Contact Modeling and Analysis of InAs HEMT

Seung Hyun Park, Mehdi Salmani-Jelodar, Hong-Hyun Park, Sebastian Steiger, Michael Povoltsky, Tillmann Kubis, and Gerhard Klimeck

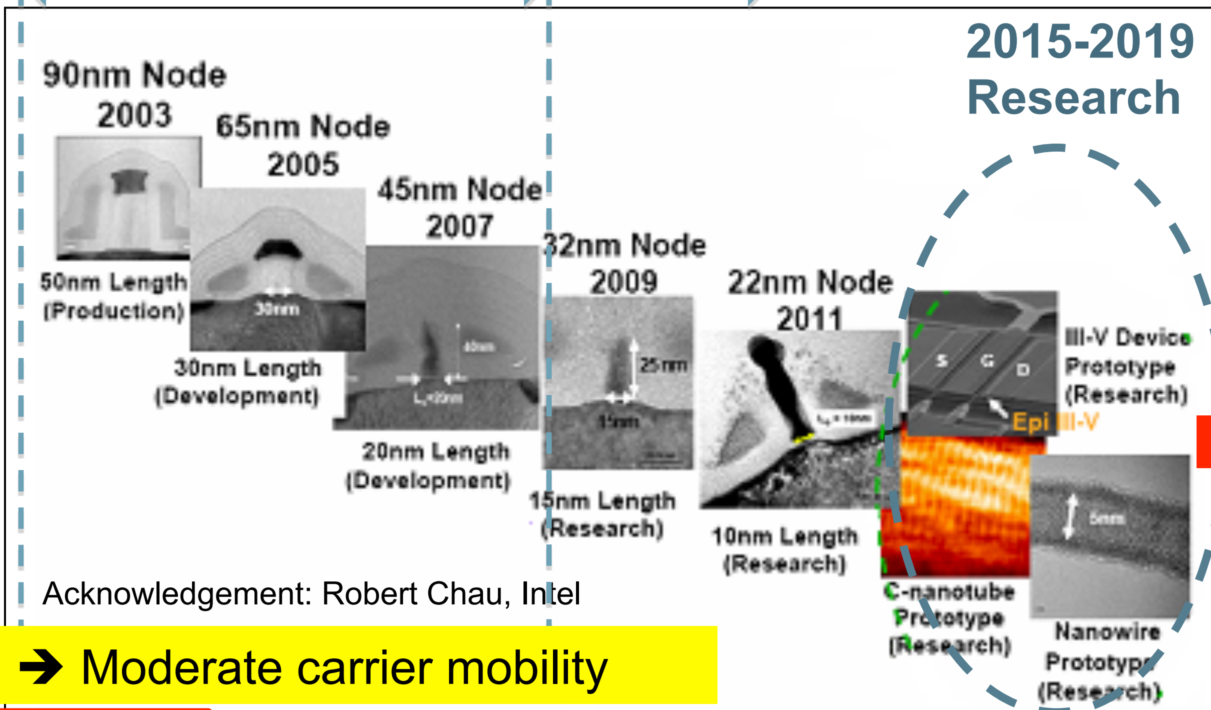
Network for Computational Nanotechnology (NCN)
Electrical and Computer Engineering
Purdue University

Towards III-V MOSFET

- Channel doping
- S/D doping

- Strained-Si channel
- High-k dielectrics

- Device geometries
- Channel materials
- High-k dielectrics and metal gates



New Channel Materials

Limitation of Si ➔ Moderate carrier mobility

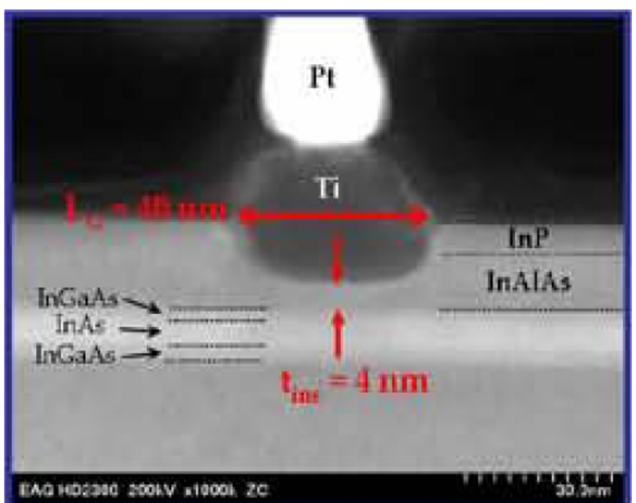
	Si	strained Si	bulk Ge	GaAs	GaN	InP	$In_{0.53}Ga_{0.47}As$	InAs	InSb
μ_e	400	1,000	3,900	8,500	1,250	5,400	8,000	20,000	30,000
μ_h	160	240	1,800	400	850	200	300	500	800
E_g (eV)	1.1	1.1	0.66	1.42	3.4	1.35	0.72	0.36	0.18

