# Development of Fluorine Plasma Treatment for AlGaN/GaN Device Isolation

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**EE412 Project**

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# Outline

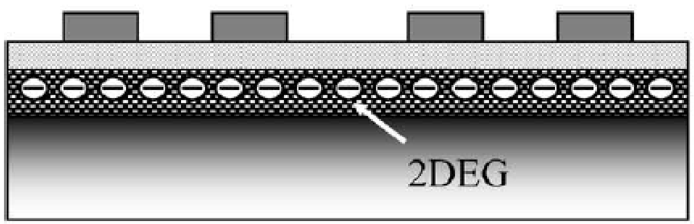
- Project objectives
- Isolation mechanism
- Methodology
- Processing and fabrication
- Results and discussion
- Future work

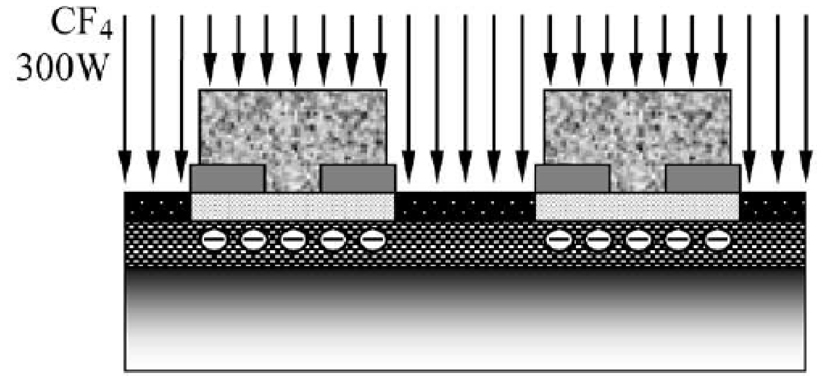
# Project objectives

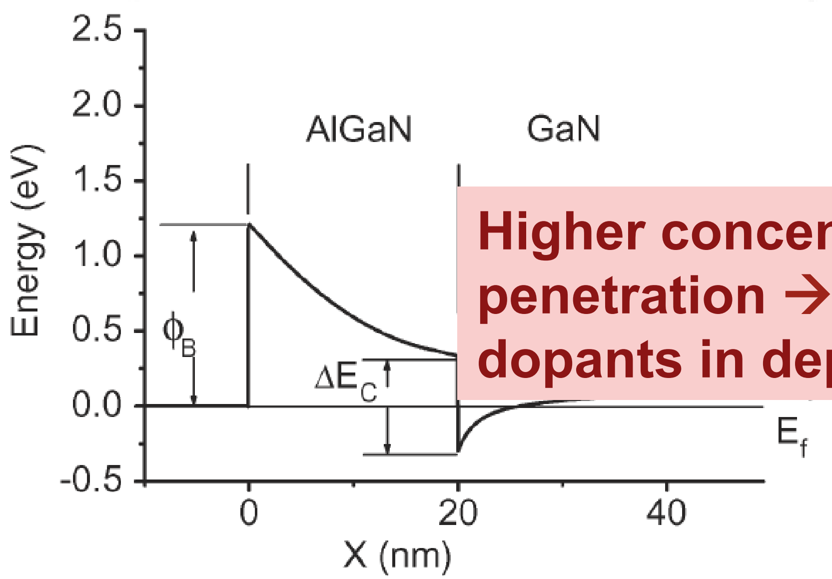
- Develop a fluorine plasma treatment (FPT) process with PT-OX for isolating active AlGaN/GaN devices
- Compare FPT with previously developed isolation technique (mesa etch using OX-35)
- Study the high-temperature characteristics of FPT isolation
- Contribute to GaN processing capabilities of SNF

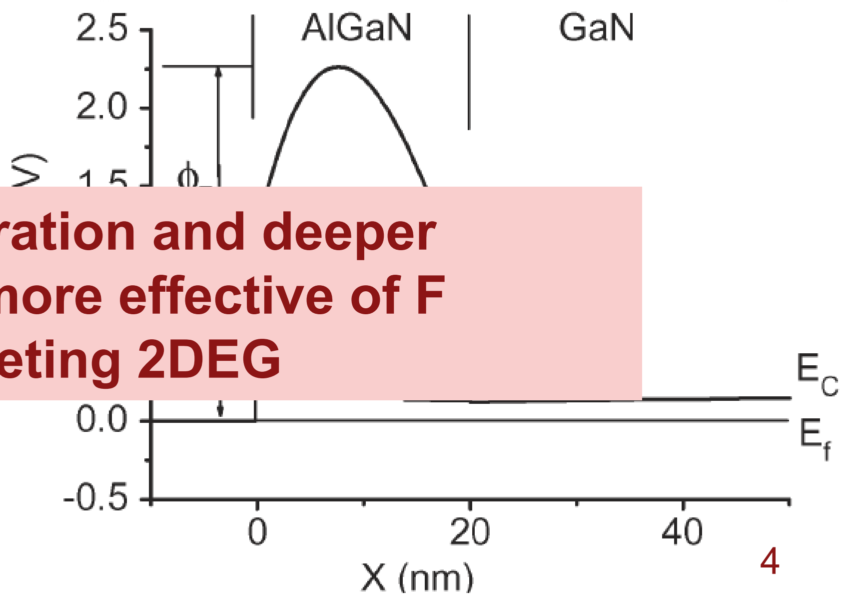
# 2DEG Isolation Mechanism

- Fluorine ions have a strong electronegativity and are negatively charged, effectively raising the potential in the AlGaN barrier and the 2DEG channel [1][2]



