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Effects of 2 MeV Ge^+ Irradiation on AlGaN/GaN High Electron Mobility Transistors

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Outline

- Background
- Radiation Simulations
- Affect on:
  - DC device characteristics
  - Affect on Schottky Gate
  - Isolation/TLM structures
- Off-state stress
- Conclusions

Background

- GaN radiation hardness surpasses GaAs due to higher binding energy of GaN.
- Results in reduced radiation defects in GaN.
- Many studies performed on effect of protons and α-particles on GaN device performance.
- Earth's magnetosphere composed of:
  - 85% protons
  - 14% α-particles
  - 1% heavy ions
- Solar flares can result in heavy ion irradiation up to several hundred MeV.

Proton Irradiation

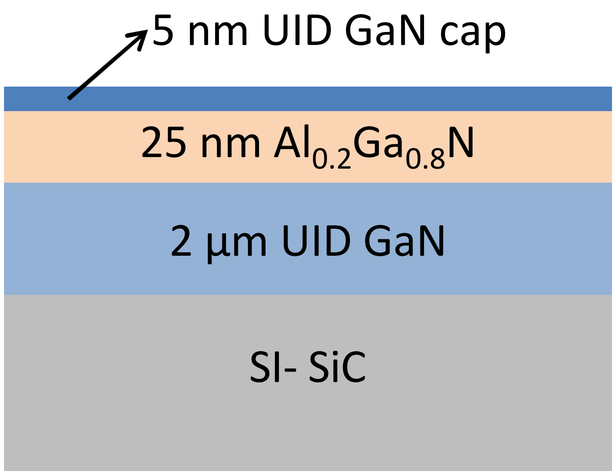
- Carrier removal rate ~$10^2 – 10^3$ cm^{-1}
- Deep trap formation with E_A=0.13, 0.16-0.18, 0.2-0.21 eV.
- At high proton doses, aggregates of primary defects can form, resulting in electron traps with E_A =0.75 and 0.95 eV
- Deep electron traps result in increase of channel resistance.

Electron Irradiation

- Primary defect in GaN from electron irradiation is N vacancies.
- Results in E_A=0.16-0.18 eV

AlGaN/GaN HEMT

MOCVD epitaxial layers



Device Structure

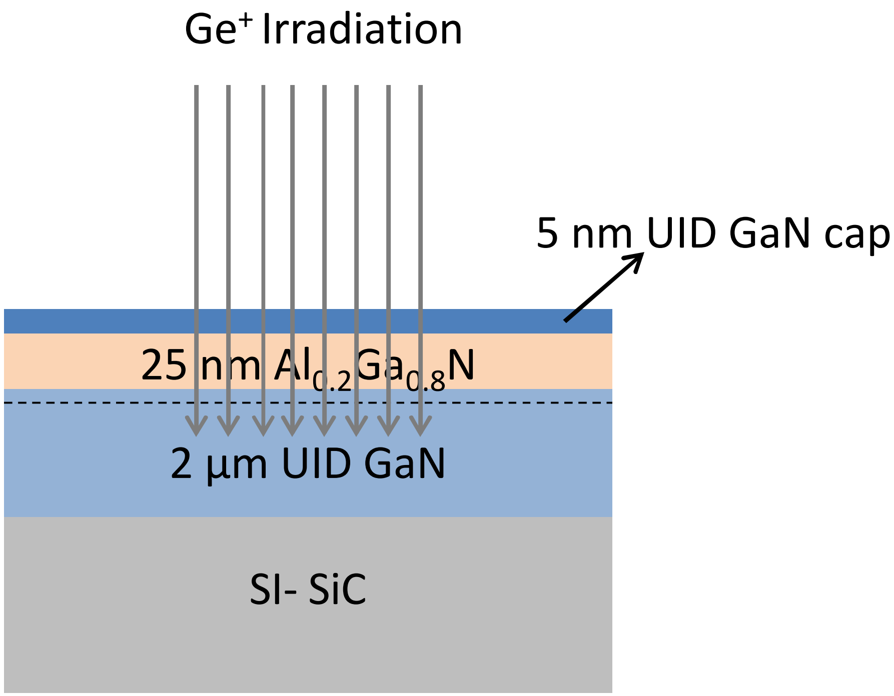
Ohmic Contacts: Ti/Al/Pt/Au
Schottky Gate: Ni/Au
Gate length: 1um
Gate width: 100um
Both HEMT and TLM structures tested