Why HEMTs?

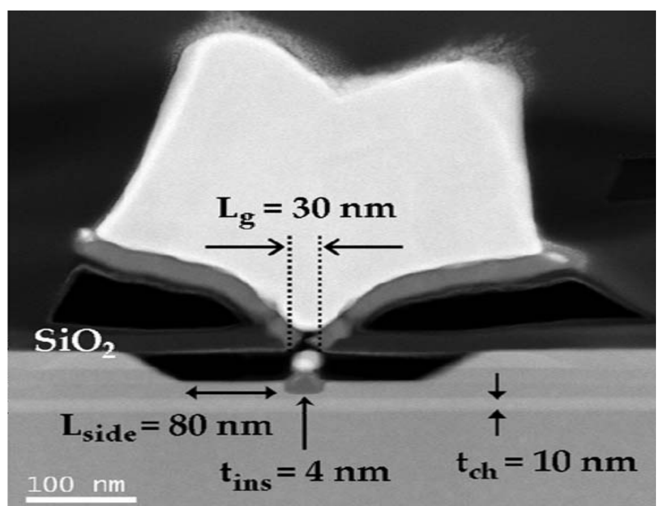
- **III-V**: Extraordinary electron transport properties and high injection velocities
- **HEMTs**: Similar structure to MOSFETs ***except high-κ dielectric*** layer
- **Excellent to Test Performances** of III-V material without interface defects
- **Short Gate Length HEMTs are Introduced by del Alamo's Group at MIT**
- **Excellent to Test Simulation Models**

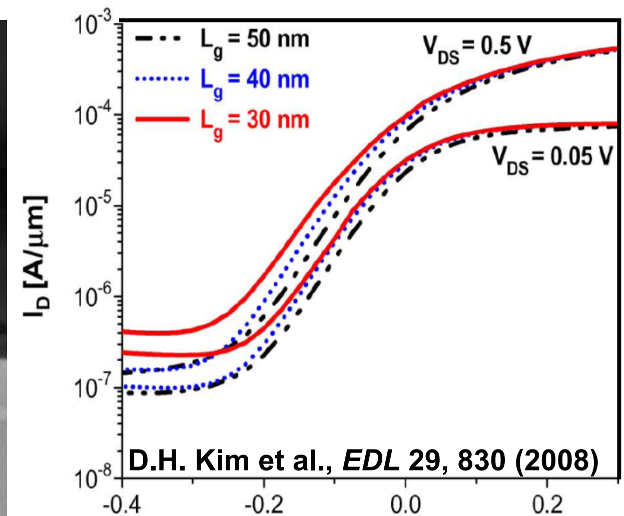
  (SS, DIBL, short channel effects, gate leakage current, scaling, …)
  - Predict performance of ultra-scaled devices

