MOCVD of InAlN/GaN on Si Heterostructures for High-Temperature High-Electron-Mobility Transistors (HEMTs)

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Outline

Motivation

Substrate and Buffer Structure

Desired film characteristics

Challenges and Solutions

Data and Results

- **XRD**
- **SEM**
- **Hall Effect**

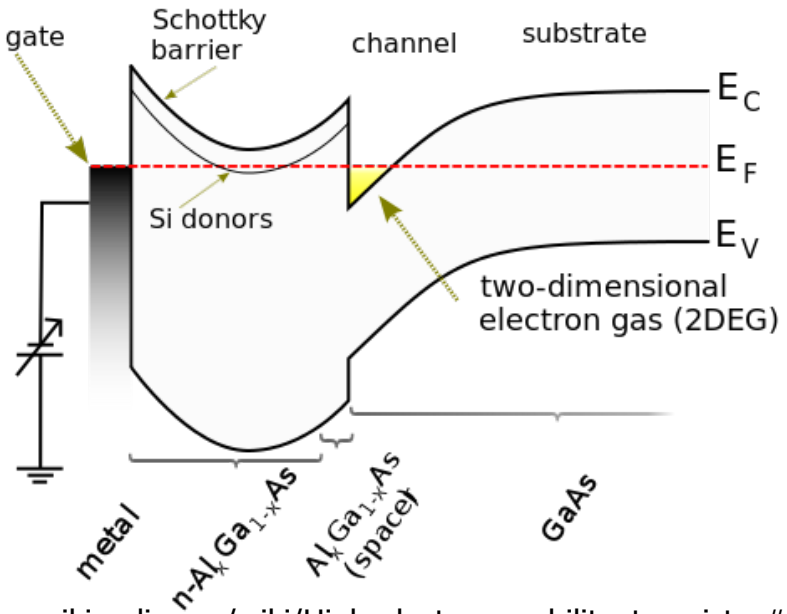
Next Steps

Motivations

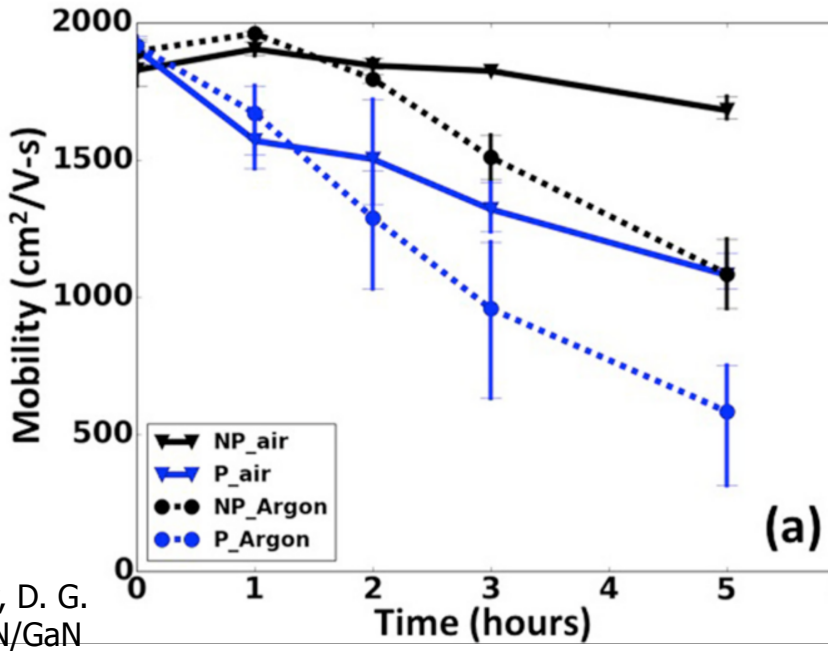
Grow InAlN-on-GaN films for fabrication of high-temperature resonators

High-Electron-Mobility Transistors (HEMTs): heterojunction between materials with different bandgaps produces 2D quantum well (2DEG) at interface

Use of InAlN lattice-matched to GaN reduces strain relaxation at elevated temperatures



https://en.wikipedia.org/wiki/High-electron-mobility_transistor#/media/File:HEMT-band_structure_scheme-en.svg



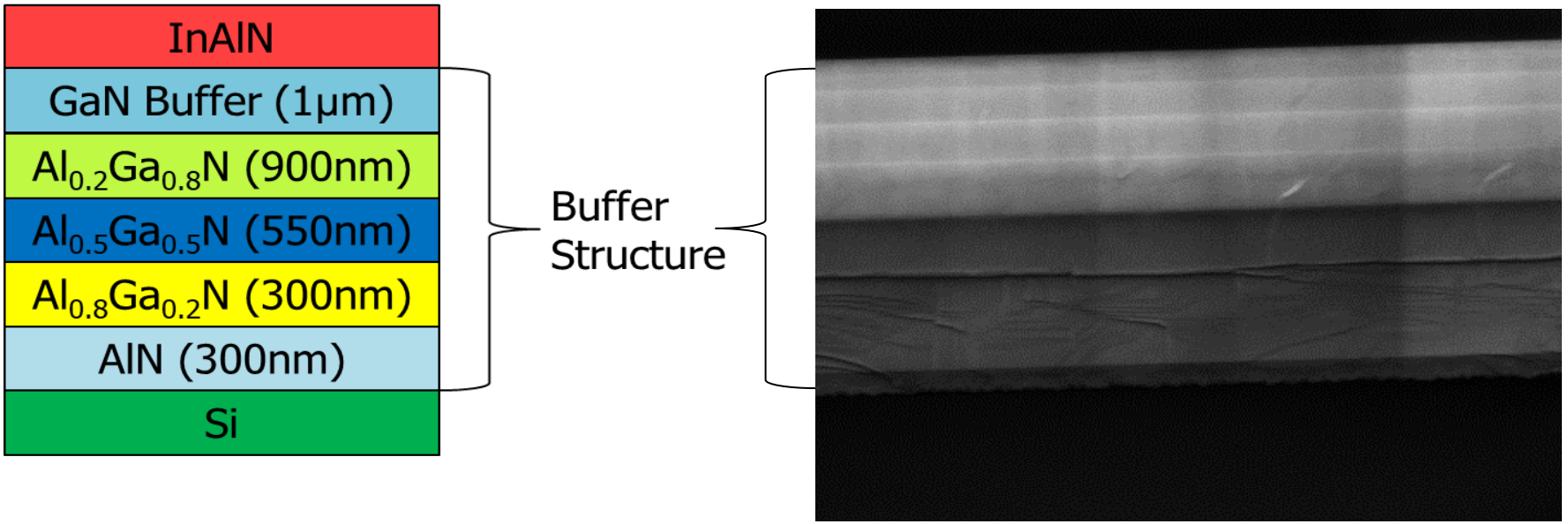
Hou, M., Jain, S. R., So, H., Heuser, T. A., Xu, X., Suria, A. J., & Senesky, D. G. (2017). Degradation of 2DEG transport properties in GaN-capped AlGaN/GaN heterostructures at 600° C in oxidizing and inert environments. Journal of Applied

Substrate and Buffer Structure

Grown on (111) silicon so the substrate can be etched to release finished devices.

Buffer structure engineered to have 0 net strain at the GaN surface

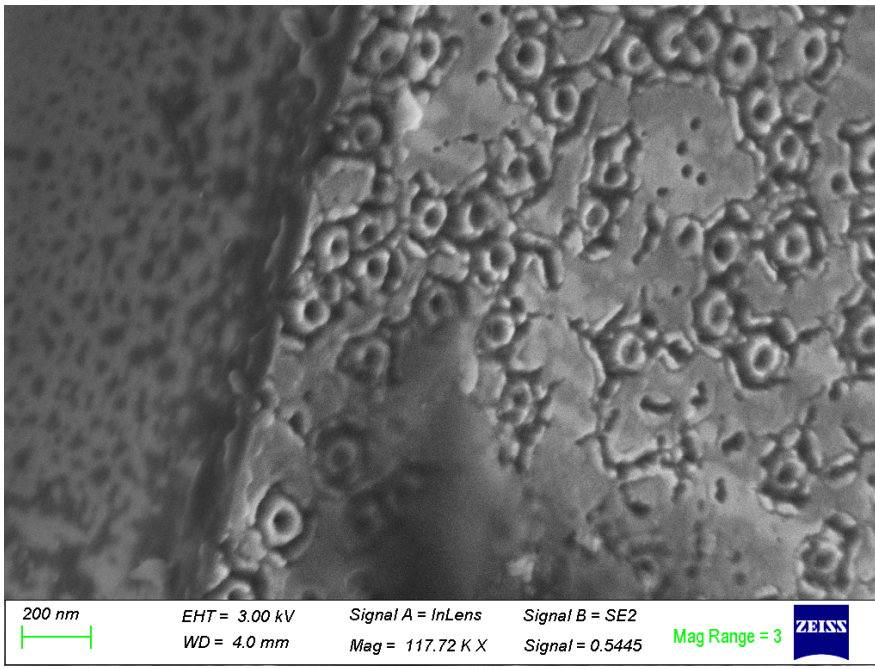
Buffer structure grown on a single wafer, then fractured to produce InAlN growth templates



