MOCVD Growth Calibration for GaN LED on Silicon

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EE412, Spring 2015

Outline

Introduction
- Motivation
- Previous Work

Methodology
- Tools
- Device Structure
- Tasks

Experiment & Results
- n-GaN doping calibration
- p-GaN doping calibration
- AlGaN verification
- InGaN calibration

Conclusion
- Summary of work
- Proposed future work
- Main contribution to SNF

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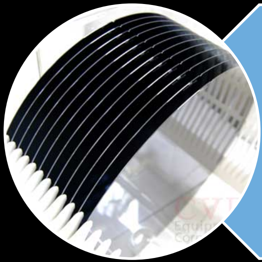
Motivation

UV/blue/white light LED

- Multi-billion $ market
- Nobel prize



Silicon substrate

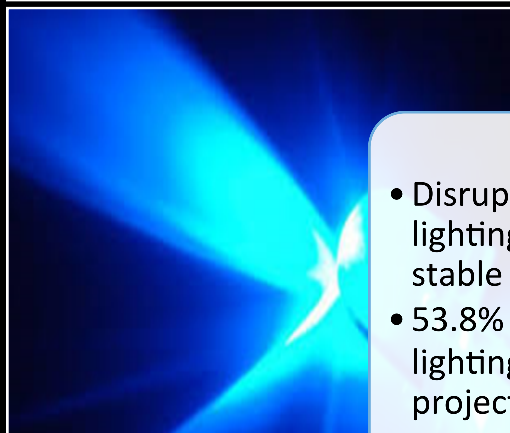
- Cost effective
- But makes growth challenging

Value to SNF

- Enabling short-wavelength LED research
- Making new III-N materials available in SNF

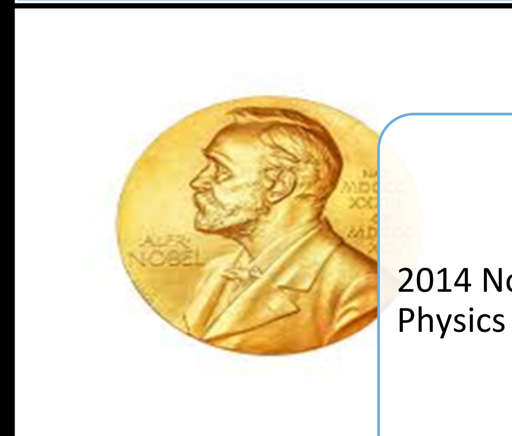
Previous Work

UV/blue/white light LED



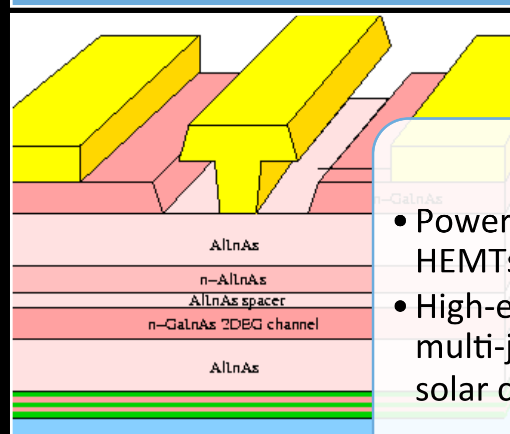
- Disrupting the lighting 100-year-stable industry
- 53.8% street lighting, 93.8% projected by 2023[2]

III-N MOCVD Technology



2014 Nobel prize in Physics

Other Applications



- Power devices & HEMTs
- High-efficiency multi-junction solar cells

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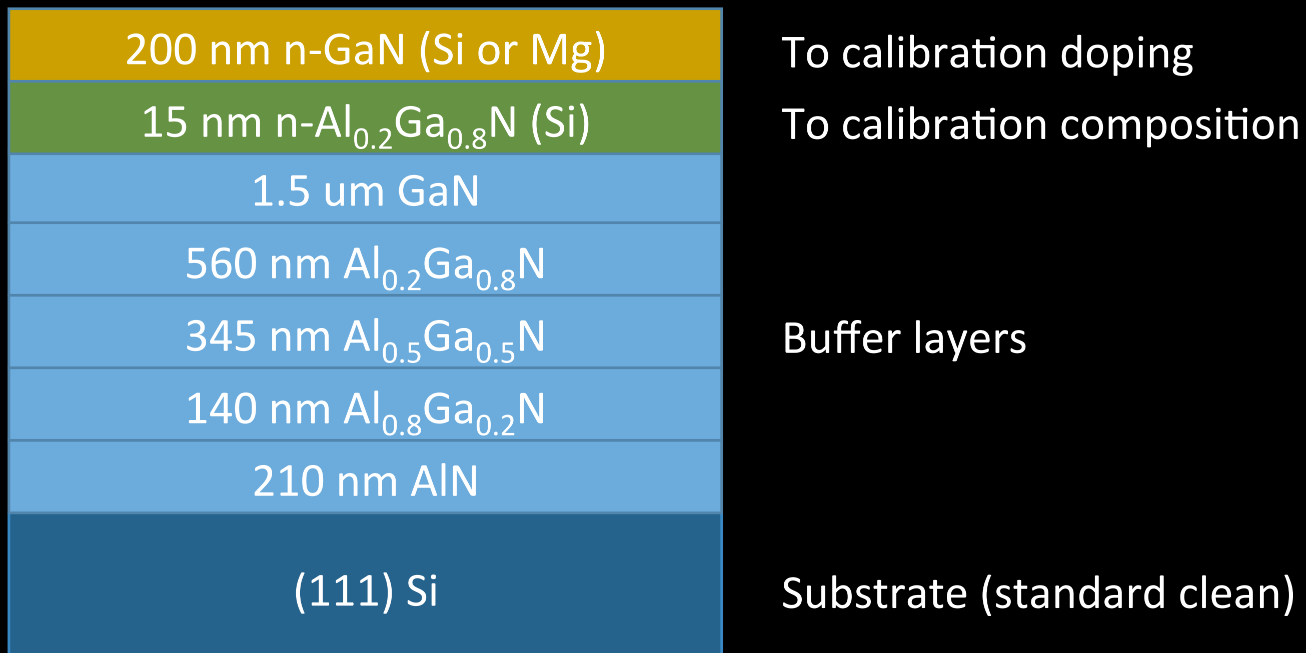
Tools

