Indium-free Transparent Ohmic Contacts to N-polar n-type GaN

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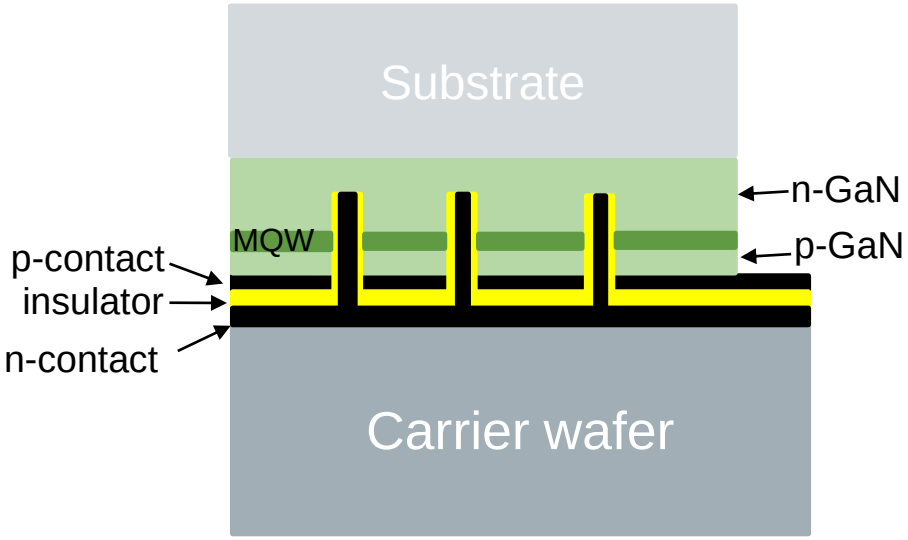
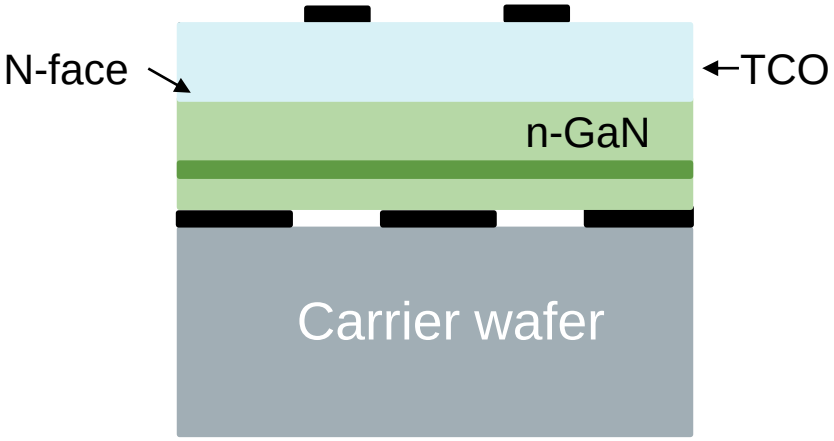
INREP
Towards Indium free TCOs

Why transparent contacts to N-face n-GaN?

- Simplify processing and improve efficiency of ‘vertical’ LEDs

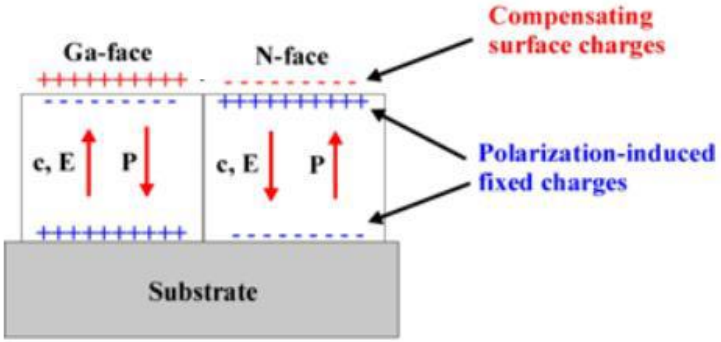


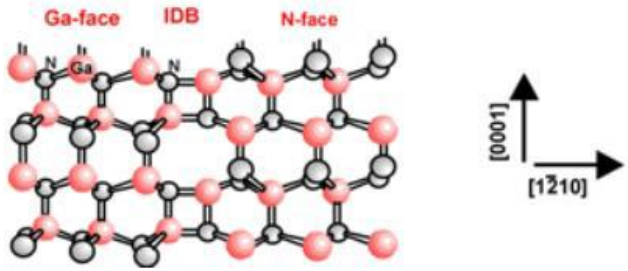
Typical structure of a high-efficiency LED



