InN/GaN heterojunction electrical behavior

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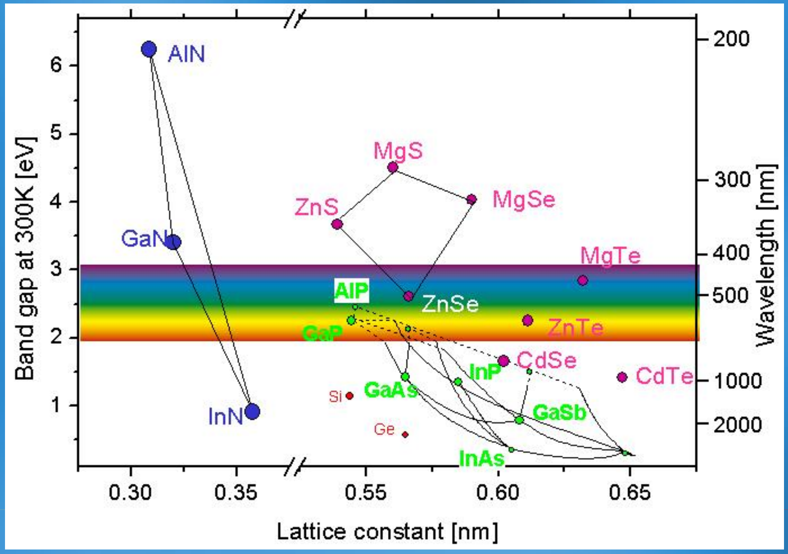
INITIAL TRAINING NETWORK RAINBOW

Outline

- Introduction and motivation
- n-type unintentional conductivity
- InN/GaN interface
  - Effect in electrical behaviour
- Sample characterization
  - AFM , XRD (on- and off- axis)
  - Dislocation calculations
- Electrical measurements
- Conduction model
- Conclusions

Introduction and motivation

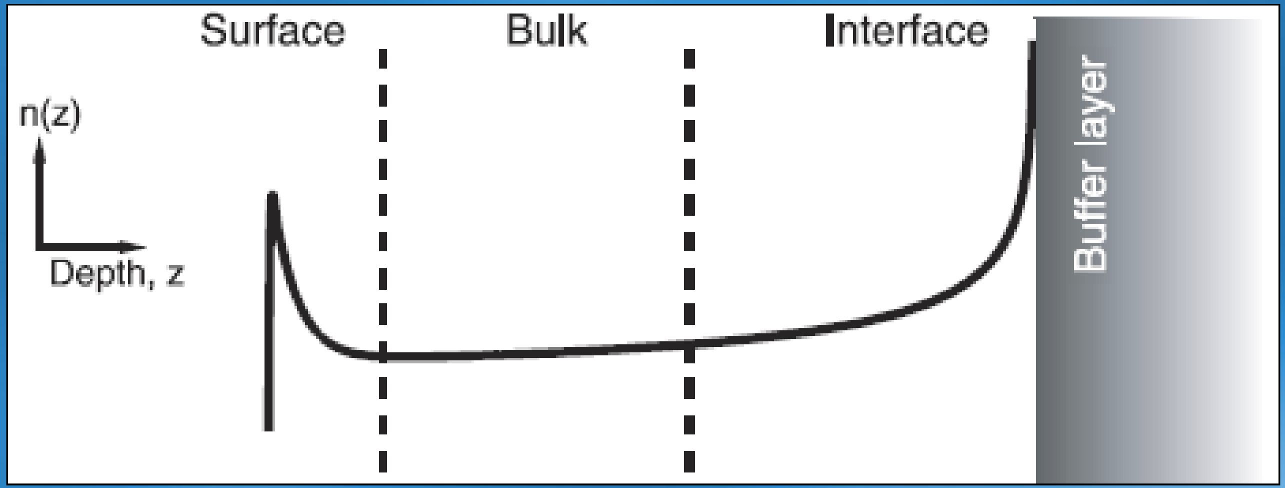
- InN is the less known III-N semiconductor
  - Very small band gap (~0.7 eV)
  - Low effective mass
  - High electron mobility



