Analyzing radiation induced defects in GaN MESFETs and JFETs using AC transconductance method

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Jerry Zhao

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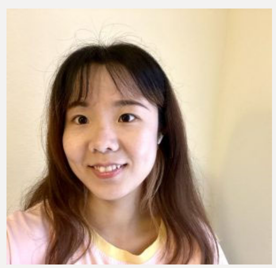

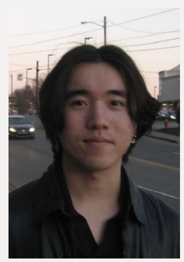

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Year 2 accomplishments

- Revising AC transconductance method for
  - GaN MESFET
  - GaN JFET
- Pre-rad and post-rad characterization of GaN MESFET and JFET using
  - AC transconductance method
  - Low frequency 1/f noise

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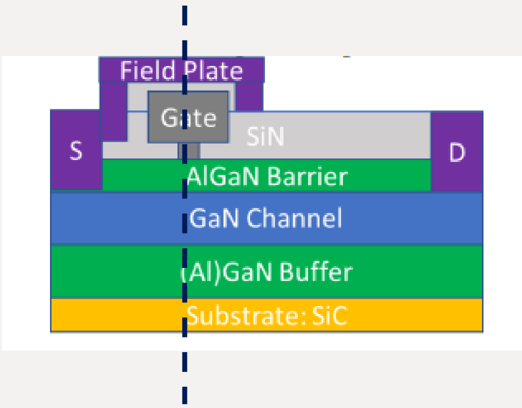
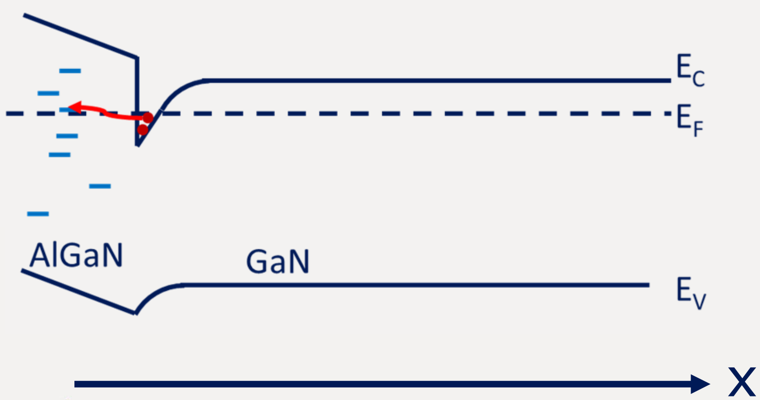
AC transconductance method - conventional





- Proposed by **TP Ma (Sun et al, IEDM 2012)**
- Frequency dispersion of ac G_m reflects variation of carrier density in the channel
  - Due to capture/emission of carrier in "oxide" traps
- For an AC signal on the gate (δV_g) with frequency ω, the traps with time constant τ higher than $1/\omega$ are not likely to respond
- As ω decreases, traps with relatively long τ start responding and cause a change in AC Gm
- Trap time constant is determined by both $\mathbf{E_T}$ and **x**
- Thus, ac gm method gives trap profile both in energy and space

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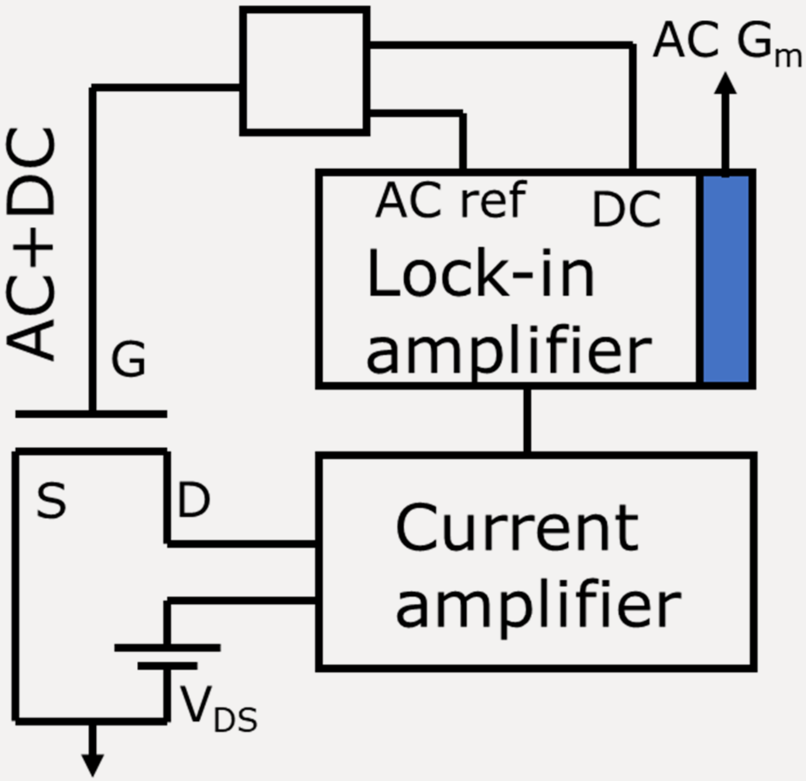
Experimental setup



