Charge Transport in III-V Nitrides: Polarization and alloy effects

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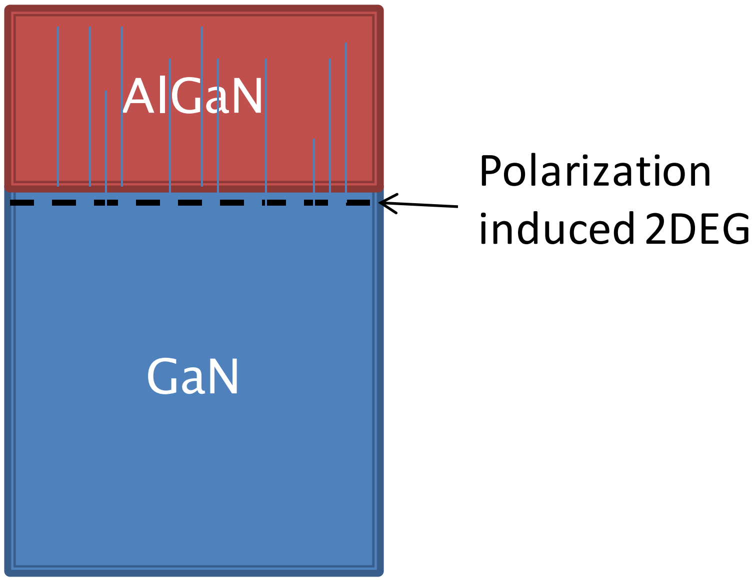
Outline

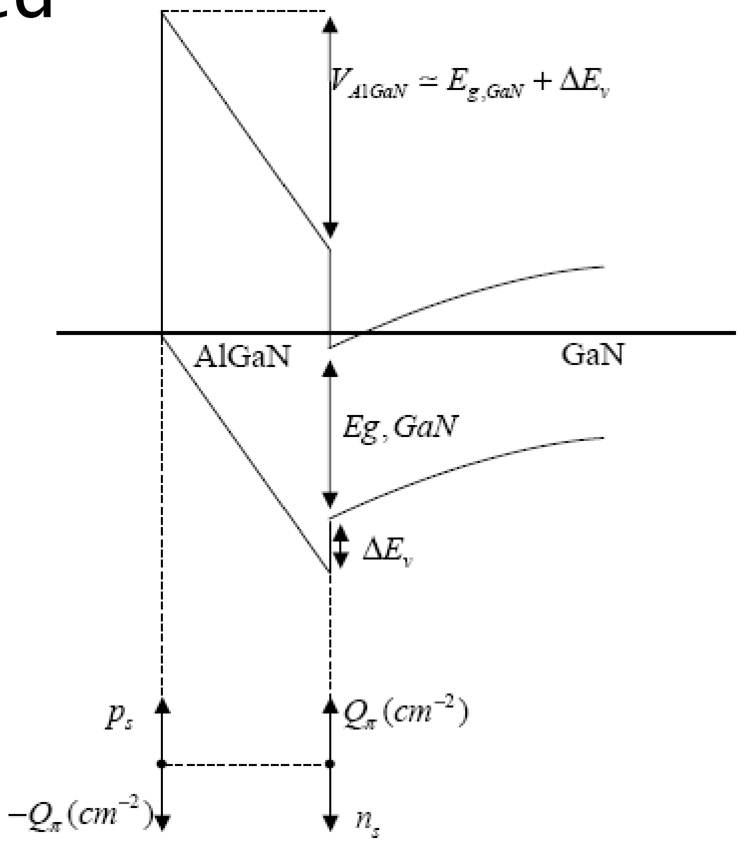
- The problem – Improve GaN HEMT performance
  - Lattice matched InAlN/GaN
  - Alloy scattering
  - AlN spacer
- Our part: Examine alloy scattering

HEMT	RT Mobility (cm^2/Vs)	n_s (cm^{-2})
AlGaN/GaN	1600	1.5e13
InAlN/GaN	320	2.5e13
InAlN/AlN/GaN	1200 – 1600	1.2 – 2.5e13
AlN/GaN	1600	2.5e13

