Nanoscale MOSFETs with alternative channel materials

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Thanks to ....
Framework

• Aggressive scaling has pushed $L_G$ below 20nm

• Innovative device architectures (FDSOI, finFET, nanowires)

• New materials are being used for the channel, dielectrics, interconnects, ...
Experimental Characterization: Instrumentation (UniCAL)

Electrical characterization at wafer level: DC, pulsed and noise
Set-up for design and realization of electronic boards
Experimental Characterization: Measurement (UniCAL)

- **I-V, C-V**
  - Higher mobility

- **Reliability: hot carriers (HC)**
  - Worst HC degradation due to lower bandgap

- **1/f noise**
  - Higher 1/f noise due to Ge outdiffusion in the gate stack

**imec devices**: Ge pMOSFETs versus reference Si pMOSFETs (same gate stack)
Modeling and simulation activities

• assessment of different channel materials (on-current, SS, scalability….)
• influence of gate dielectrics (e.g. mobility reduction in MOSFETs with high-k gate stack)
• comparison of device architectures (e.g. finFET vs. nanowire)
Simulation approaches

- Full quantum
  - Atomistic DFT / tight binding Hamiltonians
  - $k \cdot p$ Hamiltonian
- Multi-subband (semi-classical)
  - D-BTE
  - MSMC,
- Semi-classical MC
- Drift-Diffusion
Case study: III-V MOSFETs

- E.U. project III-V-MOS
- target: III-V semiconductor based n-MOSFETs at and beyond the 14 nm node
- aims:
  - to develop high-level and TCAD models
  - to narrow down the technology development options
  - to deliver models to end users in semiconductor manufacturing industry and research labs
Case study: III-V MOSFETs

- High-level models vs. experiments, examples:

  **Material properties**

  ![Graph showing material properties](image)

  - exp. IBM
  - \( k \cdot p: \text{UniBO+UniUD} \)

  **Interface properties**

  ![Graph showing interface properties](image)

  - exp. IMEC
  - TCAD: UniMORE

  **Carrier mobility**

  ![Graph showing carrier mobility](image)

  - exp. IBM
  - MSMC: UniUD
Case study: III-V MOSFETs

- TCAD models, examples:
  - Mobility model calibrated on IMEC’s data (UniBO)
  - Model for short channels validated vs MSMC (Unibo+UniUD)
  - TCAD employed for variability studies (UniMORE)
Graphene Transistors

Graphene is a 2D crystal, gap-less with very high carrier velocity.

Ballistic NEGF simulations: comparison between TB and constant or non-parabolic effective mass (UniBO)

Nano-ribbons have a gap and allow for reasonable $I_{on}/I_{off}$
Graphene Transistors

- Low mobility in nano-ribbons
- exp.: literature and partner AMO
- Development of MC to include scattering
- sanity check:
  - MC w/o scatter (UniUD) vs NEGF (UniPI)

• estimate of RF performance with scattering (UniUD)
Graphene Transistors

Alternative transistor architectures (E.U. project GRADE)

Graphene-Base-Transistor

Graphene-Base-Heterojunction-Transistor

Comparison with an optimized SiGe n-p-n HBT shows GBHT superior performance
Future developments

- activities on III-V MOSFETs
  → III-V APDs for X-rays (UniUD)

  → proposal MONET (UniUD+PoliTO): III-V photo-detectors for ToF cameras

- activities on graphene
  → other 2D materials (UniPI, UniUD)

  → pressure sensor in graphene (UniUD+KTH)

- know-how on modeling of III-V and other materials can be exploited also in power devices (GaN, SiC)