$$AC\ G_m = \frac{Lock - in\ output\ current}{AC\ peak - to - peak\ voltage}$$

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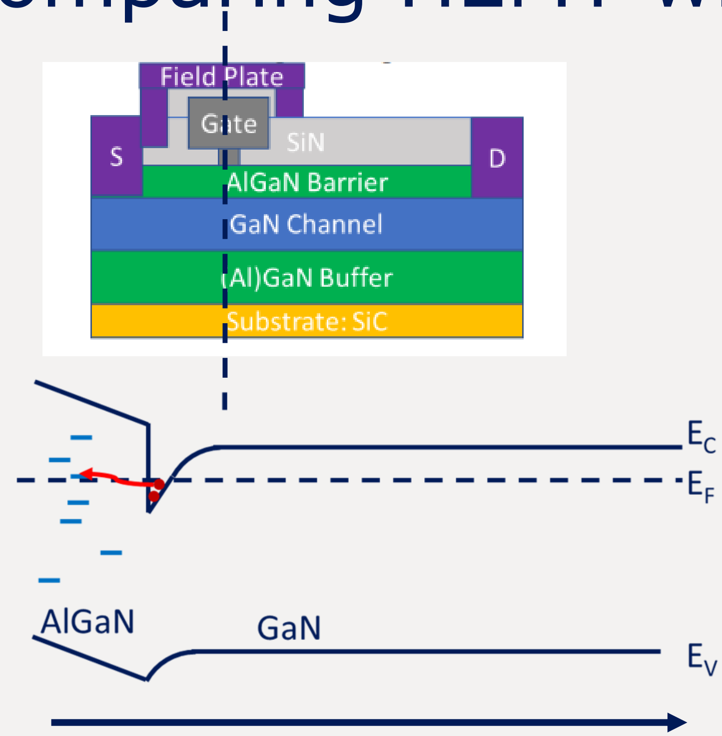
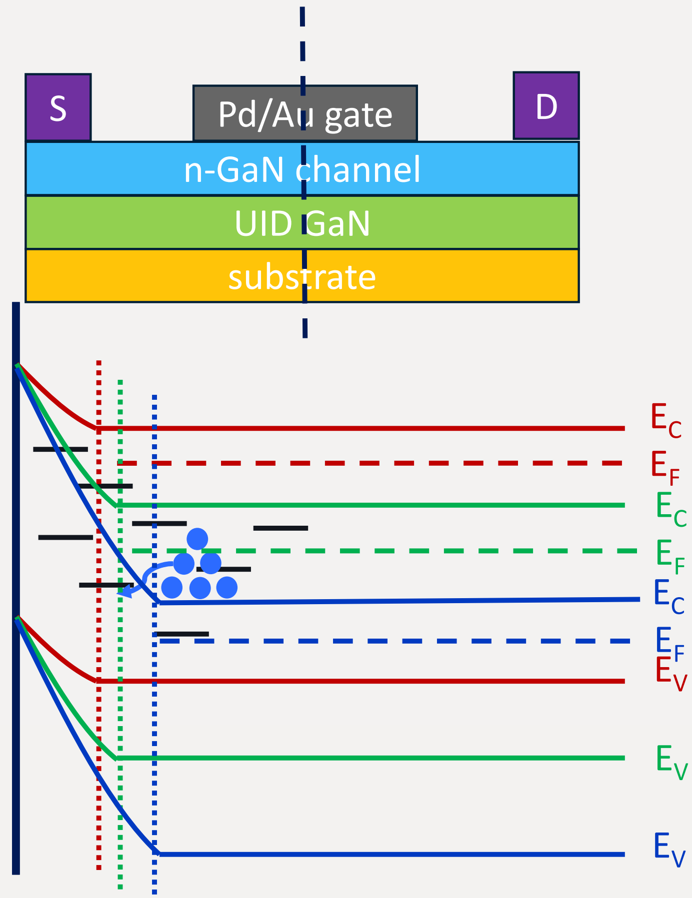
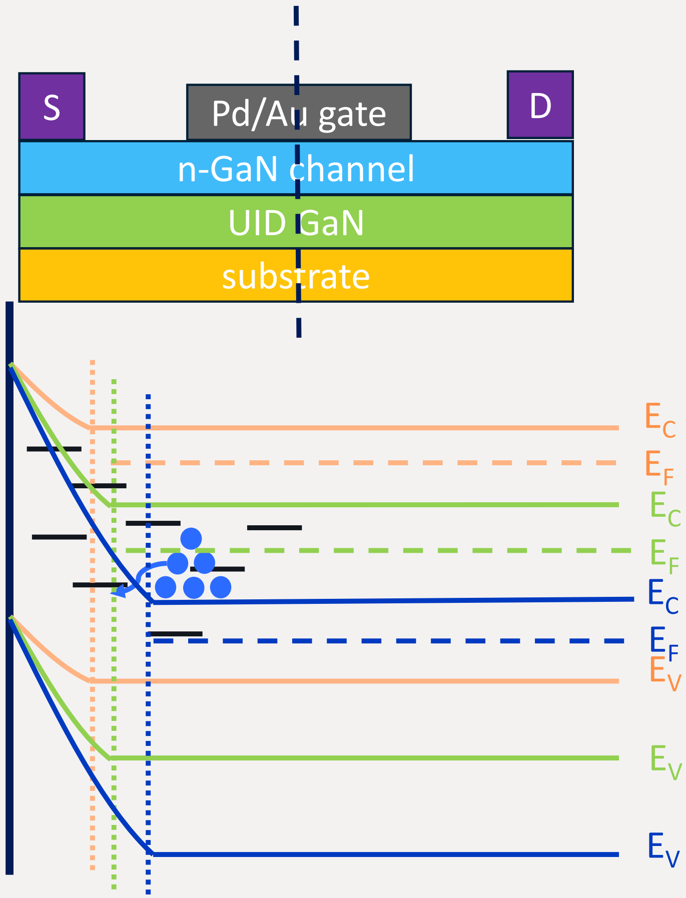
Comparing HEMT with MESFET for AC-Gm





A new model needs to be developed for AC transconductance on MESFETs

AC transconductance on MESFET - modified



- ✓ Frequency dispersion of ac G_m reflects variation of carrier density in the channel
  - Due to capture/emission of carrier in depletion region
  - But, depletion width and channel position varies with V_G!
- ✓ For an AC signal on the gate (δV_g) with frequency ω, the traps with time constant τ higher than $1/\omega$ are not likely to respond
- ✓ As ω decreases, traps with relatively long τ start responding and cause a change in AC Gm

