Effects of Mg-doping on the Electrical and Optical Properties of InN

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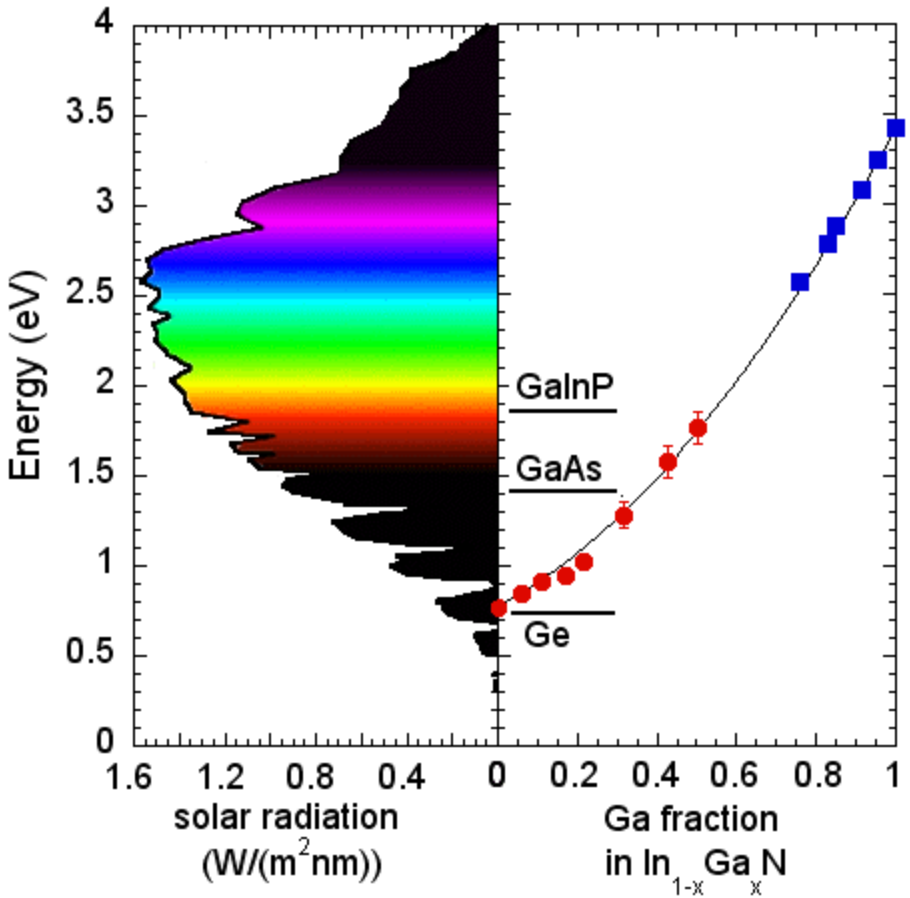
InGaN Multijunction Cells



- **Potential for increased efficiency and decreased cost**

  - Band gap tuning for optimal energies

  - Simplified deposition - only one alloy system

- **Superior radiation resistance[1]**

[1] J. Wu *et al.*, J. Appl. Phys. **94** (2003) 6477 and S. X. Li *et al.*, Phys. Rev. B **71** (2005) 161201(R).

Major Challenge

- Formation of p-type $In_{1-x}Ga_xN$ ($x < 0.7$)
  - Propensity for n-type doping
  - Surface electron accumulation ($2x10^{13}$ to $3x10^{14}$ cm^{-2})

I. Mahboob *et al.*, Phys. Rev. Lett. **92**, 36804 (2004).
S.X. Li *et al.*, Phys. Rev. B **71** (16), 161201 (2005).
H. Lu *et al.*, Appl. Phys. Lett. **82**, 1736 (2003).

