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Improving Time-Dependent Gate Breakdown of GaN HEMTs with p-type Gate

A.N. Tallarico[1], N. Posthuma[2], B. Bakeroot[3], S. Decoutere[2], C. Fiegna[1], **E. Sangiorgi[1]**

[1] **ARCES-DEI, University of Bologna, Cesena, Italy**

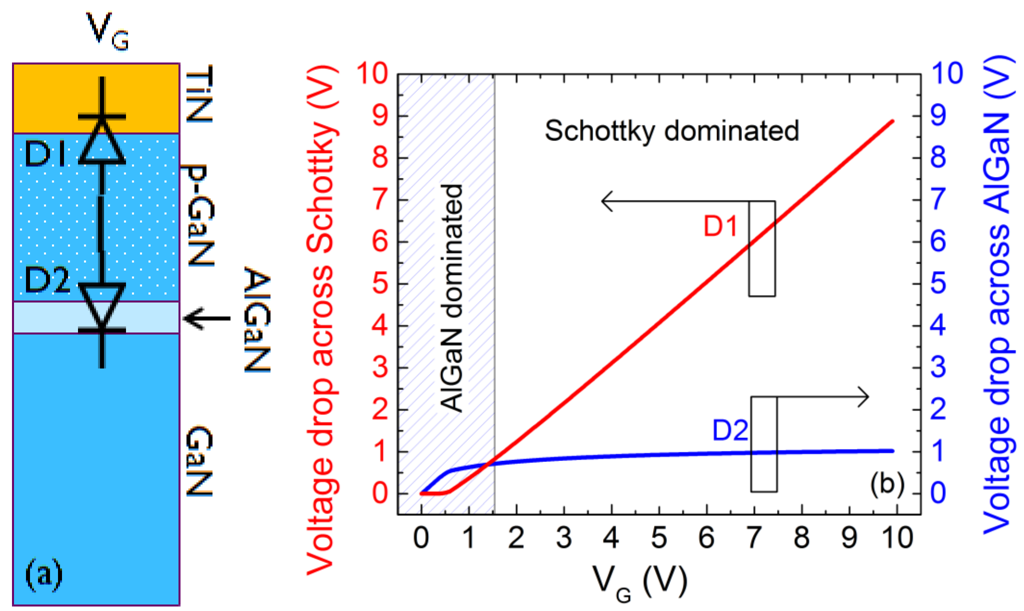
[2] PMST, imec vzw, Leuven, Belgium

[3] CMST, imec and Ghent University, Ghent, Belgium

Outline

- Introduction to Time-Dependent Gate Breakdown of p-gate GaN HEMTs
- Devices under test and Process gate-stack splits
- Results and Discussion
- Conclusions

Time-Dependent Gate Breakdown (TDGB)



- When a positive bias is applied on the gate, the Schottky diode (D1) is reverse-biased sustaining a high voltage drop, whereas the PiN diode (D2) is slightly forward-biased [1].
- The Schottky junction is not always the cause of the gate failure under forward gate stress;
- Failure's spot can occur in different regions and caused by different mechanisms depending on the temperature [2], gate-stack configuration, etc.
- **In this work, the cause leading to TDGB at room/low temperatures is investigated.**

[1] A.N. Tallarico et al., *IEEE EDL, 2017*, DOI: 10.1109/LED.2016.2631640
[2] A.N. Tallarico et al., *IEEE T-ED, 2019*, DOI: 10.1109/TED.2019.2938598