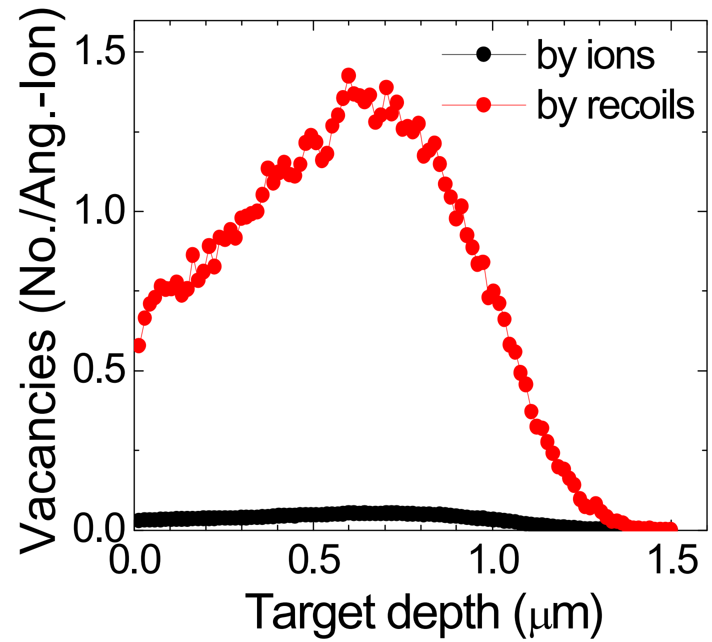
Heavy Ion Irradiation

2 MeV Ge^{+}

Dose range:
$5x10^{10}$ to $5x10^{12}$ cm^{-2}

SRIM Simulations

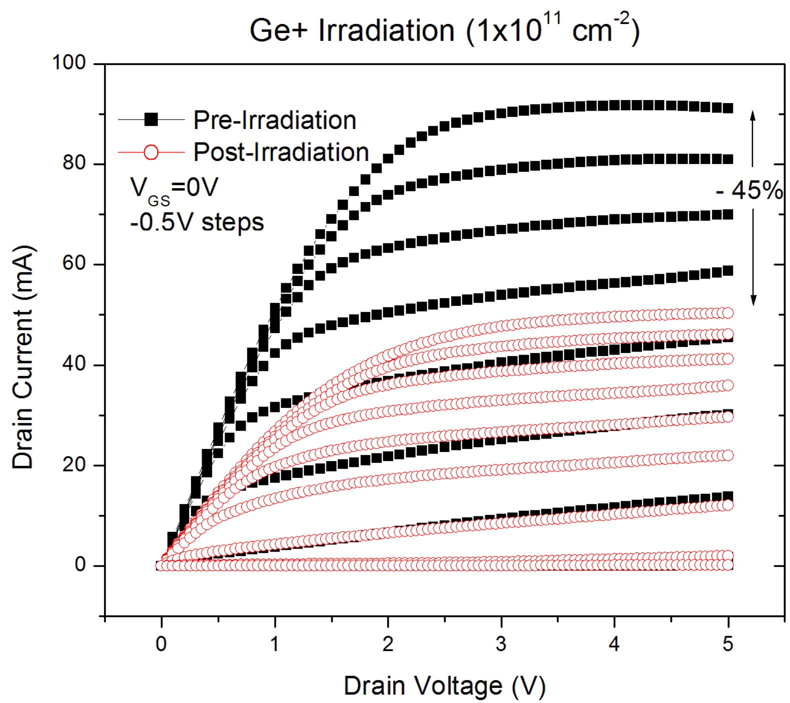


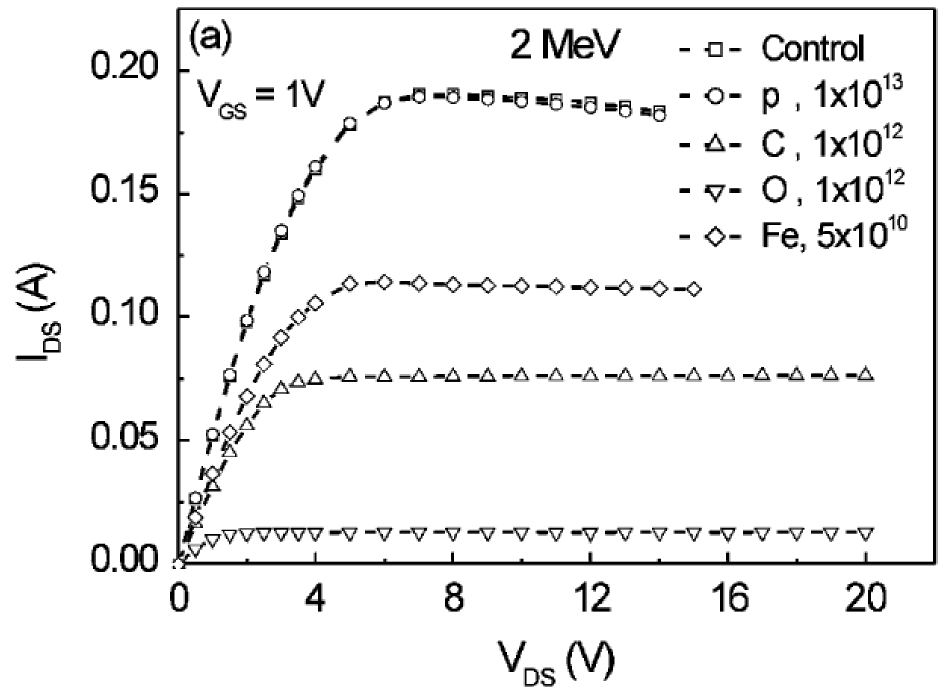


Stopping Range of Ions in Matter (SRIM) simulation indicates end of range of ions ~0.65 μm in HEMT structures.

