Quantum
Mechanical &
Electromagnetic
Systems
Modelling Lab

Master thesis @ quest

Prof. Dries Vande Ginste

quest.

Introduction.

Quest – quantum mechanical and electromagnetic systems modelling lab

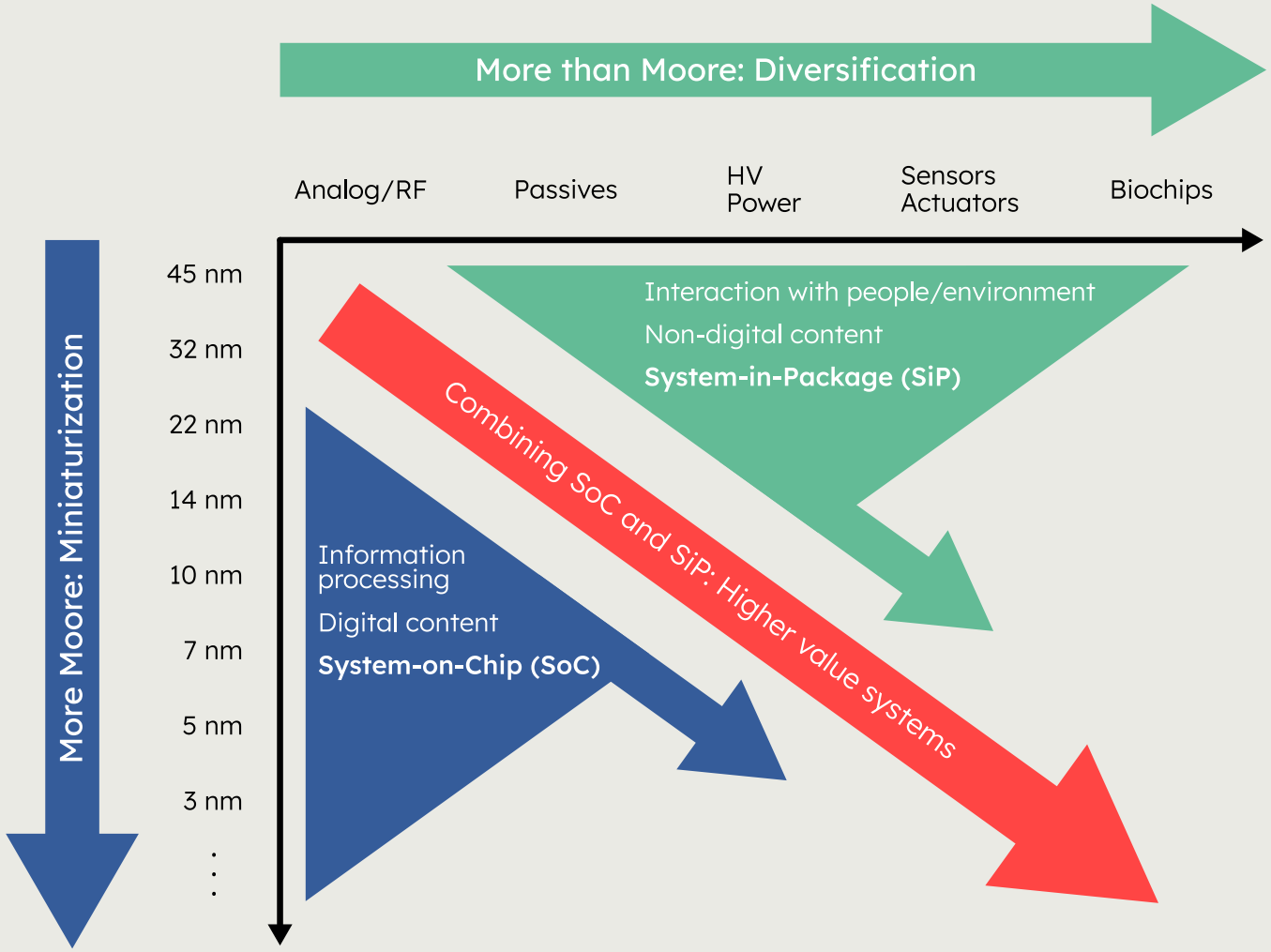
- Founded: 1 March 2021
- **Scope** goes beyond traditional electromagnetics (see also further):
  > modelling of quantum mechanical/electromagnetic (QM/EM) devices and systems
  > electromagnetic compatibility, signal and power integrity (EMC/SI/PI)-aware design and measurements
- Novel research domain with high academic + industrial relevance
- Create knowledge + critical mass
- Reach-out to relevant (academic and industrial) partners
- Coaching/educating/training of young researchers in a new and versatile research domain

