unipress 50

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Highlights in III-V semiconductors, THz physics and nanomaterials

Anniversary Symposium „Unipress 50”

Towards GaN-on-GaN high power transistors

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EnerGaN

Project EnerGaN

"Complete vertically integrated technological chain for vertical GaN-on-GaN power electronics: from GaN substrate to Intelligent Energy Bank" [1]
Polish National Program TECHMATSTRATEG-III/0003/2019

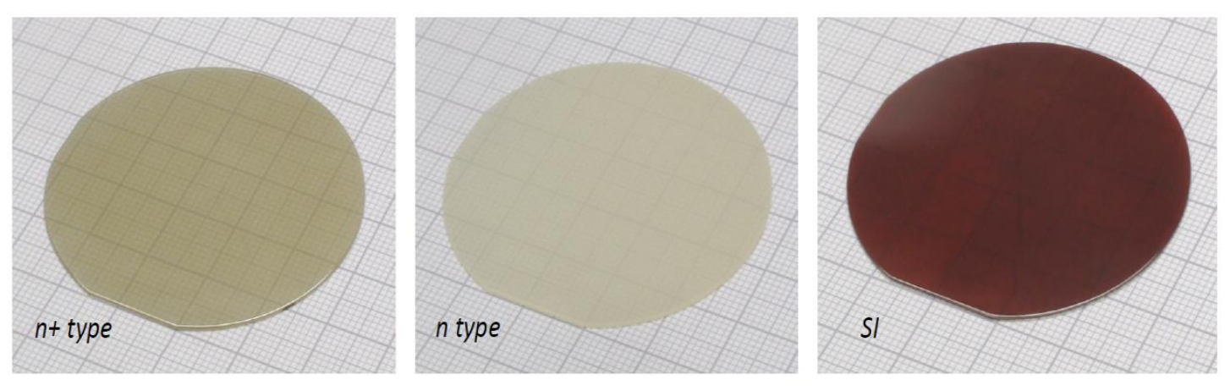
Narodowe Centrum Badań i Rozwoju · unipress · Łukasiewicz · INWEBIT · DACPOL

Project goals:

- Development of epitaxy for improved power electronics
- MOVPE growth for 2-kV class vertical switching devices (>12um thick on Ammono-GaN)
- Enabling large area devices with very low defect density for high current switches (>5mm^2)
- Demonstration of GaN advantages over SiC in vertical MOSFET inverter (125kW)

Substrates

2-inch Ammono-GaN wafers available:



- Low TDD
- High conductivity [2]
- Best structural quality
- They allow for large area devices

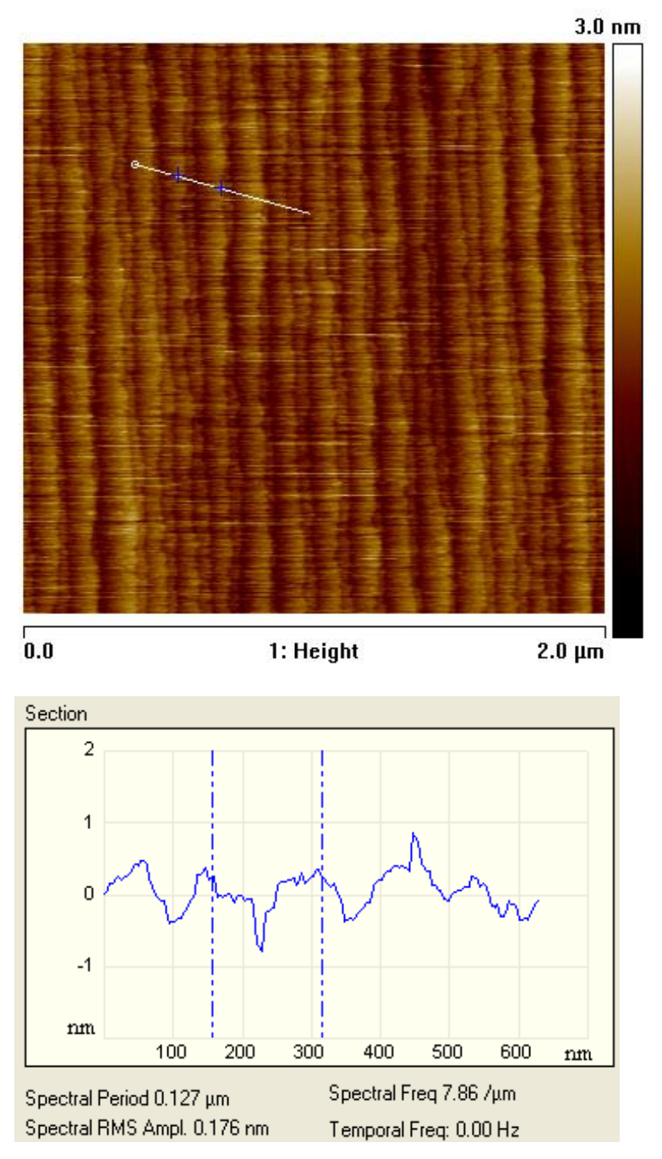
Number of TD in a circular device	Ø 60 µm	Ø 400 µm
HVPE, NEAT-GaN TDD >1e10^{6}cm^{-3}	30	1300
Am-GaN TDD <5e10^{4}cm^{-3} 1e10^{4}cm^{-3}	0 0	65 6.5