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- Introduction to Time-Dependent Gate Breakdown of pGaN HEMTs
- **Devices under test and Process gate-stack splits**
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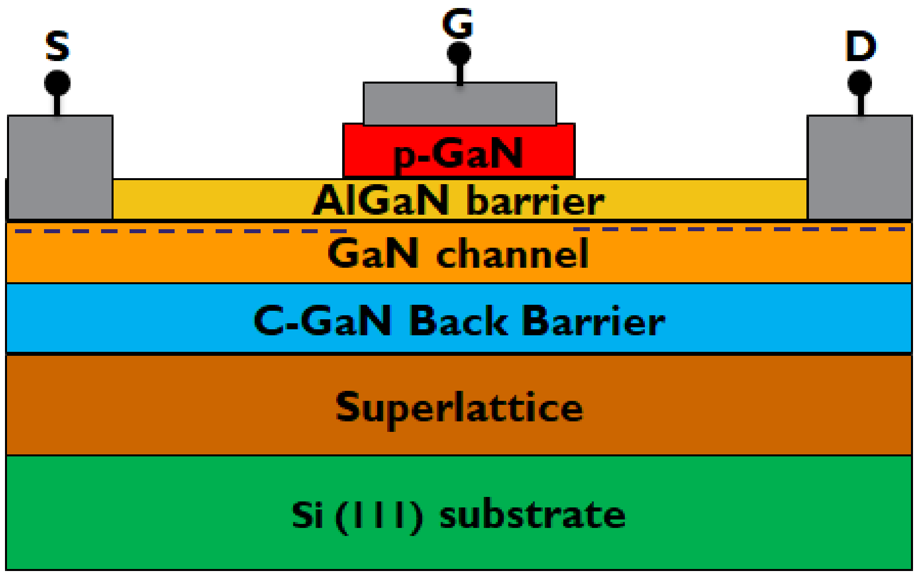
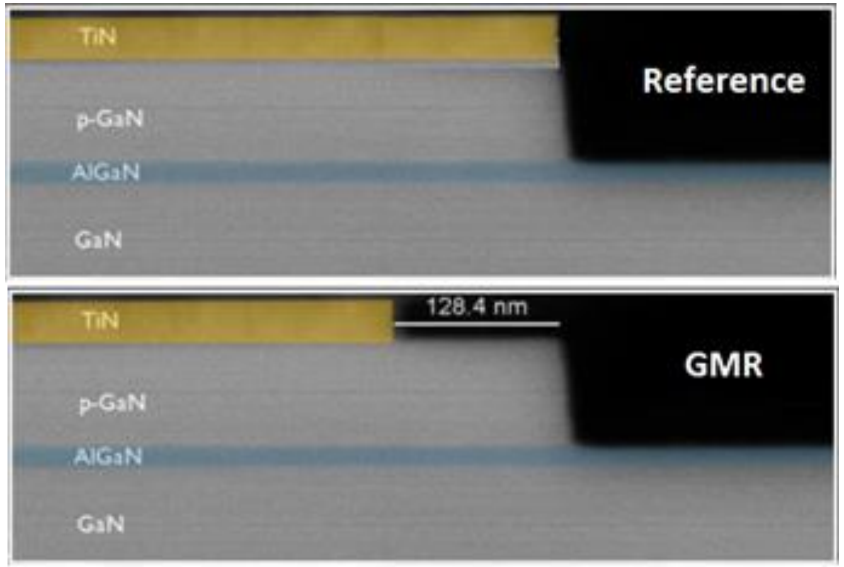
- Conclusions

DUTs: Reference vs Gate Metal Retraction (Group 1)

- GaN-based power HEMT with p-type gate, controlled by a Schottky junction, grown on 200mm Si-wafers.
- Symmetric structure for gate reliability investigation
- Gate stack suitable for voltages class from 100 to 650 V (V_{DS})





Gate
Metal
Retraction

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DUTs: GMR with different AlGaN barrier variants (Group 2)

- GaN-based power HEMT with p-type gate, controlled by a Schottky junction, grown on 200mm Si-wafers.
- Symmetric structure for gate reliability investigation
- Gate stack suitable for voltages class from 100 to 650 V
- Gate Metal Retraction

	pGaN layer		AlGaN layer	
Process	**Mg (cm^{-3})**	**pGaN (nm)**	**Al (%)**	**AlGaN (nm)**
1A	$2.7 \cdot 10^{19}$	80	25	12.5
2A	SAME	SAME	• Process 1A (reference) • From 1 to 3 means thicker AlGaN • From A to D implies lower Al%.	
2B				
3C				
3D				