- In GaN buffer below active layers

AlGaN/GaN HEMT Performance

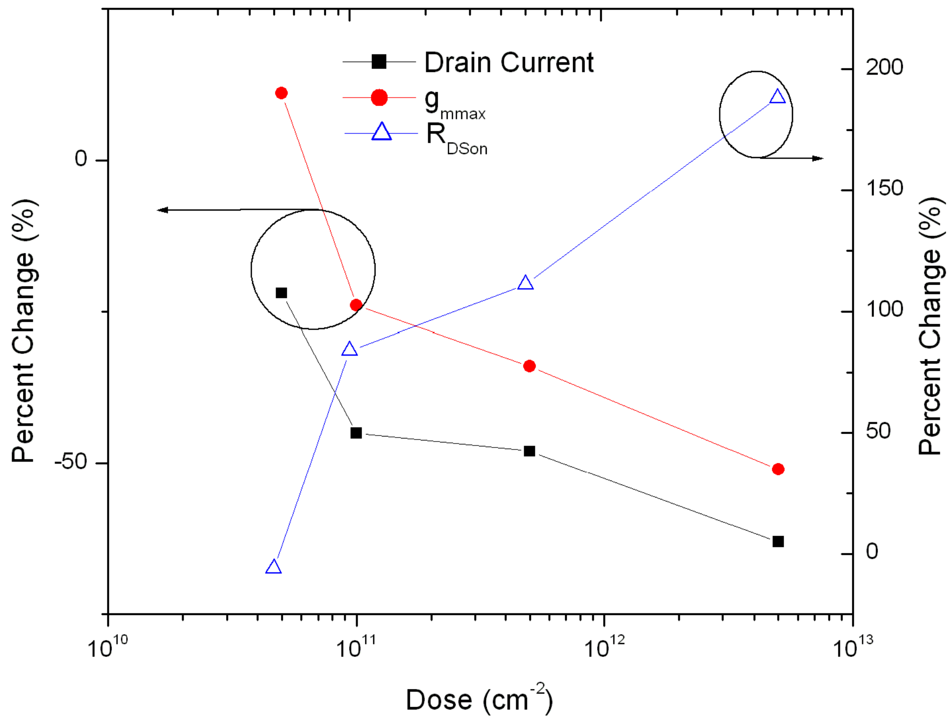




~45% drop in I_{DSS}, consistent with other heavy ion irradiation

Sonia, G. et al., *Nuclear Science, IEEE Transactions on* , **53**, 3661 (2006).

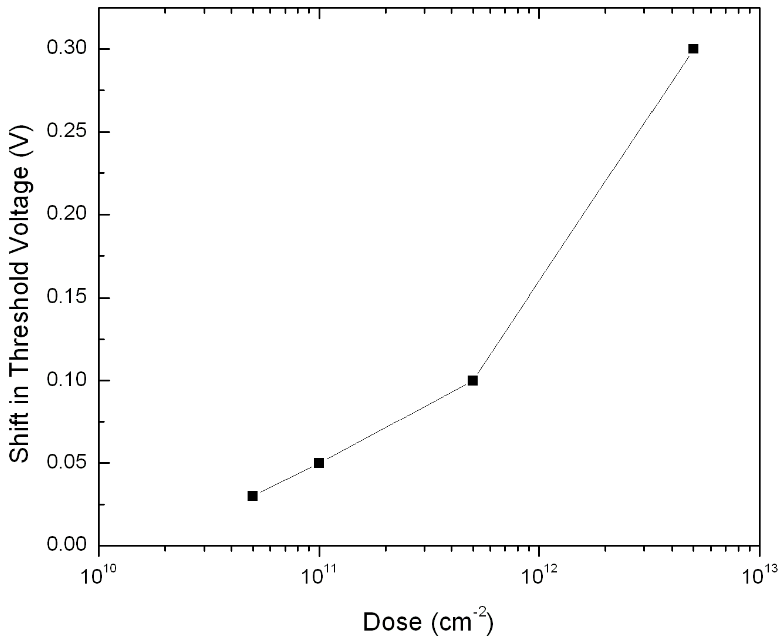
AlGaN/GaN HEMT Performance (2)

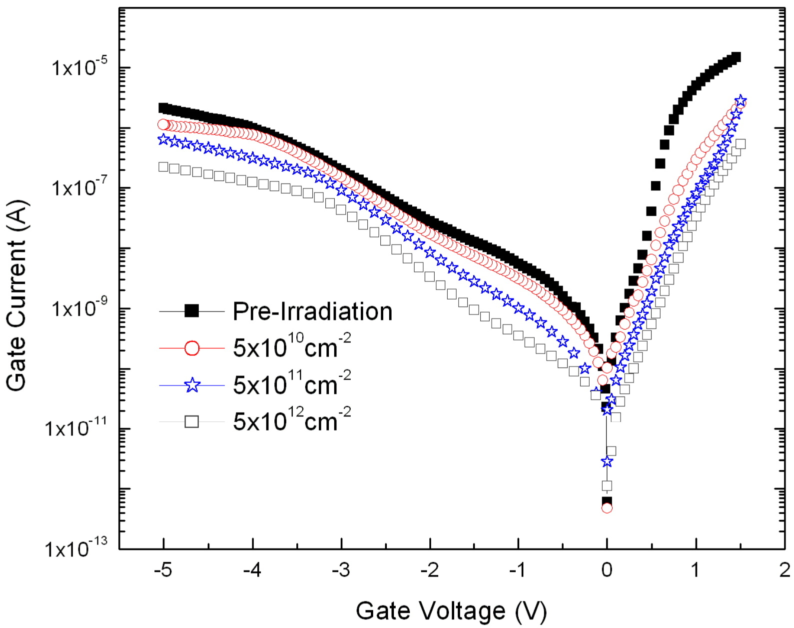


- Decrease in transconductance and drain current.
- Increase in source-drain resistance.
- Consistent with carrier removal from channel.