- Potential applications
  - Solar cells
  - Photodetectors
  - High frequency transistors

n-type unintentional conductivity

- The most accepted model: 3 region

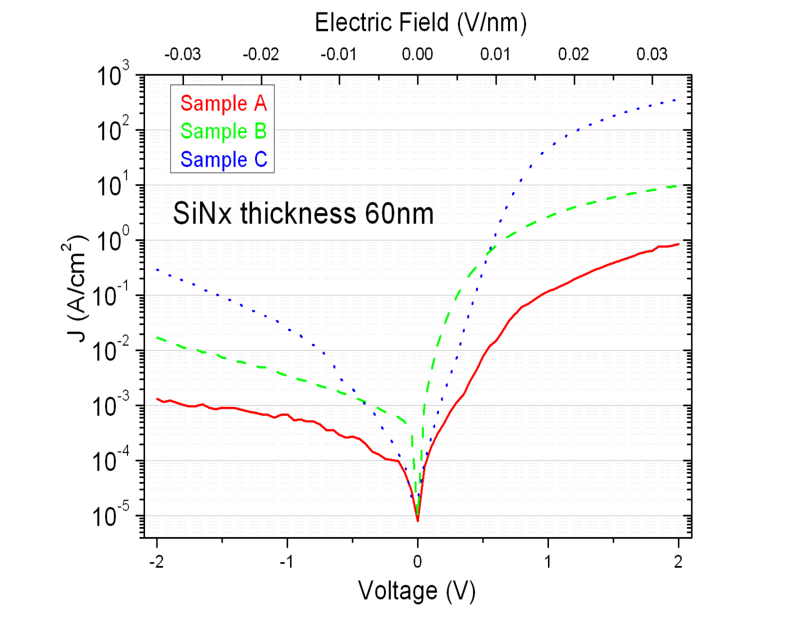


P.D.C. King, T.D. Veal, C.F. McConville, J. Phys.: Condens. Matter 21, 174201 2009

1. Strong surface accumulation due to surface states
2. Degenerate n-type nature of the bulk for donor type defect inclusions
3. Large density of threading dislocations at the interface acting as donors

Rectifying problem

- Surface accumulation layer
  - No Schottky contact
  - MIS can overcome this problem[1]
- Surface accumulation mask bulk behaviour
  - No overall p-type character→
    - no p-n fabricated so far



- High interface electron accumulation
  - Heterojunction behaviour → **OBJECTIVE OF THE PRESENT WORK**

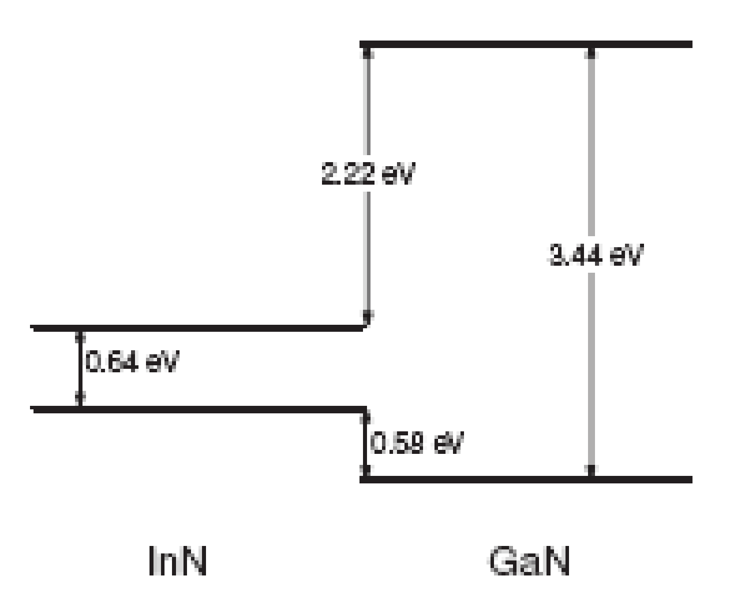
[1]T.Brazzini et al. "InN MIS rectification device" E-MRS Spring meeting 2011