- Aix-ccs MOCVD
- Hall Measurement
- Innotec & RTA
- SEM & IV
- XRD

Test Epi Structure



List of Tasks

n-GaN

- Investigate relation between doping density and SiH_4 flow rate

p-GaN

- Investigate relation between doping density and
  - Mg flow rate
  - Growth temperature
  - Annealing temperature

AlGaN

- Verify growth thickness for $Al_{0.2}Ga_{0.8}N$

InGaN

- Investigate relation between indium composition and growth temperature
- Verify crystal quality

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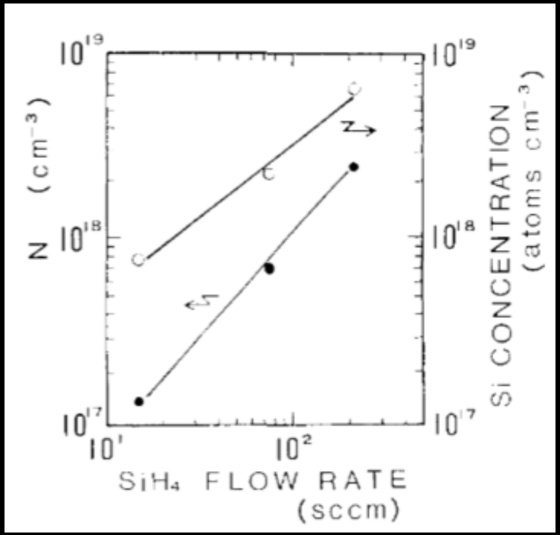
Experiment & Results - Summary

- Tool Capability Verified
  - 16 rounds of growth
  - > 120 hour of growth time
- n-GaN and p-GaN successfully grown
  - 1st time ever in SNF
  - Controllable doping achieved
- AlGaN and InGaN successfully grown
  - good crystal quality on Si substrate

n-GaN Doping Calibration

- Doping with SiH_4 diluted with H_2
- n-doping depends mainly on the ratio of Si and Ga flow rates
  - ➢ Vary SiH_4 flow, measure mobility, resistivity and doping density