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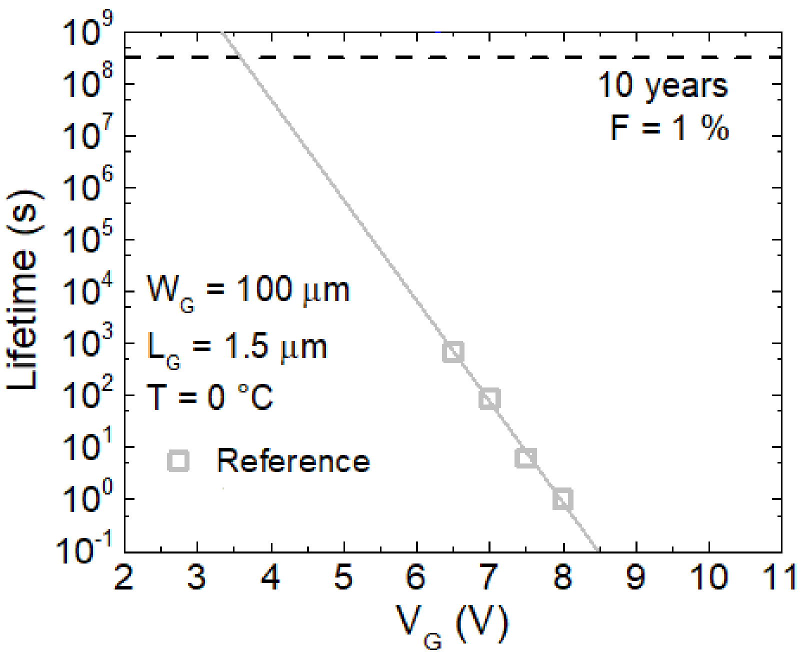
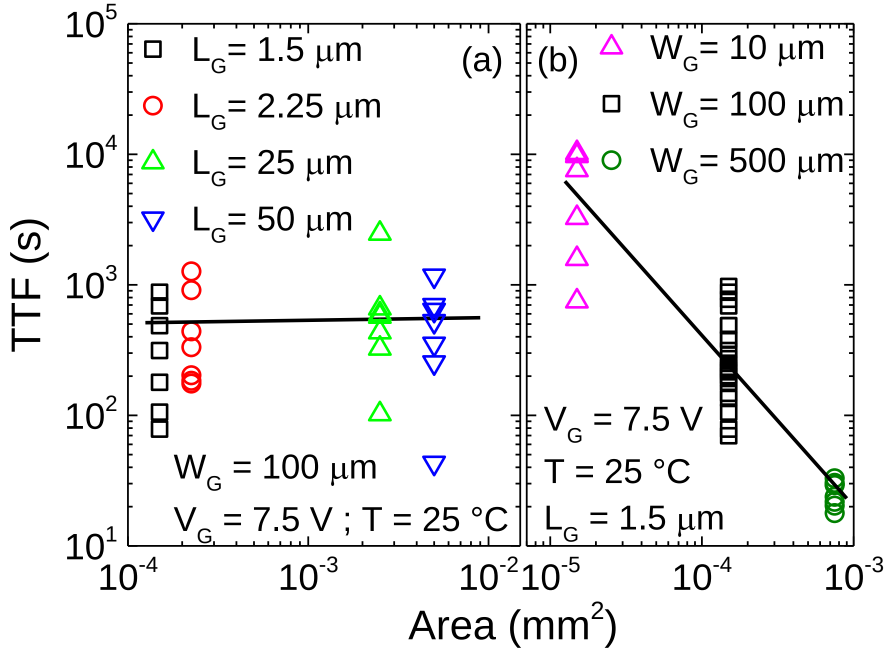
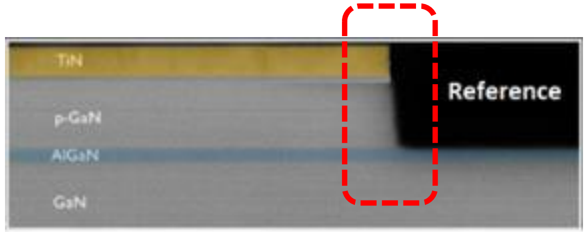
Gate Time To Failure: Reference device (1)