Structure with TCO

Background: Metal contacts to n-GaN





Ga-face

- Ohmic contacts easy to make by depositing low work function metals (Ti/Al/Ni/Au)
- onto plasma etched the surface (or annealing in N_2)
- $\rho_c \leq 8 \times 10^{-5}$ Ωcm^2 (without any surface cleaning)
- Attributed to formation of a heavily doped n+ surface layer

N-face

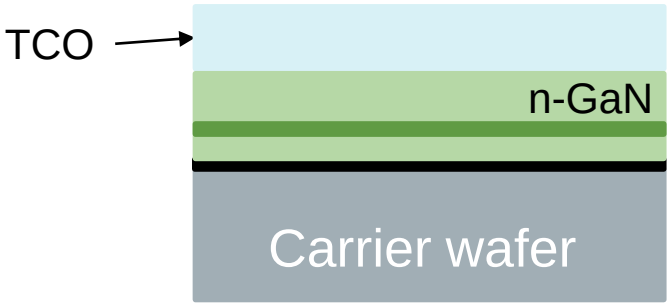
- Contact resistance typically x10 higher and non-ohmic
- We measured $\rho_c \approx 2 - 6 \times 10^{-4}$ Ωcm^2 for Ti/Al/Ni/Au contacts
- Unstable: deteriorates on annealing

Stutzmann et. al. Phys.stat.sol.(b) 228, No. 2, 505–512 (2001)

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
- H_2 plasma + vacuum break

TCOs:

Aluminium-doped Zinc Oxide (AZO)

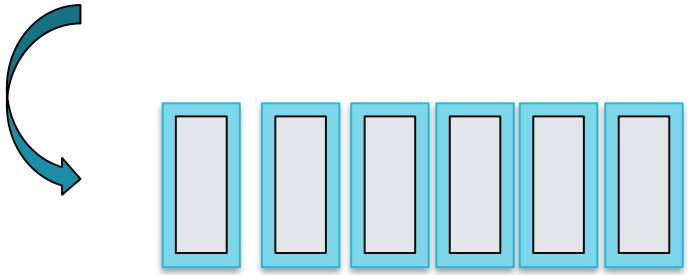
- remote-plasma sputtering
- atomic layer deposition (ALD)

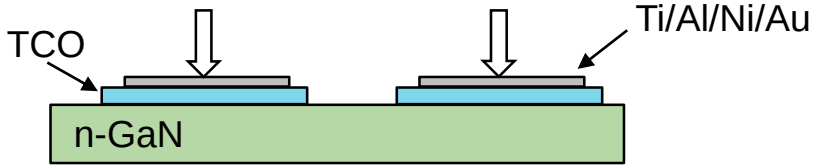
Boron-doped Zinc Oxide (ZnO:B)

