Non-Uniform Degradation Behavior Across Device Width in RF Power GaAs PHEMTs

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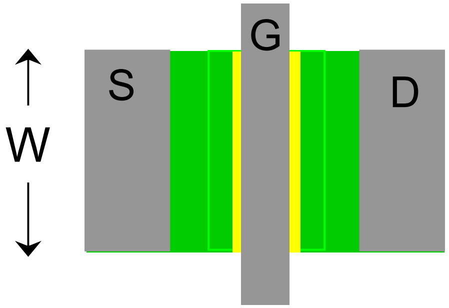
Sponsor: Mitsubishi Electric

Motivation

- Electrical degradation is serious concern in RF power GaAs PHEMTs
  - Under stressing: $\mathbf{R_D} \uparrow$ and $\mathbf{I_{max}} \downarrow \rightarrow \mathbf{P_{out}} \downarrow$
- Degradation mechanisms identified [1]-[3], but no studies of uniformity
- **This study**: investigate degradation across device width



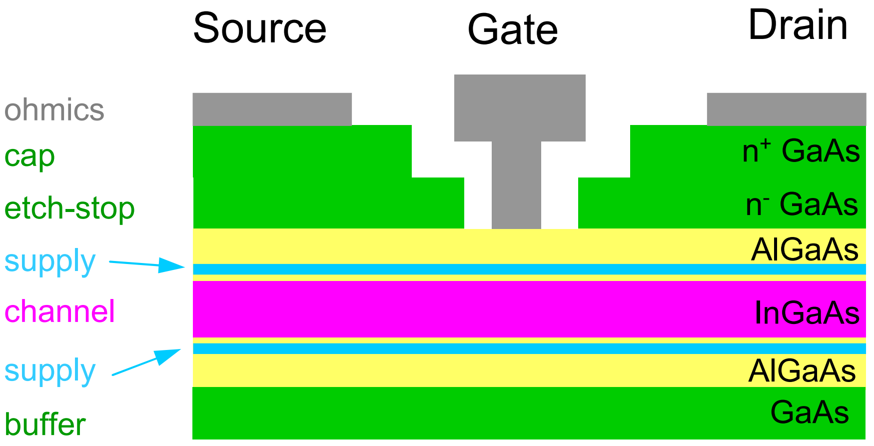
[1] del Alamo et al (IEDM 2004)
[2] Meneghesso et al (1996)
[3] Hisaka et al (GaAs IC 2003)

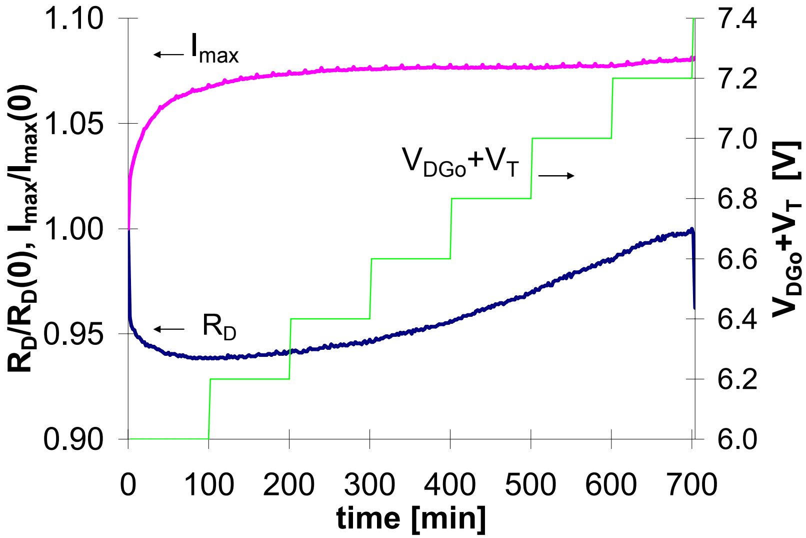
Outline

- **Introduction**
- **Experimental**
- **PHEMT Degradation**
  - Light Emission
- **TLM Degradation**
  - Light Emission
  - Materials Analysis
- **Conclusions**

Introduction

Stressing: I_D = 400 mA/mm, step $V_{DGo}+V_T$. In air @ 300 K.



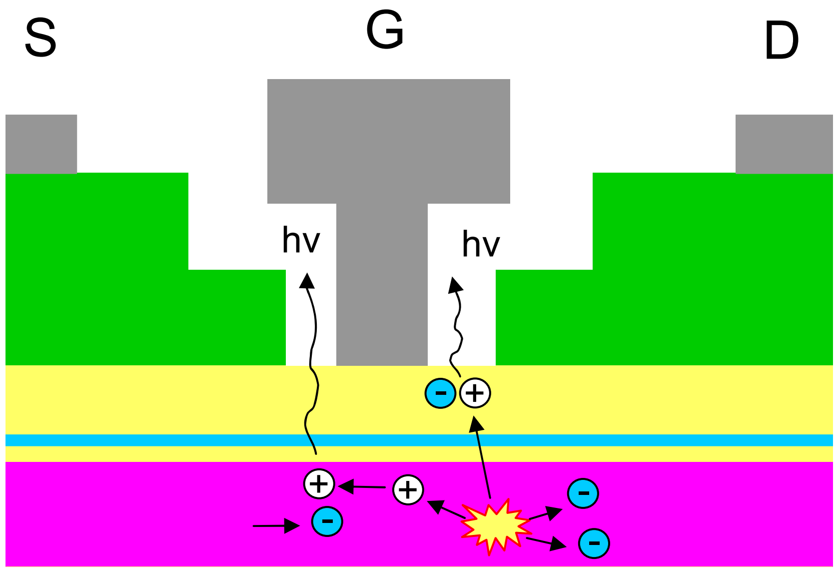


- Experimental RF power PHEMTs
- L_g = 0.25 µm, W_g = 50 µm
  f_t ~ 40-50 GHz, $BV_{DG,off}$ ~ 12-15 V

With step-stress:

- **R_D ↑**
- I_{max} ↑ (from V_T ↓)