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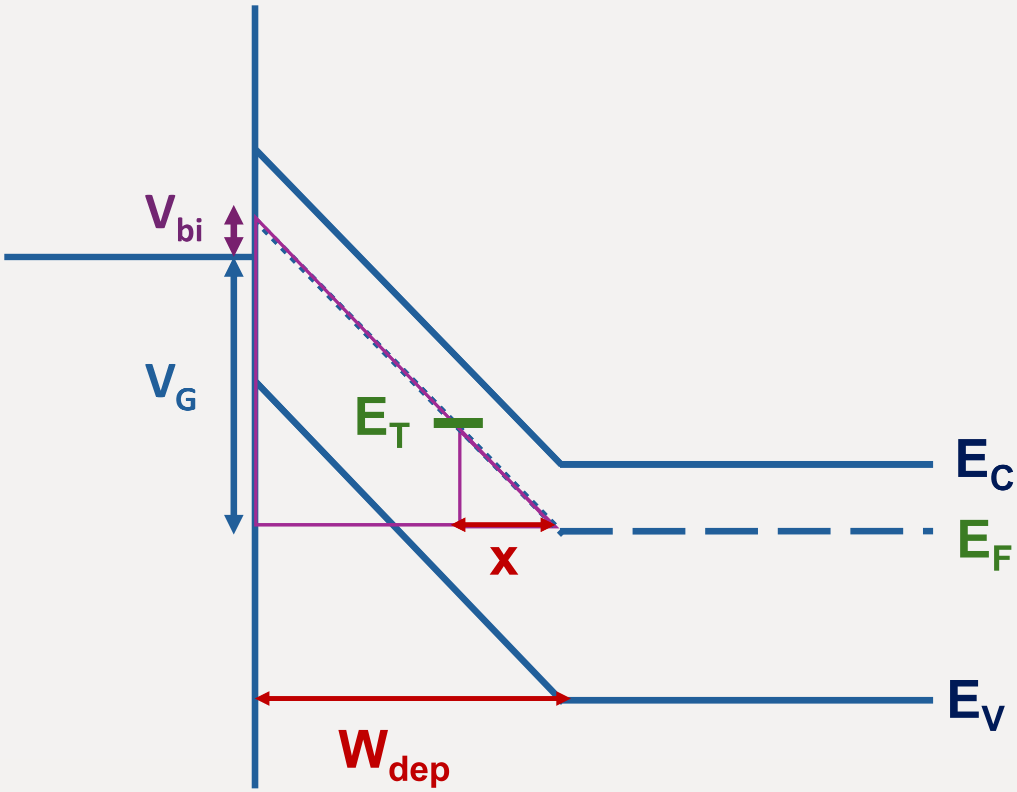
AC transconductance on MESFET-modified



$$E_T - E_F = (V_G + V_{bi}) \frac{x}{W_{dep}}$$

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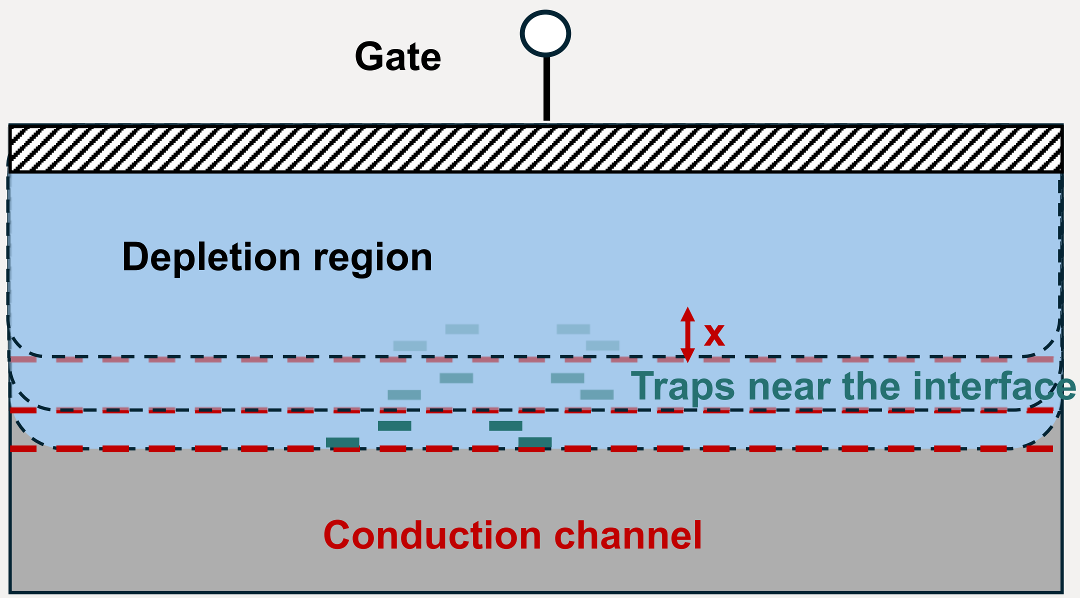
AC transconductance on MESFET

- Trap density:

$$N_T\,(E_T, x) = \frac{dGm}{dln\,(\omega)}\left[\left(1-\frac{x\,(VG)}{W_{dep}(VG)}\right)\left(\frac{x(VG)}{W_{dep}(VG)}\right) q\lambda V_{ds}\,\mu_{dc}\frac{WW_{dep}(VG)}{aL}\left(\frac{1}{\sqrt{1-\frac{V_{GS}-V_T}{V_{p0}}}}\right)\right]^{-1}$$

- Probing depth:

$$x = \lambda\, ln\left(\frac{1}{\omega\tau_0}\right)$$



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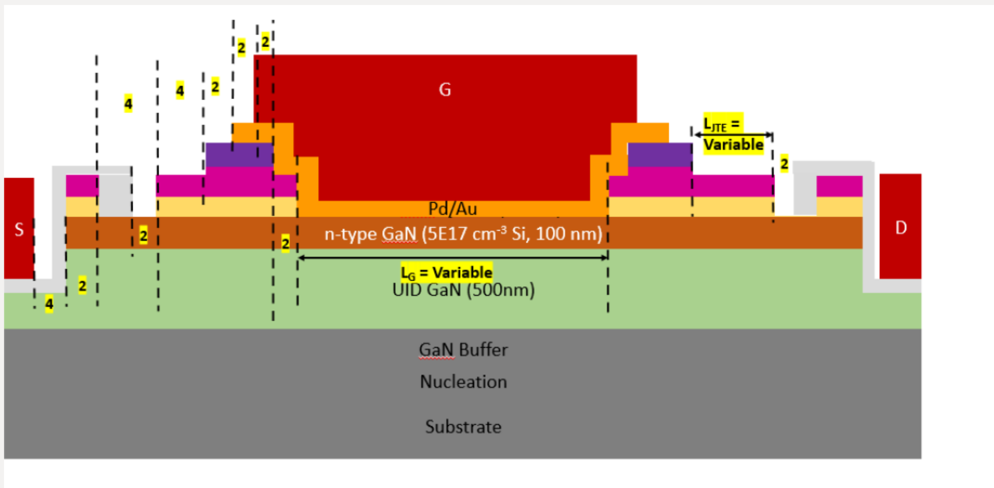
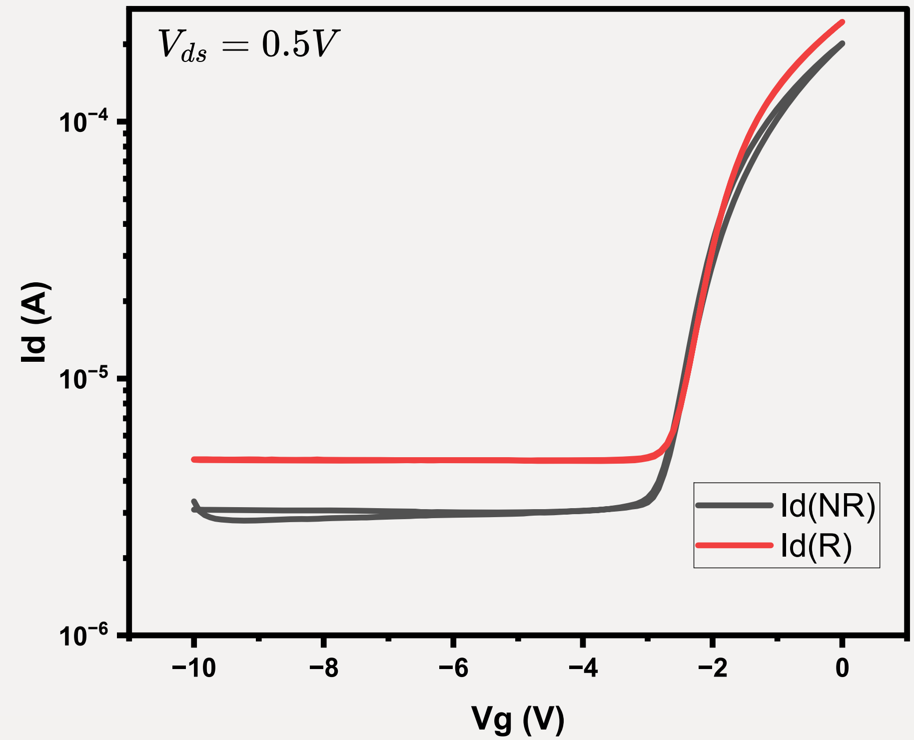
MESFET device characteristics





- Radiation condition: 10^7 cm^{-2} Au ion
- Gate leakage increase after irradiation

**Devices from Chu group, Penn State

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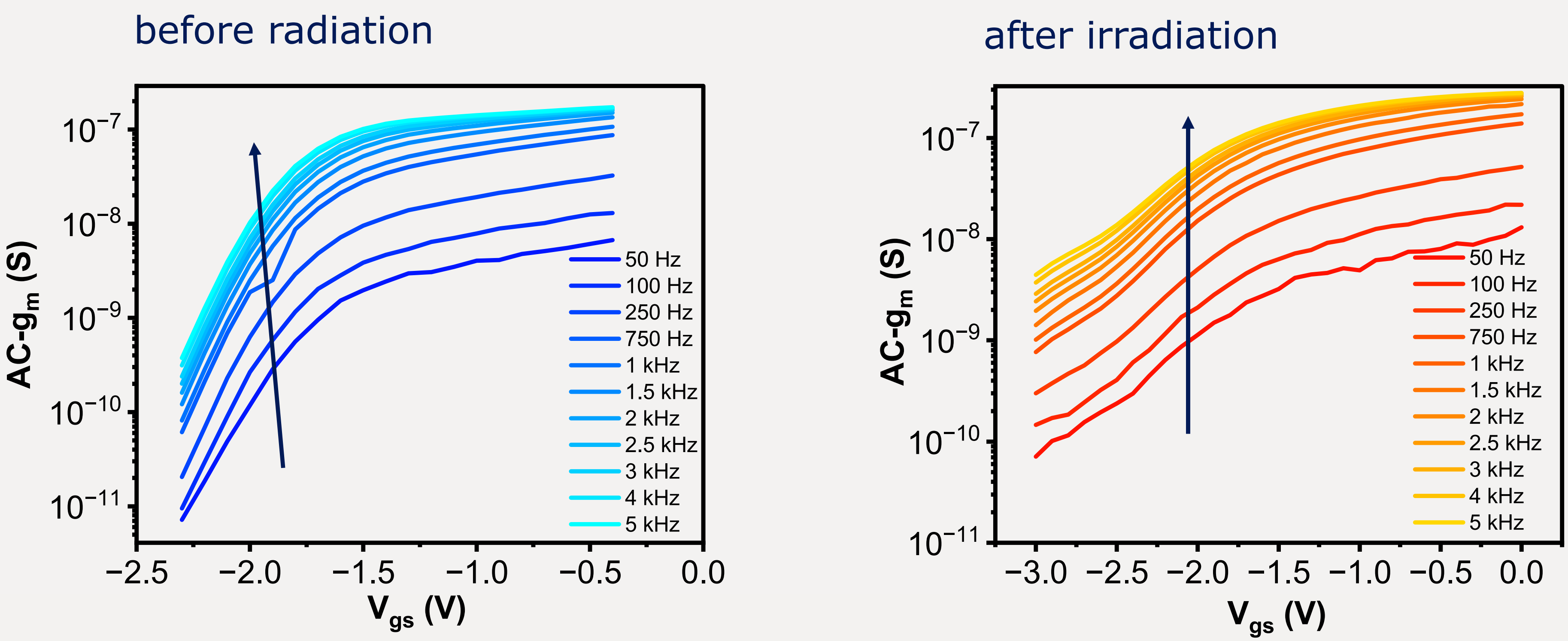
MESFET: Dispersion in ac transconductance



- AC transconductance decreases with decreasing frequency
- Traps with longer time constants respond to the lower frequencies
  - Capture electrons