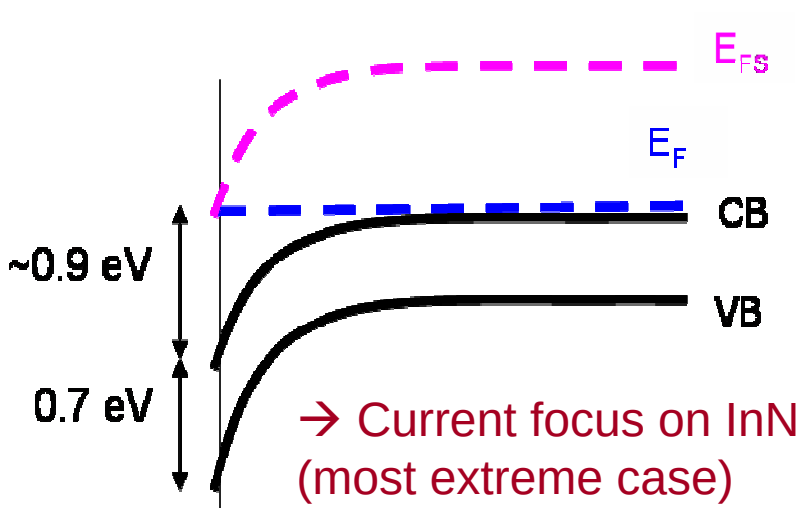
Amphoteric Defect Model

W. Walukiewicz, *Physica* B, **302** (2001) 123.

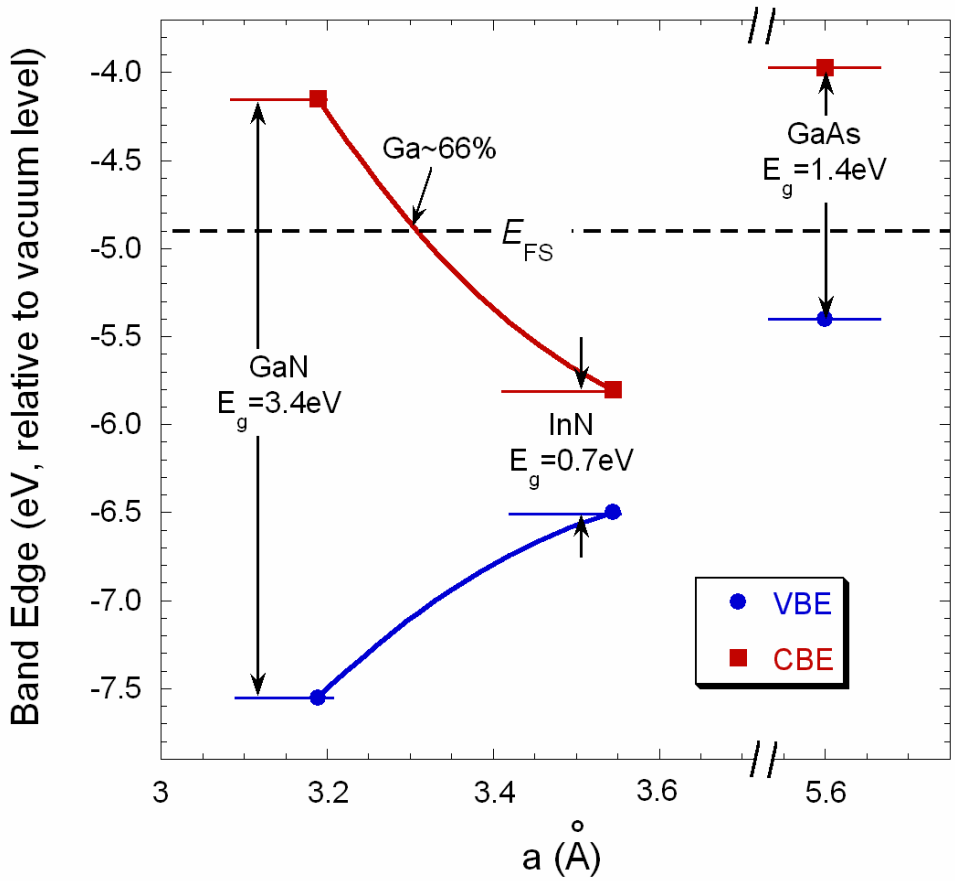
Materials Sciences Division

Explains propensity of In-rich InGaN for n-type conductivity.