2007: 40nm

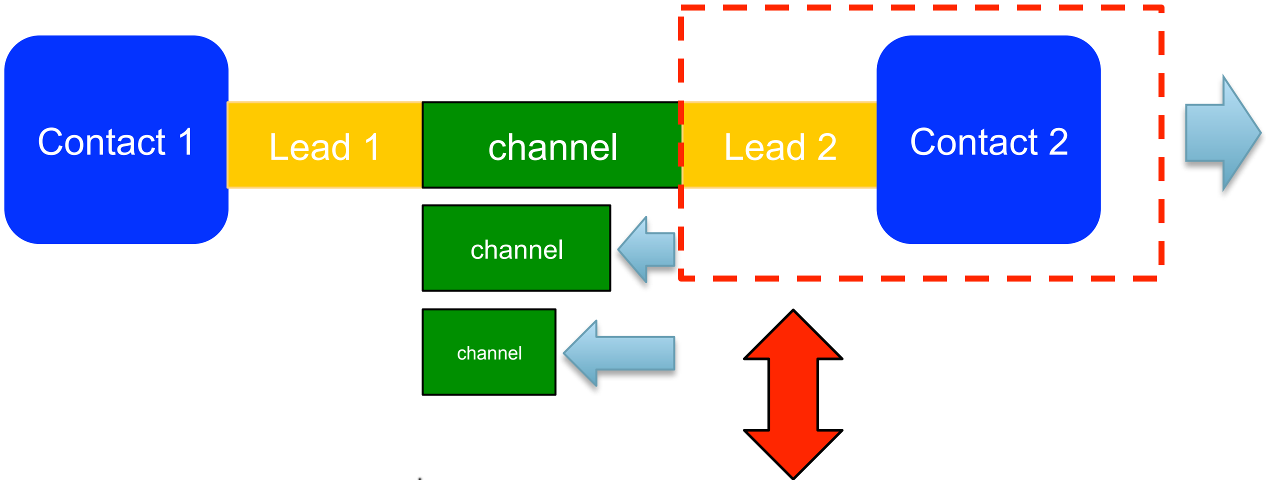


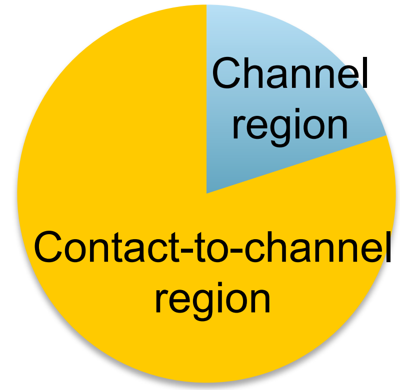
2008: 30nm



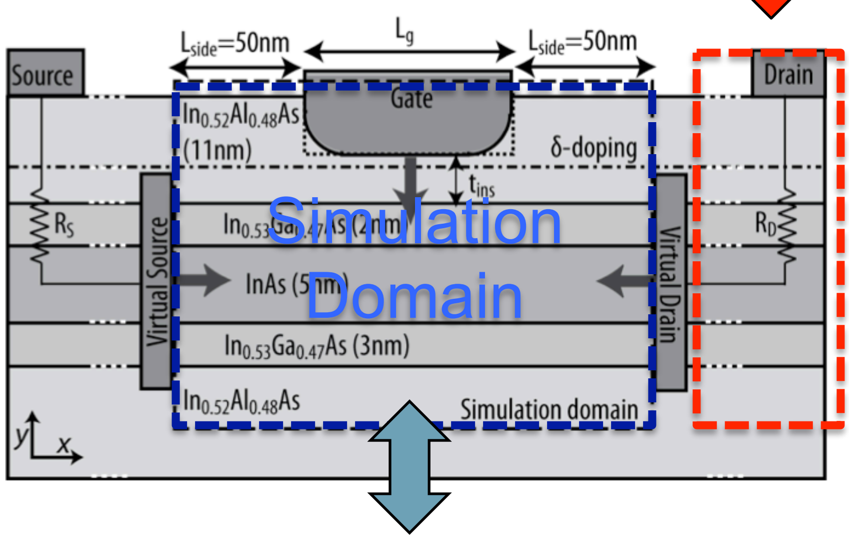


Towards realistic contact modeling





Device Pie



Simulation domain of compact model (IEDM 2009, N. Kharche et al.)

Regular compact model features:

- Used Virtual Source and Drain.
- Fit I-V characteristic in a post-processing step with series resistances ($R_{S/D}$) from experimentalist or ITRS.