Improving AlGaN/GaN HEMT

- AlGaN not lattice matched

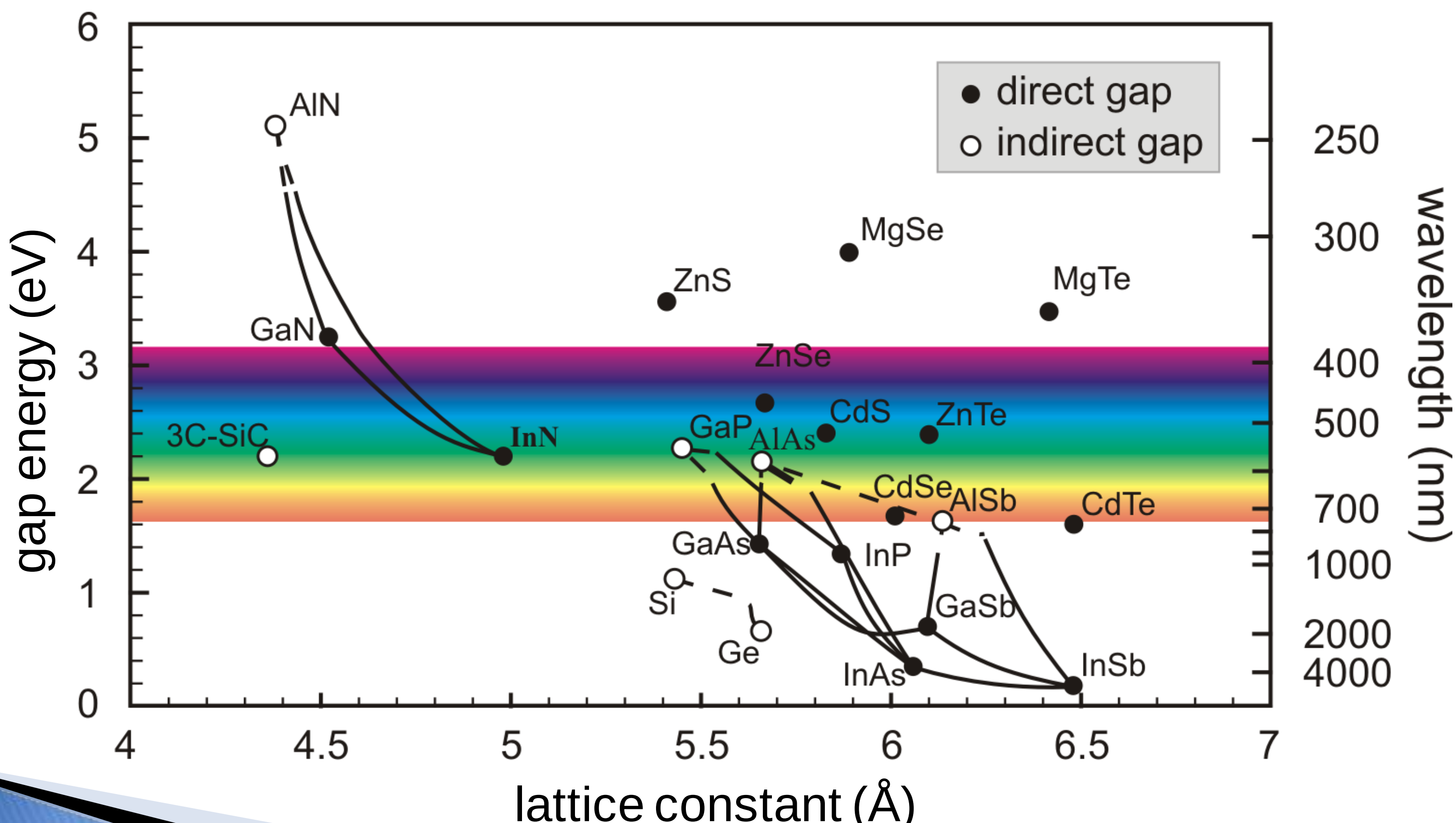




Dislocation & Alloy scattering in AlGaN

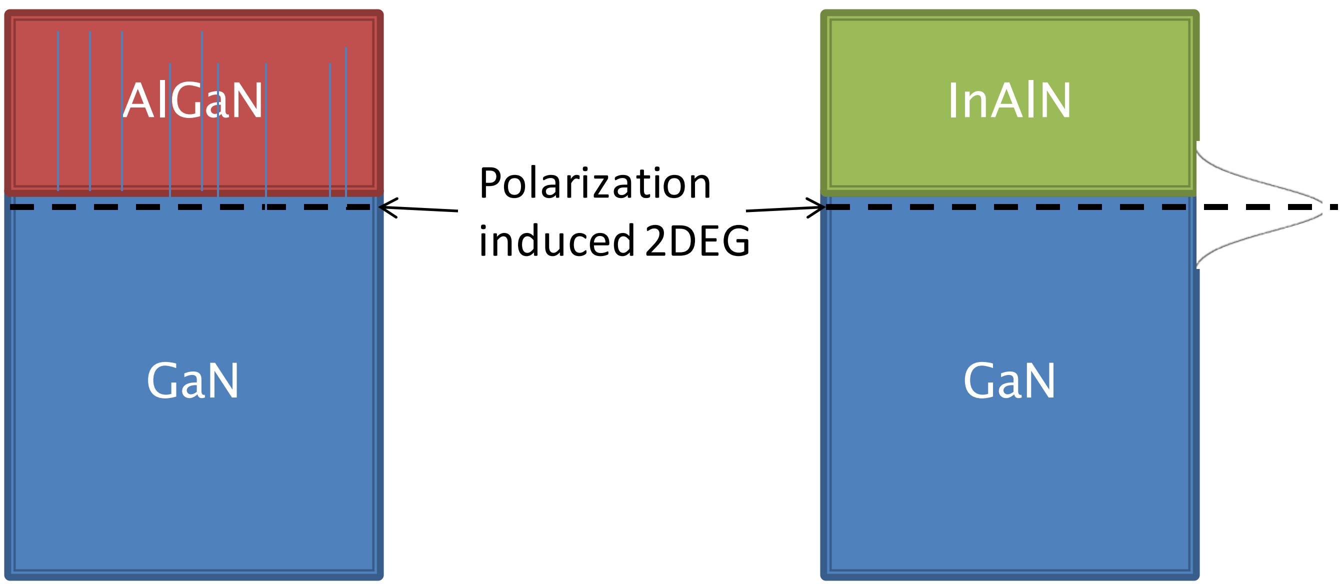
Lattice matched structure

- $In_{0.17}Al_{0.83}N$ is lattice matched to GaN



Improving AlGaN/GaN HEMT