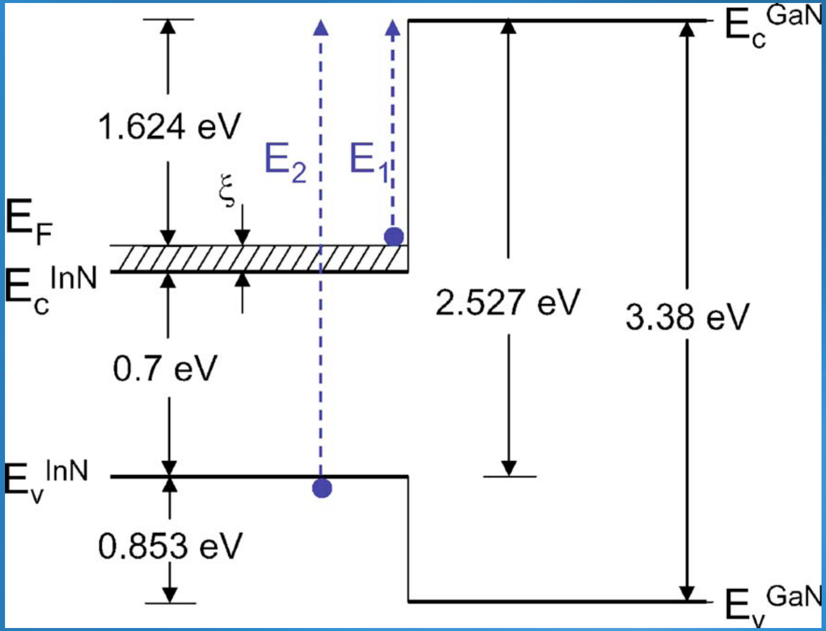
InN/GaN interface

HRXPS measurements

P.D.C.King et al.

PRB 78, 033308 (2008)





IPE spectroscopy

Z.H. Mahmood et al.

APL 91, 152108 (2007)

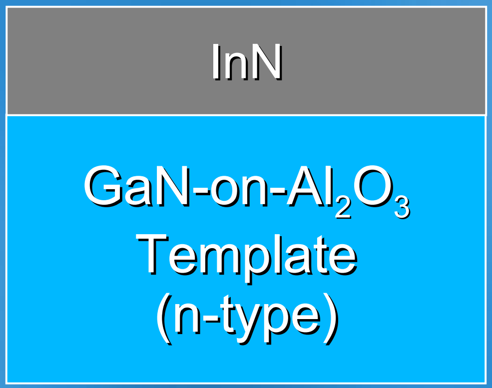
InN/GaN interface:
contributions to electrical behaviour

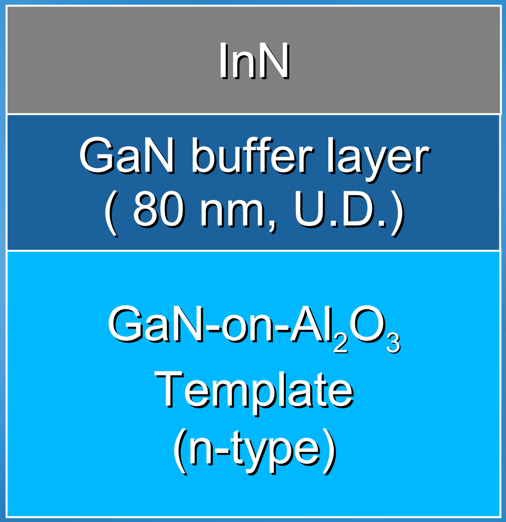
- Heterojunction band offset
- Dislocations (edge and screw)
- High polarization field in III-N nitrides
  - Strain-induced piezoelectric field screened by high carrier densities[1]

[1]P.D.C.King et al. PRB 78, 033308 (2008)

Samples

- In-face c-plane InN PAMBE
- InN-GaN 9.6% lattice mismatch[1] → Volmer-Weber growth mode – 3D islands coalescence
- T_{sub} 400ºC for InN on template
- T_{sub} 450ºC for InN on GaN buffer