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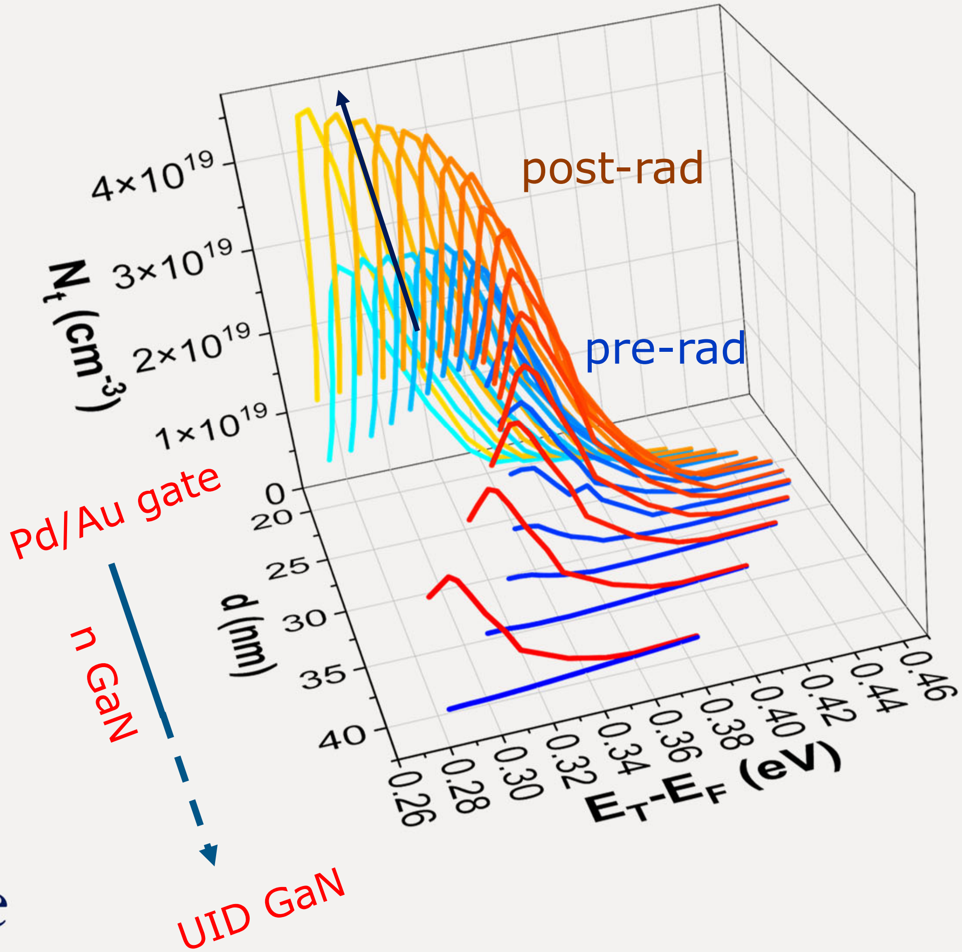
Trap distribution in energy and space



- Trap density in n-GaN depletion region increases after irradiation
- Consistent with increase in leakage after irradiation
- Further modifications:
  - E_T-E_F can be converted to E_C-E_T using TCAD simulations
  - Instead of electron capture through tunneling, other mechanisms of capture?

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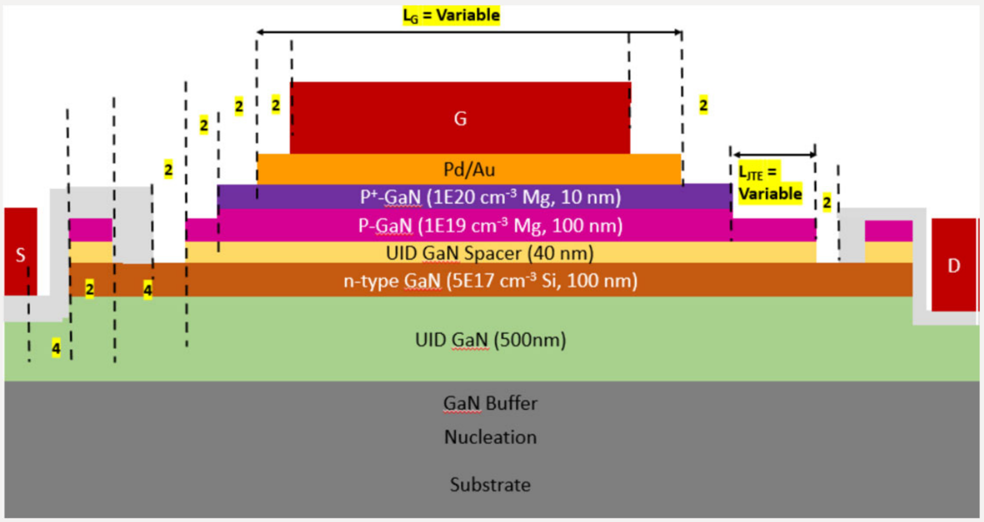
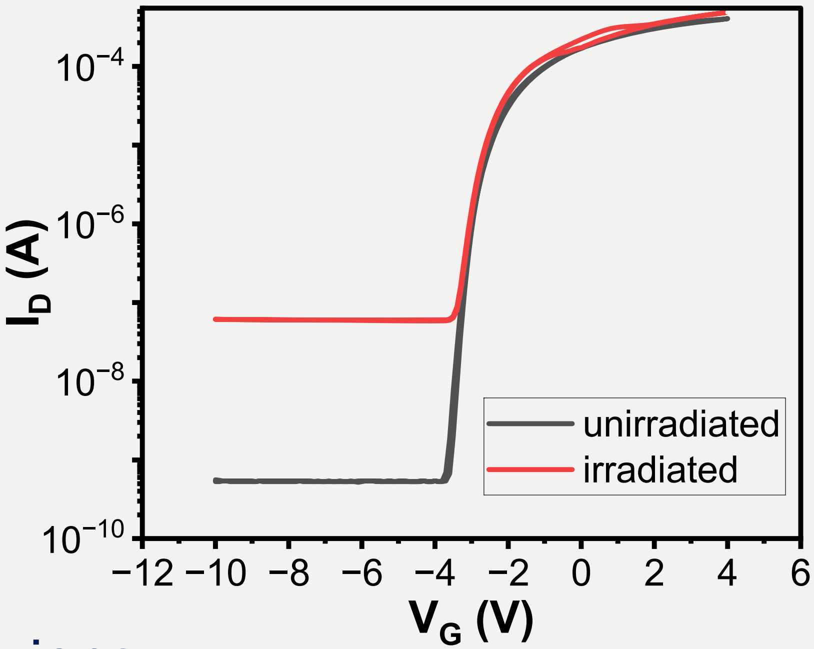
JFET characteristics





