Transparent Ohmic Contacts to N-polar n-type GaN

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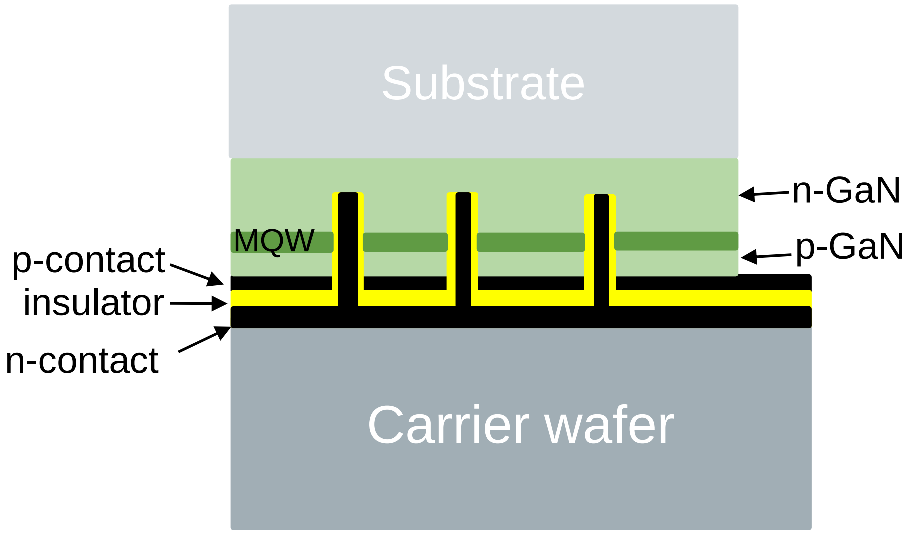
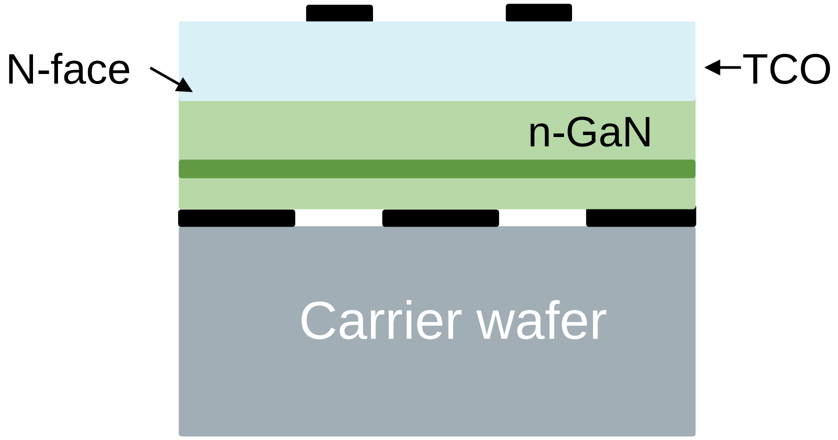
INREP
Towards Indium free TCOs

Why transparent contacts to N-face n-GaN?

- Simplify processing and improve efficiency of ‘vertical’ LEDs



Typical structure of a high-efficiency LED



With transparent contact

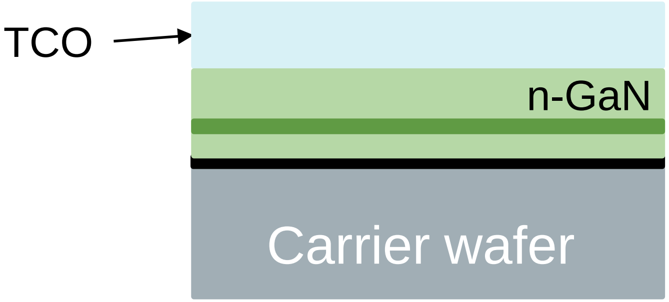
Ga-face (ion etched): Ti/Al → Contact resistance (ρ_c) ≤ 5 x 10^{-5} Ωcm^2