Light Emission & Degradation

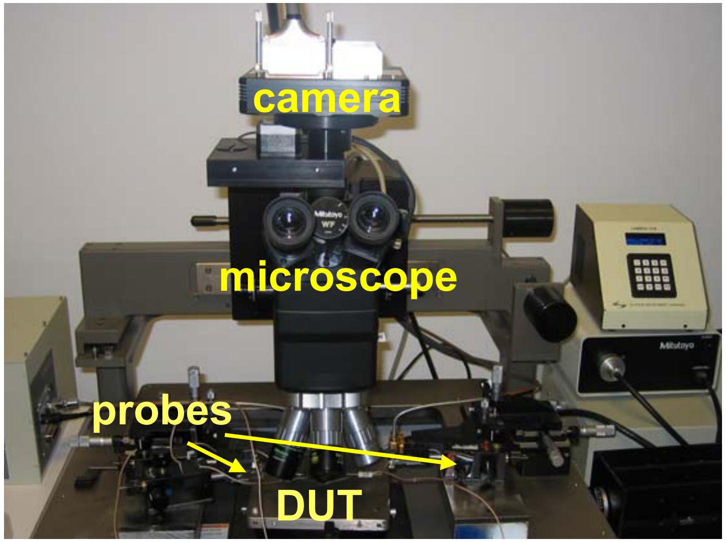


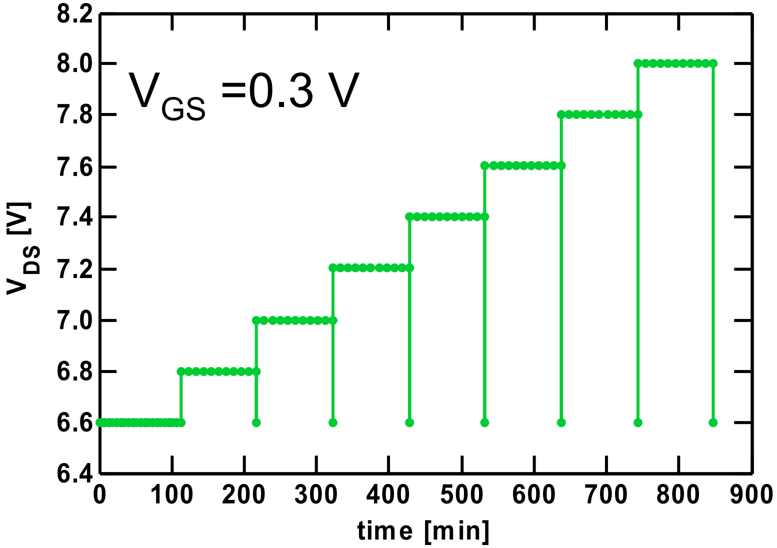
- R_D degradation due to surface corrosion [3], high E involved
- High E → impact ionization (II) → recombination → *light emission*
- Light-emission picture: ***spatial view of II, E***

[3] Hisaka et al (GaAs IC 2003)

Light-emission: Experimental

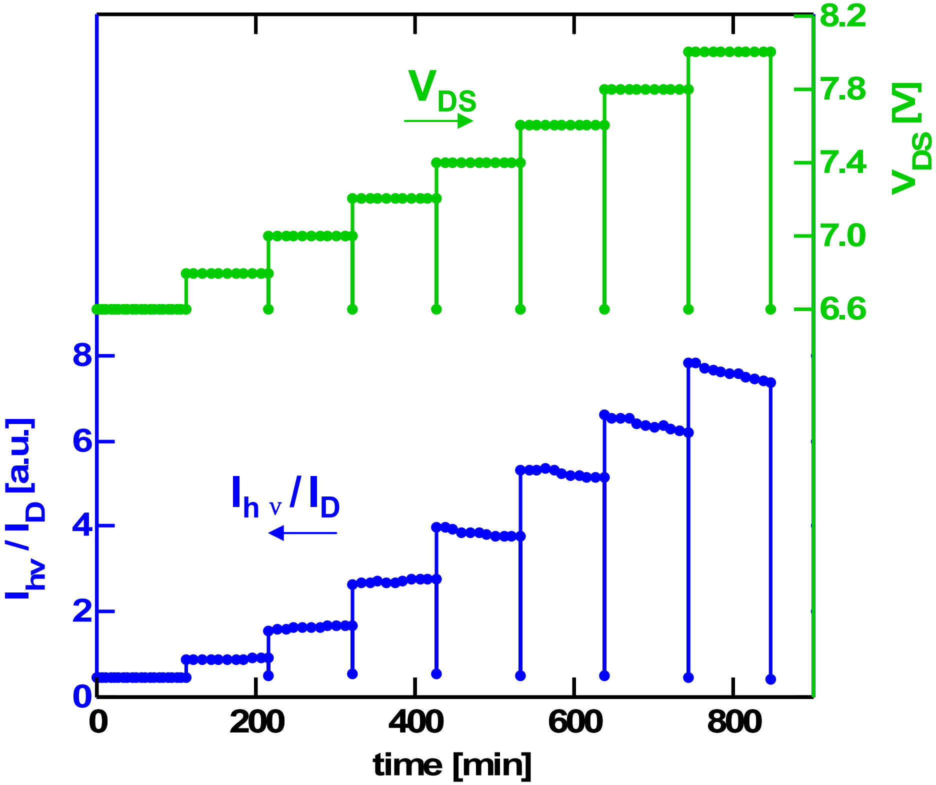
- Astronomical-grade CCD sensor
- Stressing: **constant V_{GS} & constant V_{DS}**
  - V_{DS} stepped
- Photographs taken:
  - at frequent intervals
  - at fixed (low) value of V_{DS}





Light-Emission vs. Stressing (1)