- Drain current not linear, tends toward saturation.
- Expected trend if number of deep traps approaches carrier density of channel.

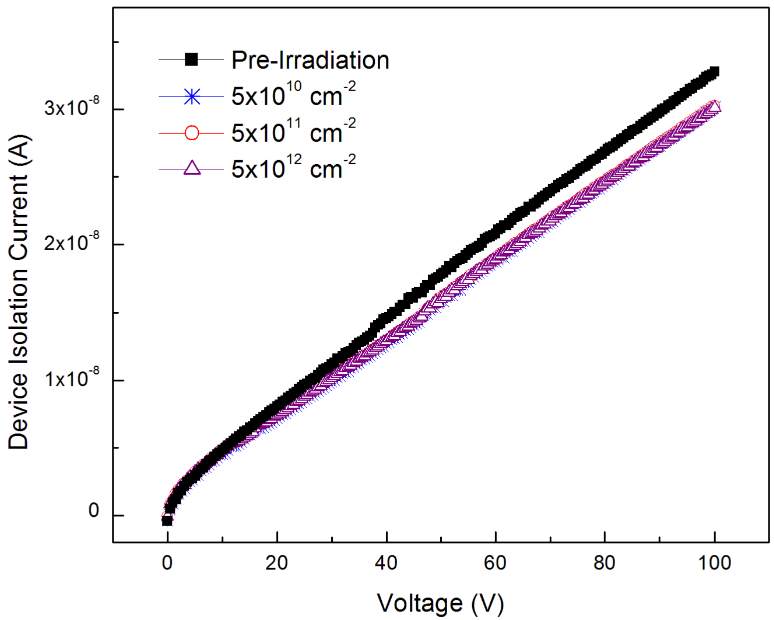
Schottky Gate

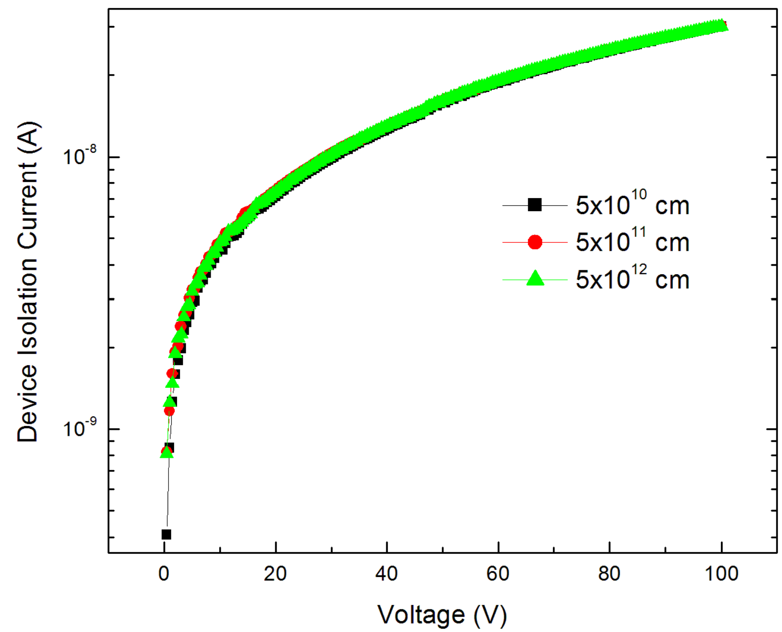




Substantial shift in V_{TH} observed with dose.
Decrease in gate leakage current with increase in dose.

