PennState

Impact of heavy ion irradiation on GaN devices

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In collaboration with Prof. Maik Lang , GSI & BNL

Overview

Many thanks to Prof. Maik Lang, Dr. Eric Quinn & Dr. Voss, Kay-Obbe & GSI members

GSI – Ar ion on-site

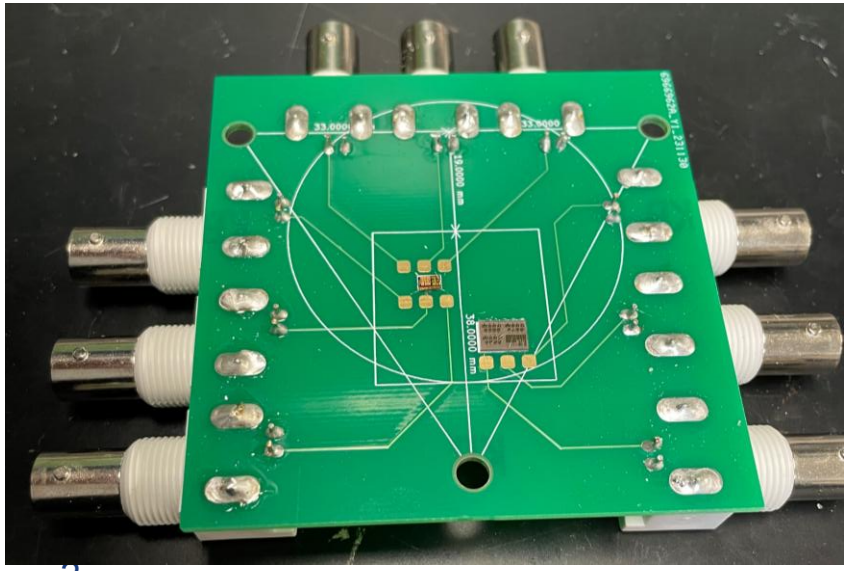
Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{40}Ar	192 MeV (4.8 MeV/u)	26 µm	10.8

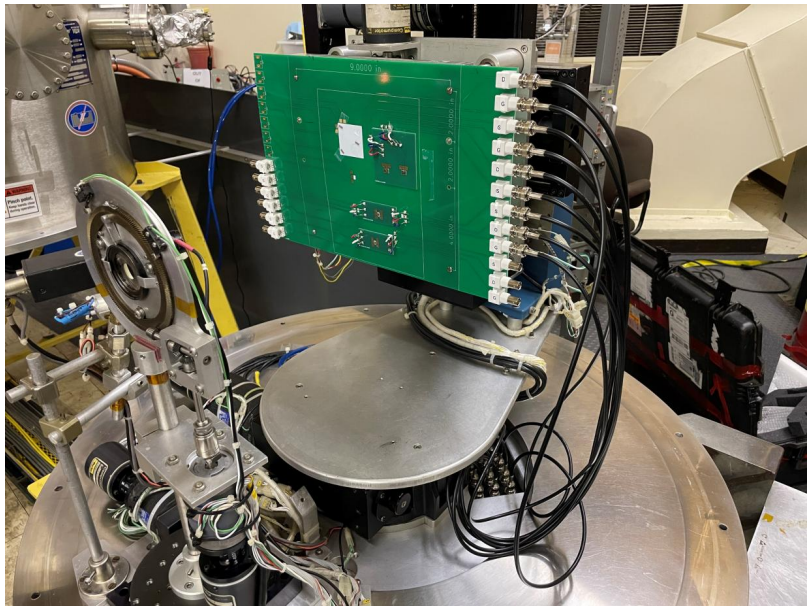
BNL – Au ion on-site

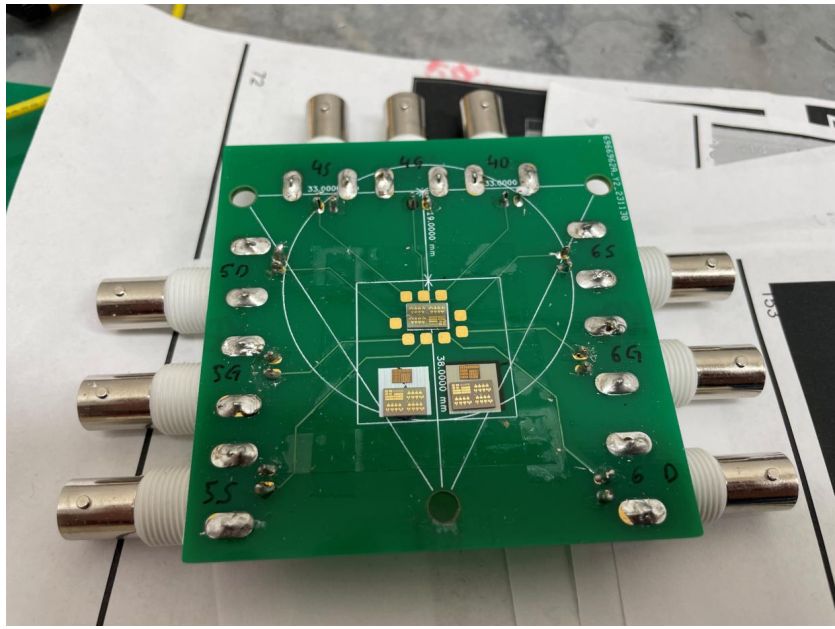
Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{197}Au	333.7 MeV (1.71 MeV/u)	15.5 µm	~64.09

GSI – Au ion

Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{197}Au	950 MeV (4.8 MeV/u)	30 µm	72.4







Overview

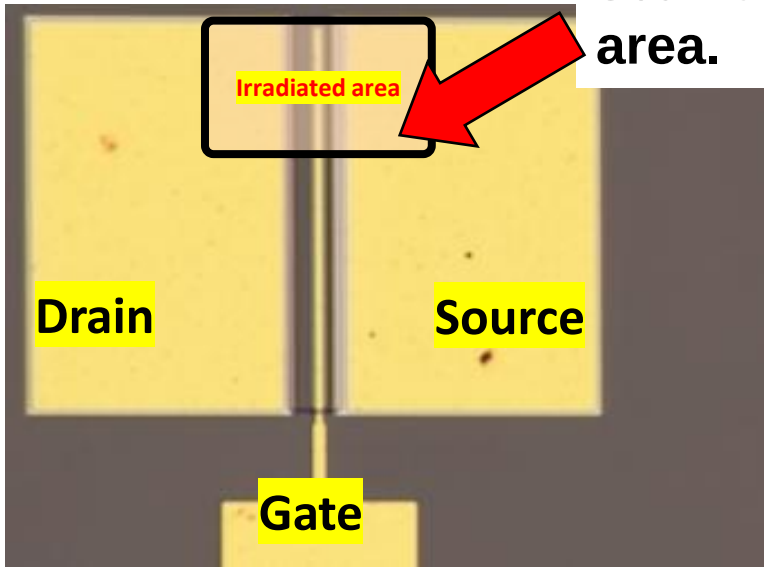
- ❑ **GSI – 192 MeV Ar – On-site test**
- ❑ **BNL – 333.7 MeV Au– On-site test**
- ❑ **GSI – 950 MeV Au – Ex-situ test**

Scanning recipe

Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{40}Ar	192 MeV (4.8 MeV/u)	26 μm	10.8

Fluence ramp

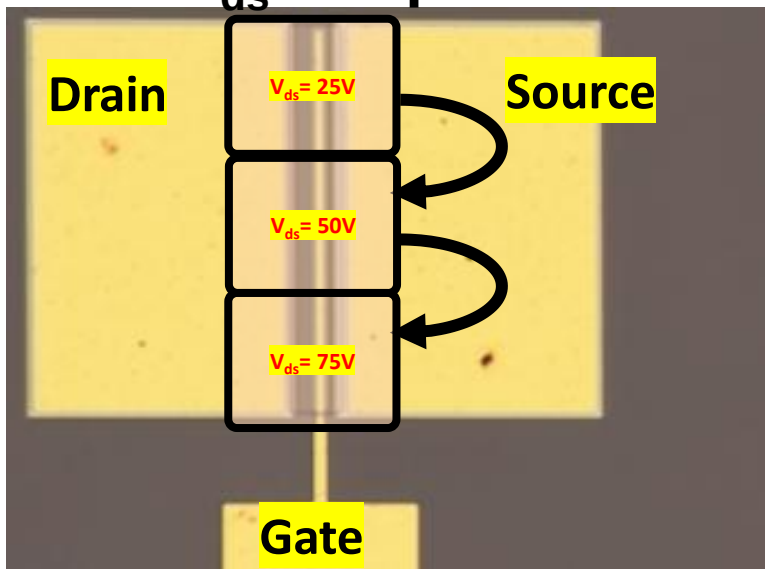
Repeatedly scan the area.

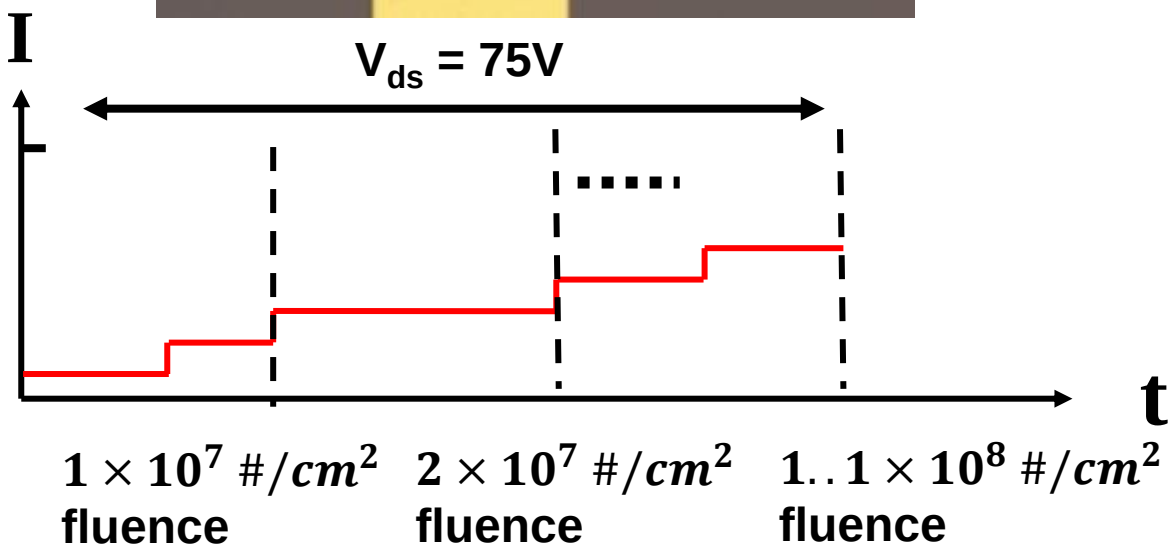


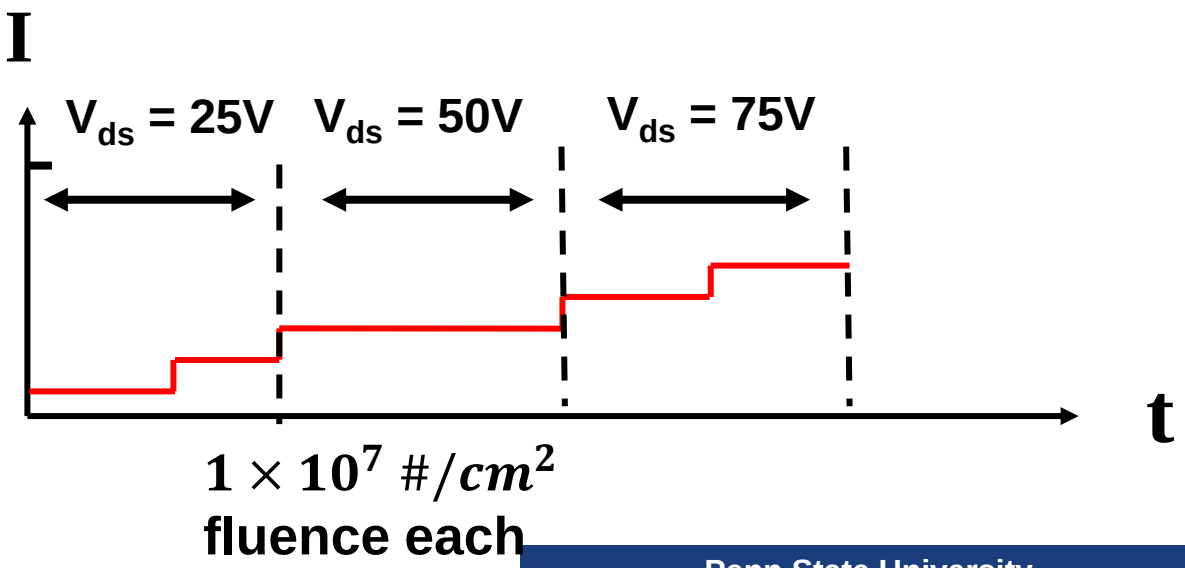
BV_{ds} = ~130V

Device bias at off-state during irradiation
(V_{ds} = variable, V_{gs} = -6 V)