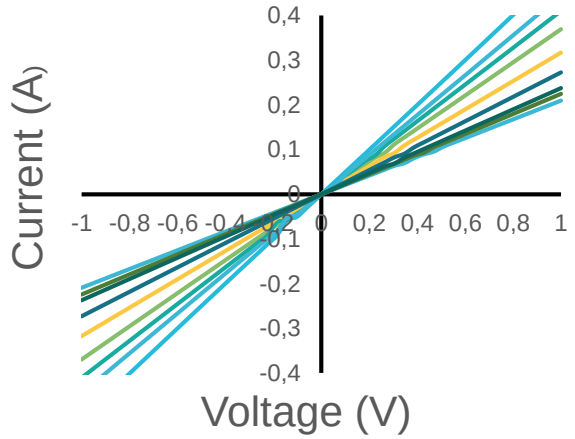
- LPCVD

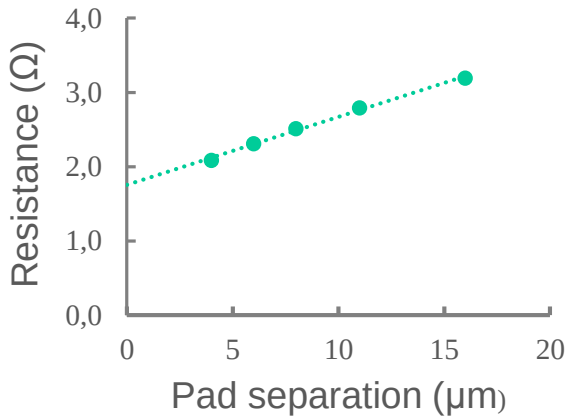
Measurement of the contact resistance between TCOs and N-face n-GaN

Contact resistances were measured with a linear transmission line structure

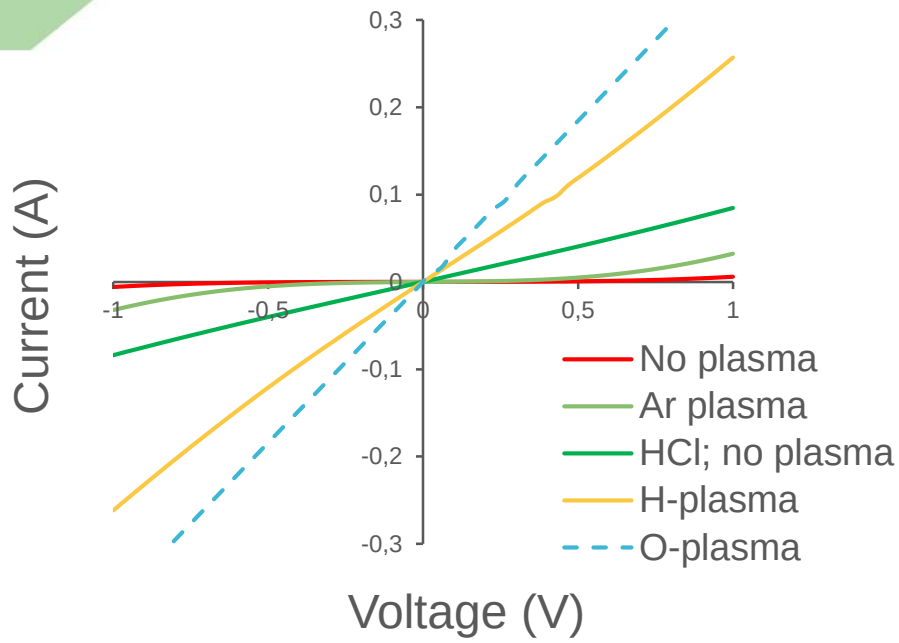








Results: effect of different surface treatments on the contact resistance



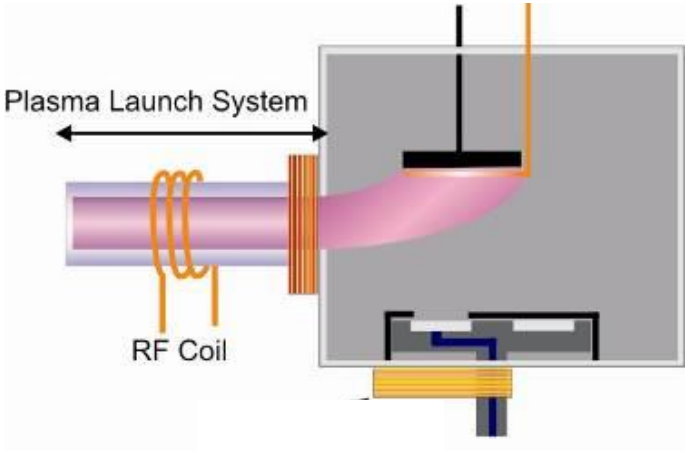
IV graphs (TL) for ALD AZO to N-face n-GaN contacts with different surface treatments