Epitaxy

MOCVD, HVPE and MBE

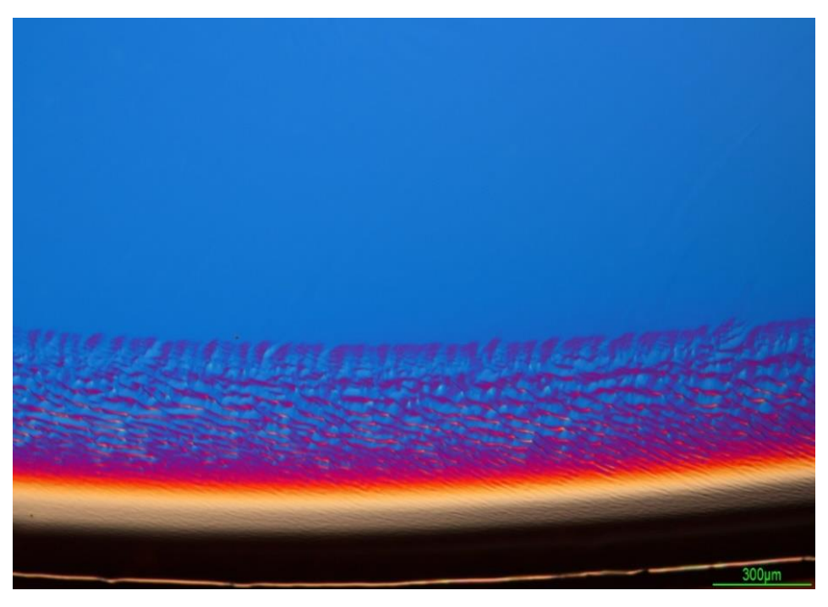
MOCVD advantages:

- good control of impurities, doping, compensation
- repeatability
- scalability



Surface morphology after epitaxy is atomically smooth.

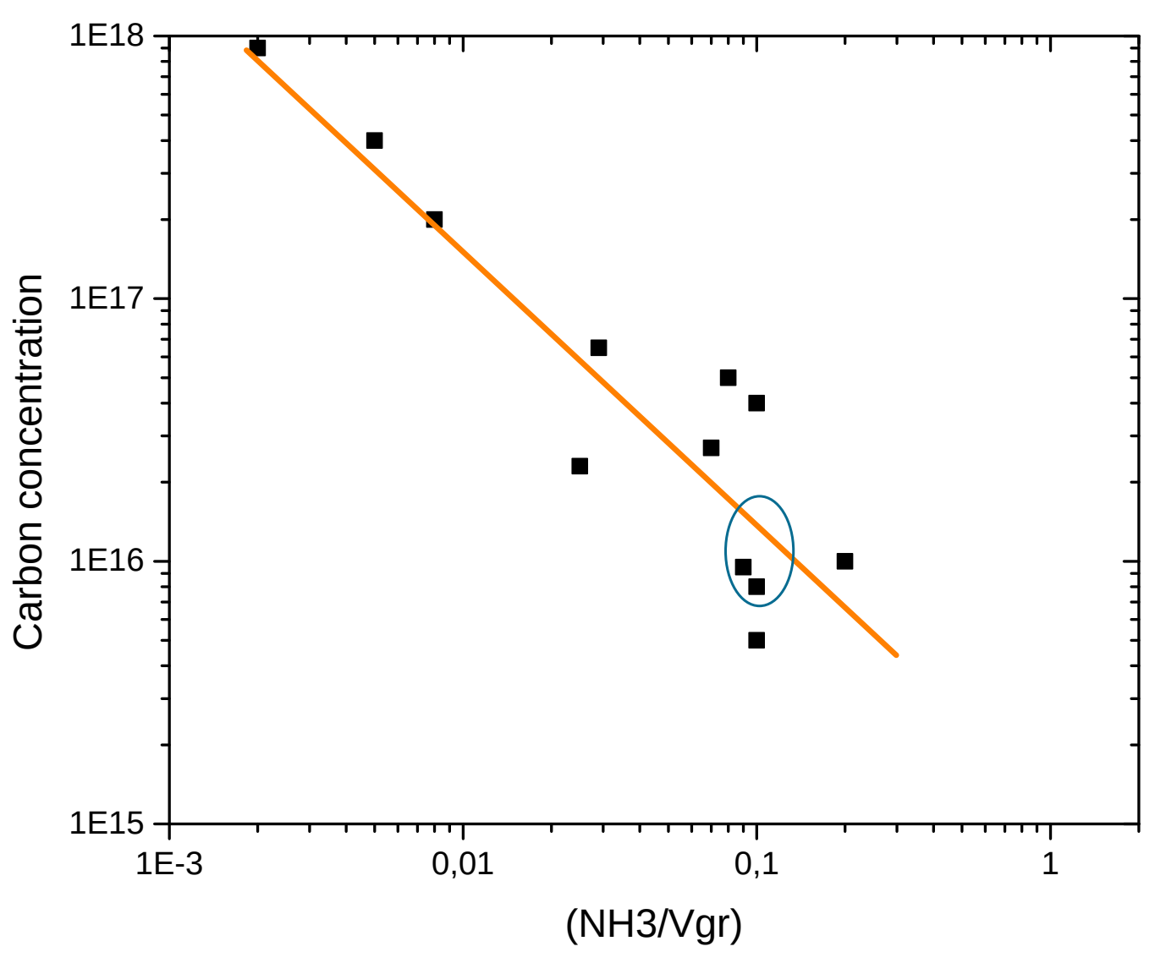
Small Edge effect is observed.