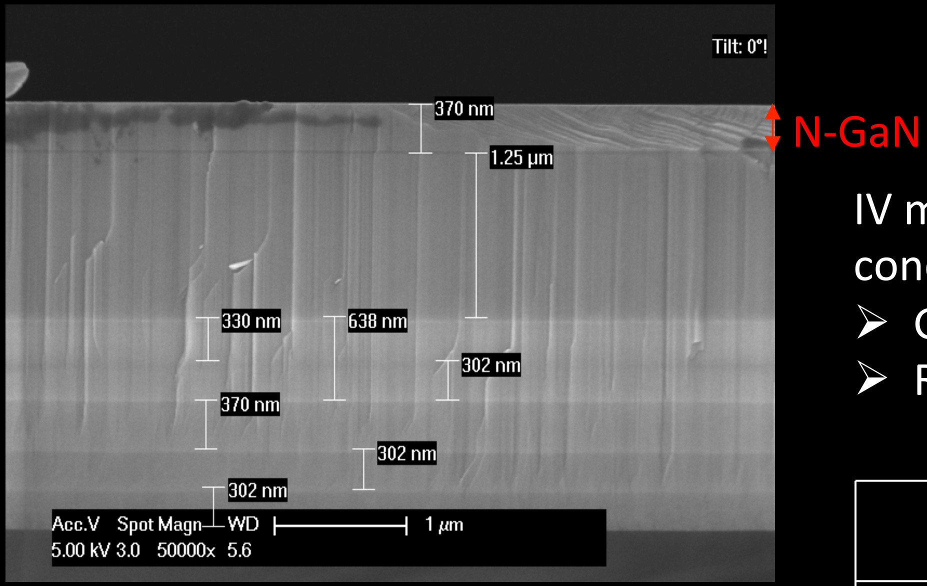


Cleaning → Grow Test Structure → Metaliz-ation → RTA → IV → Hall

Metalization: Innotec: 20nm Ti / 100 nm Al / 80 nm Pt

RTA: 850C, 35s, in N2

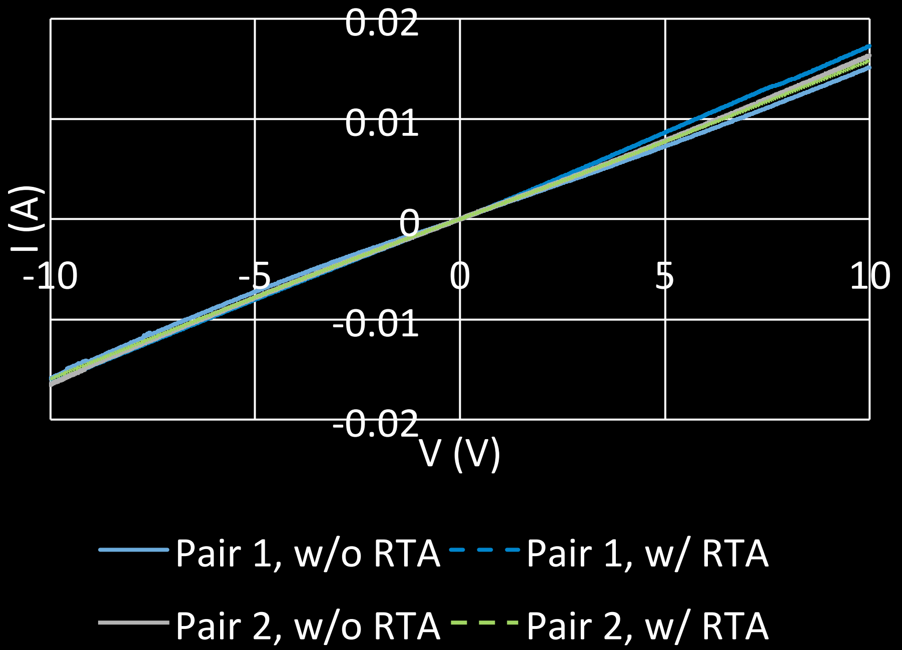
n-GaN Doping Calibration Results – SEM & IV



Smooth growth interface and expected thickness achieved

IV measurement indicates good conductivity

- Good contact quality
- RTA does not have significant effects



n-GaN Doping Calibration Results – Hall Measurement

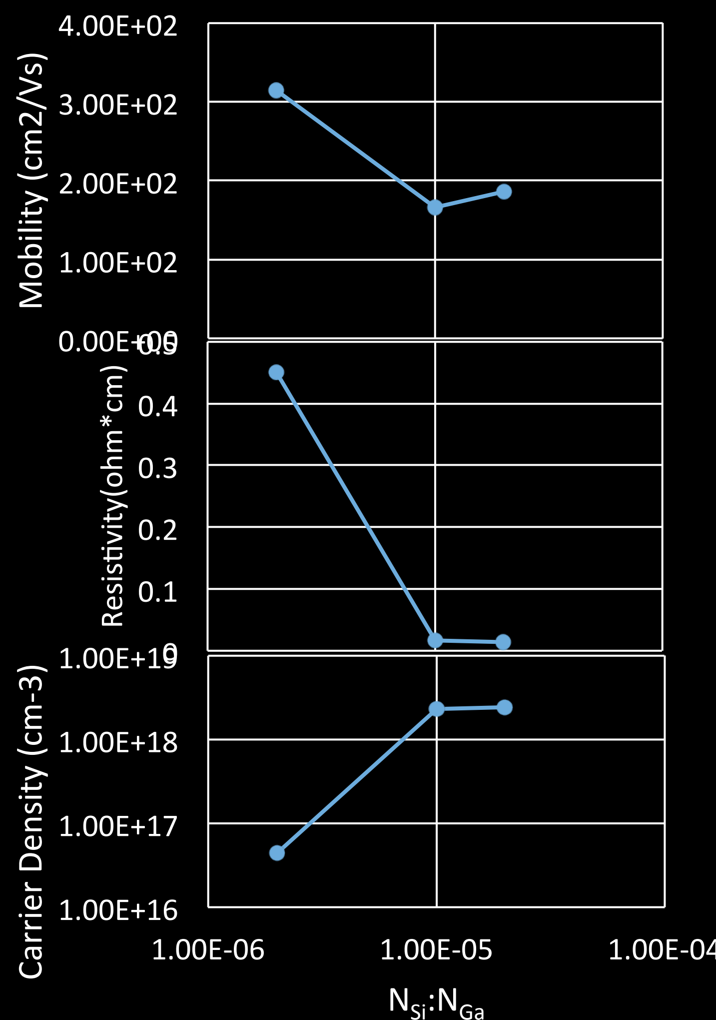
$N_{Si}:N_{Ga}$	Mobility (cm2/Vs)	Resistivity (ohm*cm)	Carrier Density (cm-3)
2.00E-06	3.2E22	0.45	4.4E16
1.00E-05	1.7E2	0.017	2.3E18
2.00E-05	1.9E2	0.014	2.4E18

Growth Temp	Growth Time	Growth Pressure	SEM Thickness
1295C	680 sec	200 mbar	352 nm

Carrier density of ~1E18 cm^{-3} achieved.