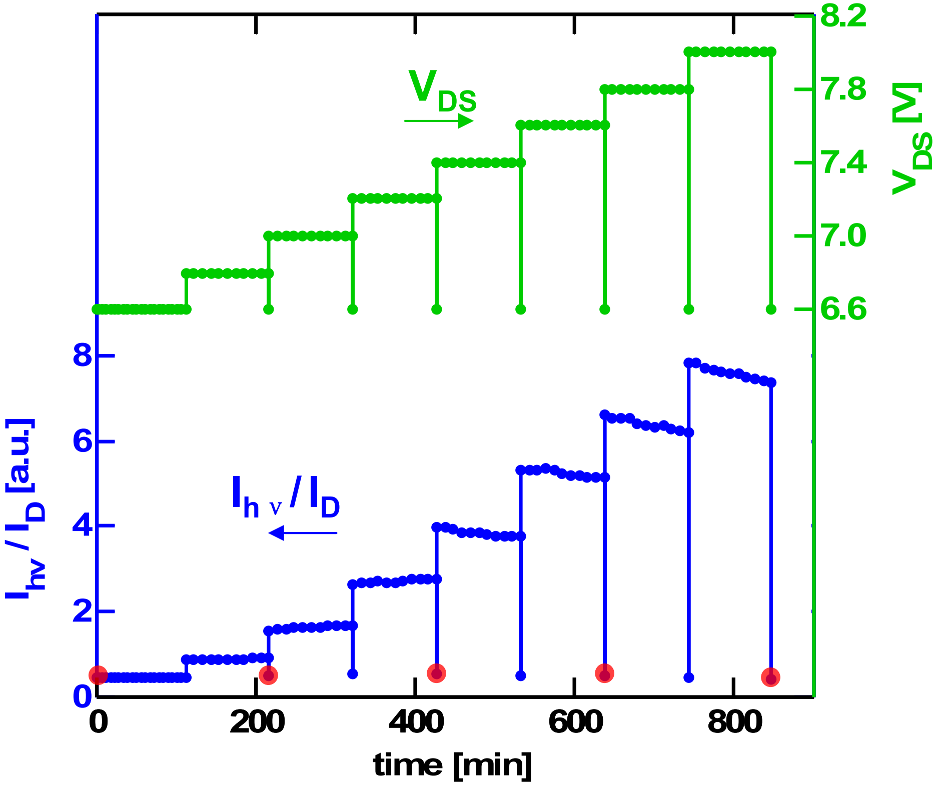
V_{GS} =0.3 V



- V_{DS} ↑ → $I_{h\nu}$ ↑
- For constant V_{DS}, $I_{h\nu}$ constant, but eventually ↓
  - ↳R_D ↑ → V_{DGo} ↓

Light-Emission vs. Stressing (1)

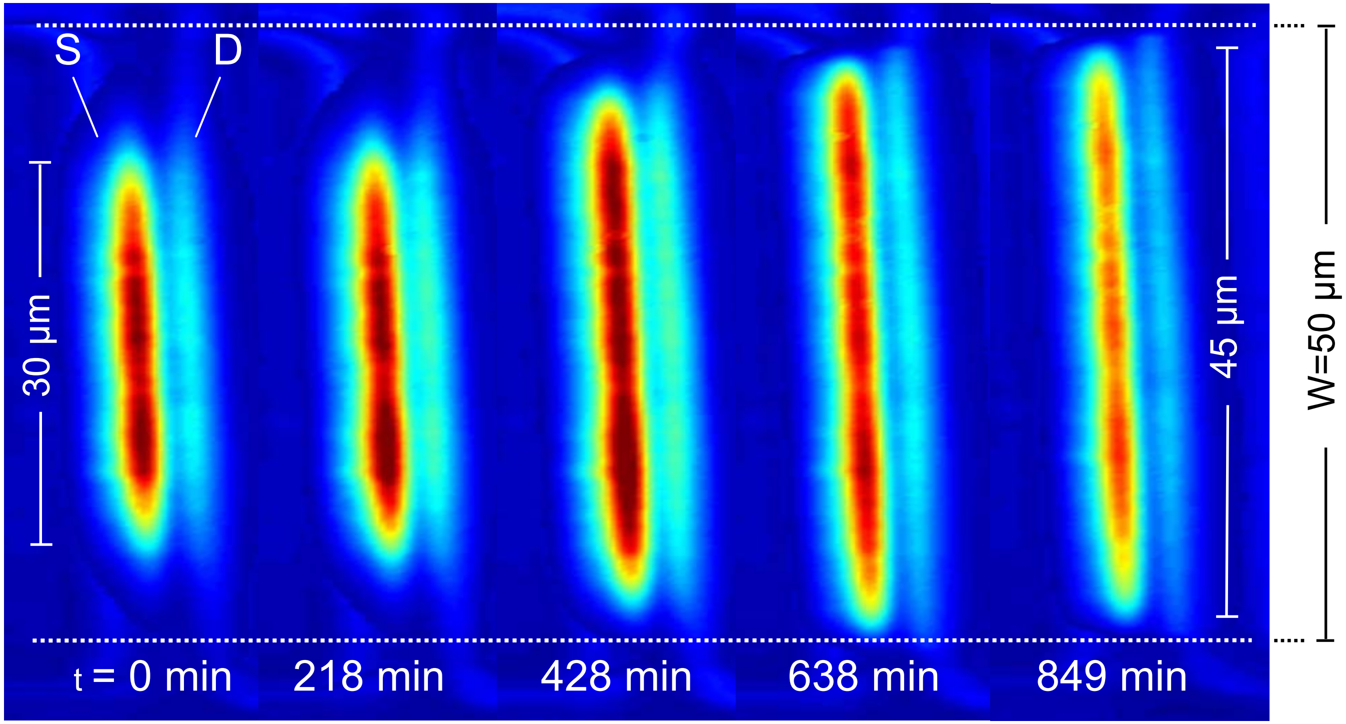
V_{GS} =0.3 V



- V_{DS} ↑ → $I_{h\nu}$ ↑
- For constant V_{DS}, $I_{h\nu}$ constant, but eventually ↓
  ↳R_D ↑ → V_{DGo} ↓

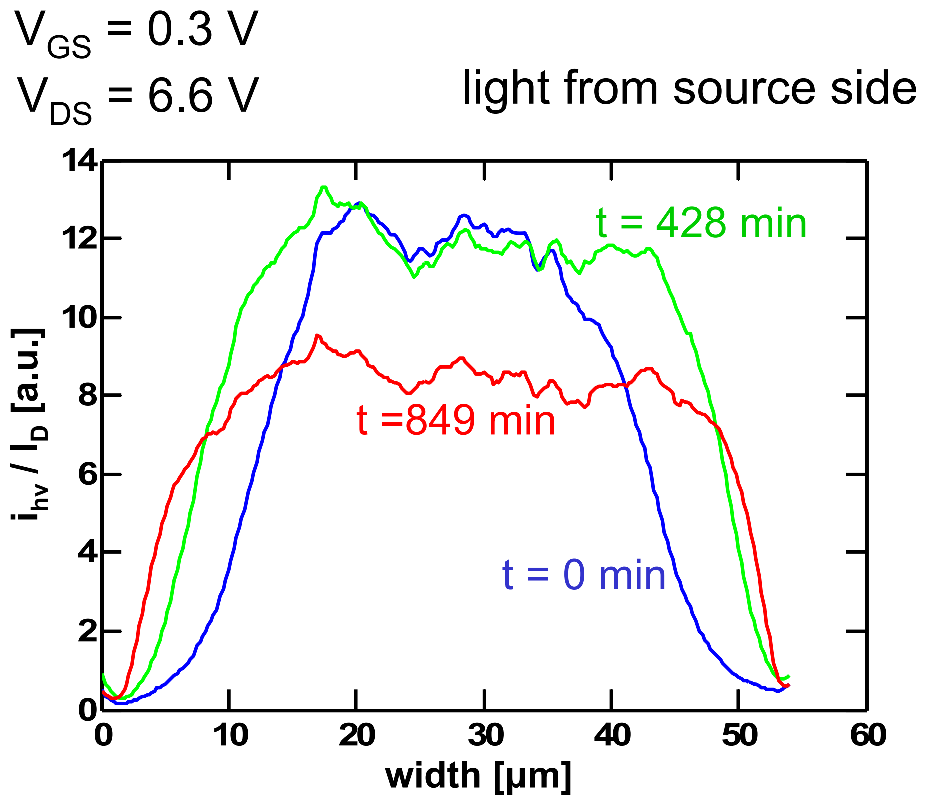
Light-Emission vs. Stressing (2)