Desired Film Characteristics

Characteristics:

- **Composition:**
  - **~16-17.5% indium required for lattice-matching to GaN**
- **Surface Quality:**
  - **Flat, relatively smooth surface required for high-quality, repeatable electrical contacts**
- **Film thickness:**
  - **Film needs to be ~10-30 nm for device operation**



Challenges and Solutions

Challenge: Residual films coating reactor walls change thermal environment

Solution: Add a short GaN growth step before growing InAlN to "season" reactor chamber

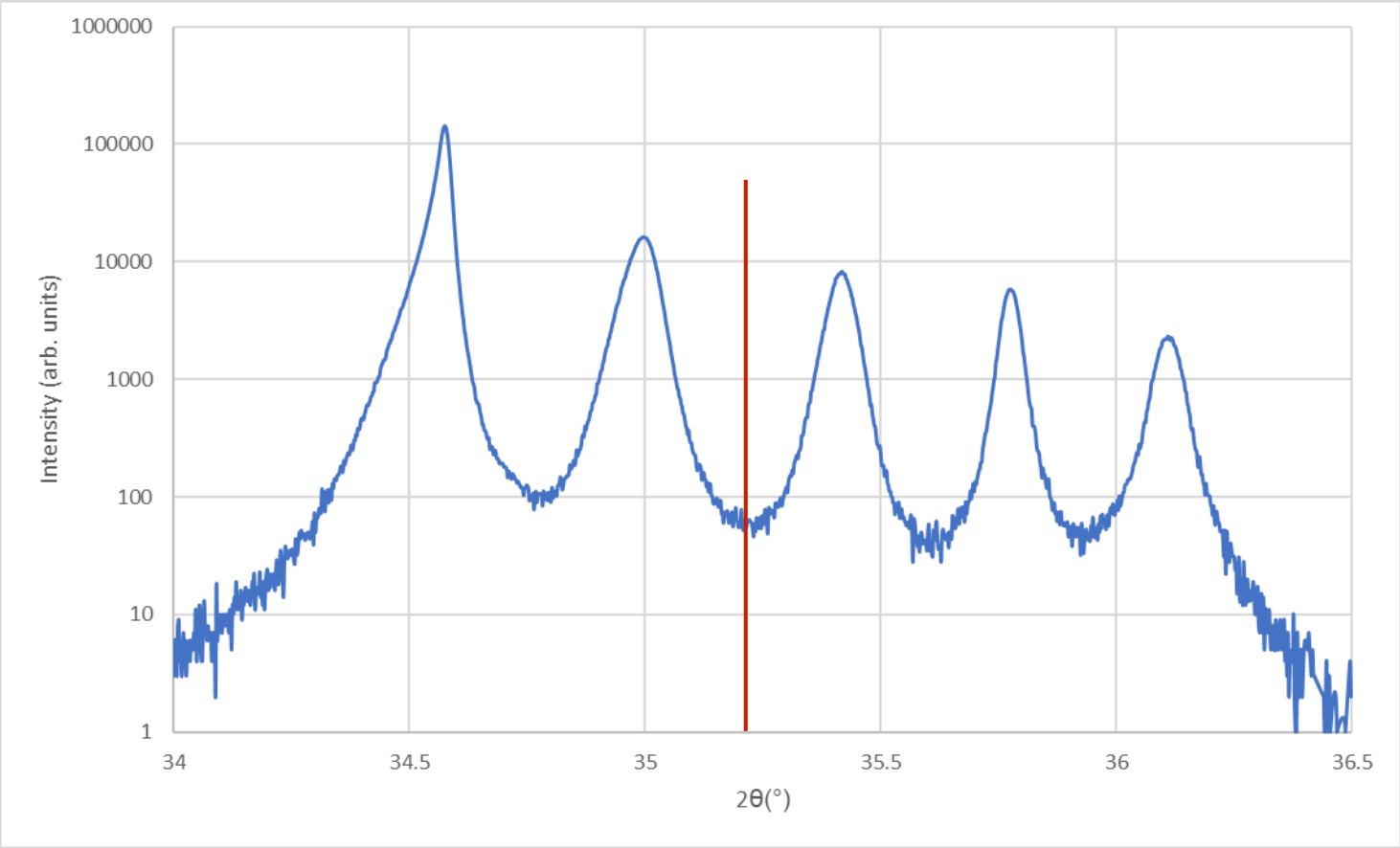
Challenge: In-situ temperature/reflectivity monitor not centered on template pieces, gives anomalous temperature readings

Solution: Manually start monitor before beginning growth, reposition sample if necessary until readings are accurate

Challenge: InAlN surface very rough, displaying very strange surface morphology

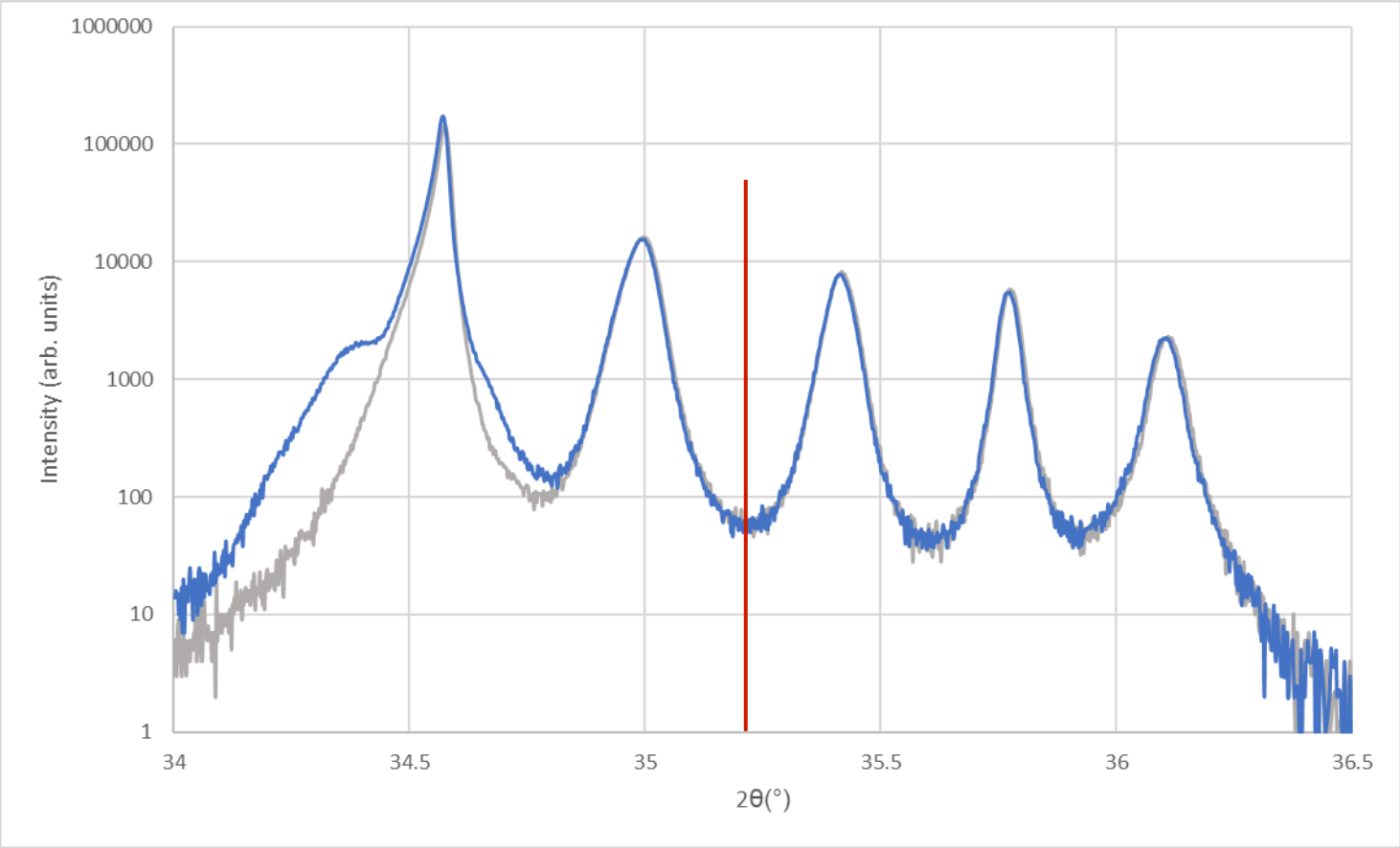
Solution: SEM shows that rough surface morphology begins after ~50-100 nm, growing thinner samples prevents it