- Radiation: 10^7 cm^{-2} Au ions
- Increase in gate leakage

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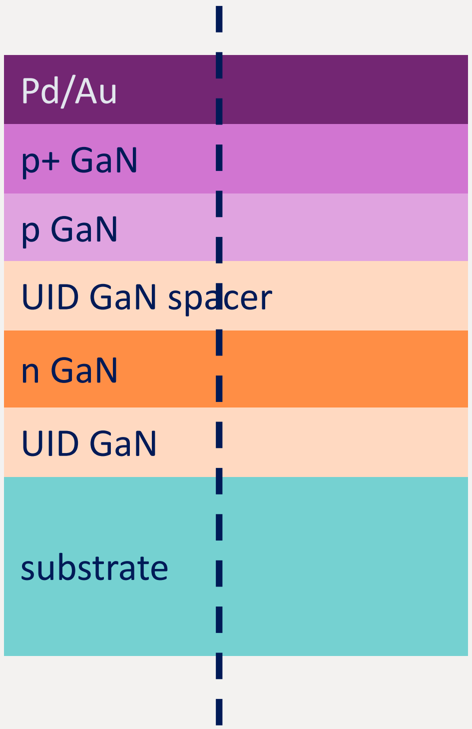
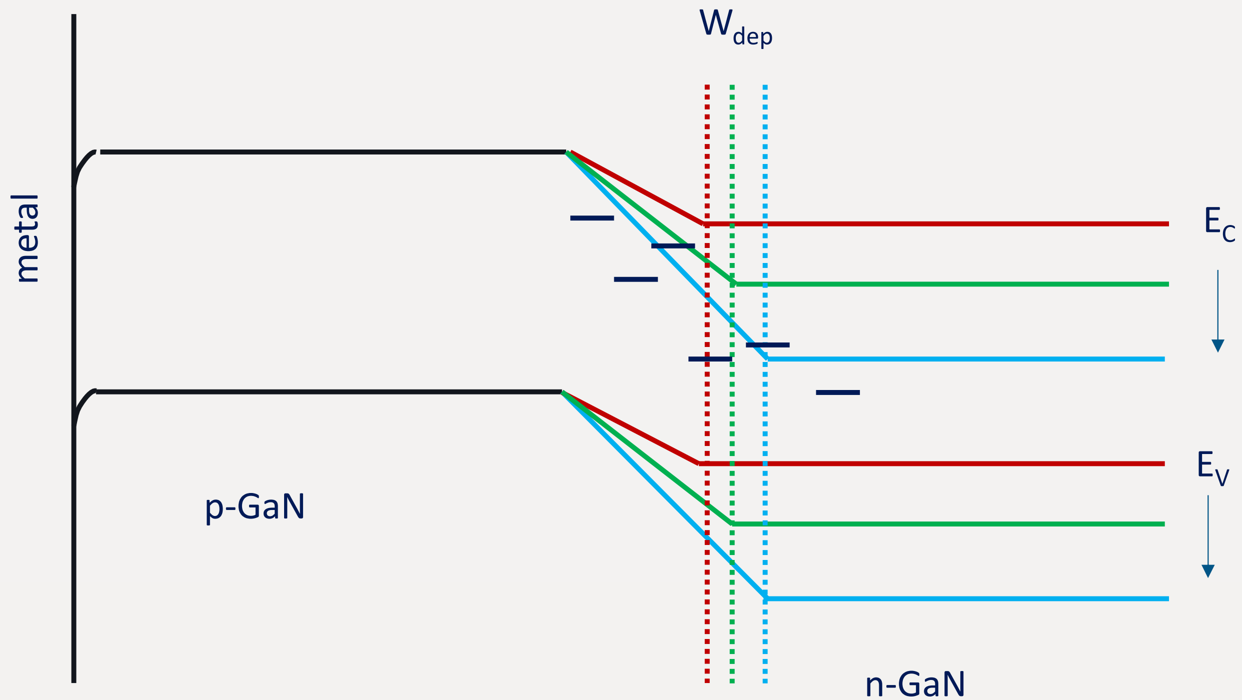
AC transconductance measurement method for JFET





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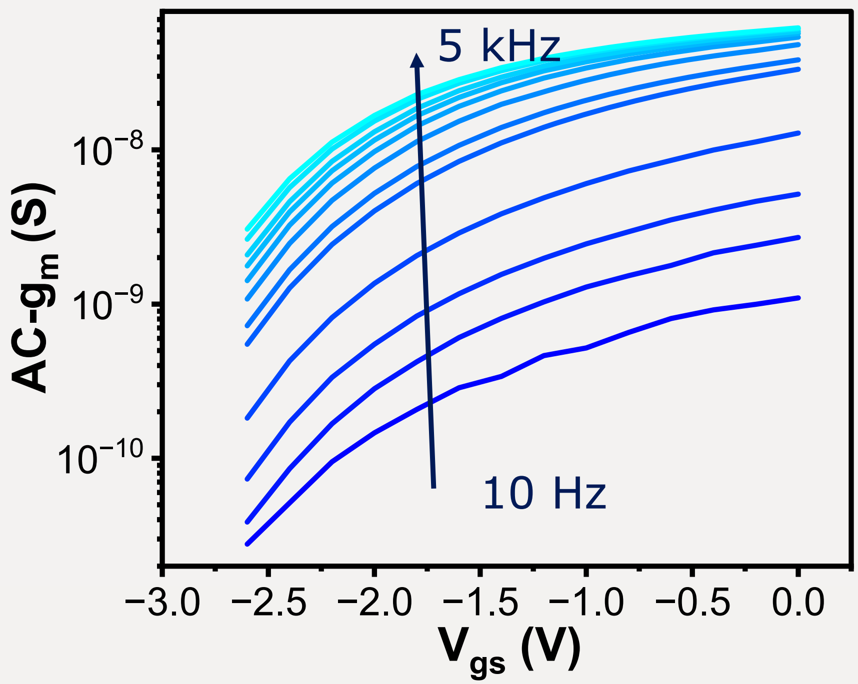
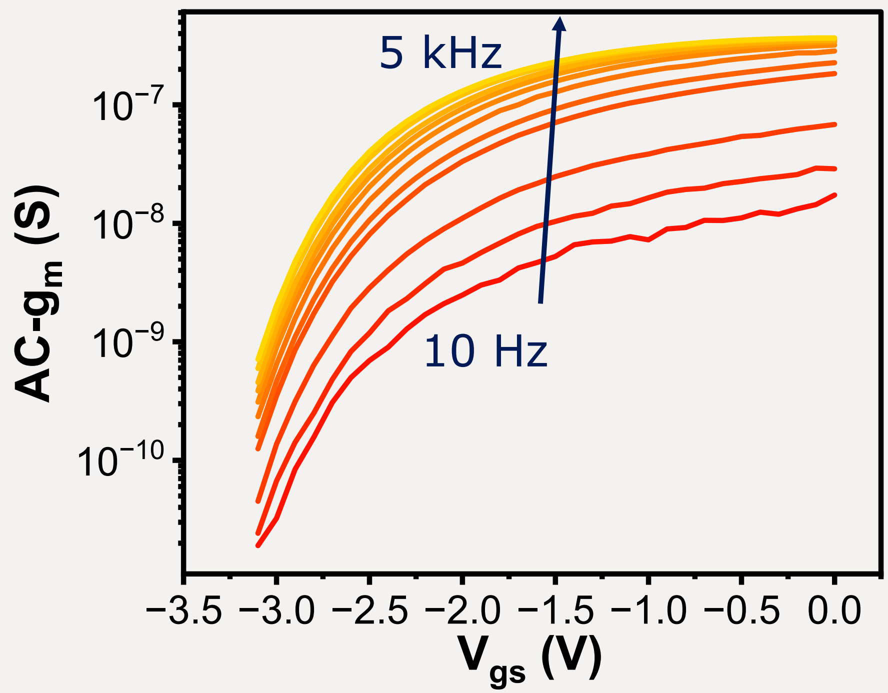
JFET: Dispersion in ac transconductance