Isolation Current





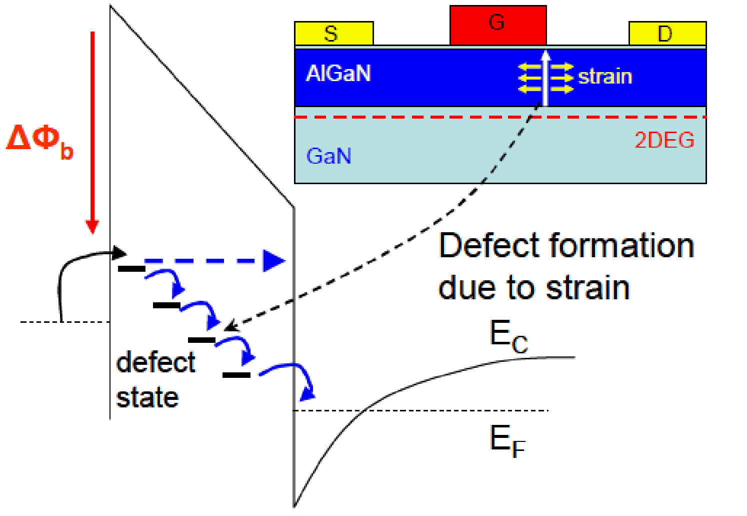
Decrease in isolation current. However, no trend with Ge^+ dose.

TLM irradiated with 5×10^{10} cm^{-2} resulted in:

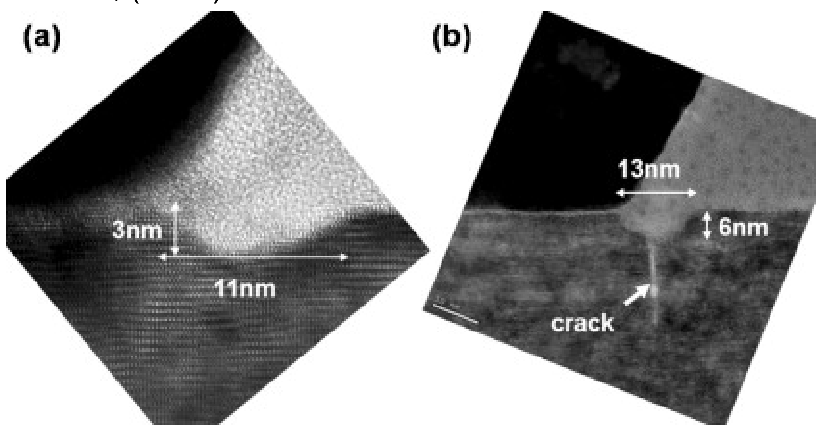
- ~4X increase in sheet resistance
- 75% decrease in specific contact resistance.