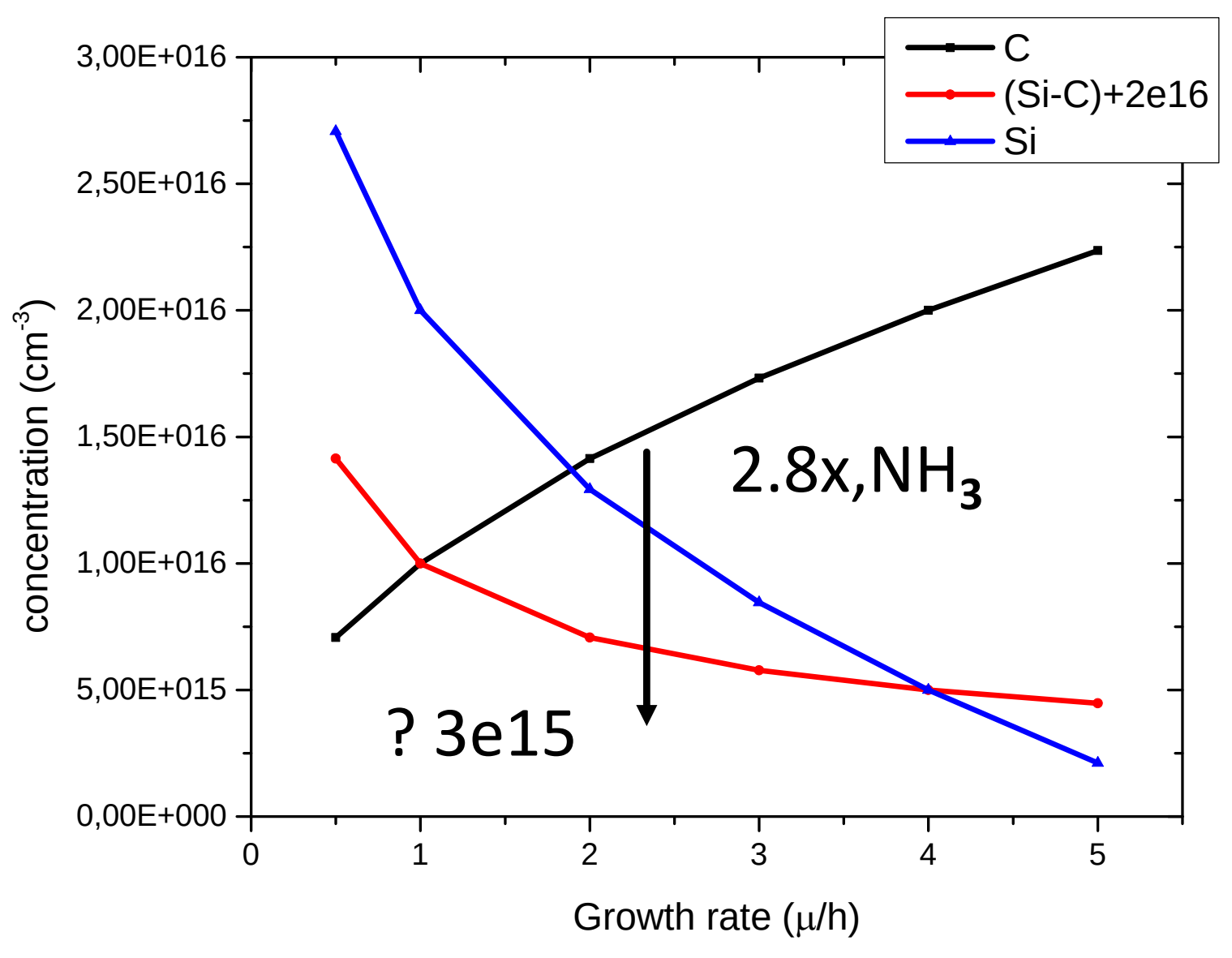


Carbon impurities in GaN films:

- -CH$_3$ elimination
- recombination with –H
  - ✓ more NH$_3$, (V/III)
  - ✓ high Temp
  - ✓ high Press

- C follows inverse V/Vgr
- C in competition with N
- More NH$_3$, less C
- Lower Vgr, less input TMGa less C

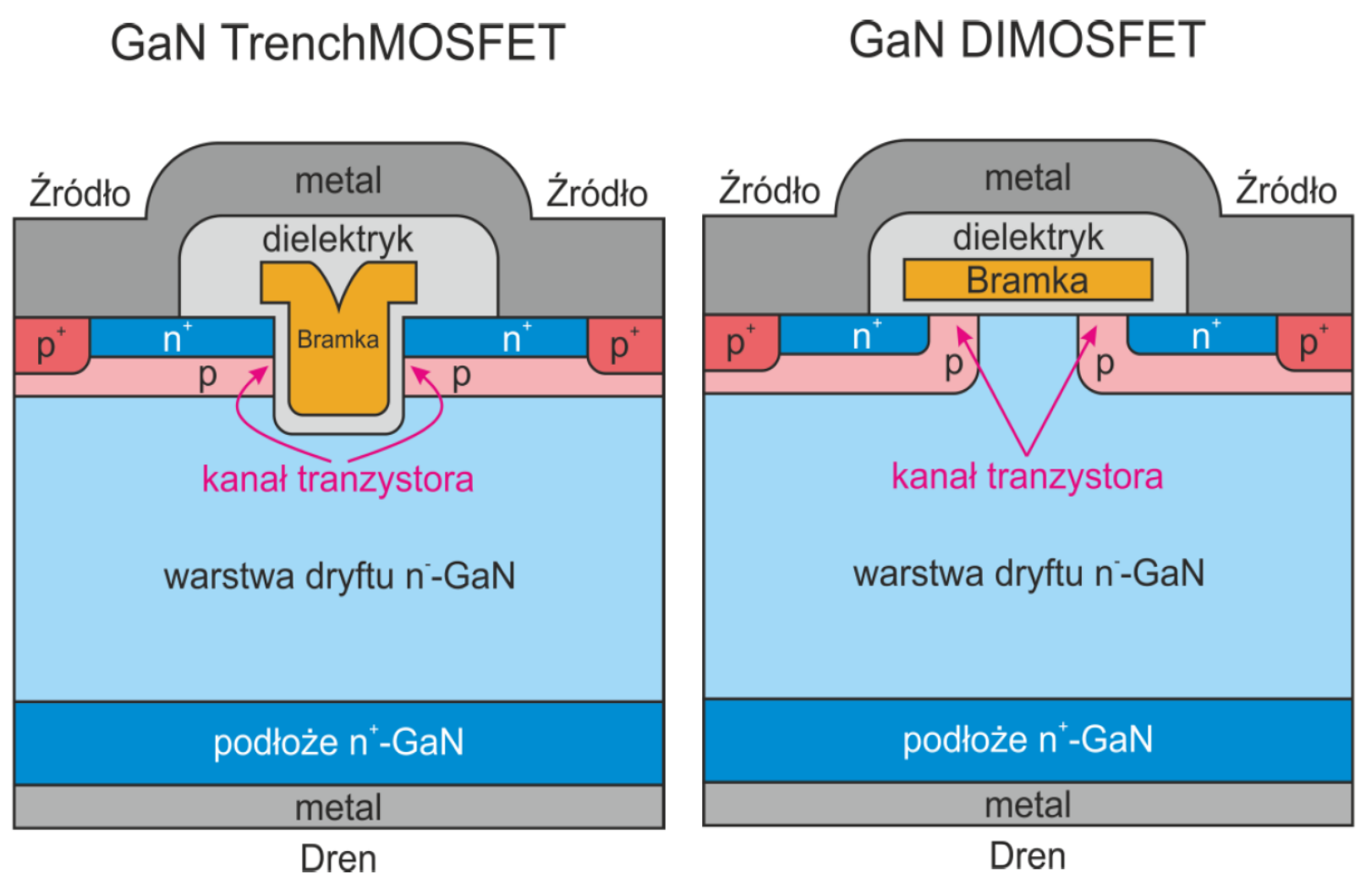


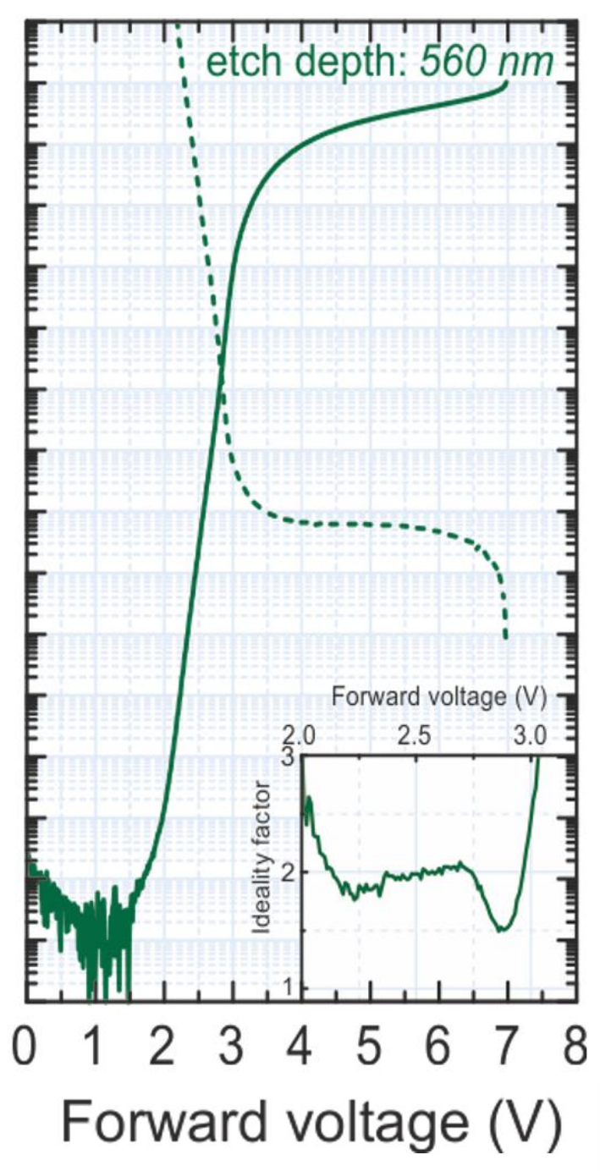


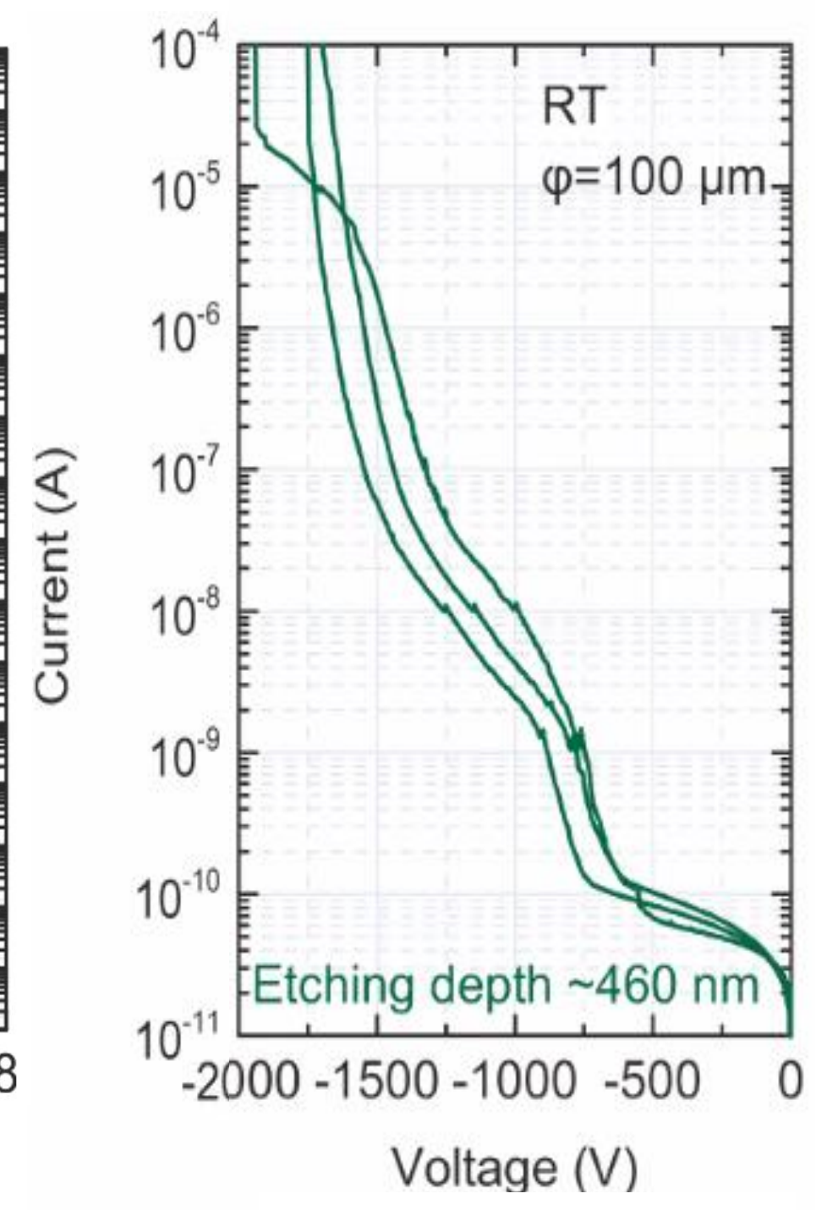
Carbon vs V$_{GR}$ empirical model
CCS@ T=1060°C, P=400torr,
NH$_3$,Si - fixed

