Highly resistive HVPE-GaN grown on native seeds – investigation and comparison of different dopants

Motivation

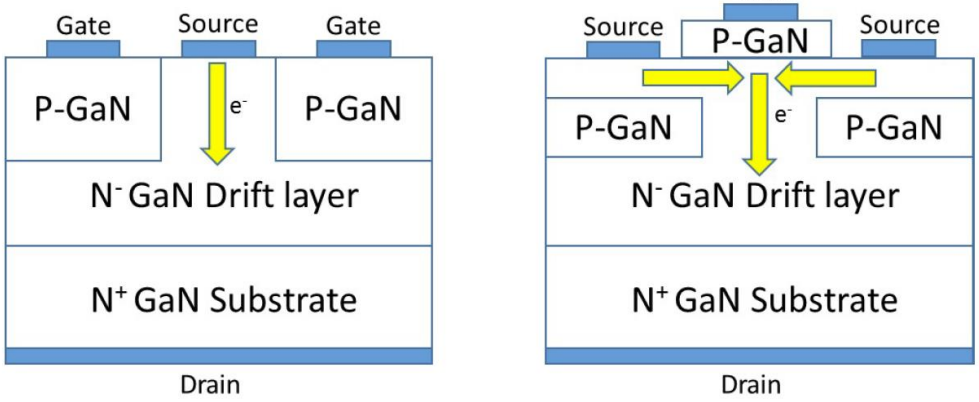
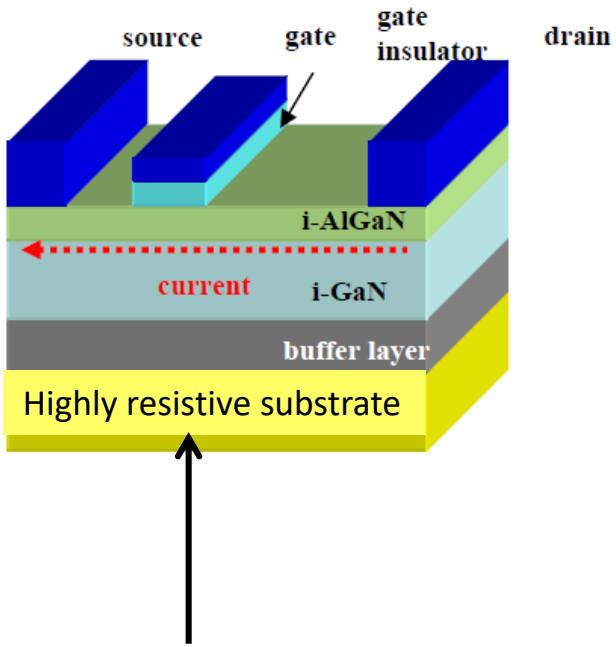


Figure 1: Two possible FET topologies. The arrows indicate the direction of electron flow.