Modeling Objective / Challenge

Objective:

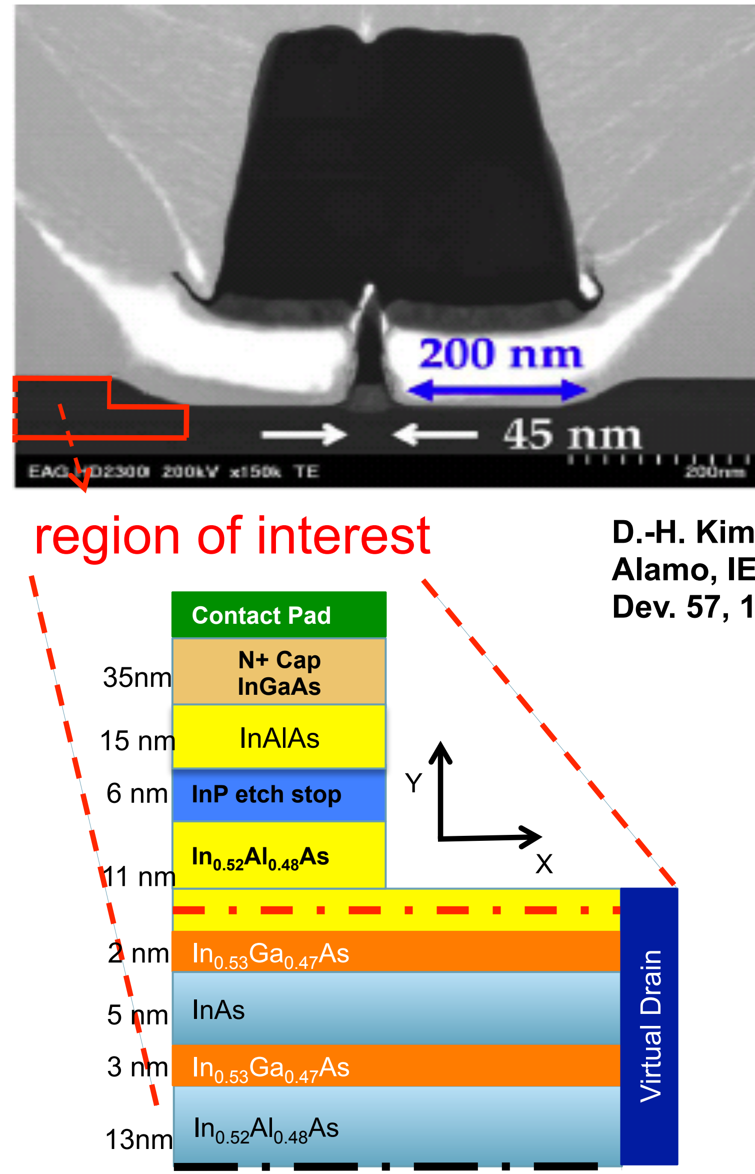
- Guide experimental III-V HEMT device design through realistic contact-to-channel region simulation

Challenge:

- 2-D geometries with multiple materials for hetero structure
- Quantum confinement
- Effects - scattering, disorder, and curved shape

Approach:

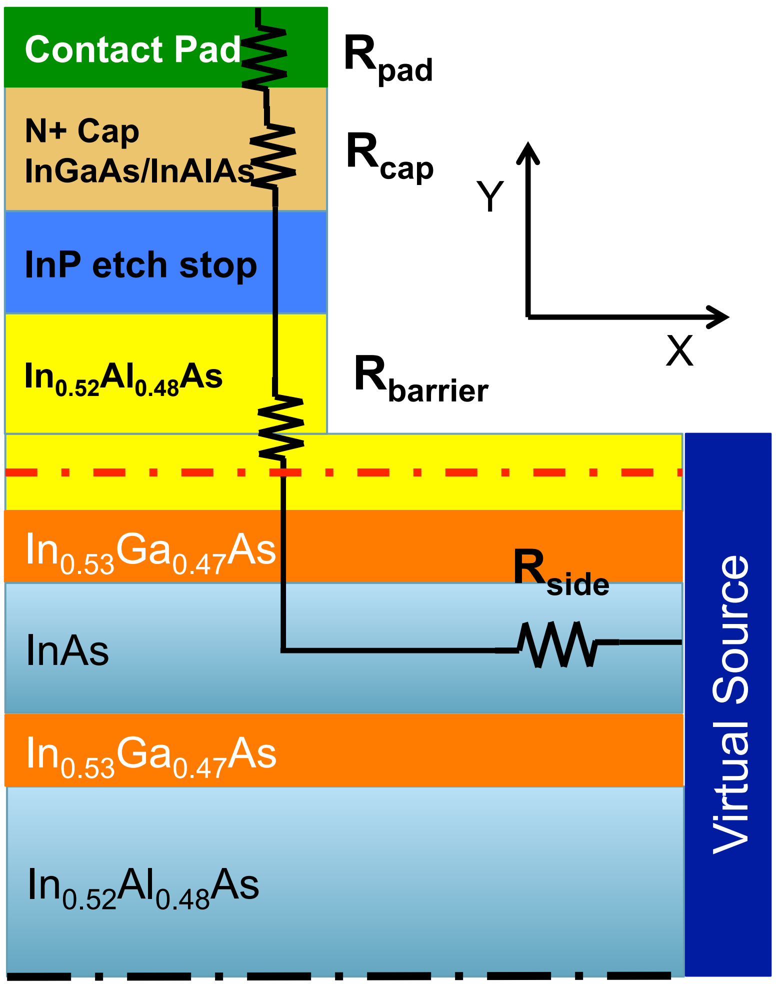
- Quantum transport simulations in realistic geometries
- Include electron-phonon scattering
- Parallel computing due to high computation cost