V_{ds} ramp







Junction FET– Fluence ramp

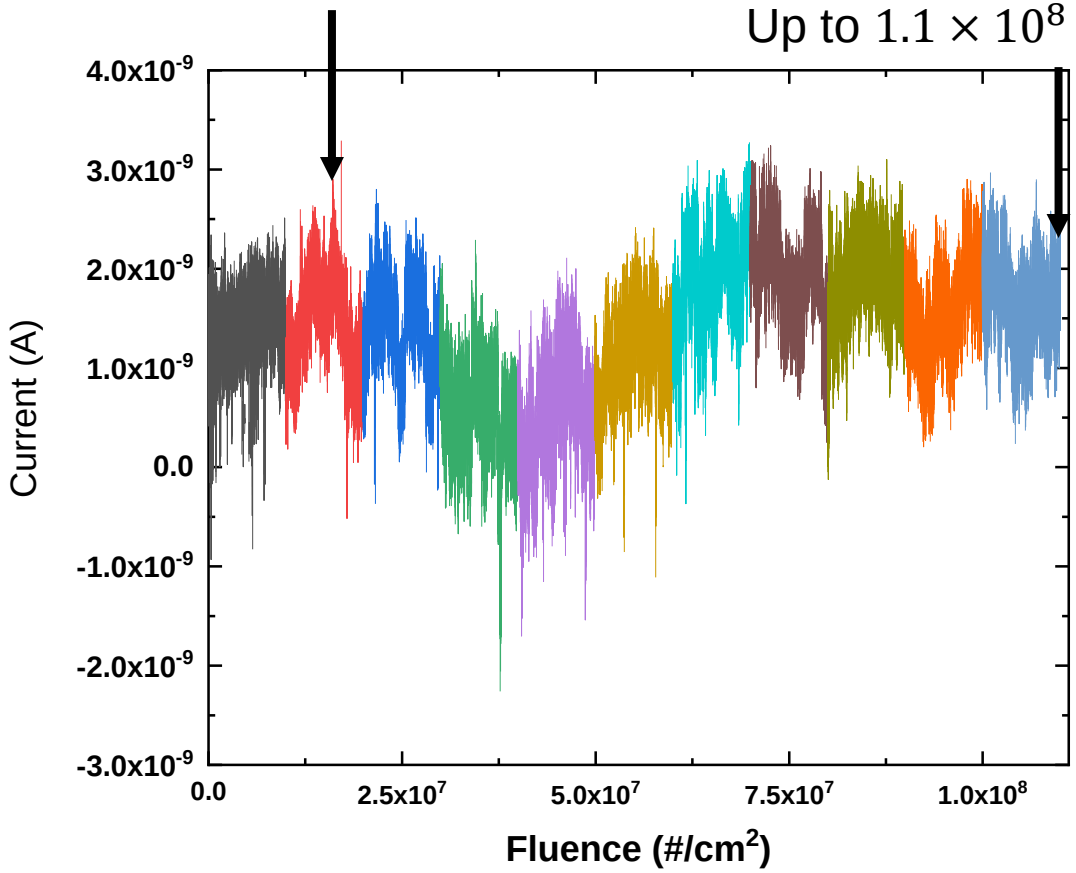
Ion	Energy	Range	LET (MeV/(mg/cm^2)
^{40}Ar	192 MeV (4.8 MeV/u)	26 µm	10.8

- No SEE detected up to 1.1×10^8 $\#/cm^2$ fluence

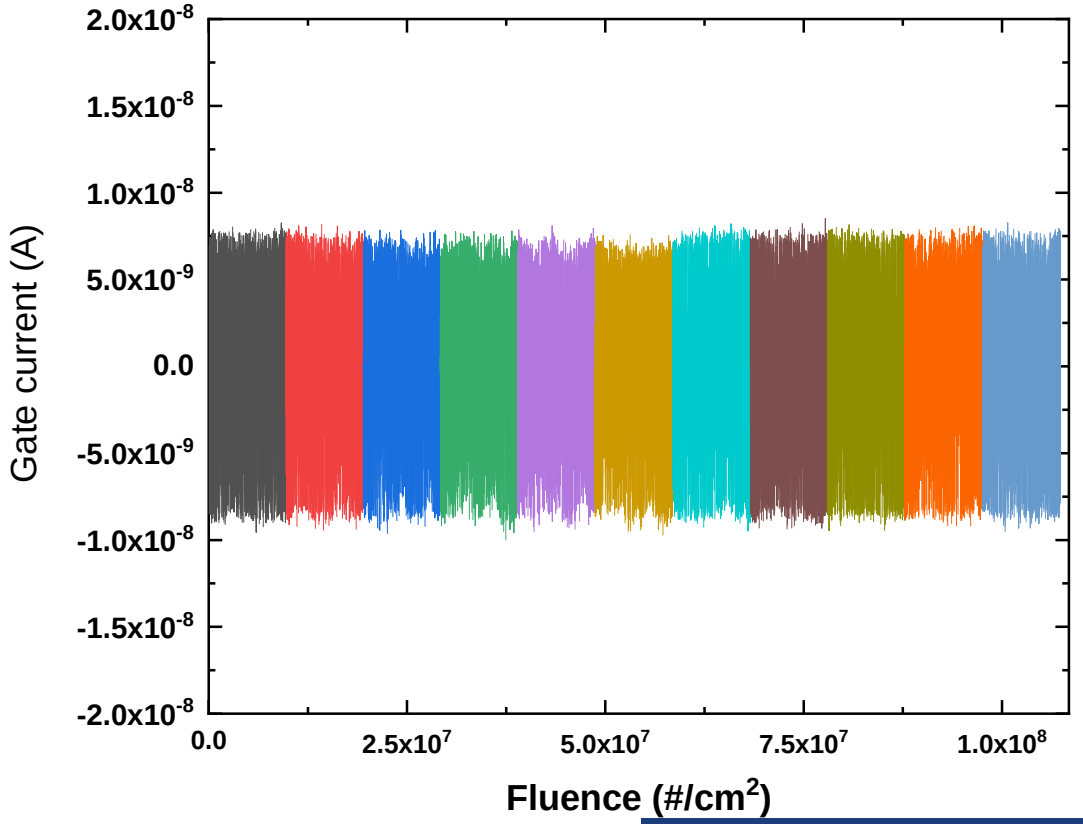
Gate current

Each correspond to 1×10^7 $\#/cm^2$ fluence

Up to 1.1×10^8 $\#/cm^2$ fluence



Drain current



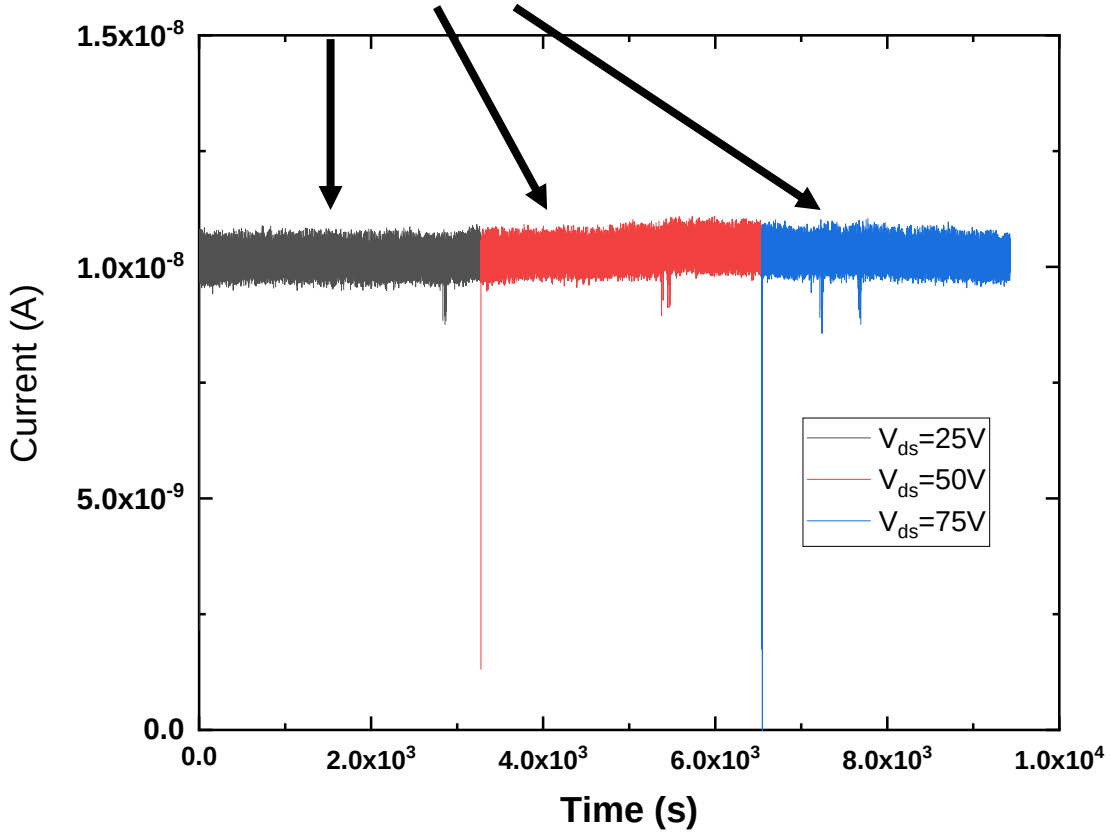
Junction FET– V_{ds} ramp

Ion	Energy	Range	LET (MeV/(mg/cm²)
^{40}Ar	192 MeV (4.8 MeV/u)	26 μm	10.8

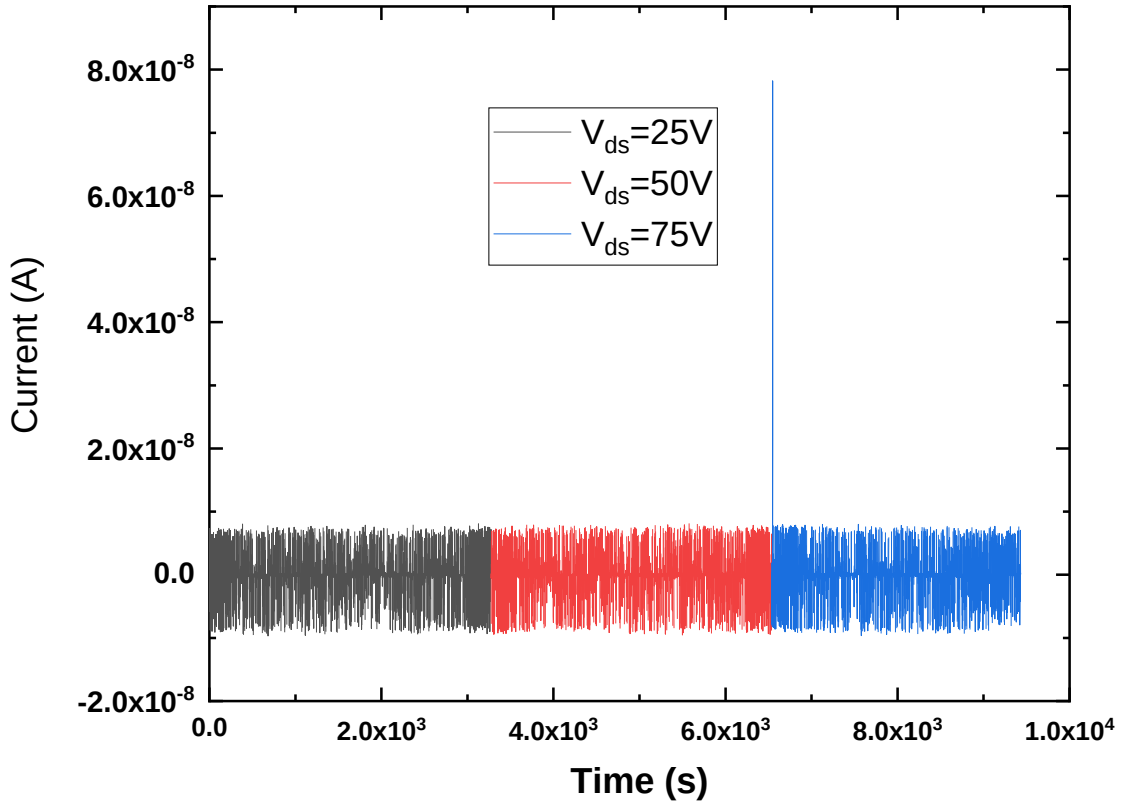
- No SEE detected up to $V_{ds} = 75\ V$

