Electrical Degradation of InAlAs/InGaAs Metamorphic High-Electron Mobility Transistors

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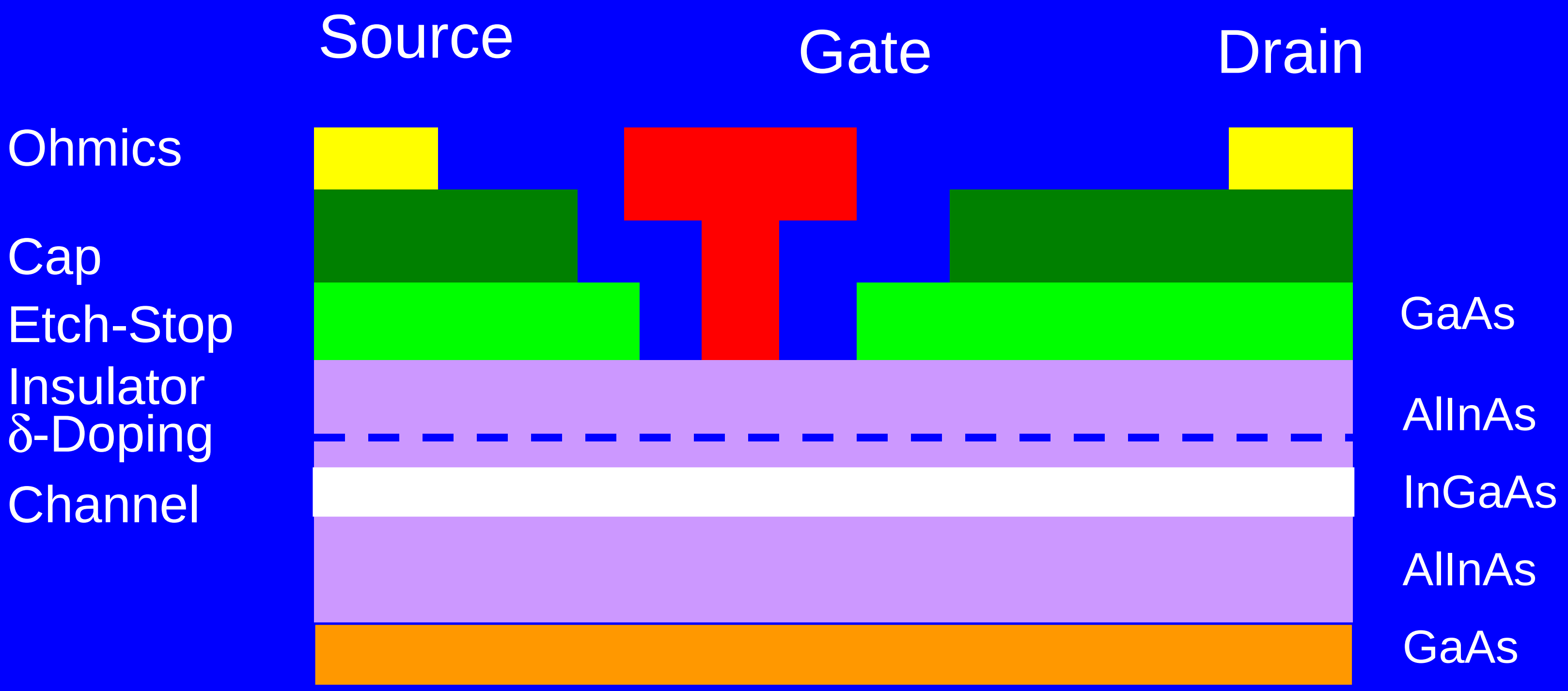
Sponsor: Agilent Technologies

Outline

- Introduction
- Electrical Degradation of mHEMTs
- Degradation of TLMs
- Degradation Mechanisms

Metamorphic HEMT: InP HEMT on GaAs Substrate



L_g= 0.125 μm, f_T= 150 GHz, g_m= 1.05 S/mm, $BV_{DG,off}$=4.8 V

Electrical Degradation of InAlAs/InGaAs mHEMTs

Little known about reliability of mHEMTs

Observations in InP HEMTs:

- **Change in R_D [Wakita et al]**
- **Change in R_D and R_S [Suemitsu et al]**
- **Change in V_T [Christianson et al]**

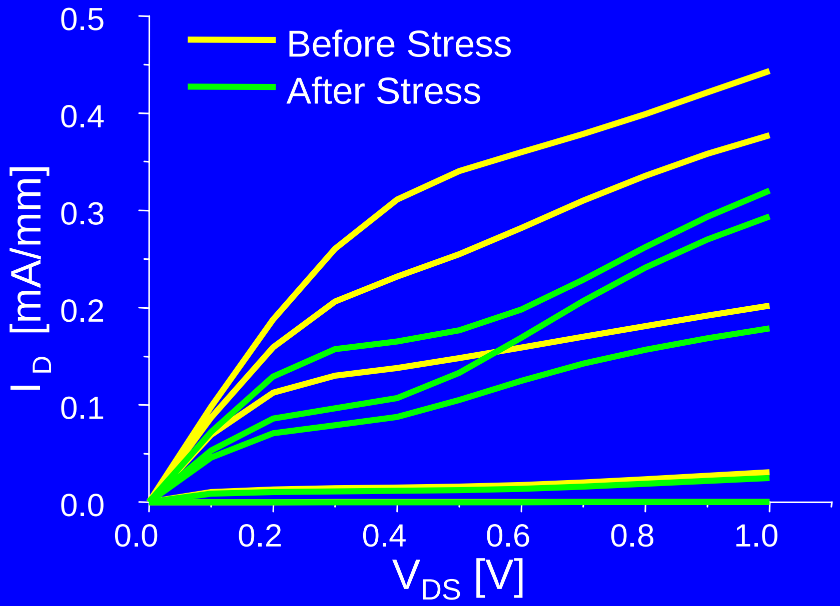
Linked to:

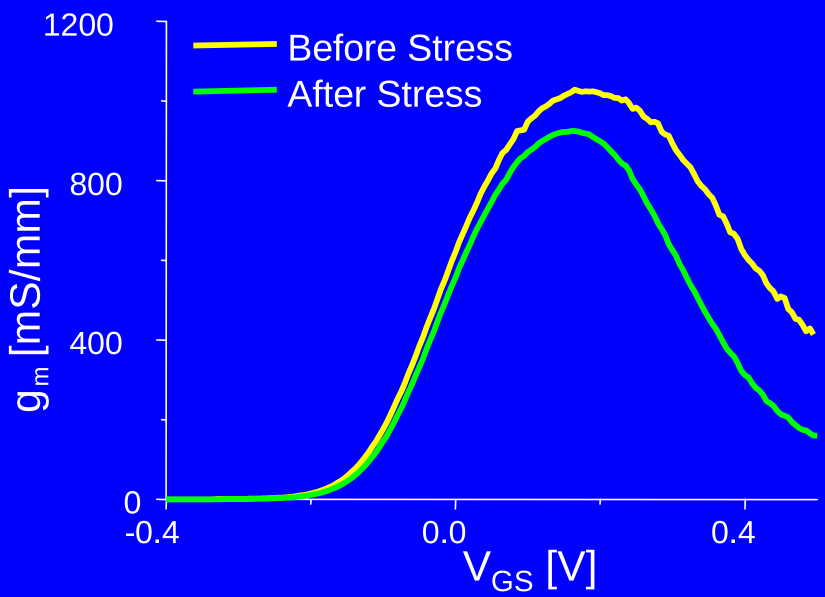
- **Impact ionization [Rohdin et al]**
- **Hot electrons [Menozzi et al]**

No systematic studies of InP HEMT electrical reliability

Effects of Electrical Stress

Stress at V_{DS}=1.5 V and I_D=250 mA/mm for 12 hours





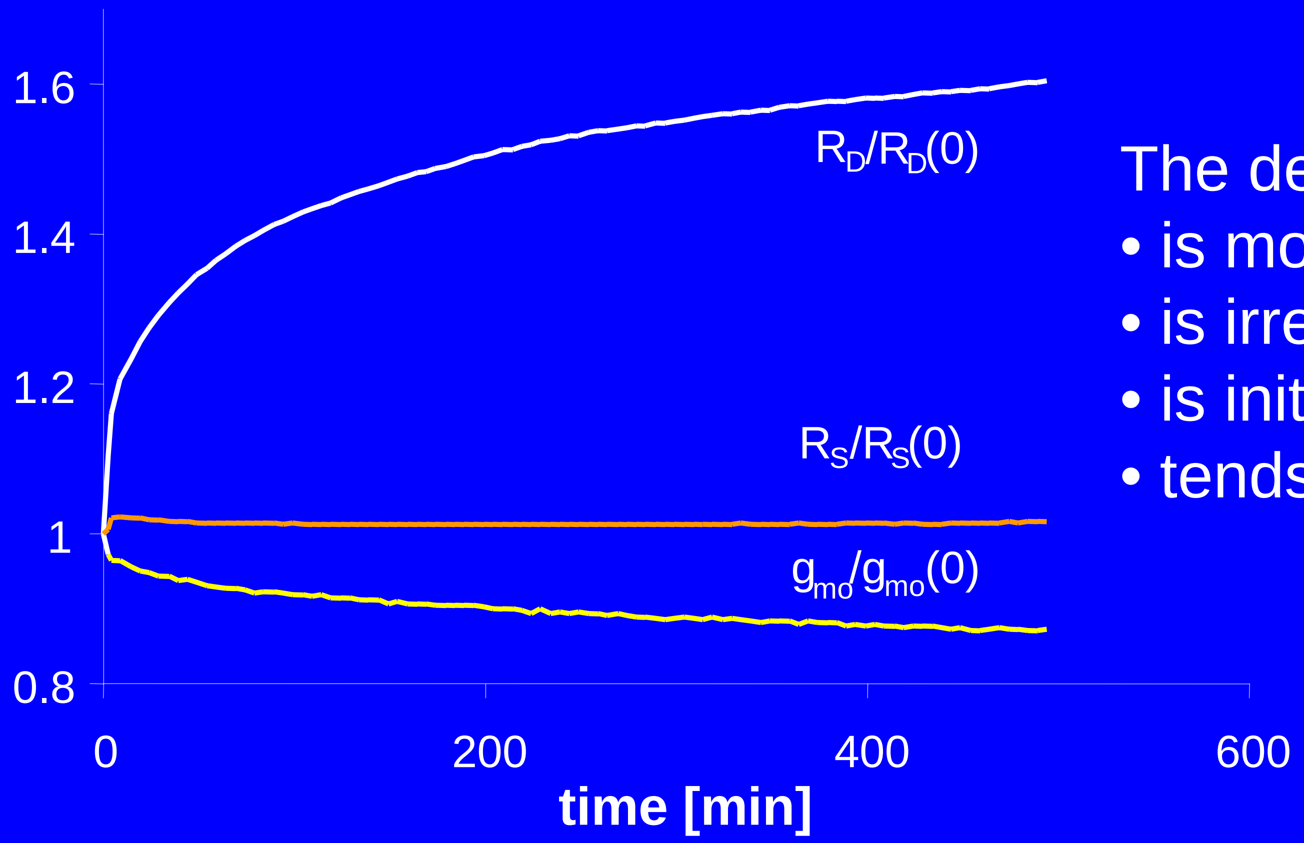
Main effects of bias stress:

- Increase in R_{DS}
- Decrease in I_D
- Decrease in g_m and f_T

Most Worrying

Time Evolution of Degradation

Stress at $V_{DGo} + V_T = 1.6$ V and $V_{GS} - V_T = 0.3$ V



The degradation of R_D

- is most important
- is irreversible
- is initially very fast
- tends to saturate

Electrical Stress Methodology

Studied several bias stress schemes:

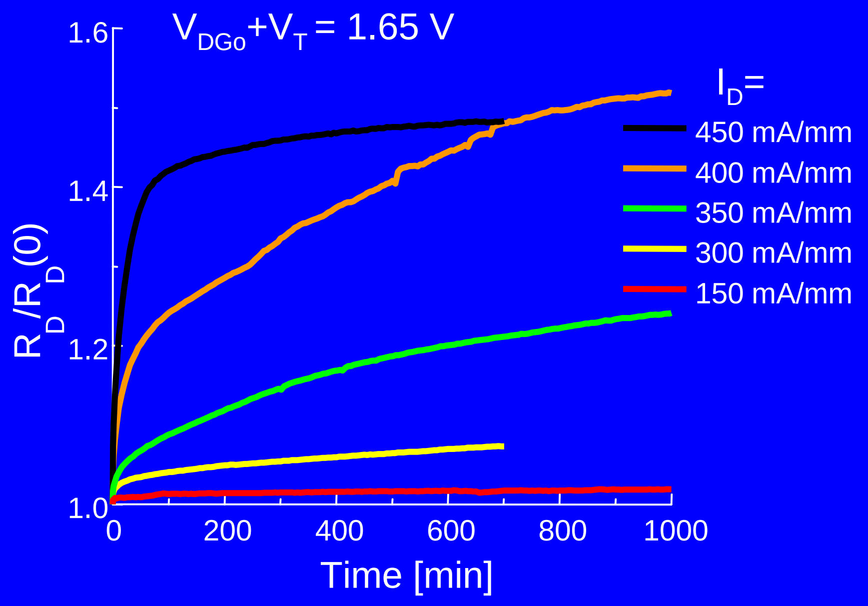
- Constant V_{DS} & constant V_{GS}
- Constant I_D & constant I_G
  - Device characteristics change → bias point changes

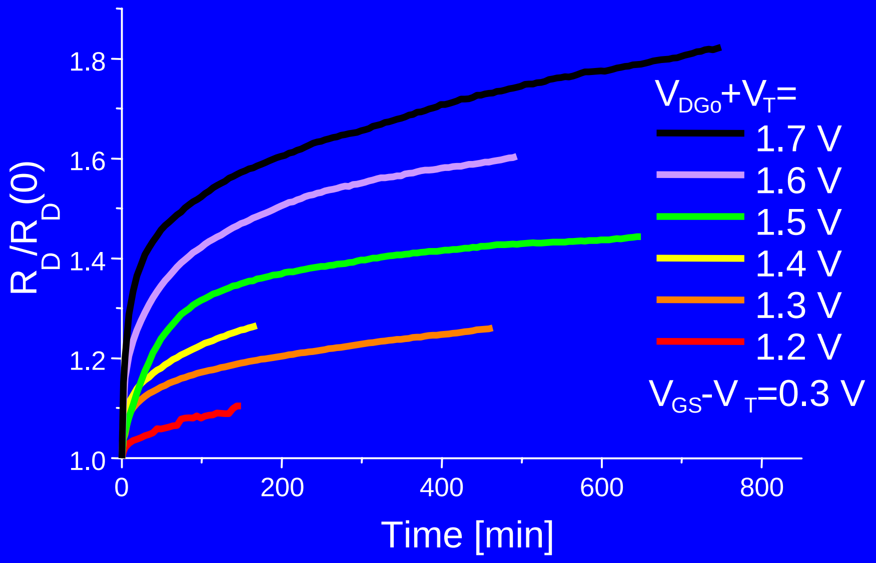
- Constant V_{DGo} & constant I_D
  - Different devices, different degradation

- Constant I_D & constant $V_{DGo}+V_T$
- Constant $V_{GS}-V_T$ & constant $V_{DGo}+V_T$
  - Reproducible degradation
  - Keep impact-ionization constant

R_D Degradation Associated with Impact-Ionization ?

$$\text{Impact-ionization rate} \propto I_D \exp\left(-\frac{A}{V_{DGo}+V_T}\right)$$