D.-H. Kim, J. D. A. del Alamo, IEEE Trans. Elec. Dev. 57, 1504 (2010)

Contact resistance of InAs HEMT device

Question: Where is contact resistance from?



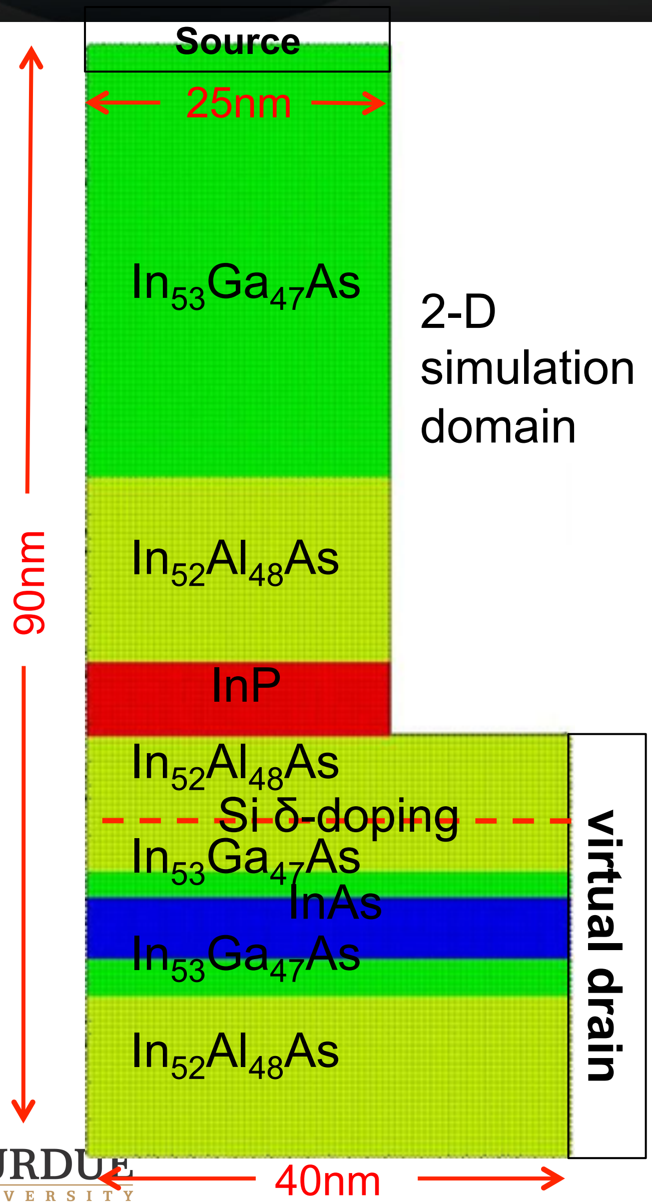
Contact resistance between the channel and the contact pad.

1. Tunneling resistance from multiple hetero-barriers in HEMT.
2. Current crowding in curved area may cause some resistance.
3. Electron-Phonon scattering.
4. Schottky barrier between contact pad and n-doped cap layer.
5. Alloy disorder and surface roughness.