Gate current

Each correspond to $1 \times 10^7\ \#/cm^2$ fluence (non- cumulative)



Drain current



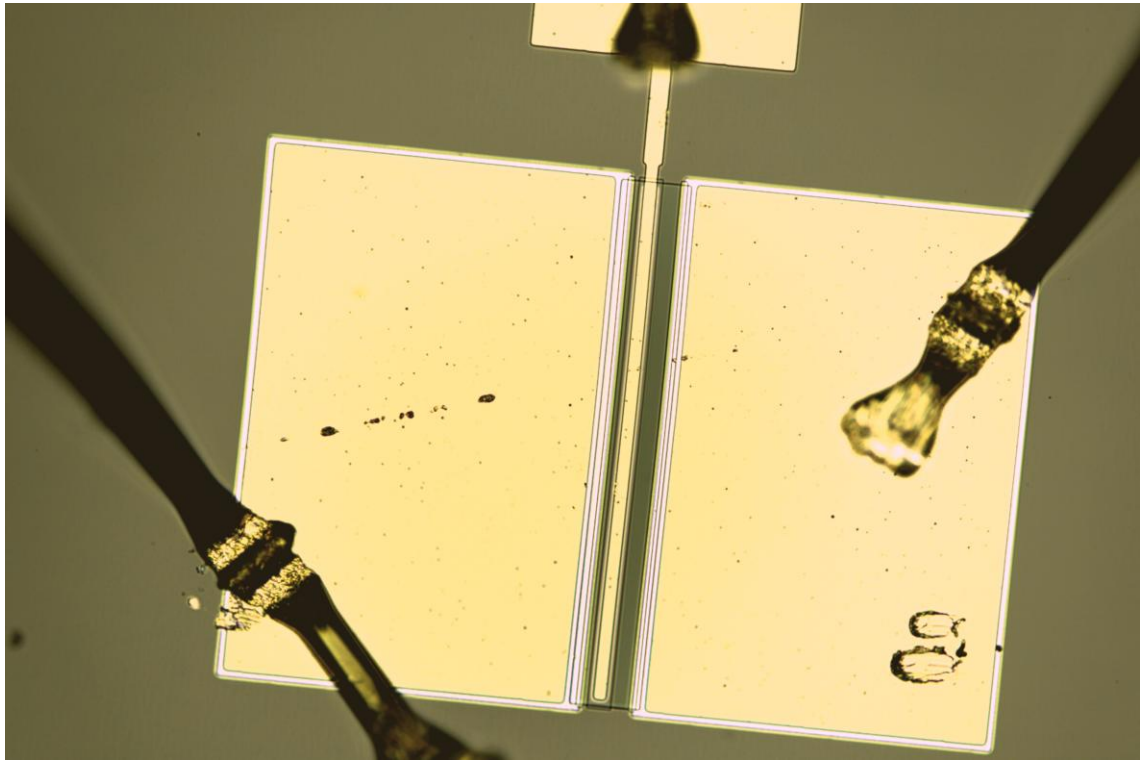
Overview

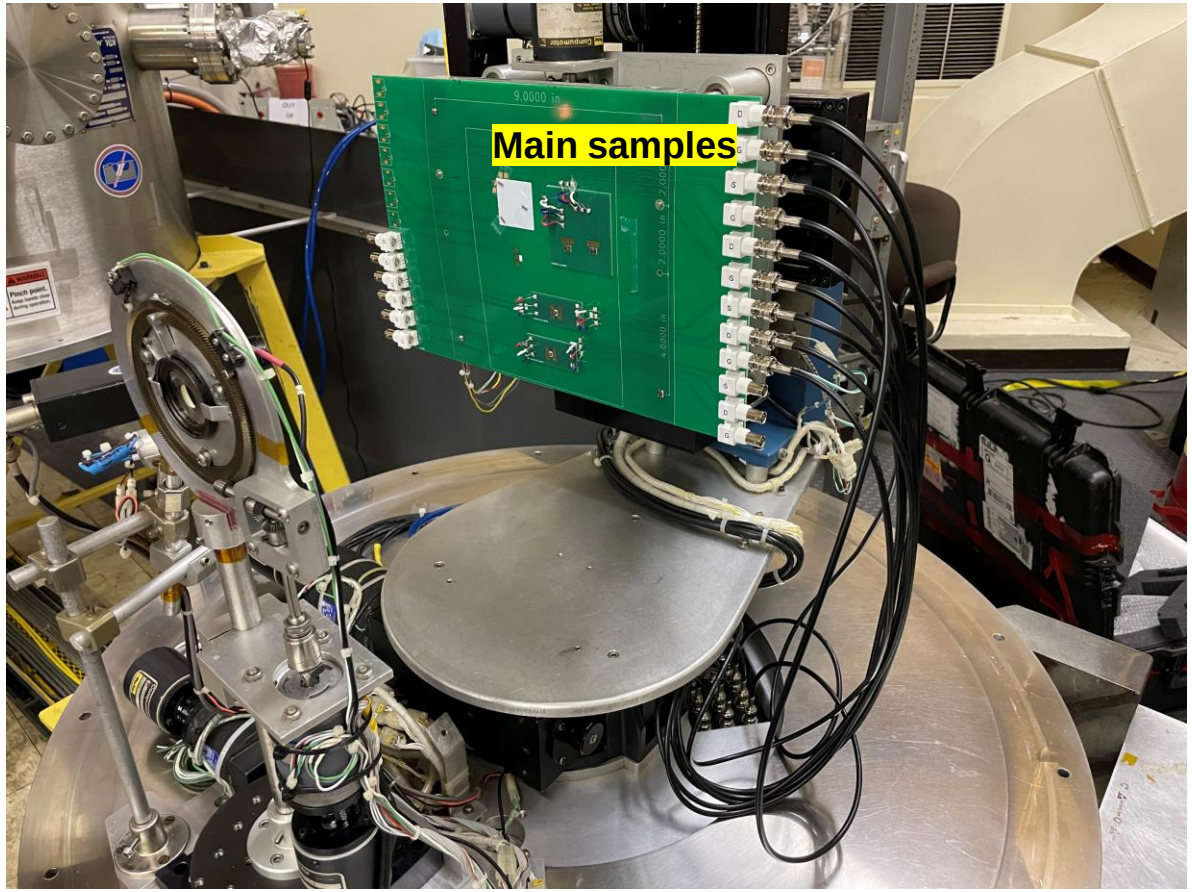
- GSI – 192 MeV Ar – On-site test
- **BNL – 333.7 MeV Au – On-site test**
- GSI – 950 MeV Au – Ex-situ test

Overview

Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{197}Au	333.7 MeV (1.71 MeV/u)	15.5 μm	64.09

- PSU fabricated JFET, wire bonded
- Device bias at off-state during irradiation (V_{ds} = variable, V_{gs} = -6 V)
- Broad beam covers full sample



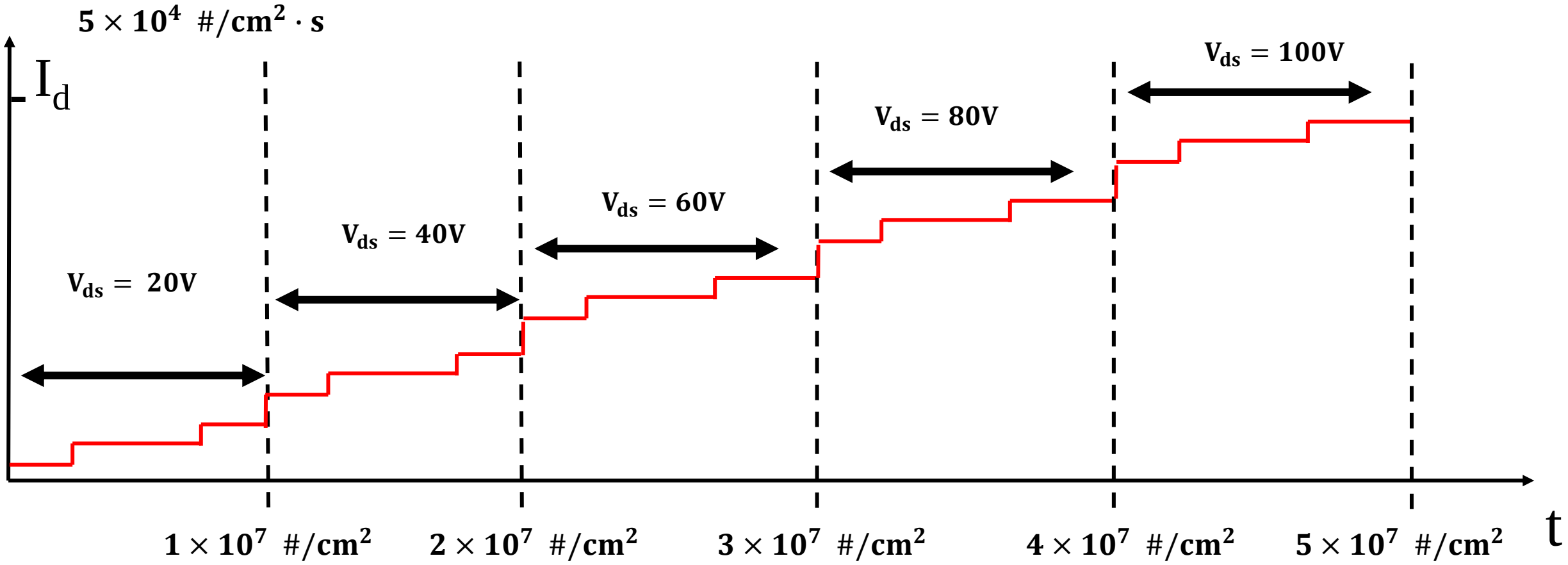


Scanning recipe

Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{197}Au	333.7 MeV (1.71 MeV/u)	15.5 μm	64.09