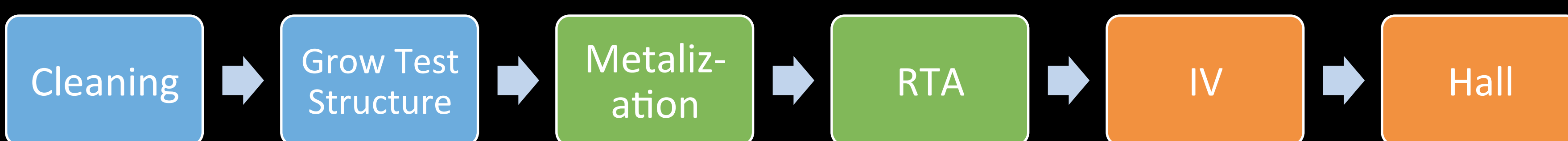
- ❖ Most optoelectronic application requires 1E17~1E18 cm^{-3}

Mobility measurement result indicates good material quality.



p-GaN Doping Calibration

- Doping with Cp2Mg (Bis(cyclopentadienyl)magnesium).
- Calibration very complicated: p-doping depends on multiple parameters:
  - Mg and Ga flow rate ratio
  - Growth temperature
  - Post growth annealing (Mg dopant activation) temperature & time
  - p-GaN metal contact is also difficult to make



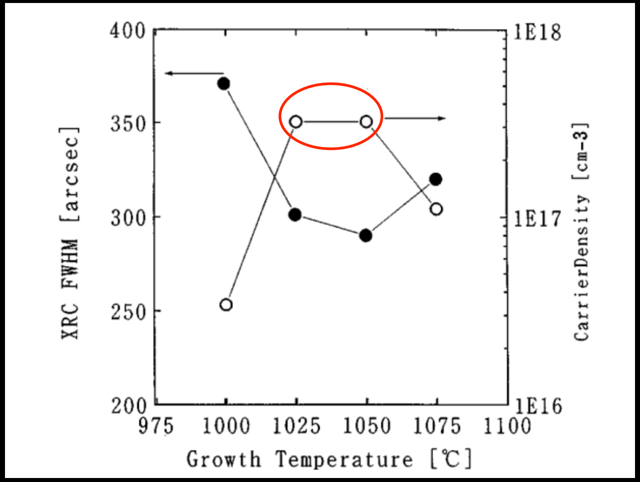
Innotec: 20nm Ni / 20nm Au

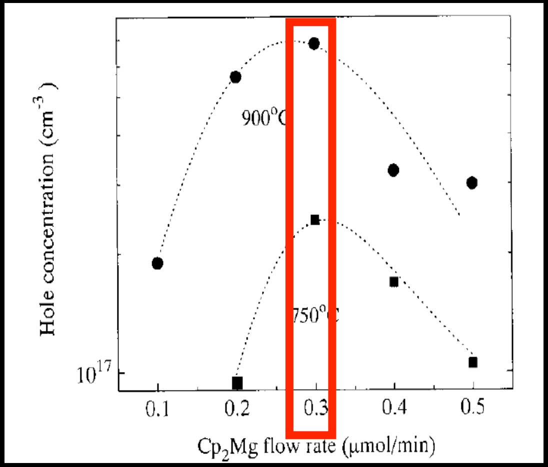
10 min @ 500C
20% O_2 ,80% N_2

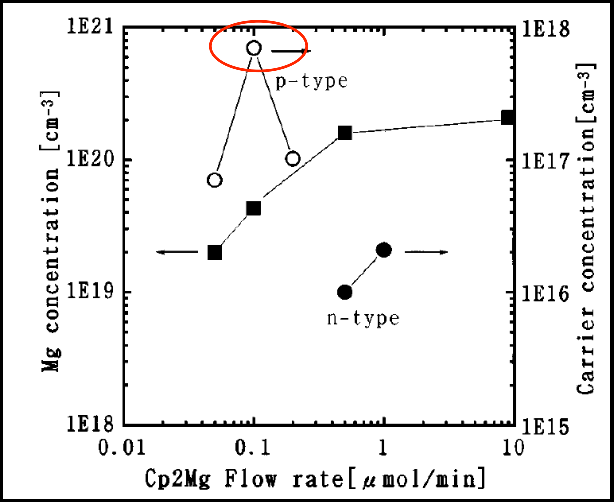
Experiment Design – Parameter & Variables

- Mg and Ga flow rate ratio
- Growth temperature
- Post growth annealing (Mg dopant activation) temperature & time
- p-GaN metal contact is also difficult to make

Extremely narrow growth window!!