1 2 3 are taken into the account

4 5 are being implemented

2D Simulations Setting



2-D hetero structures explicitly represented: Effective masses extraction, band offset, electron affinity, and other parameters

Phonon scattering mechanism is included

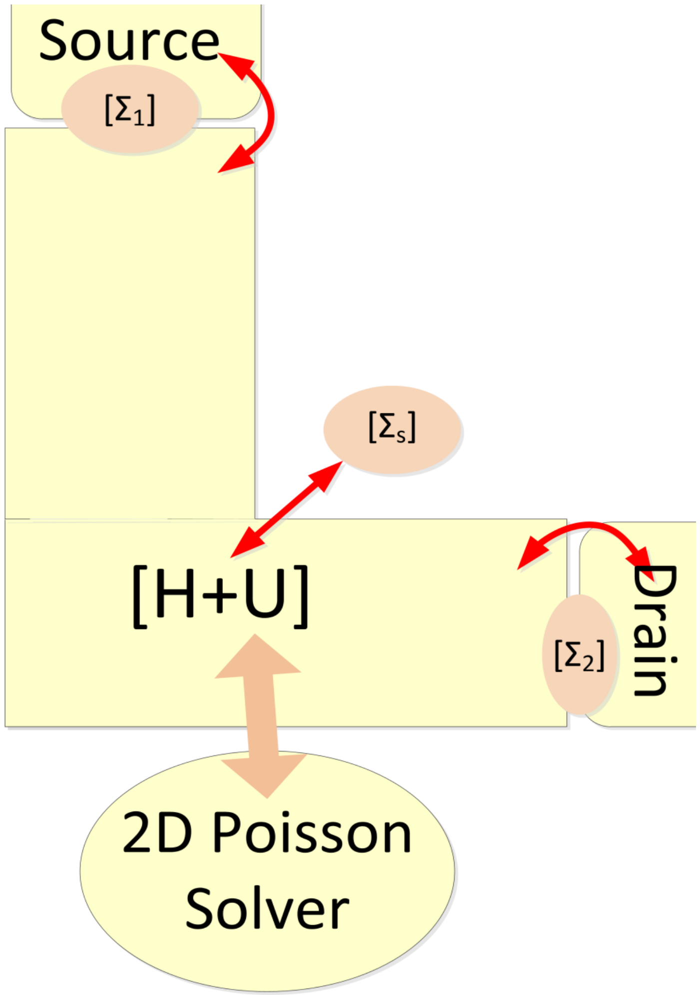
→ This is essential in this work not only for reasonable resistance value but also for making simulations convergence

Extract resistive characteristic from I-V:

V_{DS} = 0.5~0.15V for experimental V_{DD} = 0.5V

→ Considered voltage drop from the channel and series resistances measured experimentally

Simulation Approach



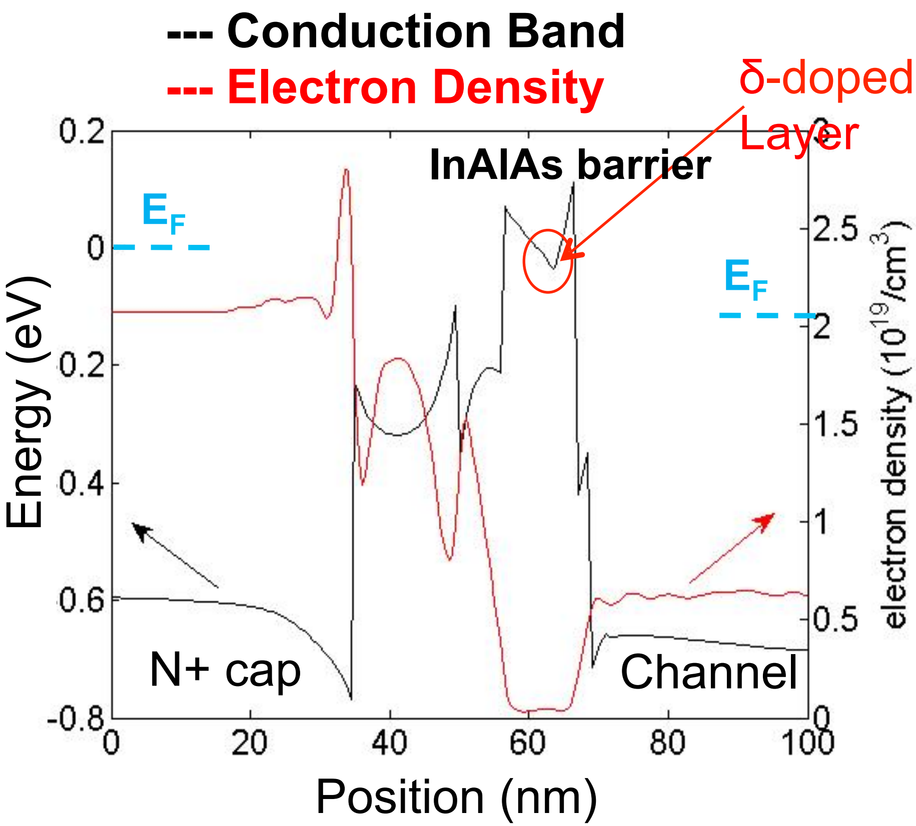
- Real-space non-equilibrium Green's function (NEGF) formalism within effective mass approximation
- Self-consistent Born approximation for phonon self-energy functions[1]
- Bulk phonon parameters based on deformation potential theory[2]

