Fabrication of AlGaN/GaN HEMTs

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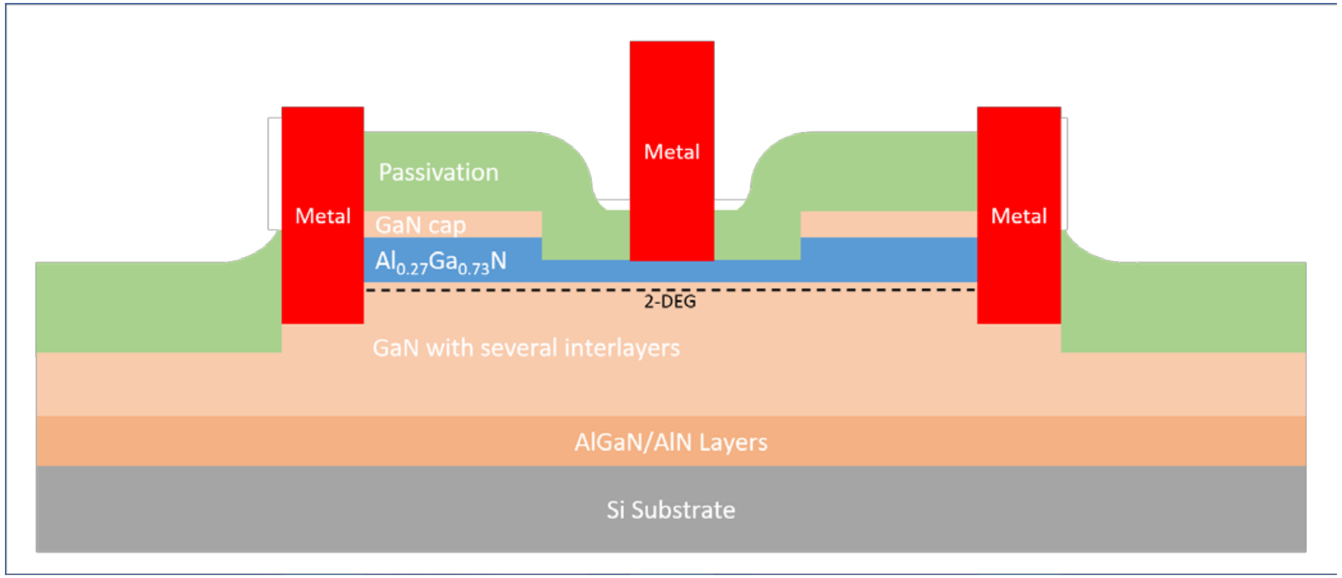


Project Goals

- Fabricate RIT's first AlGaN/GaN High Electron Mobility Transistors. Specifically, enhancement-mode HEMTs.
- Electrically test and characterize produced transistors to correlate to multiple processing conditions.

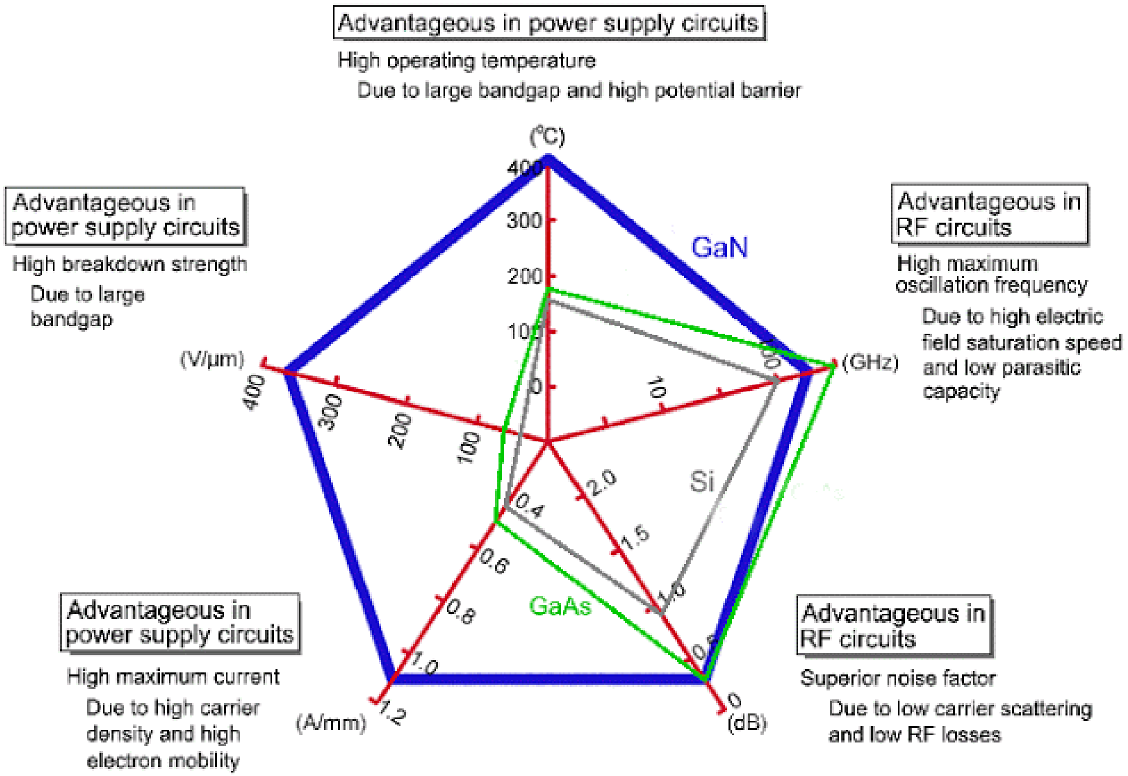
GaN

GaN is a III-Nitride compound semiconductor.

- Has a band gap of 3.4eV.
- Has a Wurtzite crystal structure
- High breakdown field
- High saturation velocity
- It is a piezoelectric material.

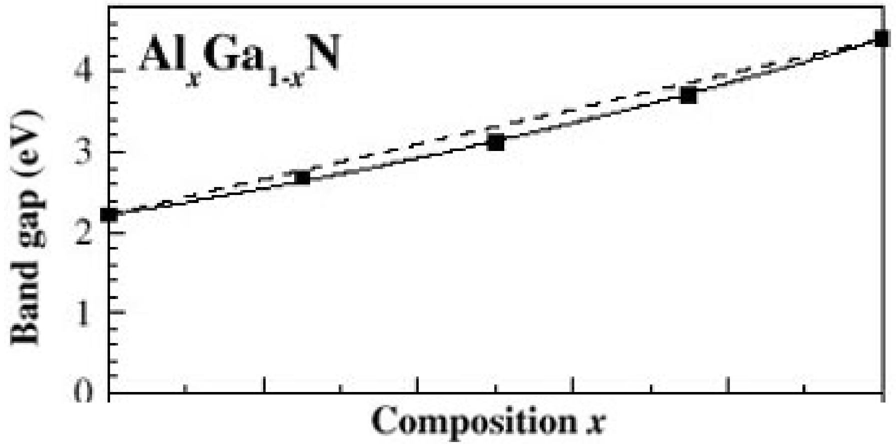
GaN Applications:

- LEDs
- Cars
- Power Switching
- Telecommunications
- Military



AlGaN

- AlGaN is a ternary compound.
- AlGaN can also be grown by MBE or MOCVD.
- The addition of Al produces a change in the bandgap.
- The bandgap of AlGaN can be controlled by changing the percentage of Al present compared to Ga.
  - Bandgap changes roughly follows Vegard's Law, with some deviation



[1]

[1] Dridi, Z., Bouhafs, B. and Ruterana, P. (2003). First-principles investigation of lattice constants and bowing parameters in wurtzite AlxGa1 xN, InxGa1 xN and InxAl1 xN alloys. Semiconductor Science and Technology, 18(9), pp.850-856.

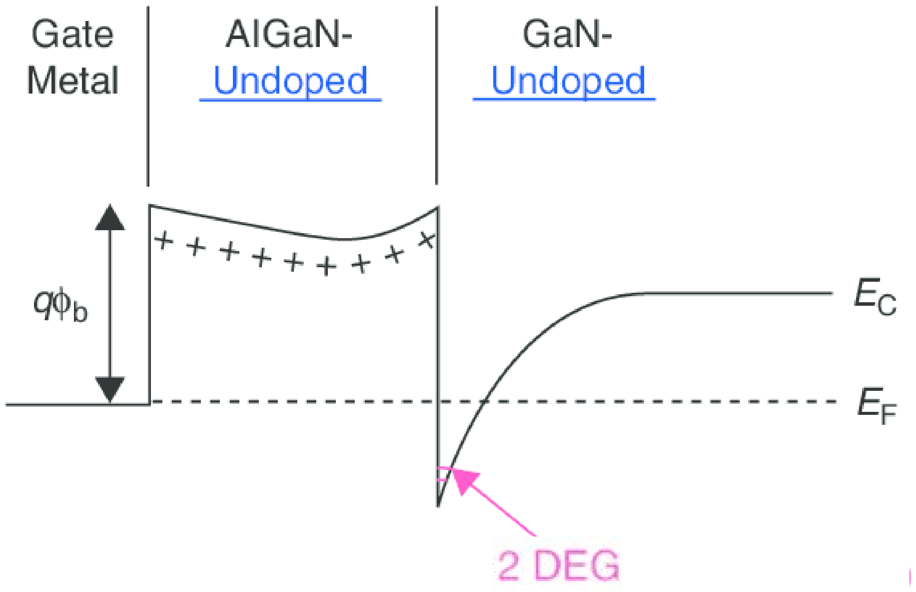
GaN Substrate Types

- GaN is grown on a variety of substrates.
  - GaN-on-Si
  - GaN-on-SiC
  - GaN-on-sapphire
- GaN-on-Si provides the possibility for future integration between Si-based devices and GaN power devices.