Tokunaga, H., et al. "Growth condition dependence of Mg-doped GaN film grown by horizontal atmospheric MOCVD system with three layered laminar flow gas injection." Journal of crystal growth 189 (1998):

p-GaN Doping Calibration Results – Parameter Matrix

Annealing Temp. = 750 C

		N_{Mg}/N_{Ga}			
Growth Temp. (C)		0.0017	0.0034	0.0068	0.0092
	1200				
	1230				
	1295				

Annealing Temp. = 990 C

		N_{Mg}/N_{Ga}			
Growth Temp. (C)		0.0017	0.0034	0.0068	0.0092
	1200				
	1230				
	1295				

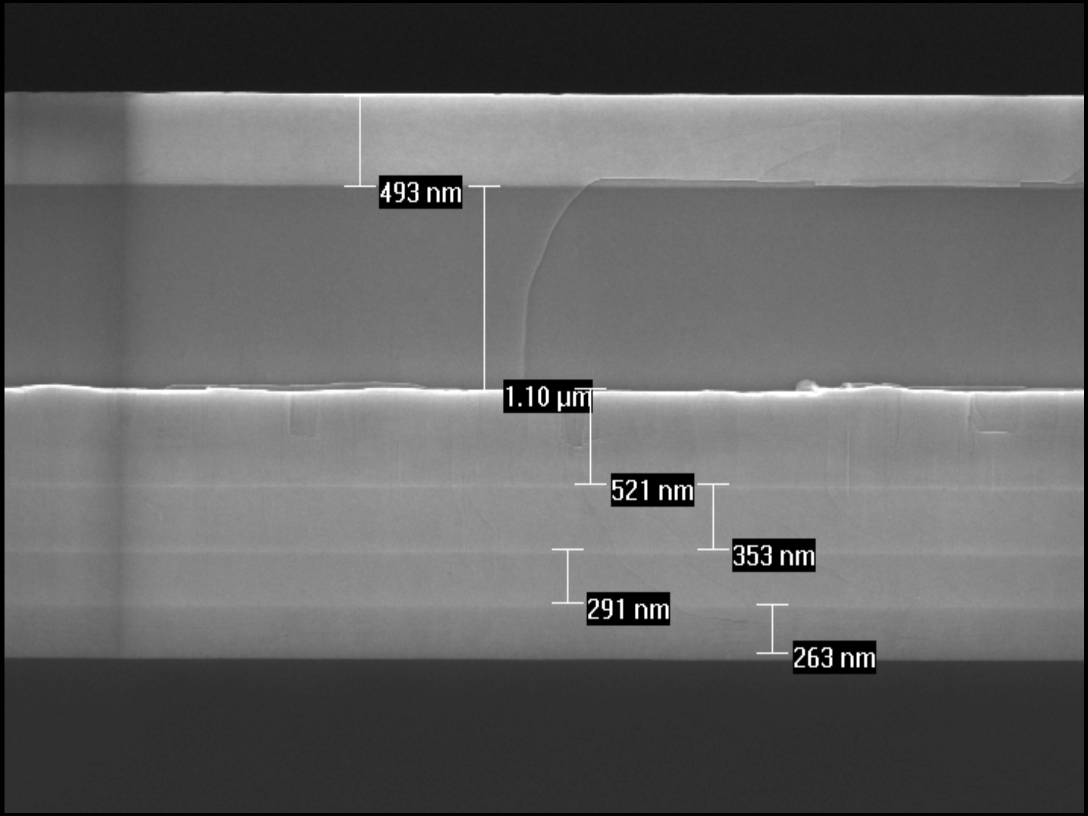
Annealing Temp. = 1000 C

		N_{Mg}/N_{Ga}			
Growth Temp. (C)		0.0017	0.0034	0.0068	0.0092
	1200				
	1230				
	1295				

Annealing Temp. = 820 C

		N_{Mg}/N_{Ga}			
Growth Temp. (C)		0.0017	0.0034	0.0068	0.0092
	1200				
	1230				
	1295				