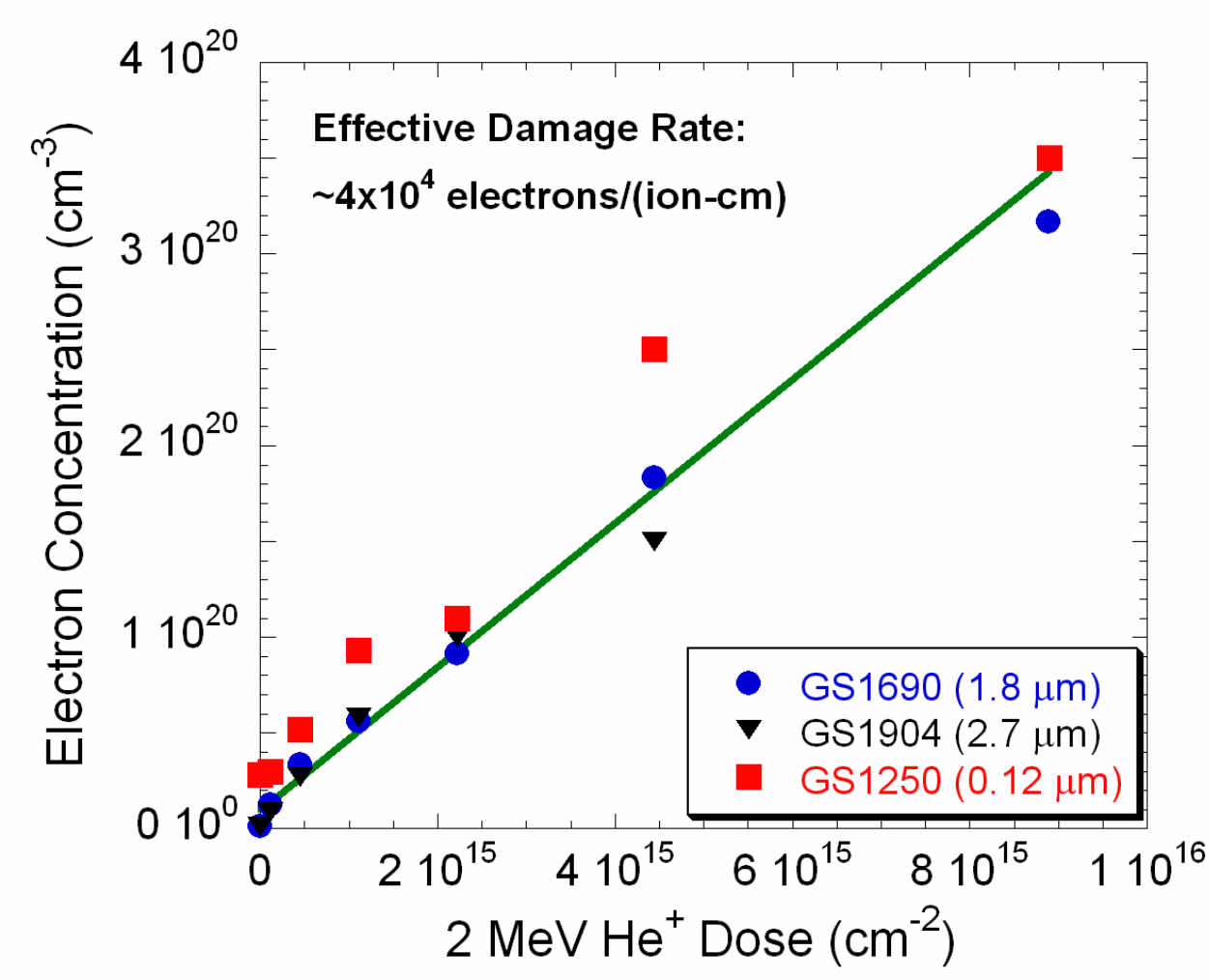
- E_{FS}: average energy level of native defects
  - Position of E_F relative to E_{FS} dictates defect type (donor/acceptor)



→ Current focus on InN (most extreme case)