- Reference devices show a relatively low maximum gate voltage @ 10 years
- TTF scales only with gate width suggesting time-dependent breakdown along the gate edges (no area dependency)



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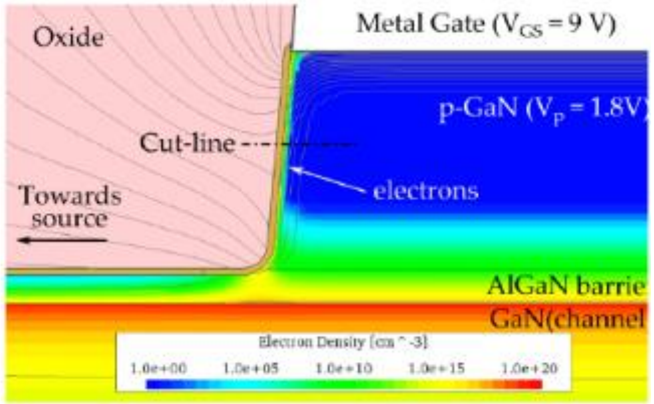
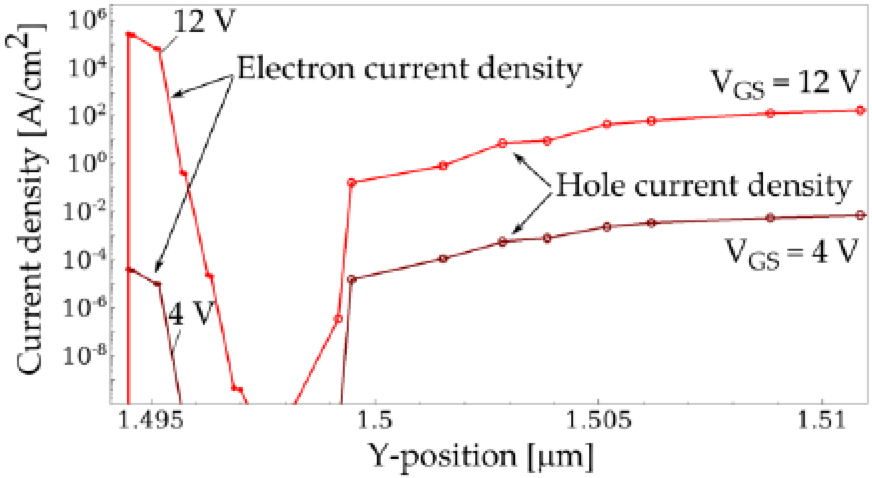
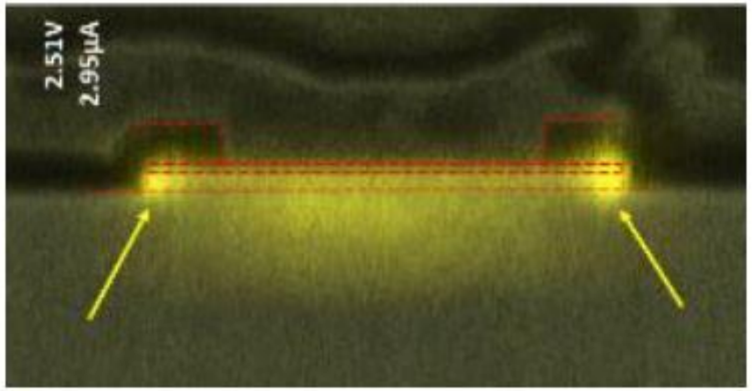
Gate Time To Failure: Reference device (2)

- **Sidewall gate leakage, causing premature gate failure, has been substantiated by TCAD simulation and EBIC measurements [3]**





Simulated electron and hole current densities at different forward gate biases of the p-GaN gate



EBIC signal measured at V_{GS}=2.5V Critical regions at the p-GaN sidewalls are marked by arrows