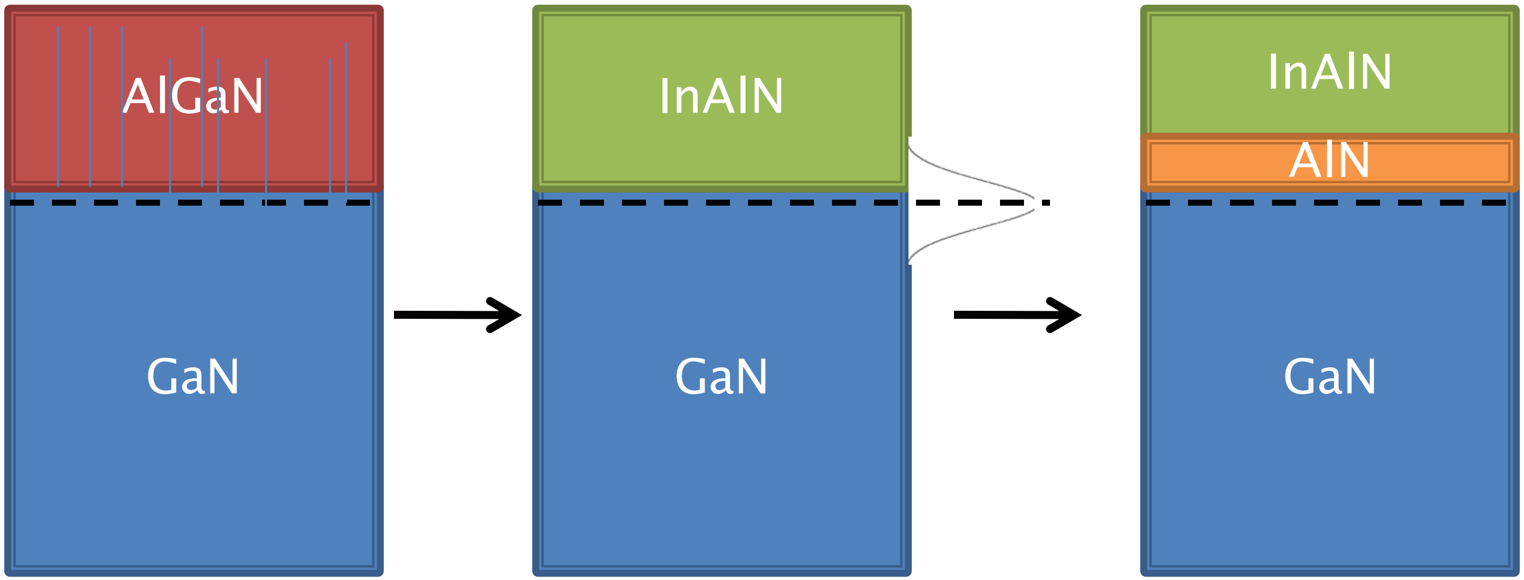
- 2DEG wave function spreads to InAlN



Issue: even stronger alloy scattering

Improving AlGaN/GaN HEMT

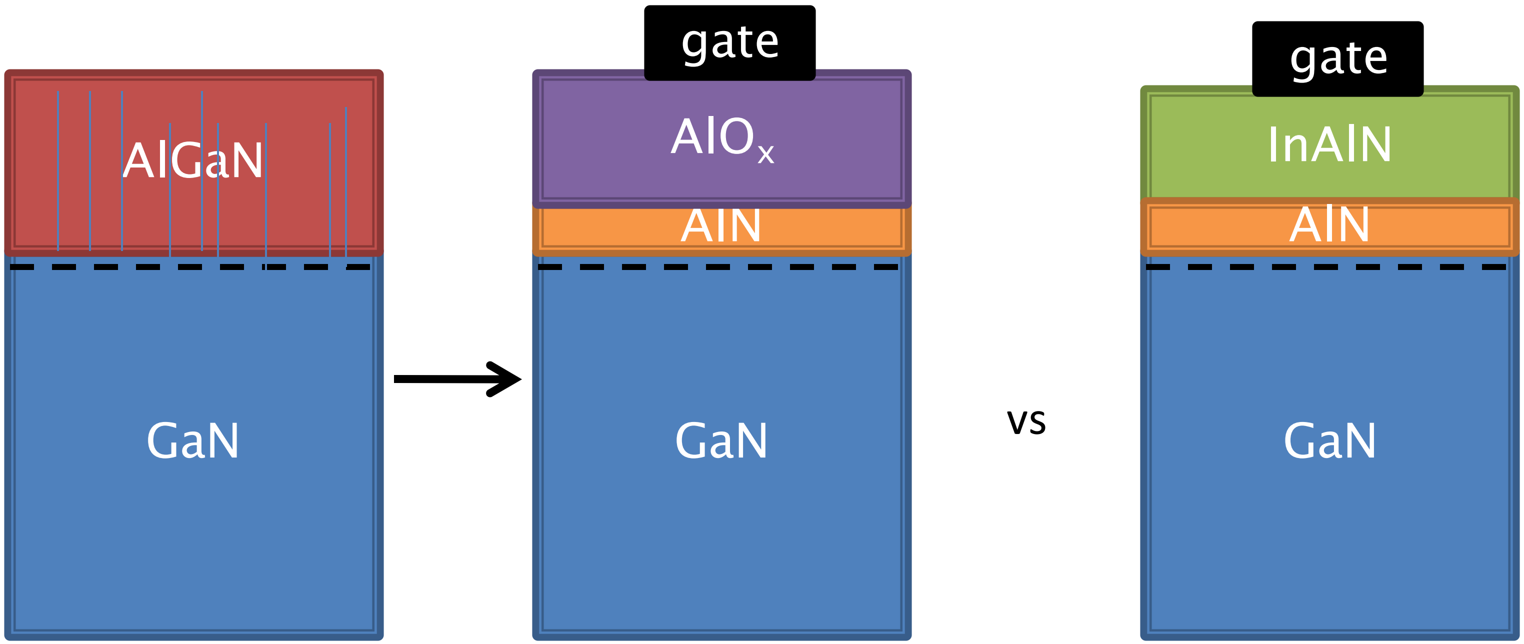
- Insert thin AlN interlayer



it's not an alloy -> no alloy scattering
thin enough -> no dislocations