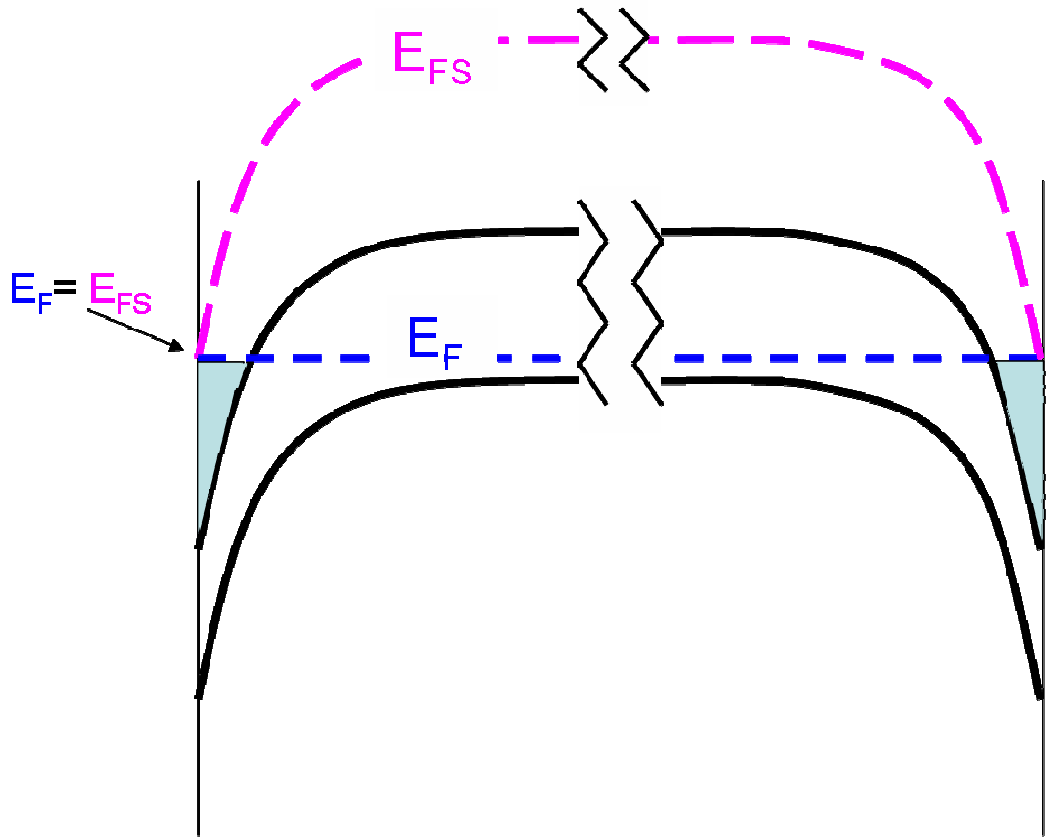
Radiation Defect Doping



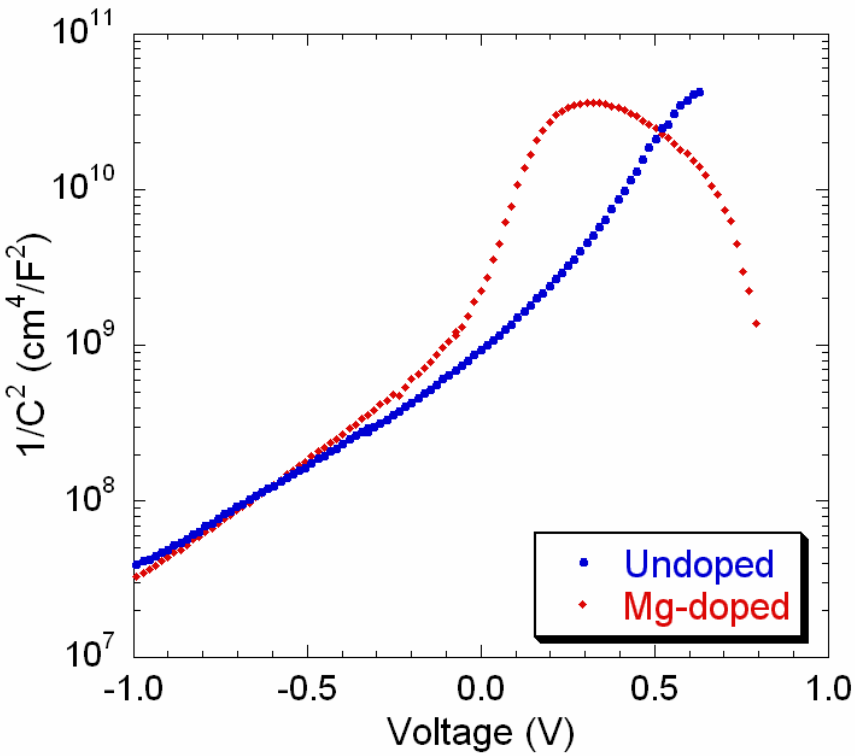
p-type, Mg-doped InN

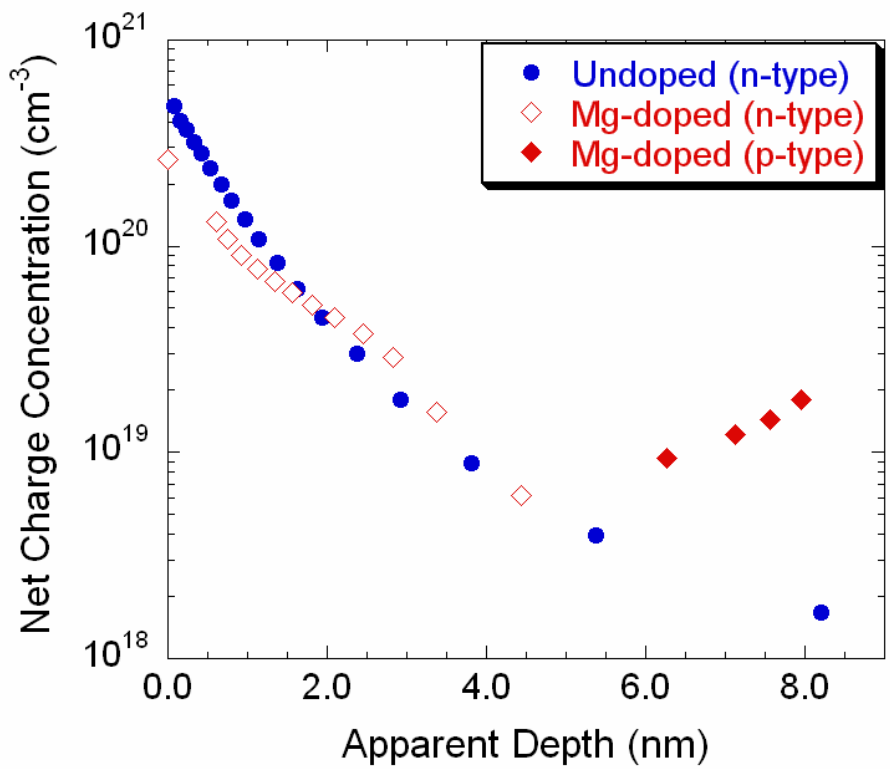
- First indication of p-type InN
  - Mg acceptors
- p-type GaN:Mg has already been realized