Thesis topics

- for M.Sc. students in Engineering Physics, Electrical Engineering and Physics and Astronomy
- tailored towards the specific study programs

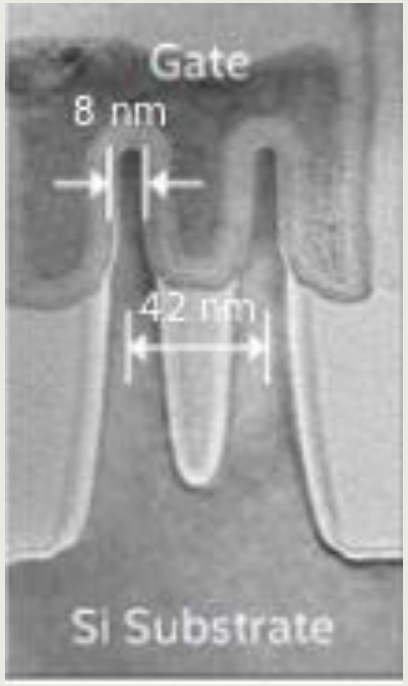
Research context and motivation.

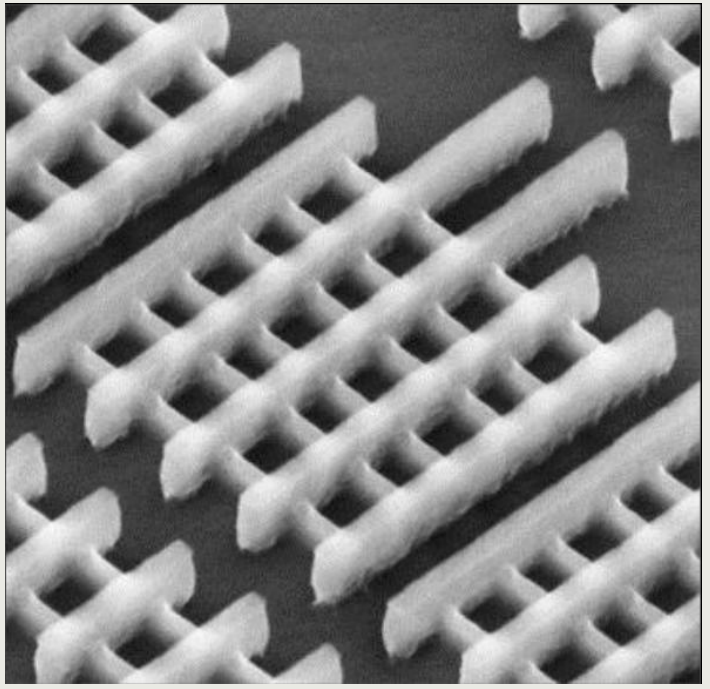
Roadmap for semiconductors.



Research context and motivation.

Example “More Moore”: Intel’s Core i7-8700K.