Improving AlGaN/GaN HEMT

- Comment: Why not AlN/GaN HEMT?



Similar dielectric constant
No need to take out the sample from MBE to make gate insulator

Experimetal work in the field

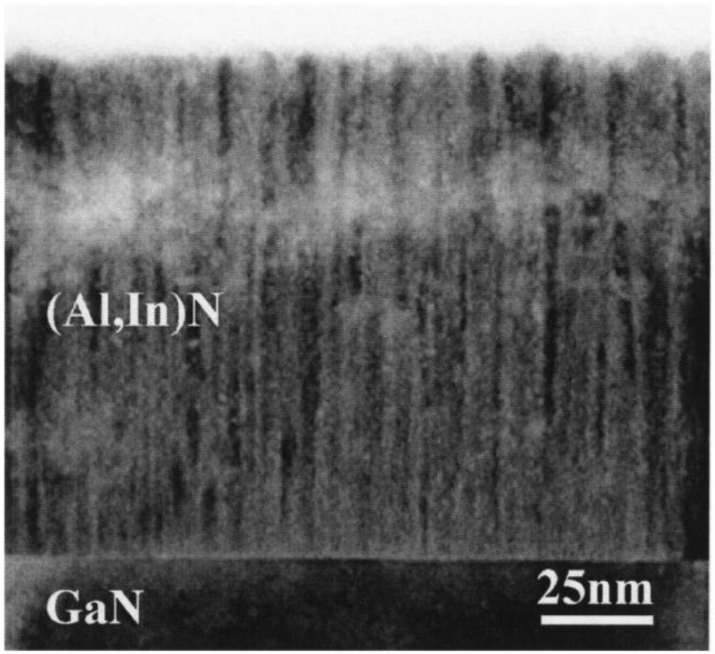
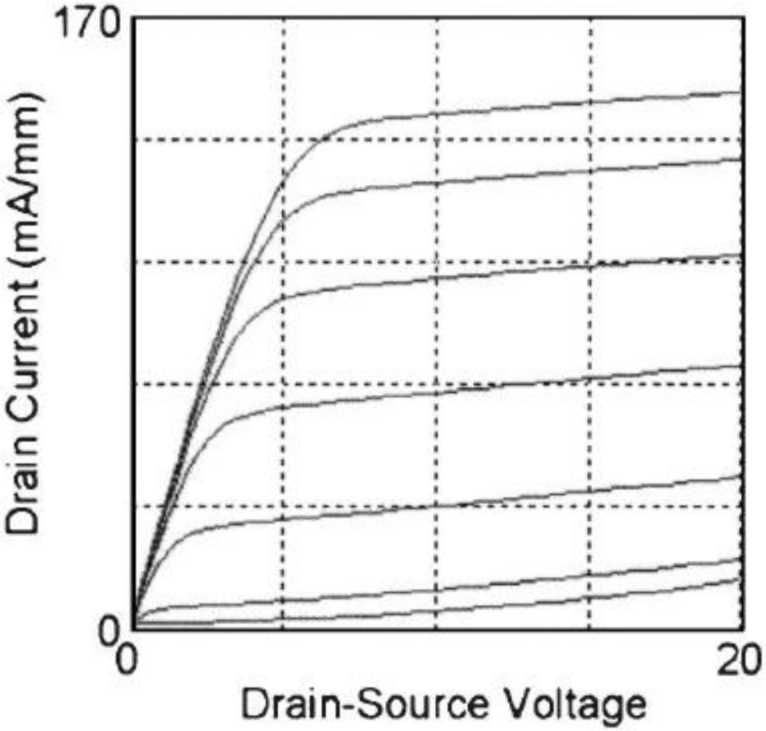