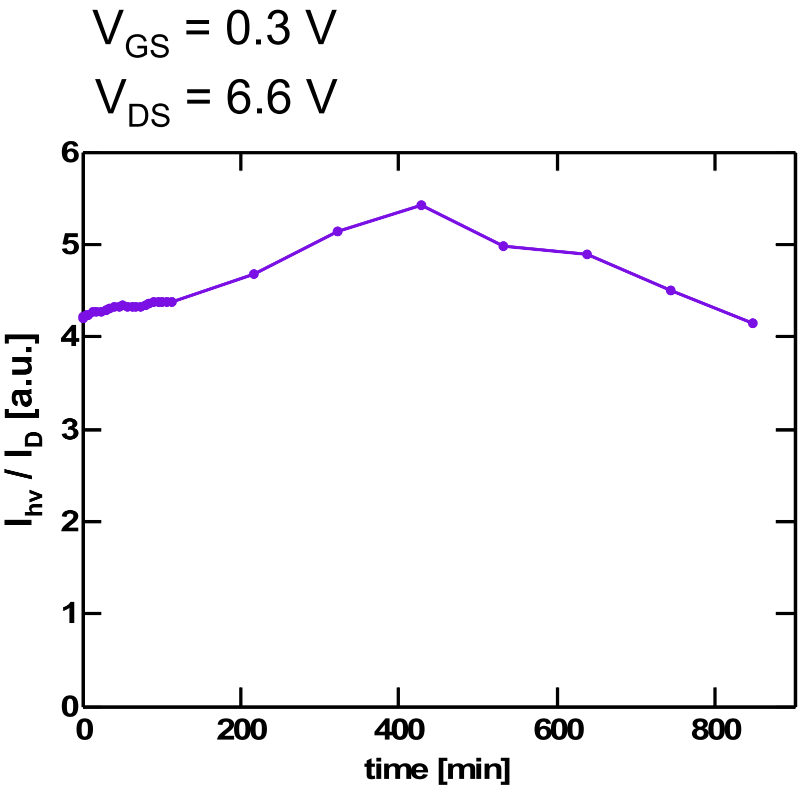
V_{GS} = 0.3 V
V_{DS} = 6.6 V



- Initially, light **concentrates in center** ~30 µm of width
- With stressing: (1) light **spreads out** along width
  (2) **weakens** in intensity