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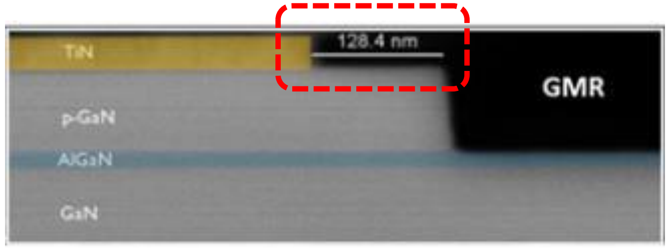
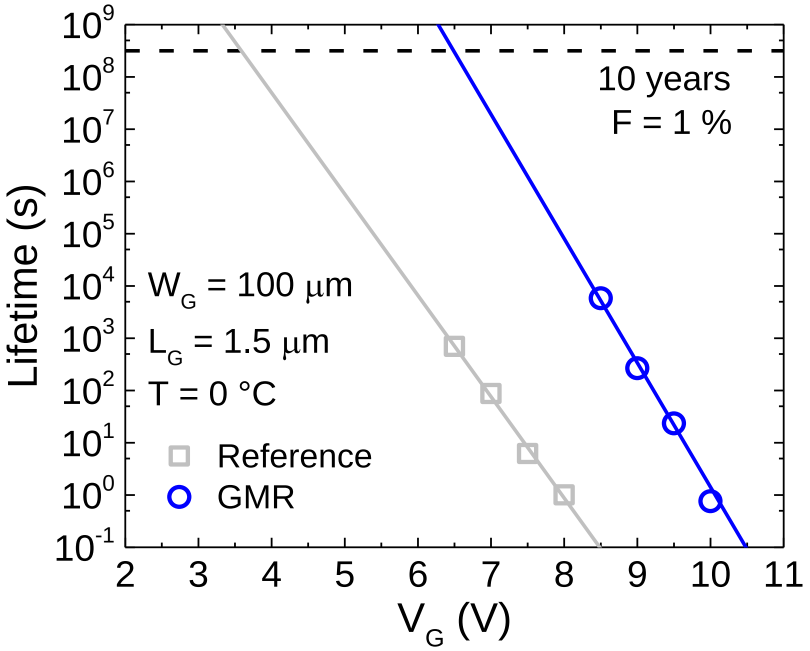
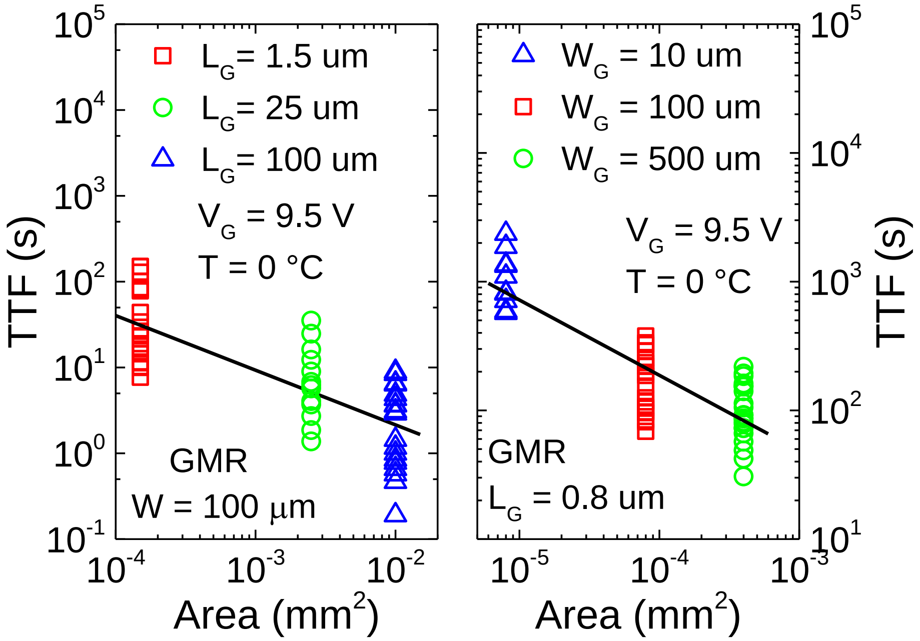
[3] S. Stoffels et al., *IEEE IRPS 2019*, DOI: 10.1109/IRPS.2019.8720411