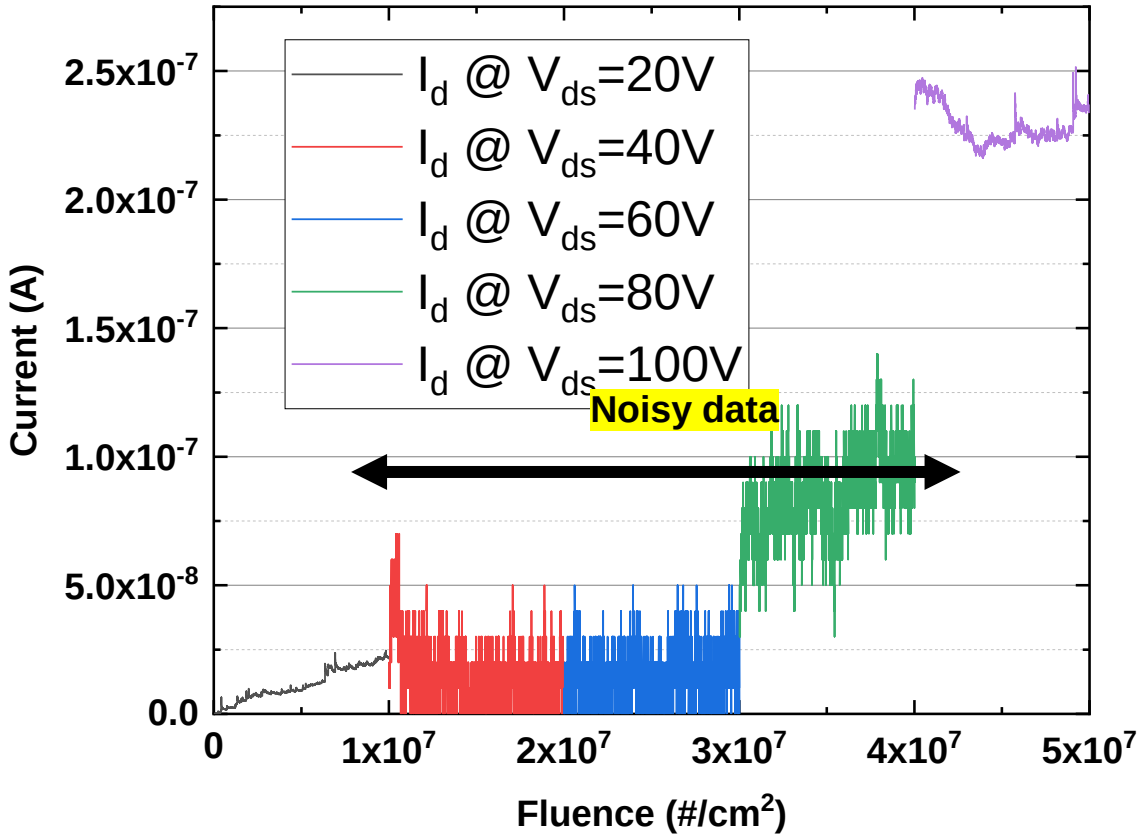
Sampling interval : 50ms

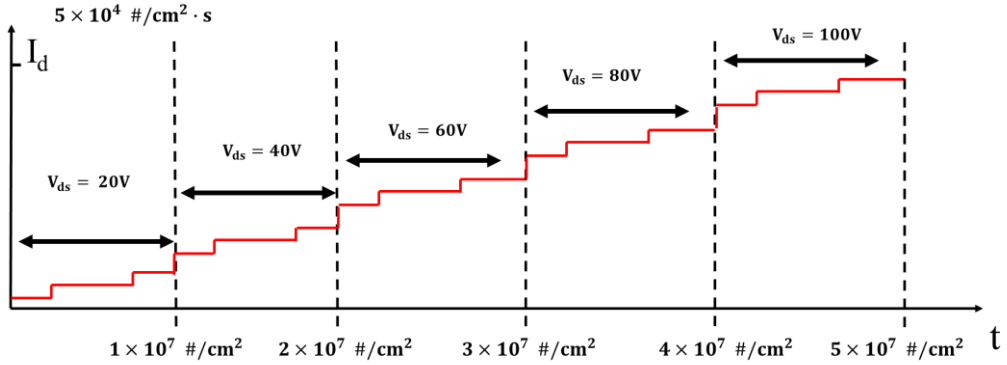
BV_{ds} = ~130V



PSU JFET – Full I-t @ 5e7 #/cm² fluence

Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	333.7 MeV (1.71 MeV/u)	15.5 μm	64.09



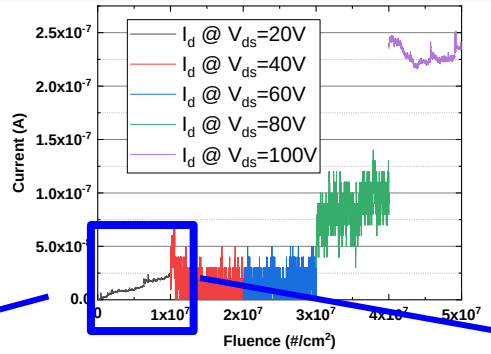


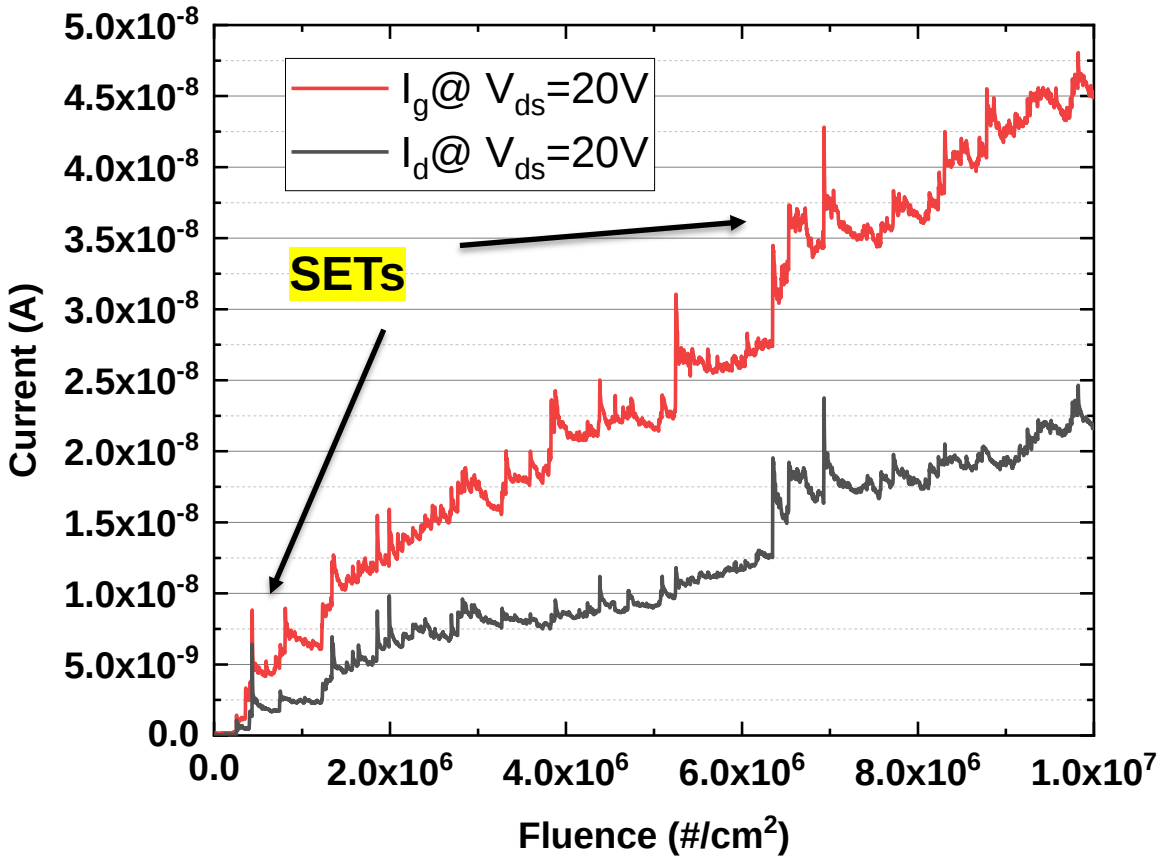
❖ ***Tool calibration likely caused the noisy data between 40~80V***

- Gradual increase of off-state leakage current over fluence and V_{ds}
- No destructive SEE observed

PSU JFET – V_{ds} = 20 V @ 1e7 #/cm² fluence

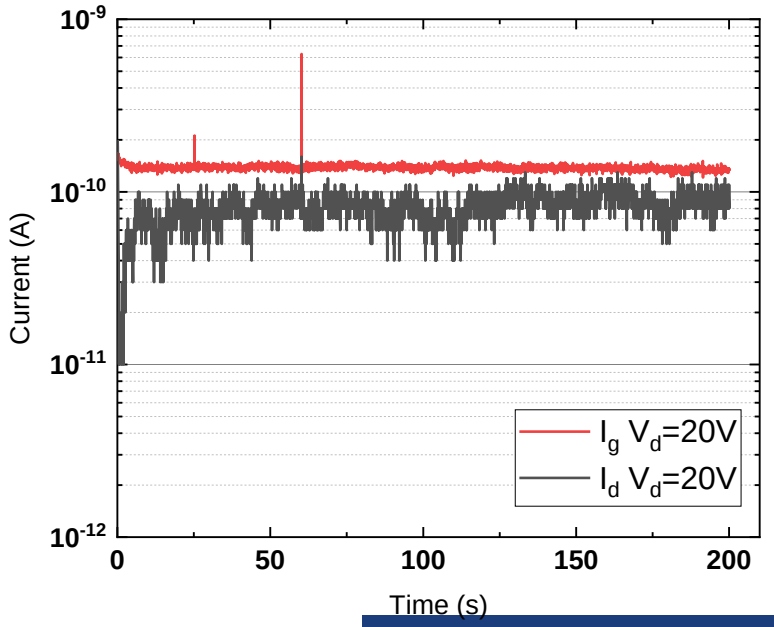
Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	333.7 MeV (1.71 MeV/u)	15.5 µm	64.09





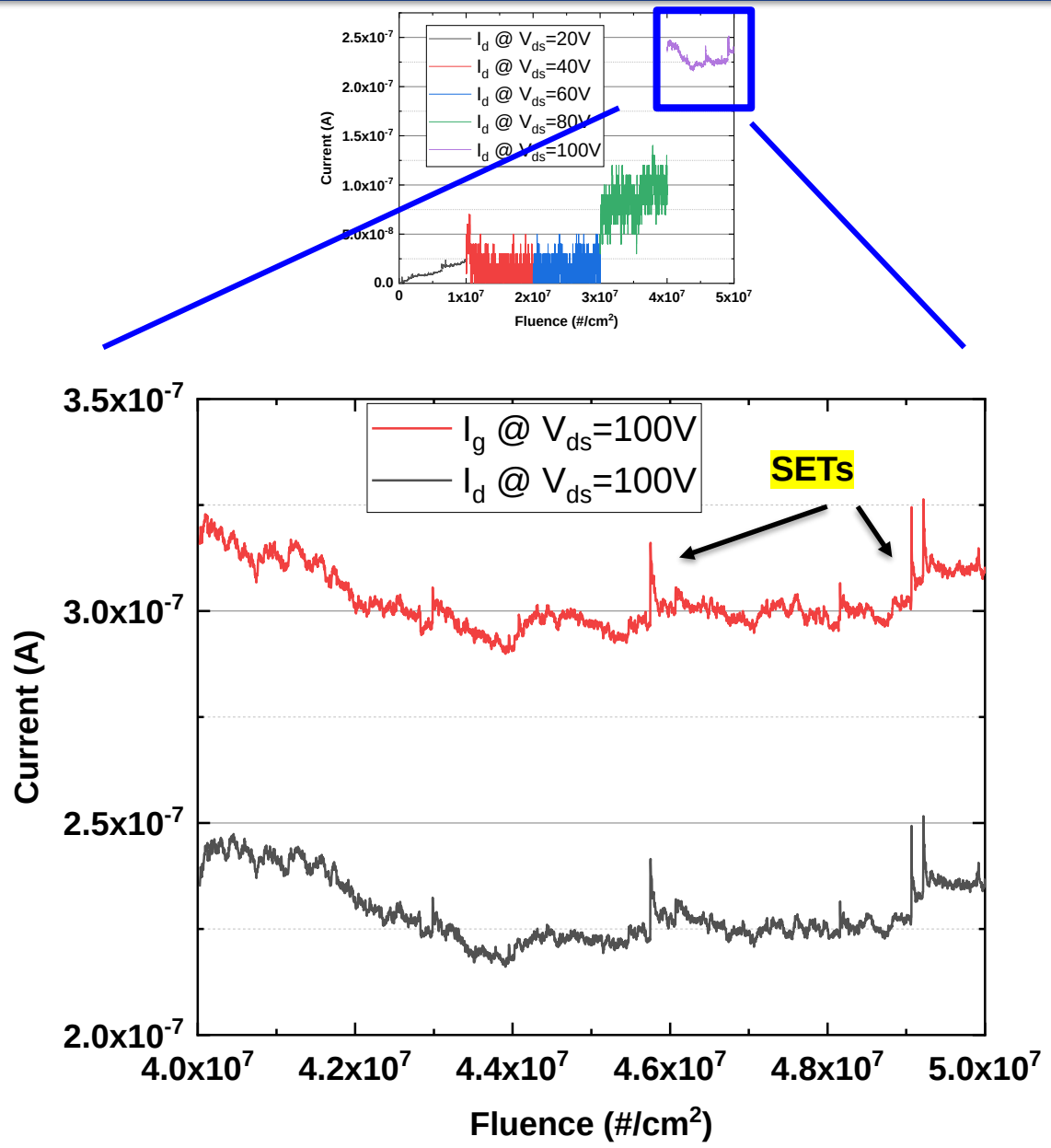
- Leakage current increasing constantly
- Each SET in I_d always correspond to one in I_g.