- C in competition with Si
- Must be ballanced to get net electron concentration
- N$_D$=Nsi+No-Nc

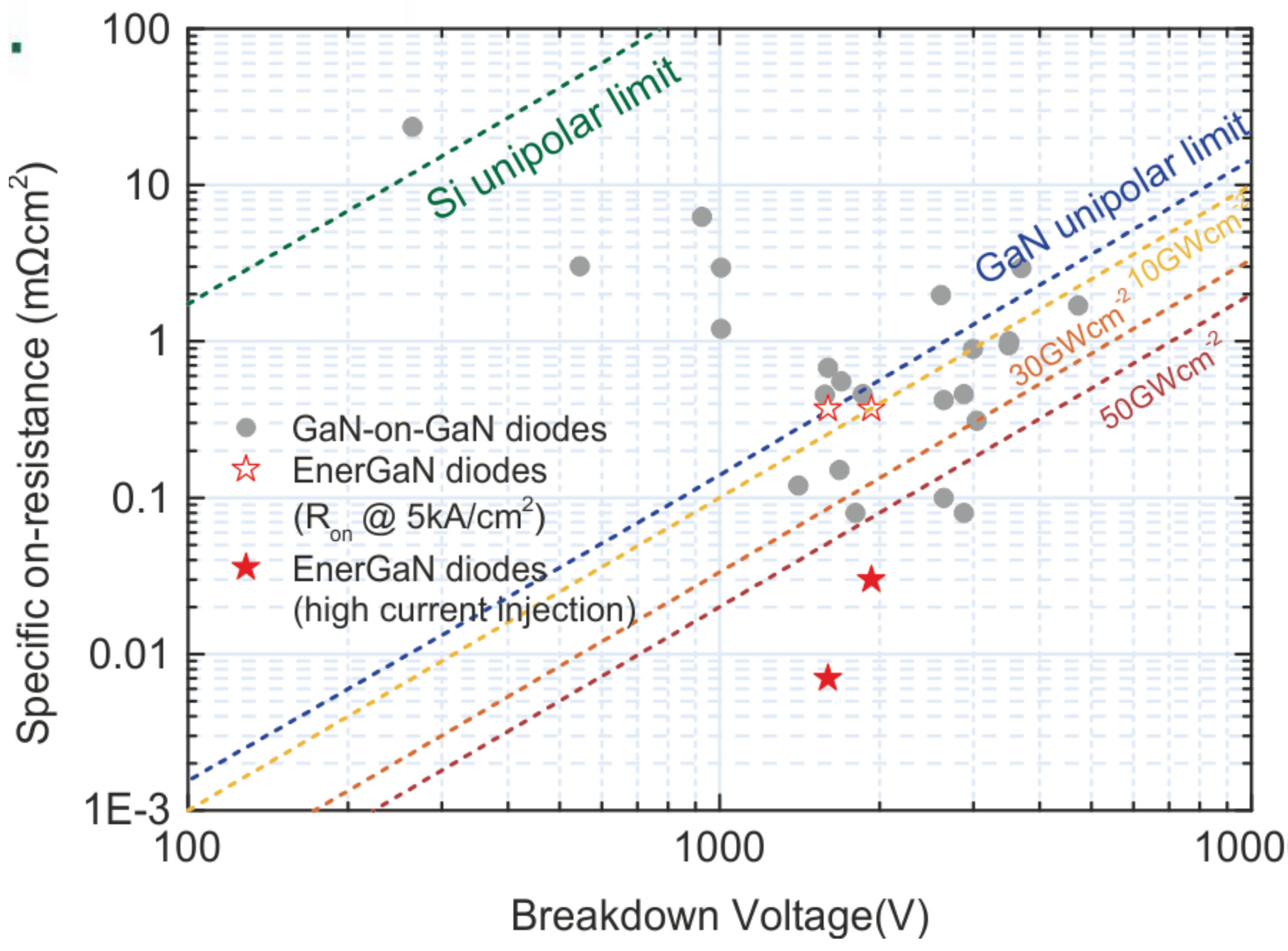
Transistor Structures





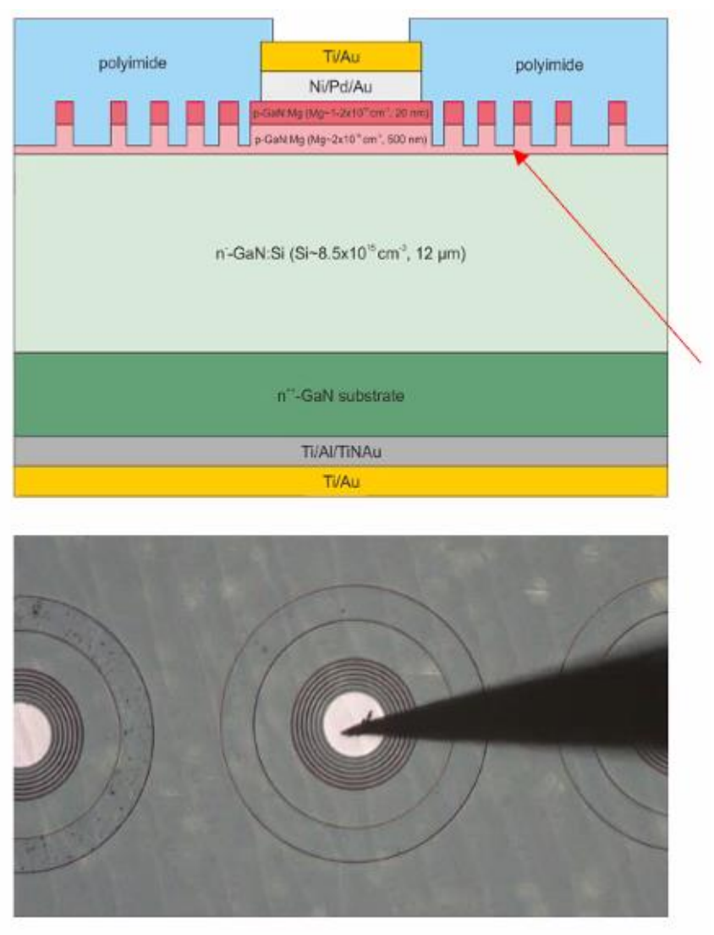