R. E. Jones *et al.*, Phys. Rev. Lett. **96** (2006) 125505.



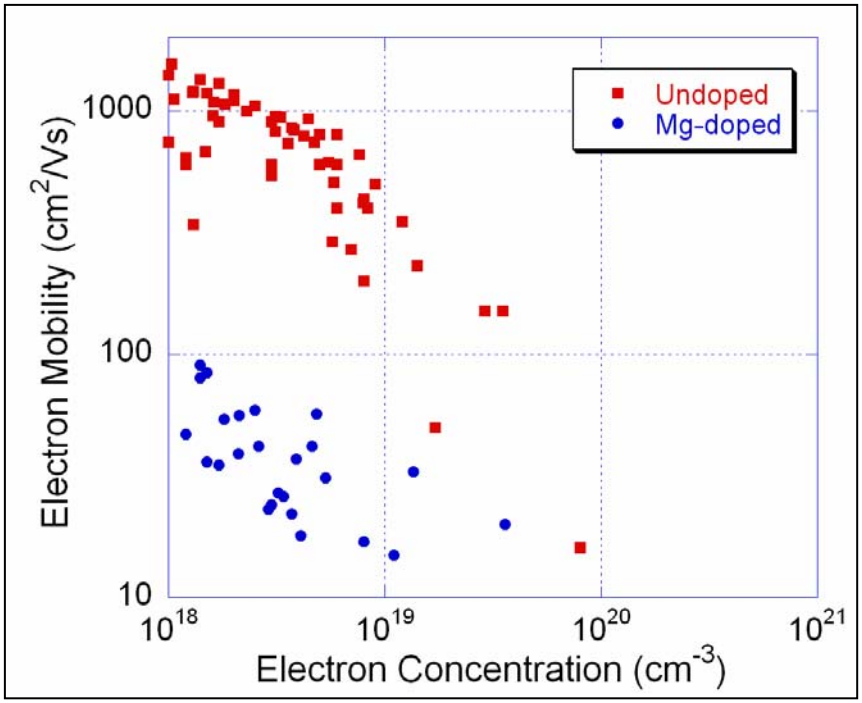
Capacitance-Voltage Measurements



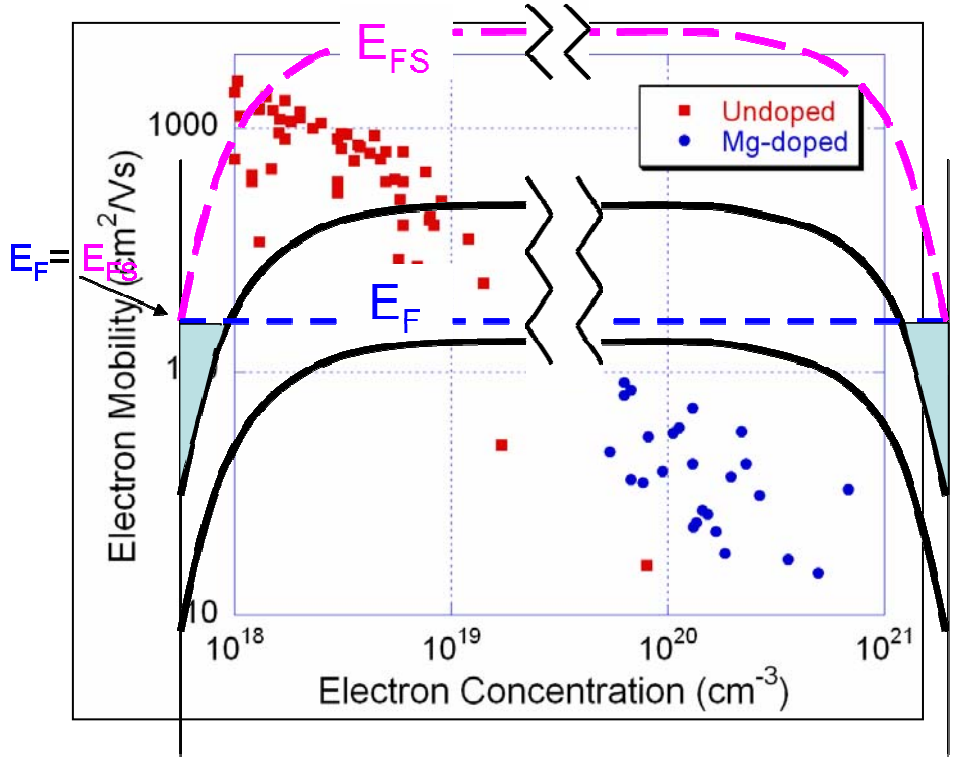


- Slope change consistent with surface electron accumulation/inversion
- Sign of slope -> carrier type