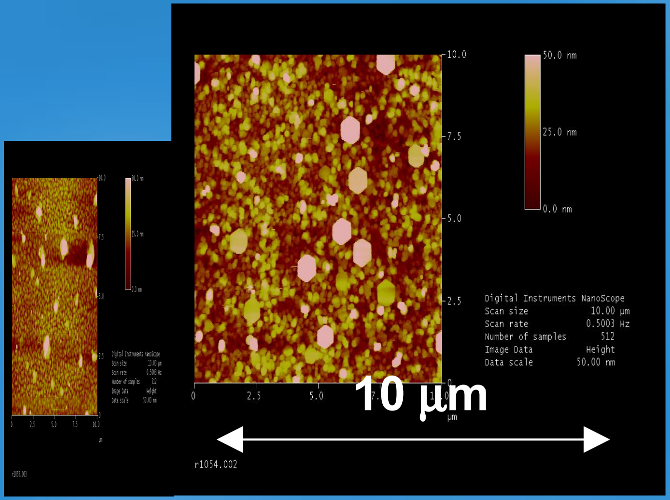


[1]“InN and related alloys” T.D.Veal, C.F.McConville, W.J.Schaff

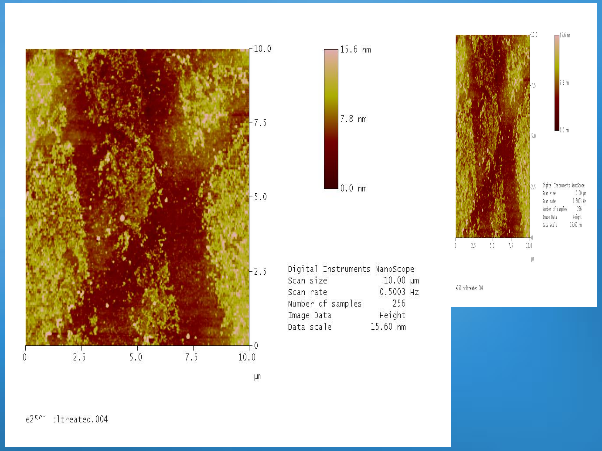
Samples:

AFM roughness

- InN/$GaN_{template}$/Al_2O_3:
  - 7.2 nm (RMS)

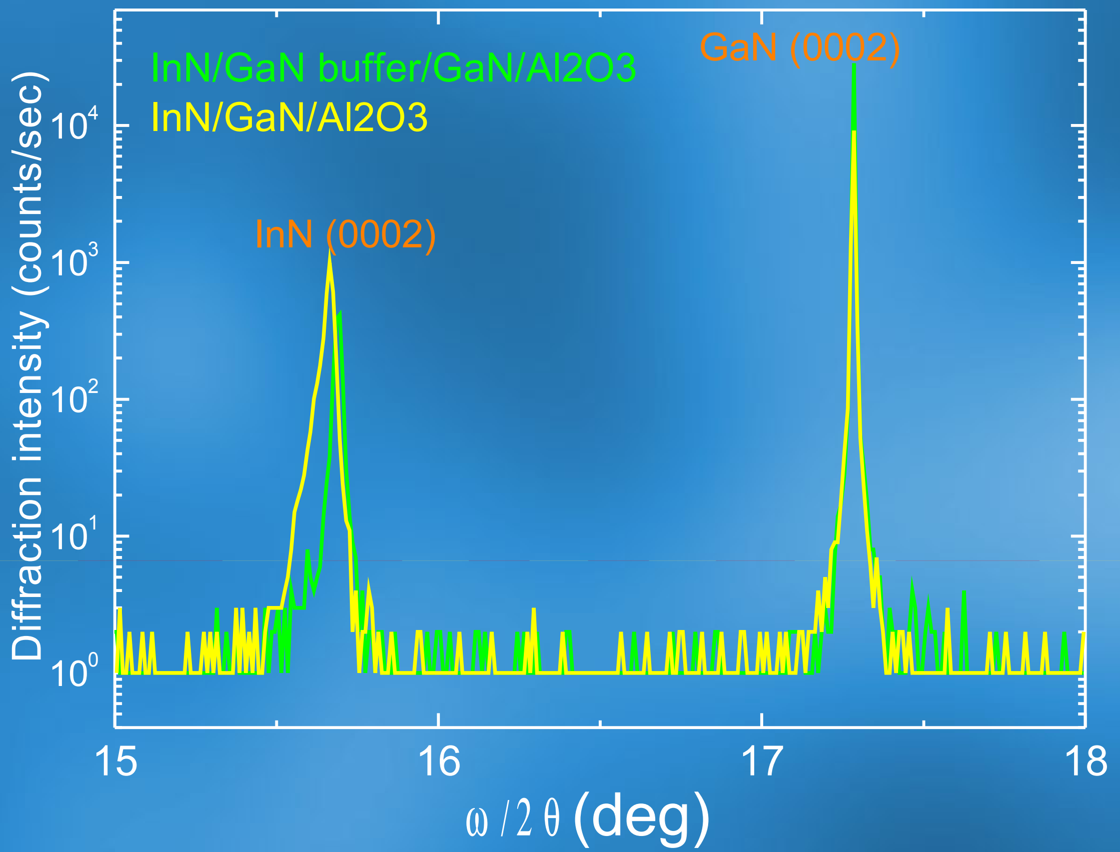


- InN/GaN_{buffer}/$GaN_{template}$/Al_2O_3 :
  - 0.7 nm (RMS)