- GaN-on-Si wafers typically cost $500 per wafer.
- GaN-on-SiC wafers can cost up to $3000 per wafer.

AlGaN/GaN Interface

- The interface between layers of AlGaN and GaN result in the formation of a 2-Dimensional Electron Gas (2-DEG)
- This is due to the formation of a triangular quantum well at the interface between the AlGaN and GaN.
- The quantum well therefore allows for electrons to be confined in one dimension, while being allowed to move in the other two.



[2]

[2] Trew, Robert. (2004). Wide bandgap transistor amplifiers for improved performance microwave power and radar applications. 15th International Conference on Microwaves, Radar and Wireless Communications, MIKON - 2004. 1. 18 - 23 Vol.1. 10.1109/MIKON.2004.1356844.

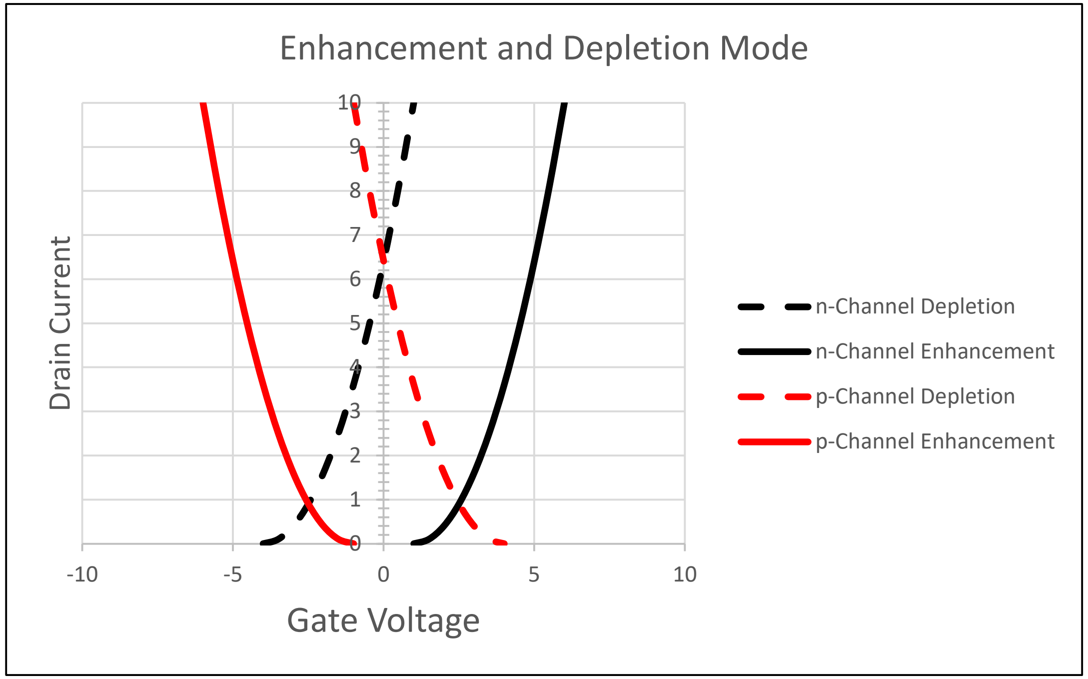
What is a HEMT?

- A High Electron Mobility Transistor is essentially a heterojunction FET.
- It uses the presence of an electron channel at the interface of the heterojunction.
- The presence of the electron channel allows for very high mobilities.

- HEMTs are therefore ideal for uses in RF and mm-Wave devices.

Enhancement Mode vs Depletion Mode

- Normally-On (Depletion-Mode) devices conduct current when the gate bias is 0V.
- Normally-Off (Enhancement-Mode) devices remain off and do not conduct current when the gate bias is 0V.
- AlGaN/GaN HEMTs are inherently depletion-mode devices.

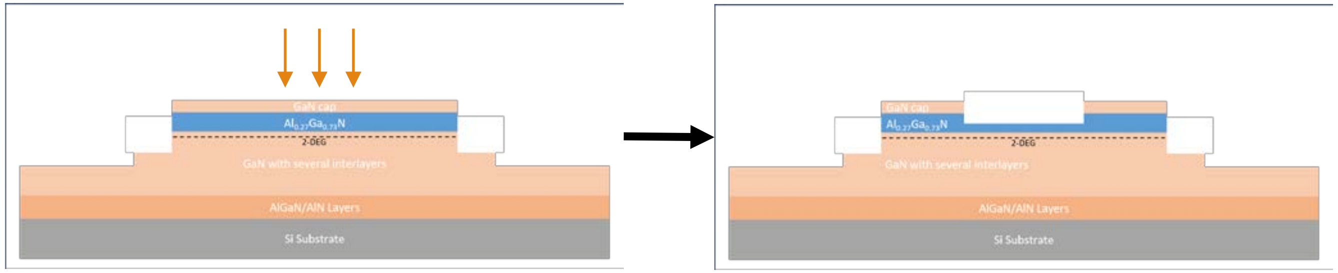


Enhancement and Depletion Mode in MOSFETs

Gate Recessing and F-Plasma

Gate Recessing:

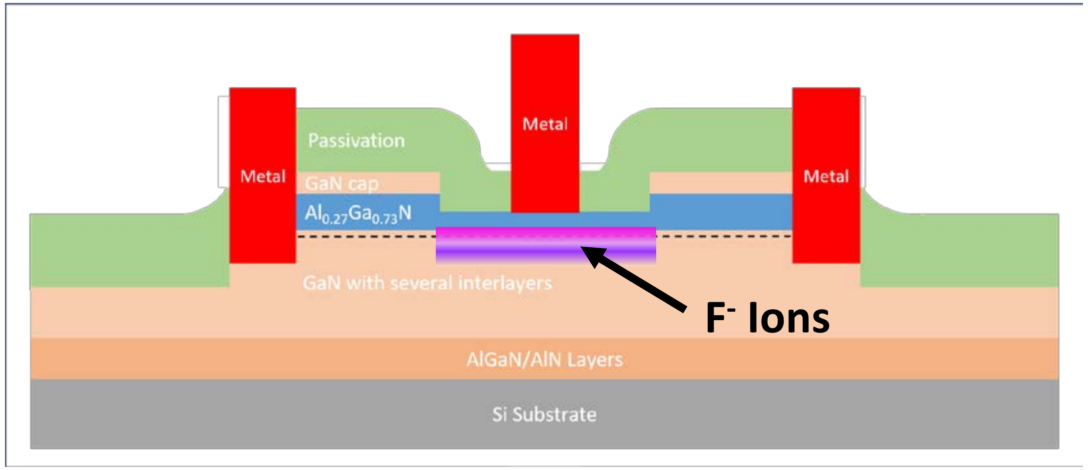
- Thinning the AlGaN gate regions



Gate Recessing

Fluorine Plasma

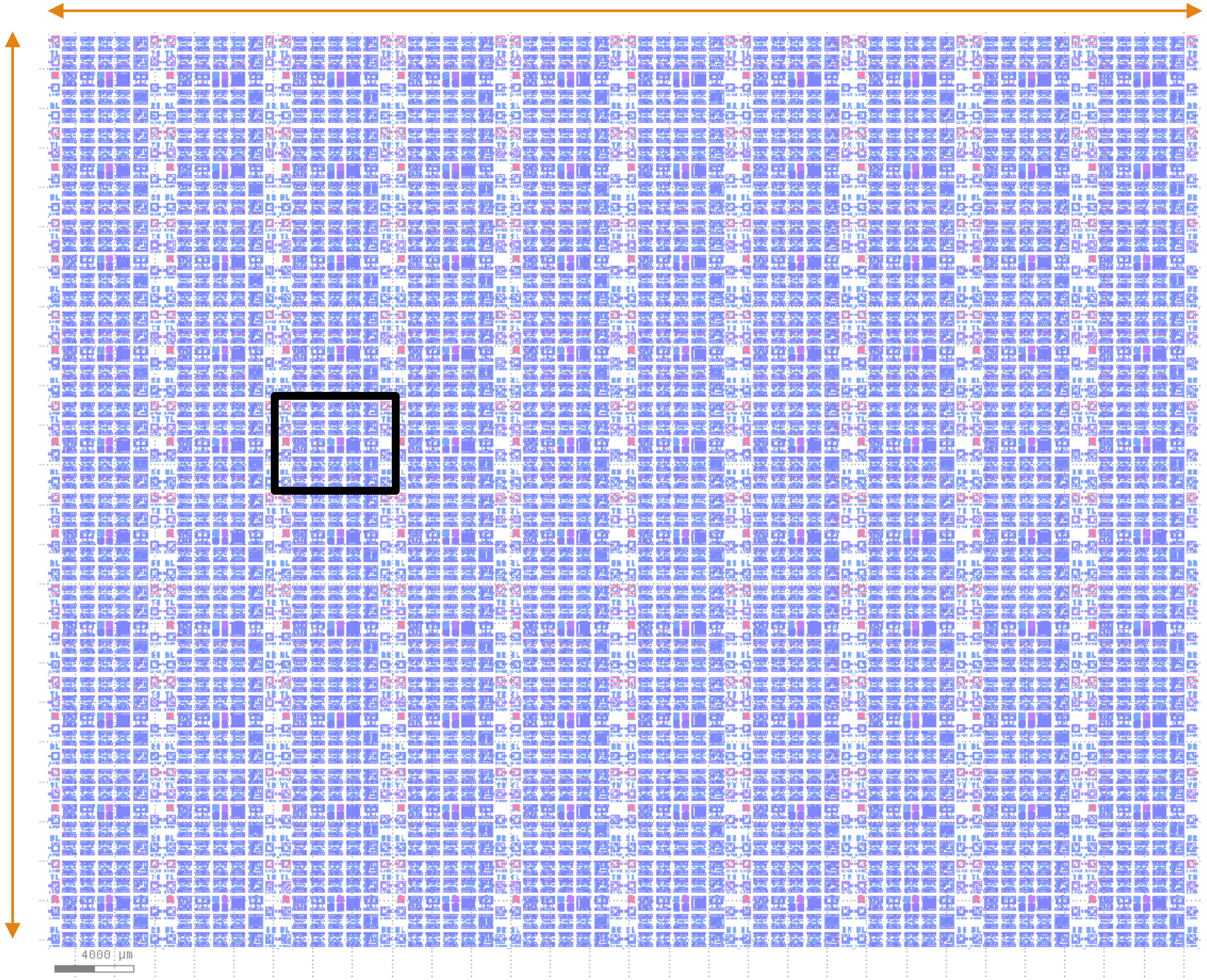
- Exposing the gate regions to a fluorine plasma to introduce F^- ions.



Fluorine ions present under gate regions

Mask Design

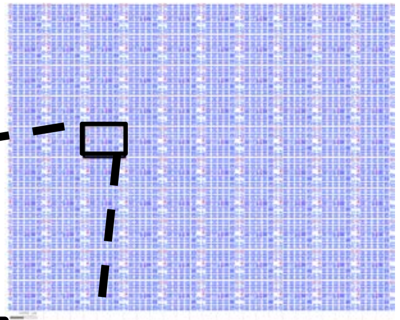
- 5 Masking Layers:
  - Mesa Isolation
  - Source/Drain Etch
  - Gate Recess
  - Contact Cut Etch
  - Metal
- Final mask consists of a single cell arranged in a 10x10 array.

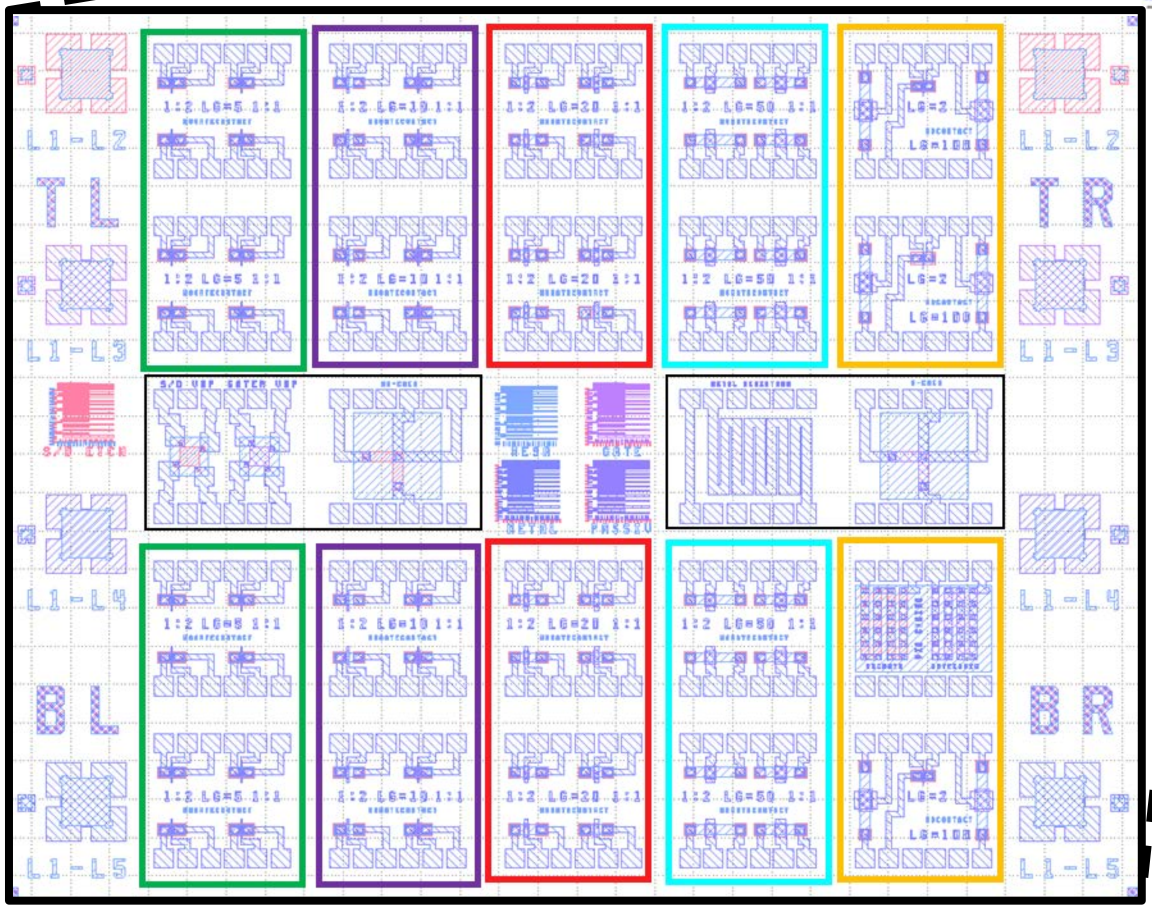


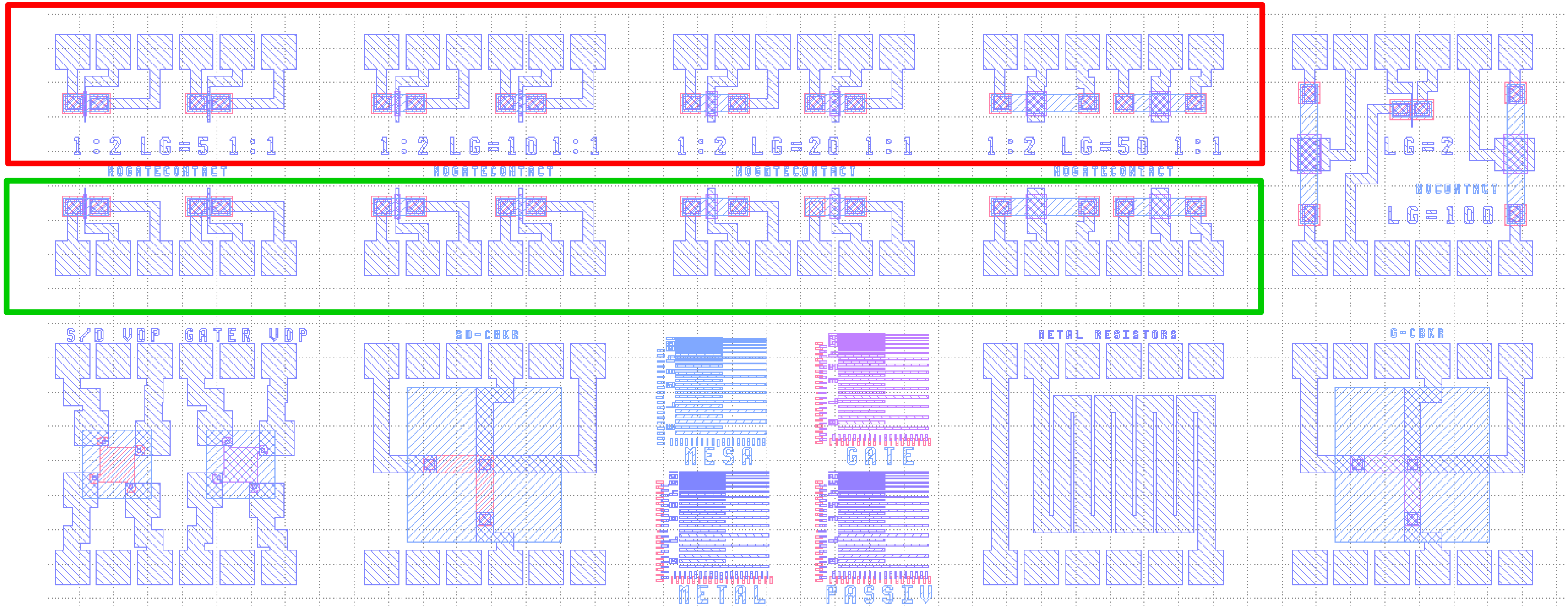
Single Cell Layout

Devices with Gate Lengths of:

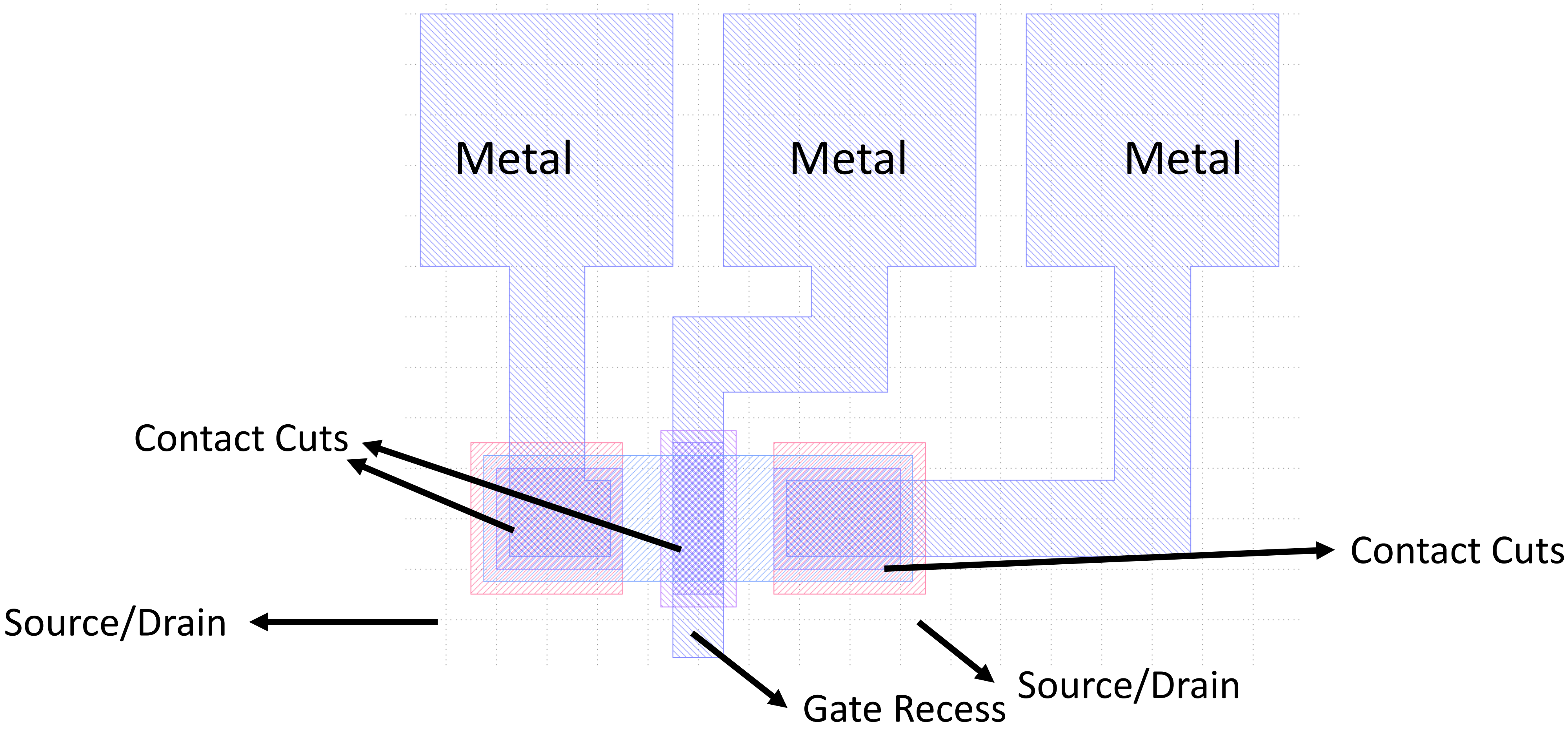
- 5µm
- 10µm
- 20µm
- 50µm
- 100µm
- Van Der Pauw’s, CBKRs and Metal Resistor







1:2 LG=5 1:1
1:2 LG=10 1:1
1:2 LG=20 1:1
1:2 LG=50 1:1
LG=2
NOGATECONTACT
NOCONTACT
LG=100
S/D VDP
GATER VDP
SD-CBKR
MESA
GATE
METAL
PASSIV
METAL RESISTORS
G-CBKR


Metal
Metal
Metal
Contact Cuts
Contact Cuts
Source/Drain
Gate Recess
Source/Drain

Tools Used For Fabrication

SCS Manual Spin Coater

Karl Suss MA-55

Chemical Wet Benches

LAM 4600 (Cl_2 RIE Etcher)

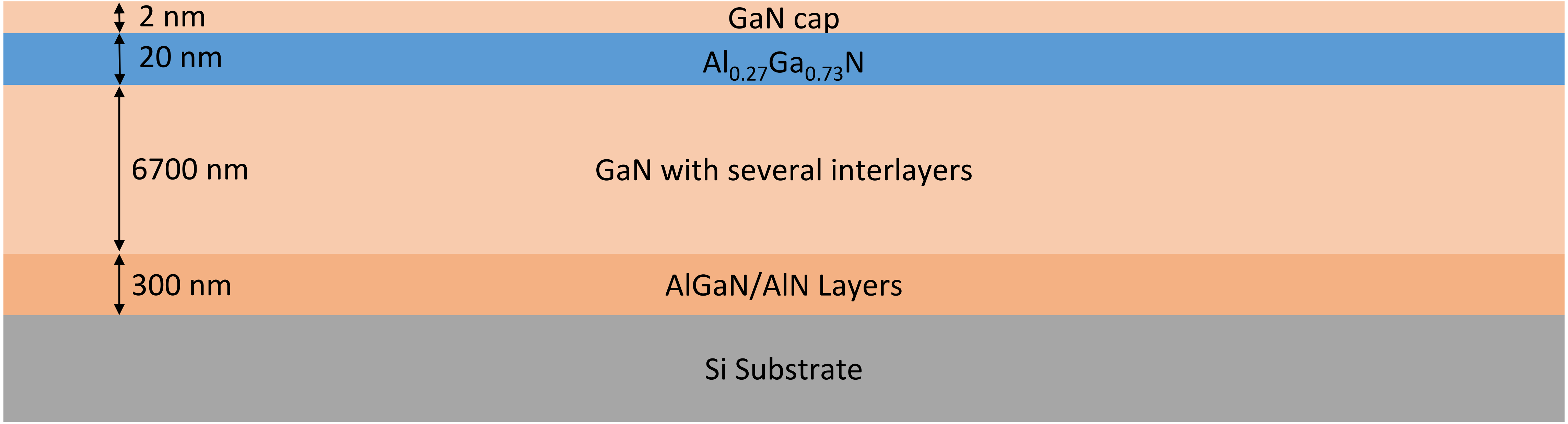
Trion Phantom III

Ultratech S200 ALD

CHA E-Beam Evaporator

LAM 4600: Cl_2 RIE Etcher used for etching GaN

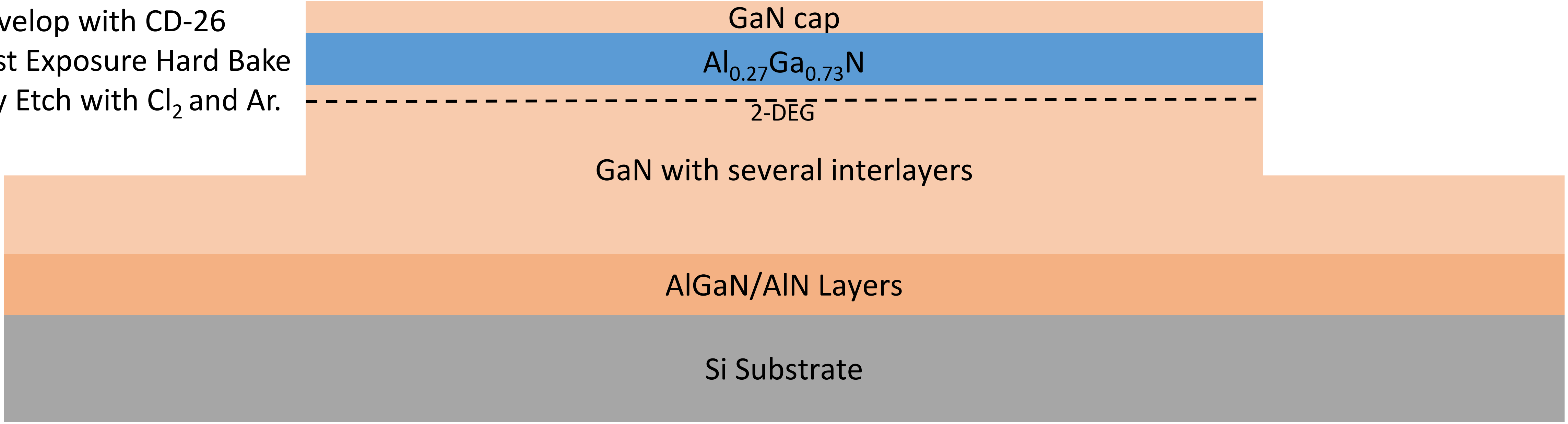
Initial Substrate



Mesa Isolation

Mesa Isolation Steps:

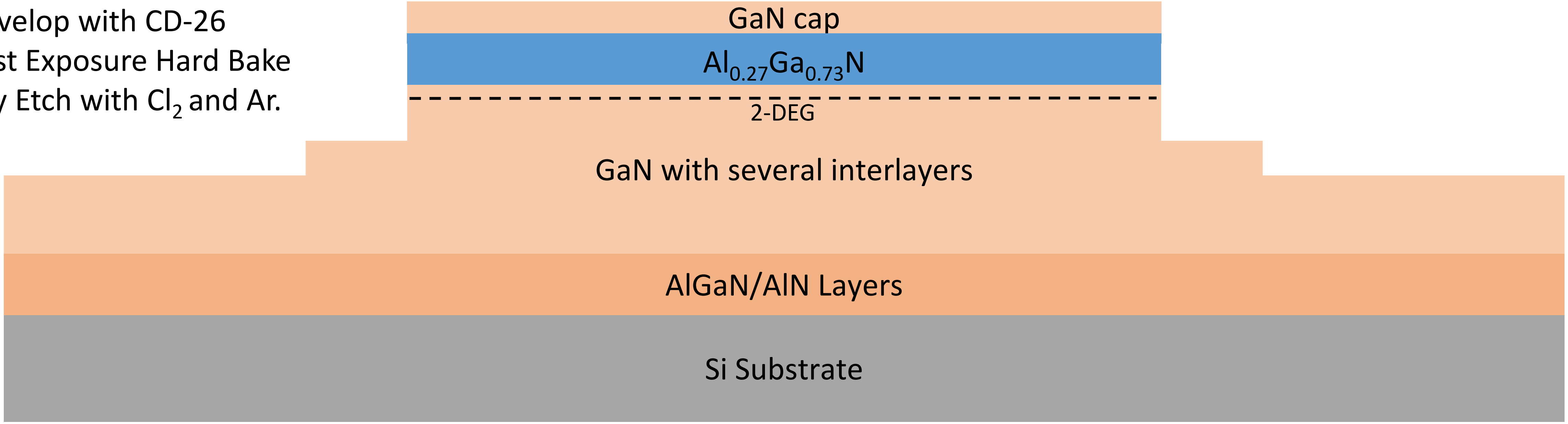
- Coat HMDS
- Bake
- Coat HPR-504 Photoresist
- Soft Bake
- Expose
- Develop with CD-26
- Post Exposure Hard Bake
- Dry Etch with Cl_2 and Ar.



Source Drain Etch

S/D Etch Steps:

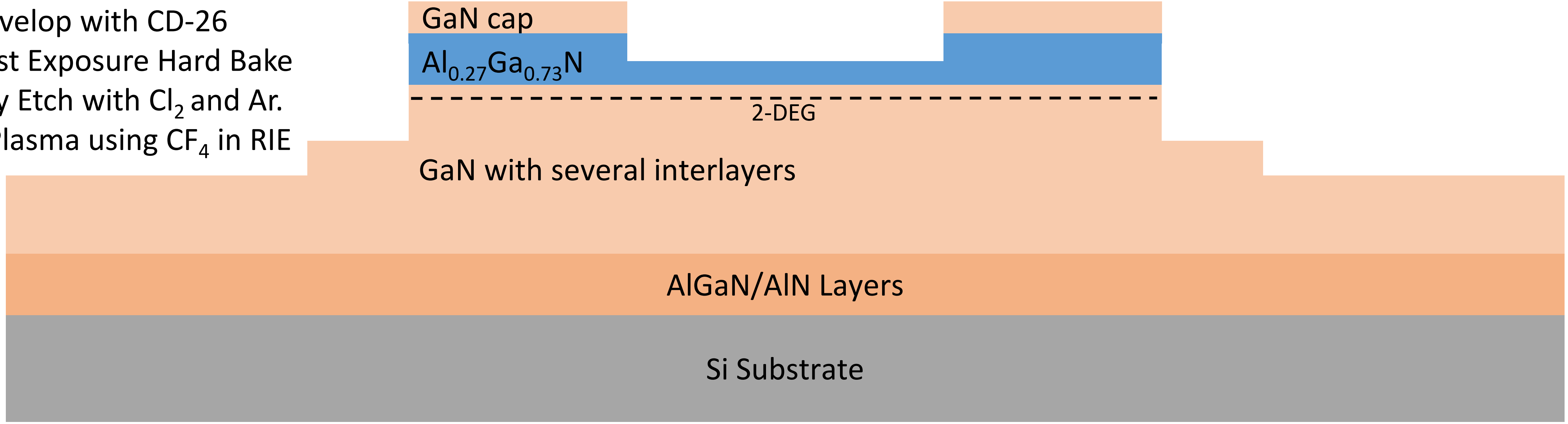
- Coat HMDS
- Bake
- Coat HPR-504 Photoresist
- Soft Bake
- Expose
- Develop with CD-26
- Post Exposure Hard Bake
- Dry Etch with Cl_2 and Ar.



Gate Recessing

Gate Recess Steps:

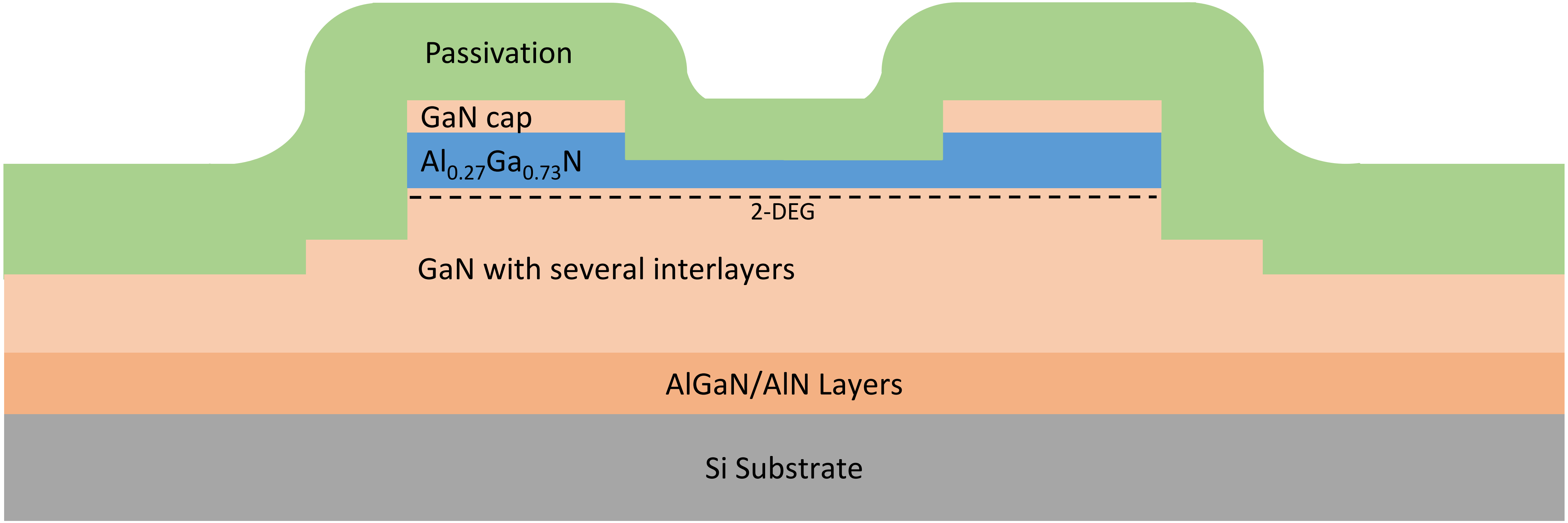
- Coat HMDS
- Bake
- Coat HPR-504 Photoresist
- Soft Bake
- Expose
- Develop with CD-26
- Post Exposure Hard Bake
- Dry Etch with Cl_2 and Ar.
- F Plasma using CF_4 in RIE