N-face (ion etched): Ti/Al → $\rho_c \approx 2 - 6 \times 10^{-4}$ Ωcm^2 and deteriorates on annealing

Samples and Preparation

Substrate: LED structure, bonded to carrier

ICP etched to N-face n-GaN



Surface treatments:

- no treatment
- Hydrochloric acid
- in-situ Ar, H_2 and O_2 plasma

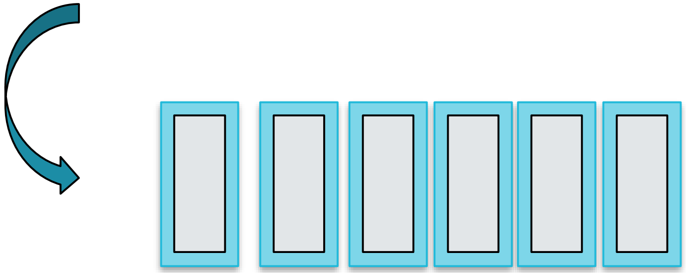
TCO:

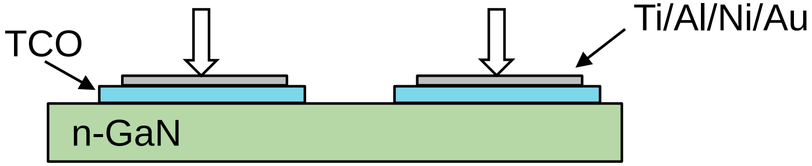
Aluminium-doped Zinc Oxide (AZO)

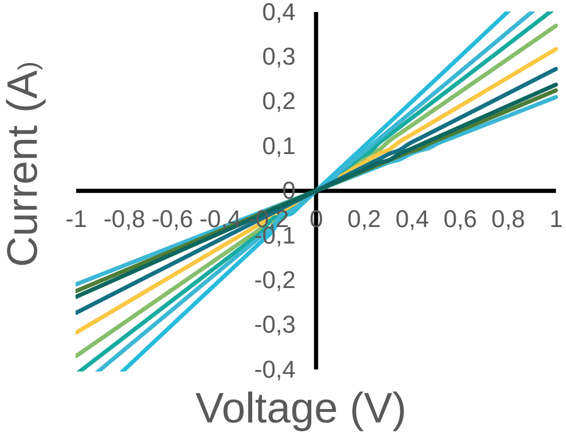
- remote-plasma sputtering
- atomic layer deposition (ALD)

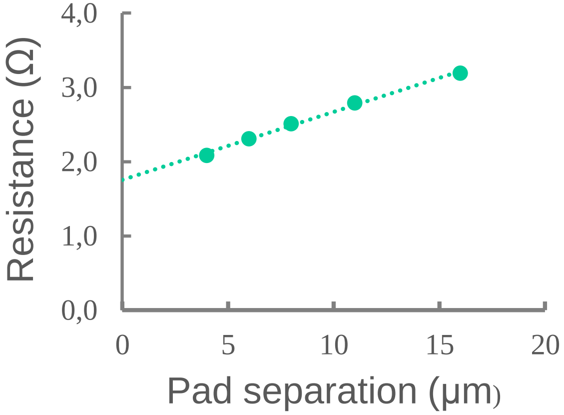
Measurement of the contact resistance between TCOs and N-face n-GaN

Contact resistances were mostly measured with a linear transmission line structure