p-GaN Doping Calibration Results - SEM



Smooth growth interface. Expected thickness achieved

p-GaN Doping Calibration Results - IV

The contact will be ohmic only if the carrier density is sufficiently high

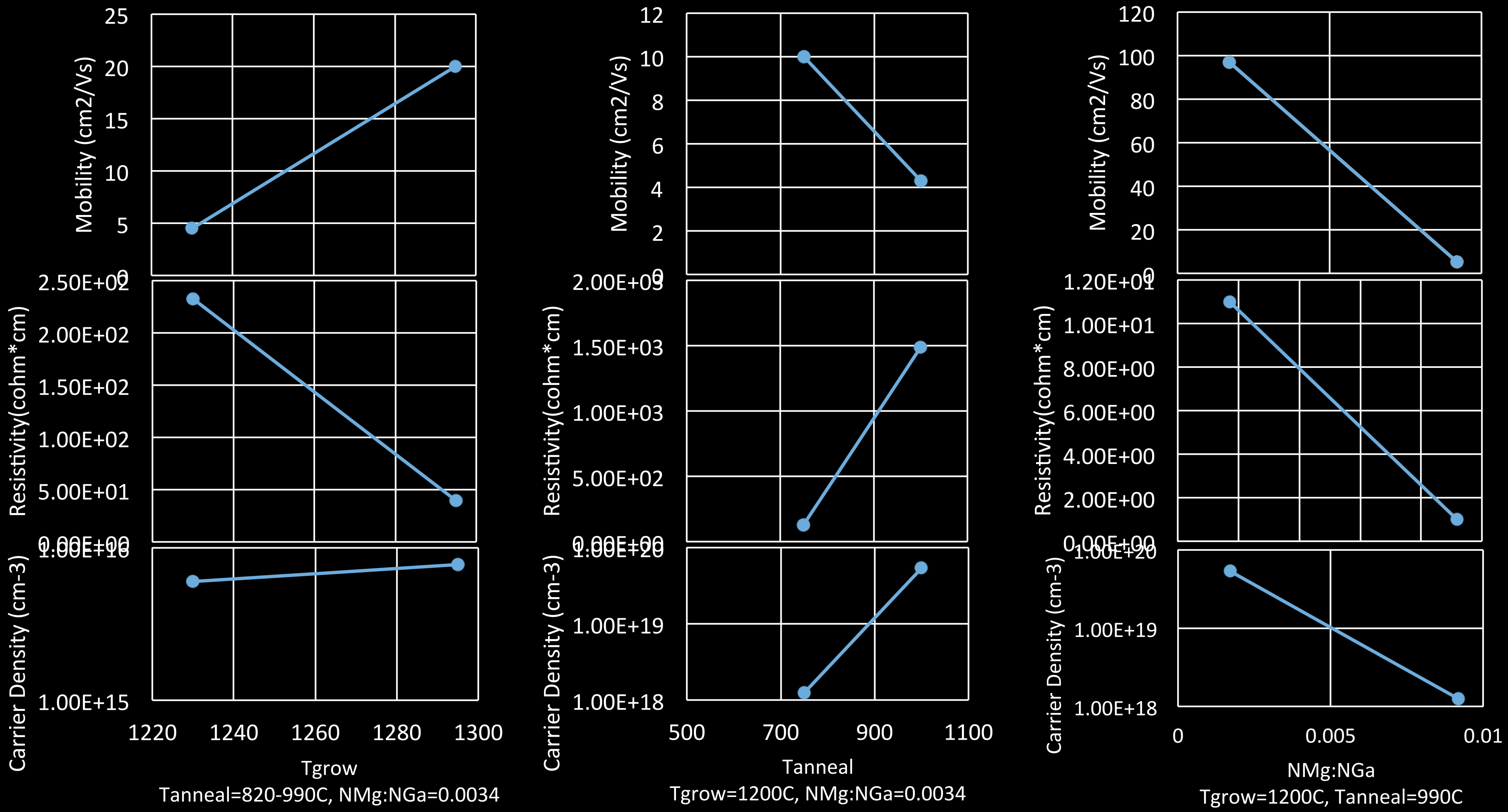
- ❖ Carrier density measurement relies on good contact
- ➢ Very challenging to conduct Hall measurement
- ▪ Contact annealing is crucial

p-GaN Doping Calibration Results – Hall Measurement

N_{Mg}/N_{Ga}	Growth Temp. (C)	Annealing Temp. (C)	Thickness (nm)	Mobility (cm^2/Vs)	Resistivity (ohm*cm)	Doping Density (cm^{-3})
0.0034	1295	750	425	10	1.28E+02	9.41E+14
0.0034	1295	1000	350	4.3	1.49E+03	1.01E+16
0.0068	1295	750	336	7.6	1.68E+03	4.76E+14
0.0034	1295	990	450	20	3.94E+01	7.73E+15
0.0034	1230	820	500	4.5	2.33E+02	6.00E+15
0.00918	1200	990	200	5.3	1.00E+00	1.25E+18
0.0017	1200	990	500	97	1.10E+01	5.34E+19

Red data are reasonable estimations.

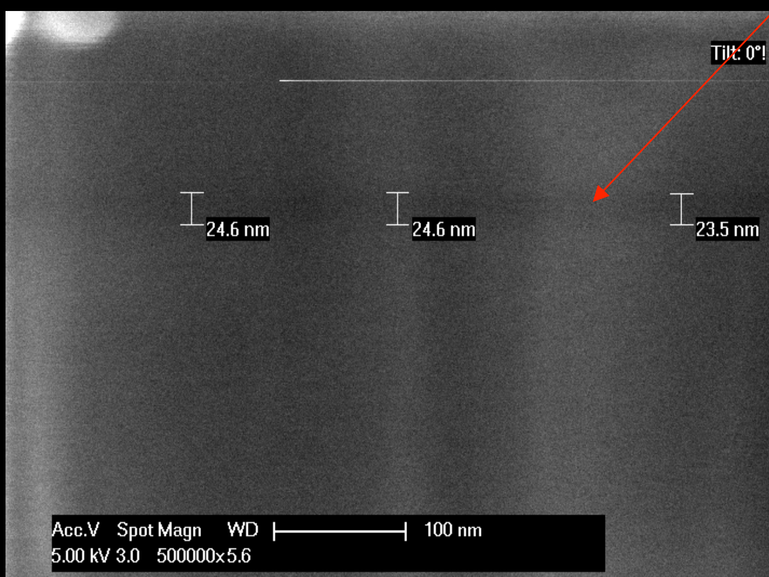
p-GaN Doping Calibration Results – Hall Measurement