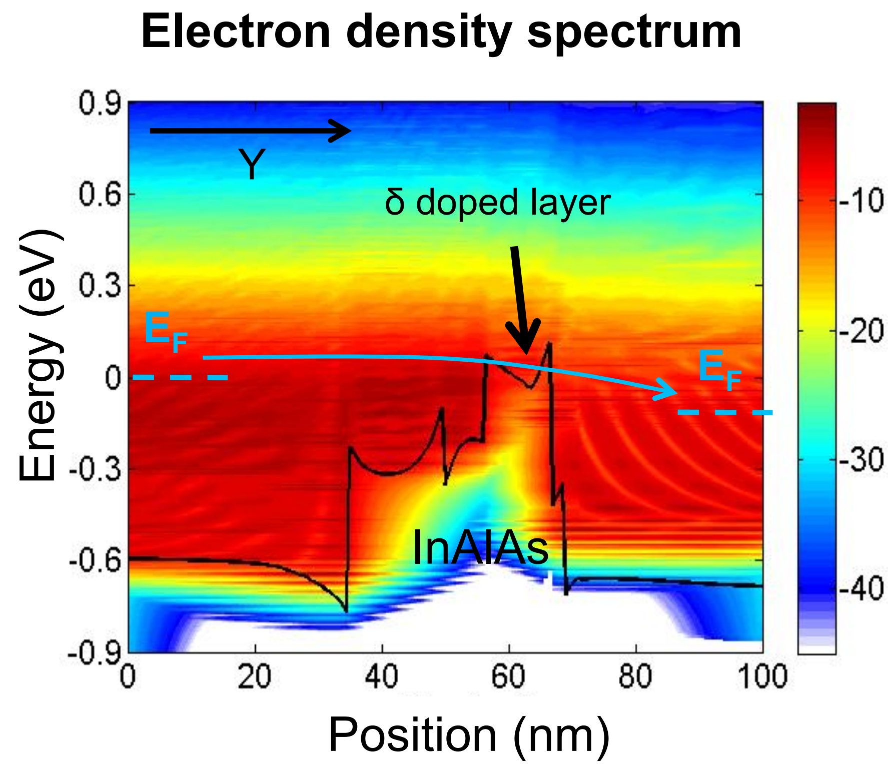
NEMO5 (NanoElectronic Modeling Tool)

- Self-consistent NEGF-Poisson Solver for transport calculation
- Parallel processing with more than 2000 cores

[1] S. Jin et al., JAP 99, 123719 (2006)
[2] M. Lundstrom, *Fundamentals of carrier transport* (Cambridge Univ. Press)