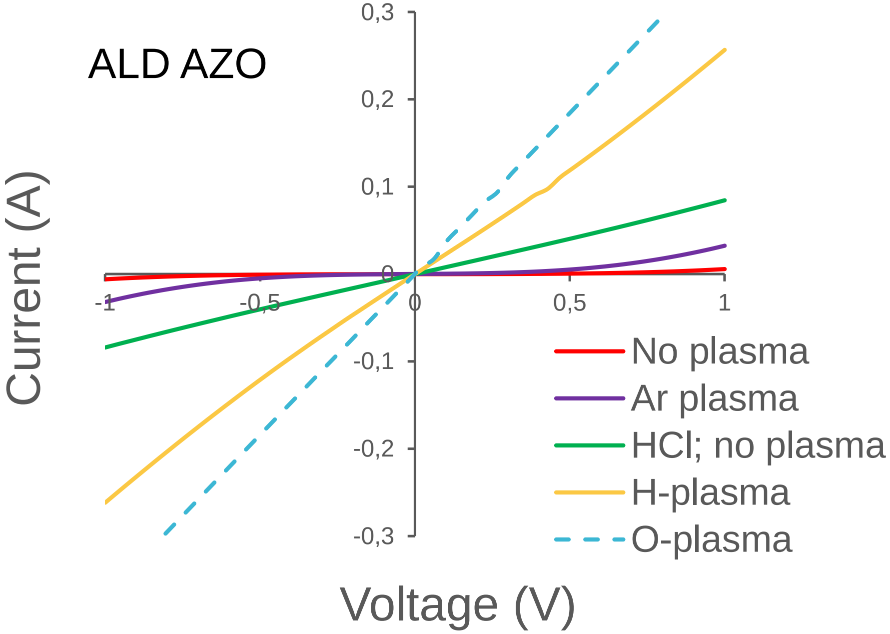








Results: effect of different surface treatments on the contact resistance

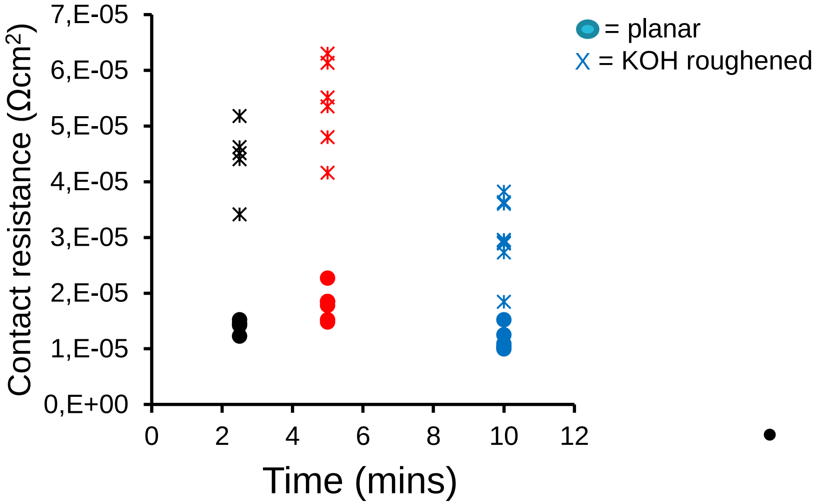


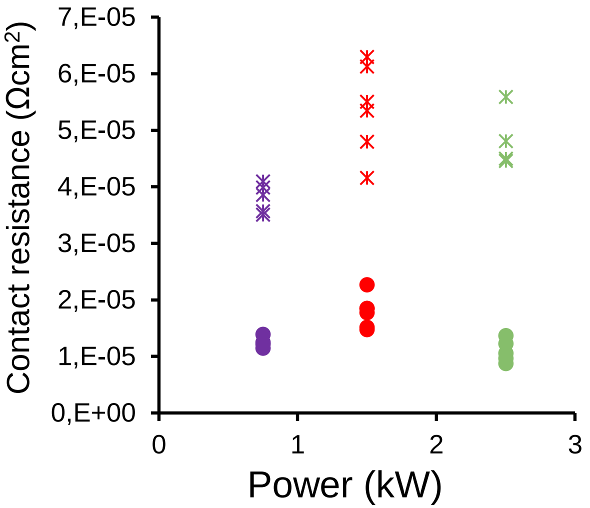
Treatment	Contact resistance ρ_c (Ωcm^2)
No plasma	N/A
Ar plasma	N/A
HCl/No plasma	> 1×10^{-3}
H plasma	~ 8×10^{-5}
O plasma	~ 3.5×10^{-5}
Ti/Al/Ni/Au	~ 2×10^{-4}