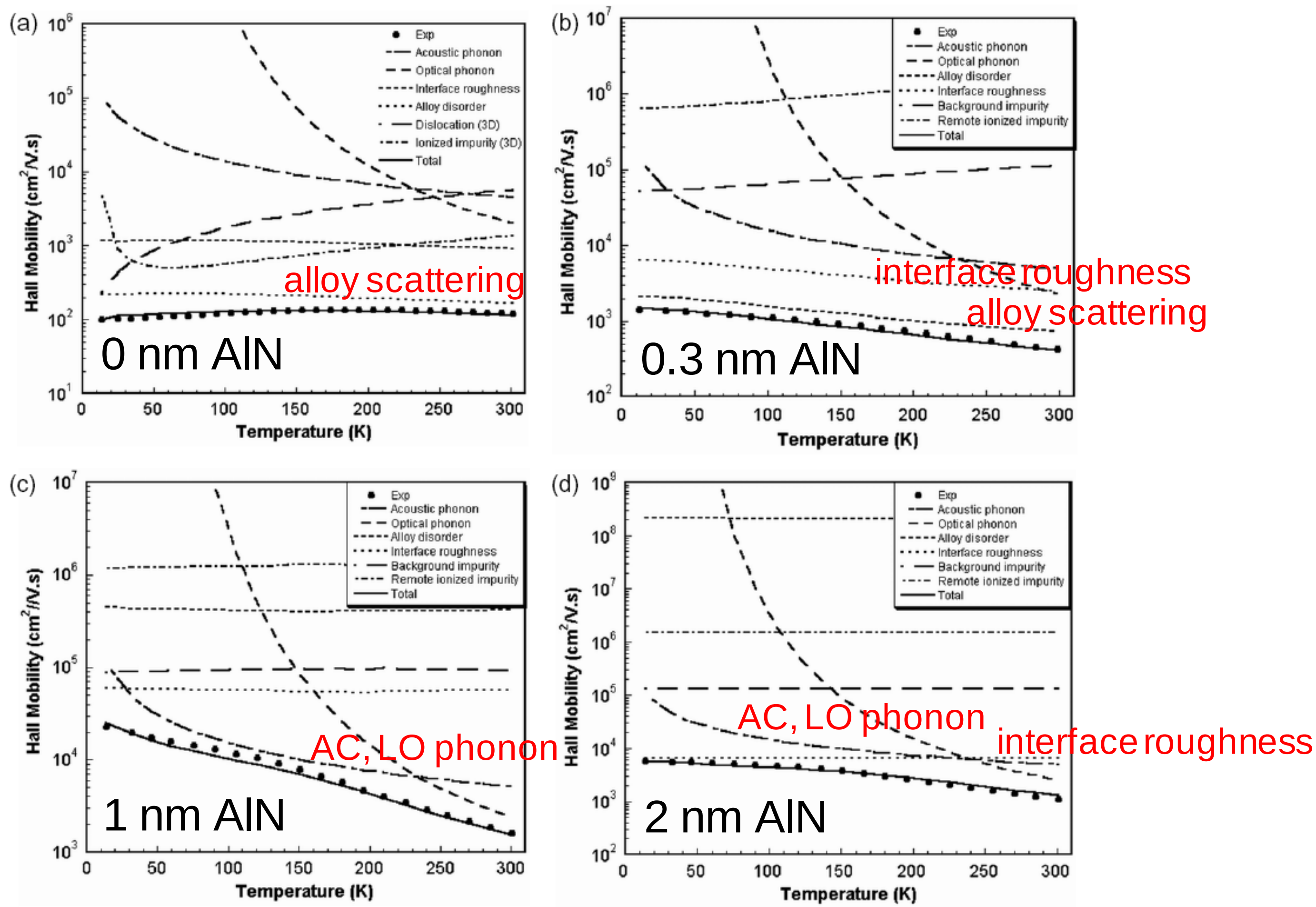
FIG. 3. HR-TEM of 1000 Å InAlN/GaN (sample D) near the interface, showing lateral contrast modulation. This may be due to composition modulation or strain modulation in the InAlN.