before radiation



after irradiation



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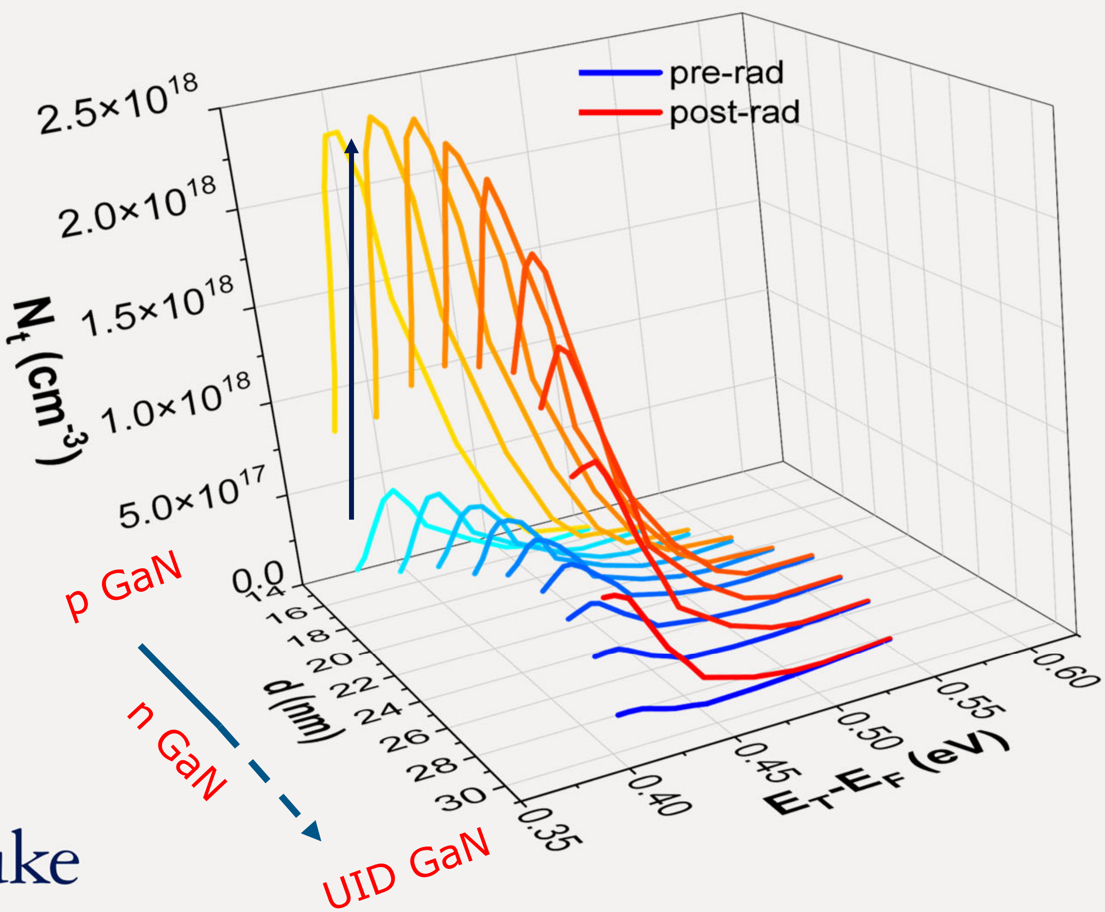
- AC transconductance decreases with decreasing frequency
- Traps with longer time constants respond to the lower frequencies
  - Capture electrons

Trap distribution in energy and space



- Increase in trap density in n-GaN depletion region after irradiation

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Year 2 accomplishments

- Revising AC transconductance method for
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  - GaN JFET

- Pre-rad and post-rad characterization of GaN MESFET and JFET using
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  - Low frequency 1/f noise