Bulk highly resistive GaN

Vertically operating

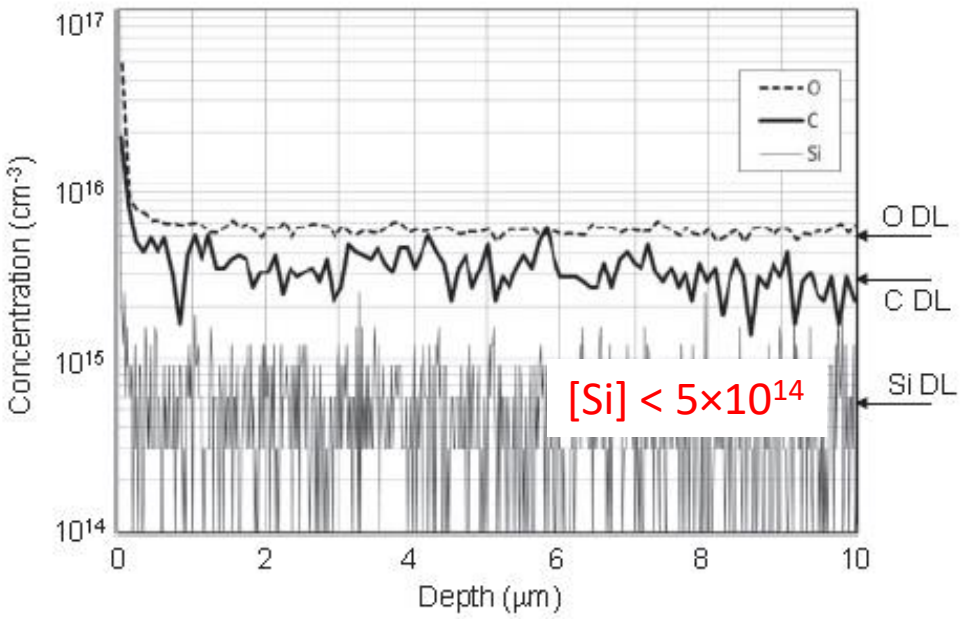
Laterally operating

Undoped HVPE-GaN

SCIOCS

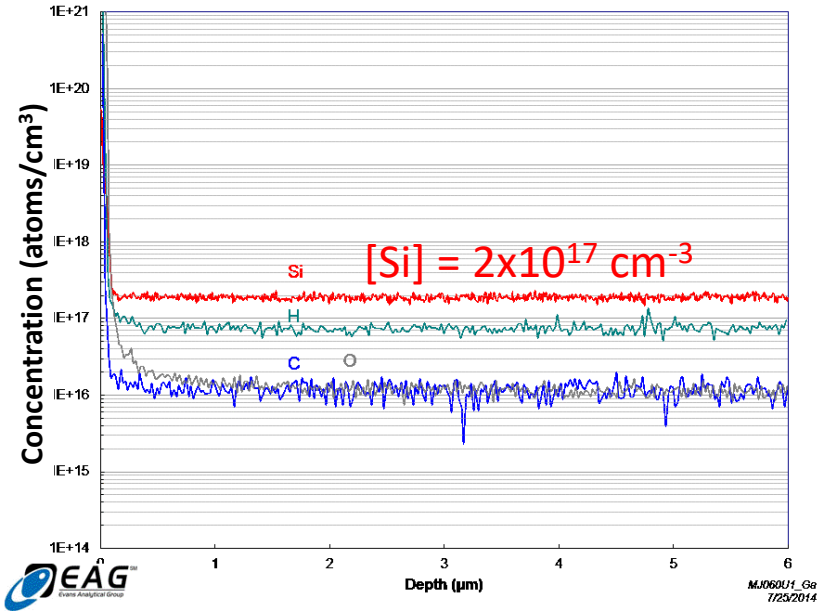
Quartz-free reactor

$\rho = 1\times10^{9}\ \Omega\cdot cm$



unipress

Quartz reactor

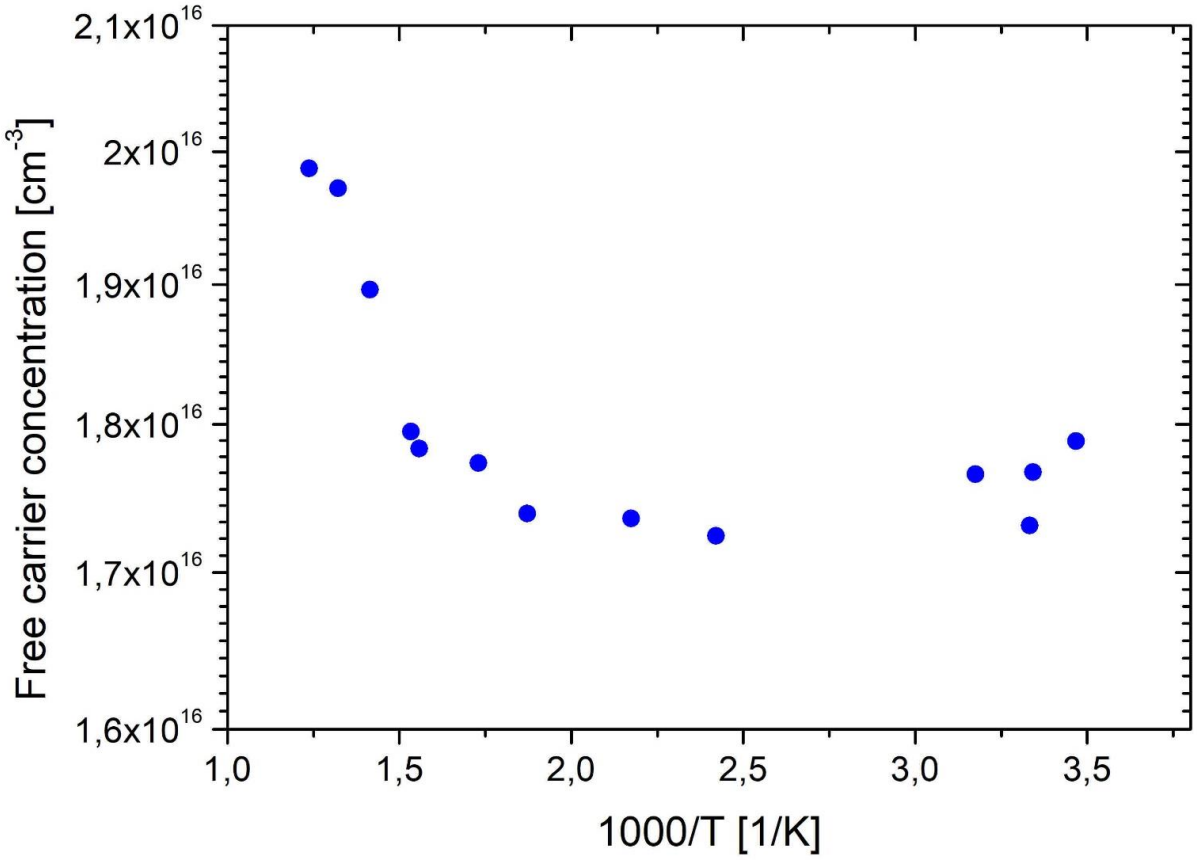


H, Fe, Cr, Ni, Ti, Cl, and B below detection limits

H. Fujikura et al., Jpn. J. Appl. Phys. 56, 085503 (2017)

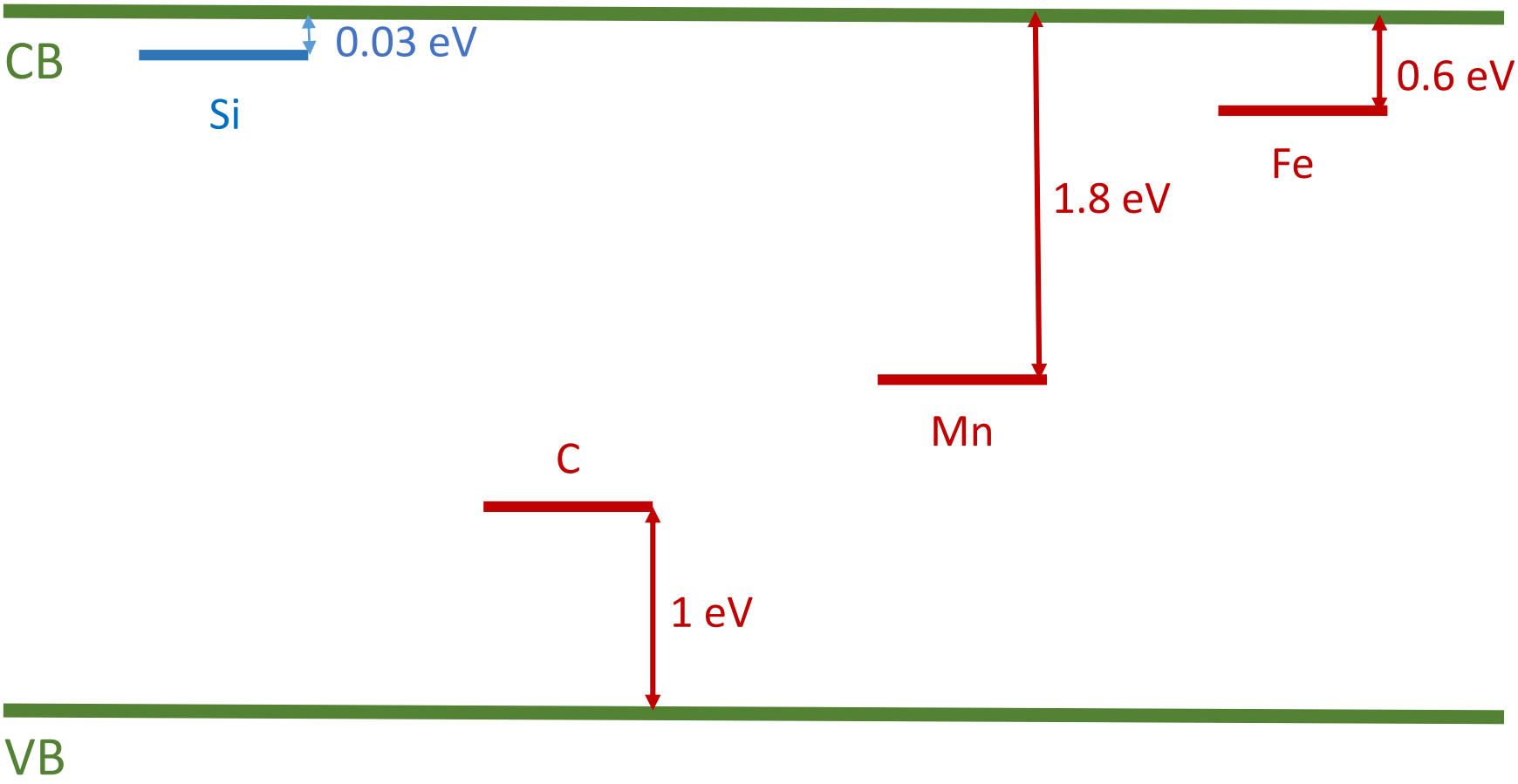
J.A. Freitas Jr. Et al., J. Cryst. Growth 456 (2016) 113–120