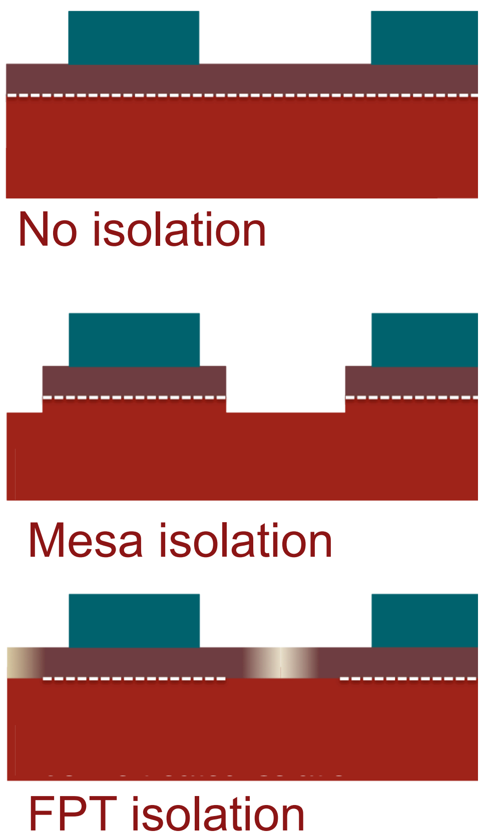



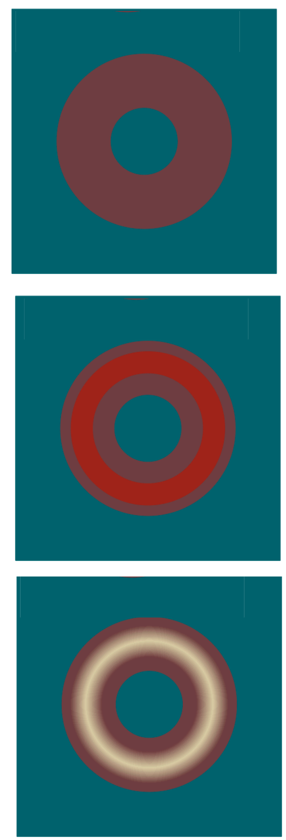



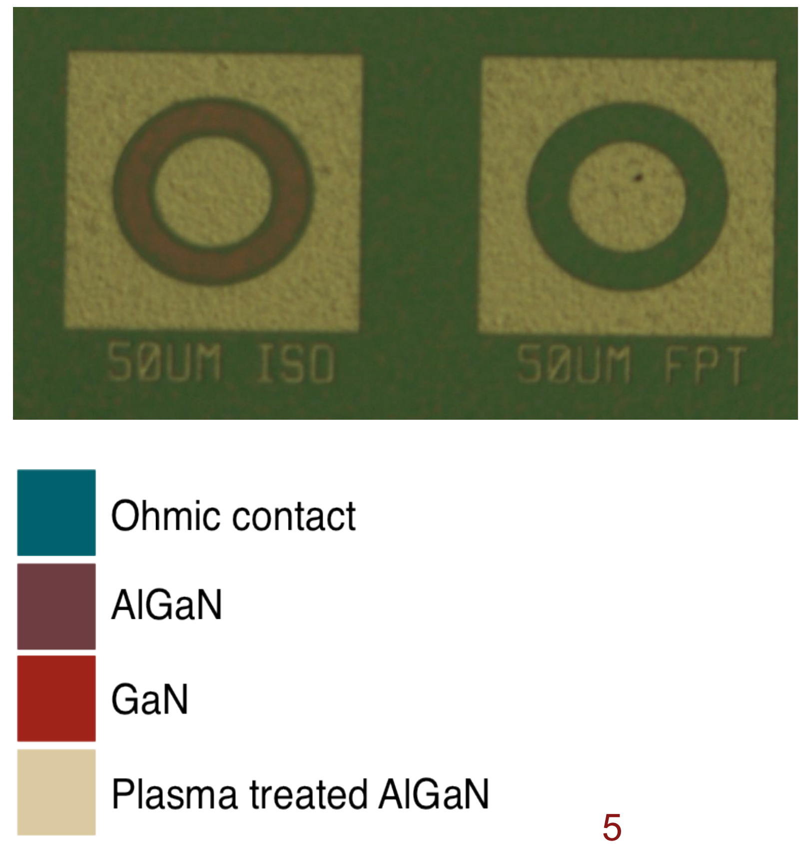

**Higher concentration and deeper penetration → more effective of F dopants in depleting 2DEG**

# Methodology: Testing structures

- Developed test structures to determine if FTP could be used for isolation in replacement to mesa etching
- Figure of merit for isolation:
  - Leakage current

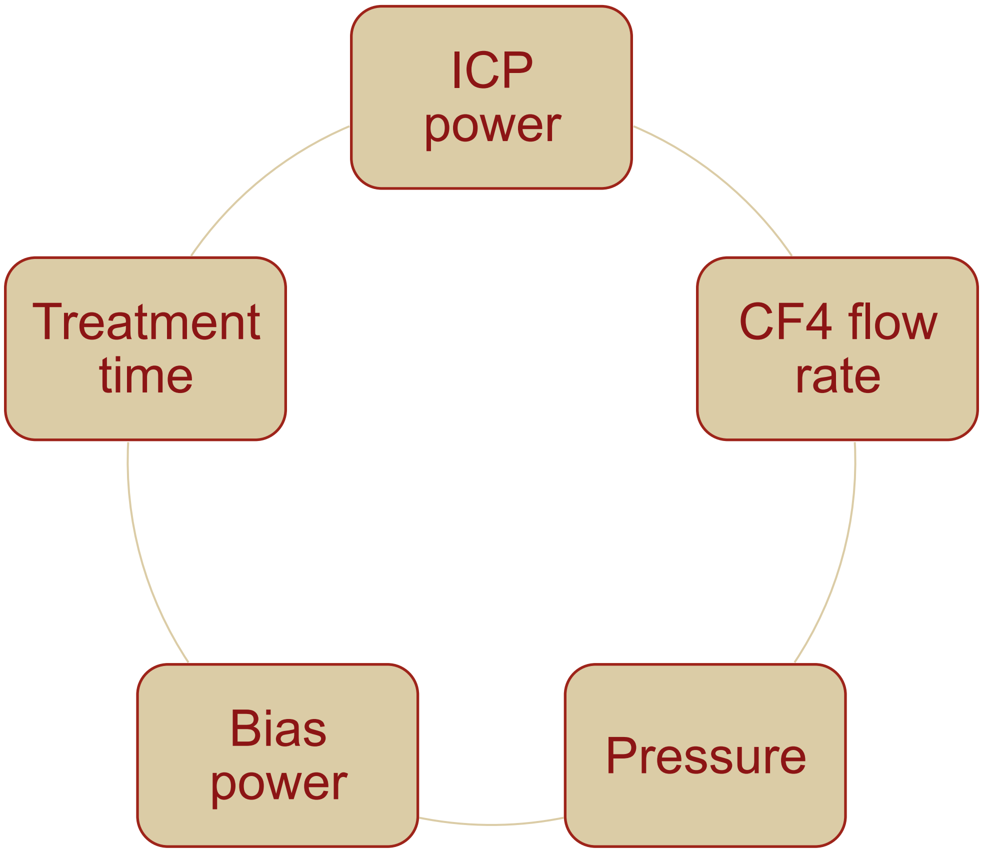


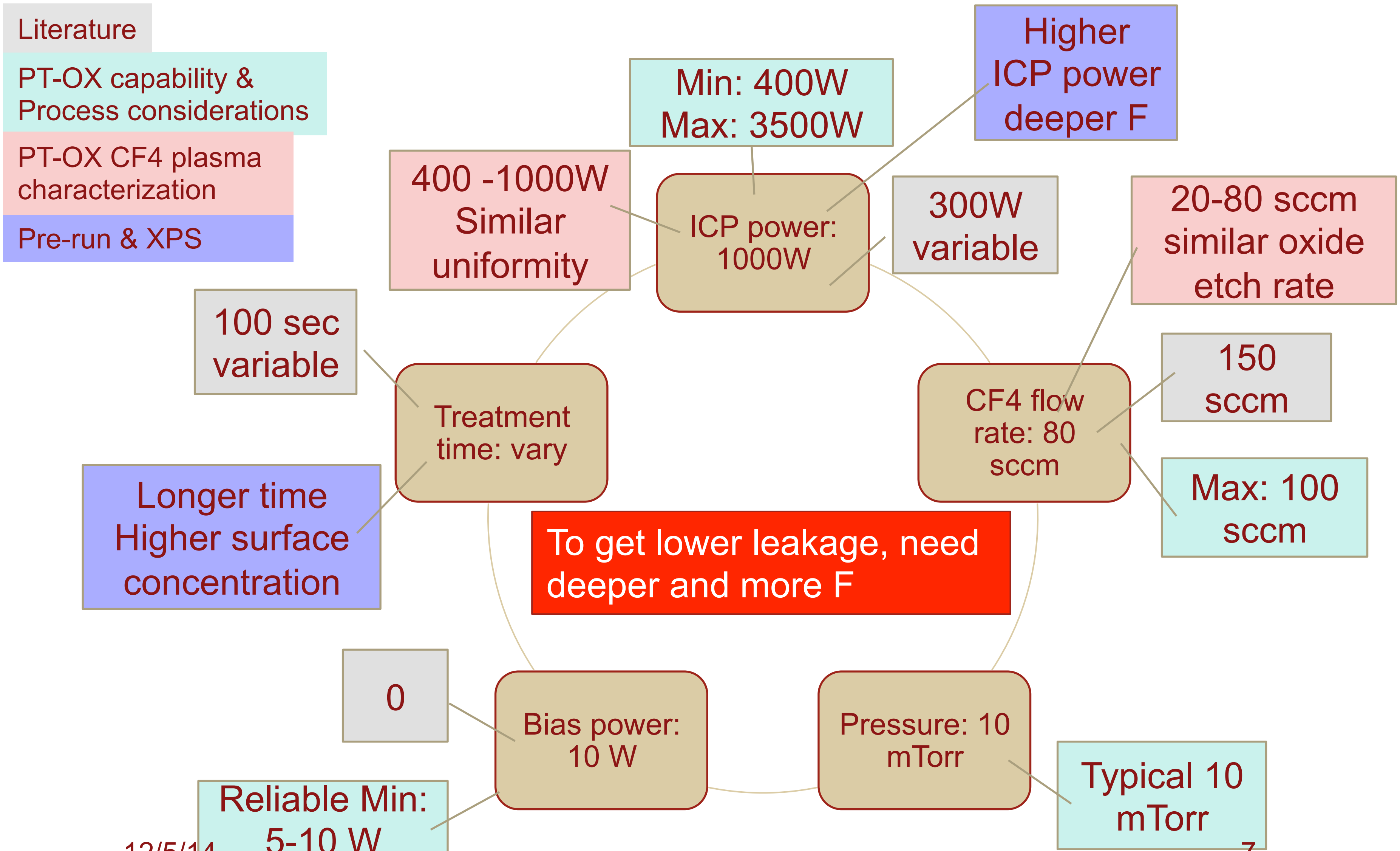


# Methodology: Design of experiments

- Literature
- PT-OX capability and process considerations
- Plasma characterization
- AlGaN/GaN pre-run and XPS characterization
- Isolation mechanism



# Methodology: Design of experiments



# CF4 plasma characterization

- Two plasma uniformity characterizations
  - Tested etch rate of thermal oxide across 4” wafer
  - Varied flow(20, 50, 80 sccm) and power (400, 700, 1000 W)
    - Flow had little effect on etch rate
    - Power uniformity was repeated and see little uniformity variance

*Etch rate variance = (max etch rate – min etch rate)/(2 X avg etch rate)