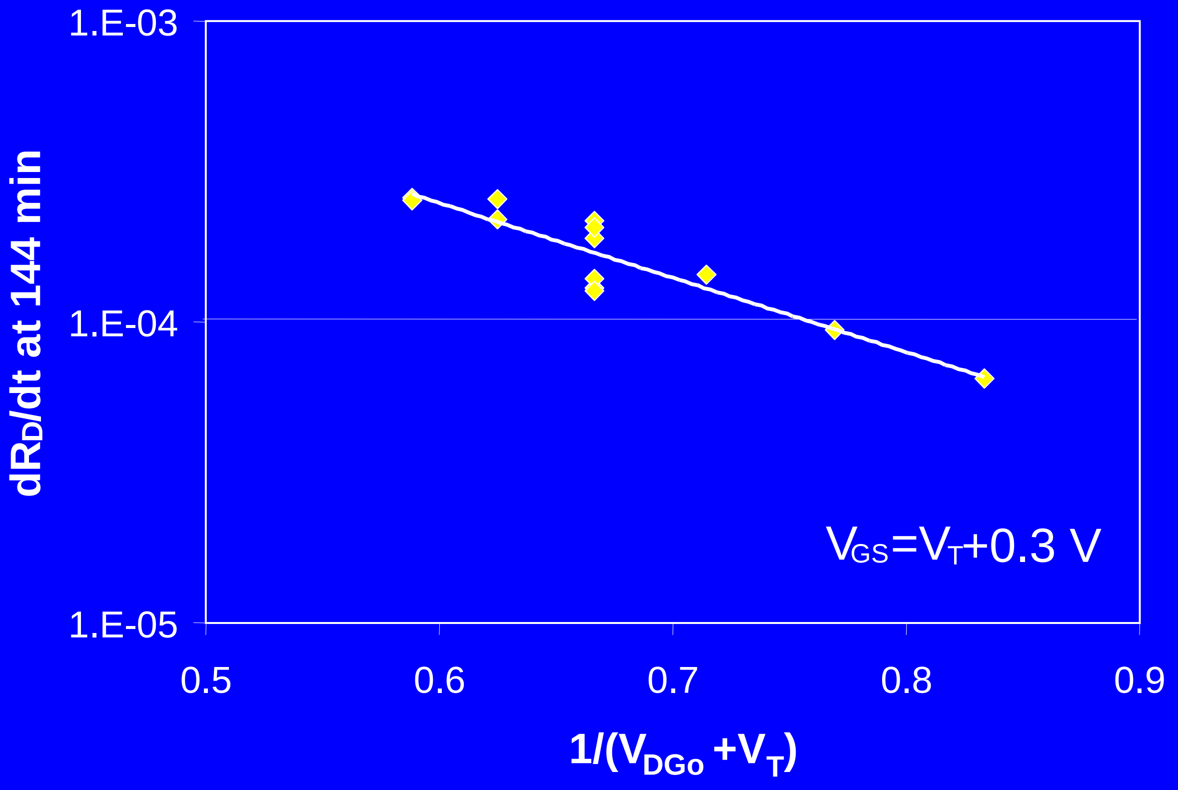




Higher impact-ionization → Higher degradation

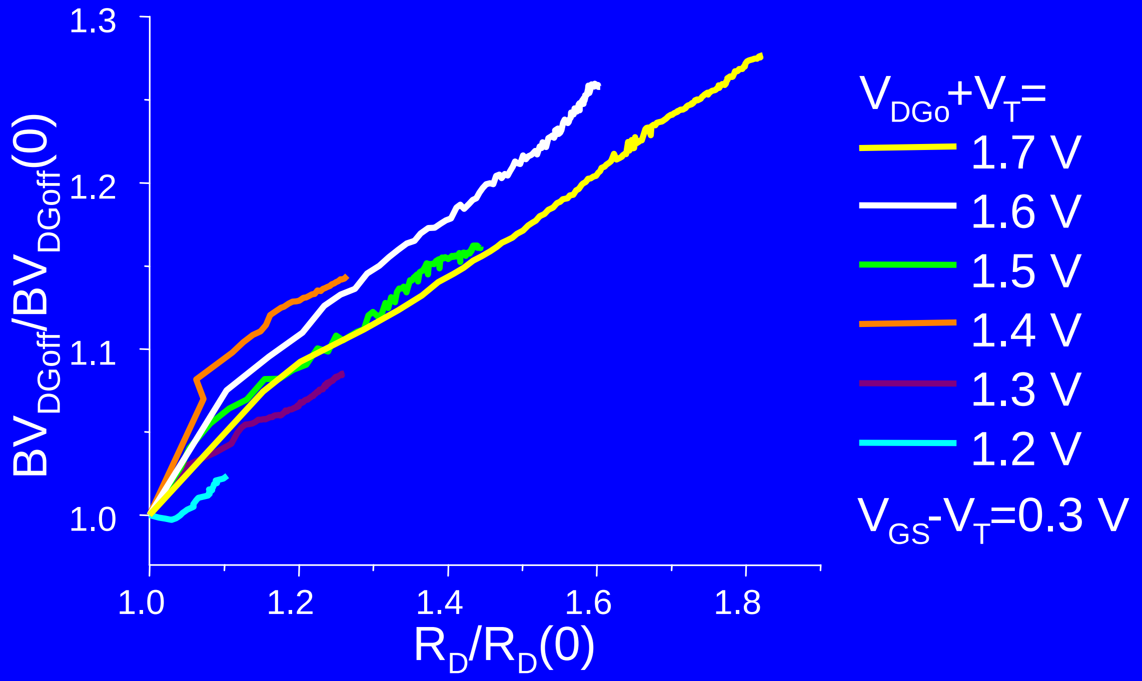
Impact-Ionization behind R_D degradation

$$\text{Impact-ionization rate} \propto I_D \exp\left(-\frac{A}{V_{DGo}+V_T}\right)$$



Degradation rate follows classical impact-ionization behavior

Other Drain-Related Figures of Merit Change



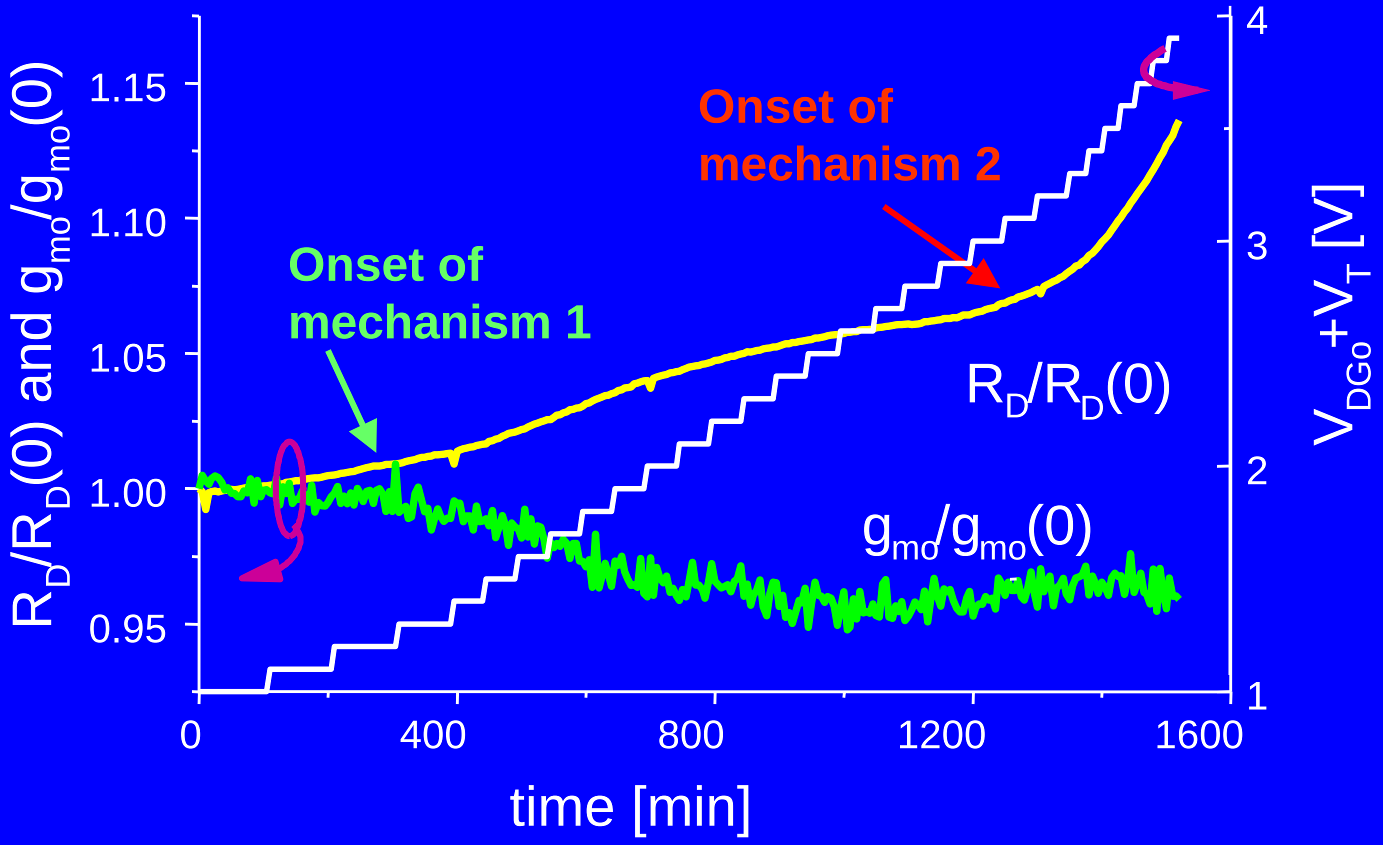
Both BV_{DGoff} and R_D depend on n_s on drain side