H-plasma also worked for: AZO by remote plasma sputtering ($\rho_c = 2\text{-}8 \times 10^{-5}\ \Omega cm^2$)
B:ZnO by PECVD
textured (KOH roughened or ion etched) n-GaN

O-plasma didn't work for: AZO by remote plasma sputtering

Process window for H_2 plasma treatment: remote sputtering system



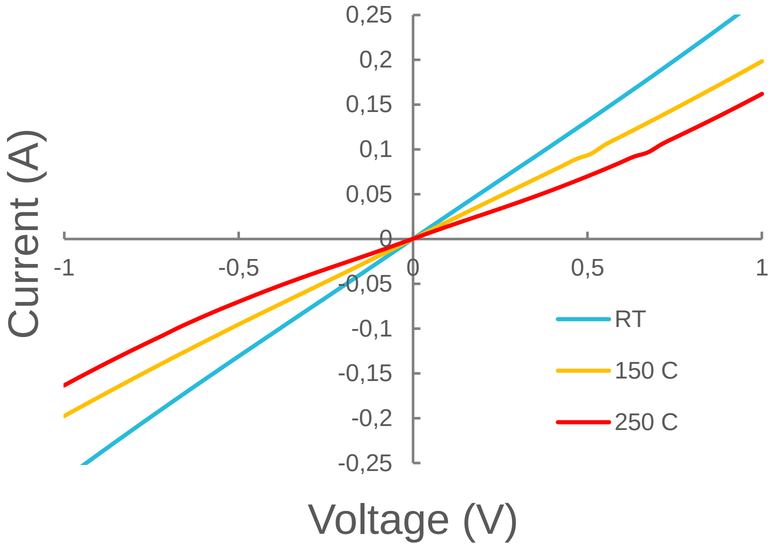


Varied

1. Exposure time
2. Plasma power

- **Contact resistance is *insensitive to exposure time and plasma power***
- ***For both planar and KOH roughened surface***
- ***But with an O-plasma the contacts were non-ohmic for all exposure times and plasma powers tried***

