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Impact of the Al Mole Fraction in the Bulk- and Surface-State Induced Instability of AlGaN/GaN HEMTs

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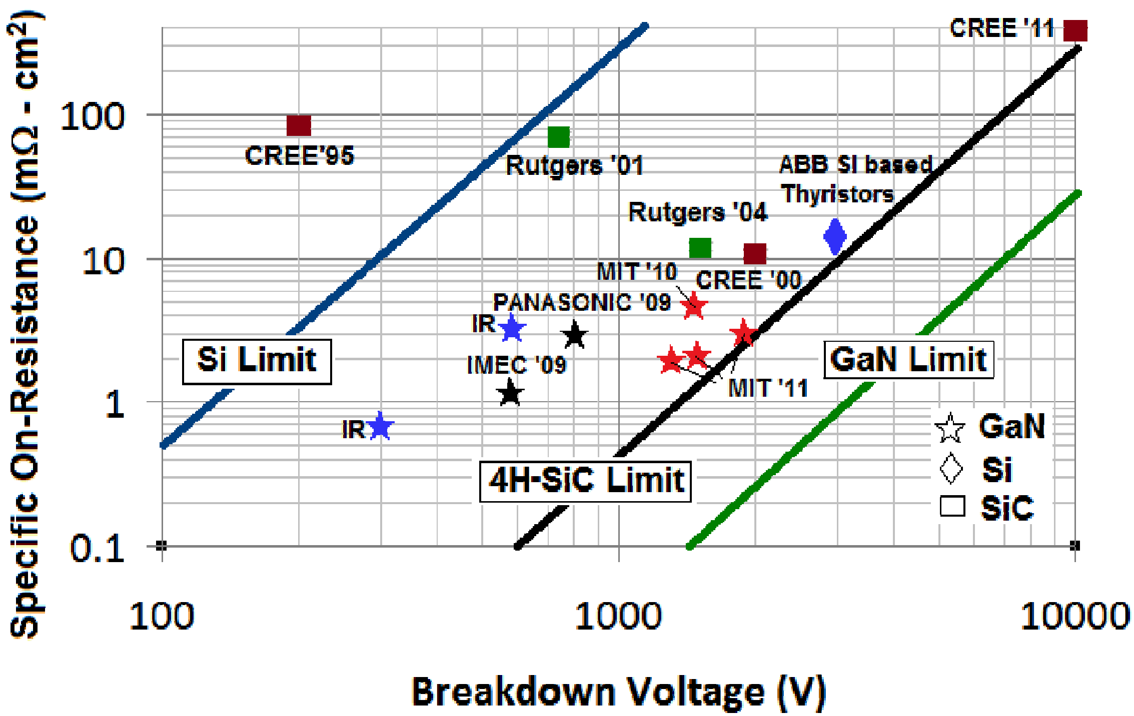
2012 MRS SPRING MEETING

GaN HEMTs for High Breakdown Voltage



Wide bandgap GaN – theoretically has the highest breakdown voltage limit for given R_{on} (among Si, SiC, GaN)

Greater commercial capability due to integration on Silicon.

Low Al percentage AlGaN required to reduce 2DEG density.
Carbon doping employed in buffer to avoid punch-through.

Degradation mechanisms widely studied for RF HEMTs, with larger Al molefraction.
Low Al molefraction AlGaN has been studied comparitively less.

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The Devices

4 Device Types

- **$Al_{0.15}Ga_{0.85}N$ (C - doped buffer - V_{br} ~ 1800 V max)**
  - **Unpassivated**
  - **Passivated ($Al_2O_3/SiO_2/Al_2O_3$)**
- **$Al_{0.26}Ga_{0.74}N$ (Undoped Buffer V_{br} ~ 600 V max)**
  - **Passivated ($Al_2O_3/SiO_2/Al_2O_3$)**
  - **Unpassivated**