Possible to make it – dislocation free
μ=320 cm^2/Vs, n_s=2e13 cm^{-2}

Molecular beam epitaxy of InAlN/GaN heterostructures for HEMTs, D. S. Katzer et al., **J. Vac. Sci. Tech. B 23, 1204, 2005**

Theoretical work in the field



Scattering in such structures are studied

The effect of AlN interlayer thicknesses on scattering processes in lattice-matched AlInN/GaN 2DEG heterostructures, A. Teke et al., *New J. of Physics* ***11 (2009) 063031***

Bound states in GaN 2DEG

- Wave function spread out to the alloy
- Fang-Howard model

$$\chi(z) = \begin{cases} 0 & z \leq 0 \\ \sqrt{\frac{b^3}{2}}\, z e^{-\frac{bz}{2}} & z \geq 0 \end{cases}$$

Wavefunction vanishes at the barrier

- Modified Fang-Howard model

$$\chi(z) = \begin{cases} M e^{\frac{\kappa_b z}{2}} & z \leq 0 \\ N(z + z_0) e^{-\frac{bz}{2}} & z \geq 0 \end{cases}$$

$\chi(z)$ leaks into the barrier

- „Modified modified" Fang-Howard model

$$\chi(z) = \begin{cases} L e^{\frac{\kappa_b z}{2}} & z \leq -a \\ M_1 e^{\frac{\kappa_a z}{2}} + M_2 e^{\frac{\kappa_a z}{2}} & 0 \geq z \geq -a \\ N(z + z_0) e^{-\frac{bz}{2}} & z \geq 0 \end{cases}$$

$\chi(z)$ leaks into the AlN interlayer and into the InAlN layer as well

Alloy scattering in InAlN

- Theoretical model

$$\frac{1}{\tau_{alloy}(E)} = \frac{2\pi}{\hbar} \Omega_0 U_0^2 x(1-x) g_{3D}(E) O(E)$$

↑ The potential ↑ =1, alloy ordering

- Virtual crystal
  - Actual potential: $V(r) = \sum_{R_A} V_A(r - R_A) + \sum_{R_B} V_B(r - R_B) + \sum_{R_C} V_C(r - R_C)$
  - Split into virtual crystal compoment & a fluctuating potential:

$$V(r) - W(r) = \sum_{R_A} (1-x)\delta V(r - R_A) + \sum_{R_B} -x\delta V(r - R_B)$$

$$\delta V(r) = V_A(r) - V_B(r)$$

„Alloy scattering in AlGaN and InGaN: A numerical study," E. Belotti et al., J. of Applied Physics 101, 123706 (2007)

Alloy scattering in InAlN

- We arrive to the expression

$$\frac{1}{\tau_{alloy}(E)} = m_1 \frac{\Omega_0}{\hbar^3} \delta V^2 x(1-x) \int_L \chi^4(z)dz$$

where

$\delta V(r) = V_A(r) - V_B(r)$ the conduction band offset

and

$$\mu_{alloy} = \frac{e\tau_{alloy}(E)}{m_1}$$

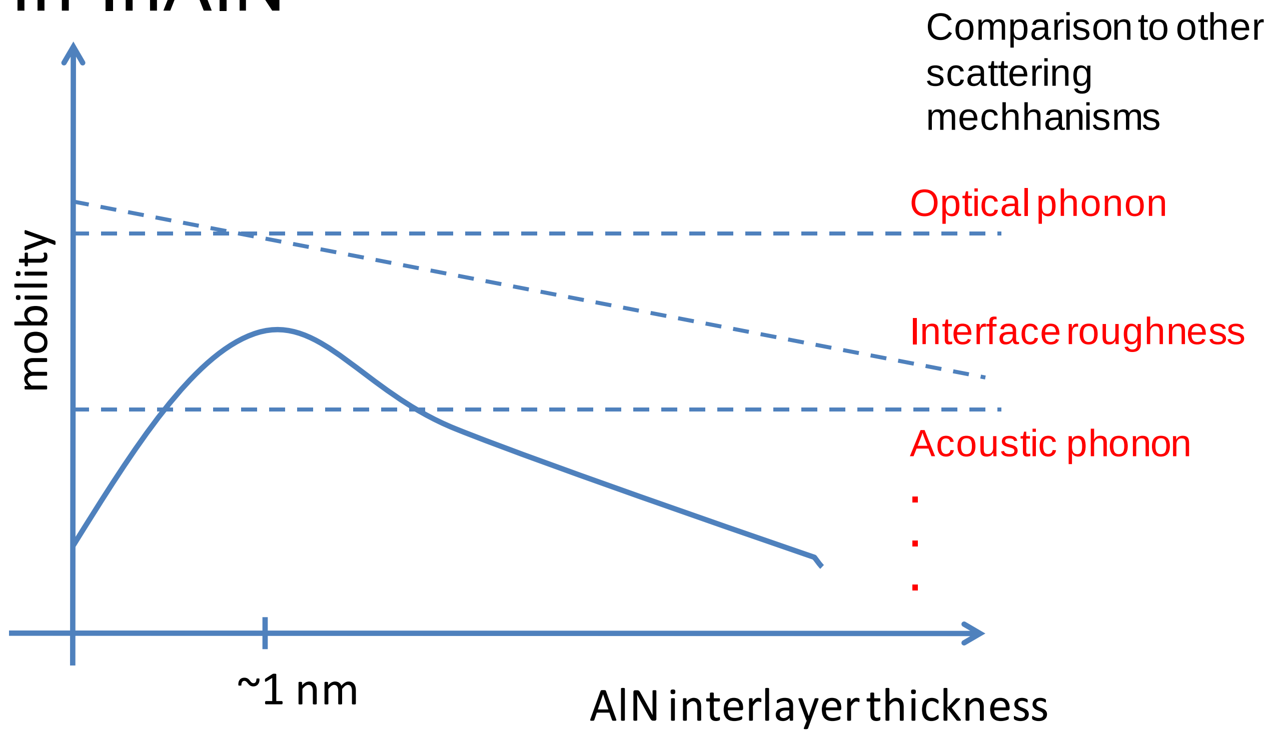
$\delta V(r) * 0.8$ gives better fit in practice due to alloy disorder