Samples:
XRD measurements

- Absolute scan ω/2θ reveals relaxed InN

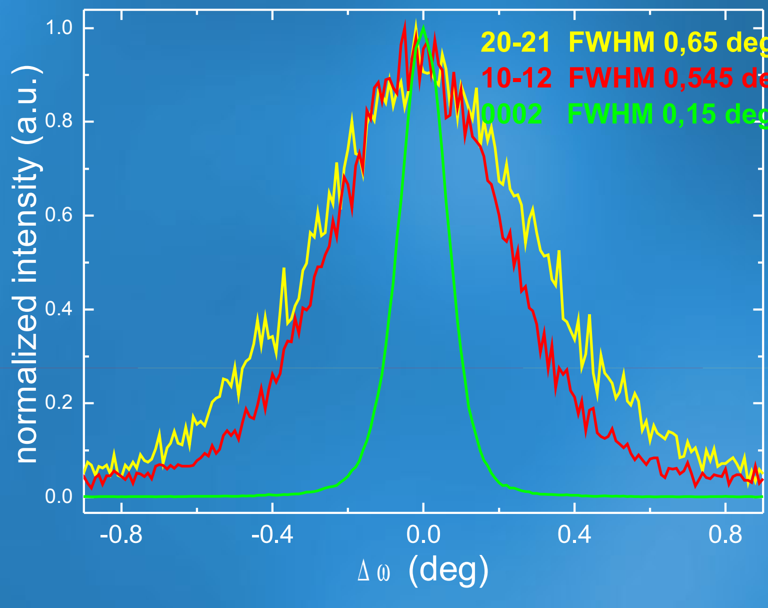


Samples:

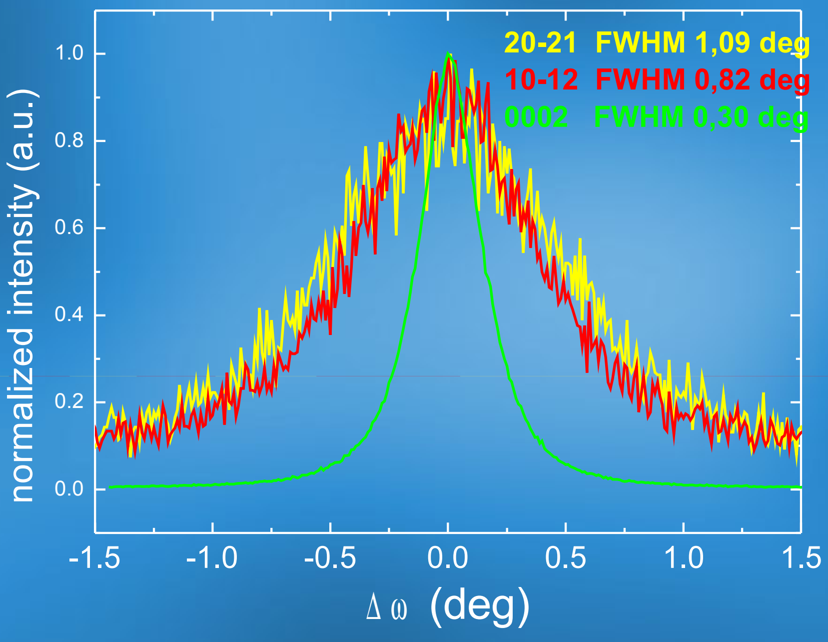
XRD measurements

- Rocking of on-axis (0002) and off-axis (10-12)(20-21)

InN / GaN buffer / GaN / Al_2O_3



InN / GaN / Al_2O_3



Samples:

Dislocation calculations [a)]