Proposed Solution: Gate Metal Retraction



GMR consists in removing 130nm of TiN metal from gate edge to suppress the sidewall leakage





- Improved gate lifetime
- TTF shows area dependency (scales with both gate width and length)

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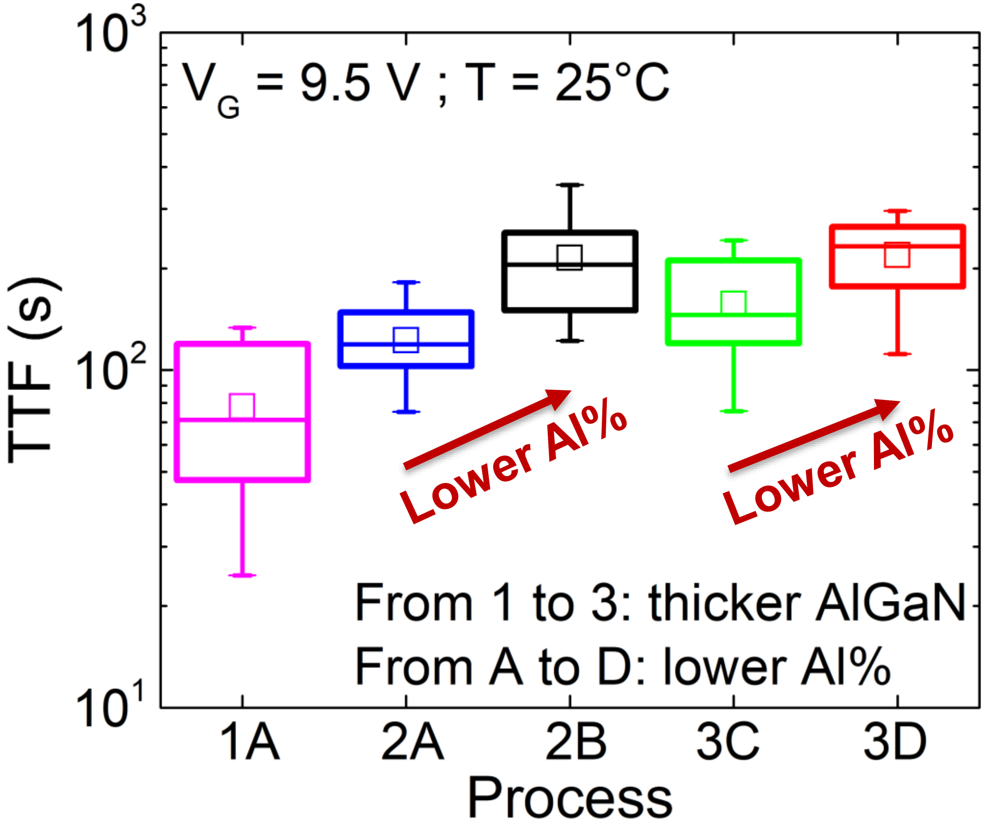
Role of the Aluminum content on gate TTF (from A to D)



- The lower Al%, the longer TTF
- The rate of defect creation (structural) in the AlGaN barrier layer decreases when the crystalline lattice of the AlGaN is subjected to weaker mechanical stress, i.e. when lower Al% is adopted

Process	Mg (cm^{-3})	pGaN (nm)	Al (%)	AlGaN (nm)
1A	$2.7 \cdot 10^{19}$	80	25	12.5