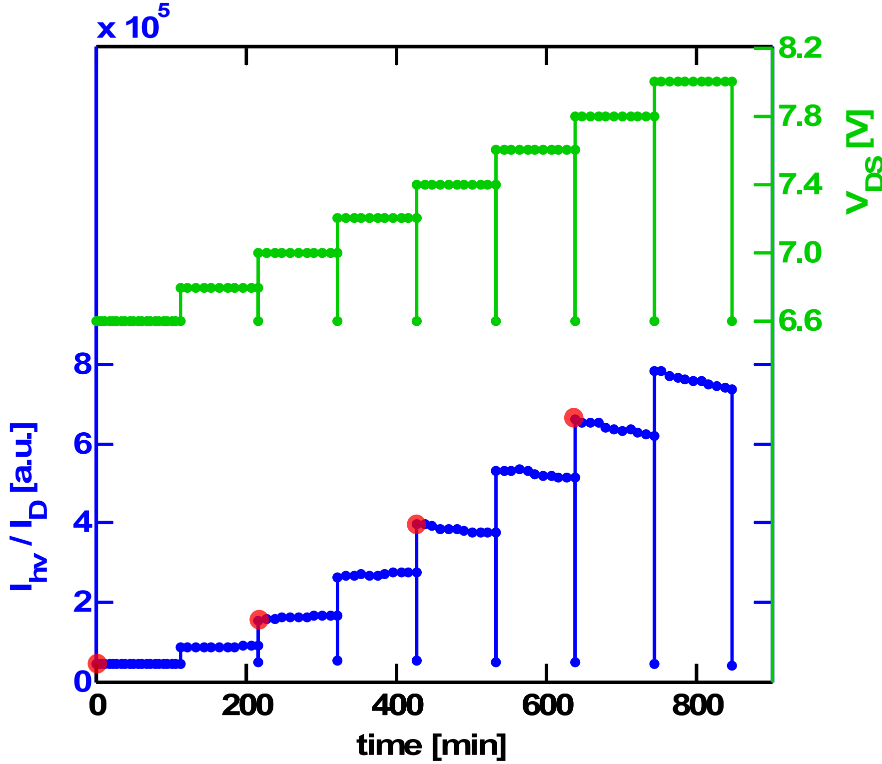
Light Emission vs. Width

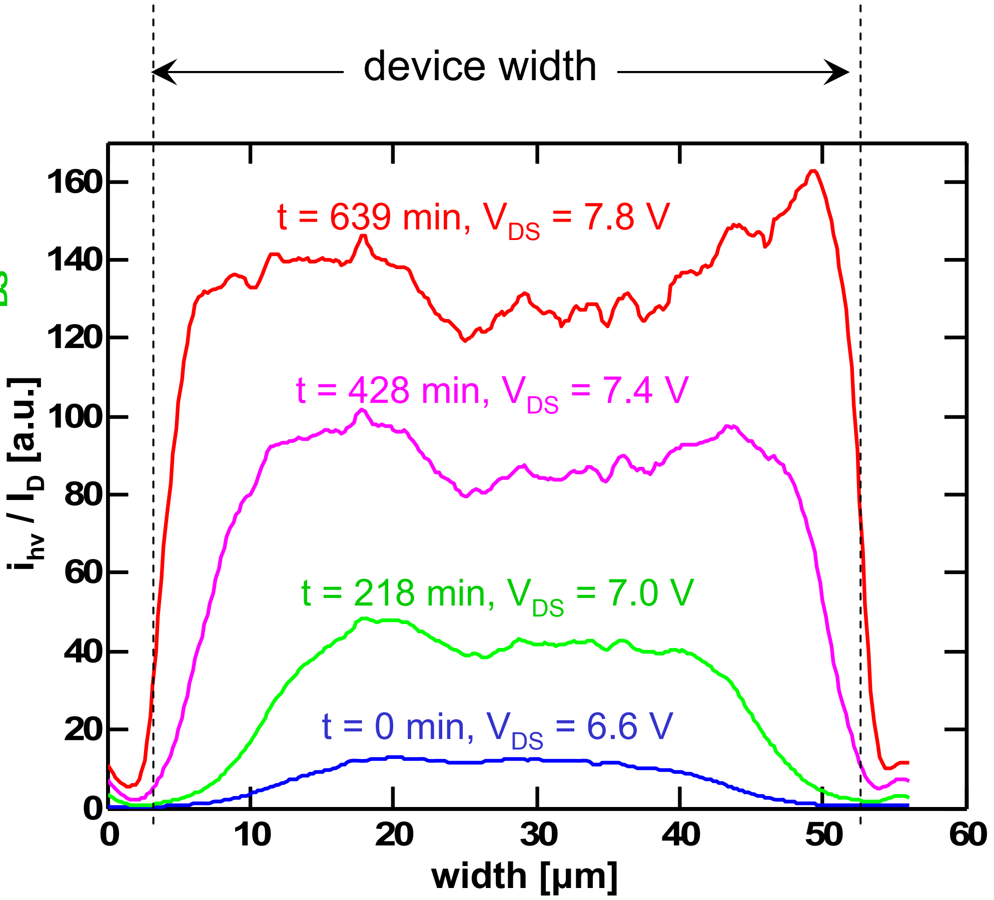




- 1^{st} half: light spreads out → I_{hv} ↑
- 2^{nd} half: intensity decreases → I_{hv} ↓

Light Emission During Stressing

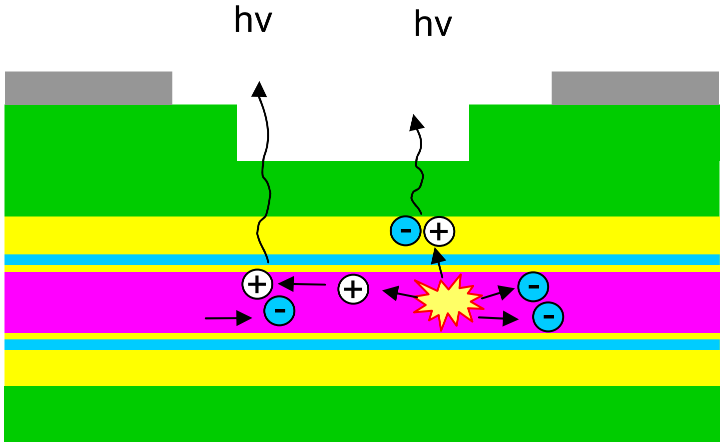


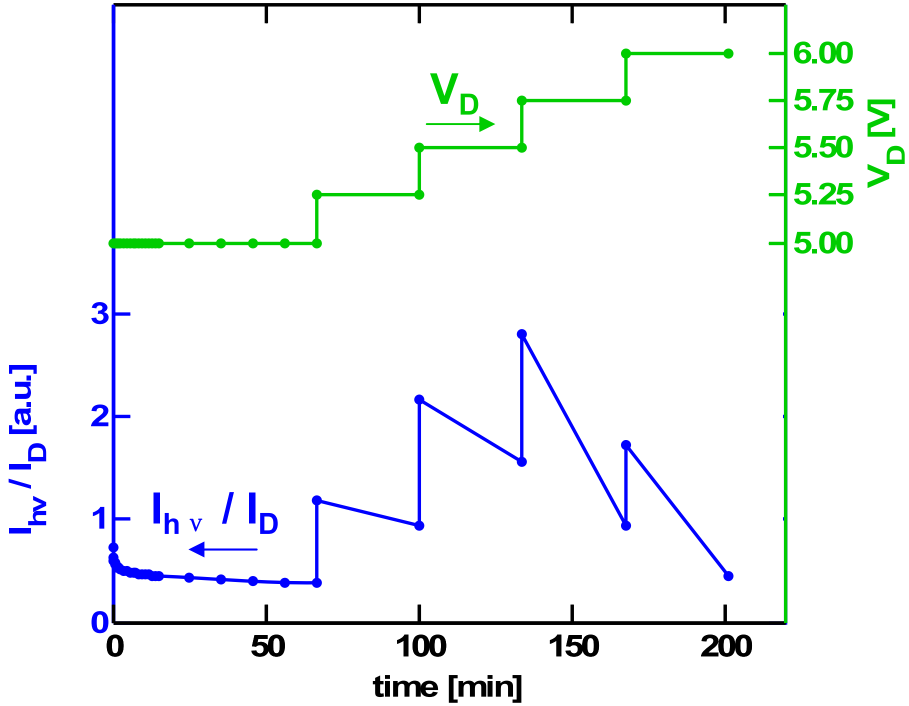


- During stressing, at high bias:
  - early stages: degradation peaks ***in center***
  - advanced stages: degradation peaks ***at edges***

Light-Emission of TLMs (1)