Undoped HVPE-GaN

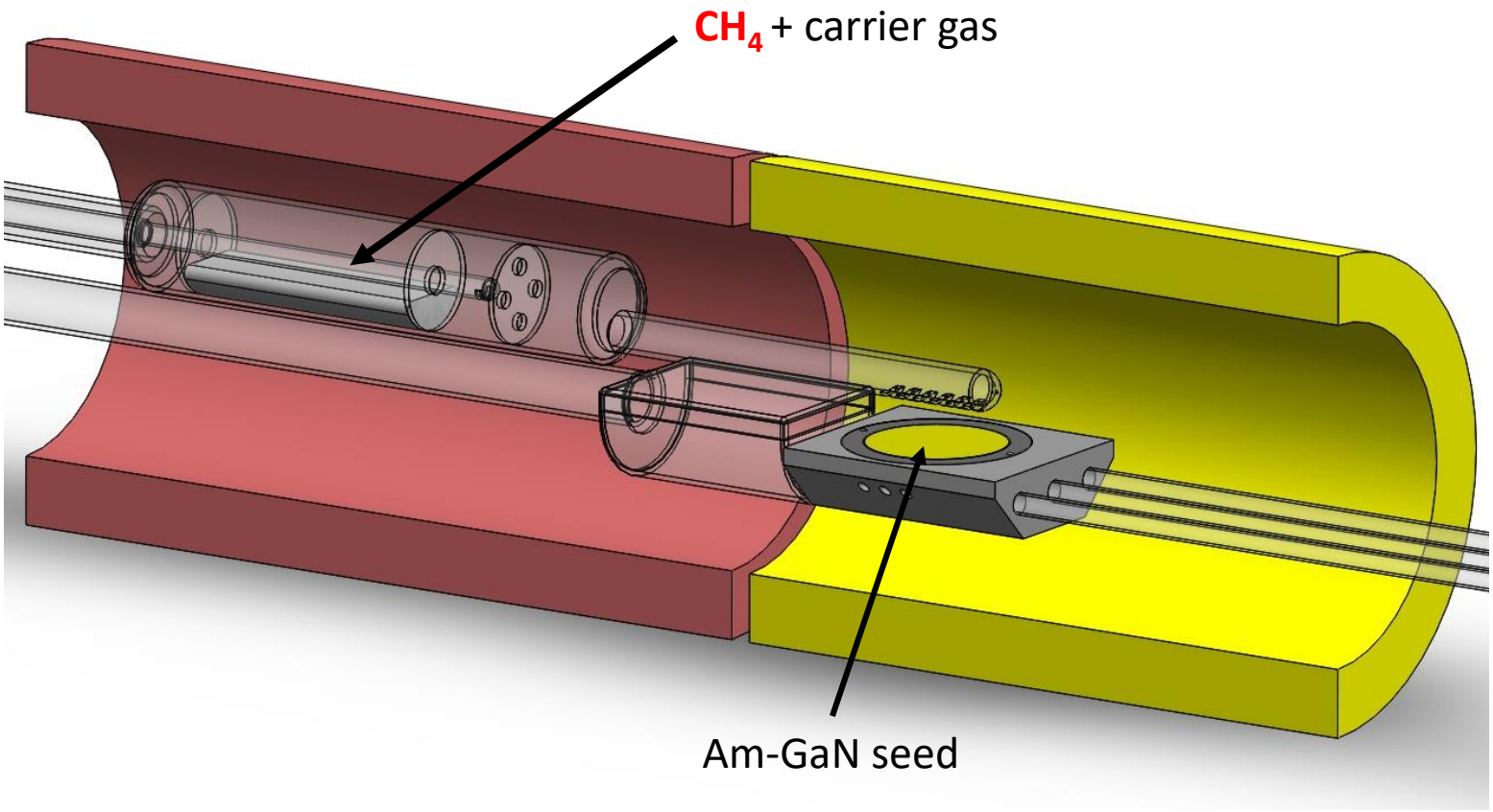


Hall measurements in Van der Pauw configuration

Dopants in GaN

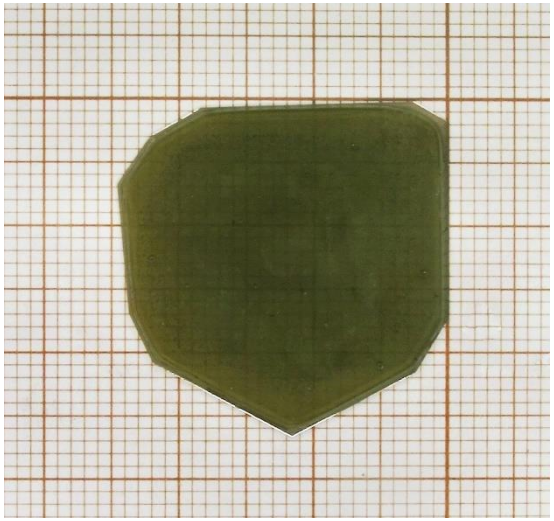


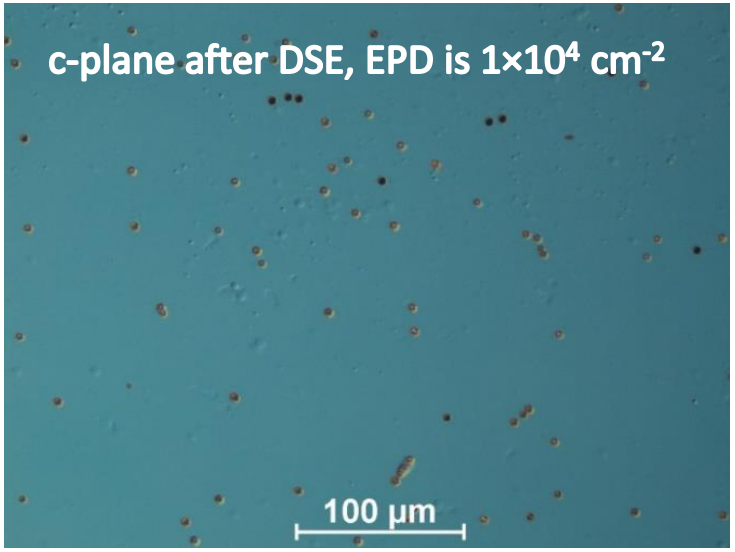
C-doped GaN

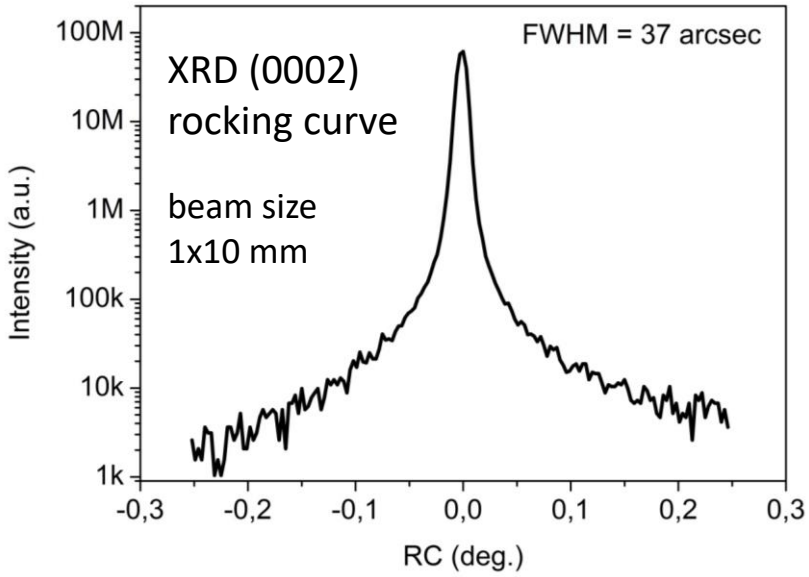


Source zone T= 850°C **Growth zone T= 1050°C**

C-doped GaN



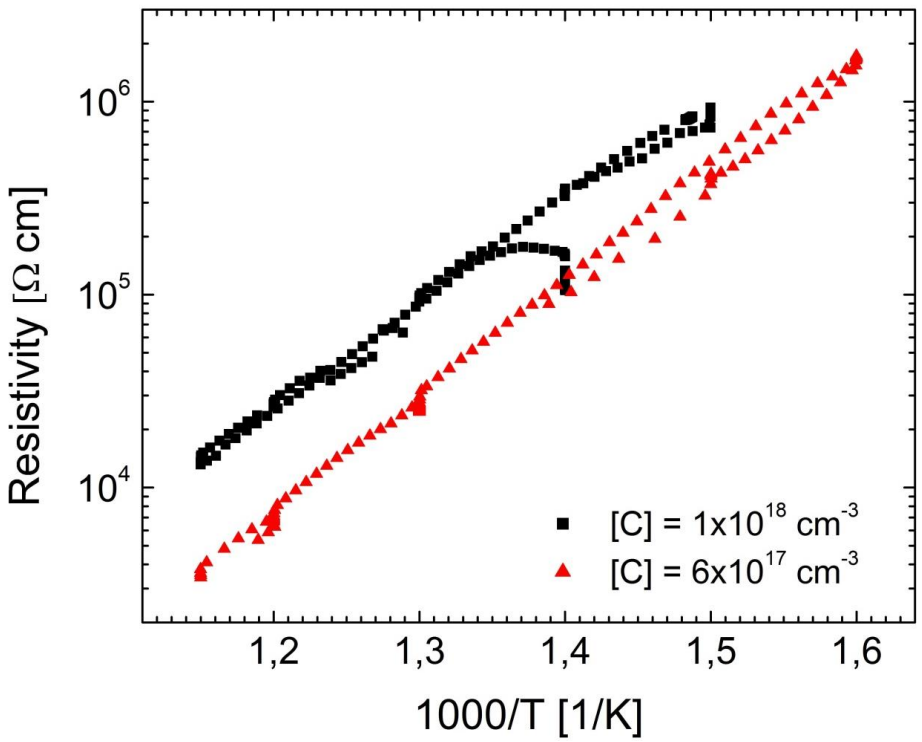


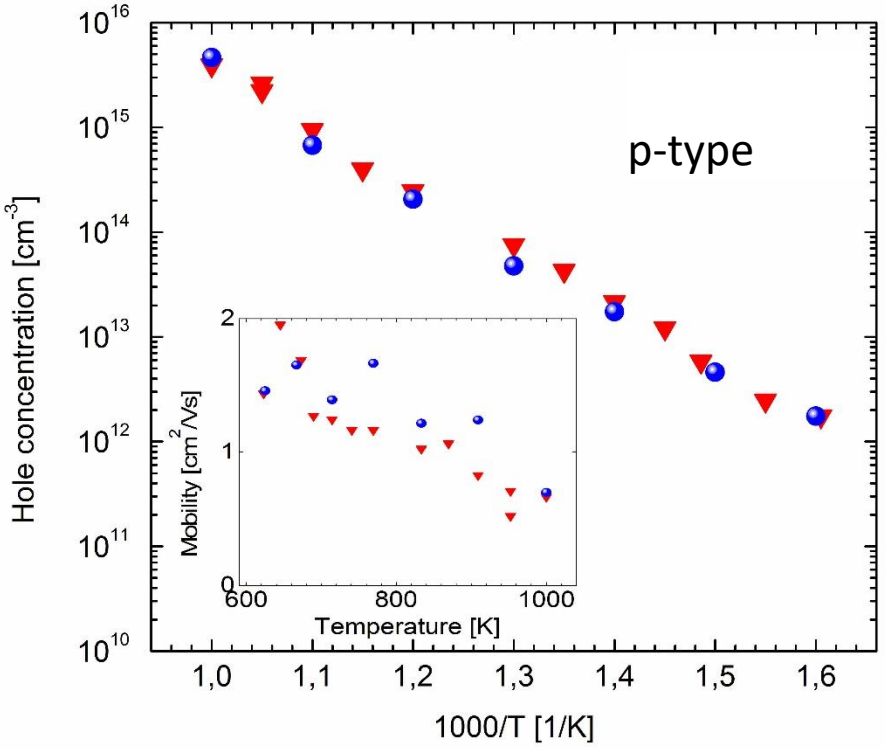


M. Iwinska et al., Appl. Phys. Express 10, 011003 (2017)

C-doped GaN

@RT: $\rho > 10^8\ \Omega$cm





Activation energy ~1 eV