Electron Mobility in InN:Mg

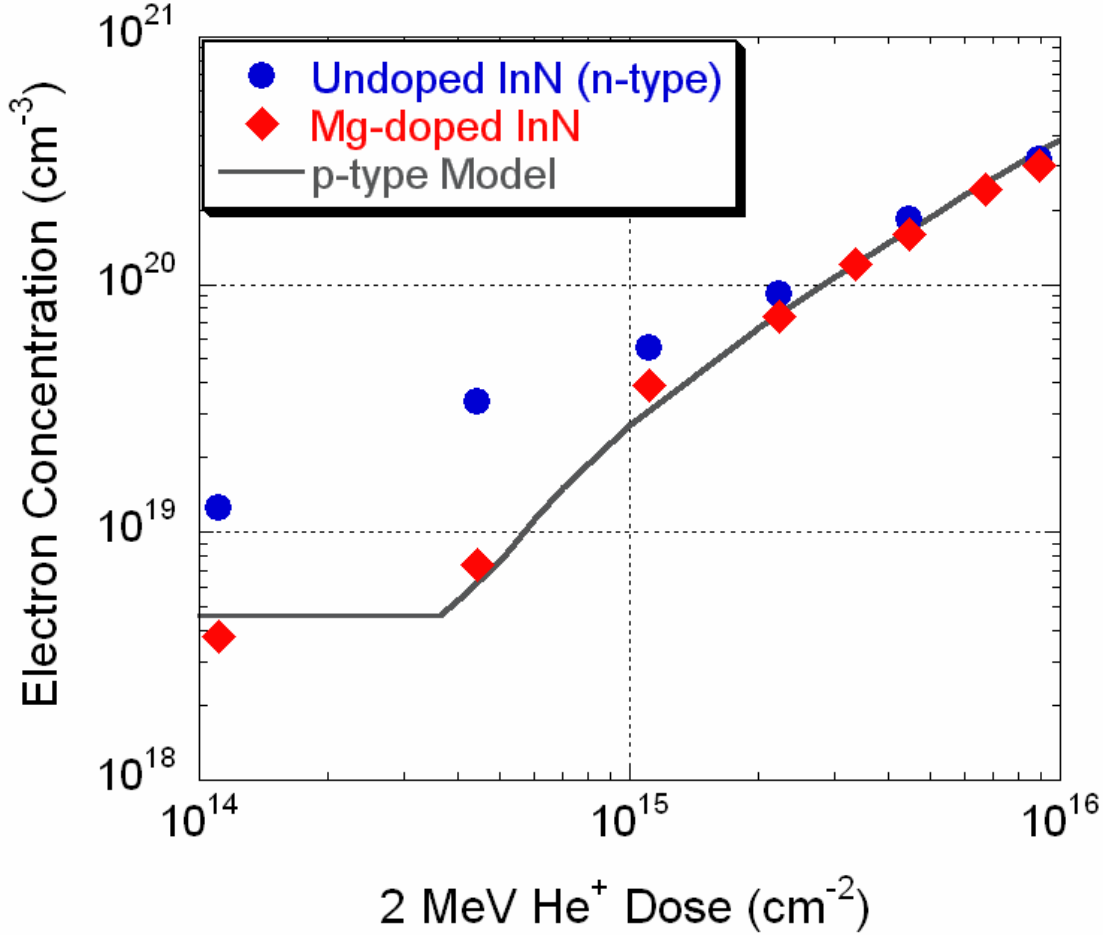


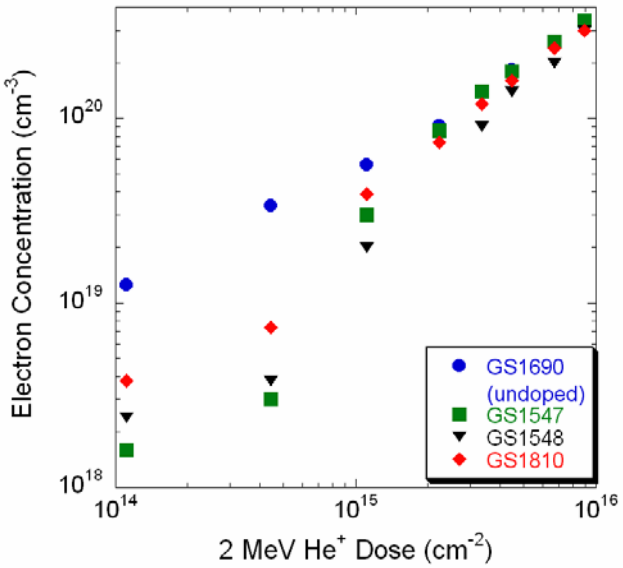
Assuming n-type InN:Mg