TLM: same structure as PHEMT, but *no gate*

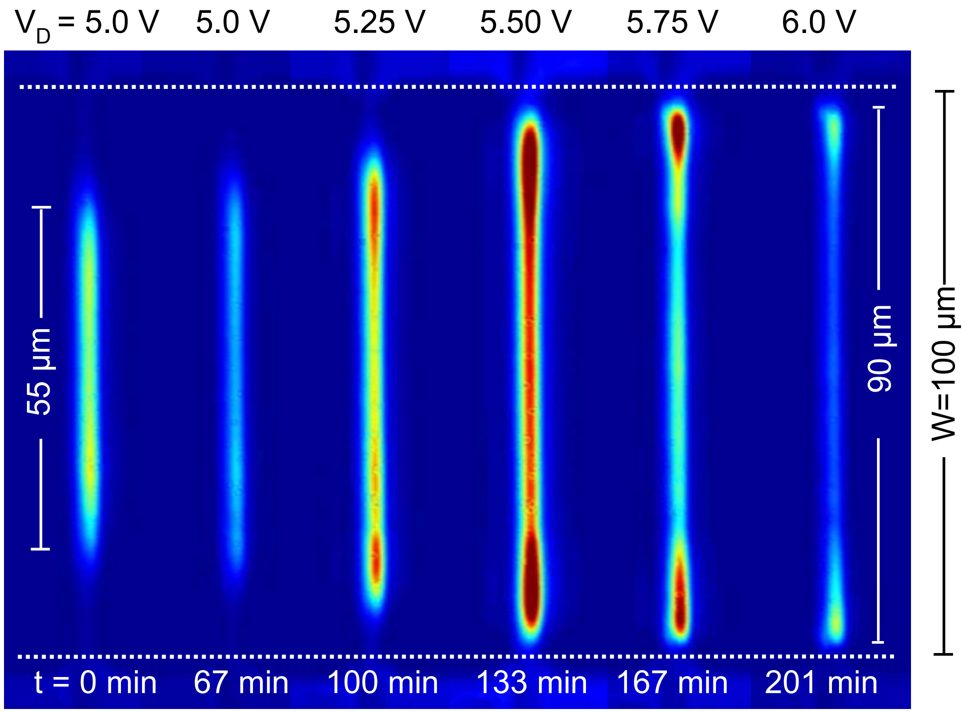




- $V_D \uparrow \rightarrow I_{h\nu} \uparrow$

- Constant $V_D \rightarrow I_{h\nu} \downarrow$
  ↳ $R \uparrow \rightarrow II \downarrow$

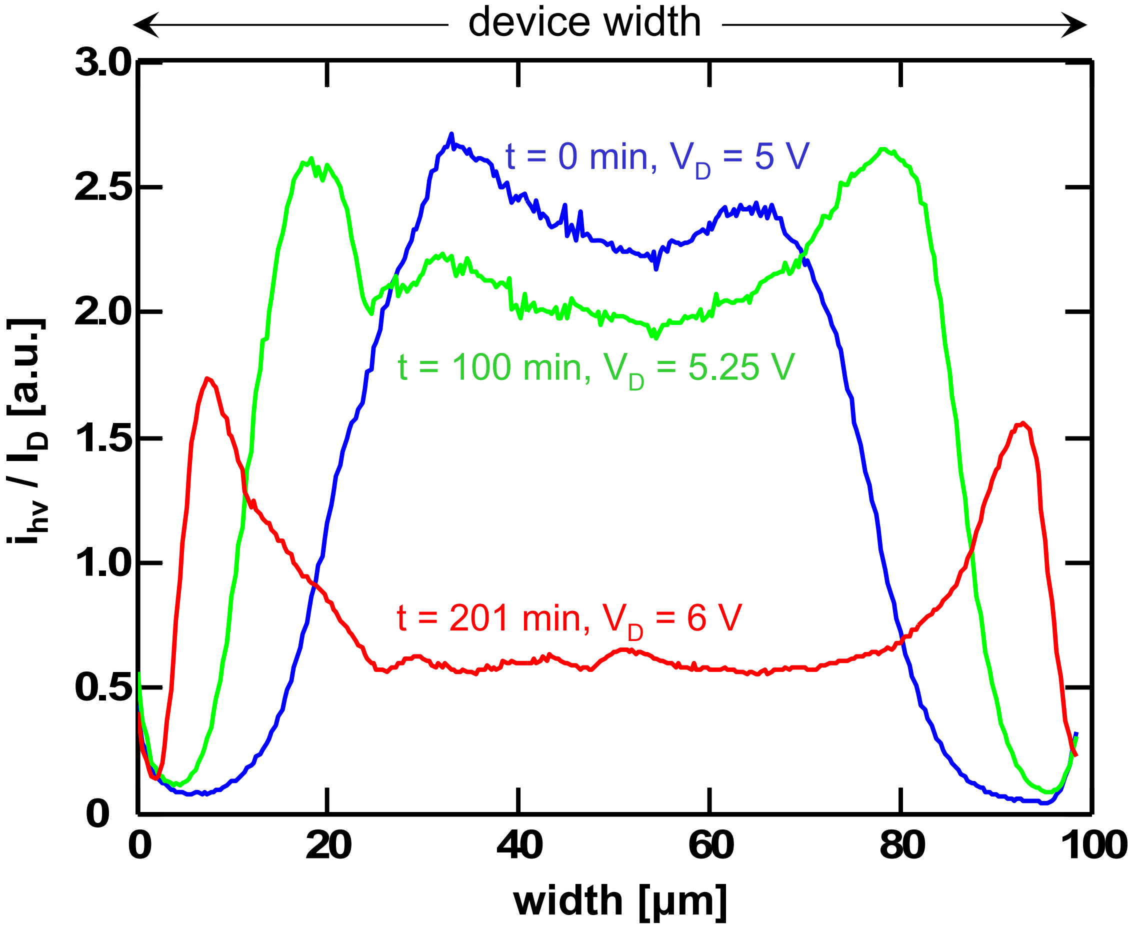
Light Emission of TLMs (2)



- Light initially concentrated in center
- With stressing:
  - Light spreads out over width of TLM
  - $I_{h\nu}$ ↓ (for constant voltage)

(Similar to PHEMT light emission behavior)

Light Emission vs. Width (TLMs)