H_2 plasma treatment: thermal stability of contacts

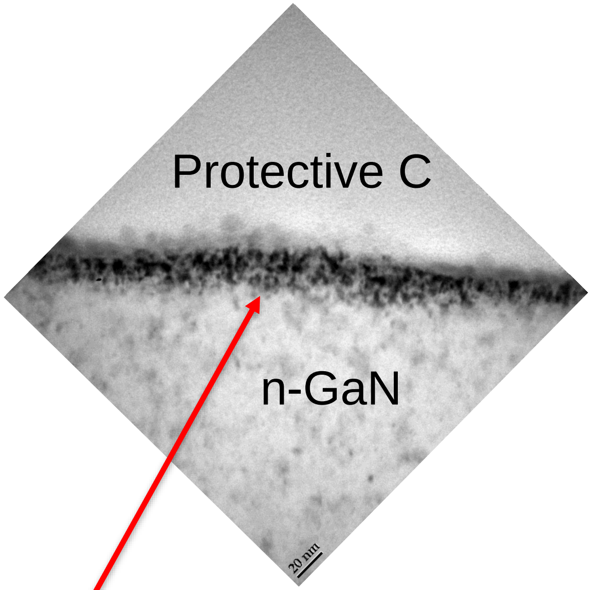


IV graphs (TL) for H-plasma treated contacts: as grown and annealed

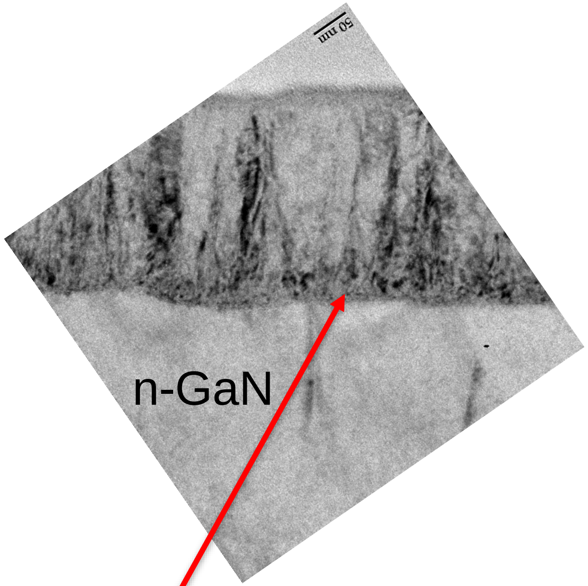
- Samples annealed in N_2 at 150ºC and 250ºC
- The contact resistance increased by a factor of ~ 3 to 4
- ρ_c (RT) ≈ 8 x 10^{-5} Ωcm^2
  ρ_c (150ºC) ≈ 2 to 3 x 10^{-4} Ωcm^2
  ρ_c (250ºC) ≈ 3 to 4 x 10^{-4} Ωcm^2

- Compared favourably to metal contacts
- Contact resistance is low enough to use in LEDs

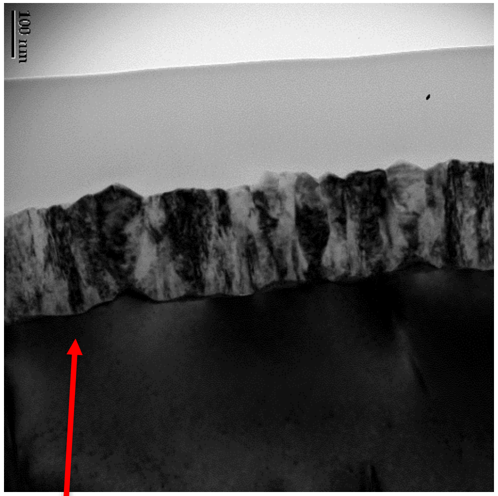
Effect of H-plasma:TEM images of interface



H-plasma, no AZO:
Layer with high defect concentration at surface of GaN (up to 20nm thick)



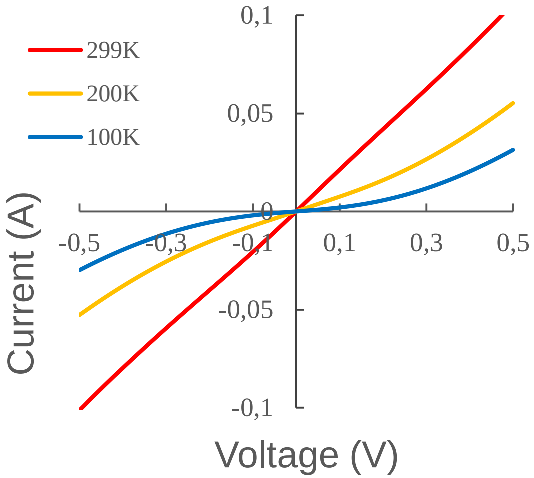
H-plasma + AZO:
nano-crystalline AZO layer at the interface
But GaN defect layer not seen



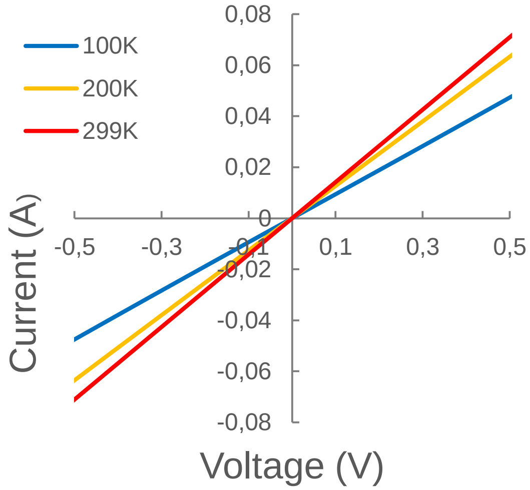
No plasma + AZO:
Neither high contrast layer seen