→ Drop in n_s probable cause of degradation

C_{dg} also degrades

Step-Stress Experiments

Improved experimental productivity

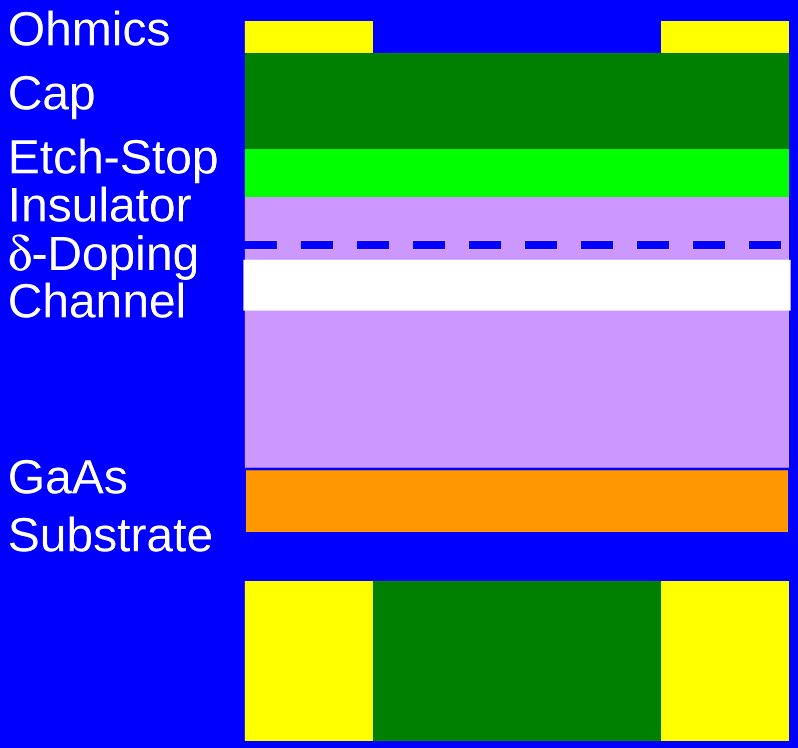


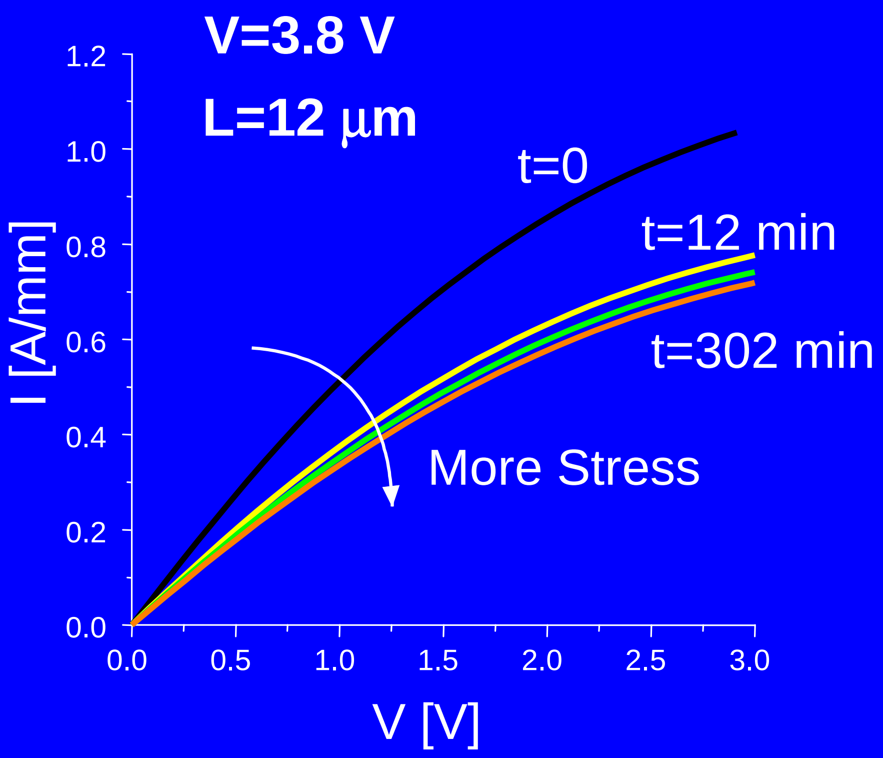
Onset of mechanism 1

Onset of mechanism 2

2 Degradation mechanisms can be identified

Simpler Case: TLMs