Assuming p-type bulk in InN:Mg

Electron Concentration in Irradiated InN:Mg





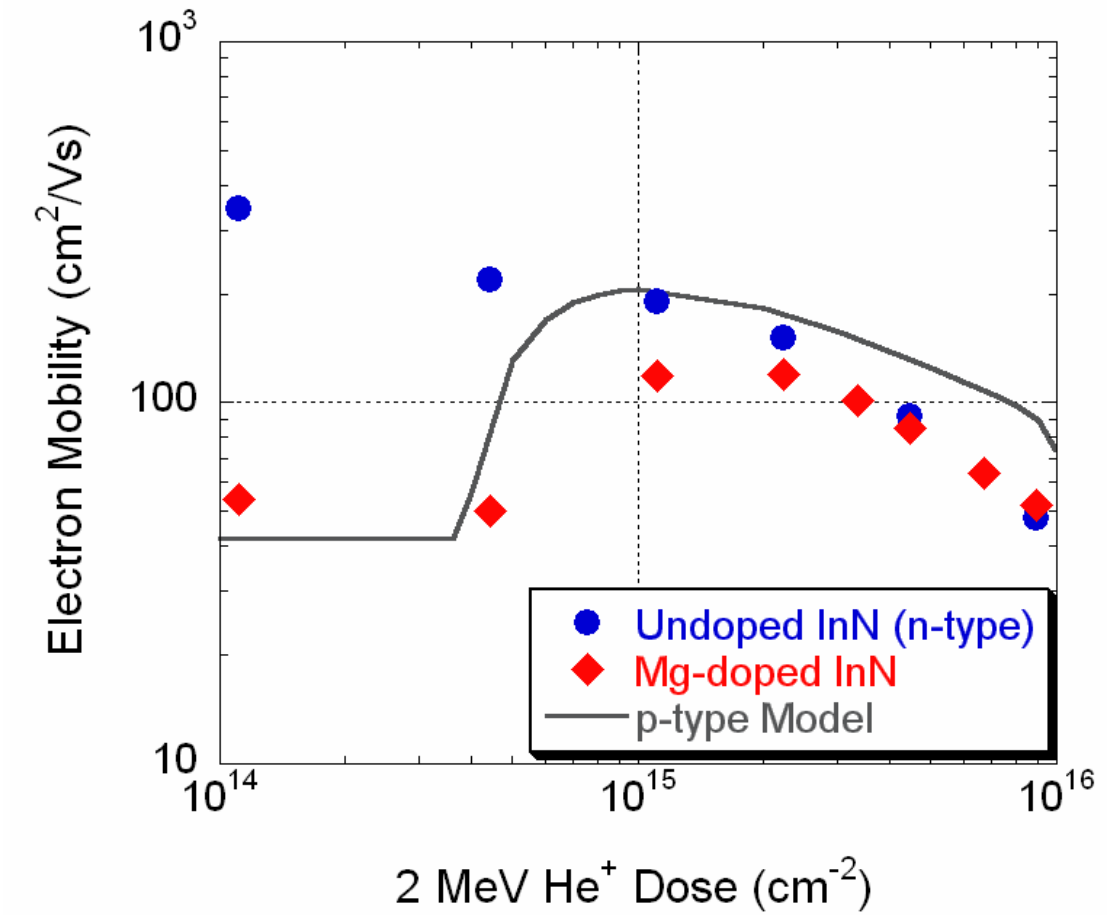
Assumptions:

n_{surf}= 2x10^{14} cm^{-2} μ_{surf}= 42 cm^2/Vs

$$n_{Hall}\mu_{Hall}^2 = n_{surf}\mu_{surf}^2 + n_{bulk}\mu_{bulk}^2$$

$$n_{Hall}\mu_{Hall} = n_{surf}\mu_{surf} + n_{bulk}\mu_{bulk}$$

Electron Mobility in Irradiated InN:Mg

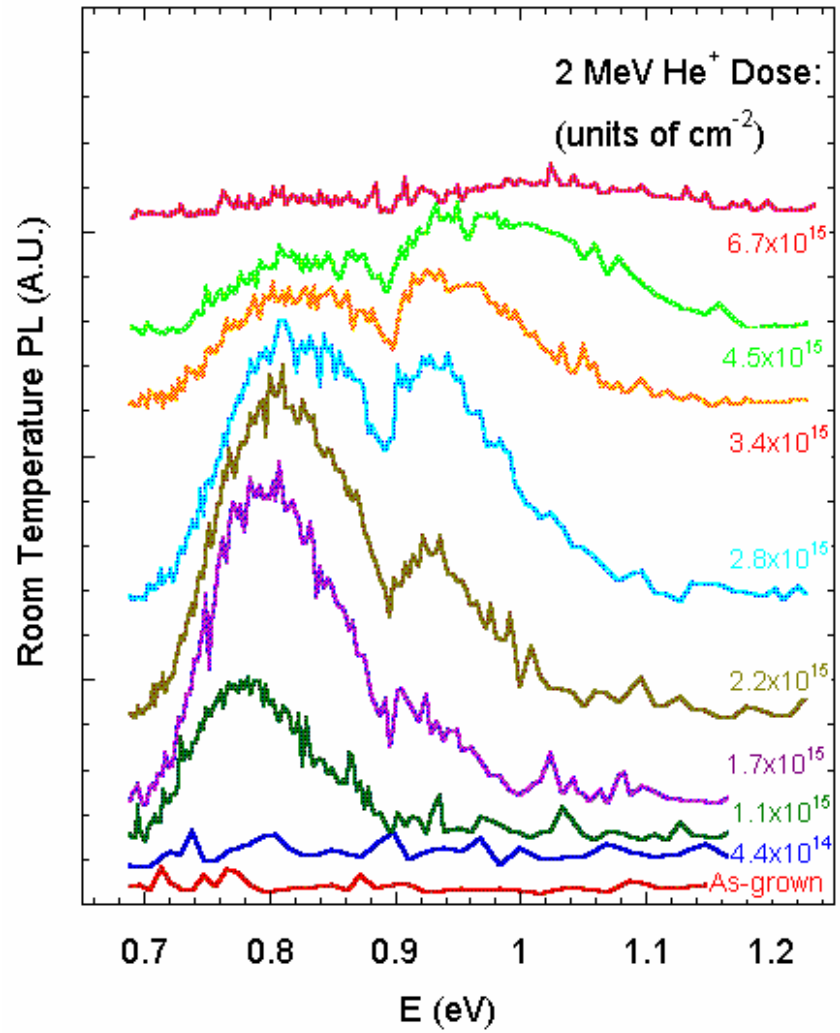


$$n_{Hall}\mu_{Hall} = n_{surf}\mu_{surf} + n_{bulk}\mu_{bulk}$$
$$n_{Hall}\mu_{Hall}^2 = n_{surf}\mu_{surf}^2 + n_{bulk}\mu_{bulk}^2$$

Assumptions:

n_{surf}= 2x10^{14} cm^{-2} μ_{surf}= 42 cm^2/Vs

Photoluminescence of Irradiated InN:Mg



- No PL in as-grown, Mg-doped InN (undoped films have PL)
- PL recovery after conversion of bulk to n-type
- PL quenching at high He^+ doses, as in undoped InN

Note: Spectra are vertically offset

Conclusions

- InGaN: potential for high efficiency, multijunction solar cells
- First demonstration of p-type InN using Mg-acceptors
  - Several different experimental techniques
- Remaining challenges:
  - Contact to p-type material
  - Acceptor ionization energy not yet determined (free hole concentration?)

R. E. Jones *et al.*, Phys. Rev. Lett. **96** (2006) 125505.

Acknowledgements

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