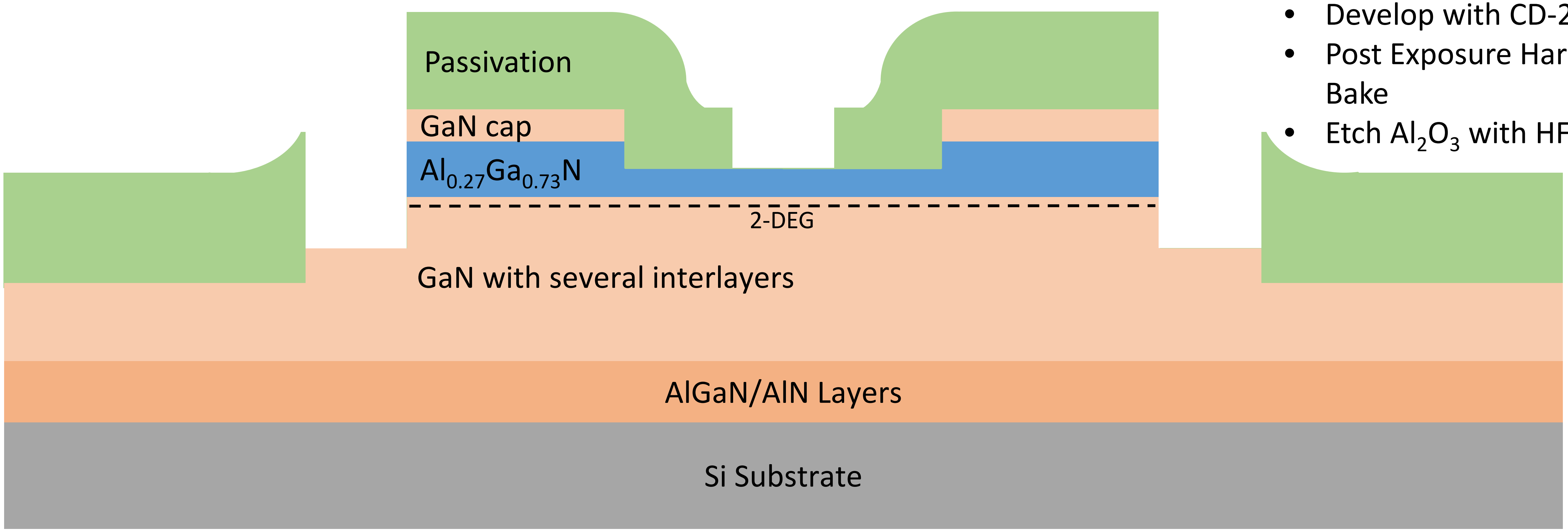
Passivation Deposition

Passivation Steps:

- Deposit 25nm of Al_2O_3 by Atomic Layer Deposition



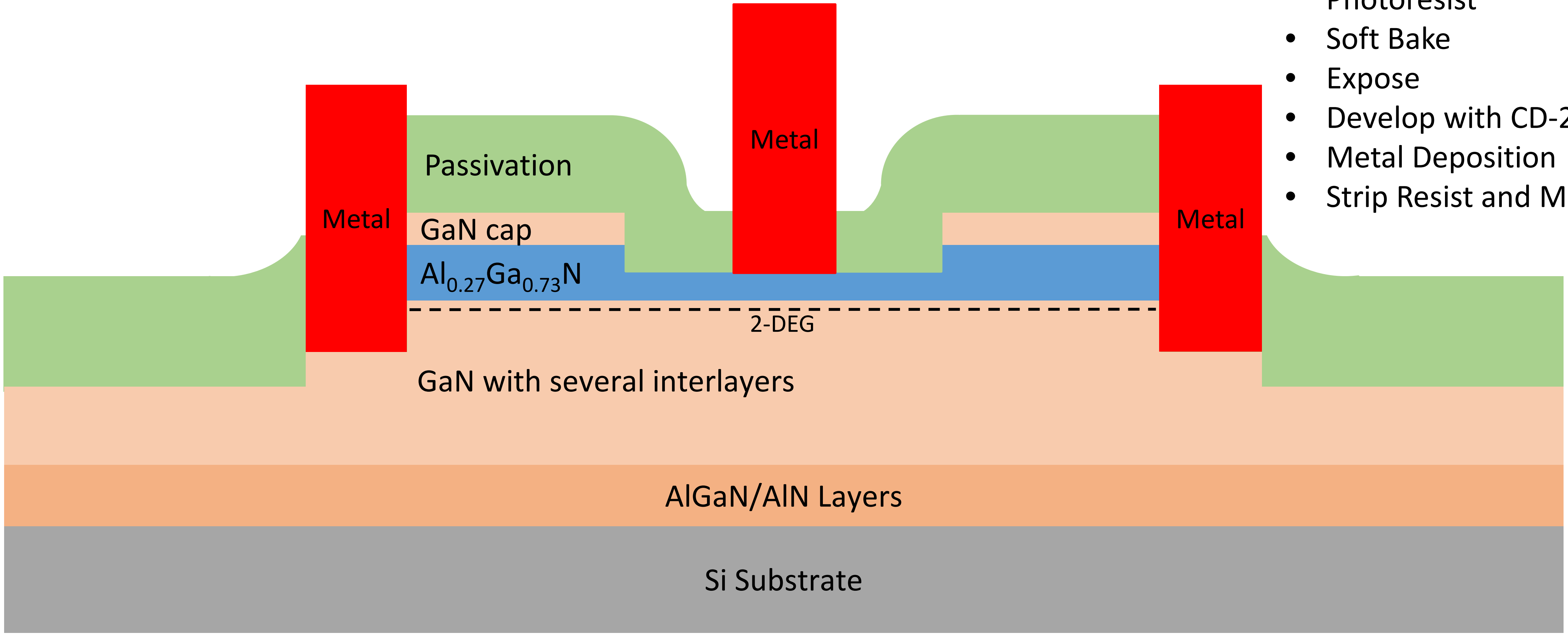
Contact Cut Etch



Contact Cut Steps:

- Coat HMDS
- Bake
- Coat HPR-504 Photoresist
- Soft Bake
- Expose
- Develop with CD-26
- Post Exposure Hard Bake
- Etch Al_2O_3 with HF