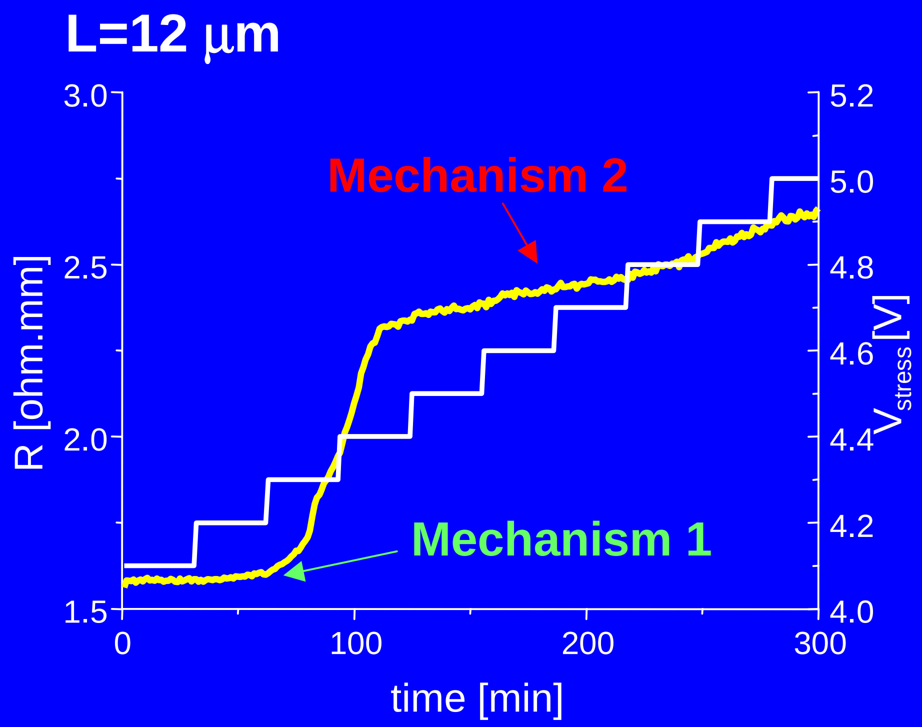


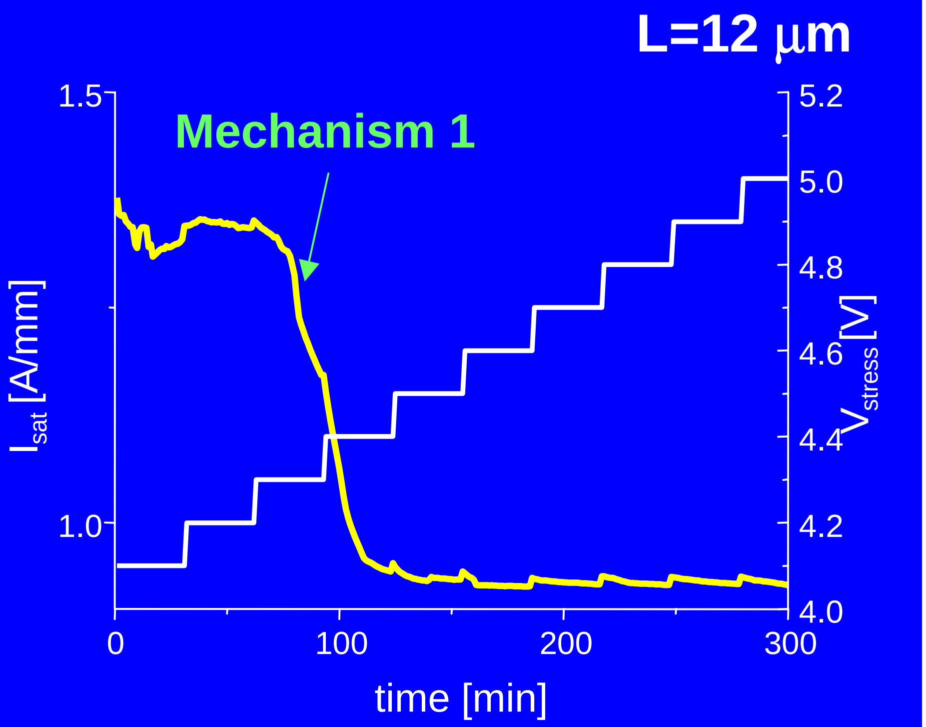


Integrated TLMs : uniform field in channel

Only two figures of merit: R, I_{sat}

Time Evolution of TLM Degradation



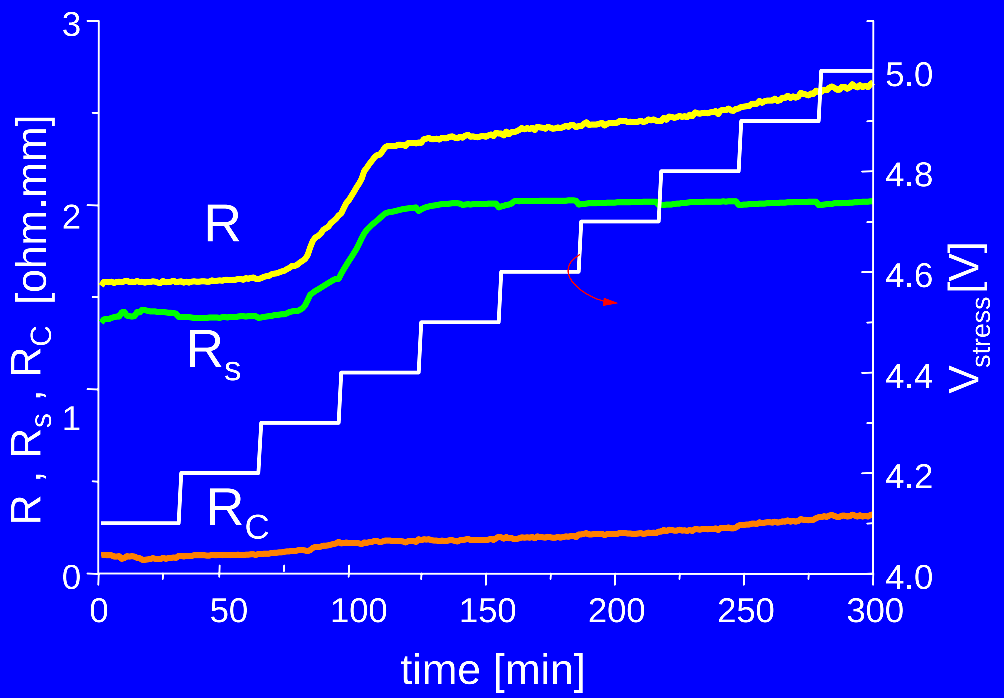


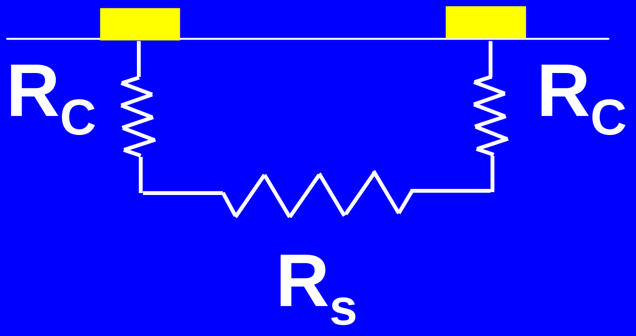
Two mechanisms appear:

V<4.5 V R and I_{sat} track each other ⟶ $n_s \downarrow$

V>4.5 V only R increases

Increase of Lateral and Contact Resistance



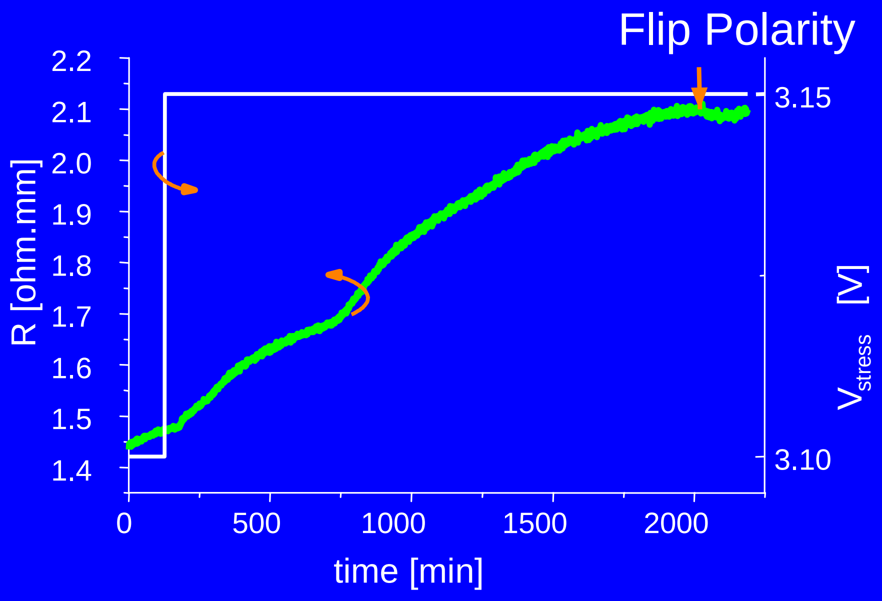


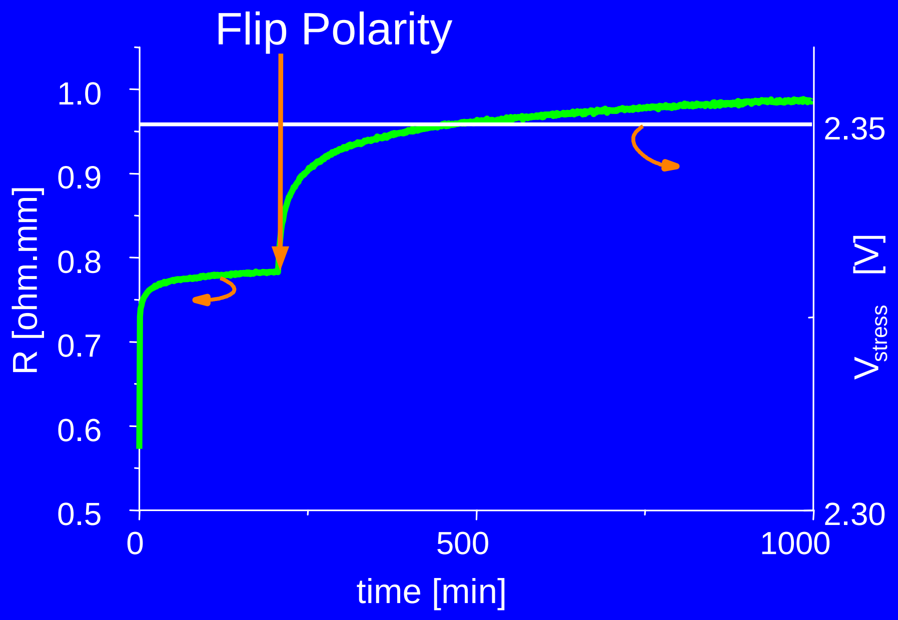
$$R=R_s+2R_C$$

Mechanism 1: Degradation of $n_s \rightarrow R_s\uparrow, R_C\uparrow$

Mechanism 2: Degradation of R_C only

Field Reversal





Mechanism 1

Independent of stress polarity

⬇

Uniform degradation

Mechanism 2

Dependent of stress polarity

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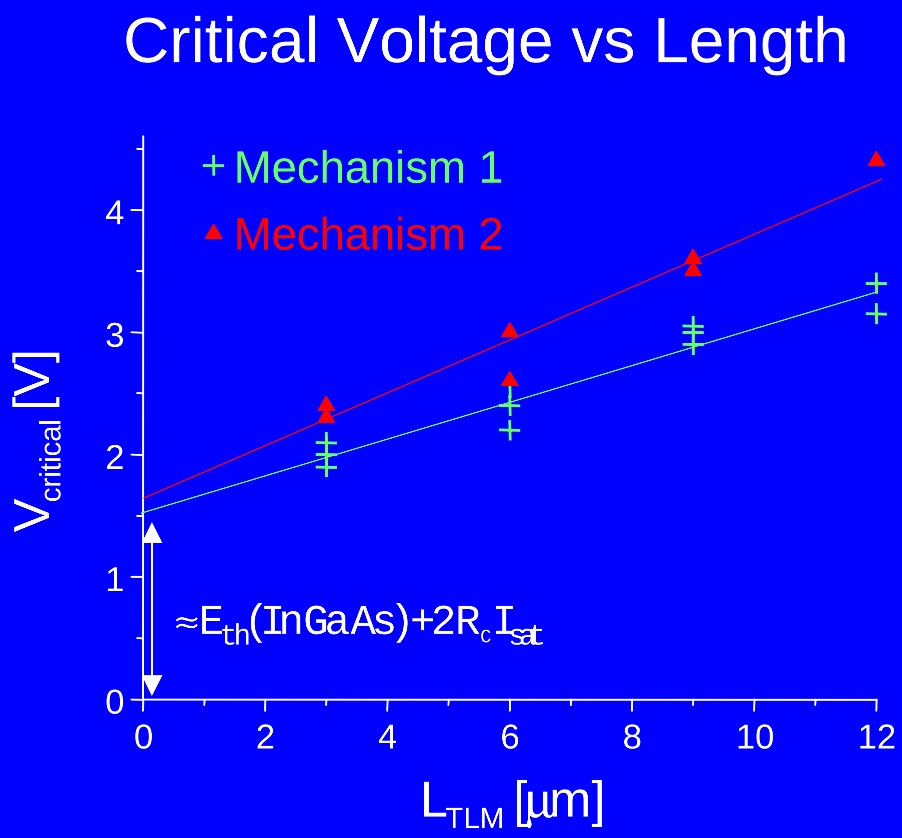
Degradation of one ohmic contact

Critical Voltage for Degradation



Threshold of degradation ≈ Threshold of impact-ionization

Degradation exhibits constant-field behavior

Degradation Mechanisms

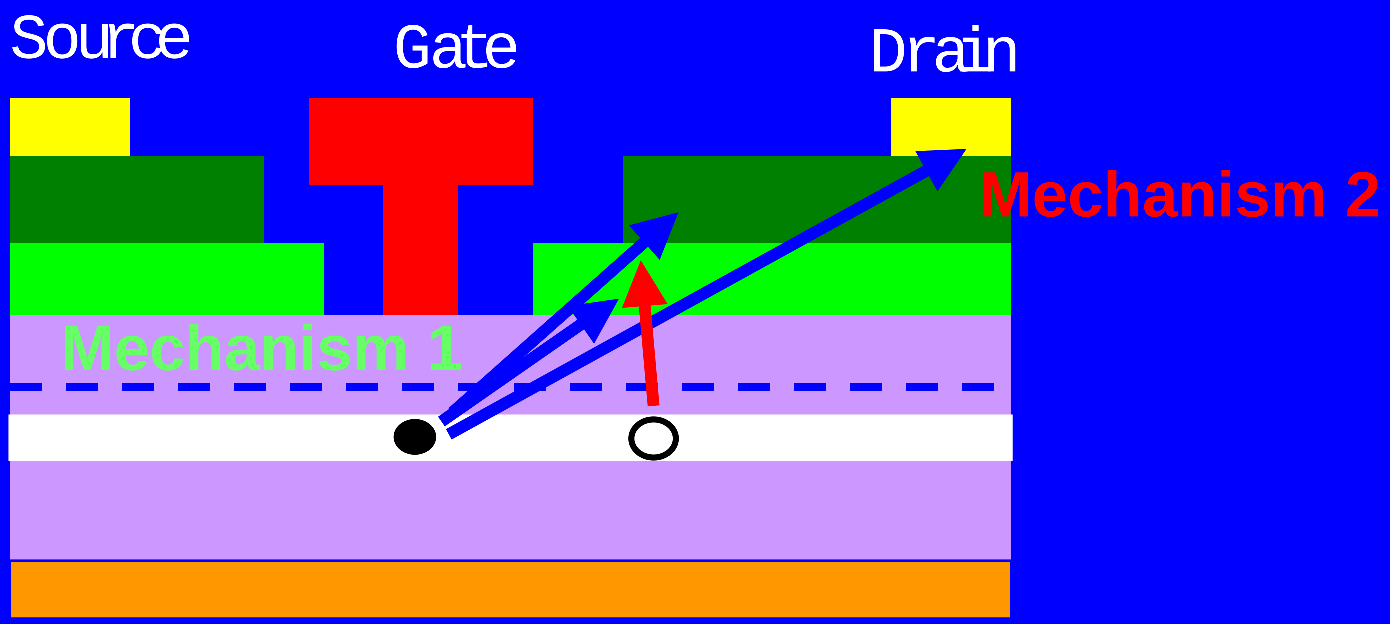
Mechanism 1

- Occurs at lower voltage
- n_s drops on drain-side
- Saturates
- Occurs at surface (cap plays a role)
- Correlated with impact-ionization (also temperature)
- Polarity Independent

Mechanism 2

- Occurs at higher voltage
- Drain-ohmic contact degrades
- Does not saturate
- Polarity Dependent

Degradation Mechanisms



Mechanism 1

- Hot electron/hole generation by impact-ionization
- Hot carriers change drain side of device (trapping, recombination-enhanced damage) close to surface

Mechanism 2

- Hot electrons
- Drain-ohmic contact degrades

Nothing specific about metamorphic substrate

Conclusions

- Degradation in mHEMTs correlated with impact-ionization
- Two degradation mechanisms identified
  - Extrinsic drain surface
  - Drain ohmic contact
- No specific degradation mechanism identified specifically associated with metamorphic substrate