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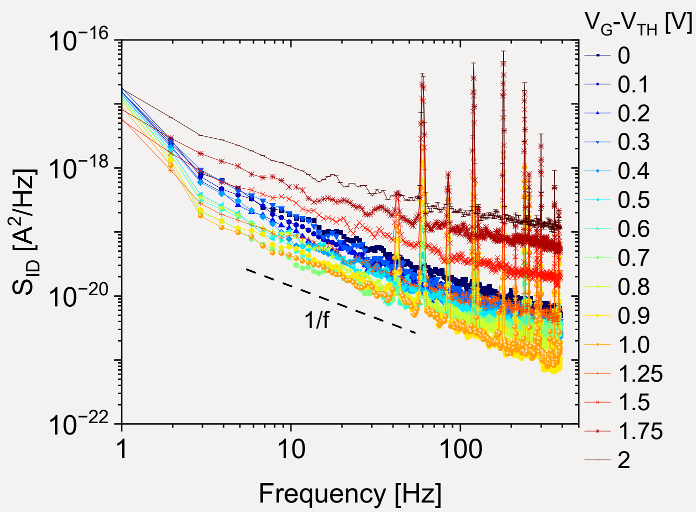
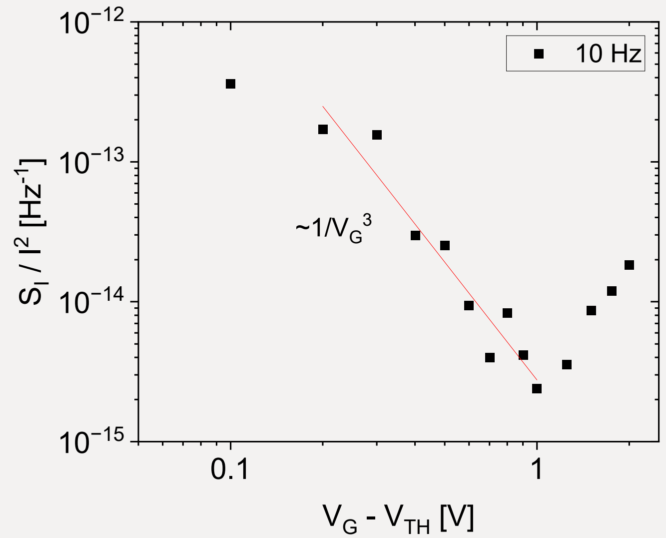
Low frequency 1/f noise - MESFETs





- Noise trend shifts as device switches from linear to saturation
- Linear region shows $1/V_G^3$ trend
  - Noise originating from the gated portion of channel
- Noise profile indicates a broad distribution of traps (corroborated by ac-gm)

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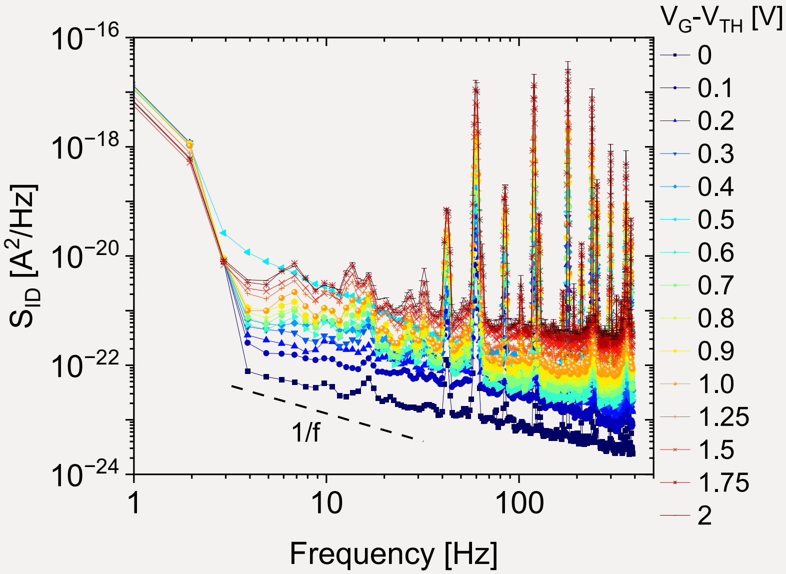
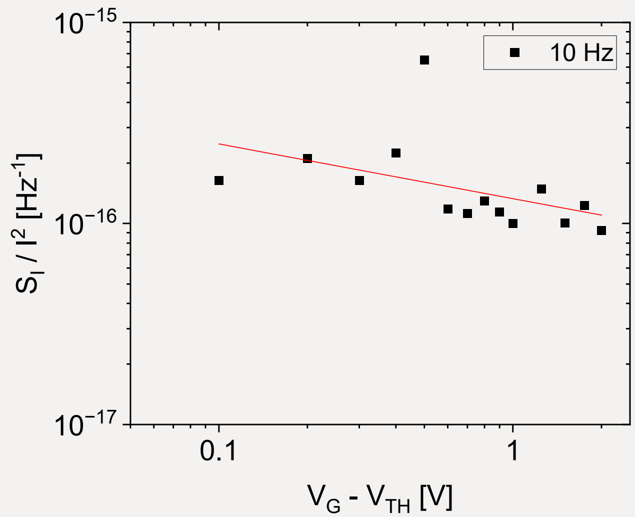
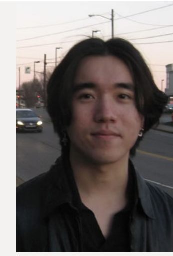
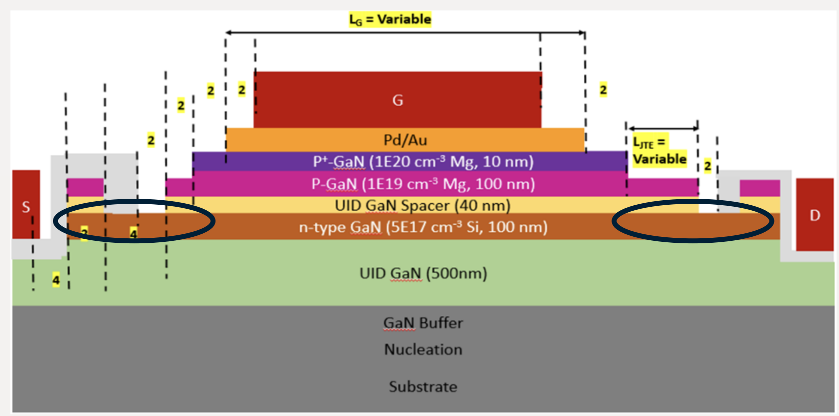
Low frequency 1/f noise - JFETs







- No clear correlation with V_G
- Noise scales linearly with current
- Measured noise mainly stems from ungated region of channel



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Year 2 accomplishments

✓Developed a new model for AC transconductance method on

- GaN MESFET
- GaN JFET

✓Pre-rad and post-rad characterization of GaN MESFET and JFET using

- AC transconductance method
- Low frequency 1/f noise

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What next?

- Refine AC transconductance model
  - What is the mechanism of carrier trapping-detrapping
    - Tunneling? Others?
- Correlate AC transconductance with conductance method for MESFET and JFET
  - Conductance method model needs to be re-defined
- Further measurements on JFETs and MESFETs under irradiation
- Measurements on HEMTs before and after radiation