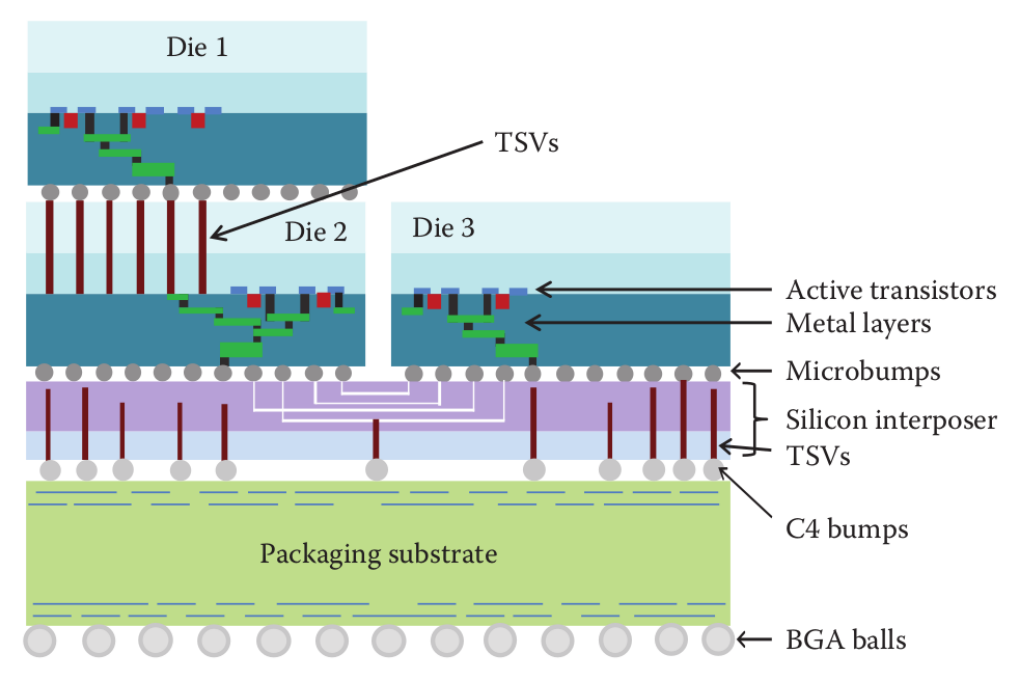


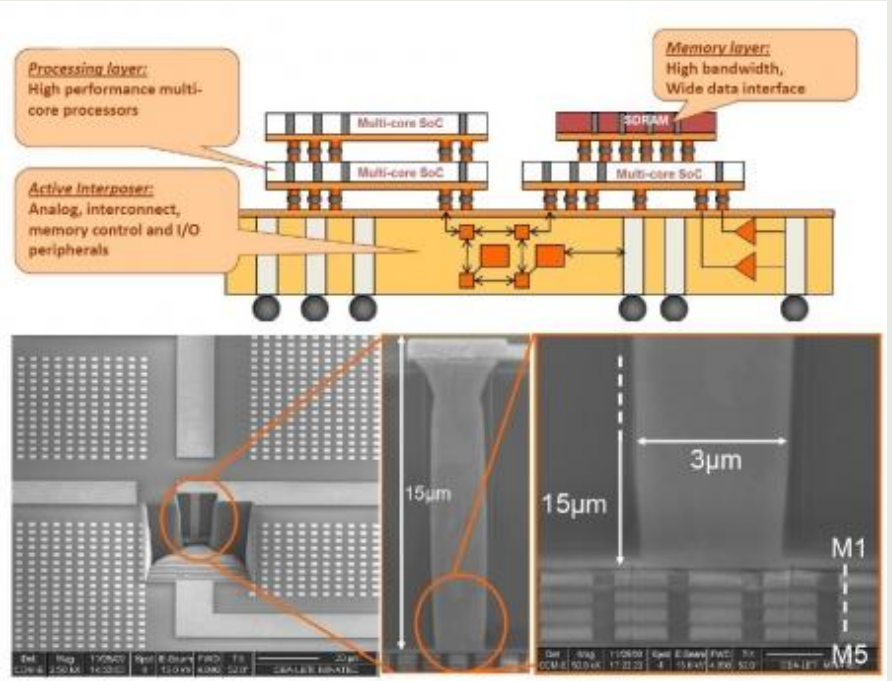


> **Full-wave** EM simulations needed
> But highly **multiscale**

Research context and motivation.

Example “More than Moore”: 3-D Ics.





> Again **multiscale** problem + very heterogeneous
>
> Also: **multiphysics** problem

Research context and motivation.

Example: quantum devices.