Band stucture calculation

- 1D Poisson to find out:
  - band offset
  - 2DEG charge density

Proposed result of the work

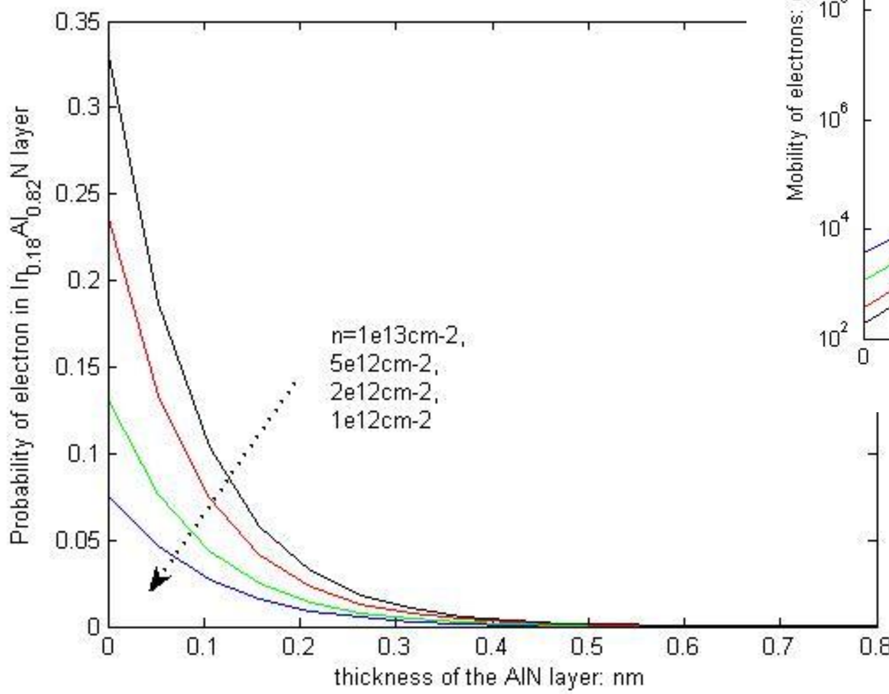
- τ_{alloy} in InAlN

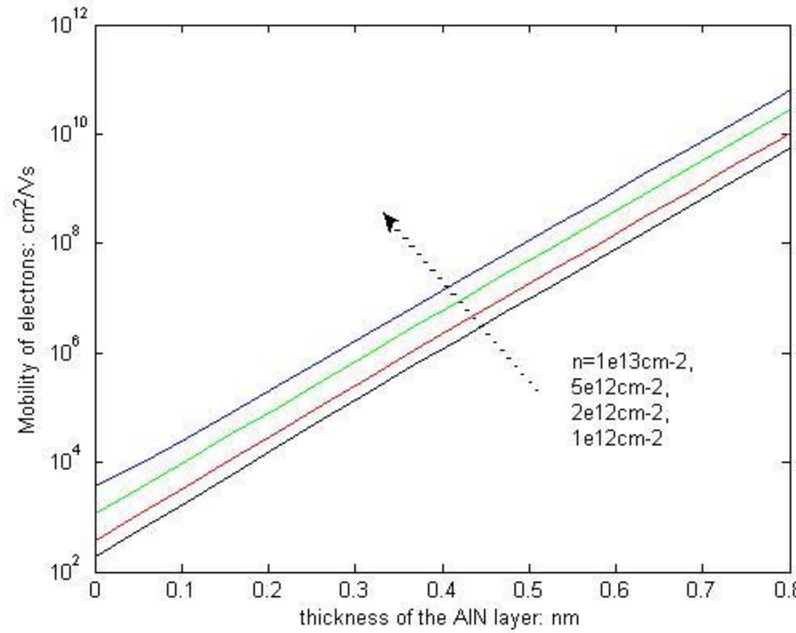


- Is that a „large perturbation”?