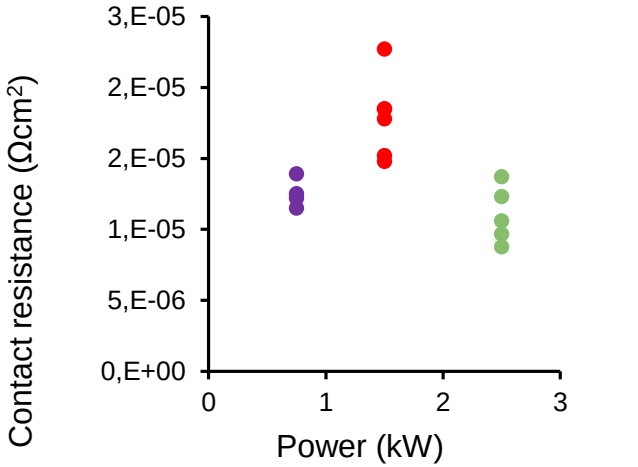
Treatment	Contact resistance ρ_c (Ωcm^2)
No plasma	N/A
Ar plasma	N/A
HCl/No plasma	~ 5 x 10^{-3}
O plasma	~ 3.5 x 10^{-5}
H plasma	~ 8 x 10^{-5}
Ti/Al/Ni/Au	~ 2-6 x 10^{-4}

H-plasma also worked for: AZO by remote plasma sputtering (ρ_c = 2-8 x 10^{-5} Ωcm^2)
B:ZnO by LPCVD

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

Process window for H_2 plasma treatment: remote sputtering system

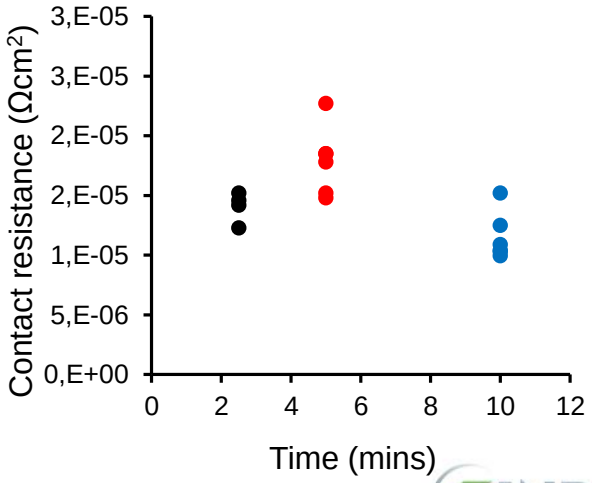




Contact resistance vs plasma power

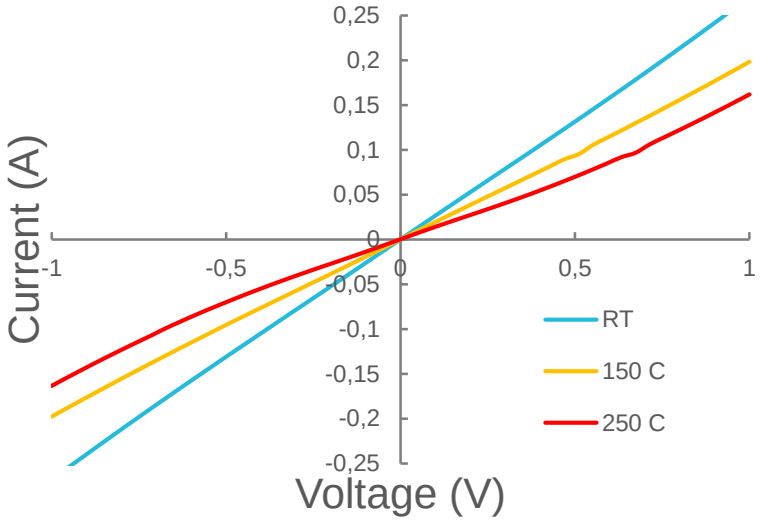
Varied:
1. Exposure time
2. Plasma power

- **Contact resistance is *insensitive to exposure time and plasma power***
- ***However, with an O-plasma the contacts were non-ohmic for all exposure time and plasma powers tried***