$$\rho_s = \Gamma_y^2 / 1.88c^2 \qquad \rho_e = \Gamma_z^2 / 1.88a^2$$

InN/GaN buffer

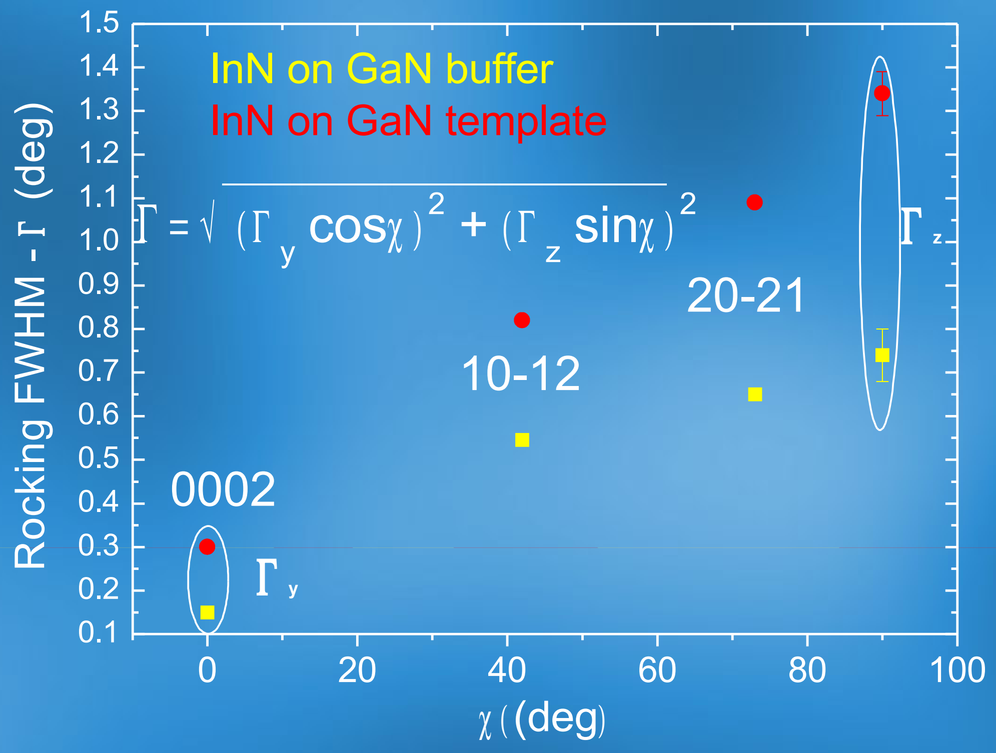
$\rho_s = 1.1 \times 10^9\ cm^{-2}$

$\rho_e = 72 \times 10^9\ cm^{-2}$ [b)]

InN/template

$\rho_s = 4.4 \times 10^9\ cm^{-2}$

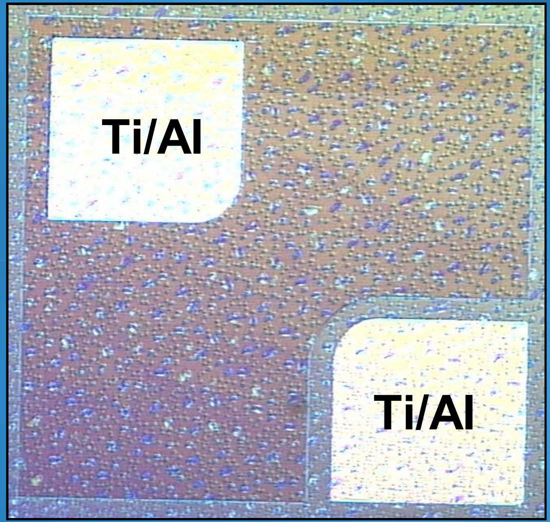
$\rho_e = 260 \times 10^9\ cm^{-2}$

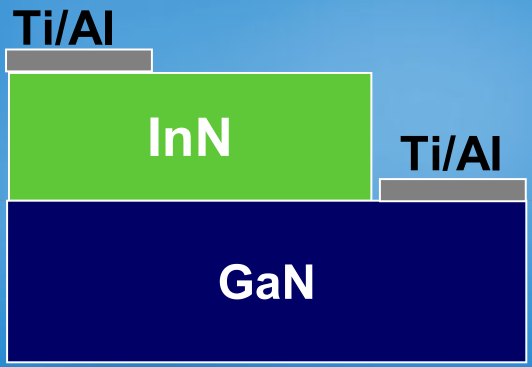


a) T.D.Veal "InN and related alloys" CRC Press
b) In agreement with Vilalta-Clemente A. et al *Physica Status Solidi A* **207**, 5 (2010) 1079-1082.