All devices grown on (111) Silicon

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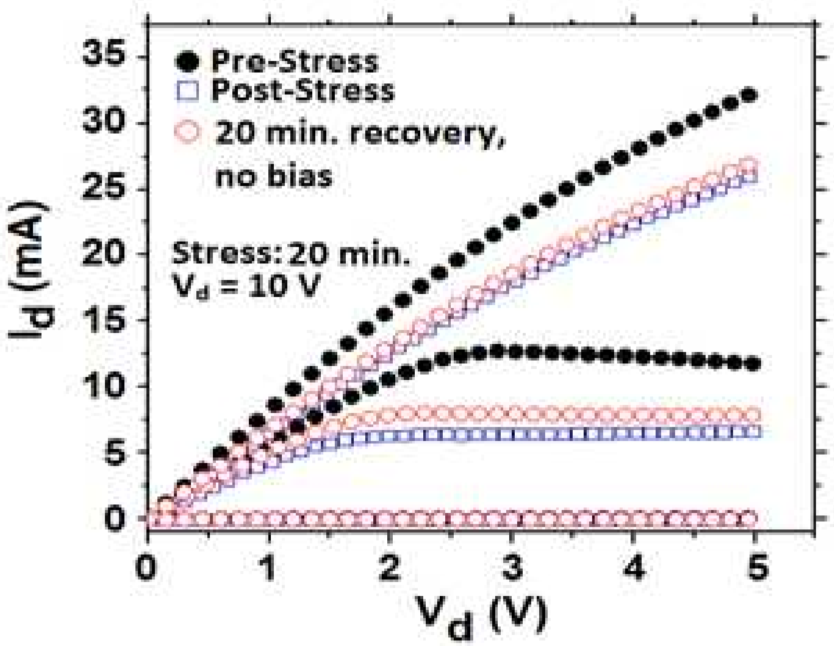
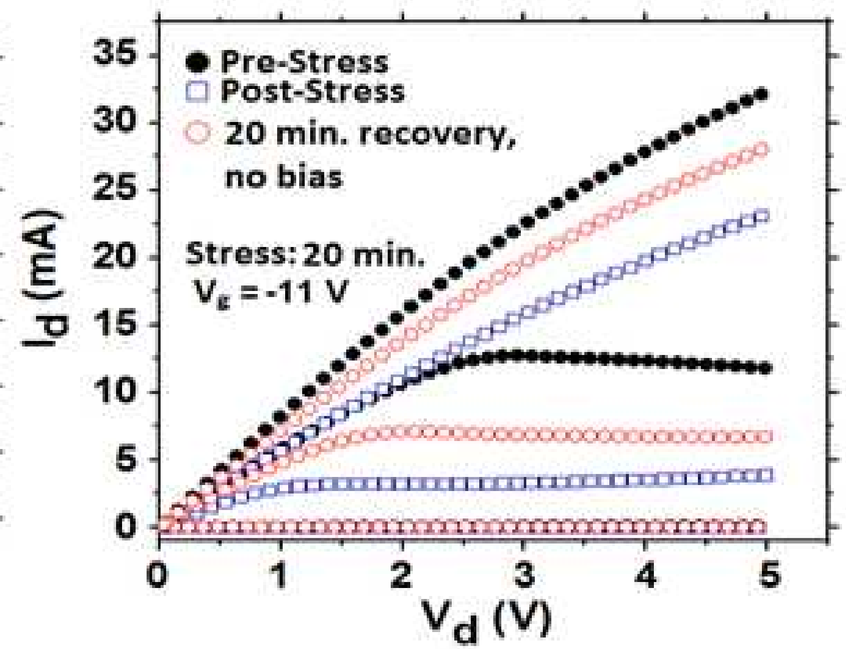
Difference Between On-State and Off-State Stress





V_{ds} = 10V, V_{gs} = 0V

V_{ds} = 0V, V_{gs} = -11V

On-State drain bias produces much slower recovery than Off-State gate bias.