XRD Data



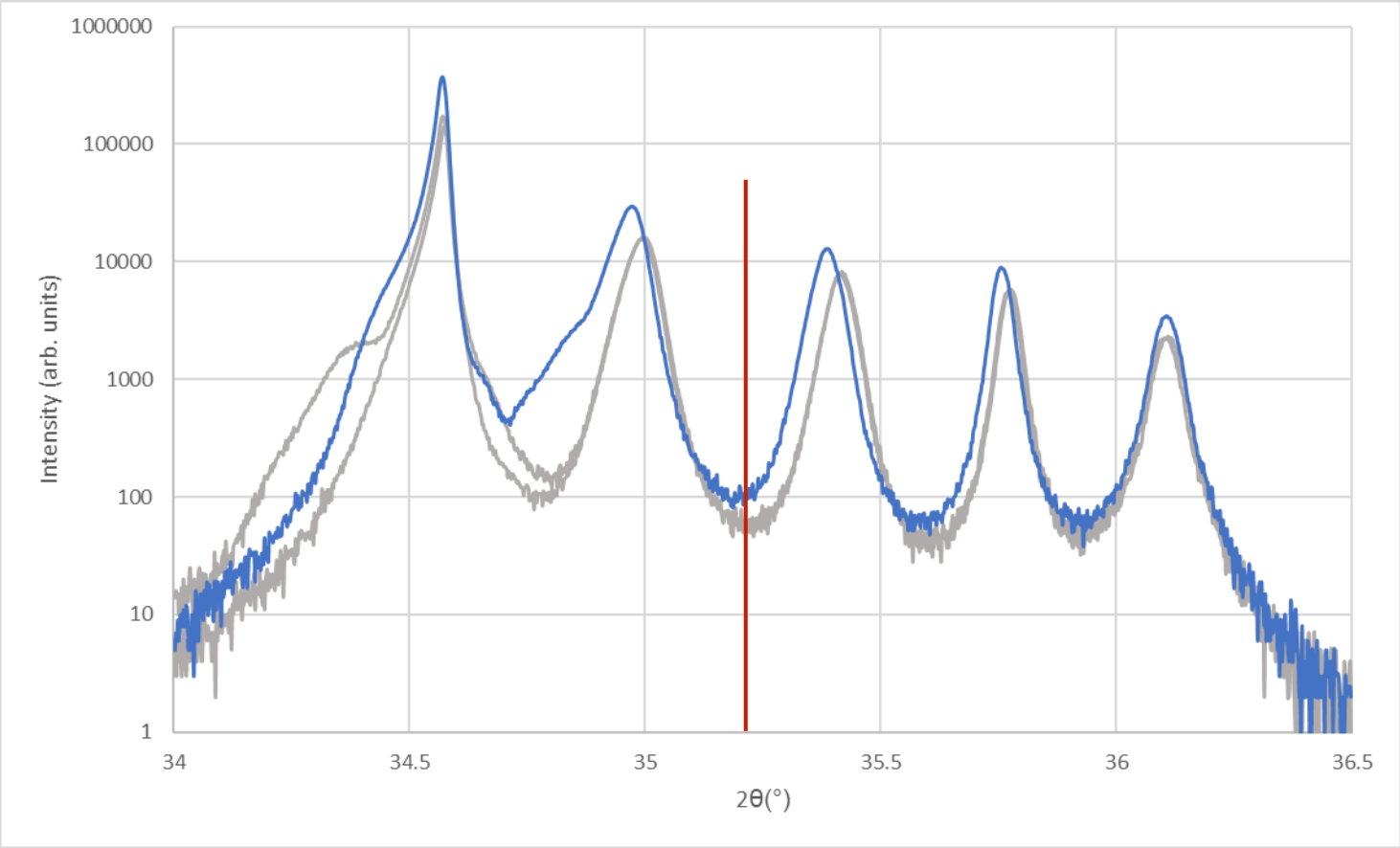
Growth #1

XRD Data



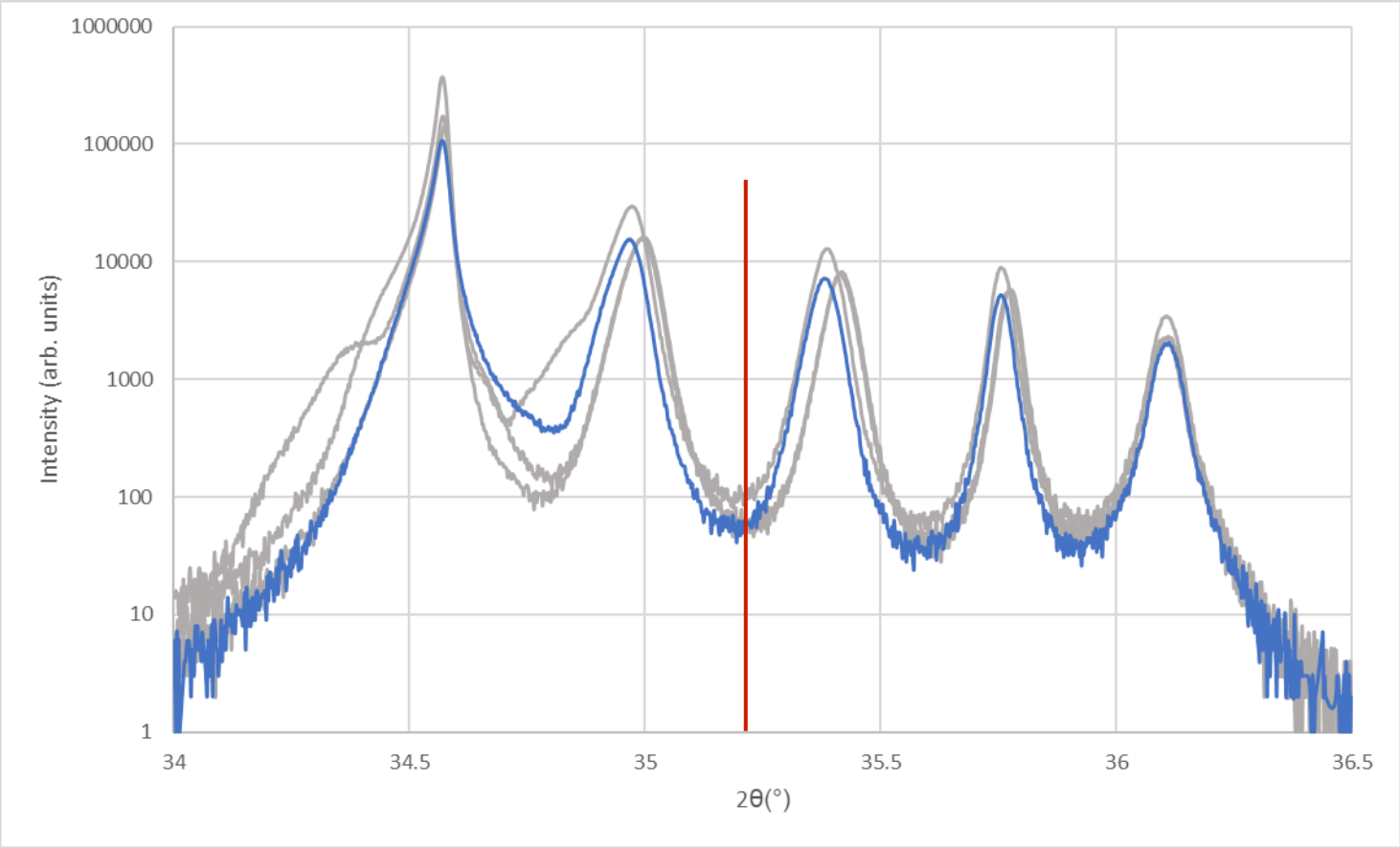
Growth #2

XRD Data



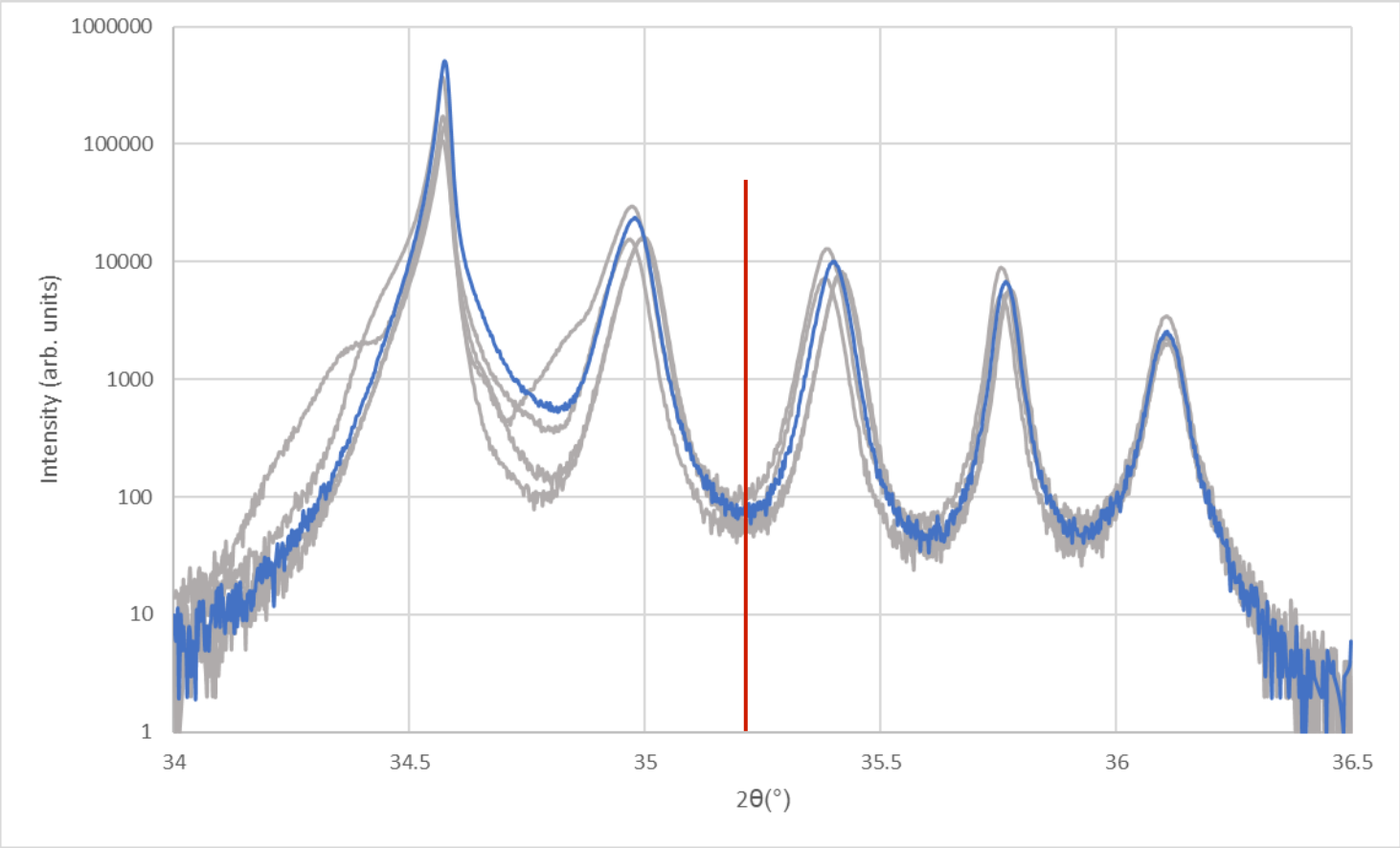