Device transient without any radiation



PSU JFET – V_{ds} = 100 V @ 5e7 #/cm² fluence

Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	333.7 MeV (1.71 MeV/u)	15.5 µm	64.09



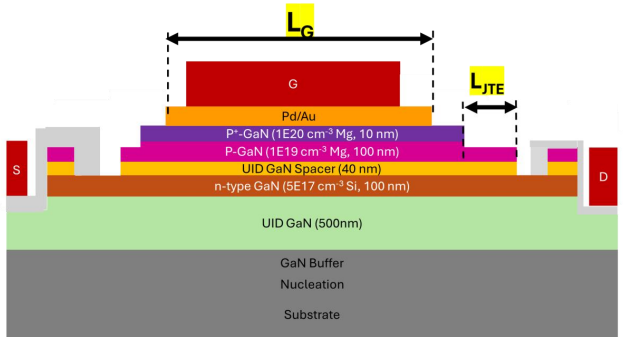
- SETs can still be observed
- Device leakage current stabilized
- No destructive SEE

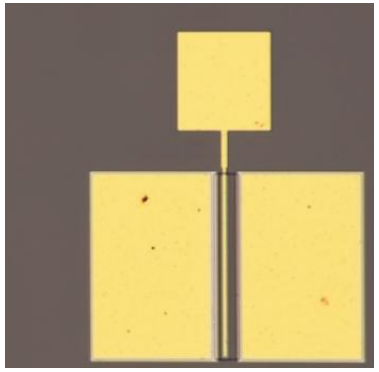
Overview

- GSI – 192 MeV Ar – On-site test
- BNL – 333.7 MeV Au – On-site test
- **GSI – 950 MeV Au – Ex-situ test**

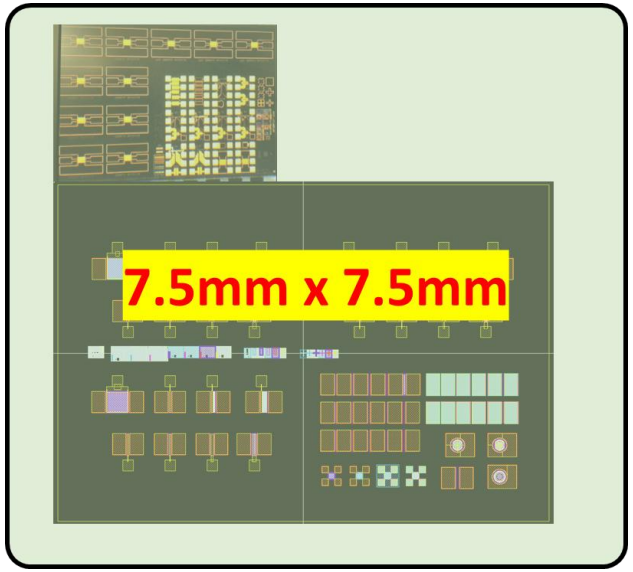
Overview

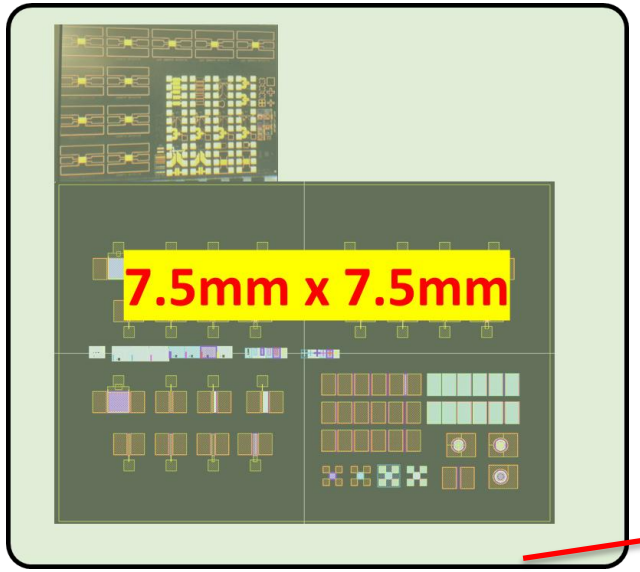
Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{197}Au	950 MeV (4.8 MeV/u)	30 μm	72.4





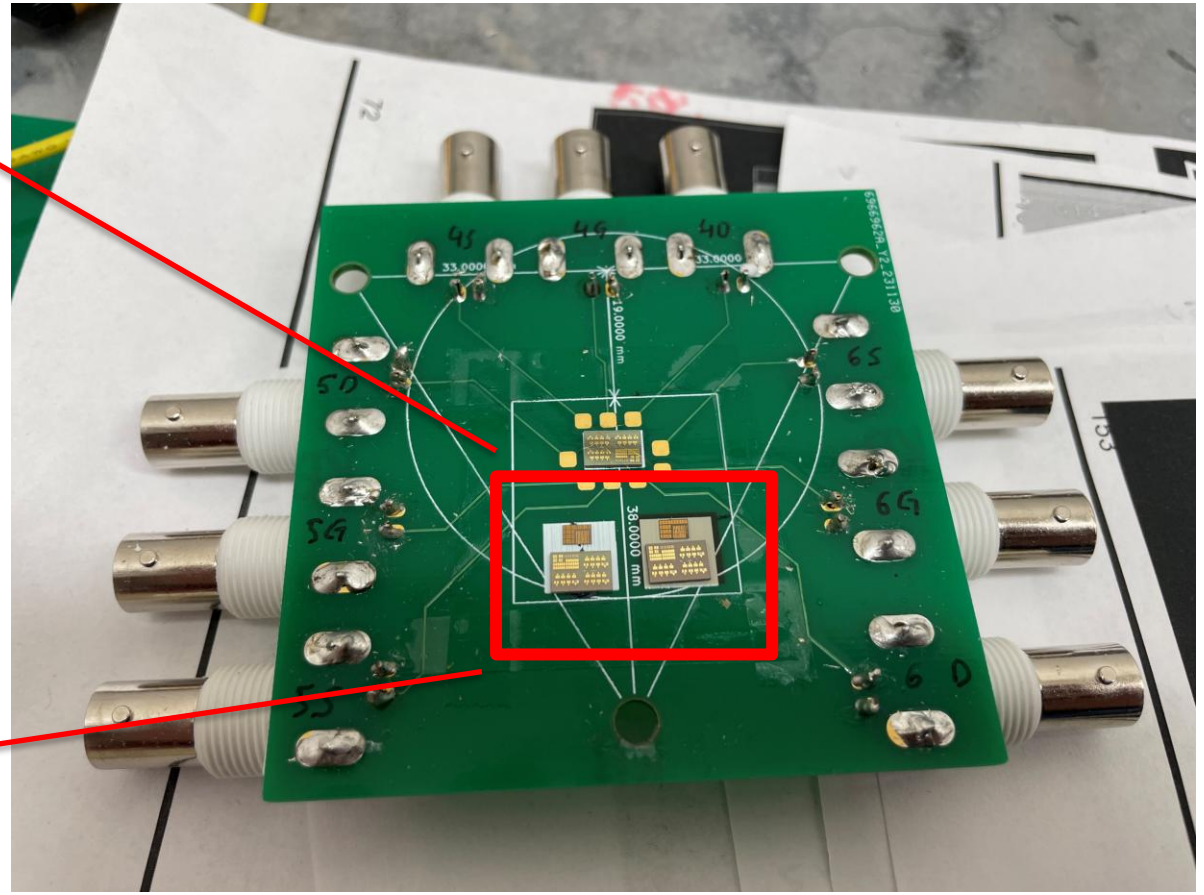
PSU made JFET samples, broad beam irradiation