M. Iwinska et al., Appl. Phys. Express 10, 011003 (2017)

C-doped GaN

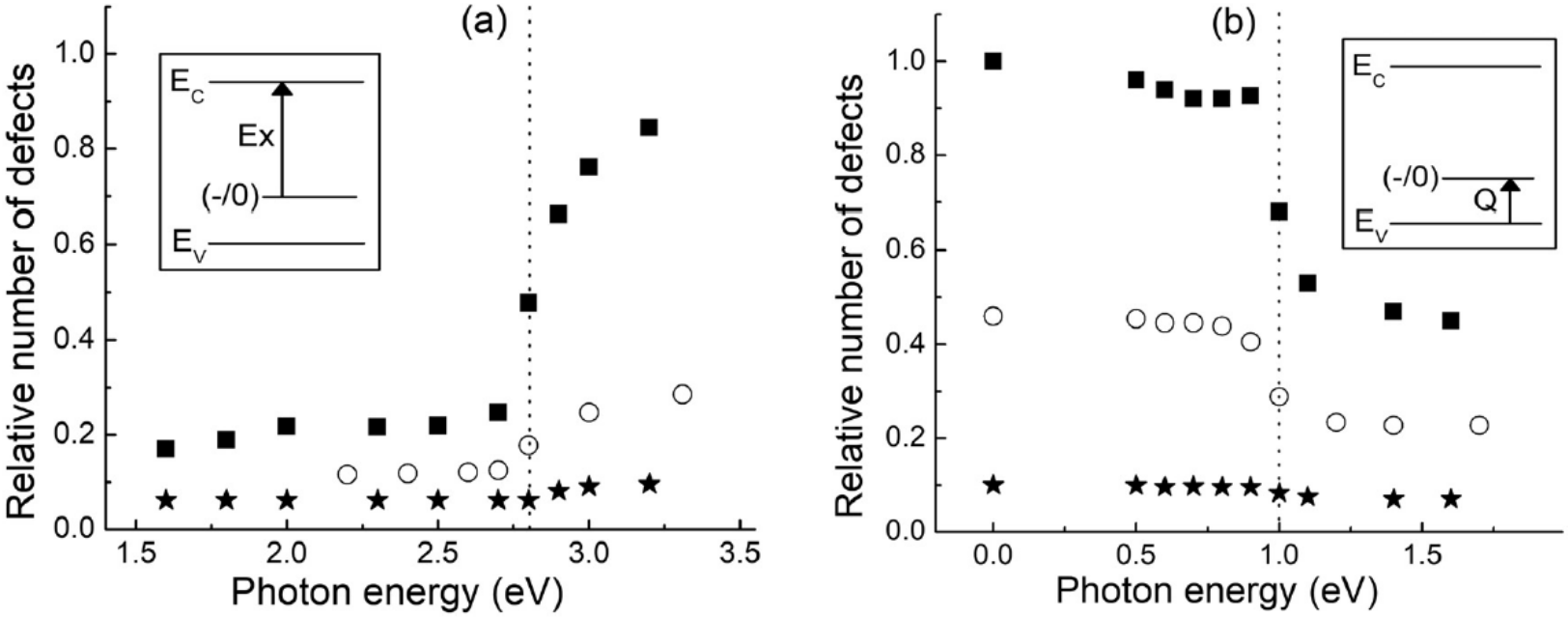
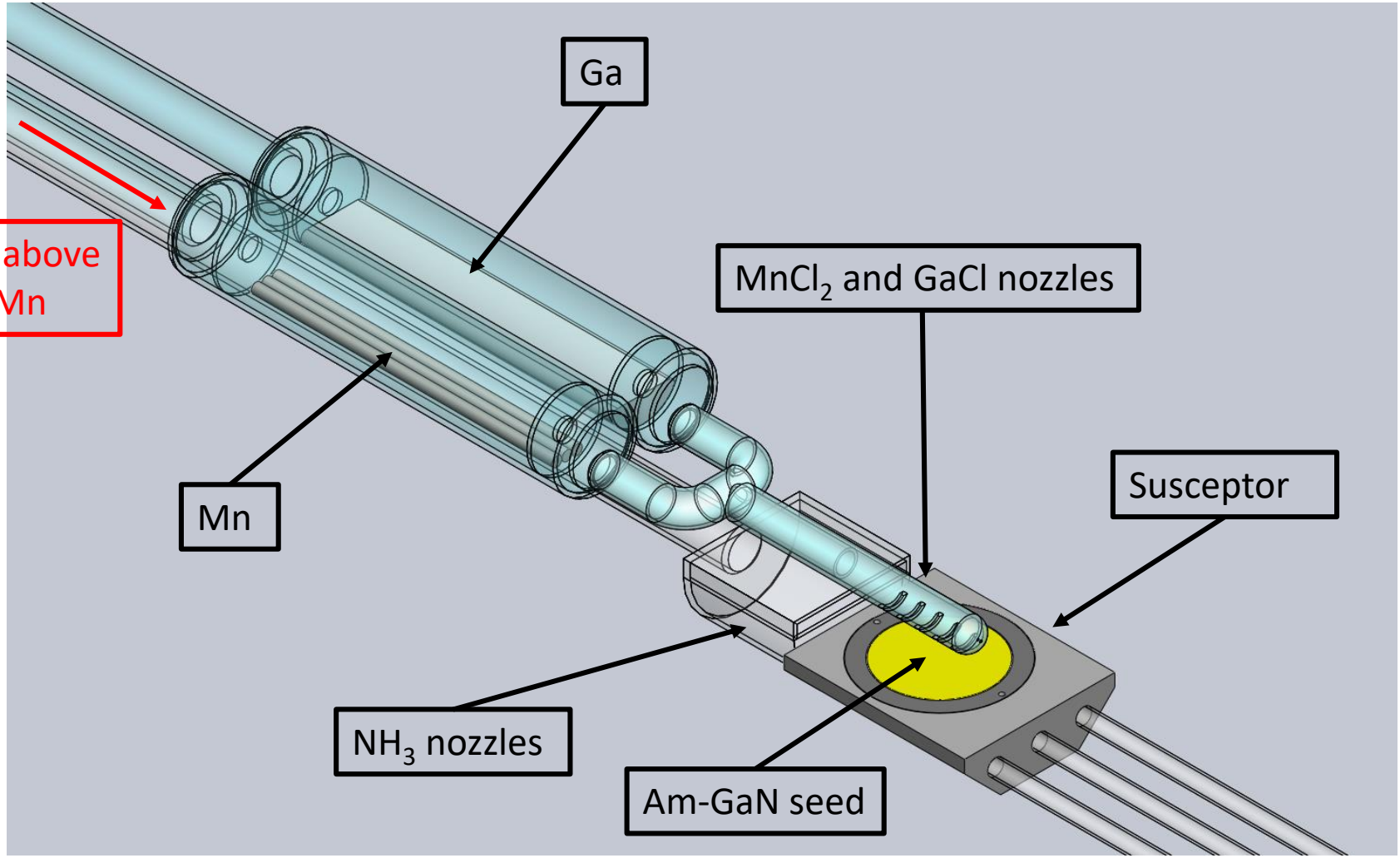


FIG. 3. Steady state photo-EPR data for $10^{19}\,cm^{-3}$ (A, square), $2.5 \times 10^{18}\,cm^{-3}$ (D, circle), and $2 \times 10^{17}\,cm^{-3}$ (G, star) C-doped samples for excitation (a) and quenching (b). Each point represents the relative number of defects observed after illumination with a particular wavelength. The dashed lines denote excitation and quenching threshold. Insets: Simple band model for excitation (a) and quenching (b).