Growth #3

XRD Data



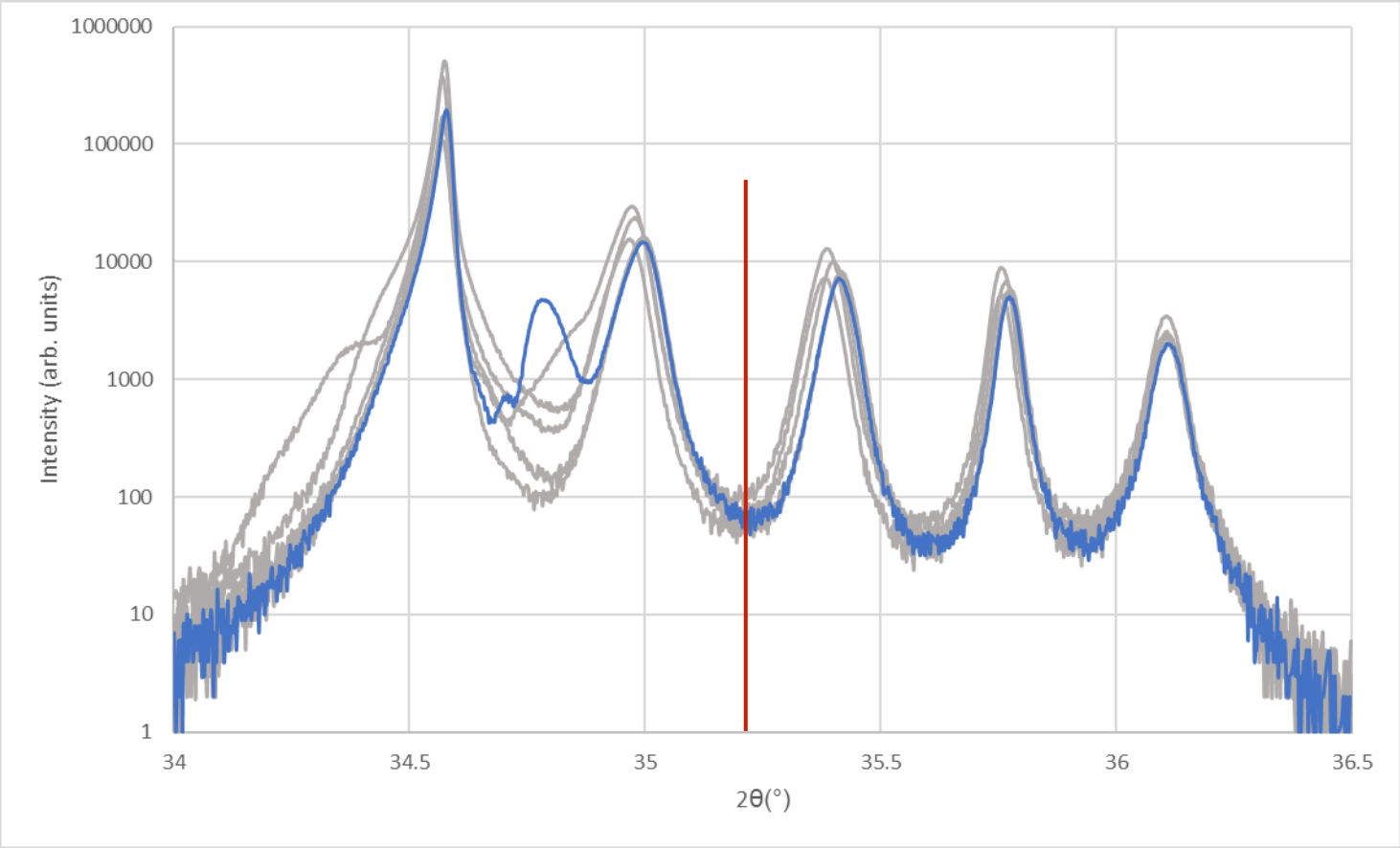
Growth #4

XRD Data



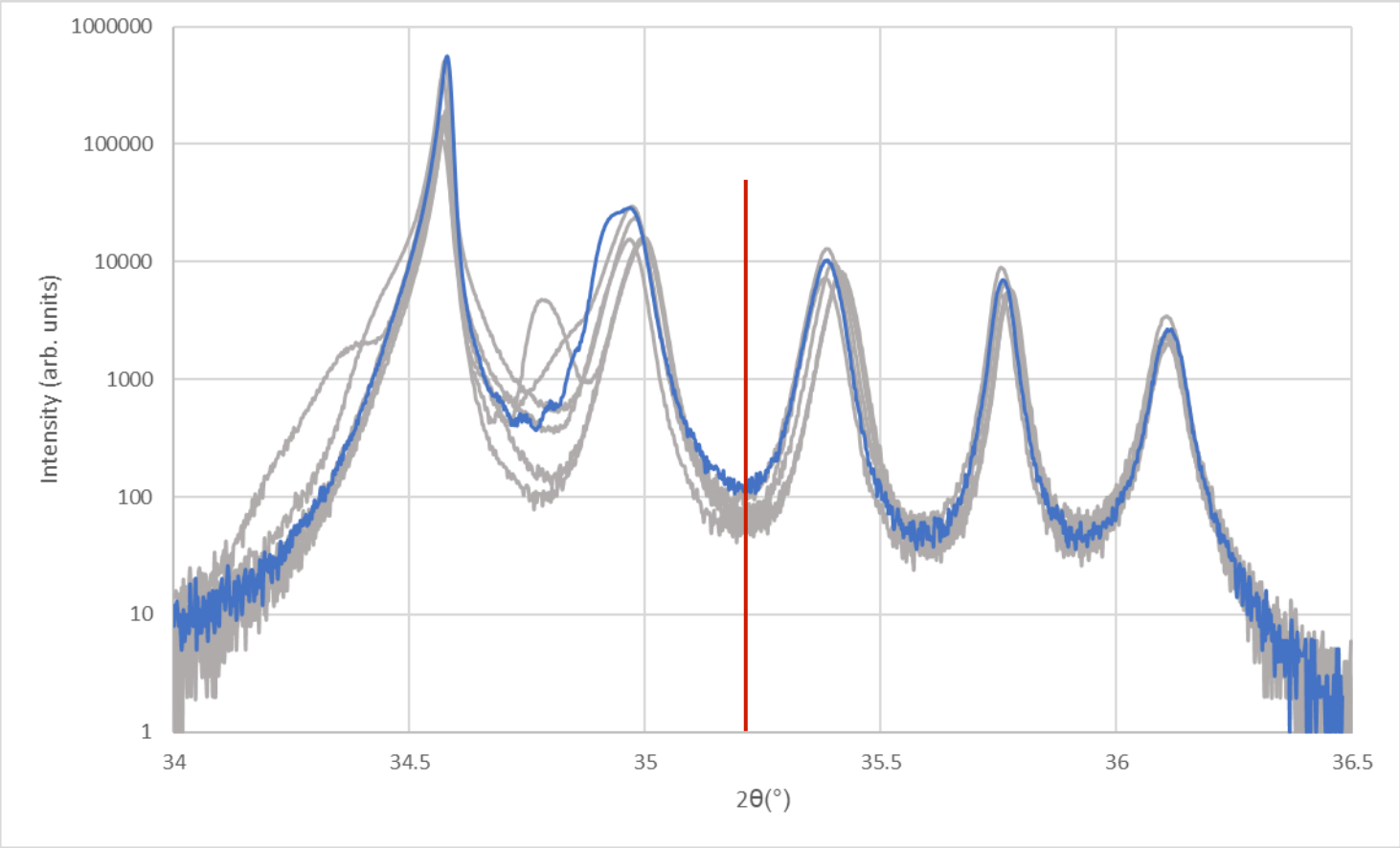
Growth #5

XRD Data



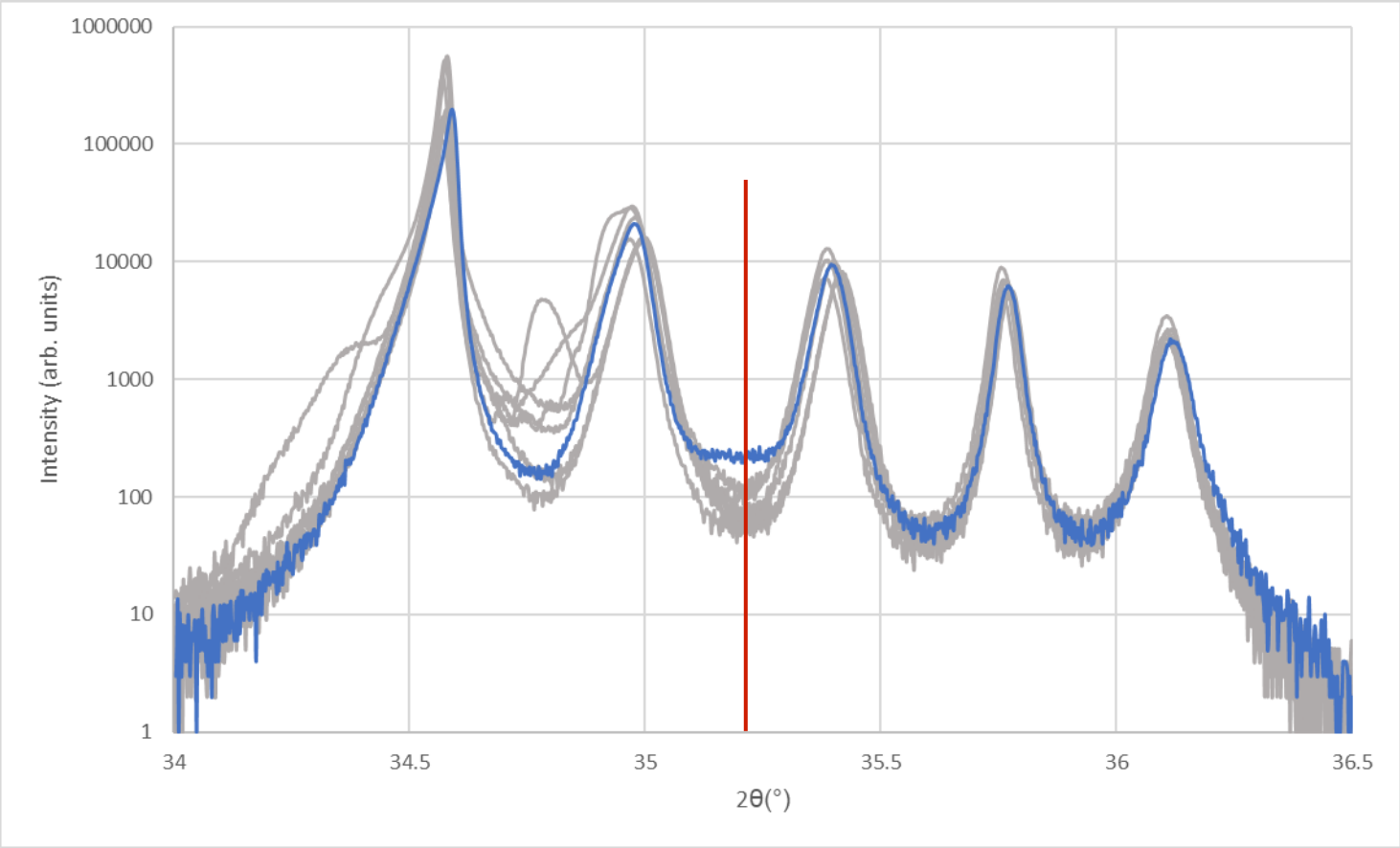