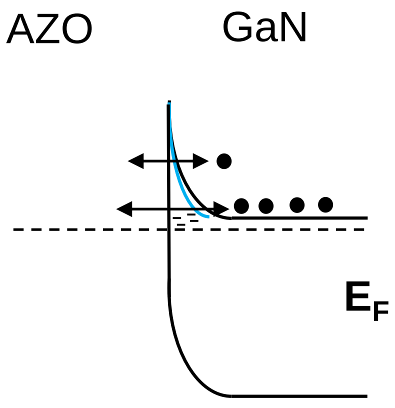
Temperature dependence of the IV characteristics and ρ_c

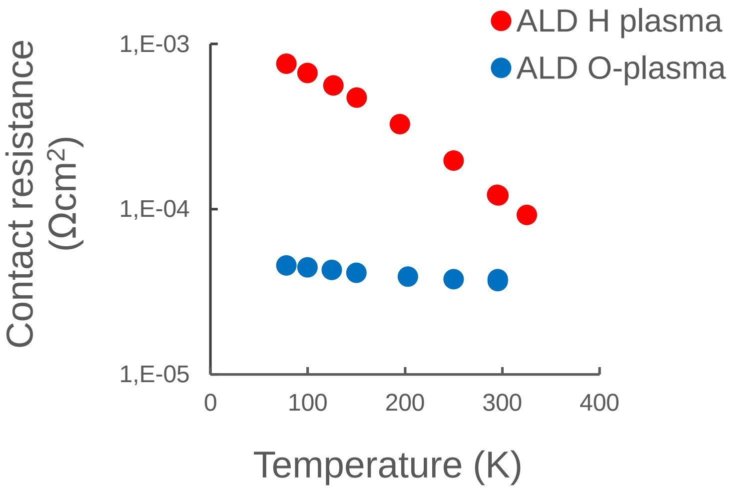
ALD H-plasma



ALD O-plasma







H-plasma/higher ρ_c :

- ρ_c decreases with temperature

O-plasma/lower ρ_c:

- ρ_c almost temperature independent
- consistent with tunnelling mechanism - defect assisted or narrow space charge region

Summary

HCl acid clean:

- Contact resistance between AZO and ICP-etched N-face n-GaN of ~5×10^{-3} Ωcm^2 → **too high for LEDs**

H-plasma

- reduced contact resistance to 2-8×10^{-5} Ωcm^2 → **suitable for LEDs**
- Wide process window
- Contact resistance increased by x3 on annealing at 150ºC

O-plasma

- With ALD contact resistance 3.5×10^{-5} Ωcm^2
- contact resistance is very weakly temperature dependent → consistent with tunnelling, possibly defect assisted or due to enhanced surface doping