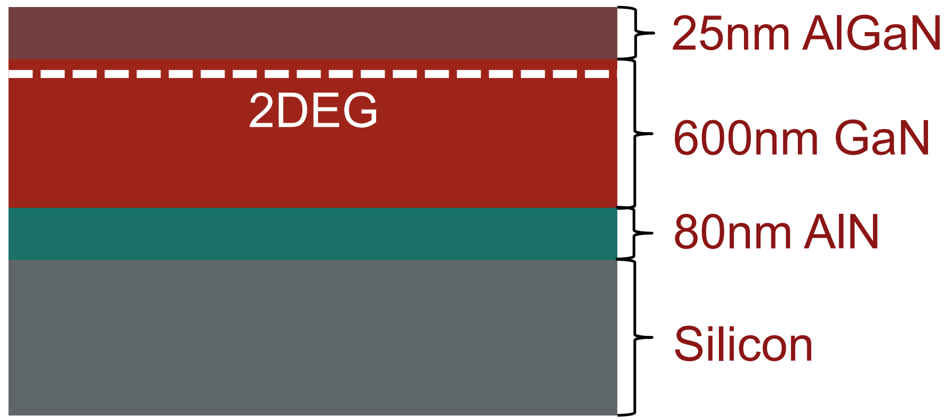
**Wafer 5 experienced huge reflective ICP power during 3 seconds of plasma lighting step (about 450W).

| Wafer ID | ICP power (W) | Avg etch rate (A/ min) | Etch rate variance* (%) |
|---|---|---|---|
| 1 | 400 | 781 | 0.92% |
| 2 | 700 | 1296 | 0.93% |
| 3 | 1000 | 1596 | 0.82% |
| 4 | 400 | 802 | 1.34% |
| 5** | 1000 | 1585 | 3.02% |

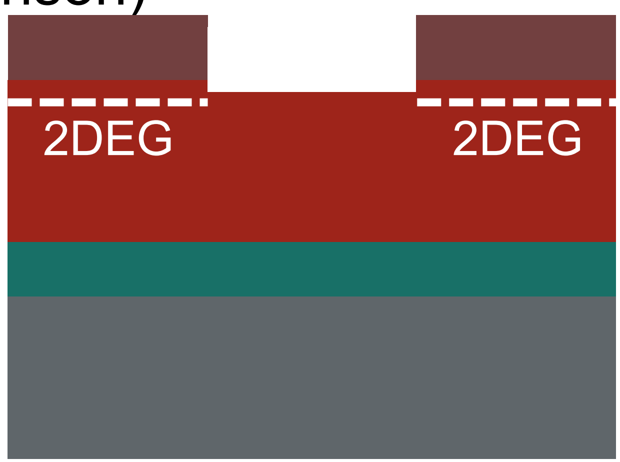
**CF4 plasma of different ICP powers showed similar uniformity (about 1-3%) → Free to choose ICP power**

# Processing and fabrication

1. AlGaN/GaN heterostructure substrate purchased from vendor

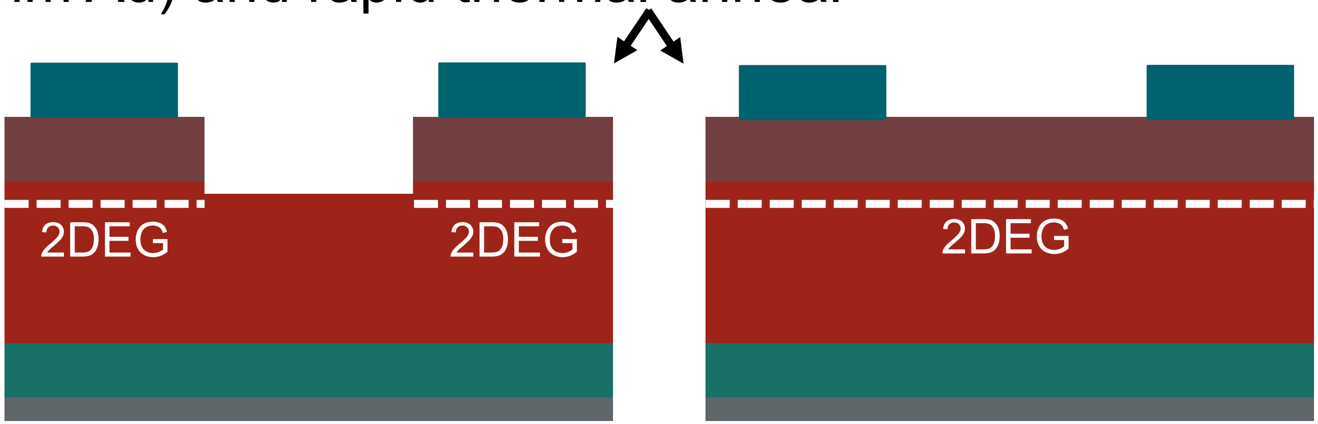



2. Mesa etch removes AlGaN to isolate the 2DEG (standard process for comparison)

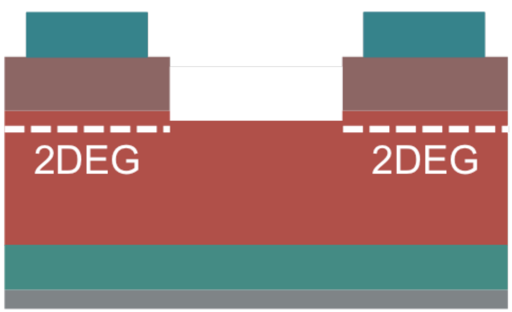


# Processing and fabrication

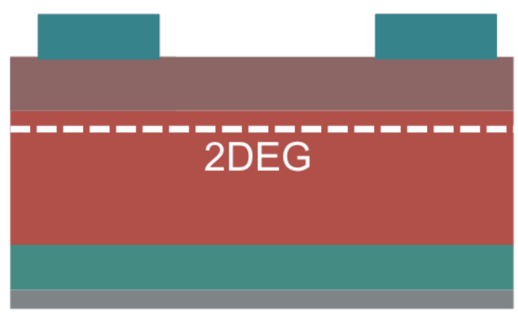
3. Ohmic contact ebeam deposition (20nm Ti, 100nm Al, 40nm Pt, 80nm Au) and rapid thermal anneal