- During stressing, at high bias, light “peaks” at edges

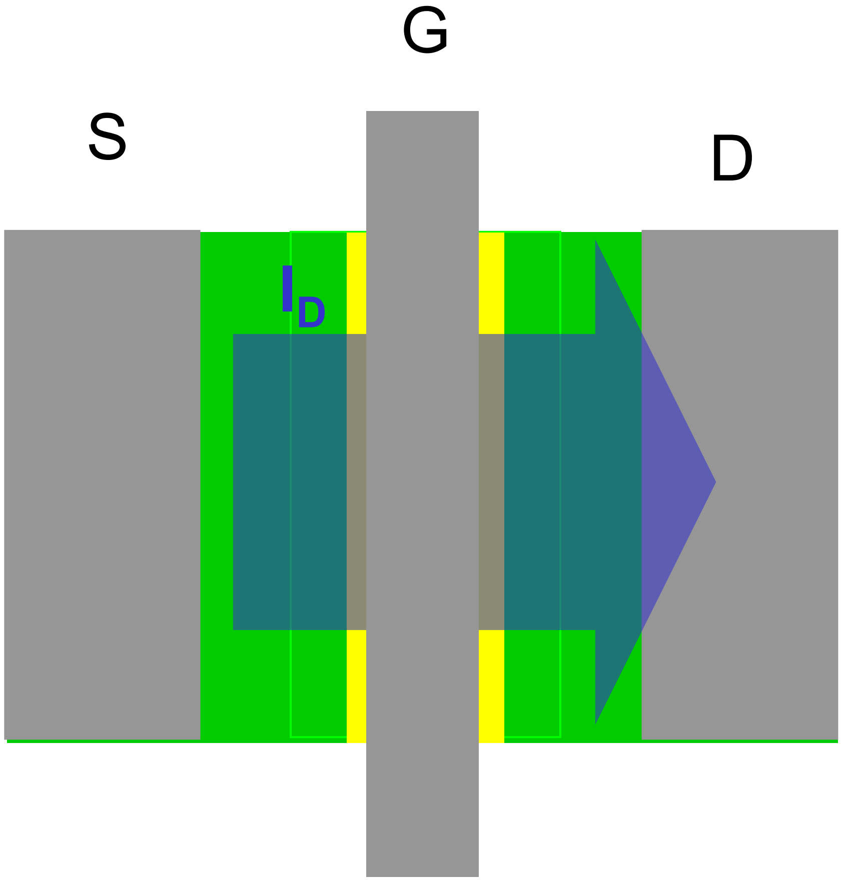
→ similar behavior in PHEMTs

Origin of Non-Uniform II

3 possible causes for non-uniform II across device width:

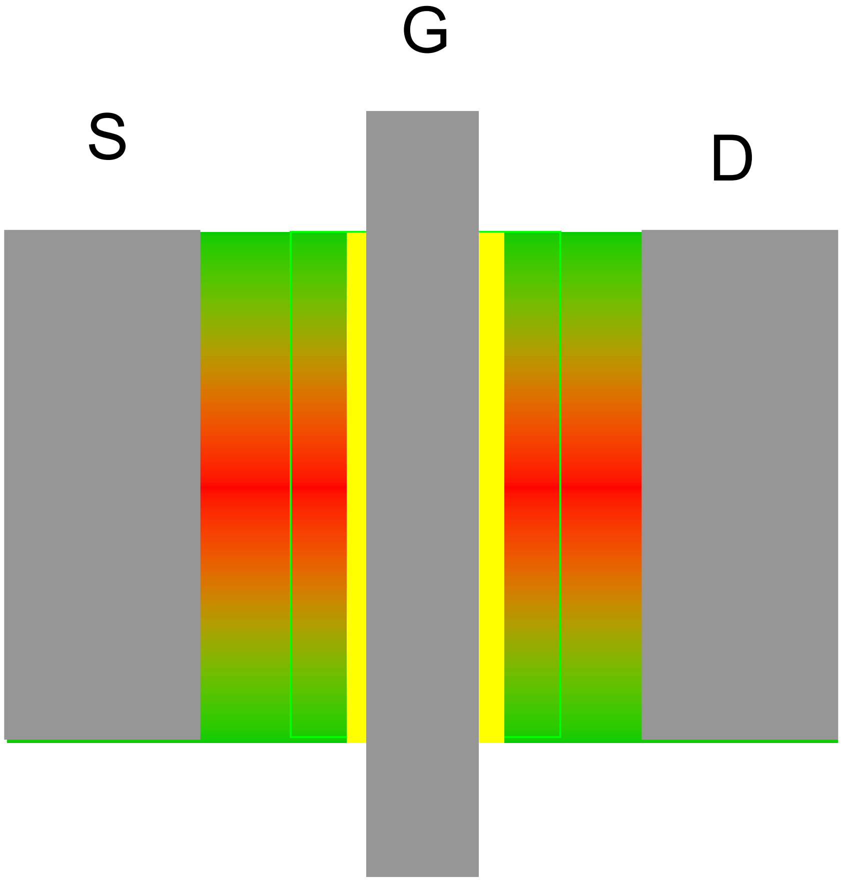
- Non-uniform I_D
- Non-uniform T
- Non-uniform E-field

Non-Uniform Drain Current ?



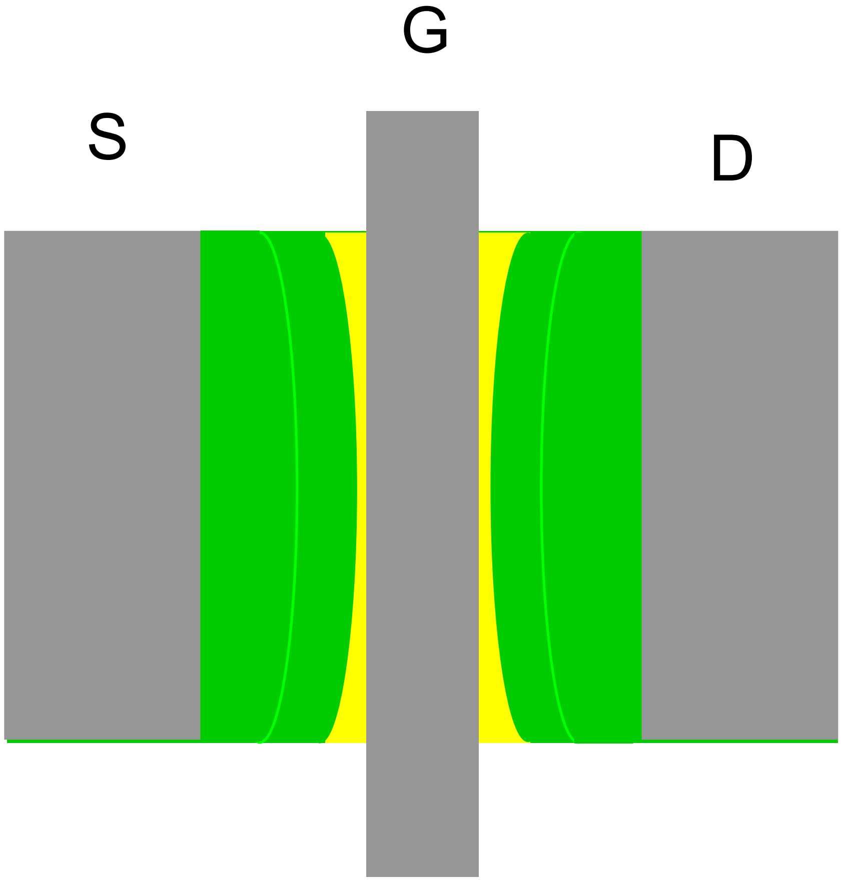
- Non-uniform I_D
  - – but II $\propto$ I_D, so requires edges be "shut off"

Non-Uniform Temperature?