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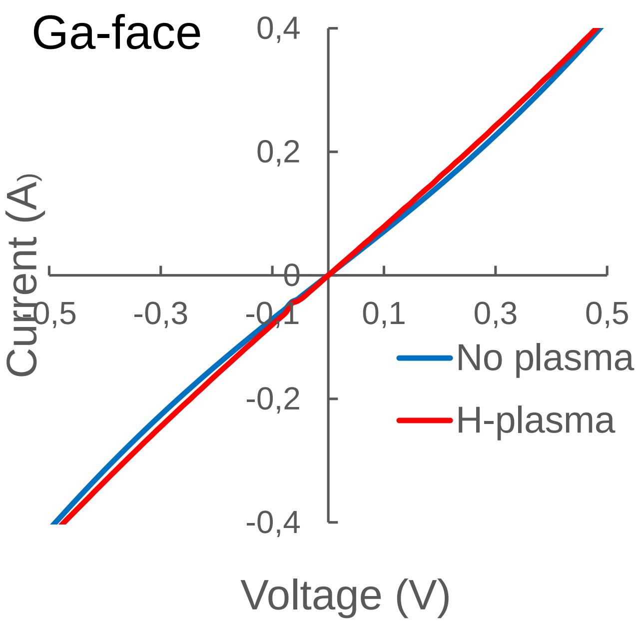
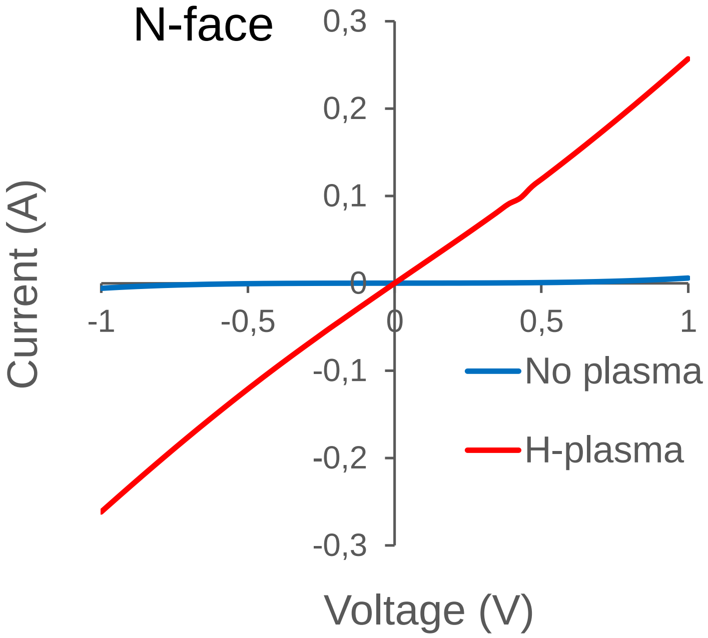
The End – thank you for listening

INREP
Towards Indium free TCOs

H_2 plasma treatment: comparison between Ga-face and N-face



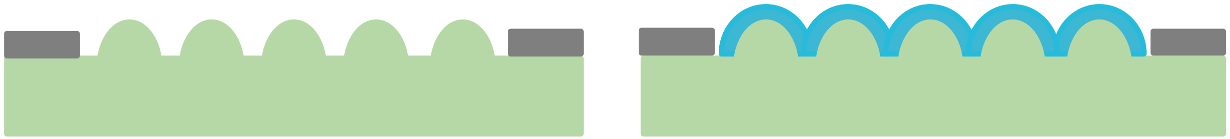


$\rho_c = 8 \times 10^{-5}\ \Omega\text{cm}^2$

$\rho_c = 2 - 8 \times 10^{-5}\ \Omega\text{cm}^2$

- Plasma clean unnecessary for contacts to the Ga-face

Light extraction efficiency



Results 1: No surface treatment

Contacts were non-ohmic for all TCOs and deposition techniques (fig. 1)

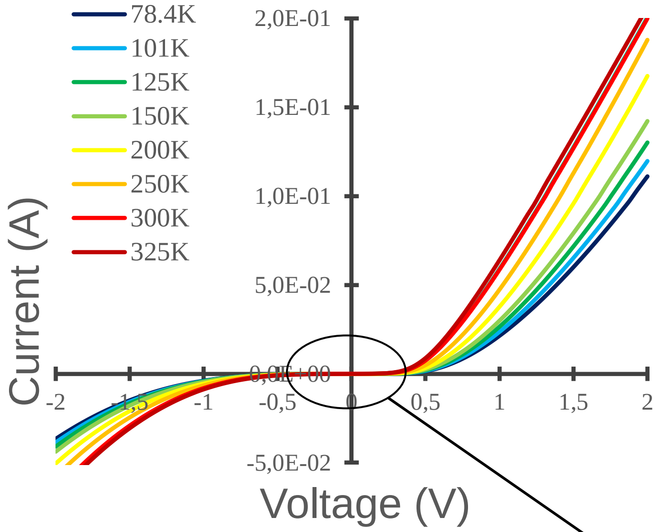
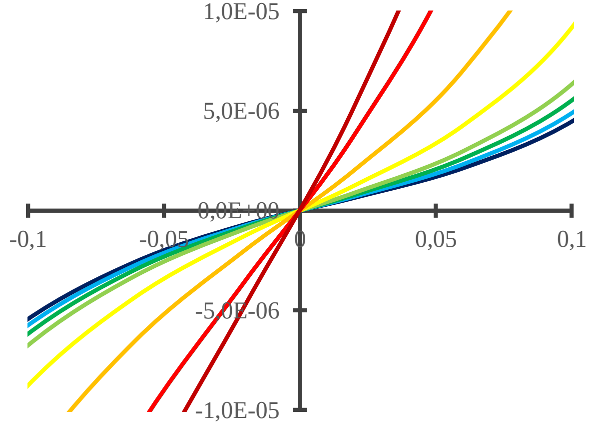