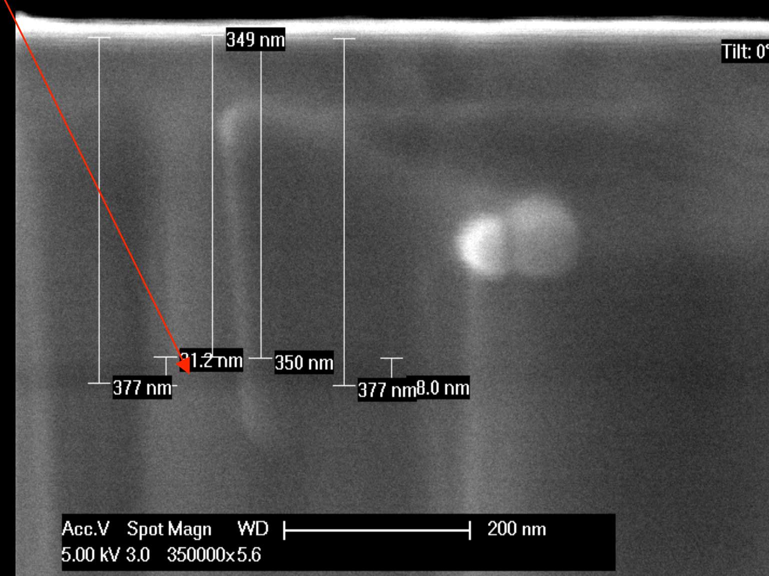


AlGaN Growth Verification

$N_{Al}:N_{Ga}$	NH3 Flow	Growth Temp	Growth Time	Growth Pressure	Thickness
0.1043	6.70E+02	1295 C	180 sec	100 mbar	23 nm

AlGaN

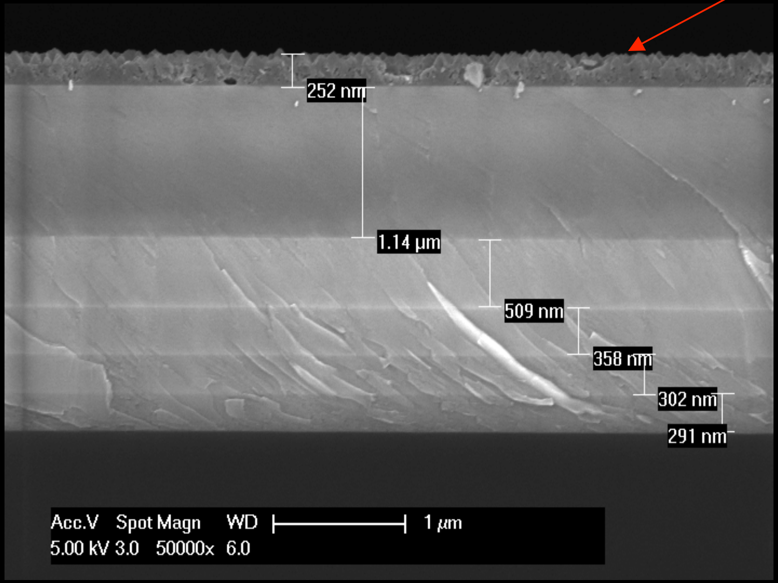




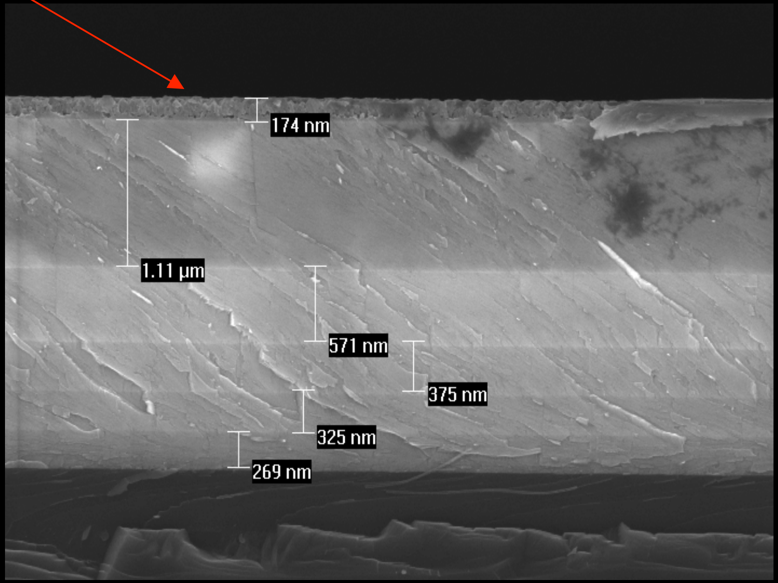
InGaN Growth Verification

N_{Al}:N_{Ga}	NH3 Flow	Growth Temp	Growth Time	Growth Pressure	Thickness	In %
1.42	4000	790C	2700 sec	400 mbar	250 nm	45
1.42	4000	850C	2700 sec	400 mbar	170 nm	36