Fluence $1 \times 10^7 \#/cm^2$

Fluence $5 \times 10^{11} \#/cm^2$



PSU FETs – Au ion fluence variance

Ion	Energy	Range	LET (MeV/(mg/cm^2))
^{197}Au	950 MeV (4.8 MeV/u)	30 μm	72.4

- Extreme high fluence destroy the device

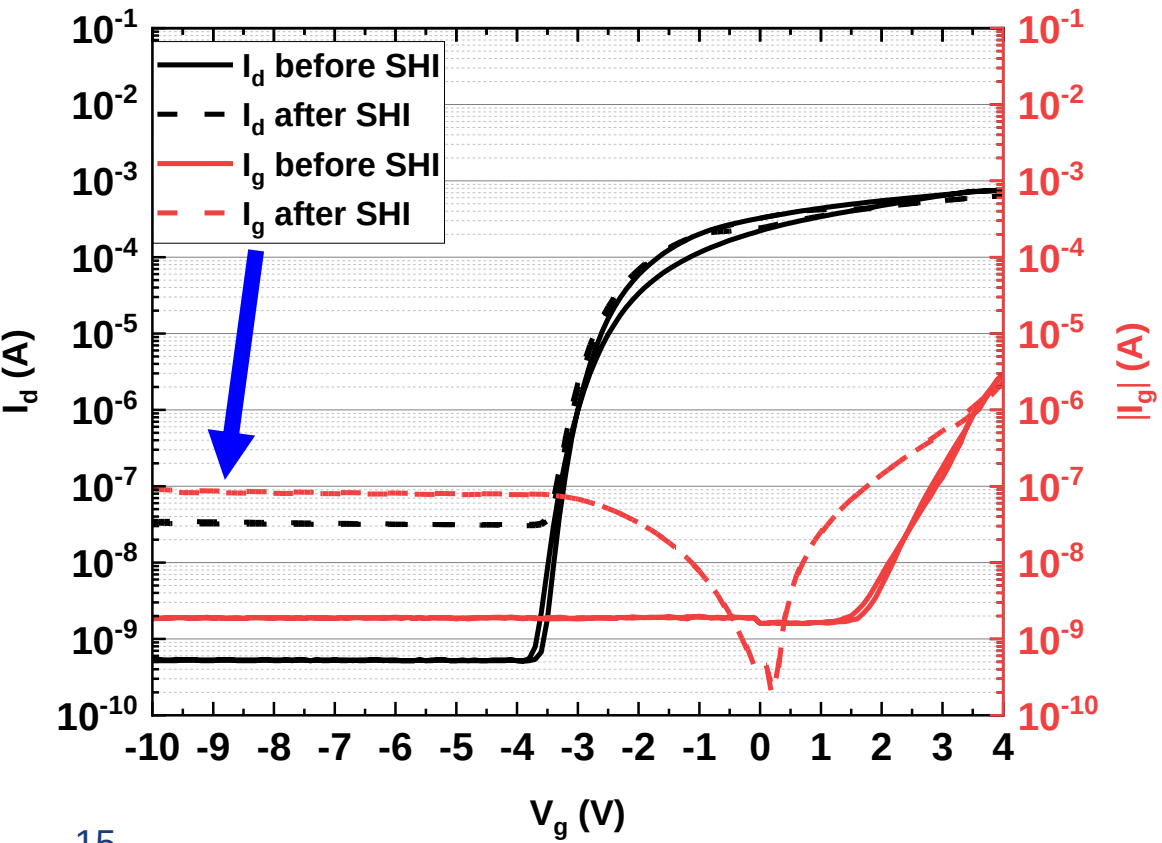
Transfer IV

Bias: V_g= -10 to 4V; V_d= 0.5V

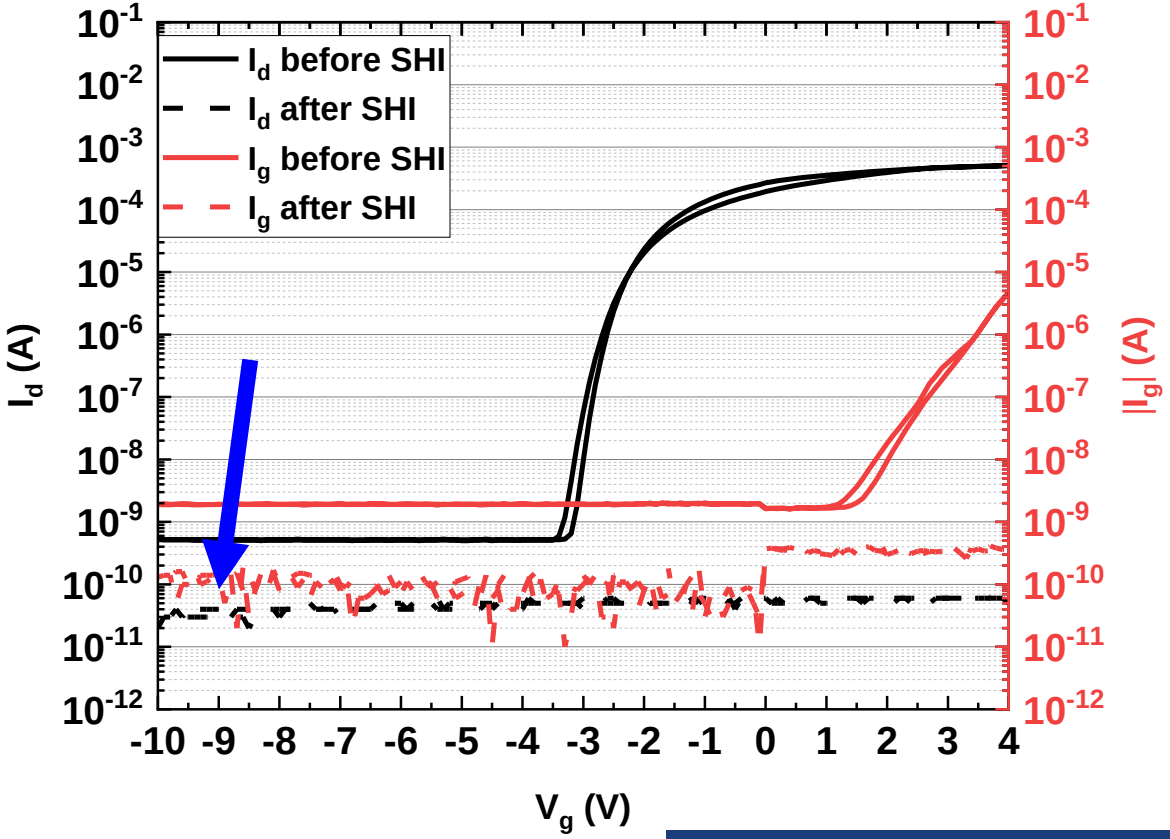
JFET

L_g=10um, L_{JTE} =10um

Au fluence = $1 \times 10^7 \#/cm^2$

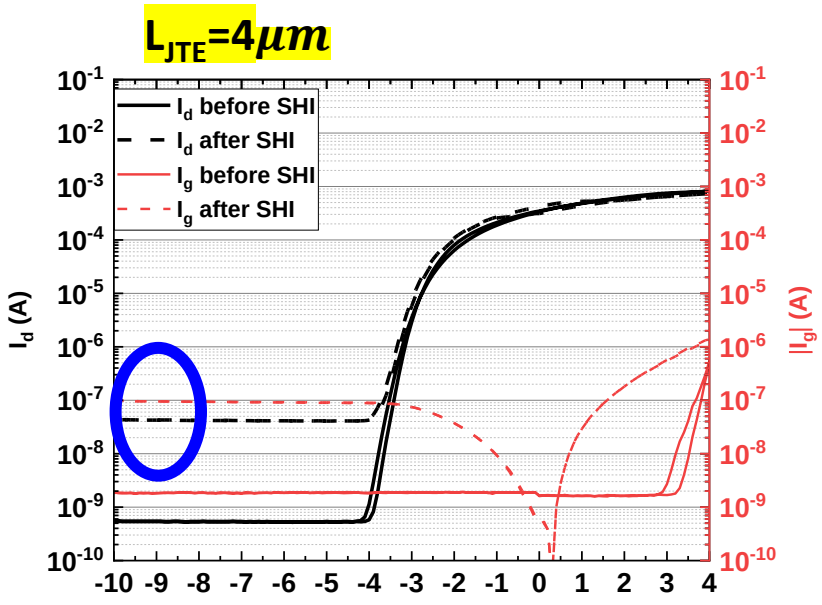


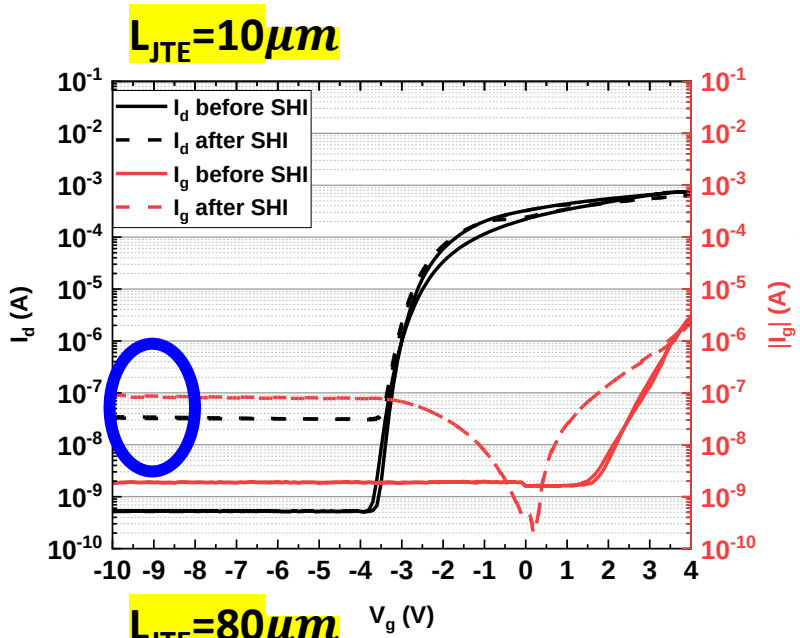
Au fluence = $5 \times 10^{11} \#/cm^2$

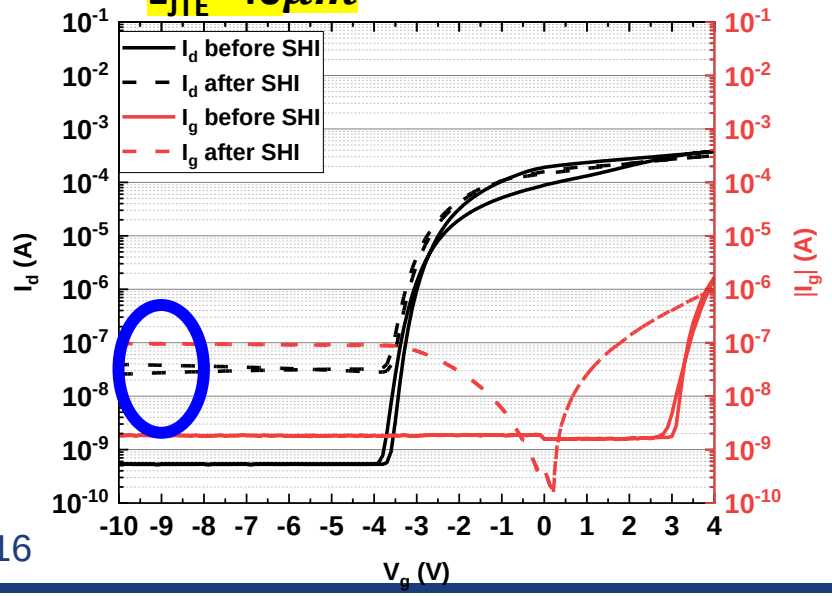


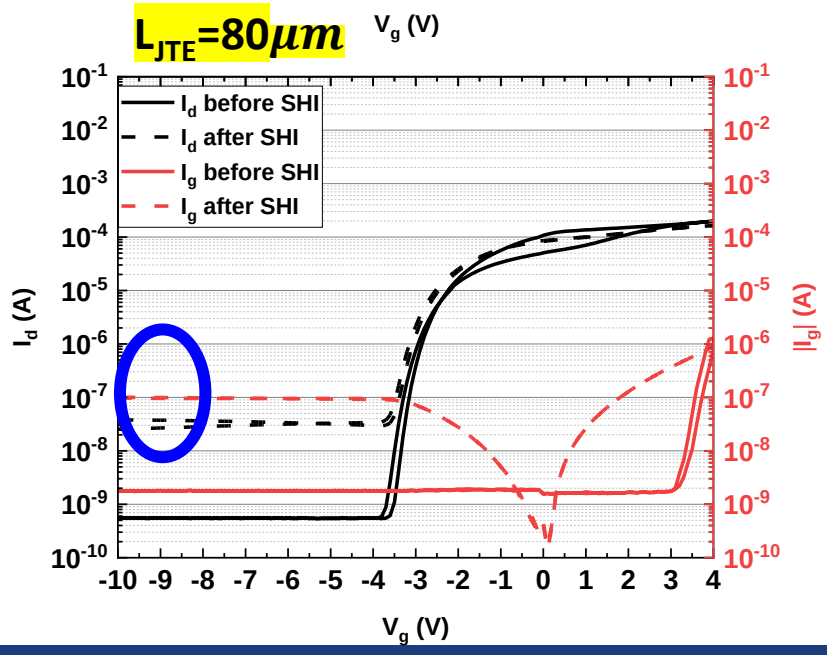
PSU JFETs – $1 \times 10^7 \#/cm^2$ fluence LJTE variance

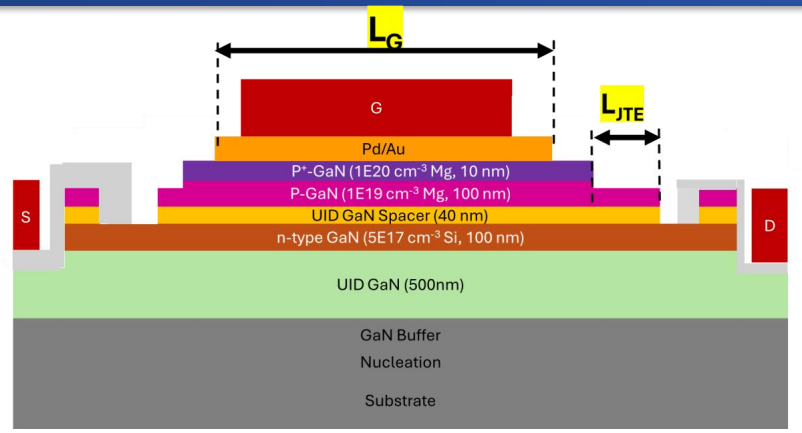
Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	950 MeV (4.8 MeV/u)	30 µm	72.4











Transfer IV

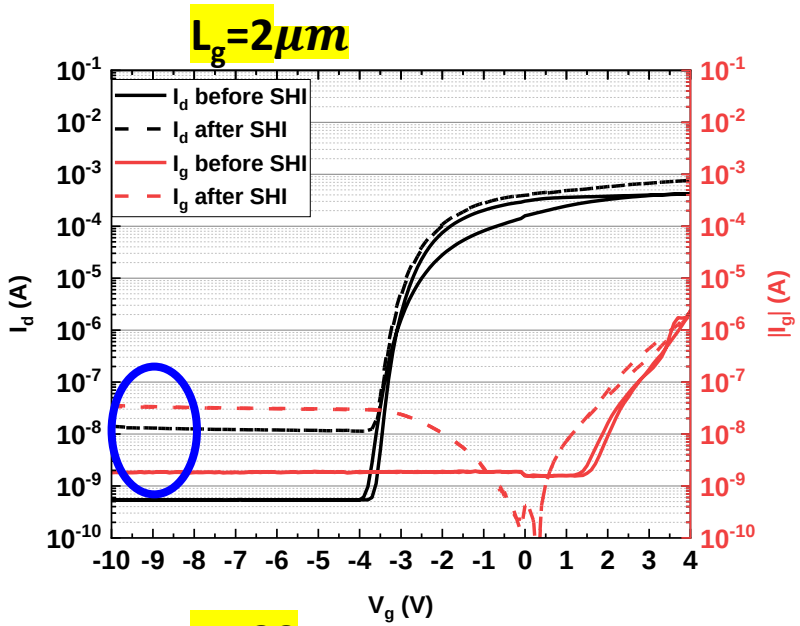
Bias: V_g= -10 to 4V; V_d= 0.5V

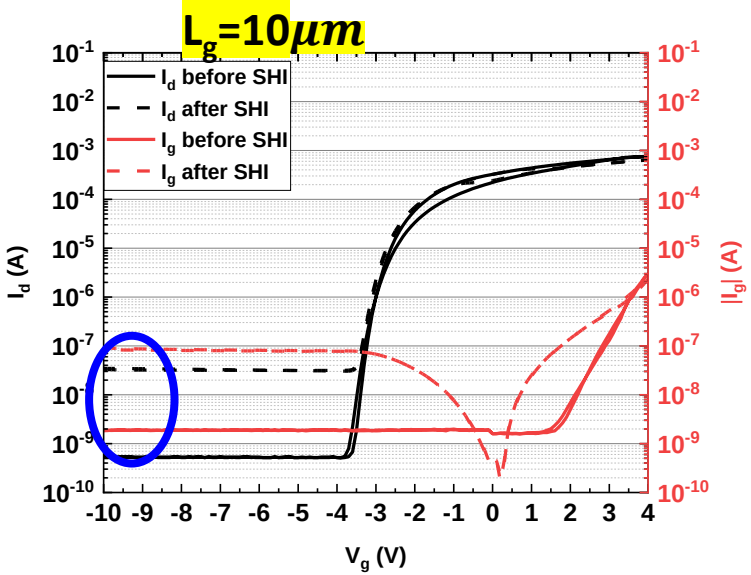
No noticeable dependence on JTE length.