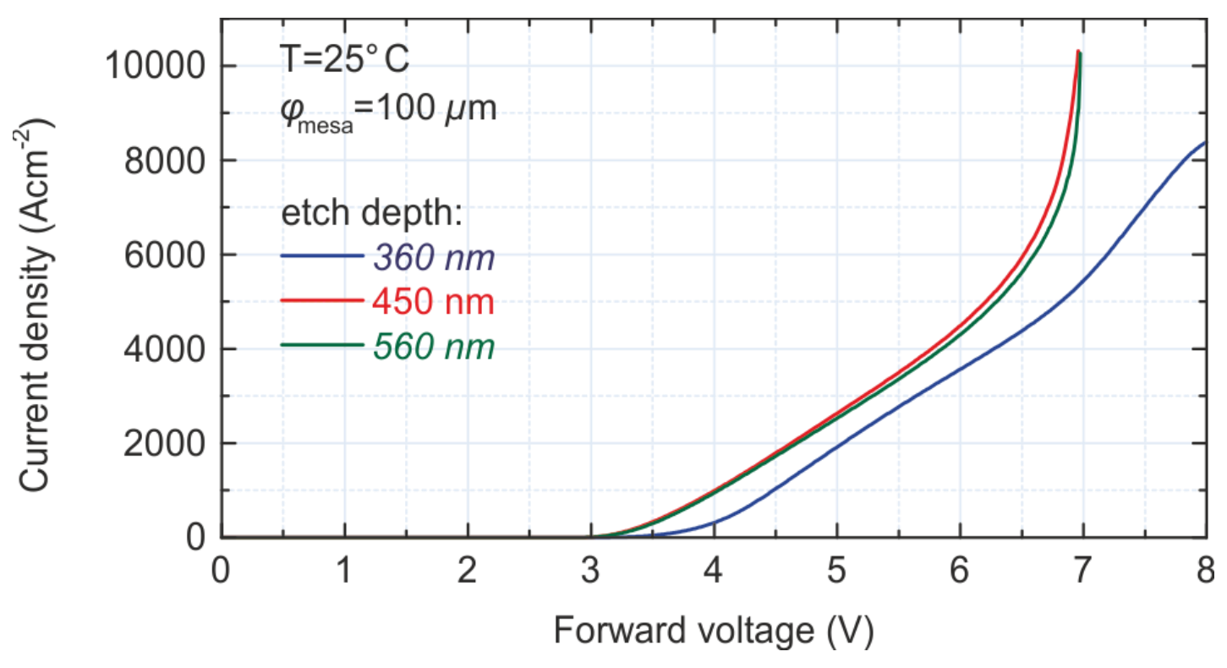
- BFOM(V$_{BR}^2$/R$_{ON, SP}$) >50 GW/cm^2
- V$_{BR}$=~1950V
- RON, SP=<0.1 mΩcm^2 under high current injection
- µ>>1000 cm^2/Vs



Test PN diodes

GaN pin [5]