2D simulation results: electron density spectrum

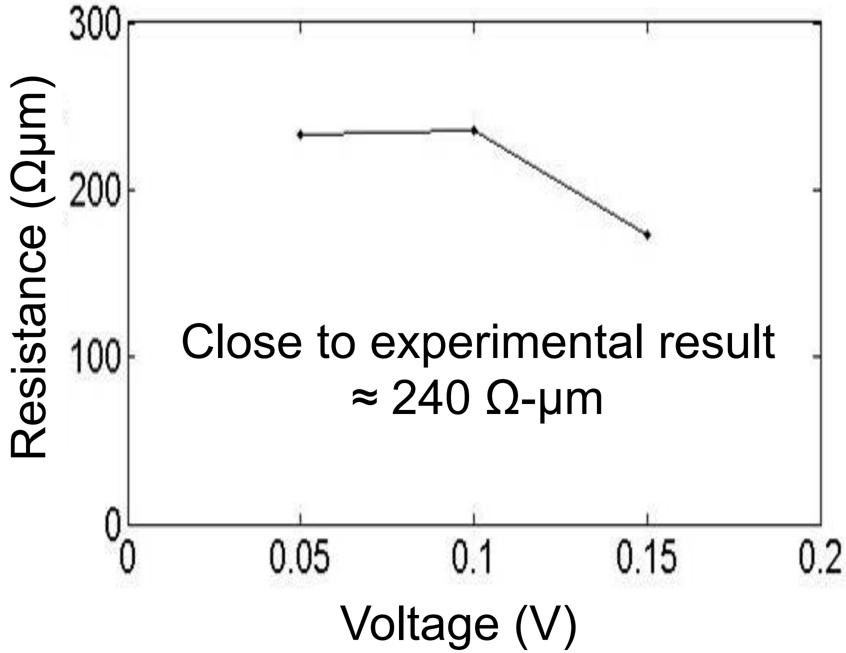


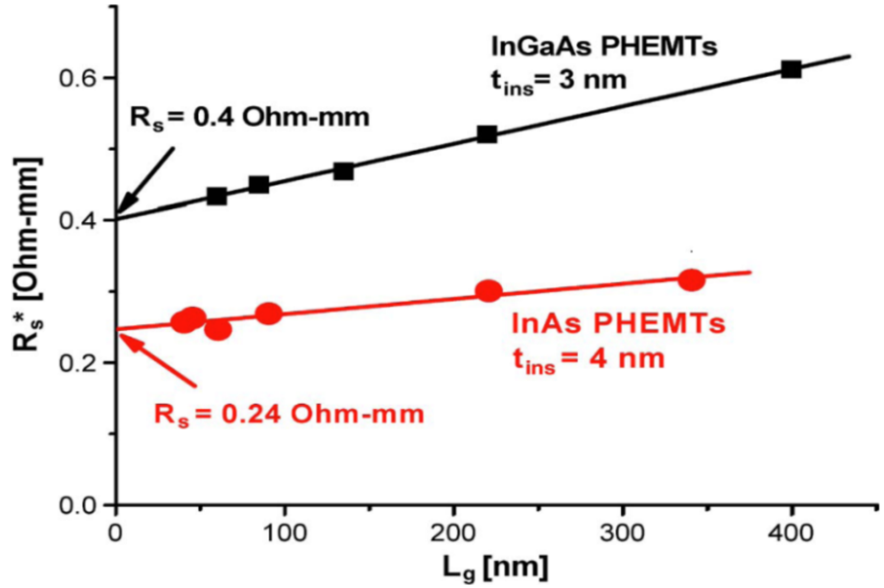


Preliminary simulation results

- Electrons are well-thermalized at source/drain regions due to phonon interactions.
- **Thick InAlAs barrier is the main element of resistance.**

2D simulation results: Resistive characteristic





D.-H. Kim, J. D. A. del Alamo,
IEEE Trans. Elec. Dev. 57, 1504 (2010)

- Resistive characteristic (Series resistance vs. Applied bias)

  → Close to experimental resistance ≈ 270 Ω-μm, but still discrepancy

- Preliminary model
  - Working on non-parabolic effective-mass for improvement
  - Schottky barrier and other scattering models (surface roughness / alloy disorder) are not yet included.

Summary / Future work

- Our First Quantum Transport Model of Contacts in InAs HEMT
  - Achievements:

    - 2D L-shaped simulation, phonon scattering, resistive behavior
  - Limitations:

    - Current EM model over-predicts the Fermi Level

      → Improve non-parabolic band structure effects

    - Phonon scattering model not fully calibrated

      → Improve calibration against experimental mobility models
- Experimental resistance and model are at the same order of magnitude
- The InAlAs barrier plays the main role in the series resistance

Thank You !