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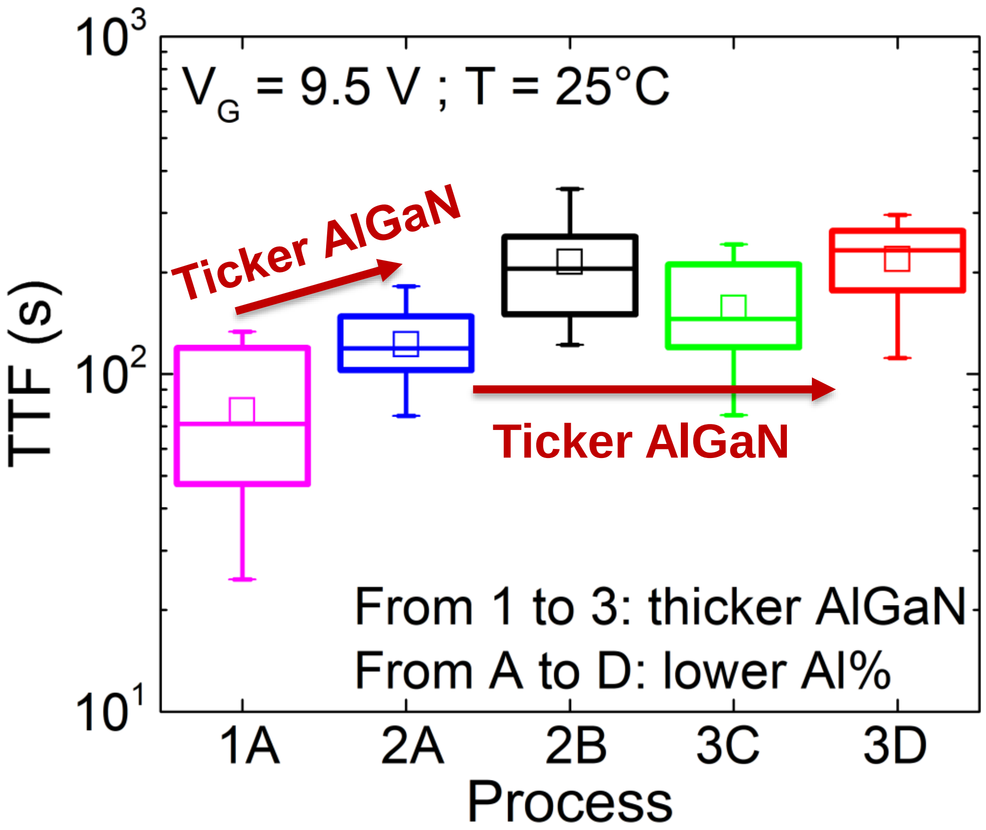
Role of the AlGaN thickness on TTF (from 1 to 3)