Zvanut et al., J. Appl. Phys. 124, 075701 (2018)

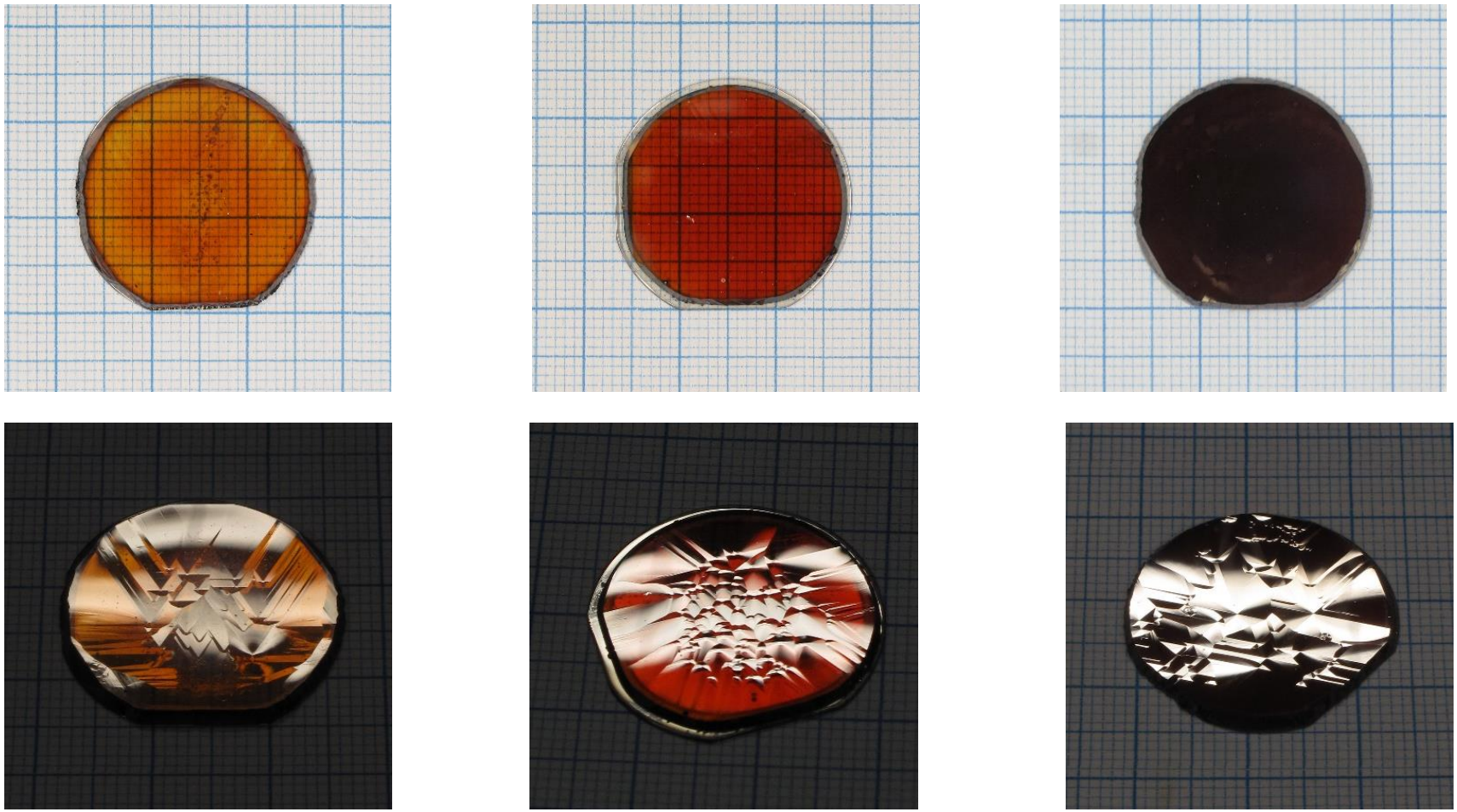
Mn-doped GaN



Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

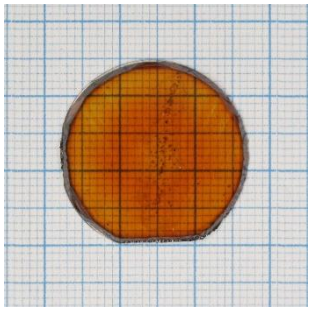
Mn-doped GaN

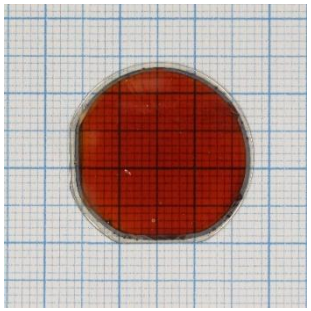
Increasing HCl flow above solid Mn

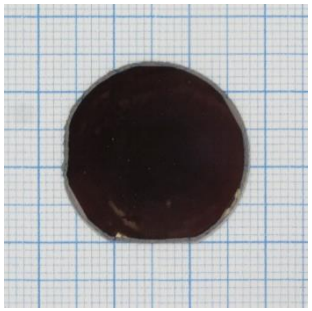


Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Mn-doped GaN



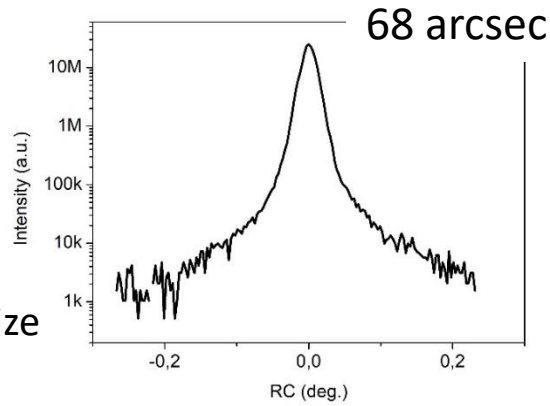


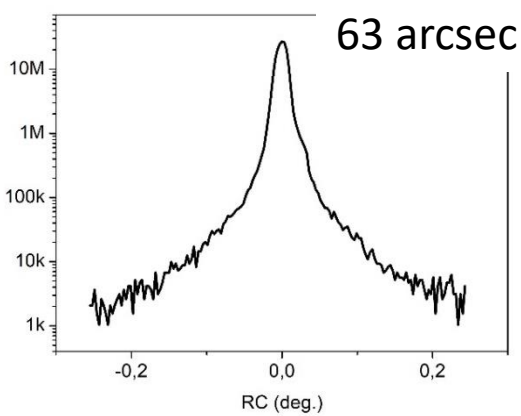


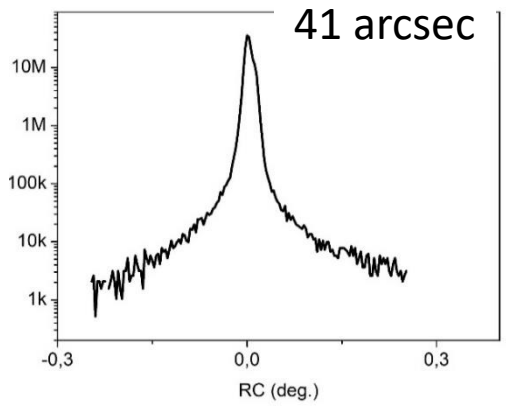
[Mn] [cm^{-3}]	3×10^{18}	8×10^{18}	2×10^{19}
[Si] [cm^{-3}]	$<1\times10^{17}$	$<1\times10^{17}$	$<1\times10^{17}$
Seed:	FWHM = 53 arcsec	FWHM = 71 arcsec	FWHM = 36 arcsec

As-grown layer:

XRD (0002) RC, beam size 1x10 mm

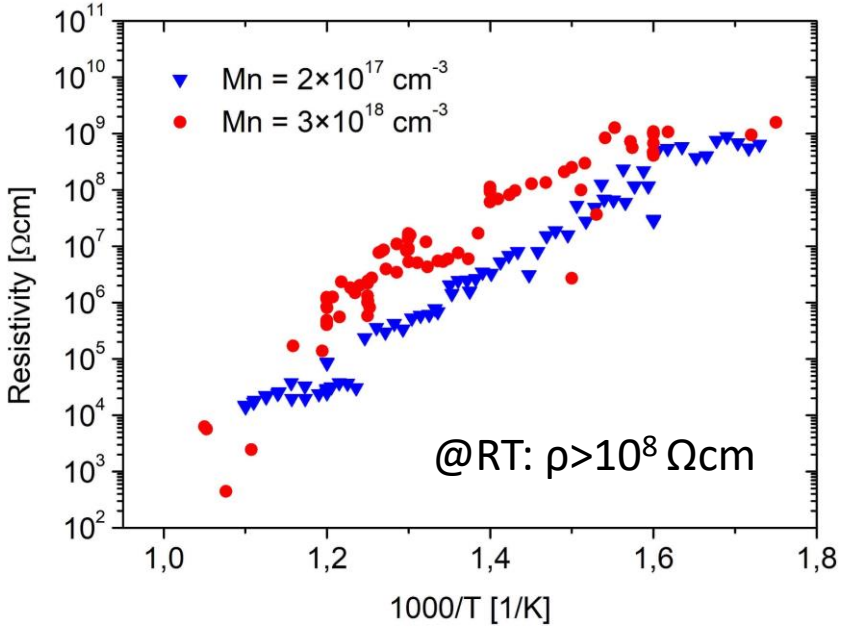


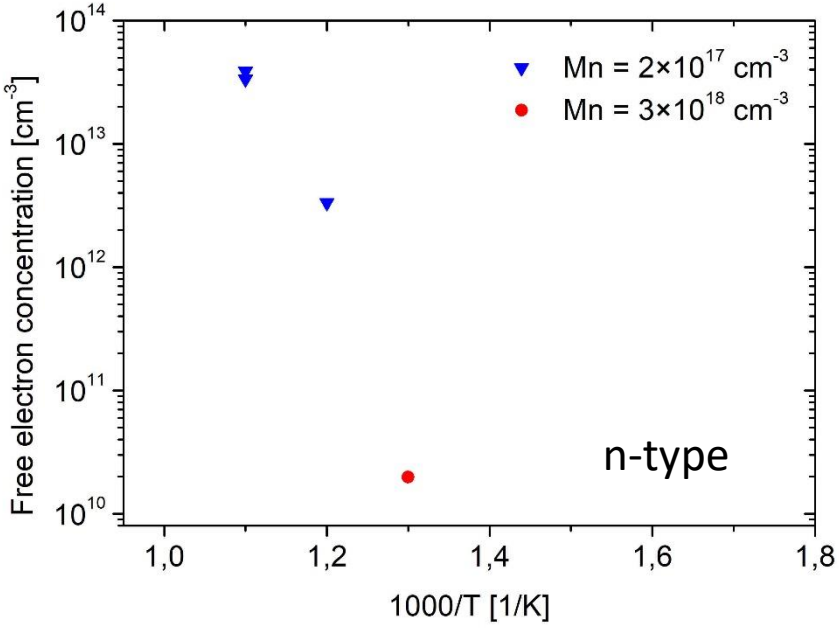




Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Mn-doped GaN



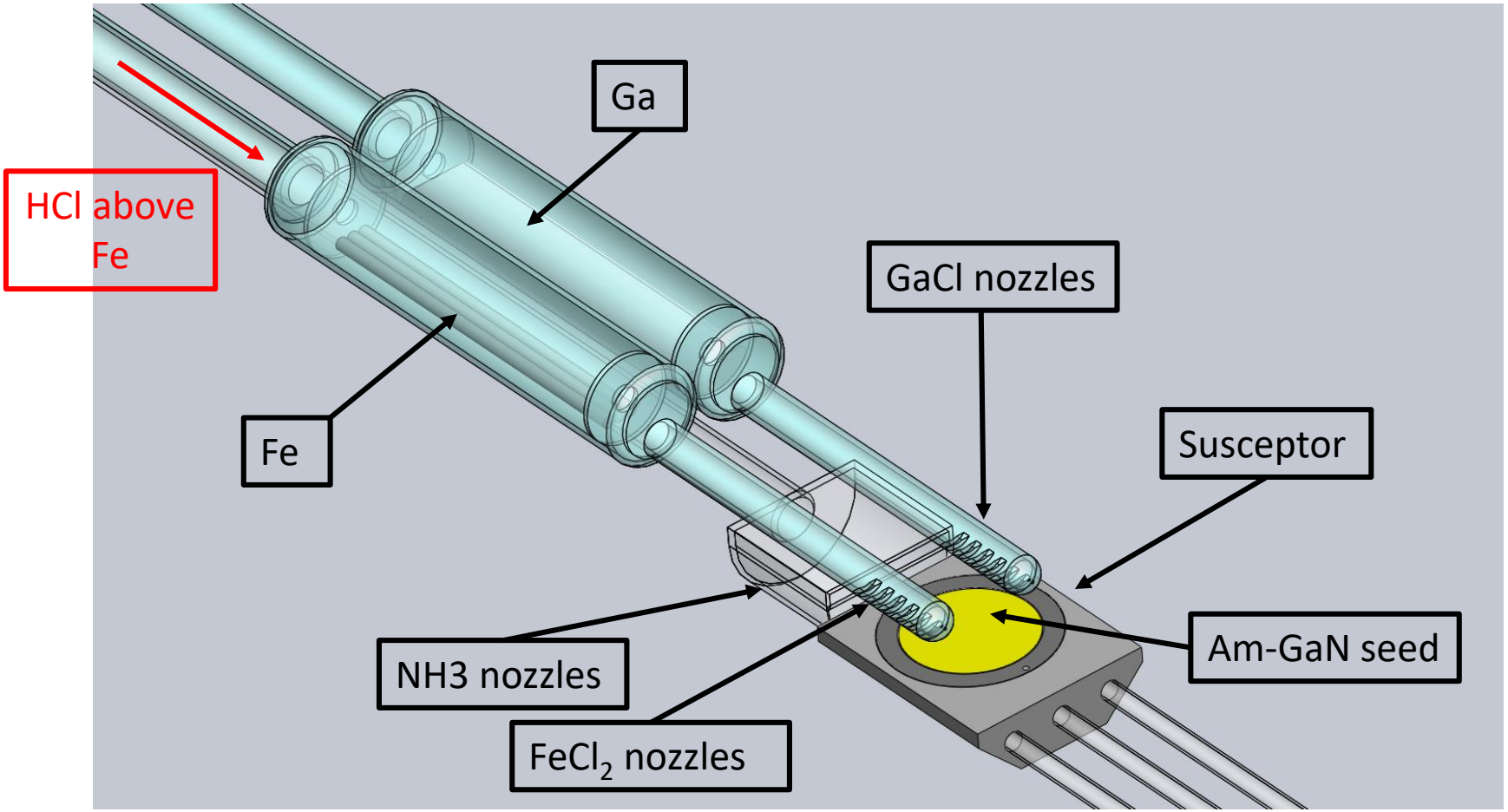


Activation energy ~1.8 eV

Measurements not possible for higher [Mn]

Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

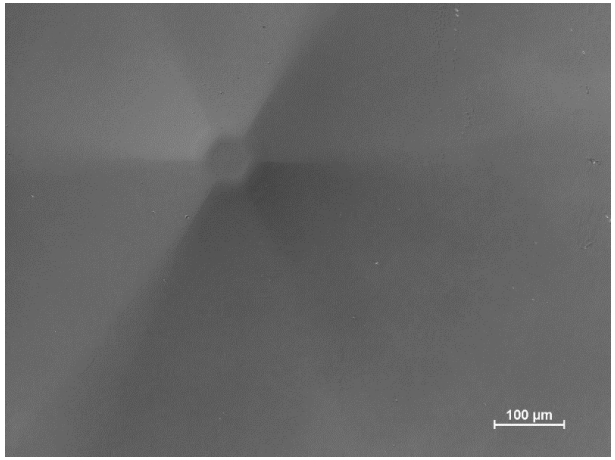
Fe-doped GaN

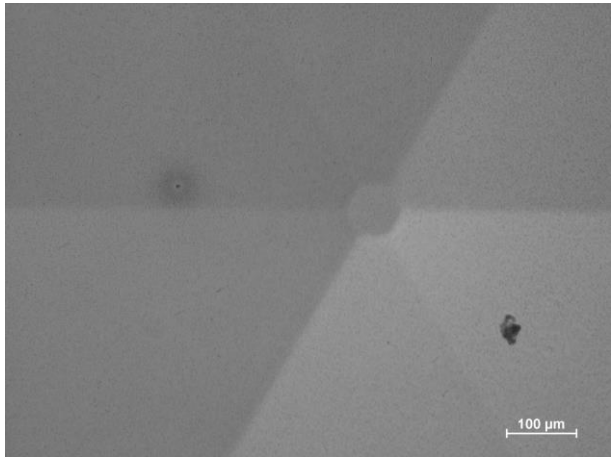


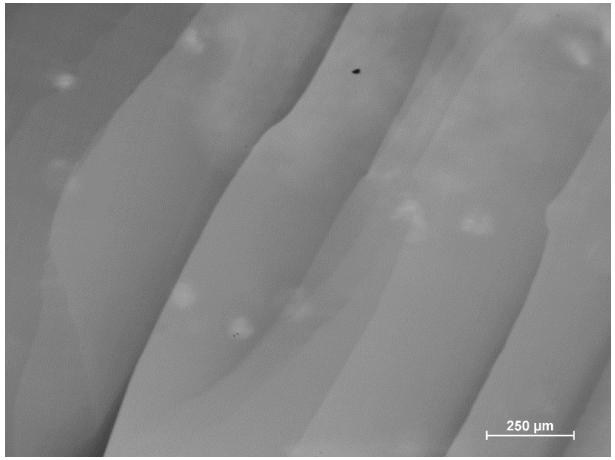
Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Fe-doped GaN