InGaN



790 C

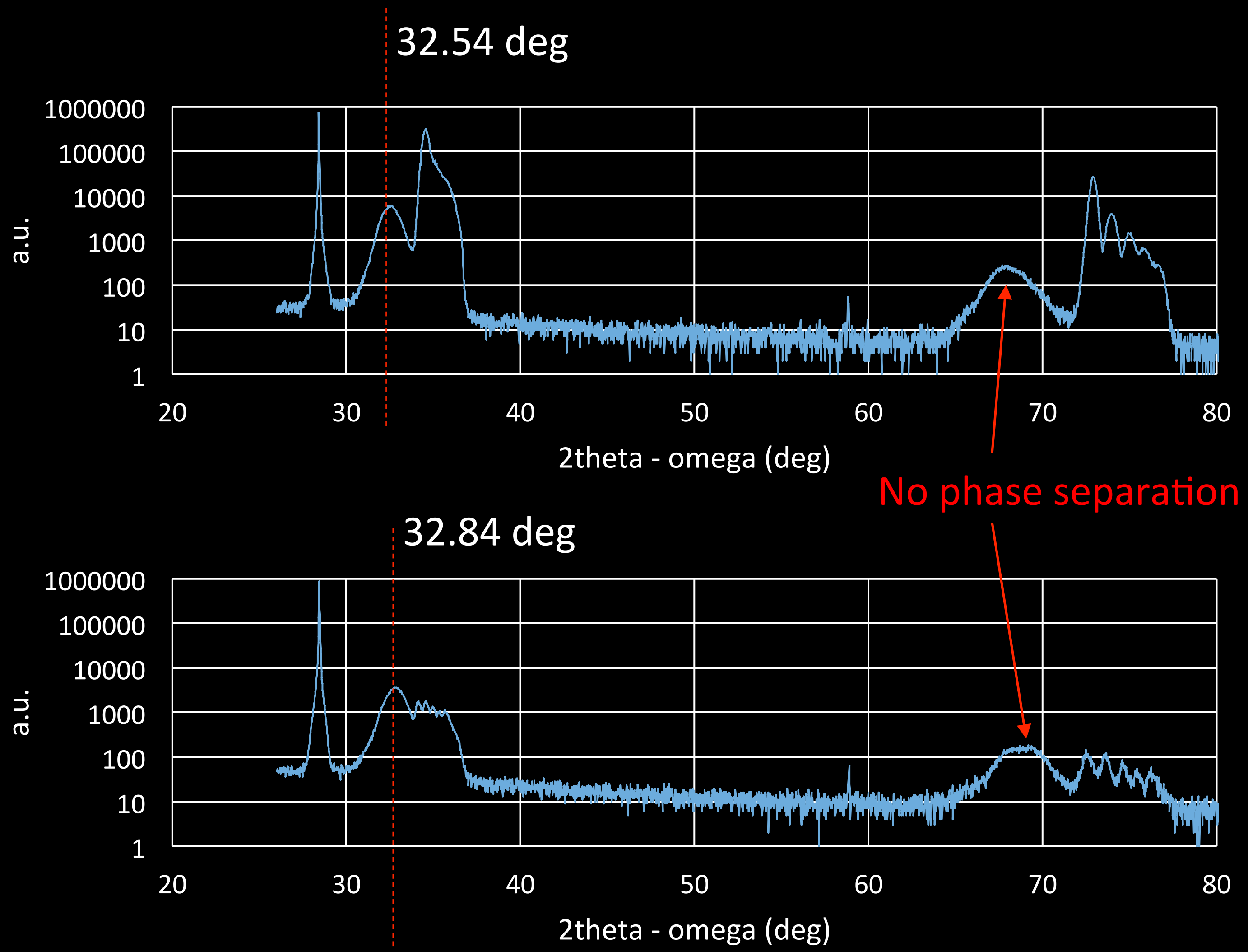


850 C

InGaN Growth Verification - XRD

790 C
In % = 45 %

850 C
In % = 36 %



Other work

- p-GaN growing thickness investigated
- RTA process for p-GaN investigated
- Growth chamber baking & brushing requirement investigated
- Indium contact and Ti/Al/Au contact for n-GaN compared

Details will be included in the final report

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Proposed Future Work

- Calibrate lower doping of p-GaN
- More InGaN and AlGaN calibration
- Try LED growth and fabrication

Main Contribution to SNF

n-GaN, p-GaN, AlGaN and InGaN growths are verified and calibrated

- Multiple new materials available at SNF!

Subsequent process investigated

- Metal contact recipe
- Metal annealing recipe

MOCVD capability tested, insights gained on MOCVD operation

- Valuable information for future Aix-ccs users

Acknowledgement

- Thanks to Xiaoqing for the mentorship, training on the MOCVD system and other help on the project
- Thanks to Prof. Howe, Dr. Mary Tang and other EE412 mentors for their valuable advice.
- Thanks to Prof. Harris for providing funding for SEM and other characterization tools.