Growth #7

XRD Data



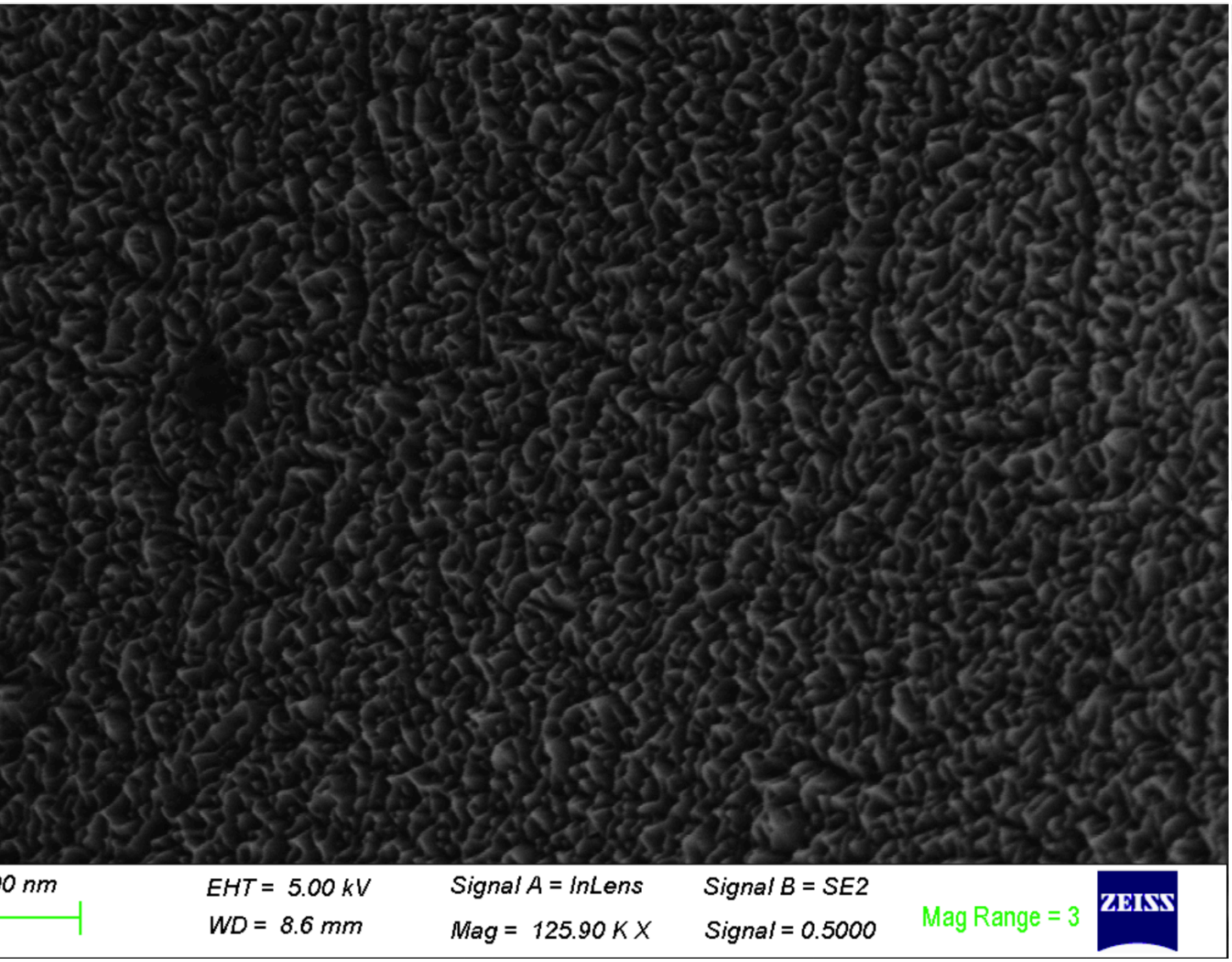
Growth #8

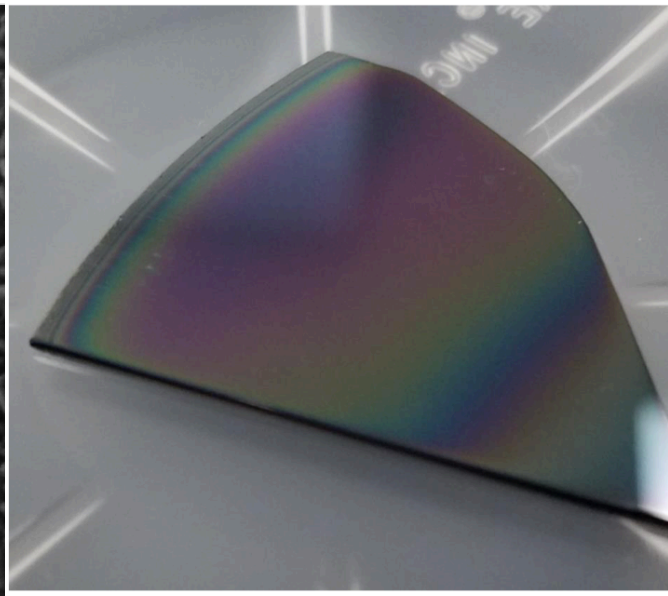
XRD Data



Growth #9

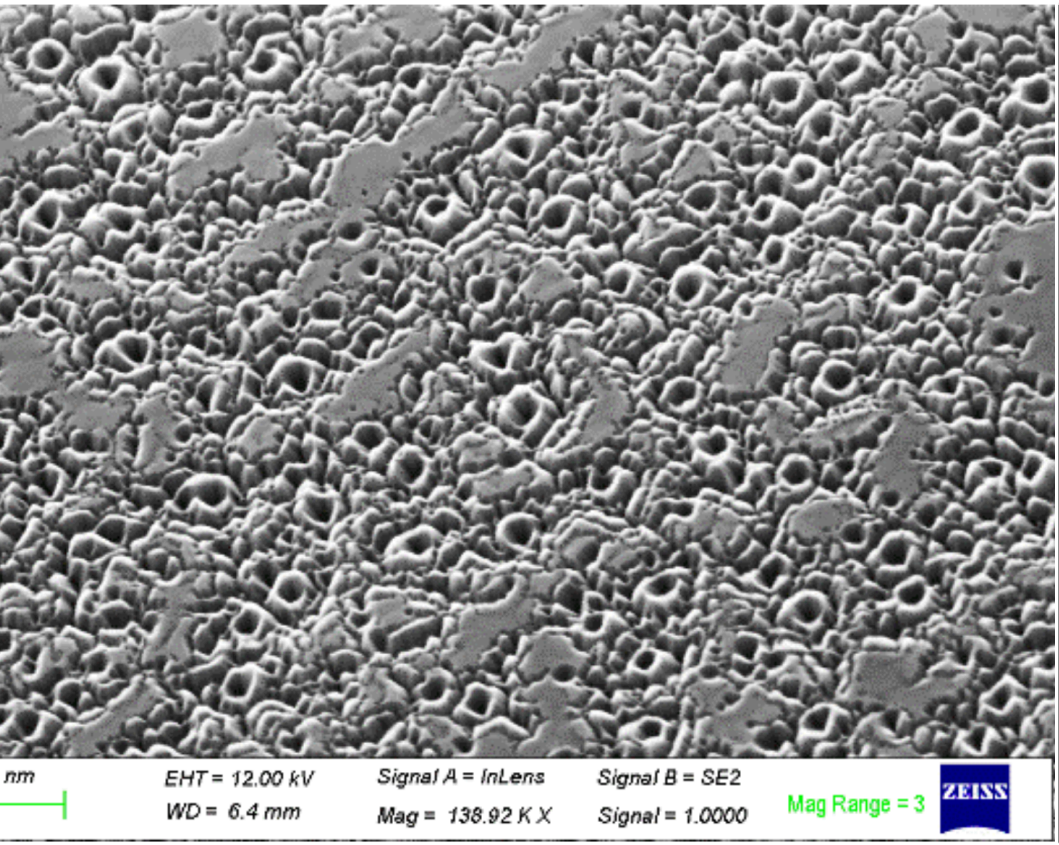
Sample #1