New **materials**

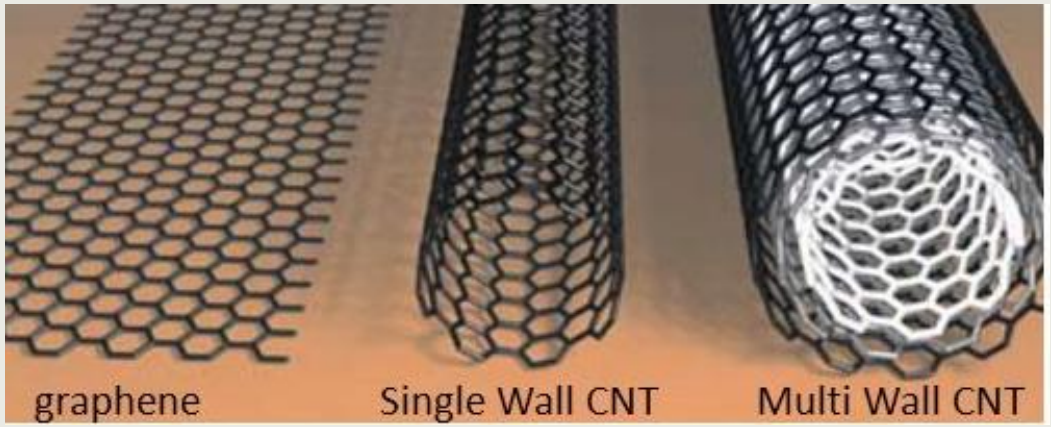
- Carbon-based: graphene and carbon nanotubes (CNT)
- Transition metal dichalcogenides (TMDC)
- Topological insulators or semi-metals
- ...

Physical **phenomena**

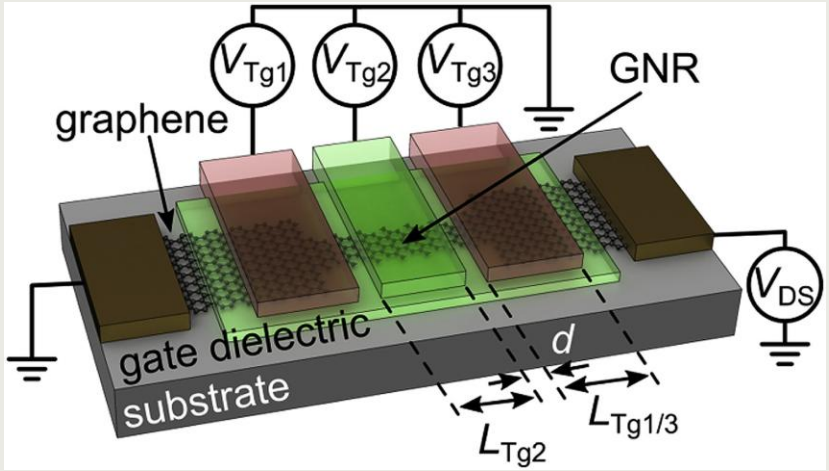
- Charge carrier confinement, ballistic transport, tunnel effect, Klein effect, ...

Modeling challenges

- Quantum mechanical (QM) aspects
- *Ab Initio* (↔ macroscopic conductivity models)
- **Multiphysics (QM/EM)**



Sub-10 nm graphene nano-ribbon (GNR) tunnel field-effect transistor



Research context and motivation.

Why do we construct (multiscale and multiphysics) computational techniques?

(Nano)electronic and quantum devices: heavily researched (applications / manufacturability)

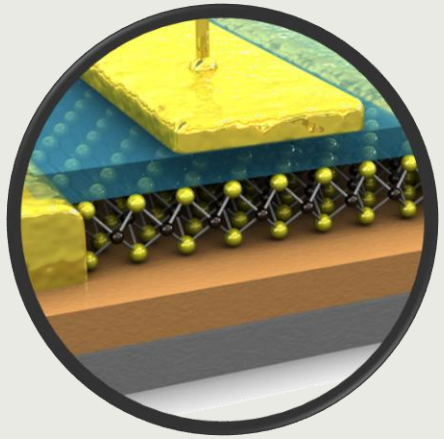
Physical phenomena occurring in these devices are not always well-understood

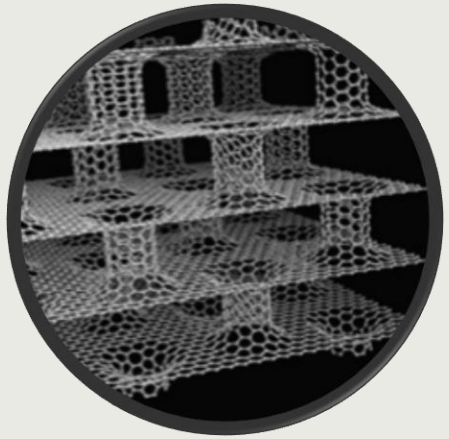
QM/EM computational tools and models lead to

> a more **thorough insight** in the functioning of these novel devices and systems;
>
> **computer aided design software**, avoiding trial and error during development.