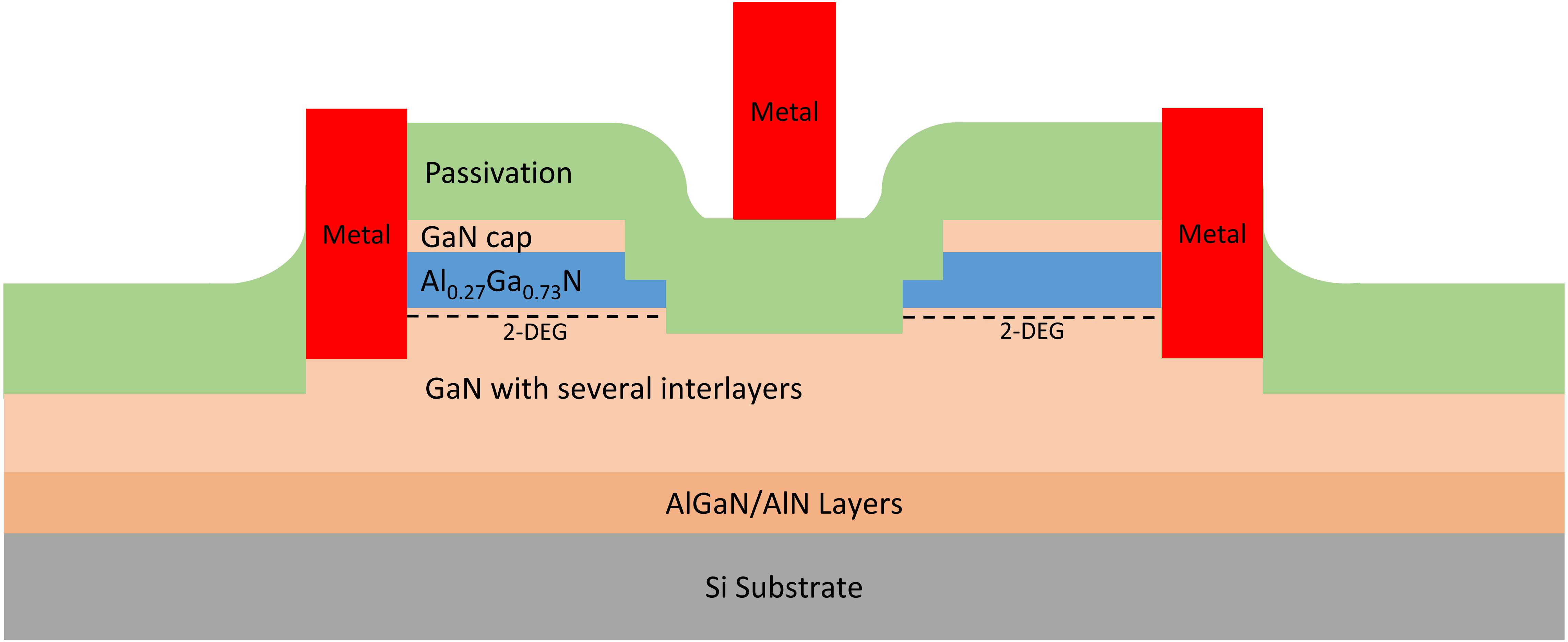
Metal Lift-off



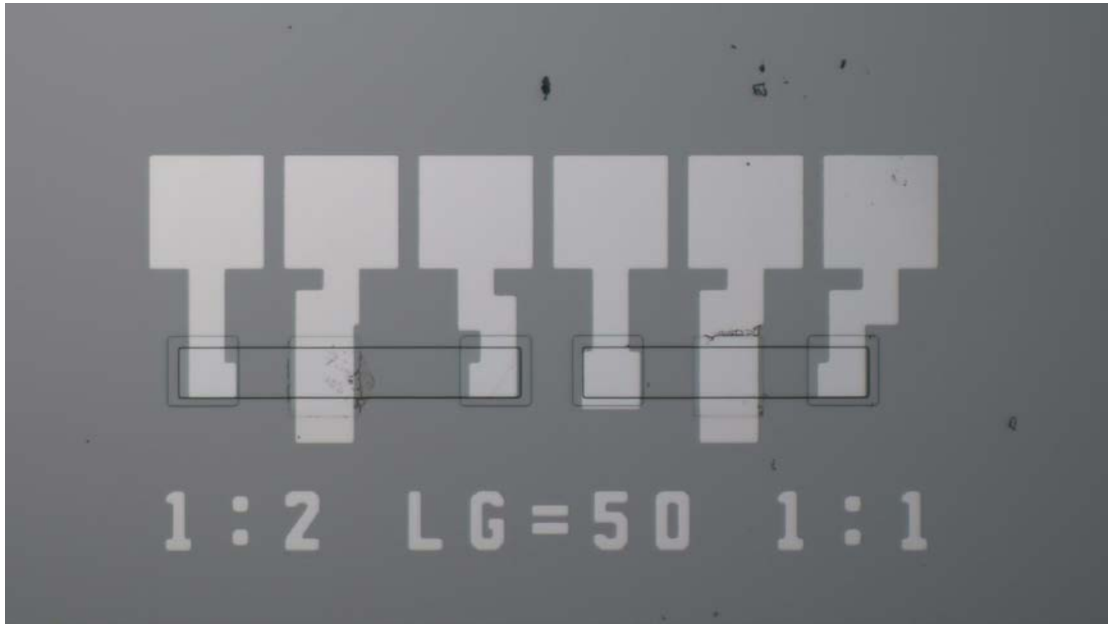
Metal Lift-Off Steps:

- Coat Lift-Off Resist
- Bake
- Coat HPR-504 Photoresist
- Soft Bake
- Expose
- Develop with CD-26
- Metal Deposition
- Strip Resist and Metal