Consistent with carrier removal from channel of HEMT

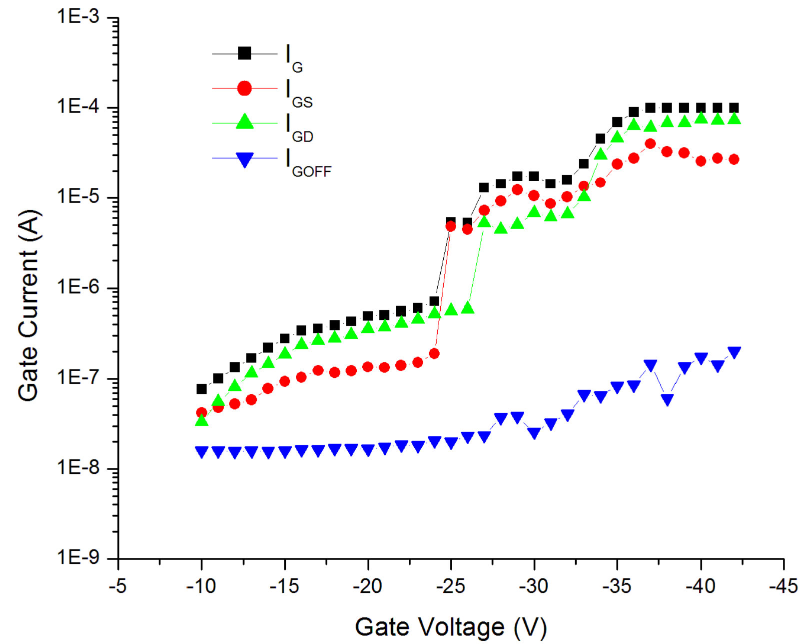
Off-State Stress



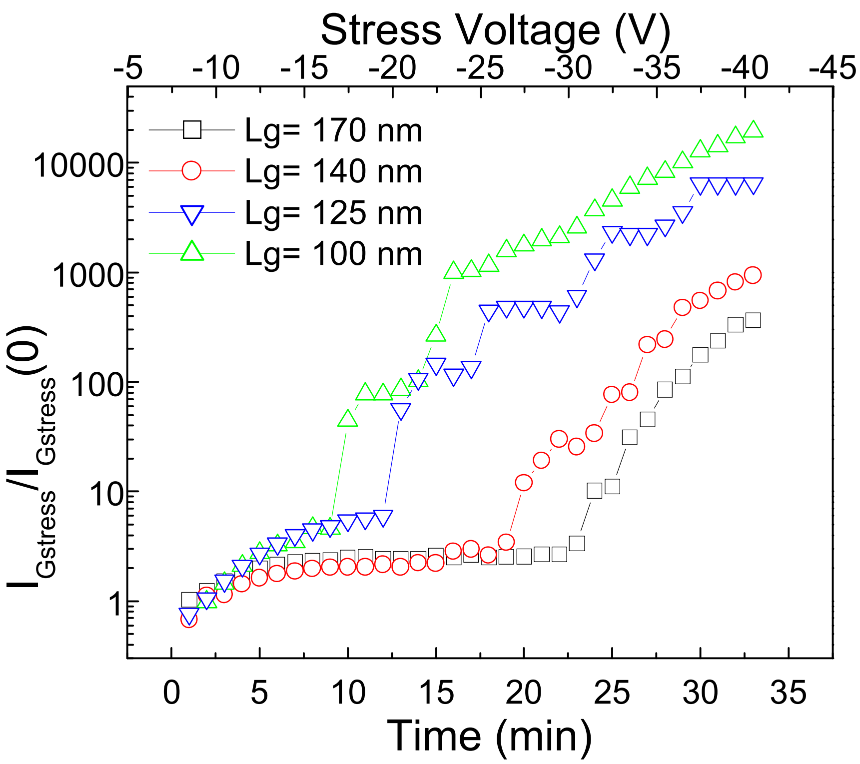