4. Fluorine plasma treatment to isolate devices using new method




Mesa isolated test structure



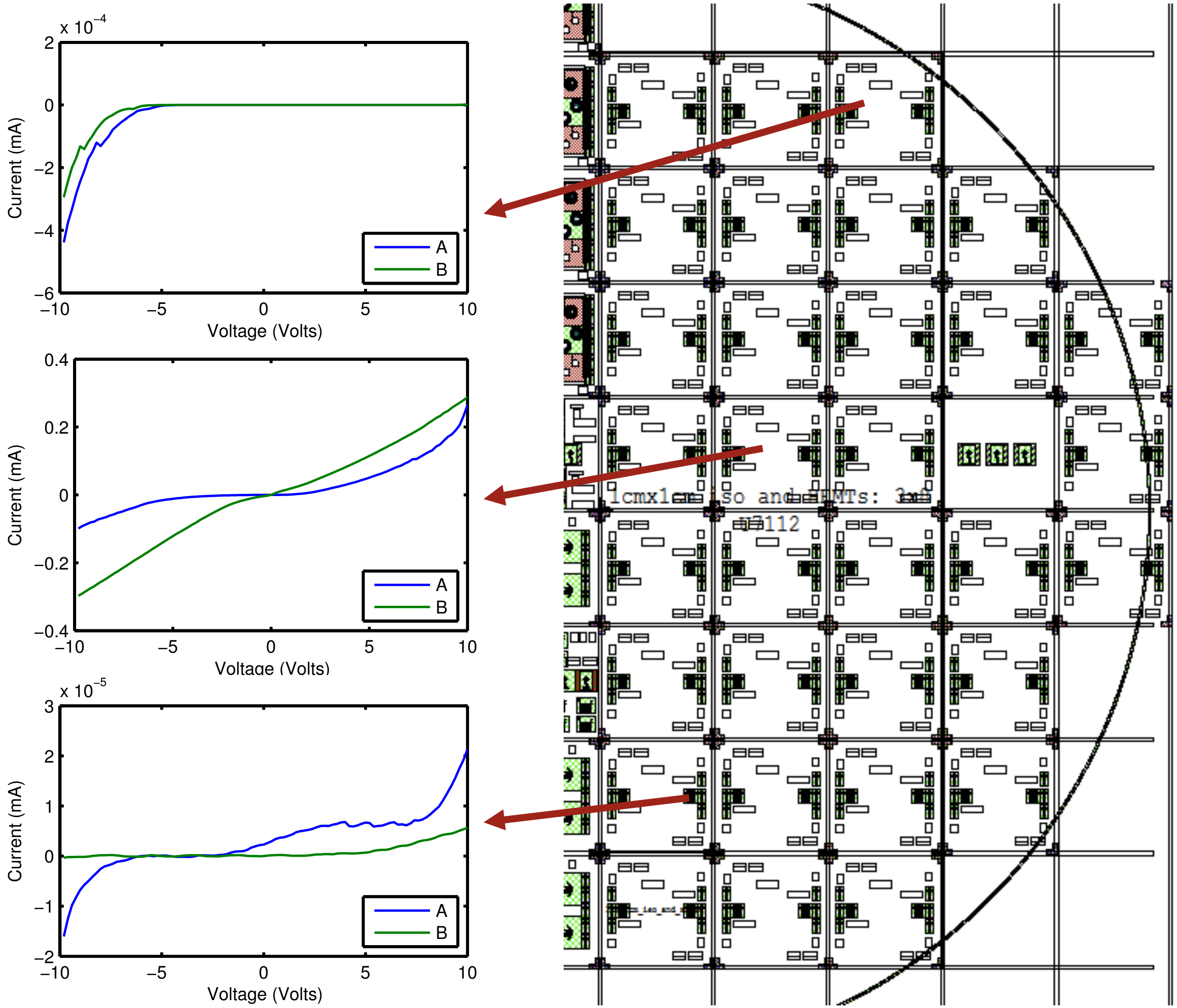

Non isolated test structure


FPT isolated test structure

# Results and discussion

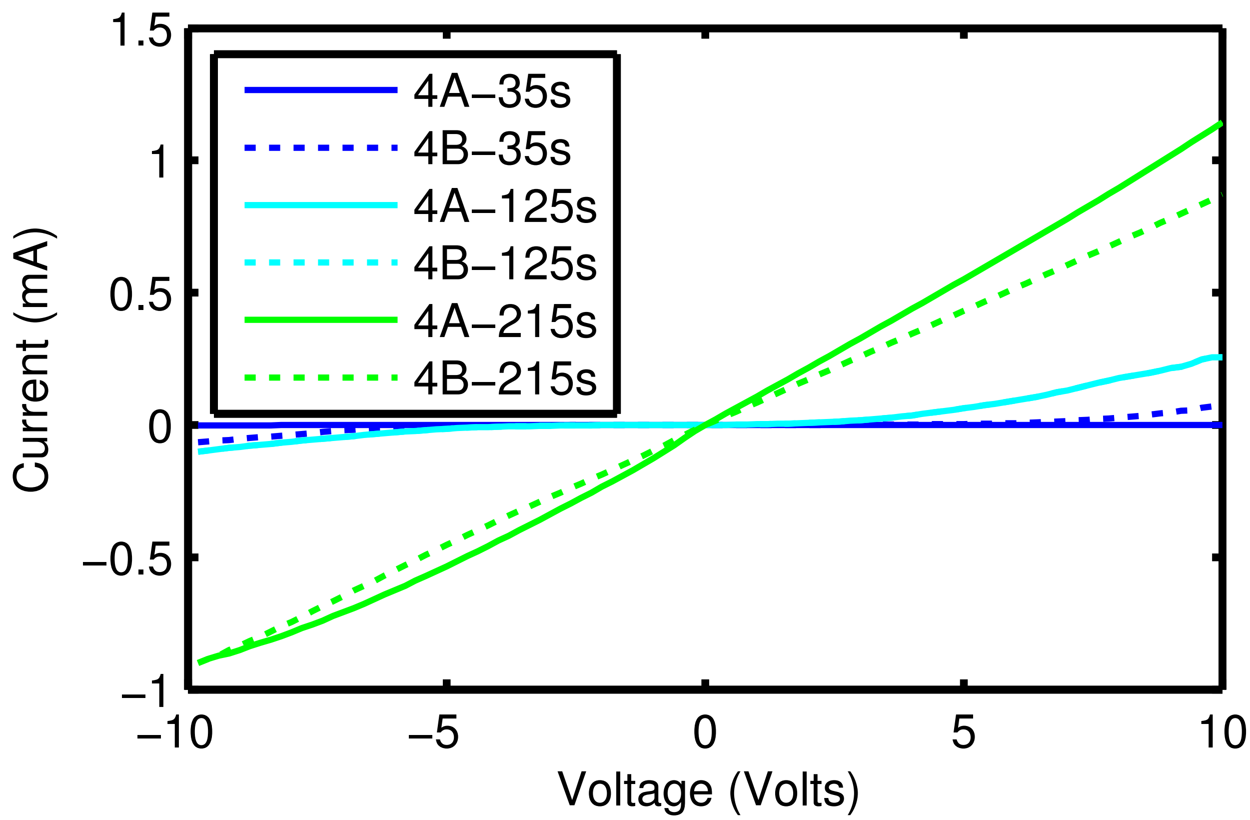
- I-V curves
  - Uniformity mapping
  - Comparing isolation mechisms
  - After 10 mins 600C anneal
- AFM
  - Step height
  - Roughness
- Aguer Electron Spectroscopy
- Bare AlGaN Thermal storage
  - XPS depth profiles

# Results: Mapping I-V Characteristics across wafer



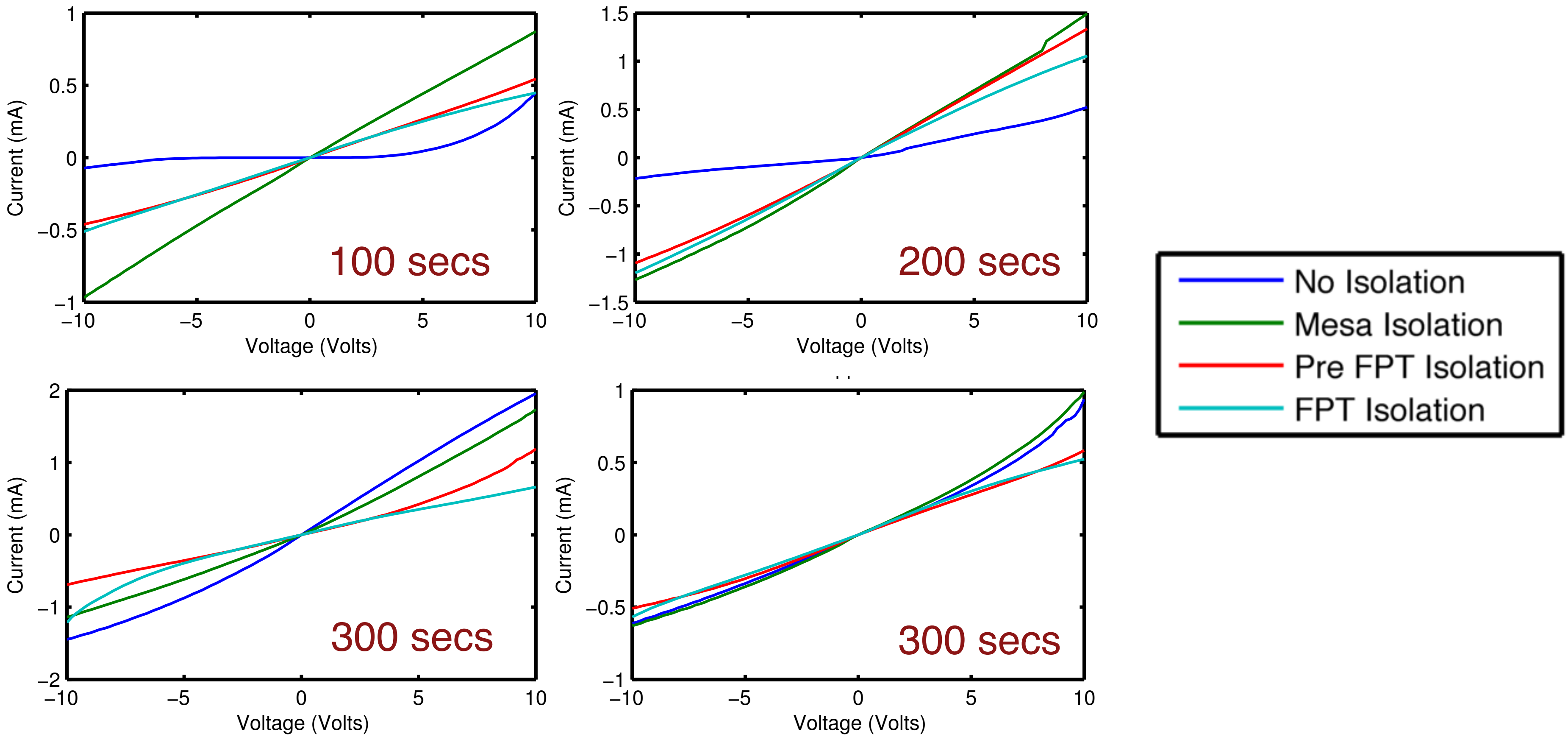
# Results: Effect of Continued Annealing