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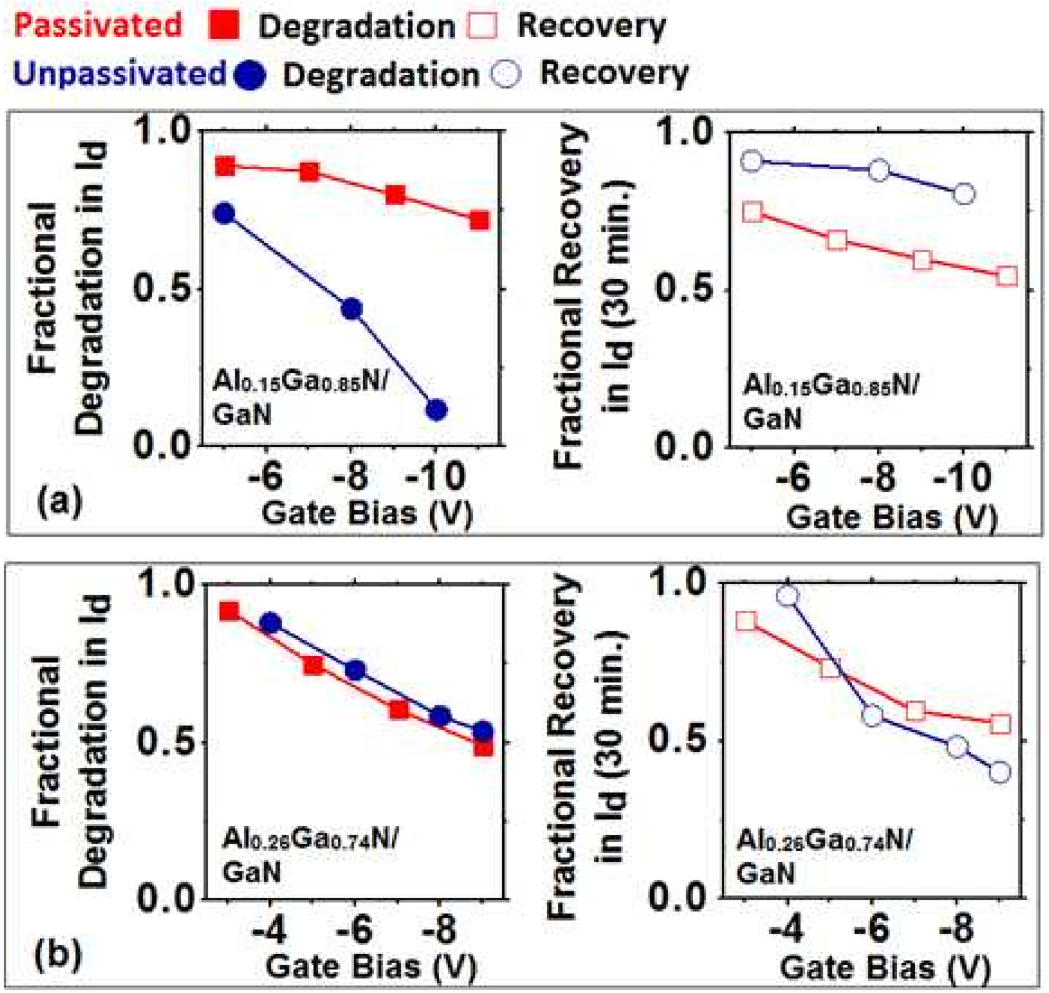
Passivated vs Unpassivated – $Al_{0.15}Ga_{0.85}N$ vs $Al_{0.26}Ga_{0.74}N$



Fractional Recovery = ($I_{d,post\text{-}recovery}$ - $I_{d,post\text{-}stress}$)/($I_{d,pre\text{-}stress}$ - $I_{d,post\text{-}rtress}$) at V_{gs} = 1 V, V_{ds} = 5 V.

Lack of passivation substantially increases trapping with fast recovery in $Al_{0.15}Ga_{0.85}N$ compared to $Al_{0.26}Ga_{0.74}N$

