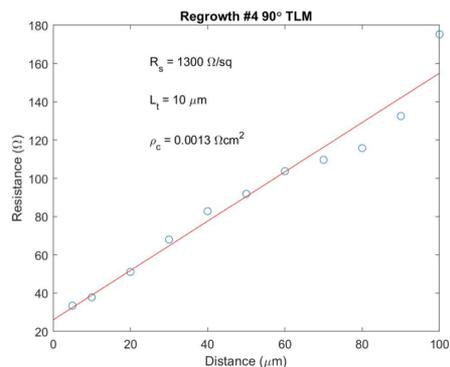
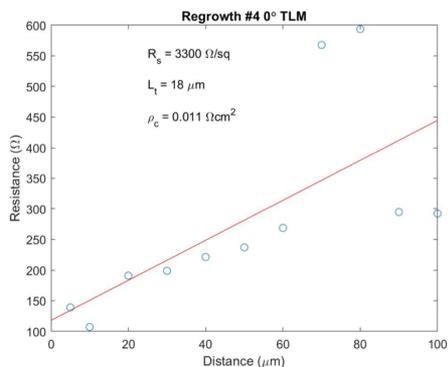
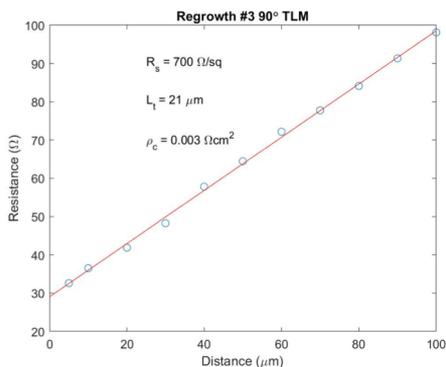
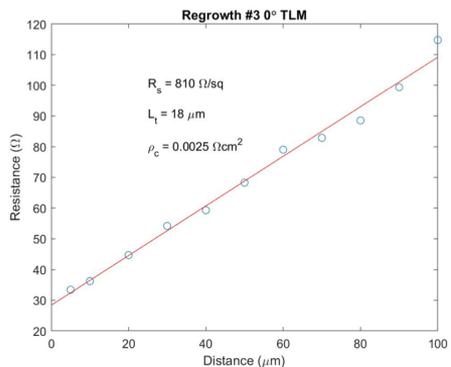
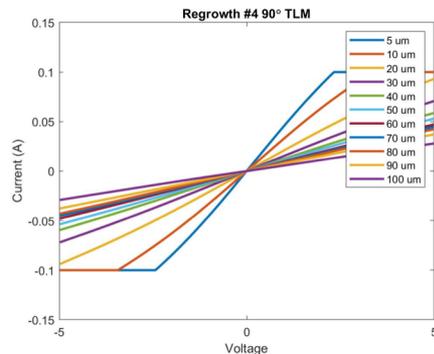
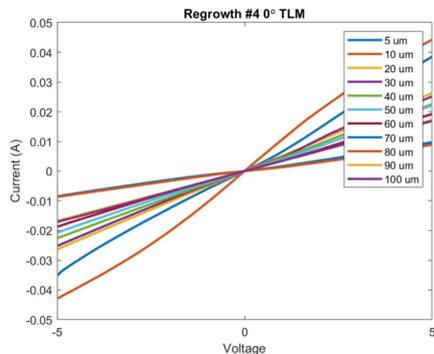
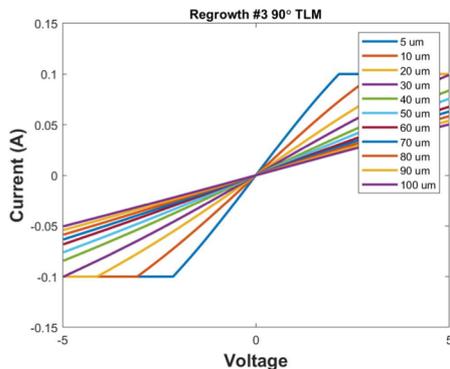
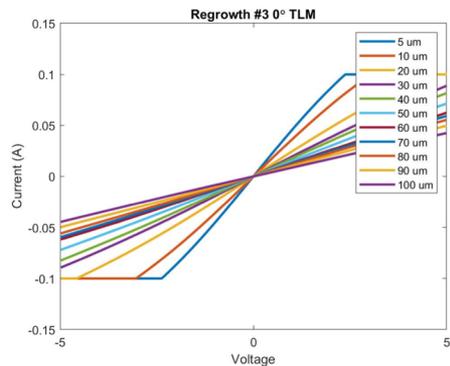


Figure 20: SEM of sample after cleaning, prior to regrowth. Sample appeared clean.

- 1. Cleaning steps prior to MOCVD regrowth were not sufficient**
 - ↳ Carbon polymer present in trenches led to poor regrowth quality
 - ↳ Cleaner samples had better growth
- 1. 50:1 HF etch of oxide mask left residue on regrown regions**
 - ↳ Less likely

Transfer Line Method (TLM) Data



Hall Device Data

Mobility (cm^2/Vs): 4.39×10^2

Sheet # (cm^{-2}): 6.55×10^{13}

Sheet Resistance (ohm/cm^2): 2.22×10^2

Carrier Type: Electrons

Take away: 2DEG is likely there, but the mobility is degraded by the regrowth/2DEG contact

Future Work

- **Secondary-ion mass spectrometry (SIMS) analysis of regrown sample composition**
- **Energy dispersive spectroscopy (EDS) on regrowth regions of sample #4**
- **Optimize Ox III-V GaN etch recipe for smoother sidewall**
- **Perform X-ray diffraction to recover orientation information**
- **Re-clean samples that have not yet been regrown in preparation for MOCVD**

Acknowledgements

This project would not have been possible without the tremendous mentorship of **Dr. Xiaoqing Xu** from conception to data analysis.

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- Dr. Michael Grundmann

Stanford Nanofabrication Facility Staff

- Dr. Usha Raghuram

E241 Coordinators

- Professor Roger Howe
- Dr. Mary Tang