Preliminary results

- Wave function penetration into the InAlN layer

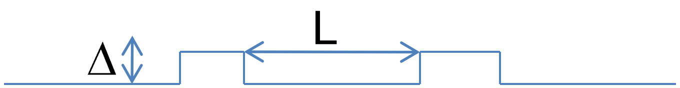


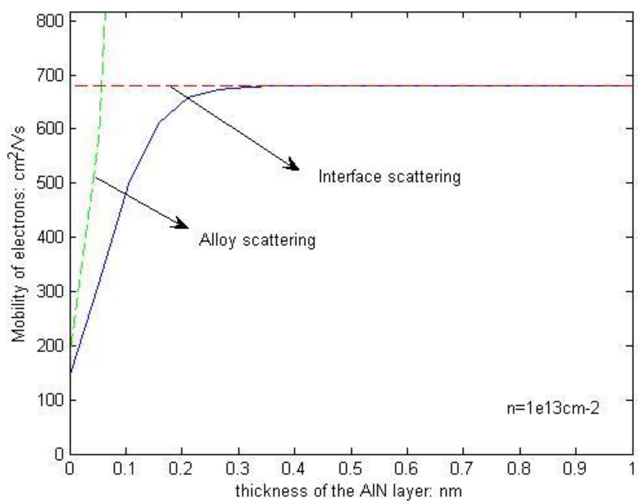


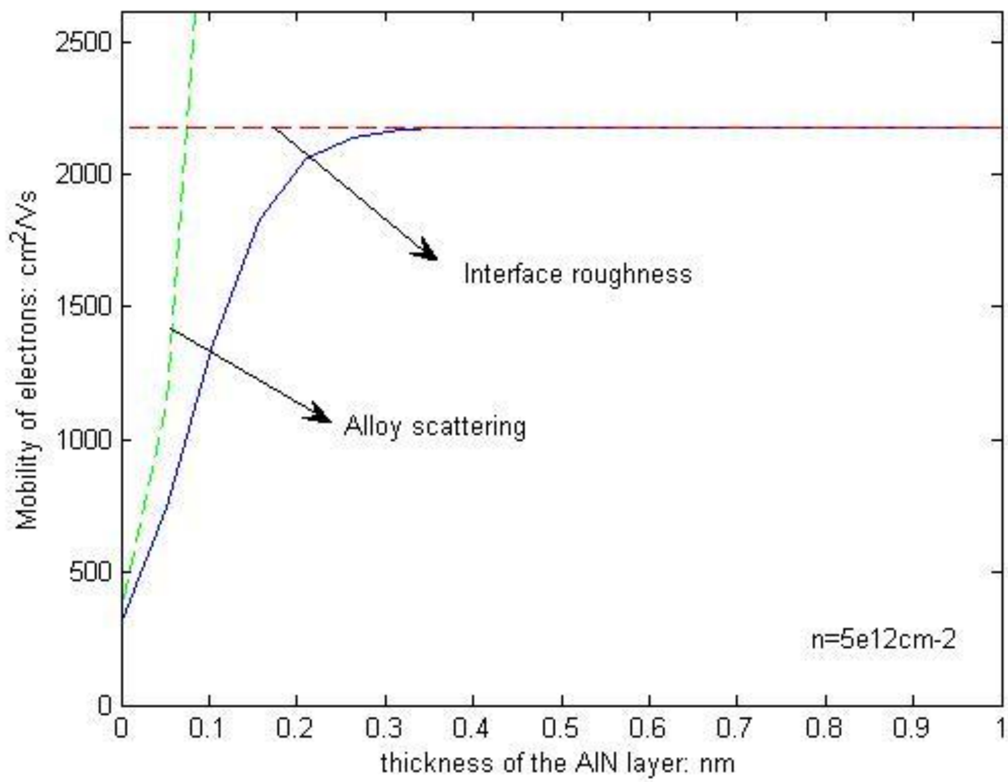
- Limitation of mobility posed by alloy scattering

Preliminary results

- Combined with interface roughness scattering
  - $\Delta = 2.5\text{Å}$, $L = 2.0$ nm







Summary

- Wave function
  - 2DEG spread out to alloy/interlayer
- Band structure
  - At different AlN interlayer thicknesses
- Scattering rate in alloy
  - Leads to mobility
- Other scattering effects

Questions

- Indium clustering? (decrease bandgap)
- AlInN 1D Poisson parameters?

Thank you for your attentention!