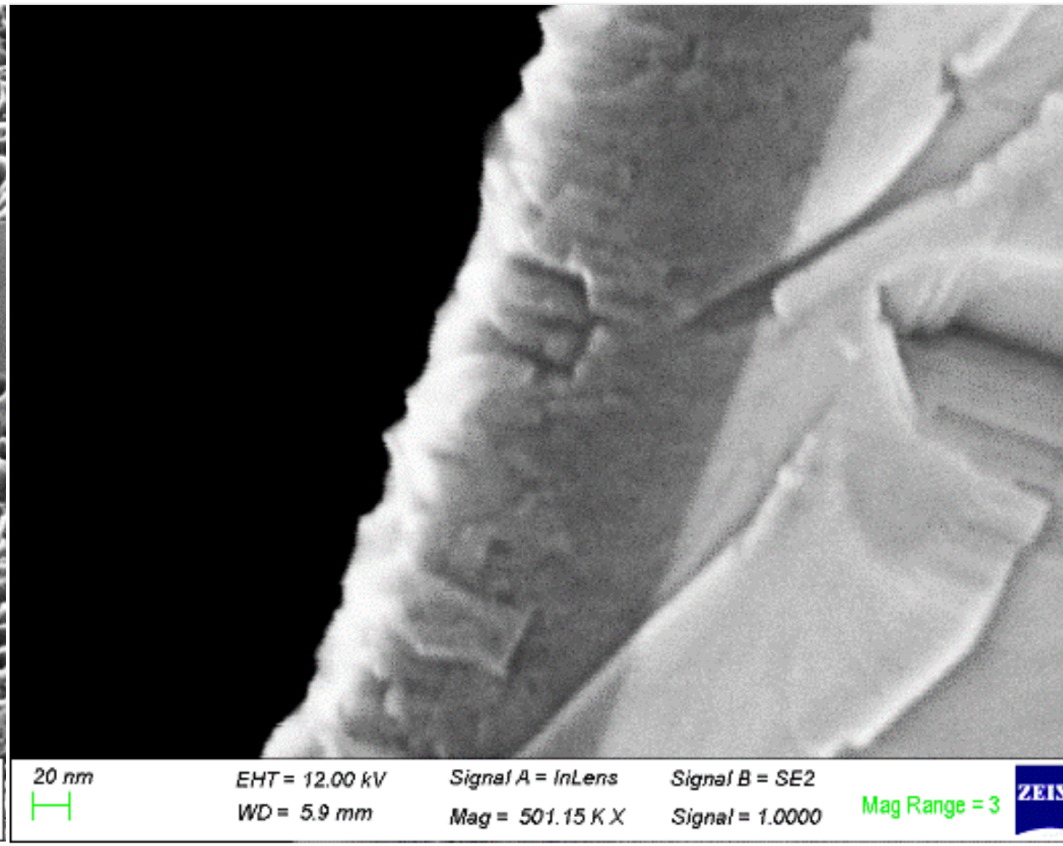




InAlN thickness ~200 nm
Surface morphology very rough

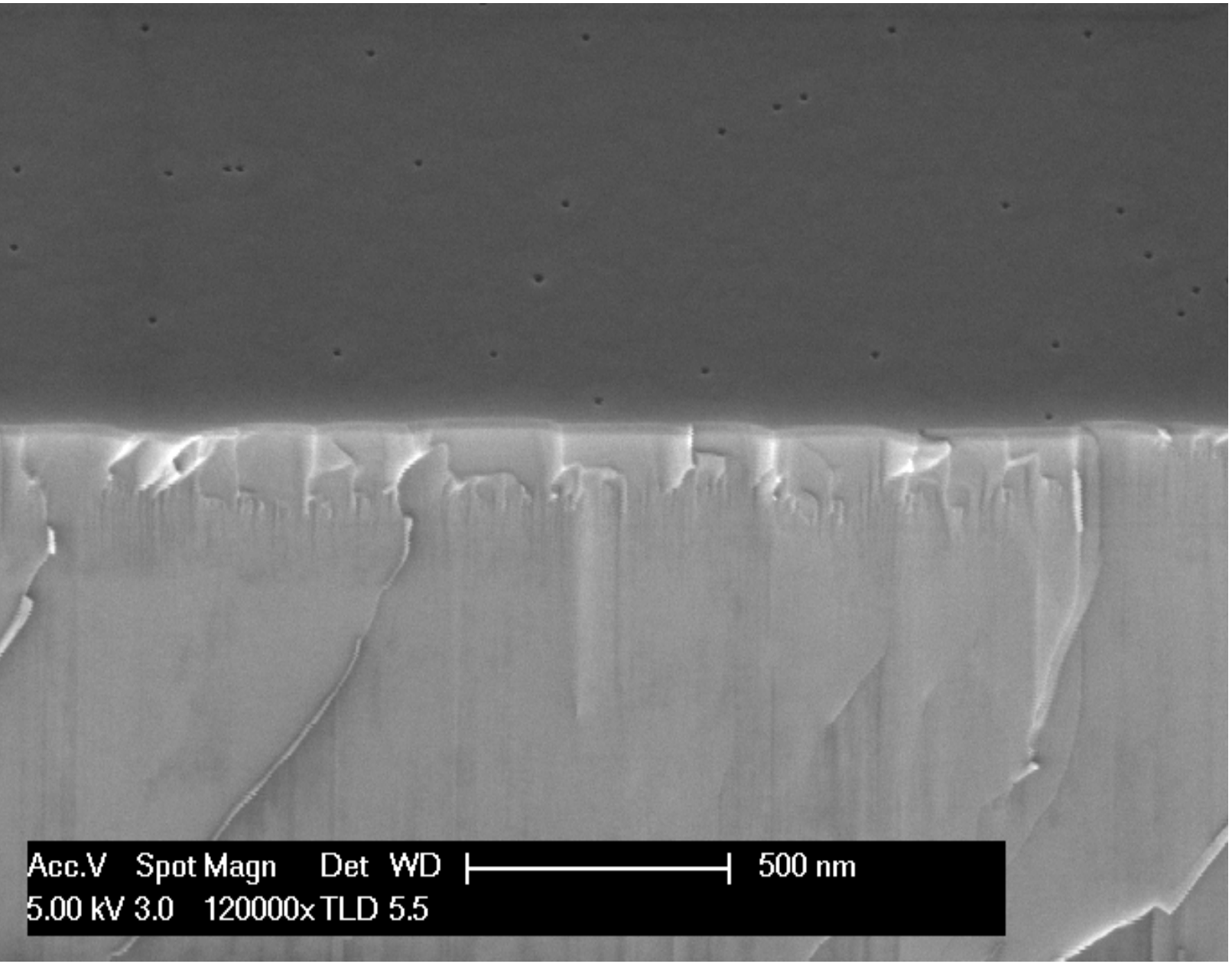
Sample #5



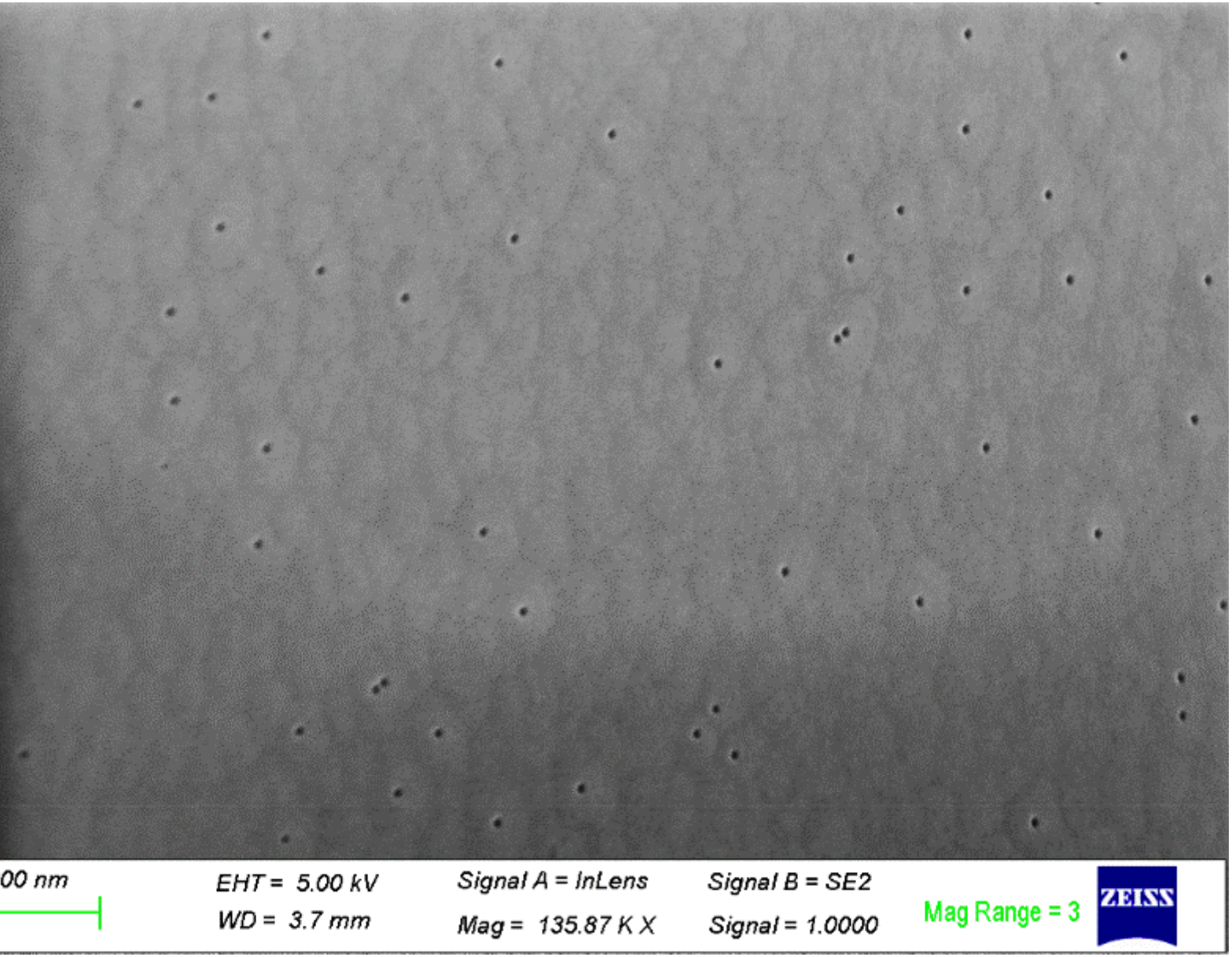


- InAlN thickness reduced to 150 nm
- Flat regions begin to appear, surface features have "barnacle-like" appearance
- Morphology grooves halt at ~50 nm from the surface