J. A. del Alamo, J. Joh. Microelectronics Reliability, 49 1200, (2009).

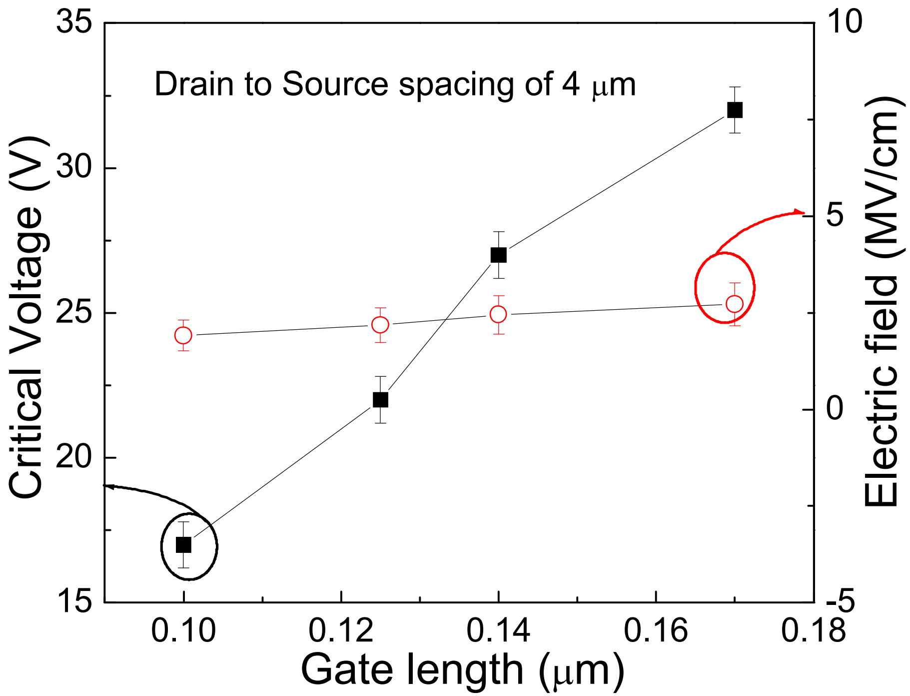


Park, et al. Microelectronics Reliability **49** (5) 478, (2009).