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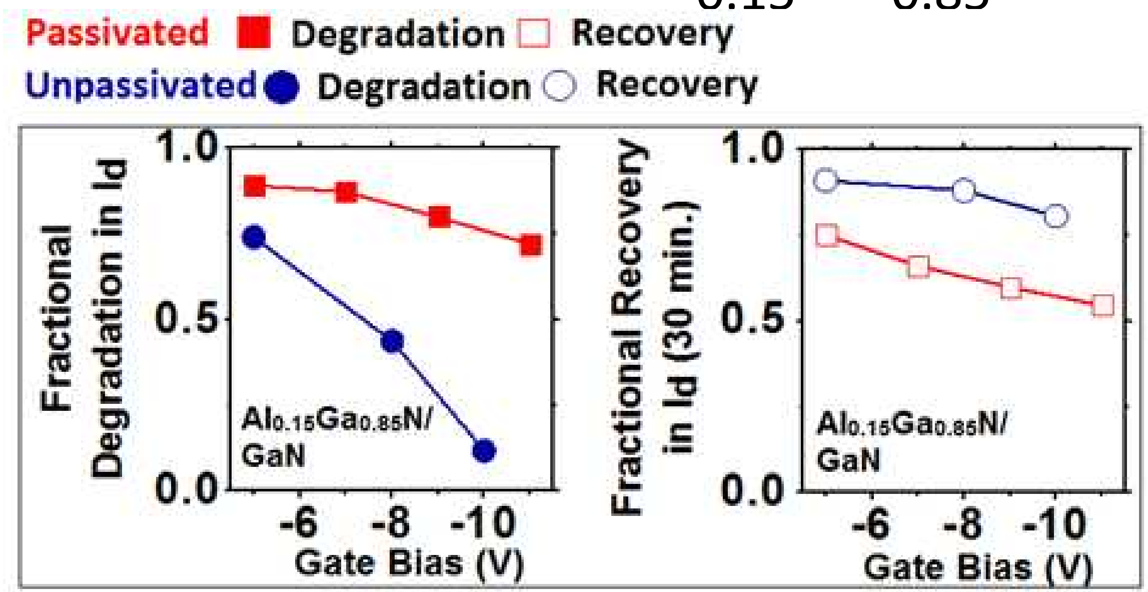
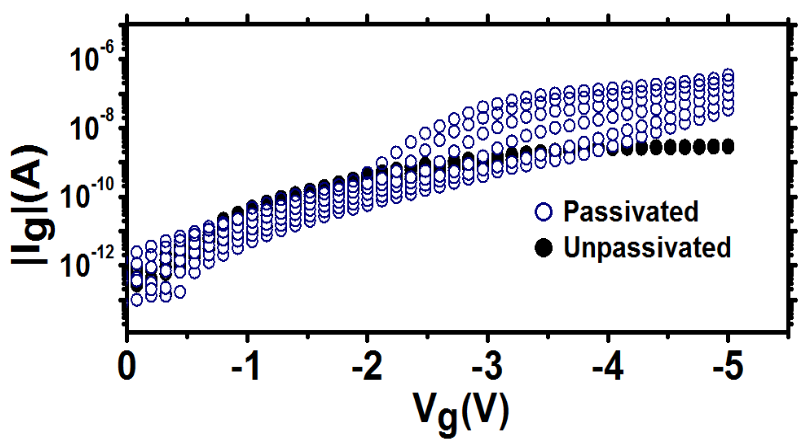
Passivated vs Unpassivated – $Al_{0.15}Ga_{0.85}N$



Passivation improves stability greatly, but gate leakage increases.



Large width power devices – require low gate leakage per unit length. Better gate dielectric need with $Al_{0.15}Ga_{0.85}N$.