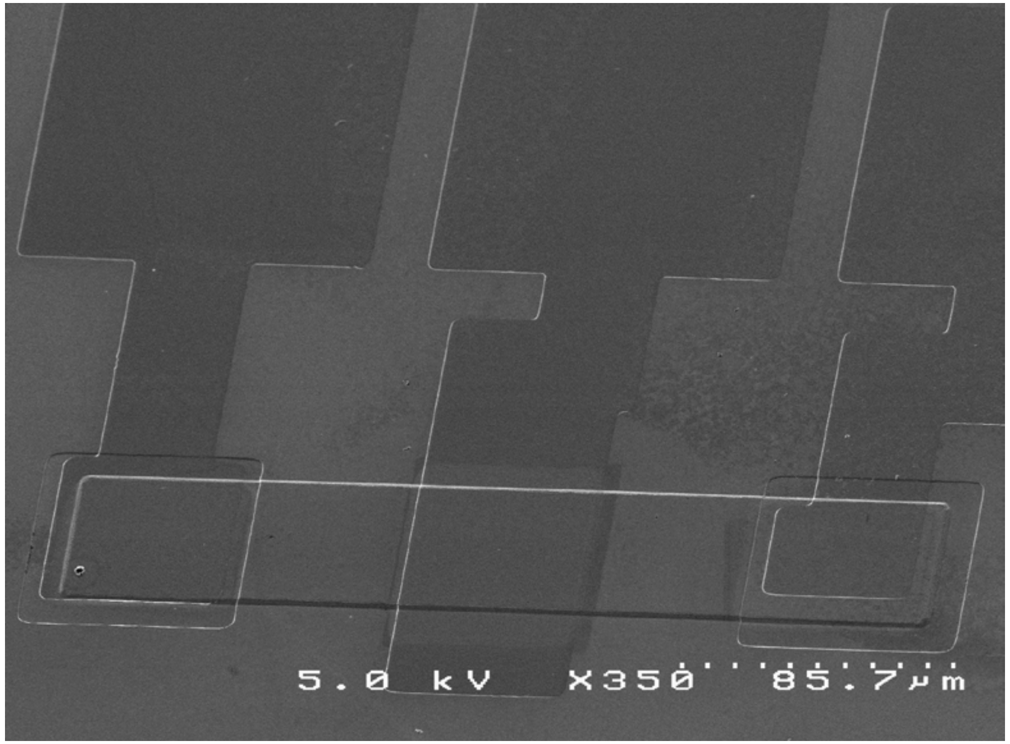
Alternate MIS-HEMT Structure



Fabrication Results

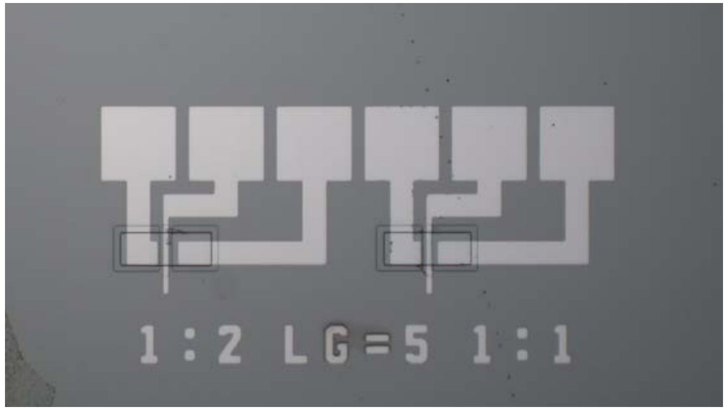


Microscope Image of L_g=50µm fabricated device

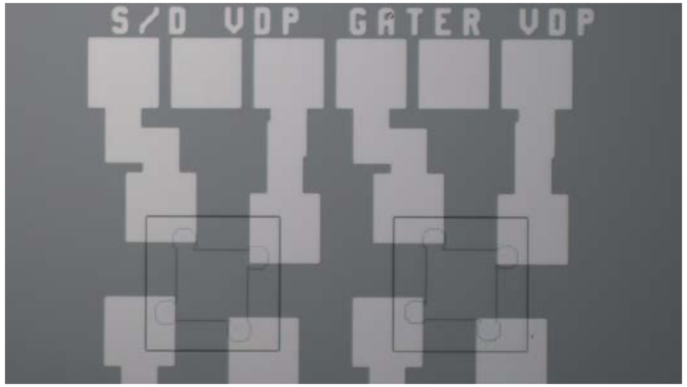


SEM Image of L_g=50µm fabricated device

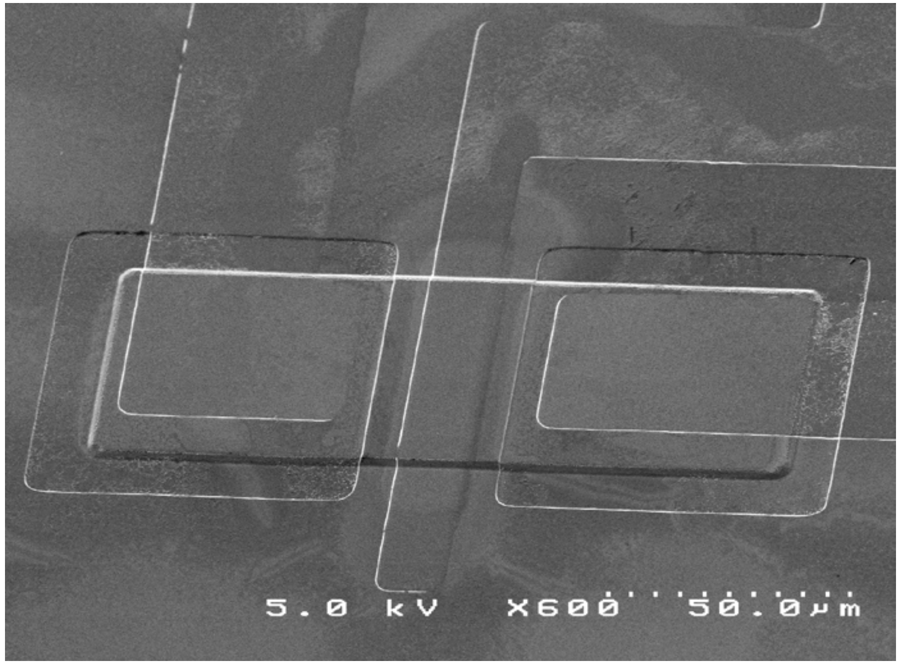
Fabrication Results



Microscope Image of L_g= 5µm device



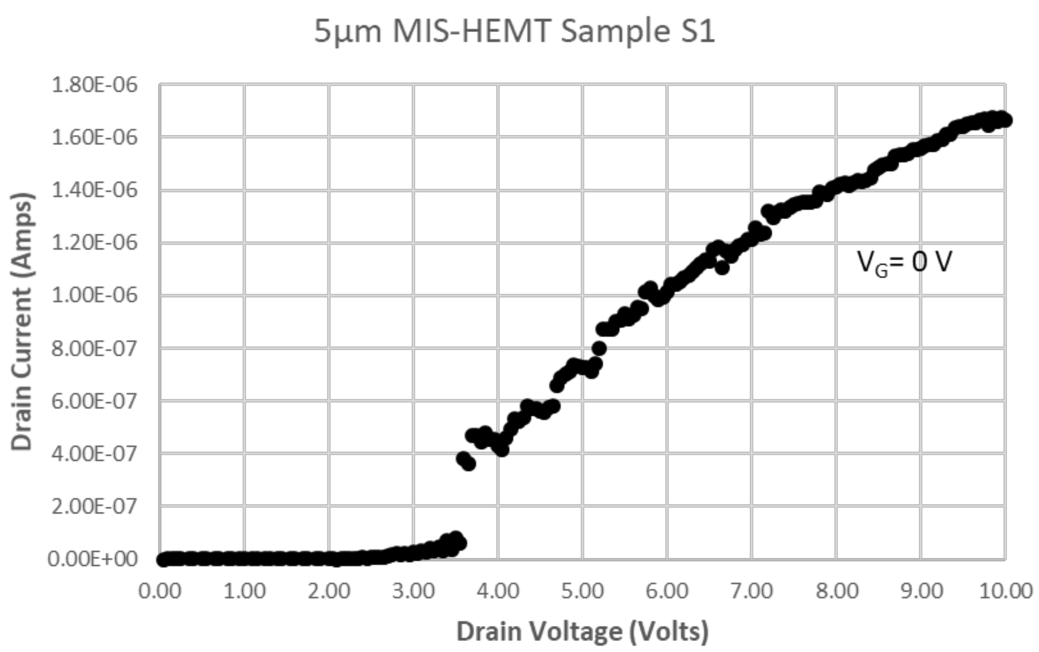
Microscope Image of Van der Pauw's Structures



SEM of L_g=5µm device with Gate Recess

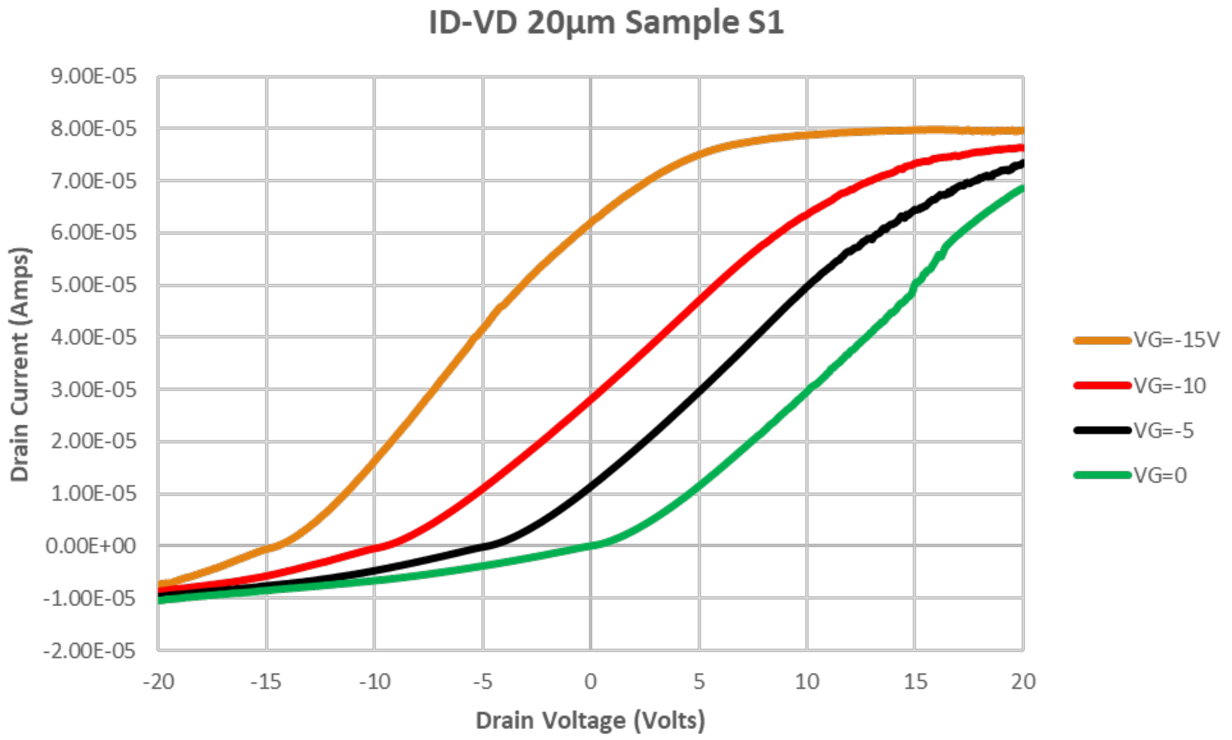
Electrical Test Results

- Ni deposited in Source, Drain and Gate regions in the same step.
- Ni forms Schottky contacts with GaN.
- Schottky contacts with the gate is necessary, but Ohmic contacts are required for the Source and Drain regions.

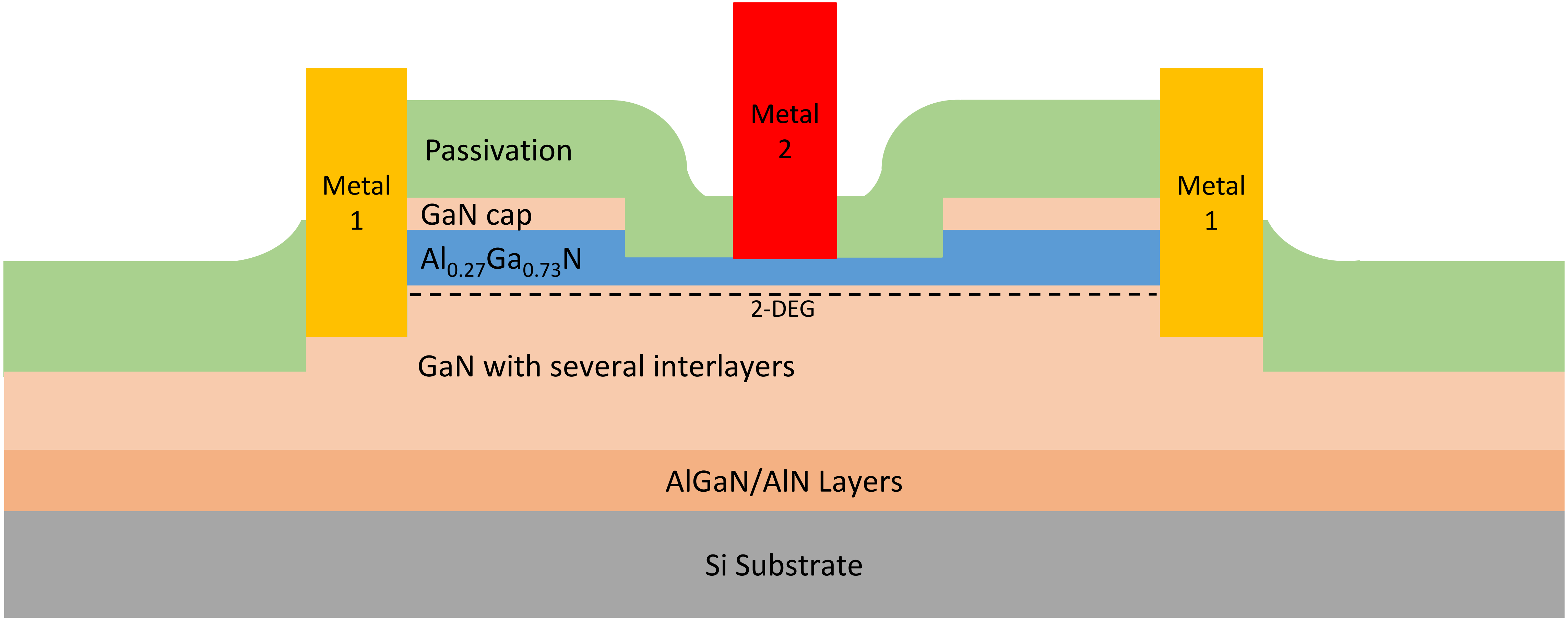


Electrical Test Results

- The family of curves obtained for devices shows significant gate leakage.
- It also shows the minimal gate control since there is a change observed as the Gate voltage is varied.



Future Work


Metal
2
Passivation
Metal
1
Metal
1
GaN cap
$Al_{0.27}Ga_{0.73}N$
2-DEG
GaN with several interlayers
AlGaN/AlN Layers
Si Substrate

Conclusion

- A first attempt at fabricating AlGaN/GaN HEMTs at RIT was made.
- An initial process flow and mask design was made.
- Electrical results showed the need to properly form metal-semiconductor contacts for Source and Drain regions. Alternate metal stacks would need to be investigated.

Acknowledgements

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- Patricia Meller, Sean O’Brien and all SMFL Staff
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Thank You