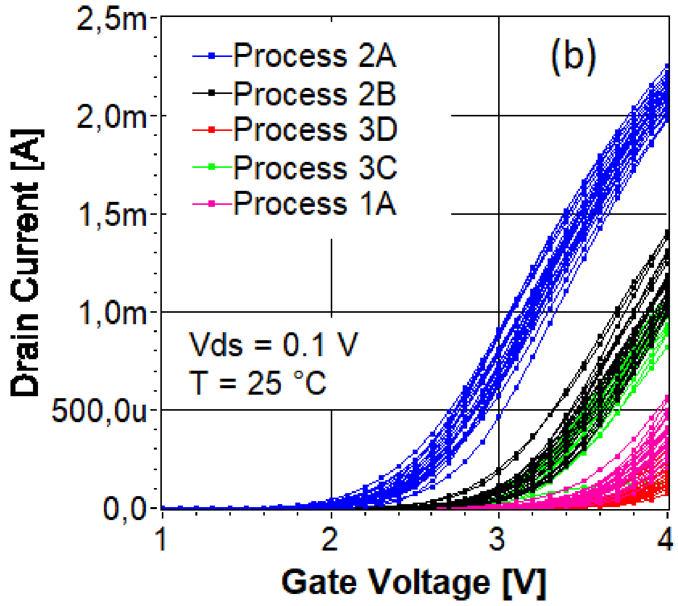


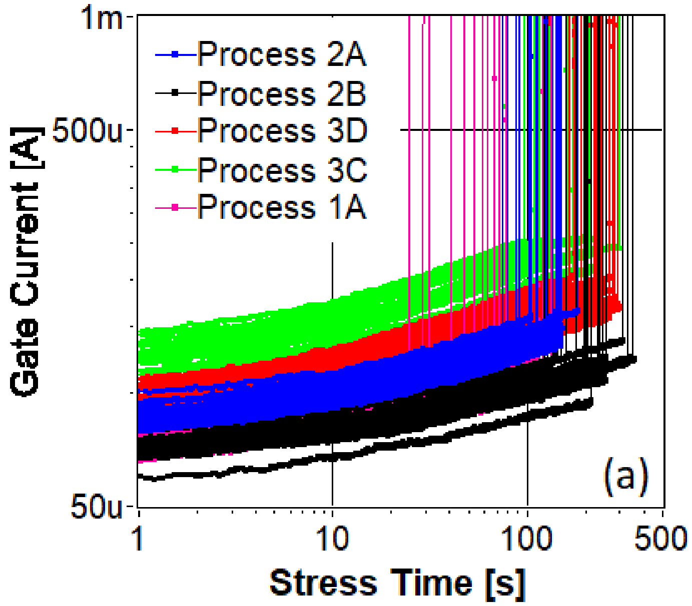
- The thicker AlGaN, the longer TTF (1A and 2A)
- However, a further thickness increase (from 2A/2B to 3C/3D) does not produce a further TTF improvement, despite the lower Al%

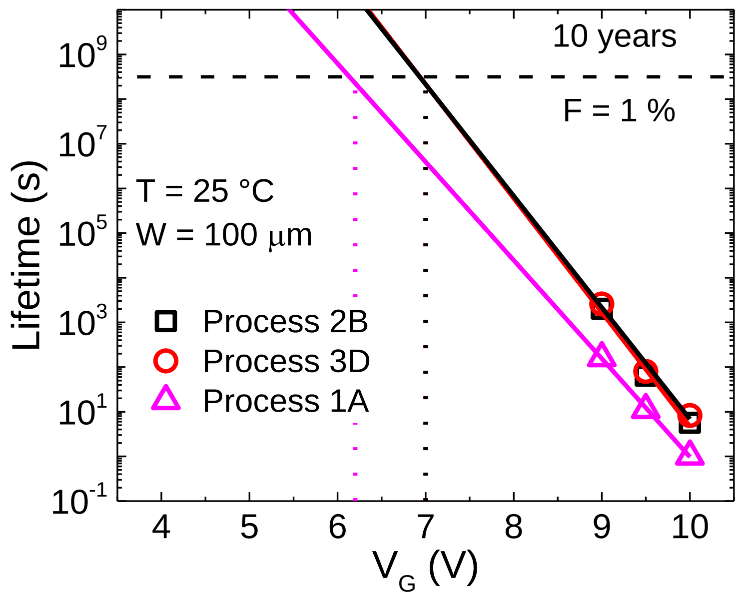
Process	Mg (cm^{-3})	pGaN (nm)	Al (%)	AlGaN (nm)
1A	$2.7 \cdot 10^{19}$	80	25	12.5

Role of the AlGaN thickness on TTF (from 1 to 3)

- The role of AlGaN thickness can be explained by the combination of two mechanisms[4]:
  - a too thin AlGaN requires the creation of only a few defects to form a percolation path (failure), hence a thicker AlGaN improves TTF (1A and 2A);
  - a too thick AlGaN implies a lower V_{TH}, which causes a higher gate leakage during the stress due to larger voltage drop on the Schottky junction at given V_G







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[4] A. N. Tallarico et al., ESREF 2020, https://doi.org/10.1016/j.microrel.2020.113872

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Conclusions

- The failure at the gate edges has been suppressed by Gate Metal Retraction, improving gate lifetime;
- The AlGaN barrier has been identified as the layer mainly responsible for TTF at room temperature [4].
- Lower Al% leads to longer TTF because of two benefits:
  - The AlGaN barrier is structurally more robust due to lower mechanical stress;
  - The gate leakage is lower due to higher V_{TH}.
- An optimum AlGaN barrier thickness at given Al% exists with respect to TTF:
  - Too thin a layer can speed up the build-up of a percolation path, reducing the TTF;
  - Too thick a barrier increases the gate leakage because of lower V_{TH}, reducing TTF

[4] A. N. Tallarico et al., ESREF 2020, https://doi.org/10.1016/j.microrel.2020.113872

Thanks for your attention