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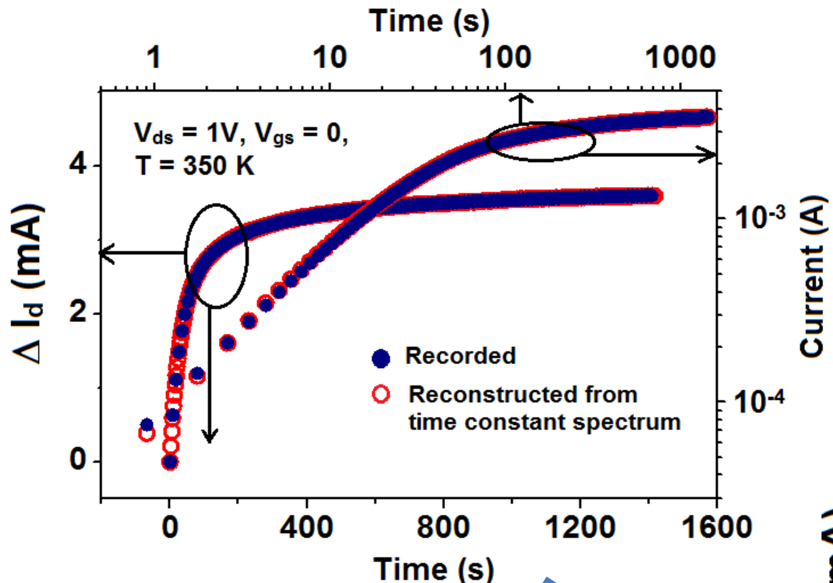
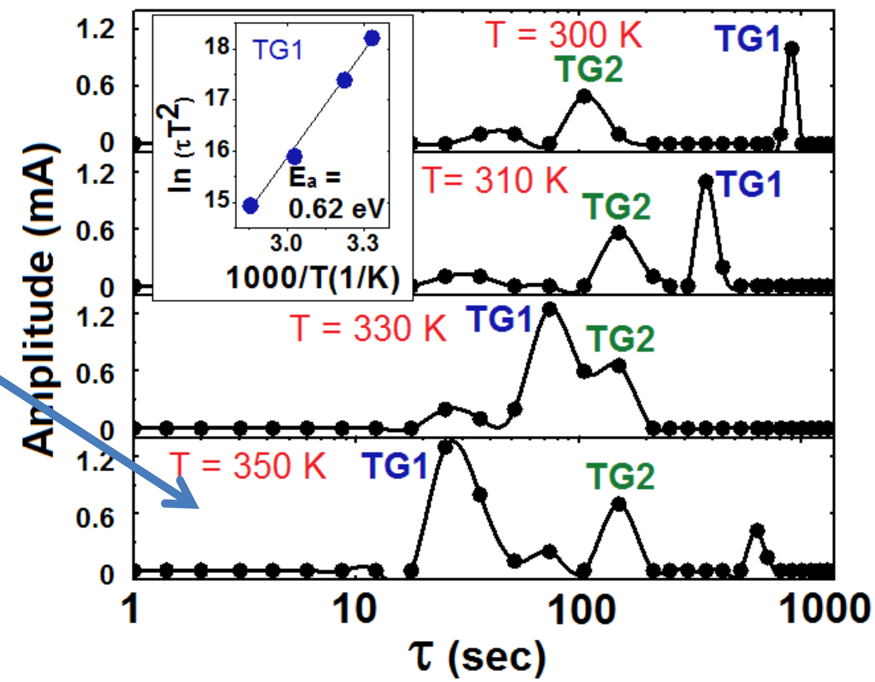
I-t based time constant spectra