Figure 1: IV characteristics for AZO deposited by ALD

IV graphs are:

- anti-symmetric at low bias,
- asymmetric at higher biases, current increases exponentially with bias
- non-saturating in reverse bias

➢Behaviour often seen in n-n isotype heterojunctions[1]



But what is the dominant conduction mechanism?

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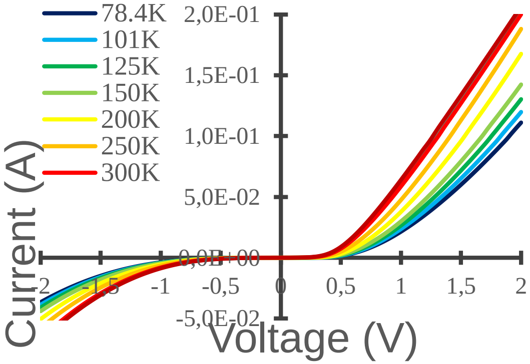
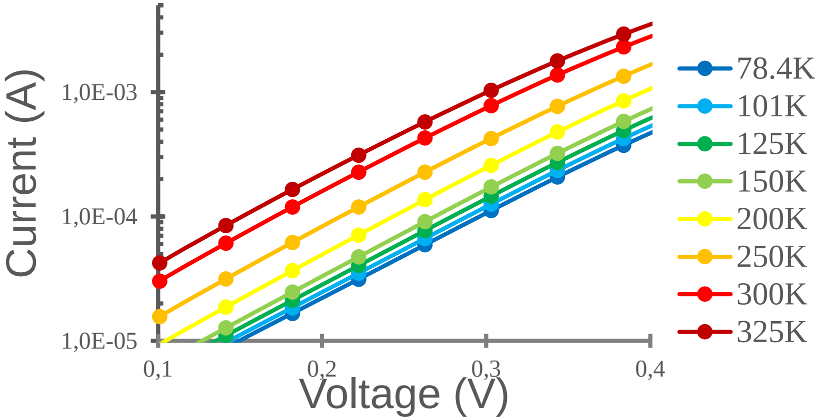
[1] Kwok K. Ng, *Complete guide to Semiconductor Devices* (Wiley-IEEE Press, 2002)

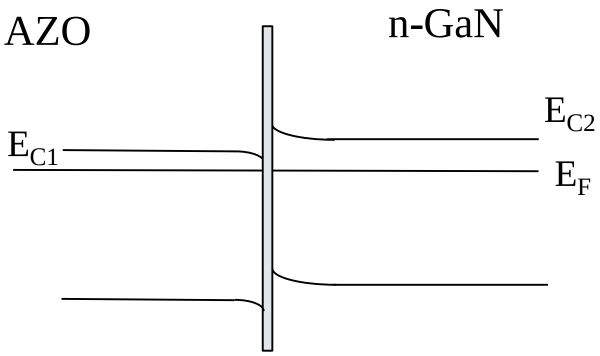
No surface treatment: temperature dependence of IV characteristics



- ➢ Conduction is NOT due to thermionic or thermionic field emission
- ➢ Conduction likely due to tunnelling through a thin barrier



Semi-log IV characteristics for n-GaN/AZO deposited by ALD



Energy band diagram

Gradient of the semi-log IV plot is **temperature-independent**