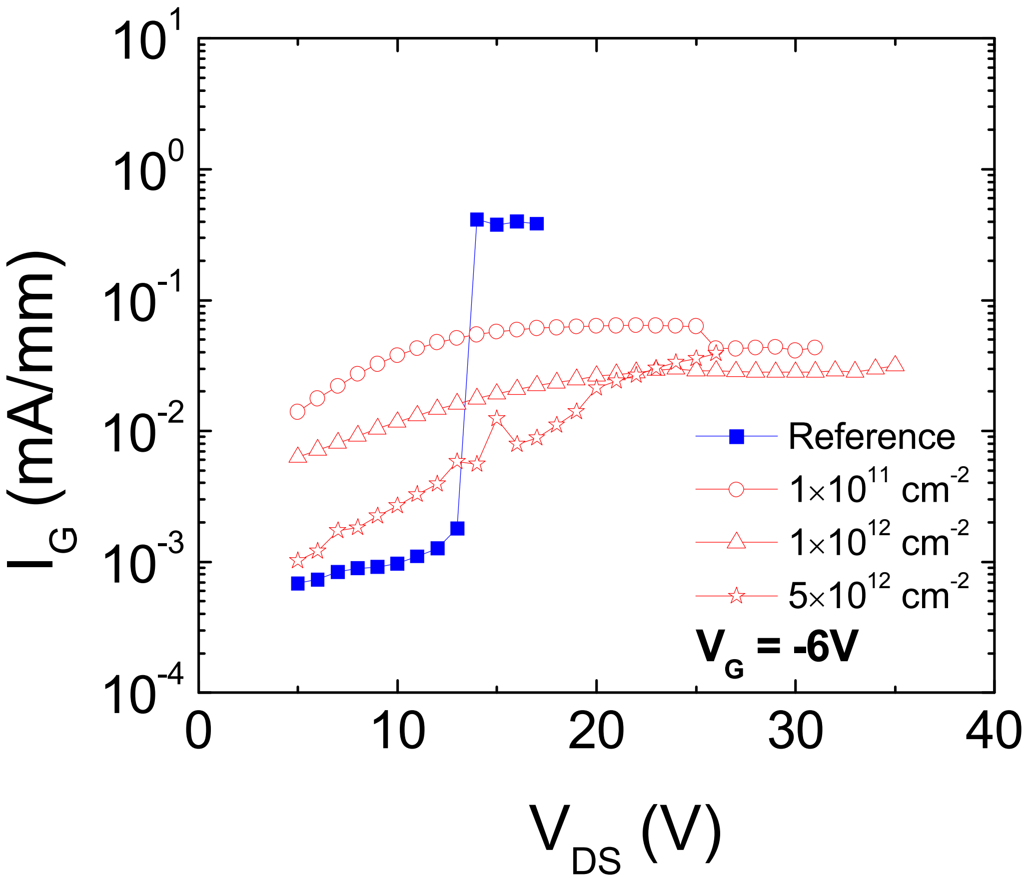
Off-State Stress (2)





Breakdown occurs at ~ 1.8 MV/cm independent of gate length

Off-State Stress (3)



- Typical V_{cri} ranges from 13 V to 15 V (believed to be field driven mechanism).
- No breakdown observed for Ge^+ irradiated devices, up to 35 V.
- Similar results observed for proton irradiated devices.
- Defects due to ion irradiation effects electric field distribution near the gate.

Conclusions

- Significant improvement of reliability of AlGaN/GaN HEMTs for 2 MeV Ge^+ irradiation.
- Critical voltage for off-state electrical stress increased from 13 V to above 35 V.
- Gate current decreased by about half after irradiation at 10^{11} cm^{-2}, indicating significant device degradation as compared to protons.

Acknowledgements

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