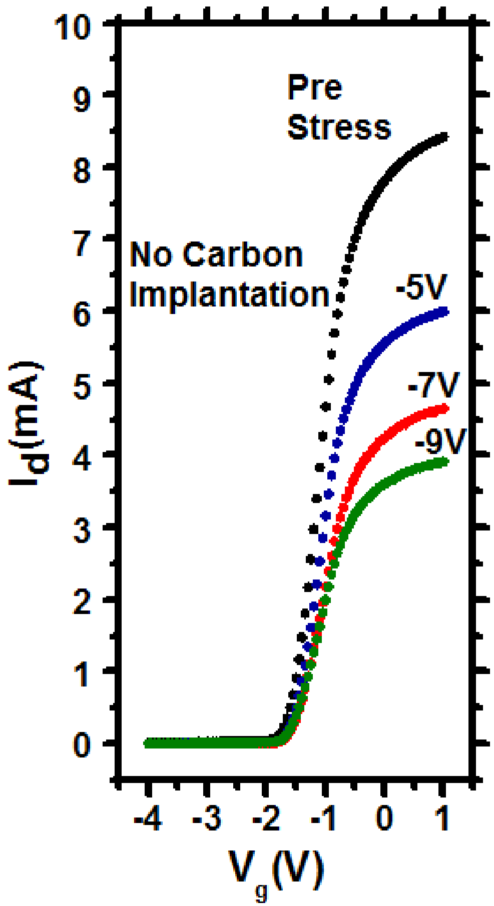


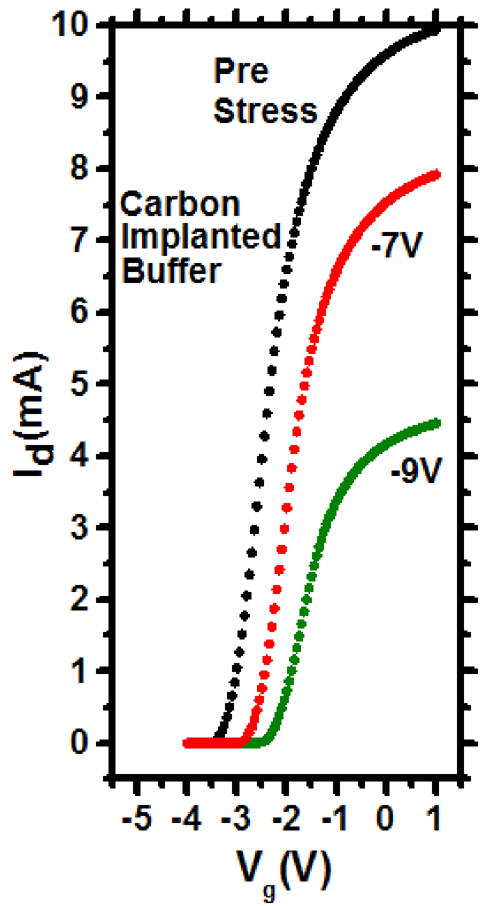
Two peaks – TG1 (Ea ~ 0.62 eV) and TG2 are seen



TG1 is temperature independent – most likely due to tunneling into 2DEG states

V_{th} shifts and spatial location of TG1, TG2





$Al_{0.15}Ga_{0.85}N$ devices (carbon doped) show Vth shifts, unlike the $Al_{0.26}Ga_{0.74}N$ Even for more than 50 % current degradation – no V_{th} shift in non-carbon implanted devices.

AlGaN is depleted .
Gate is fairly long (2 microns) – near gate trapping should not induce threshold shifts.

Vth shift is most likely due trapping in carbon-doped buffer.

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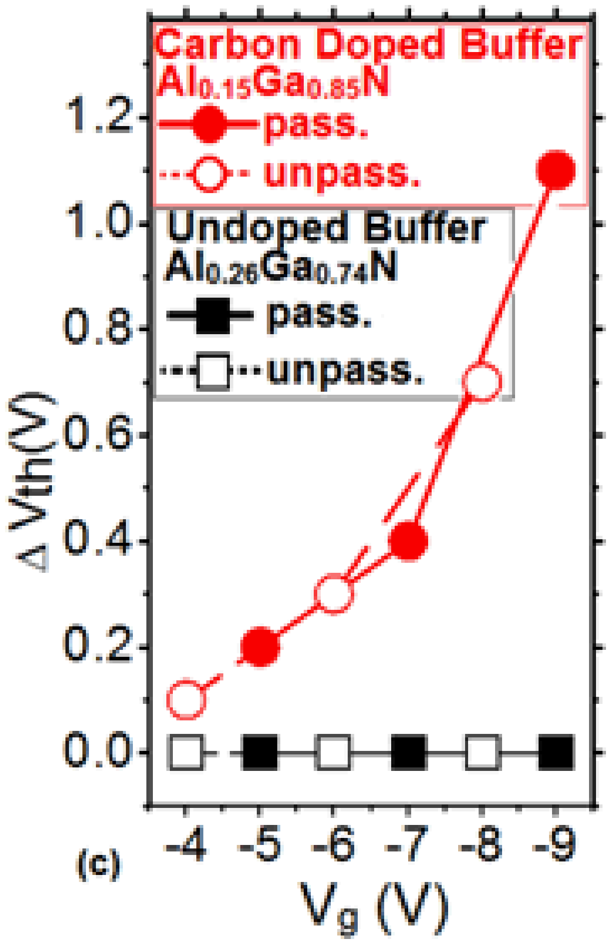
V_{th} shifts and spatial location of TG1, TG2



TG1, TG2 are seen in all devices.