Contact resistance vs exposure time

H_2 plasma treatment: thermal stability of contacts



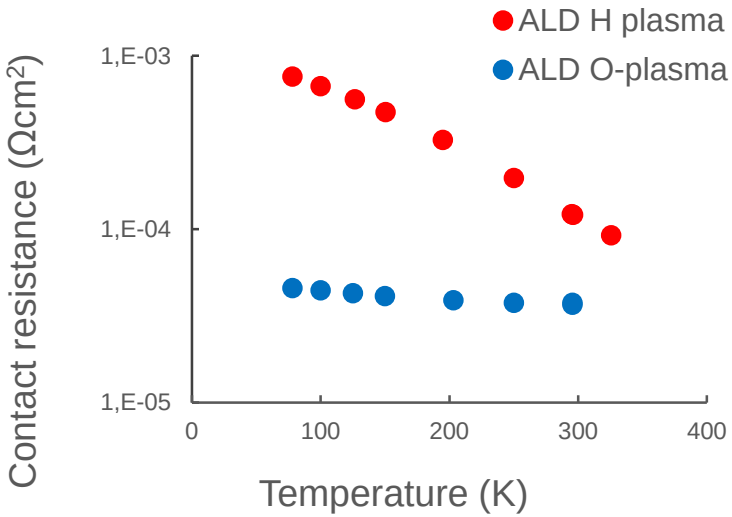
IV graphs (TL) for H-plasma treated contacts: as grown and annealed

- Samples were annealed in N_2 for 5 minutes at 150ºC and 250ºC
- The contact resistance increased by a factor of ~ 3
- ρ_c (RT) ≈ 8 x 10^{-5} Ωcm^2
  ρ_c (250ºC) ≈ 2.5 x 10^{-4} Ωcm^2

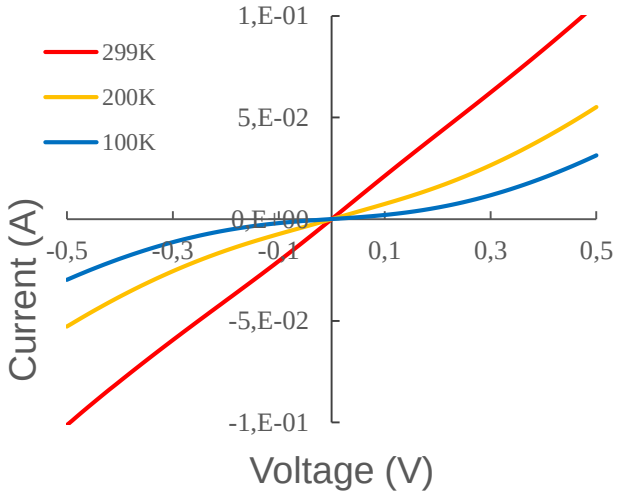
- Compared favourably to metal contacts
- Contact resistance is low enough to use in LEDs
- TCO layer could be used under metal contacts

What are the conduction mechanisms in these contacts?

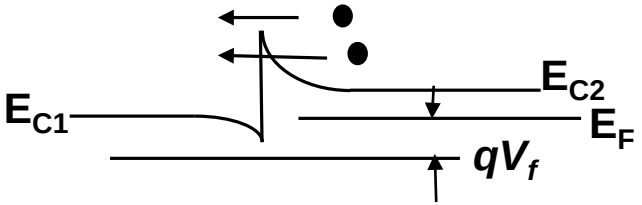
Temperature dependence of IV characteristics and ρ_c



Temperature dependence of ρ_c for different pre-treatments



IV graphs for AZO deposited by ALD with a H-plasma treatment



- Results for O-plasma are inconsistent with thermionic (field) emission theory

Summary

- Contact resistance between AZO and ICP-etched N-face n-GaN of ~$5x10^{-3}$ Ωcm^2 is too high for use in LEDs
- Exposure to an in-situ H-plasma prior to deposition of the AZO reduces the contact resistance 2-$8x10^{-5}$ Ωcm^2 → suitable for use in LEDs
- Effective for deposition by ALD, sputtering and LPCVD
- Contact resistance decreases with increasing temperature, consistent with thermionic (field) emission theory

- An in-situ O-plasma can reduce the contact resistance even further
- With an O-plasma treatment the contact resistance is only very weakly temperature dependant.

The End – thank you for listening