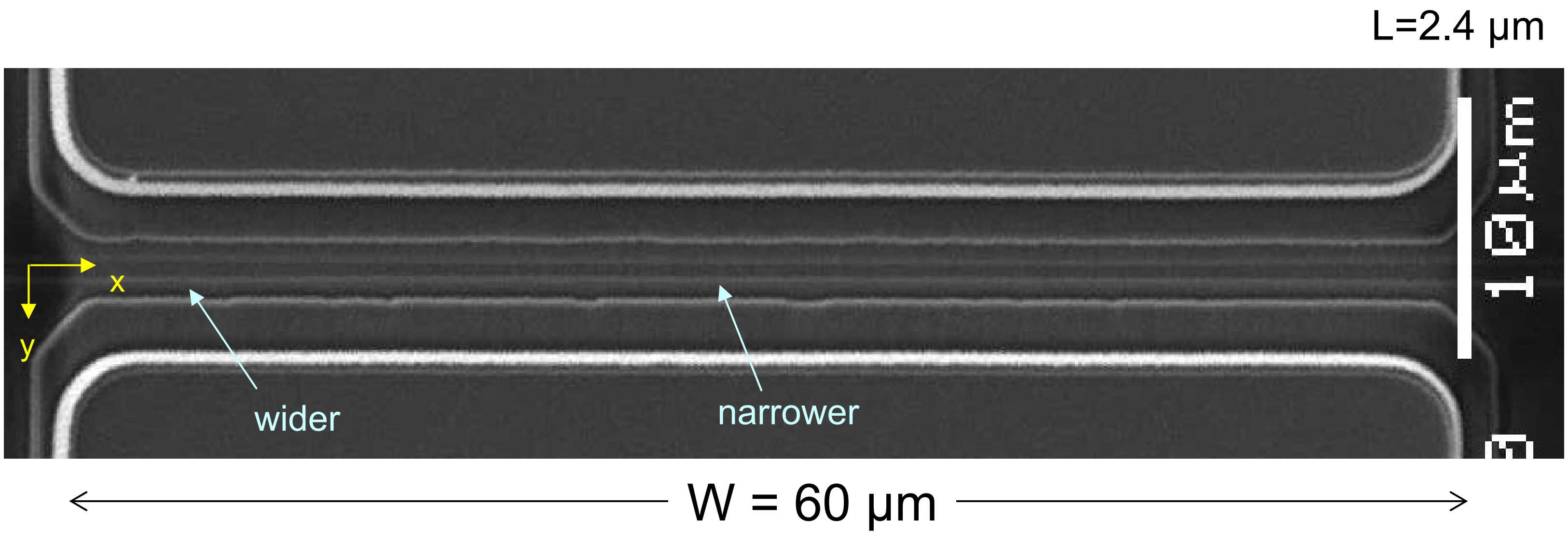
- Non-uniform T
  - – but edges should be cooler → *more* II

Non-Uniform Electric Field?



- Non-uniform E-field
  - – II $\propto$ exp(-1/E), small ΔE → large ΔII
  - – ***from non-uniform recess***

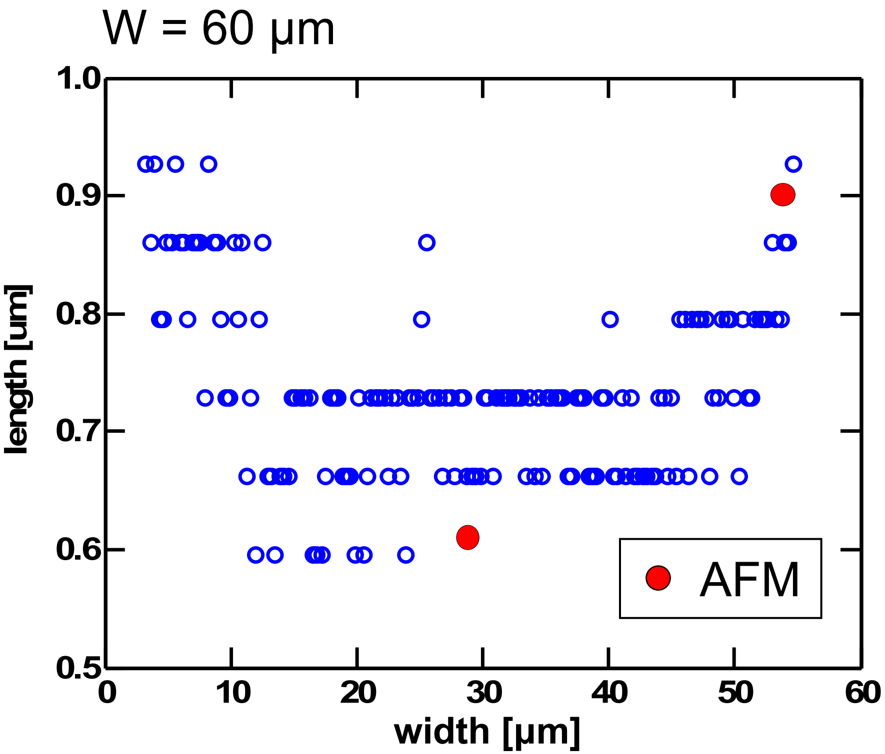
Recess Non-Uniformity (TLMs)



Examined top view of entire recess area

⇨ recess is shorter in the center

Recess vs. Width (TLMs)



- Nominal recess: 0.7 µm
- Actual recess varies:
  - – Center: ~0.6-0.7 µm
  - – Edges: ~0.8-0.9 µm

In center: electric field ↑ → II ↑

→ degradation ↑

↳*Same phenomenon likely happening in PHEMTs*

Conclusions

- Non-uniform recess geometry → non-uniform E
- Areas of higher E → areas more susceptible to degradation
- To improve long-term device reliability: ***must identify & minimize non-uniformities in device geometry***