- Due to non uniformity of IV curves across the wafer and the difference in the contact appearance, multiple anneals were completed to determine effect



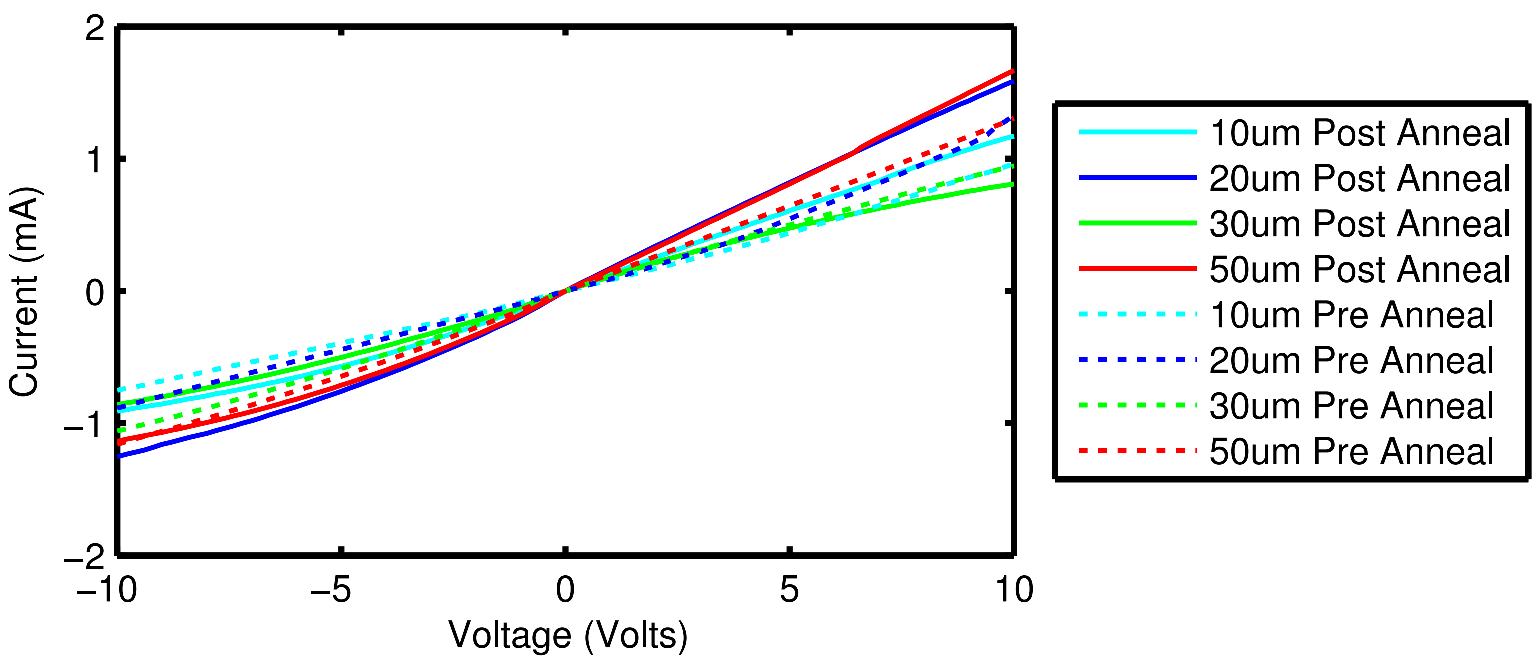
# Results: Before and After FPT

- FPT treatment had little effect on the current seen on test structures



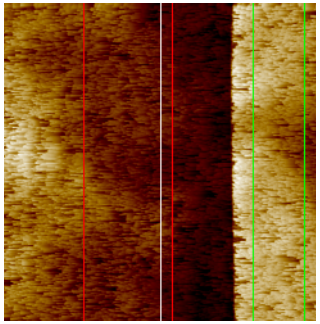
# Results: Pre and Post FPT Anneal

- Due to limited effect of FPT, tried to use a 10min 600°C anneal push down the fluorine
  - Anneal had no effect or made the isolation of devices worse

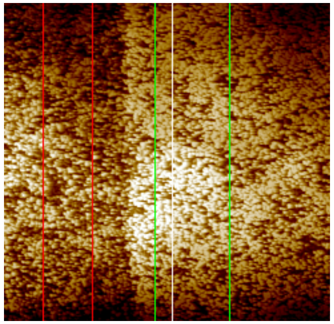


# Results: AFM imaging

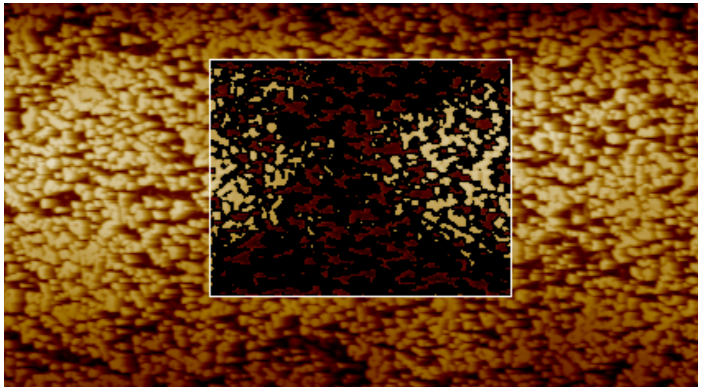
- Used AFM to verify etch and examine roughness of wafer
  - Goals to verify mesa etch reached to the AlGaN and that FPT did not etch AlGaN
    - Show etch depth was deep enough to reach AlGaN
    - Reveals FPT does etch AlGaN
  - Measured roughness to consider if wafer quality effecting results
    - Roughness is higher than expected: 14 nm



Step height for mesa: 77 nm



Step height for FPT: 31 nm

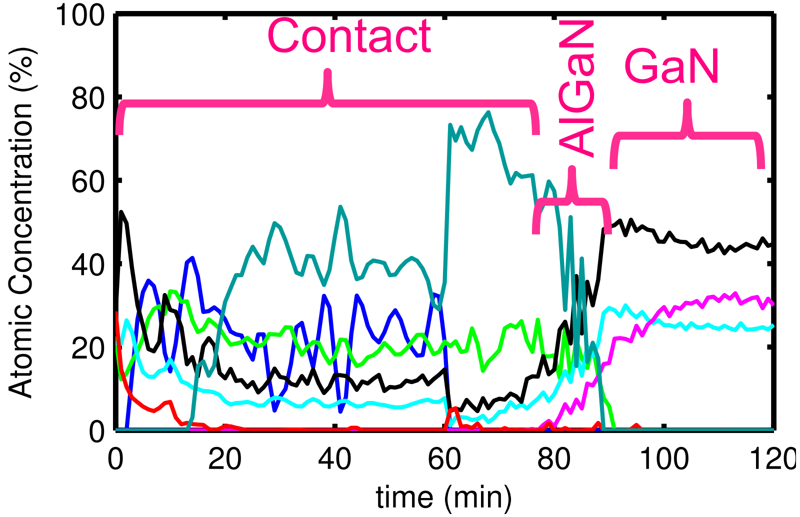


Roughness Measurements: 14 nm

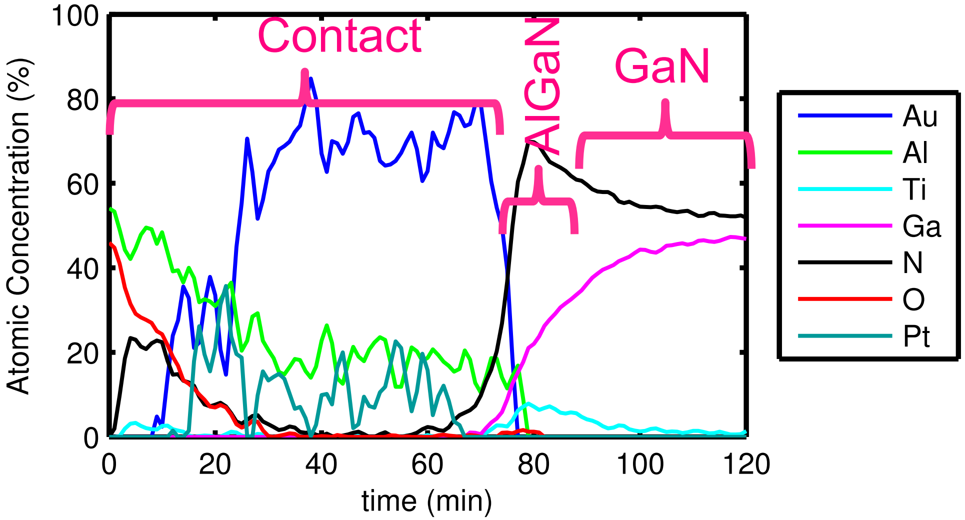
# Results: Auger Spectroscopy

- Used Auger spectroscopy to examine how multiple anneals effect the diffusion of the metals through the material