Contact processing

1. Standard cleaning process
2. Acid treatments for oxide and surface metal (In) removal
3. MESA etching (plasma RIE $SiCl_4$ + Ar, RF power 125 W)
4. GaN ohmic contact metallization (Ti/Al)
   (no thermal annealing required for rough n-GaN)[1]
5. InN ohmic contact metallization (Ti/Al)
   (no thermal annealing required)

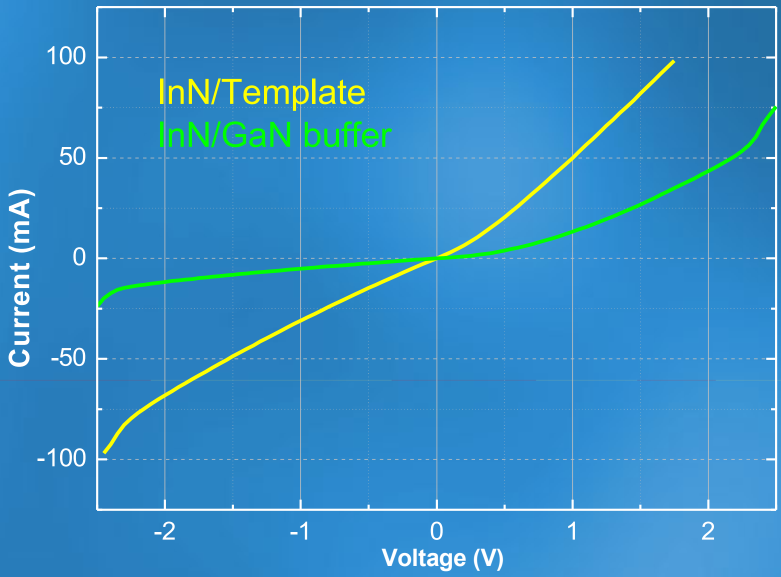


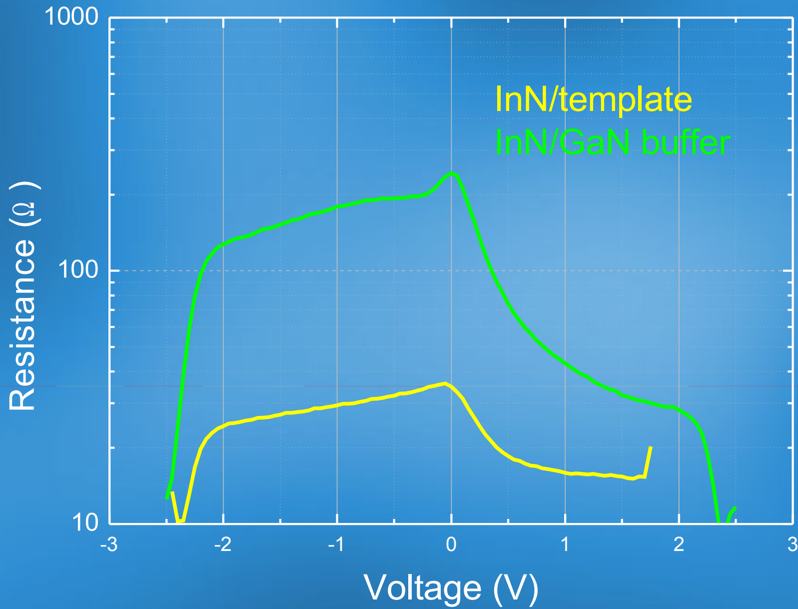


[1]S. Ruvimov et al. Appl. Phys. Lett. **69**, 1556 (1996)

Electrical measurements

- I-V show high leakage current
- Better non-linear behaviour for buffer-layered samples