Increasing HCl flow above solid Fe





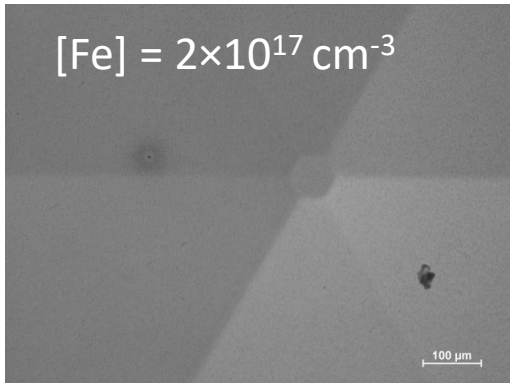


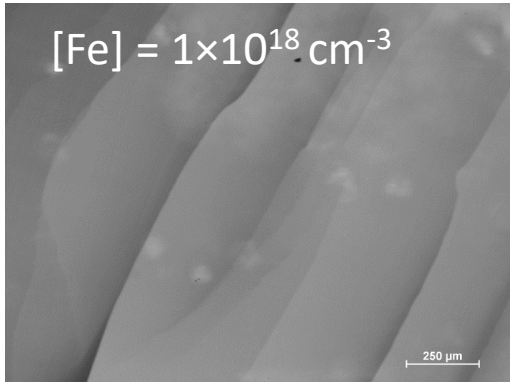
[Fe] [cm^{-3}]	**6×10^{16}**	**2×10^{17}**	**1×10^{18}**
[Si] [cm^{-3}]	1×10^{17}	1×10^{17}	1×10^{17}

Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Fe-doped GaN

Increasing HCl flow above solid Fe

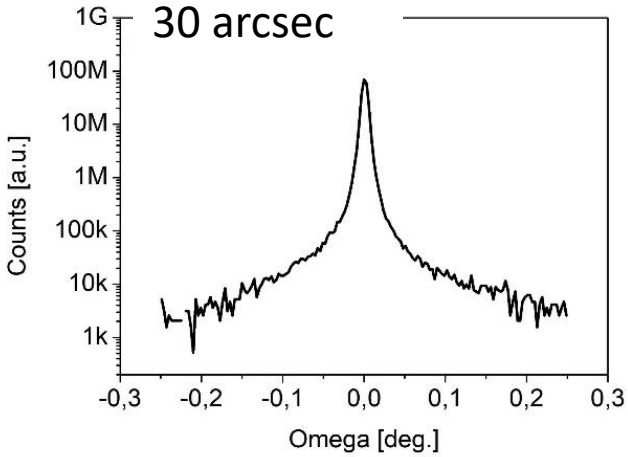


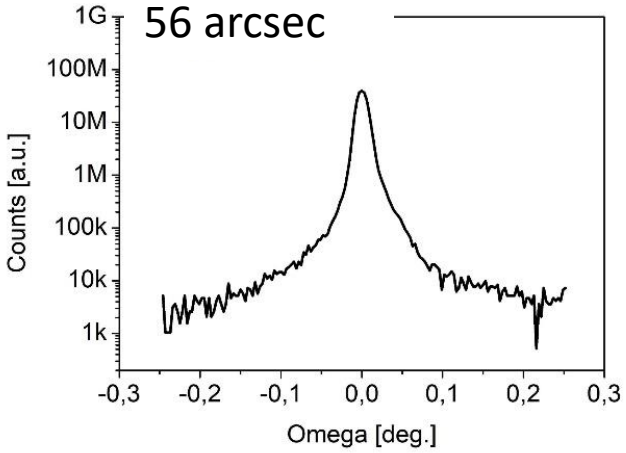


Seed:	FWHM = 30 arcsec	FWHM = 35 arcsec

As-grown layer:

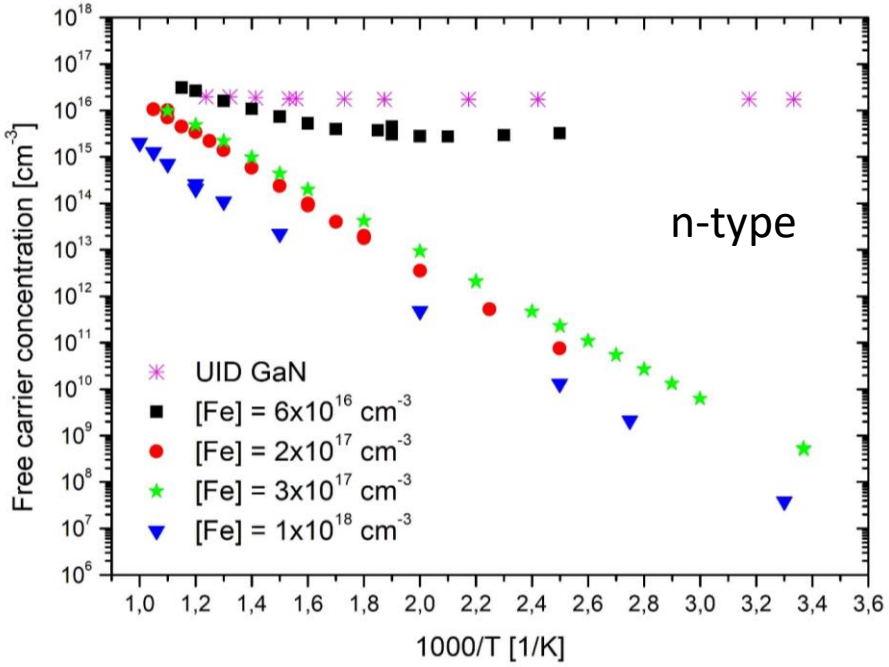
XRD (0002)
RC, beam size
1x10 mm

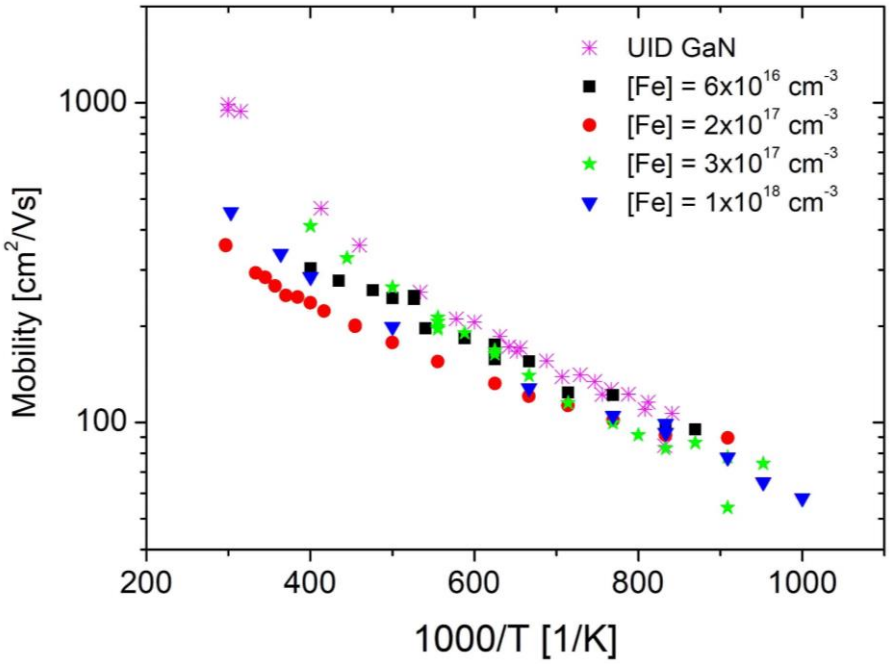




Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Fe-doped GaN

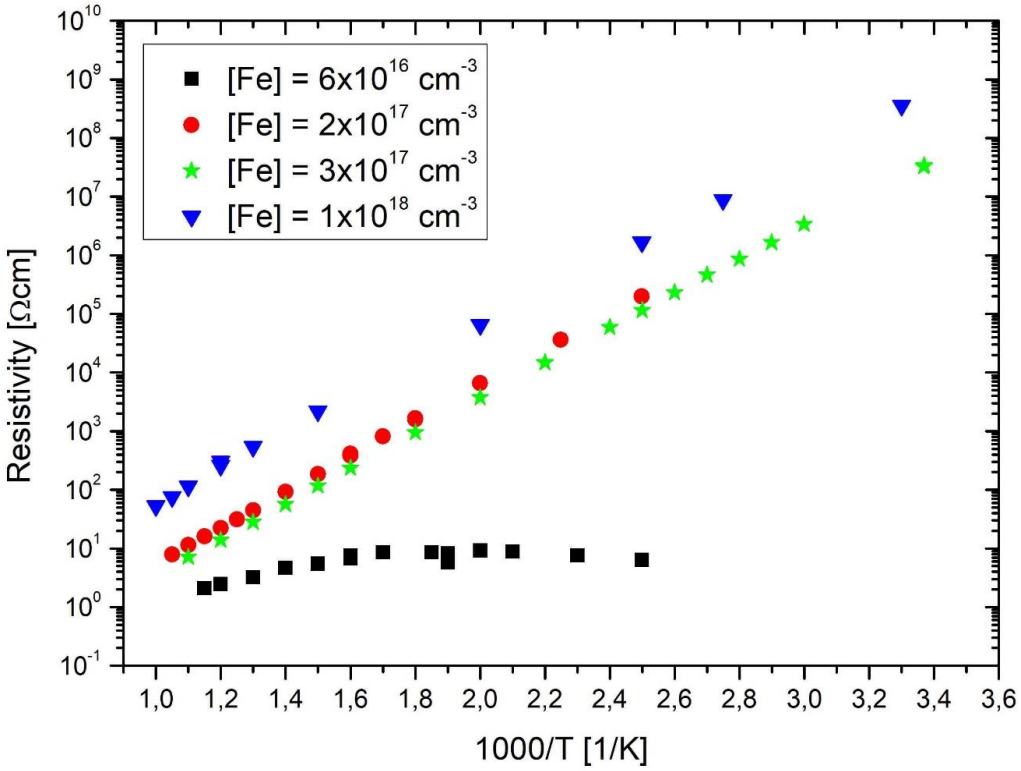




Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Fe-doped GaN

@RT: ρ ~ 10^7 - 10^8 Ωcm

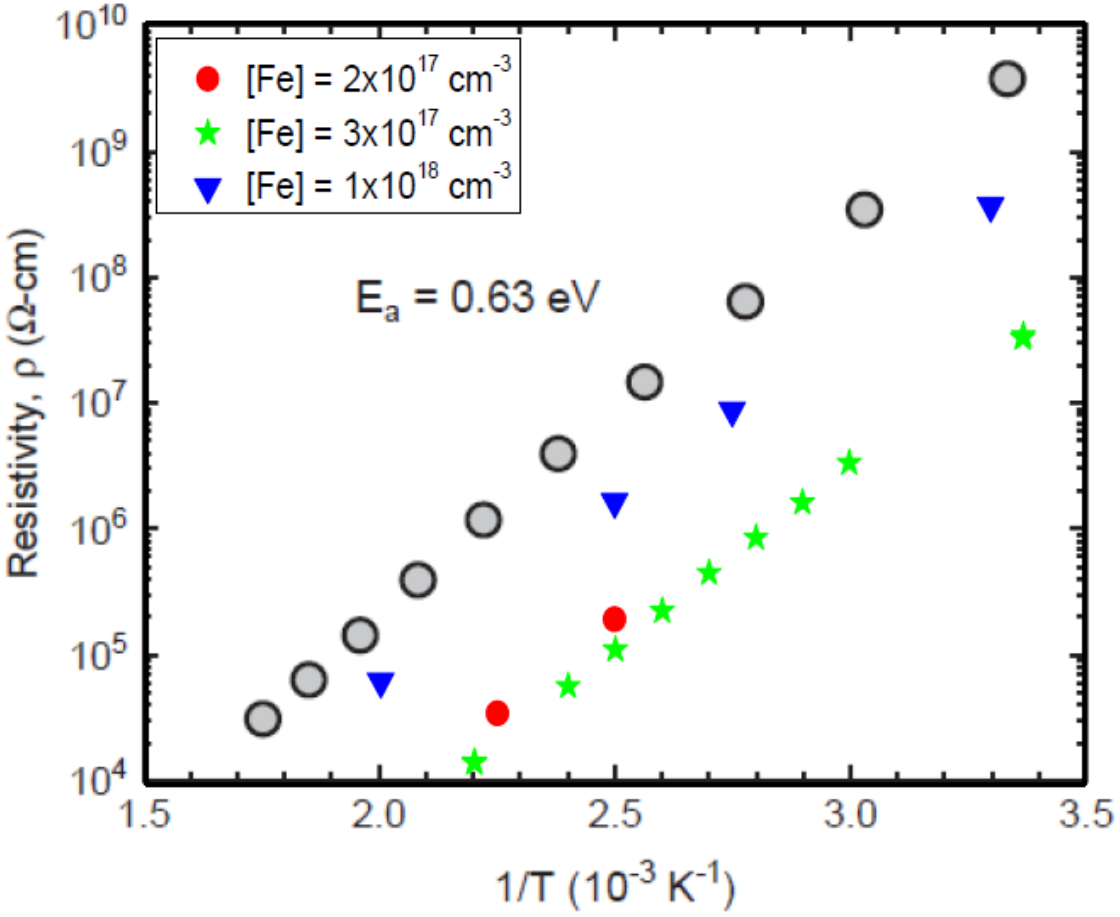


Activation energy ~0.6 eV

Iwinska et al., Jpn. J. Appl. Phys 58, SC1047 (2019)

Fe-doped GaN

- HVPE-GaN:Fe, [Fe] = 1×10^{19} cm^{-3} ([Si] = 2×10^{17} cm^{-3}, [C] = $1 \times 10^{16}$$cm^{-3}$)



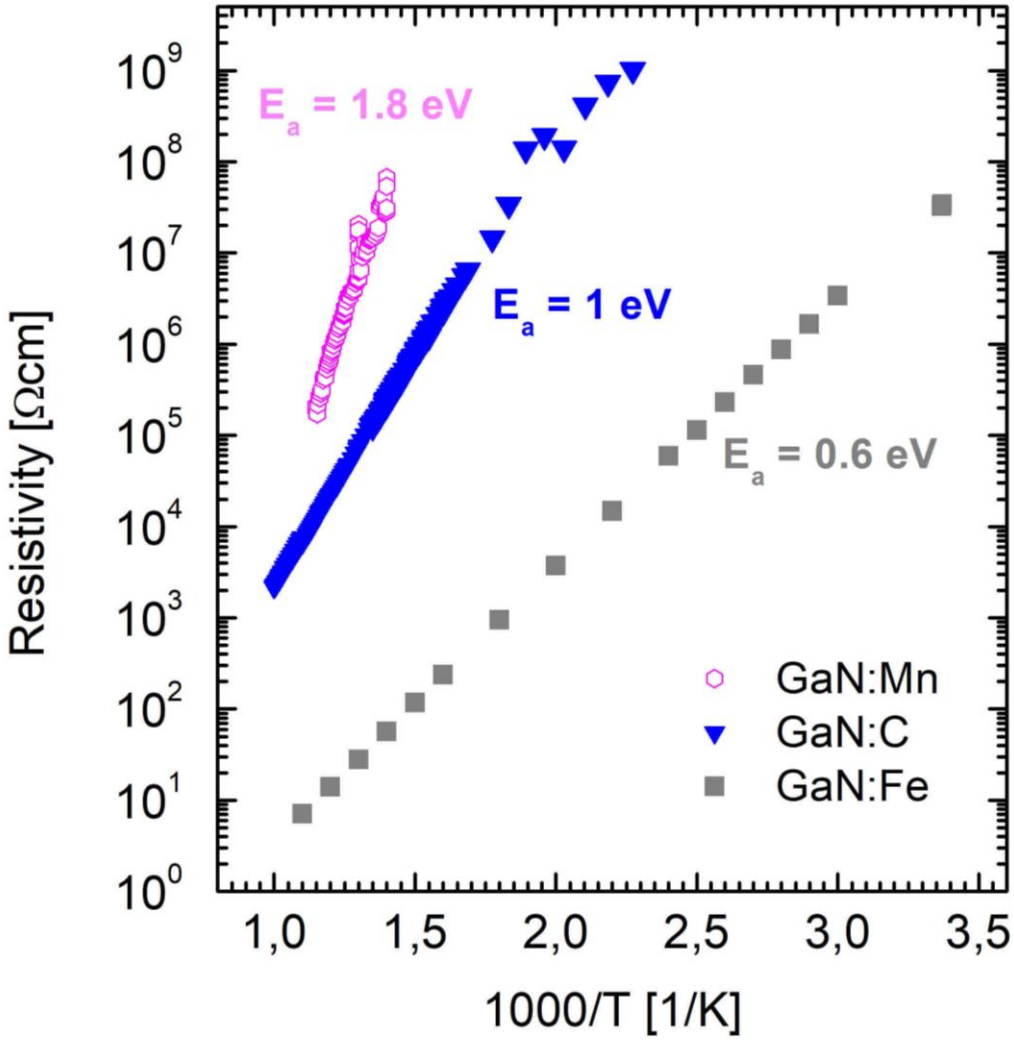
- *H. Tokuda et al.., Jpn. J. Appl. Phys.* ***57****, 071001 (2018)*

Summary

C doping
- p-type at high temperature
- highly resistive crystals
- High thermal conductivity

Mn doping
- n-type at high temperature
- highly resistive crystals

Fe doping:
- n-type
- slight deterioration of structural quality for high [Fe]
- control of free carrier concentration



*M. Bockowski et al., J. Cryst. Growth **499,** 1–7 (2018)*

Acknowledgements

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