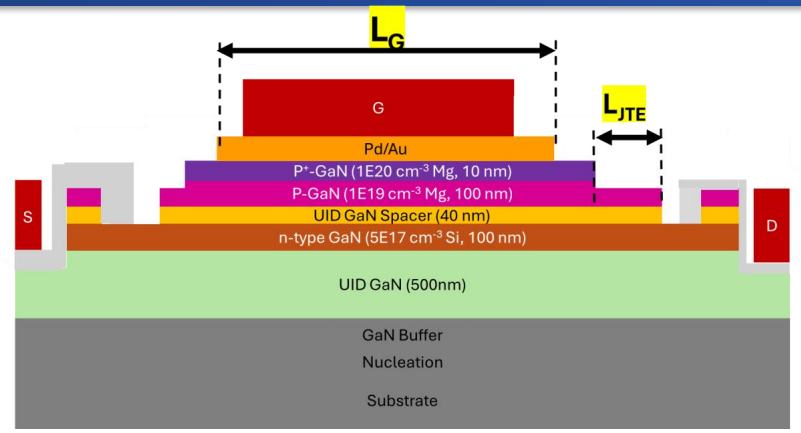
PSU JFETs – $1 \times 10^7 \#/cm^2$ fluence Lg variance

Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	950 MeV (4.8 MeV/u)	30 μm	72.4

Drain / gate current increased after radiation and showed dependency on L_g.

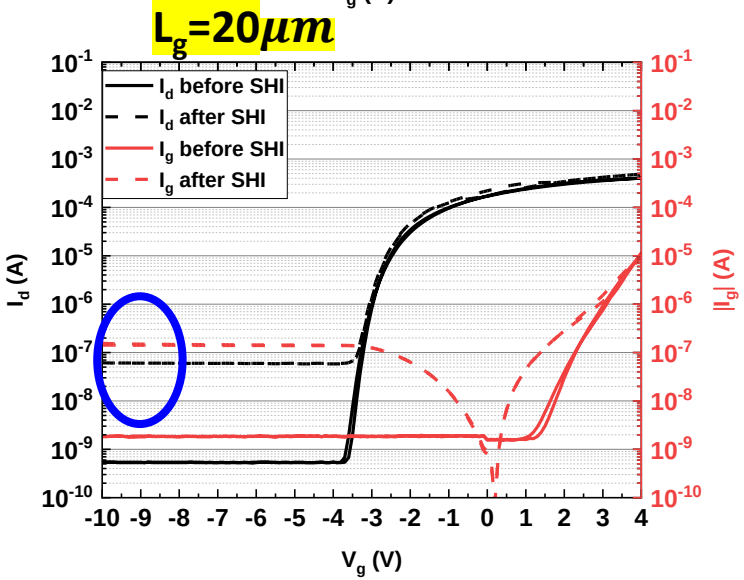


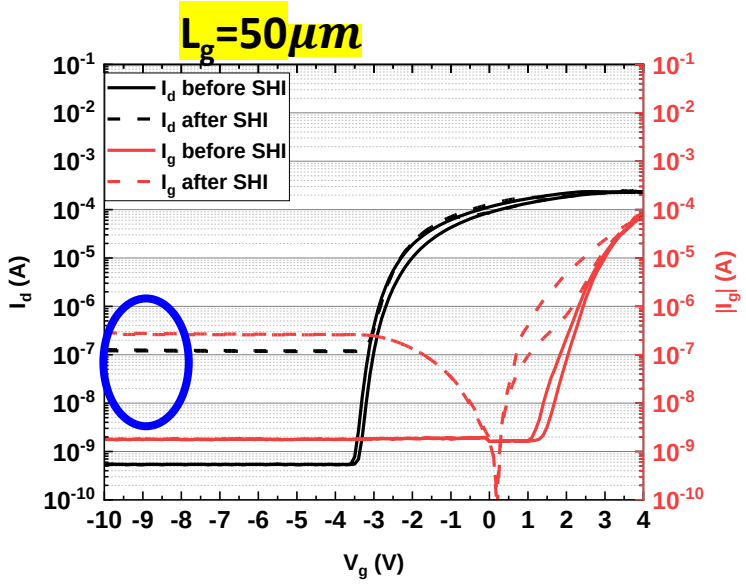


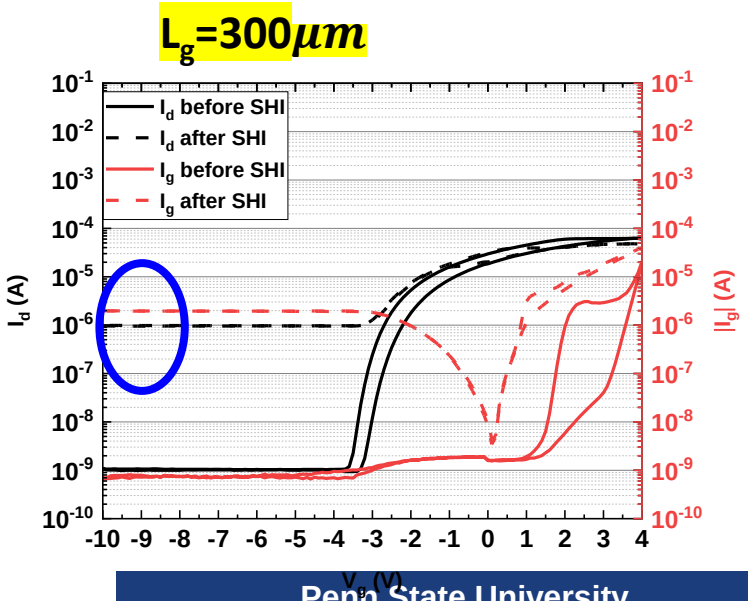


Transfer IV

Bias: V_g= -10 to 4V; V_d= 0.5V



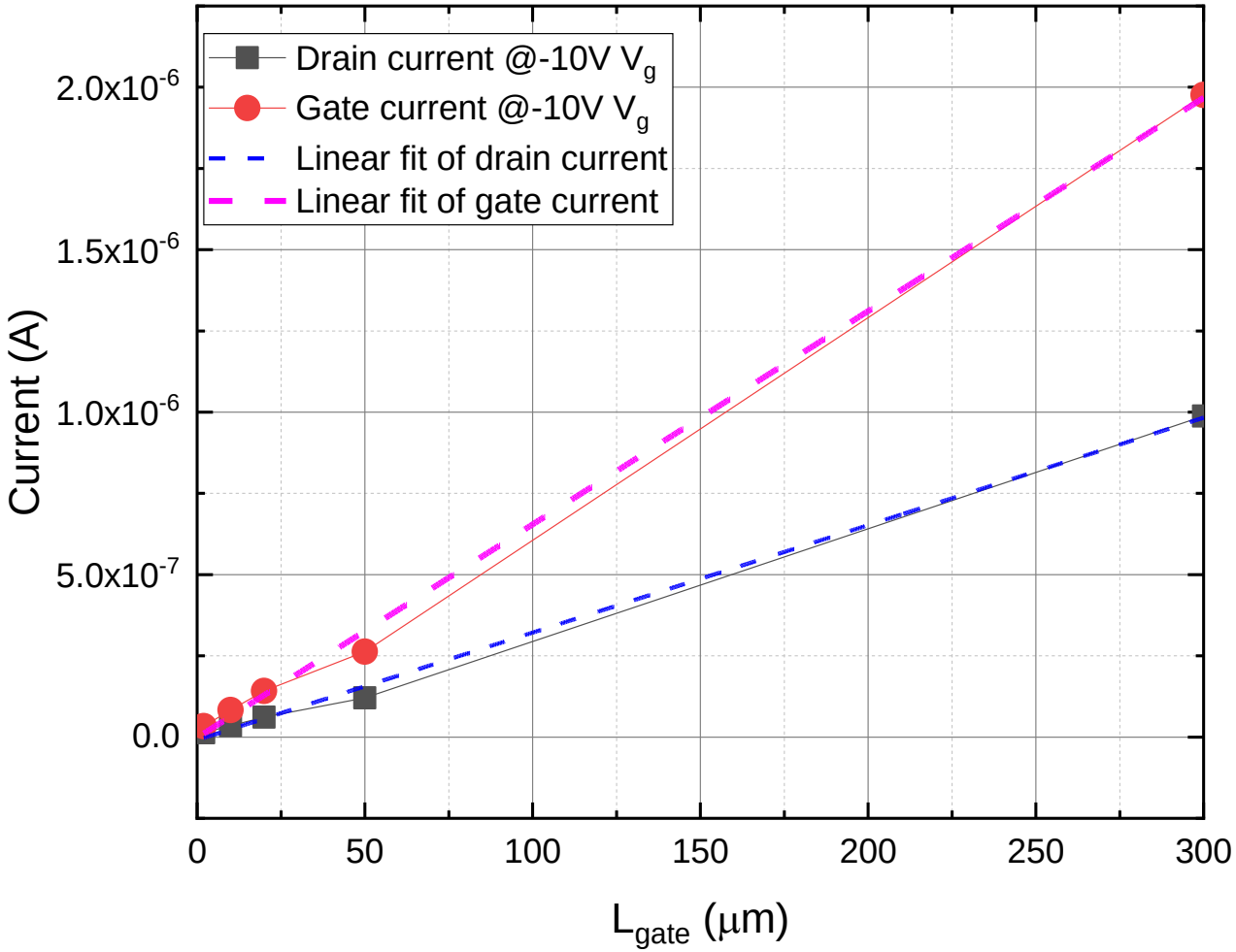


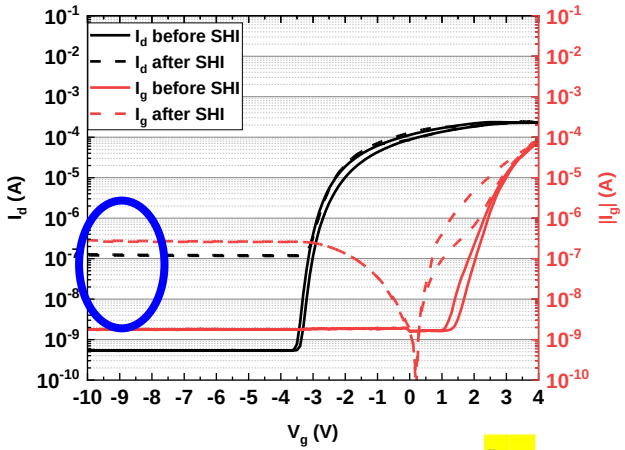


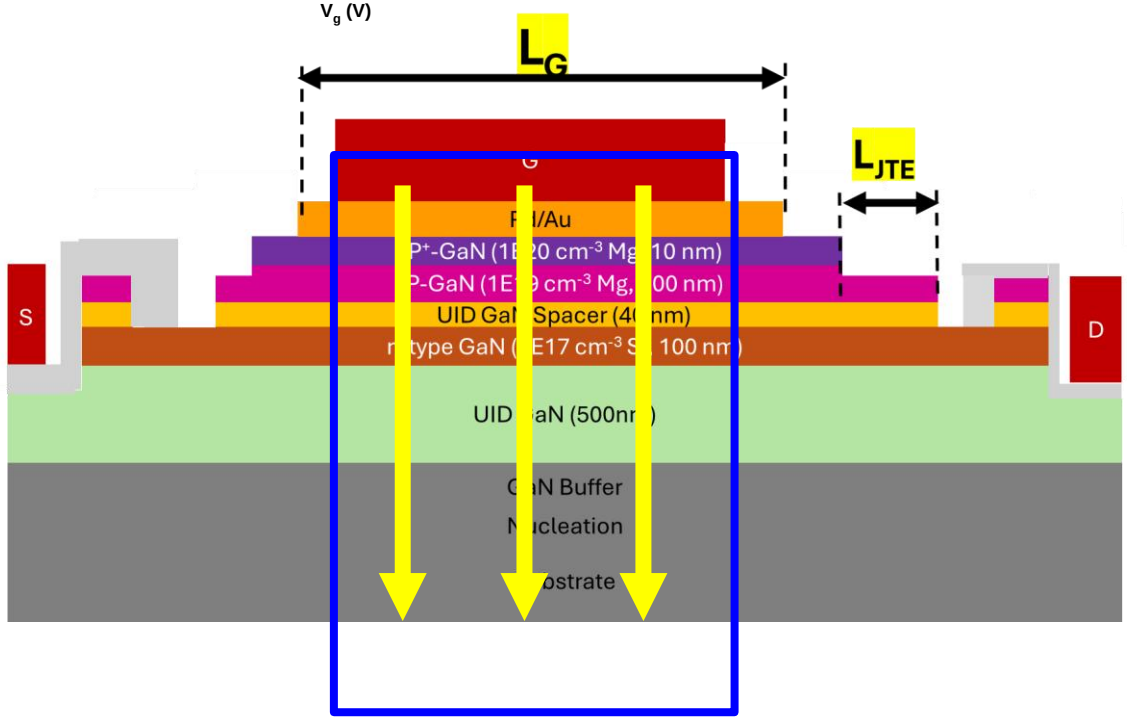
PSU JFETs – $1 \times 10^7 \#/cm^2$ fluence Lg variance

Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	950 MeV (4.8 MeV/u)	30 µm	72.4

- The leakage current is proportional to gate length (gate junction area) - > indicating junction leakage







PSU JFETs – $1 \times 10^7 \#/cm^2$ fluence temperature I-V

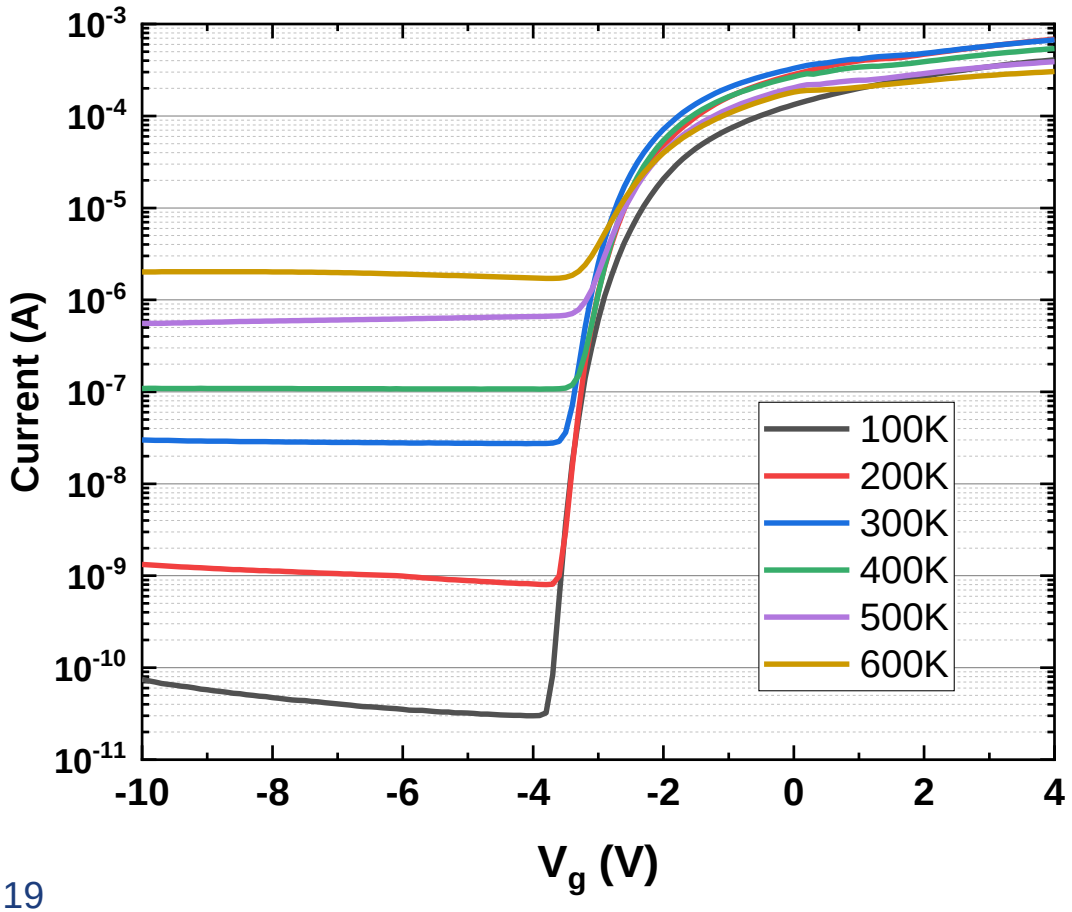
Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	950 MeV (4.8 MeV/u)	30 μm	72.4

- The leakage current is strong function of temperature

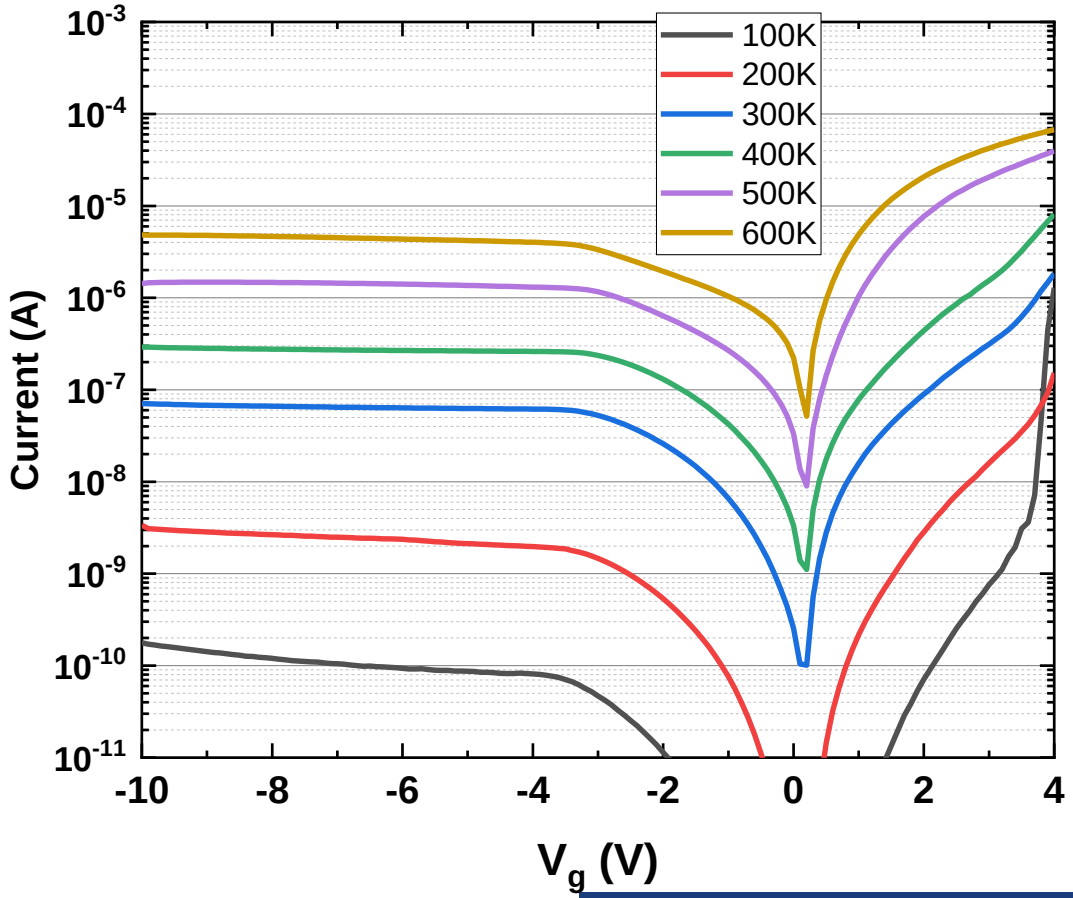
JFET

L_g=10um, L_{JTE} =10um

Drain current



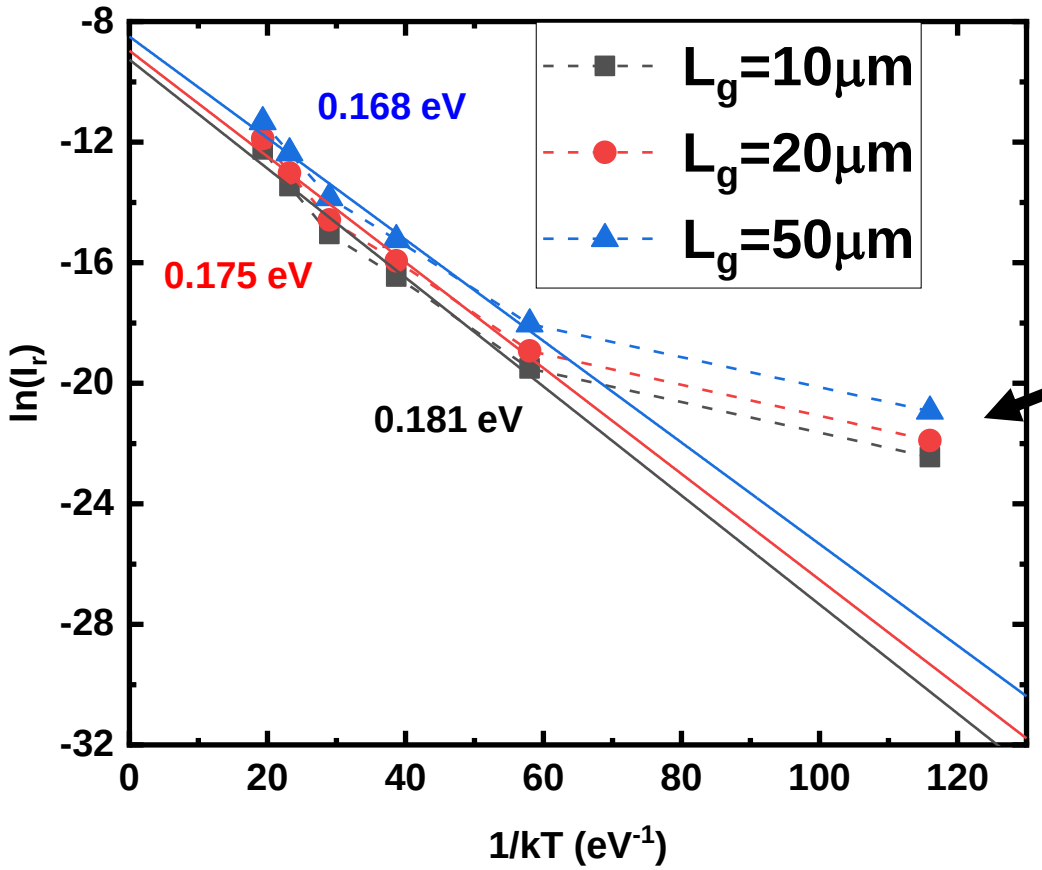
Gate current



PSU JFETs – $1 \times 10^7 \#/cm^2$ fluence temperature I-V

Ion	Energy	Range	LET (MeV/(mg/cm²)
^{197}Au	950 MeV (4.8 MeV/u)	30 µm	72.4

Arrhenius plot E_a extraction



Activation energy = 0.168 ~ 0.181 eV

100 K data point deviated from thermal current – further study required for investigating the mechanism

Summary

❑ GSI – 192 MeV Ar – On-site test

- No SEE observed

❑ BNL – 333.7 MeV Au – On-site test

- Constantly increased leakage over fluence
- Can identify SET current peaks but did not lead to any destructive SEE

❑ GSI – 950 MeV Au – Ex-situ test

- Leakage current increased after irradiation
- Is linearly dependent to junction area indicating junction leakage
- Temperature dependent leakage –

Activation energy E_a = 0.16~0.18 eV

Next

- Beam irradiation with improved PSU devices, and further components modified based on the JFET
- Additional electrical characterization for leakage mechanism study

Thank you!