V_{th} shift in carbon doped samples – there are enough buffer carriers in off-state to induce V_{th} shifts.

Should have induced slowly recoverable V_{th} shifts in all devices if they were buffer traps

Consistent with being AlGaN traps

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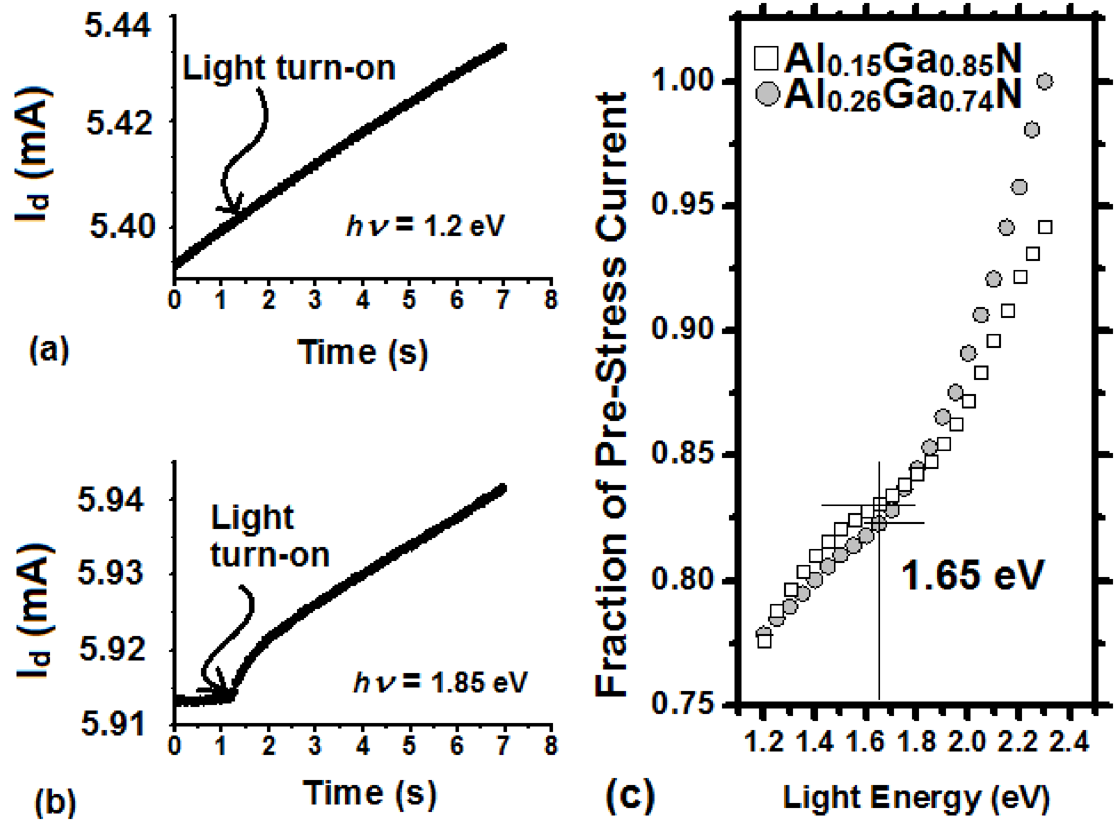
On-State Drain Bias and Optical Detrapping

Less than 50 % of the current due to on-state drain bias recovered thermally – so optical detrapping used.

Emission detected at ~ 1.65 eV.



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Conclusions

- Gate and Drain Stress produce trapping with different detrapping characteristics
- $Al_{0.15}Ga_{0.85}N$ shows much more vulnerability to gate stress in absence of passivation than $Al_{0.26}Ga_{0.74}N$ in absence of passivation.
- Buffer Carbon doping introduces threshold voltage shifts.
- Two components TG1 (E_a = 0.62 eV), TG2 (negligible temperature dependence observed in detrapping.
- Majority of drain bias induced degradation recovered at optical illumination with 1.65 eV and higher.