Sample #6

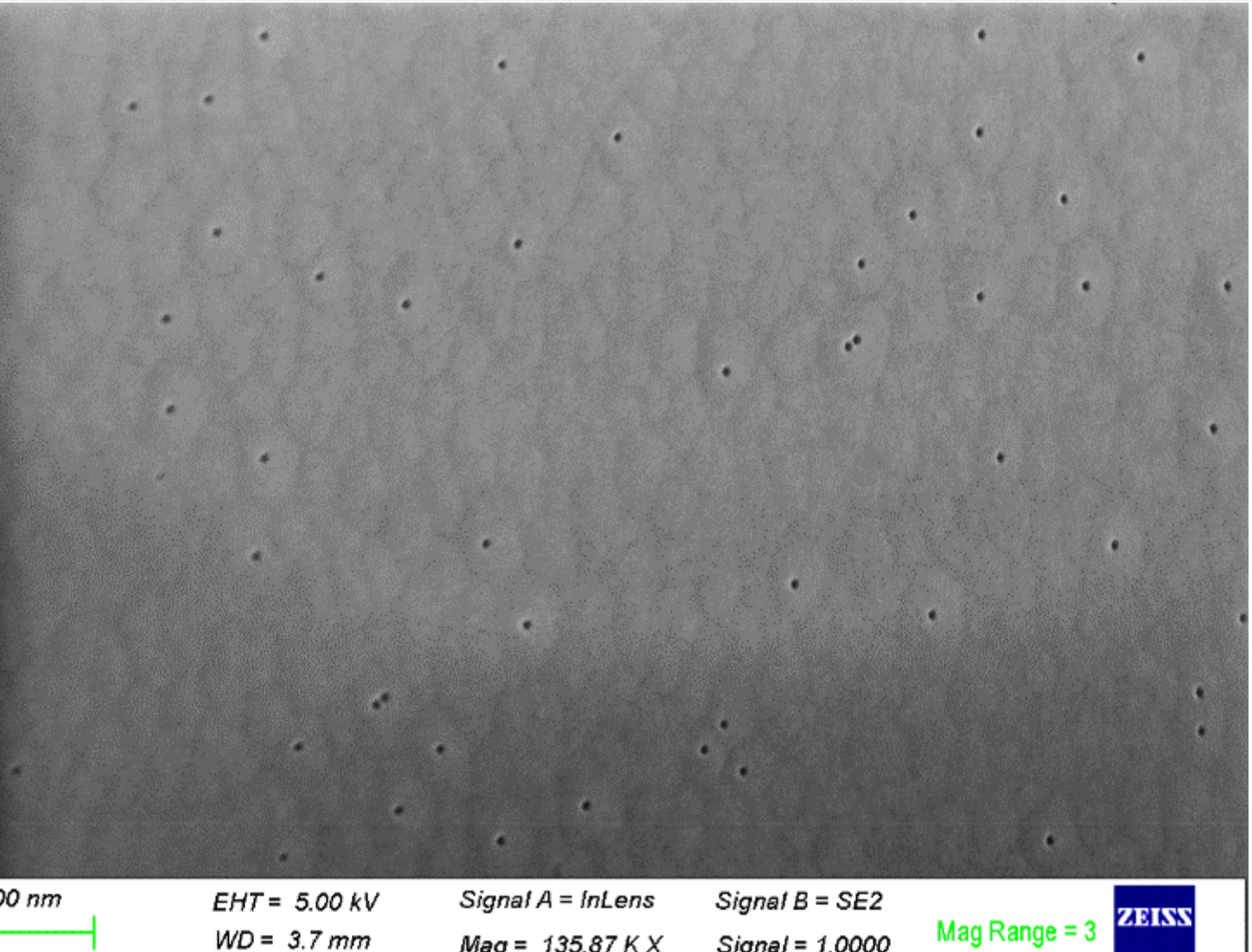


Sample #9

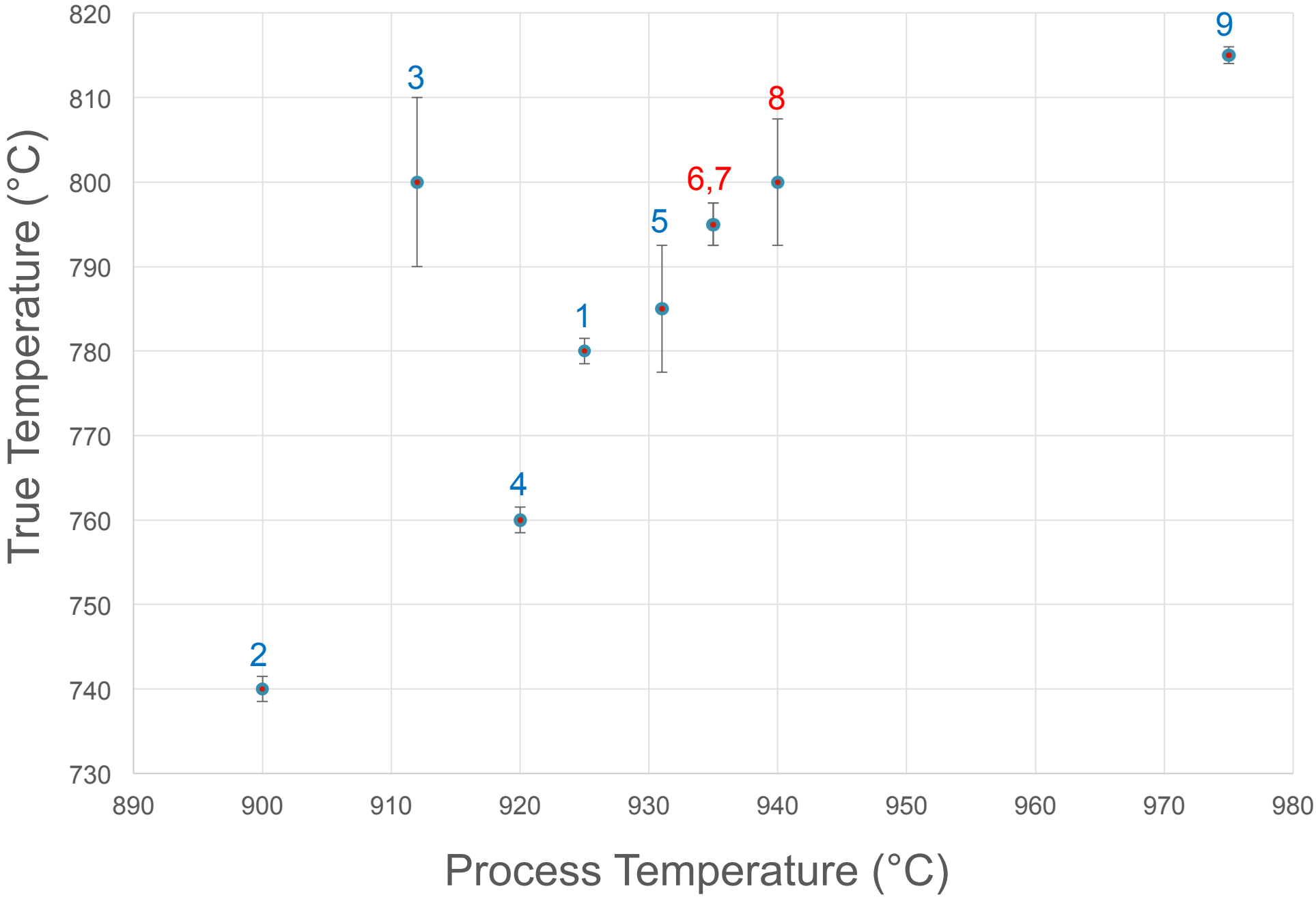

00 nm
EHT = 5.00 kV
WD = 3.7 mm
Signal A = InLens
Mag = 135.87 K X
Signal B = SE2
Signal = 1.0000
Mag Range = 3
ZEISS

Electrical Characterization - Samples #6 and #9

ample #	Growth Temperature (°C)	% Indium	InAlN Thickness (nm)	XRD (2θ)	Mobility (cm^2/V s Pre/Post RTA
	795	22	27	34.9	206 / 20.5
	815	18	25 (?)	35.2	-- / 20.5



True Temperature vs. Process Temperature



Next Steps

Grow full stack in one growth on 4” wafer to reduce edge effects and prevent inconsistencies from varying sample size

Use more sensitive Hall effect measurement tool and structure with smaller contact area to reduce effects of metal sinking on 2DEG properties

Develop metal contact stacks that are stable at high temperature

Questions?