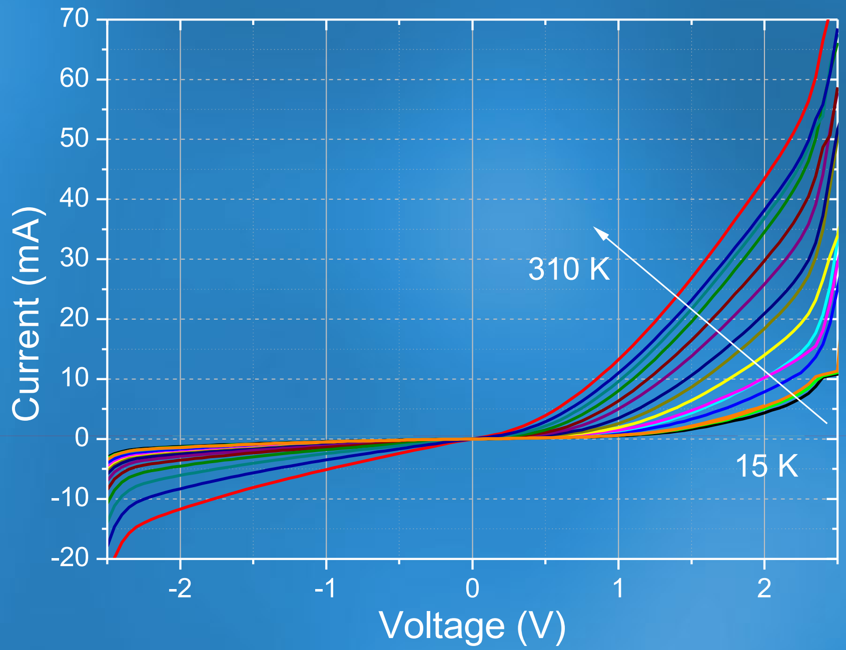




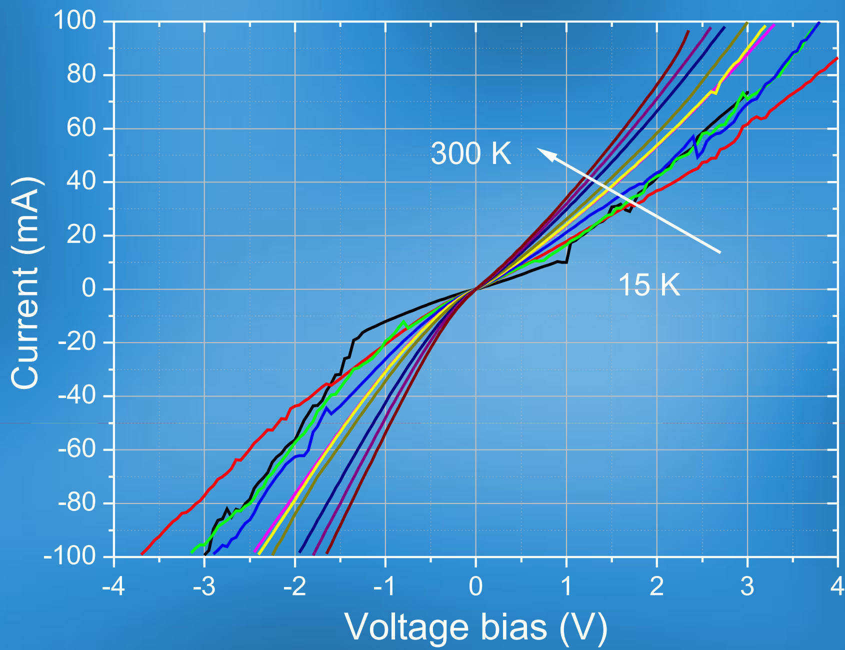
Electrical measurements

- Temperature dependence I-V characteristic
- Temperature activation behaviour
- Still high leakage at low temperature

With buffer layer

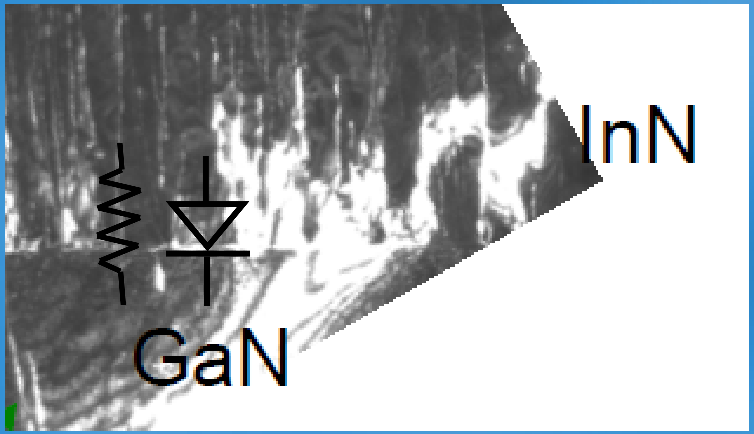


On template



Conduction mechanism

- Dislocations act as a leakage path (ohmic behaviour)
- Thermionic emission for InN/GaN buffer
- Both mechanism for the overall current-voltage behaviour



Conclusions

- High density of dislocations in InN/GaN
  - In nitrides[1] they act as leakage paths
  - In InN every dislocation is a source of donor type defect
- Rectifying behaviour
  - Not observed in InN/template grown at 400°C
  - Achievable with InN/buffer grown at higher T

Acknowledgments

- **The EU Rainbow-ITN project for funding**
- **All the highly efficient technicians in ISOM**

[1]B.S.Simpkins et al. Jour. Appl. Phys. Lett., **94**, No.3, 1448, (2003)

Thanks for your attention

Question?