AES of contact with single 35 sec anneal

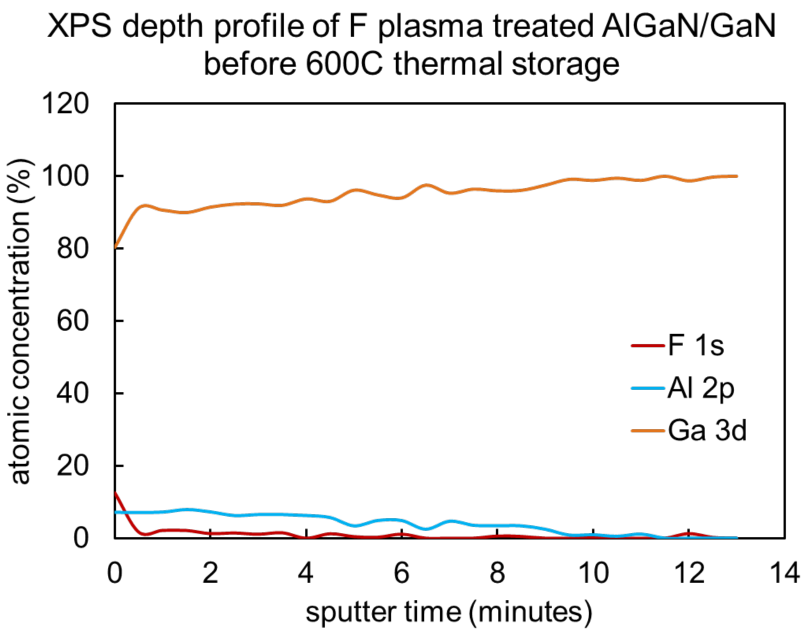


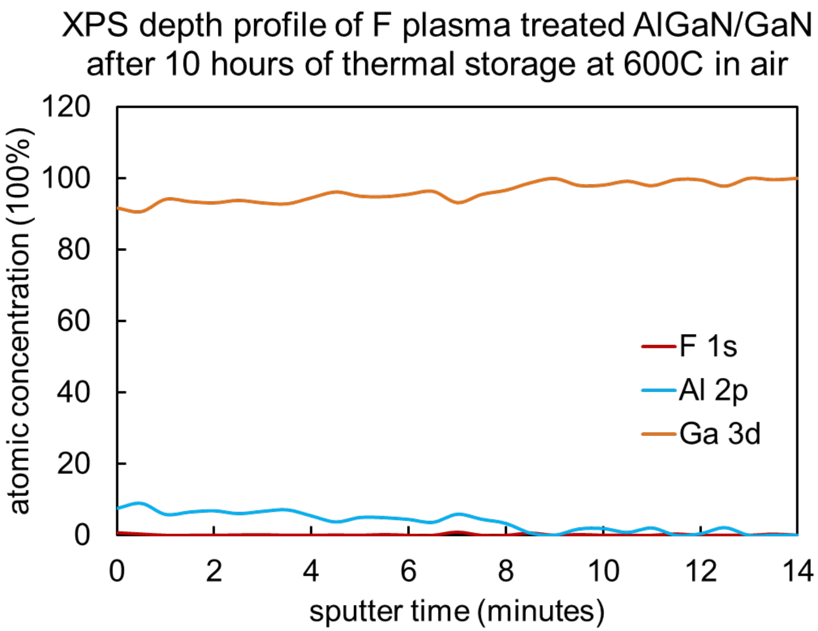

AES of contact with multiple anneal (total 245 sec)



# Results: Thermal storage tests on AlGaN/GaN

- Bare AlGaN/GaN piece was treated with fluorine plasma
- ICP power 1000 W, 300 seconds
- XPS pre- and post 10-hour thermal storage at 600C




Significant F diffusion / "evaporation"

# Summary

- Worked to develop a fluorine plasma treatment for AlGaN/GaN device isolation
  - Ran a DOE to examine uniformity, chose to test time on AlGaN/GaN samples due to surface concentration of fluorine
  - $CF_4$ plasma uniformity of PT-Ox is shown to be high
- Device fabrication of circular test structures was completed for mesa and FPT isolation.
- IV curves reveal inconstant and unexpected results
  - Trouble shooted the cause of these results (multiple anneals, afm of etch depth, AES)
  - Concerned about wafer quality
- Thermal storage of bare AlGaN/GaN heterostrucure
  - Fluorine appears to diffuse to undetectable concentrations post anneal

# Future Work

- Continue trouble shooting cause of lack of isolation and non uniform IV characteristics
  - TEM imaging to examine the heterostructure
  - Repeat experiment on unused edge and different wafer to determine if the process or wafer was unsuccessful
    - Resistivity measurements of AlGaN/GaN pre-processing
    - IV measurements before annealing

- When issue has been identified
  - Continue FPT measurements at various temperatures
  - Fabricate enhancement mode HEMTs

# References


- [1] W. Tang, K. M. Lau, and K. J. Chen, “Planar integration of E/D-mode AlGaN/GaN HEMTs using fluoride-based plasma treatment,” *IEEE Electron Device Lett.*, vol. 27, no. 8, pp. 633–635, Aug. 2006.
- [2] Y. Cai, Y. Zhou, K. M. Lau, and K. J. Chen, “Control of Threshold Voltage of AlGaN/GaN HEMTs by Fluoride-Based Plasma Treatment: From Depletion Mode to Enhancement Mode,” *IEEE Trans. Electron Devices*, vol. 53, no. 9, pp. 2207–2215, Sep. 2006.

# Backup slides

# Literature

- RIE system instead of ICP
- Plasma power 300W
- Bias 0 V
  - Minimize etching
- Flow rate 150 sccm
- Time 100 seconds
- They varied the plasma power and treatment time

# PT-OX capability and process considerations

- ICP power
  - Min: PT-OX minimum is 400 W
  - Max: PT-OX maximum is 3500 W, need to ensure etch loss is acceptable
- Plasma treatment time
  - Min: reduce run-to-run variation
  - Max: ensure etch loss is acceptable
- CF4 flow rate
  - Want to have a large flow, PT-OX max is about 100 sccm
  - Fixed at 80 sccm: reliable large flow on PT-OX
- Bias power
  - Want to minimize, but need to light plasma
  - Fixed at 10W: reliable minimal bias power on PT-OX
- Pressure
  - Fixed 10 mTorr: typical value on PT-OX