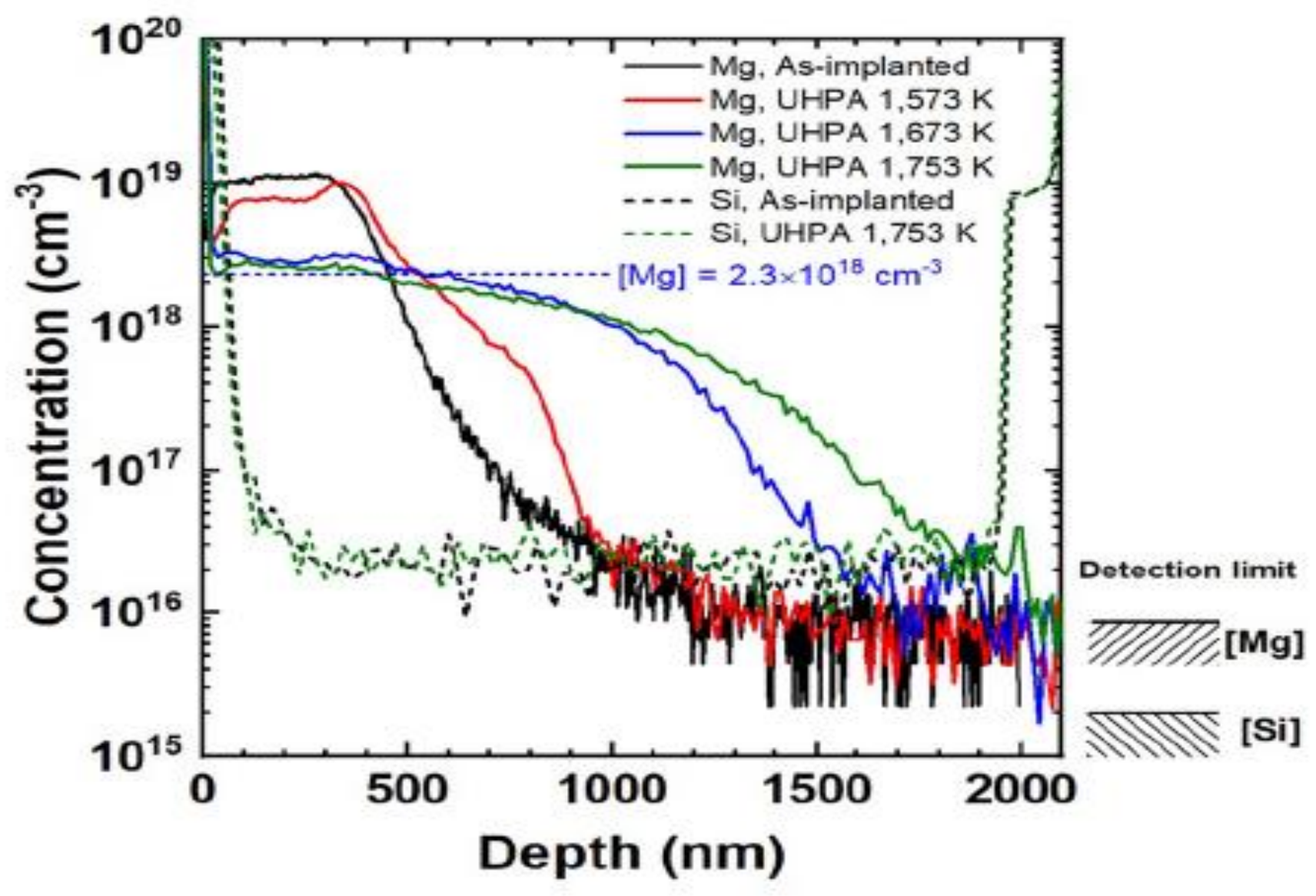




- n~1.5
- R$_{on,sp}$~0.37 mΩcm^2 for 5kA/cm^2
- R$_{on,sp}$~0.008 mΩcm^2 for 10kA/cm^2
- J$_{max}$>10kA/cm^2
- I$_{on}$/I$_{off}$ ~1x10^{14}

Processing issues

- Edge Mg-ions implantation and UHPA (>1GPa, >1300°C) [4]
- Diffusion of Mg [3]
- P-type activation



References

1. EnerGaN Program TECHMATSTRATEG-III/0003/2019: Vertically integrated technology for GaN-on-GaN electronics: from GaN substrate to Energy Saving Inteligent Power Bank, Financed by NCBiR
2. Zajac et al., Prog. Cryst. Growth Charact. Mater. 64, 63 (2018).
3. Narita et al. APEX 12, 111005 (2019) : Electric-field-induced diffusion model
4. Sakurai et al., APL115, 142104 (2019 : Highly effective activation of Mg-implanted p-type GaN by ultra-high-pressure annealing
5. Taube et al. IEEETrans on Electron Devices TED-2022-07-1716-R accepted

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