PT-OX picture

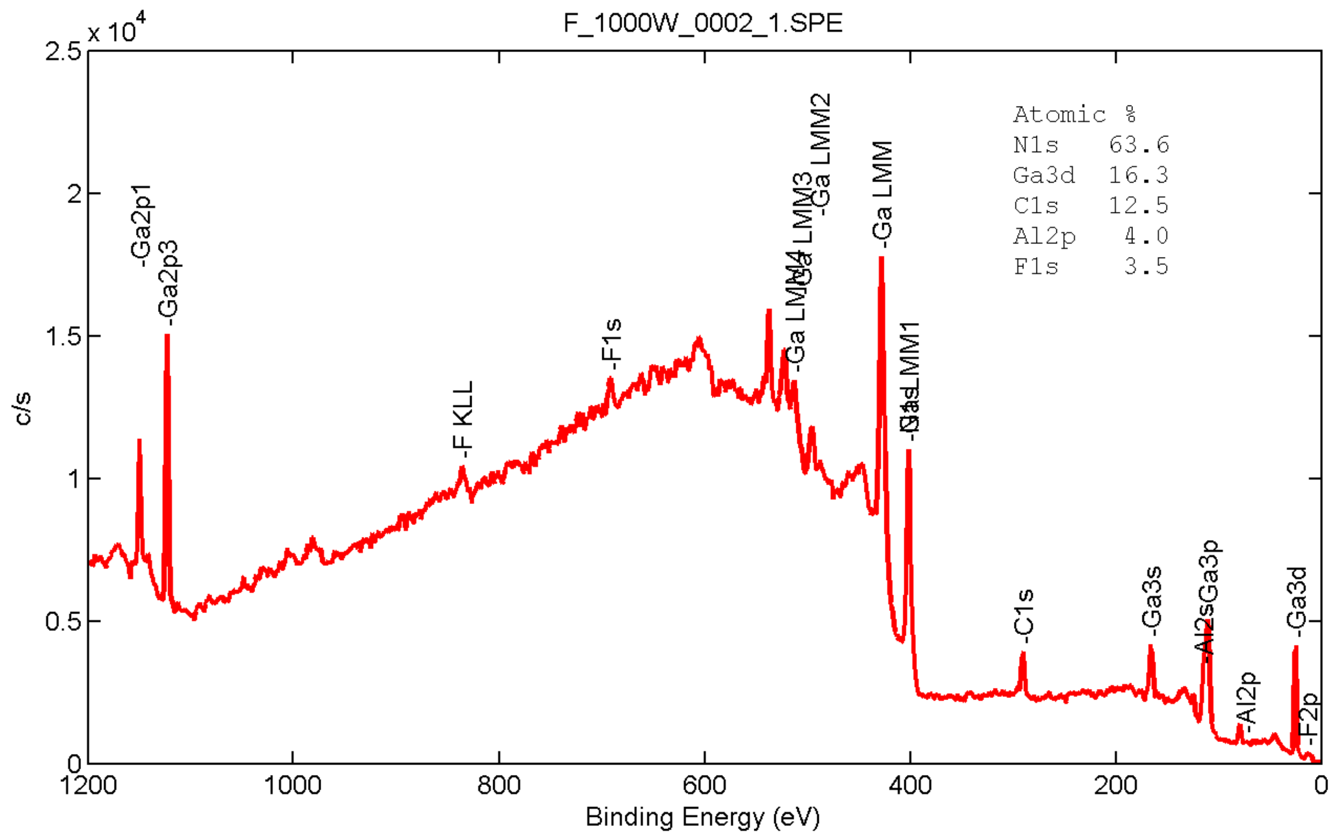
# CF4 plasma characterization

- Flow rate does not matter

# AlGaN/GaN pre-run and XPS characterization

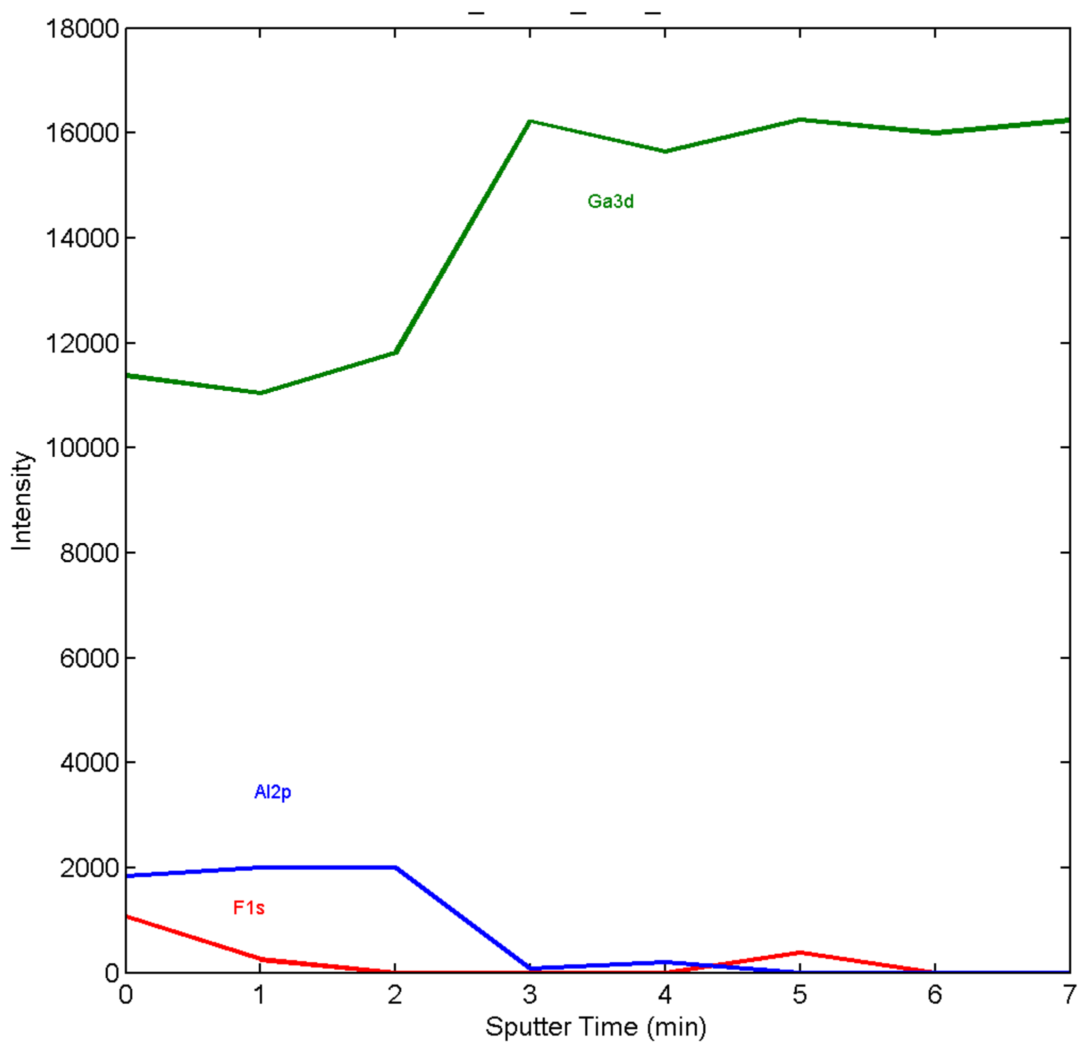
- Bare AlGaN/GaN pieces
- Three different ICP powers
  - 400 W, 700 W, 1000 W
- Two different treatment time
  - 100 seconds, 300 seconds
- PHI XPS surface survey and depth profiles
- Results:
  - ICP power determines F penetration depth
    - Want to have larger ICP power to get deeper doping
  - Time determines F surface concentration
    - Want to have longer treatment time to get higher concentration

# XPS characterization results



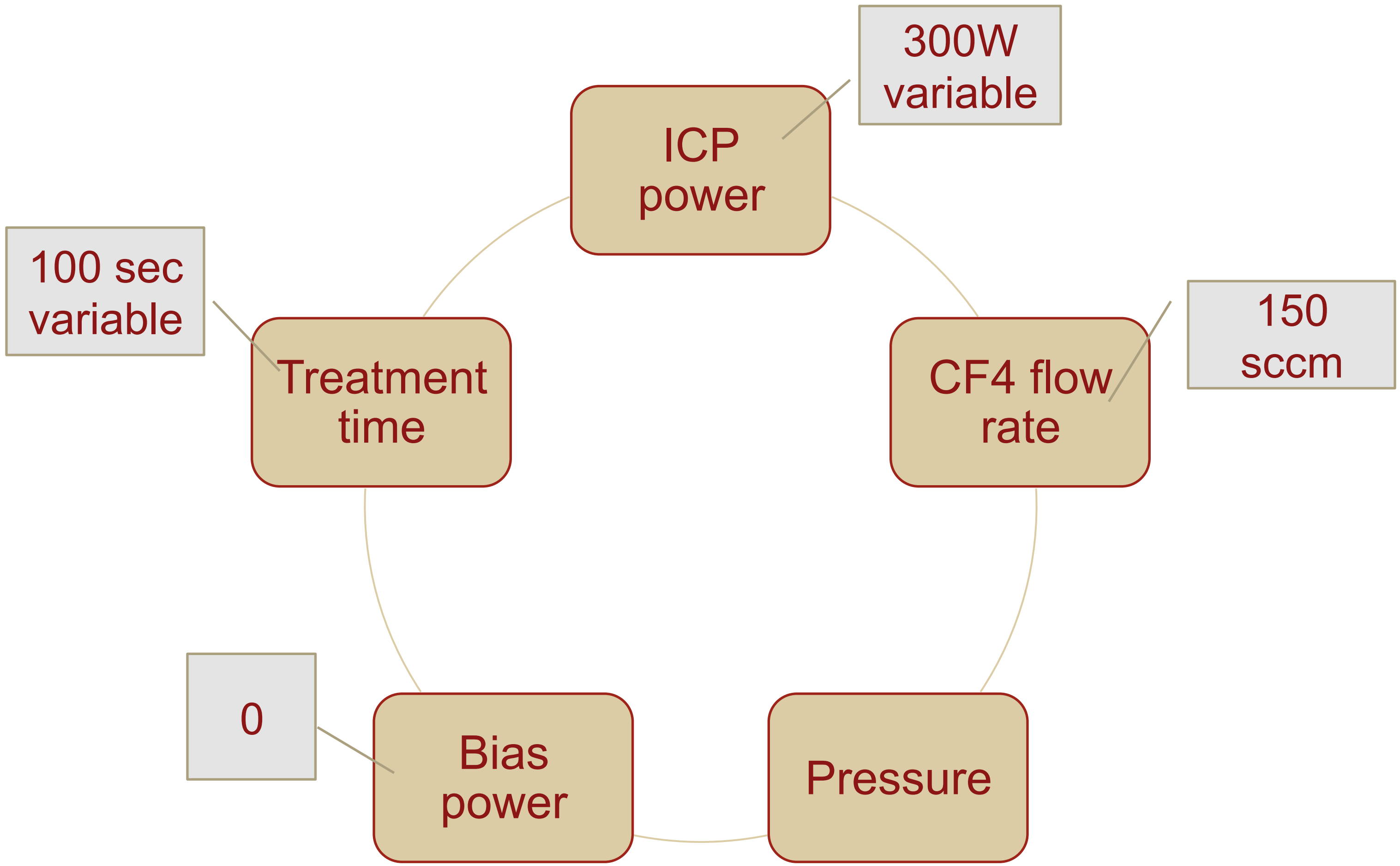

ICP 1000W

# XPS characterization results




ICP 1000W

# Methodology: Selection of variables



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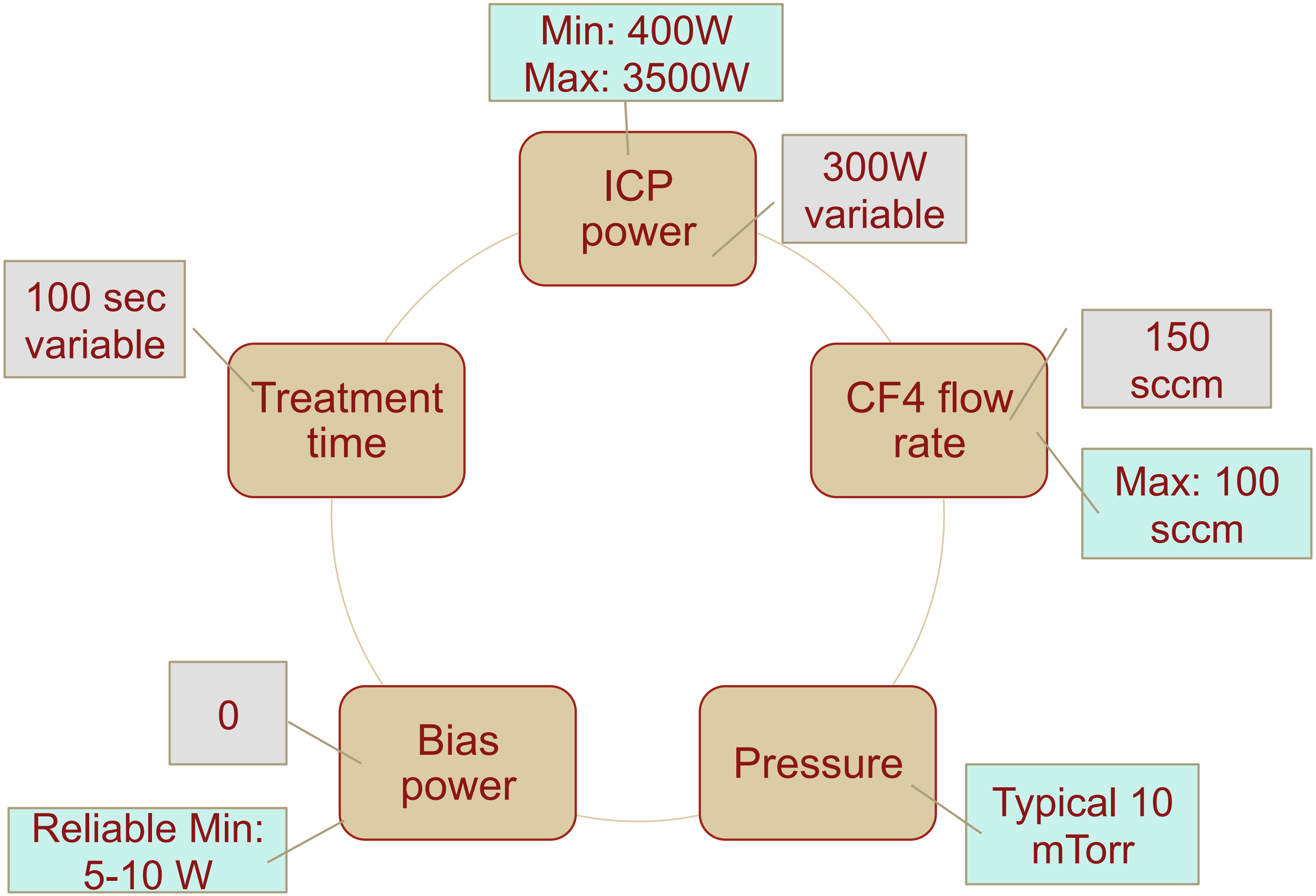

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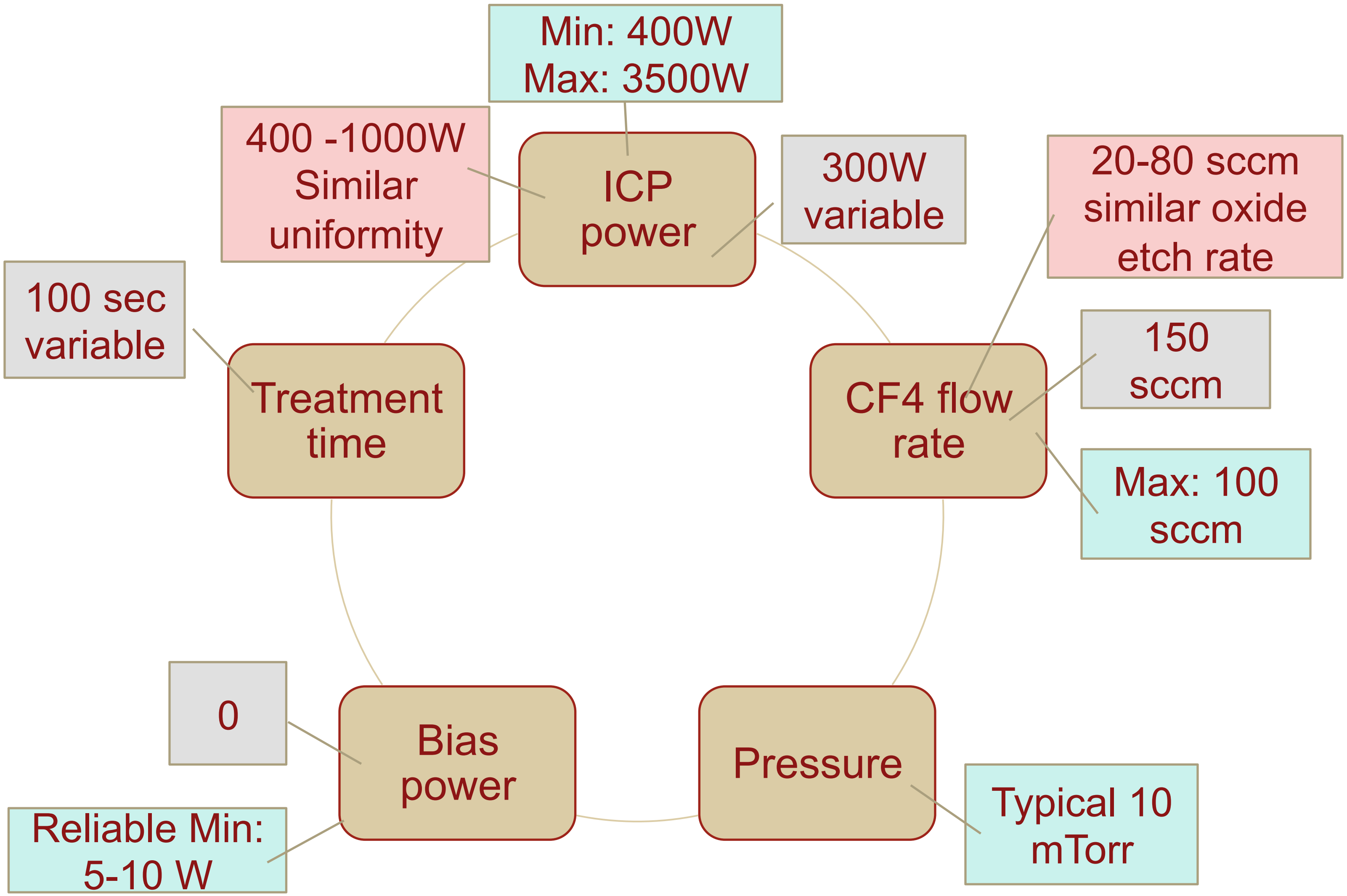

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