EMC/SI/PI-aware **designs and measurements** to gain knowledge and to validate models

Additionally, it's fun! 🤓

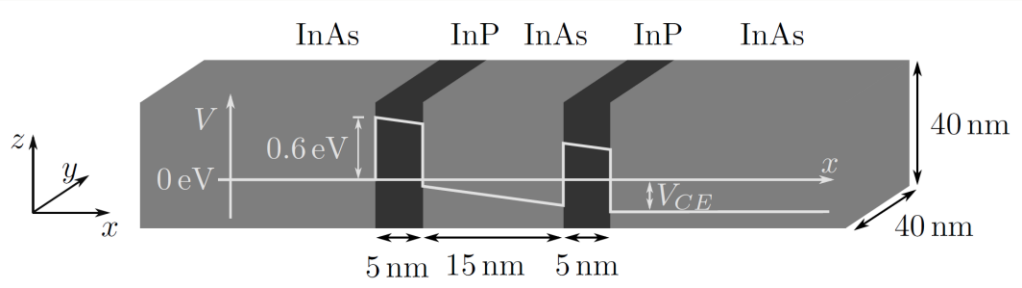


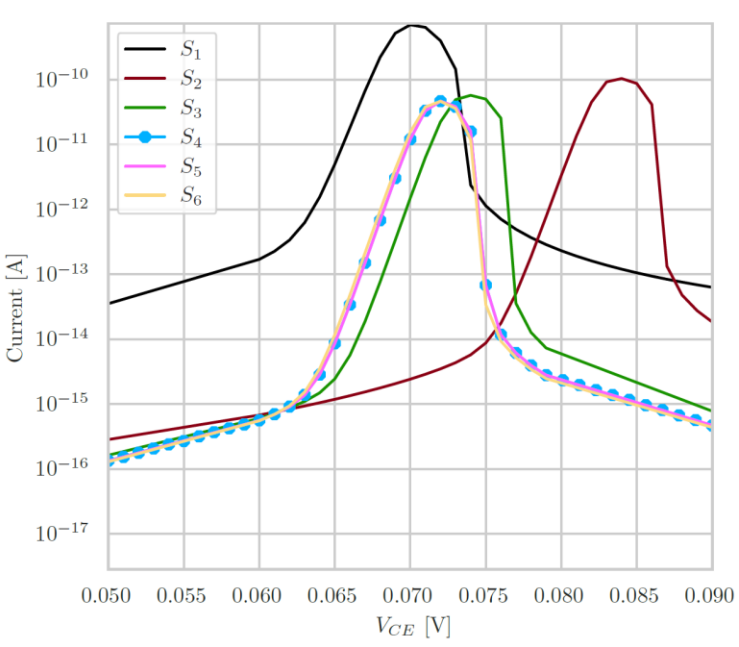


Research @ quest: some results.

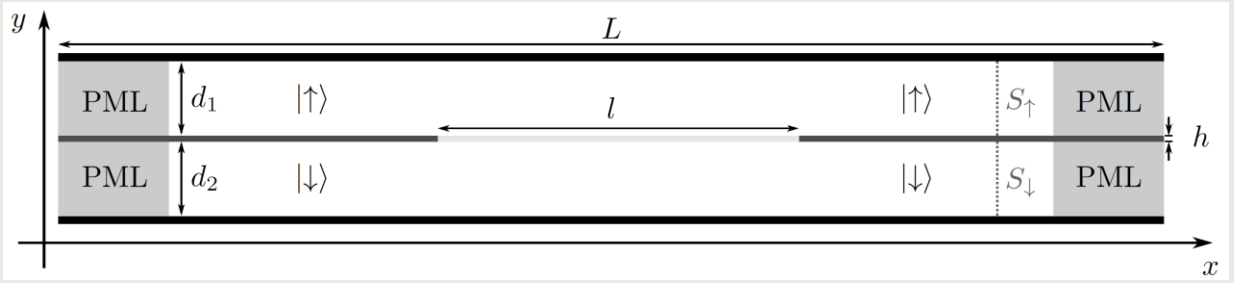
Maxwell-Schrödinger systems.

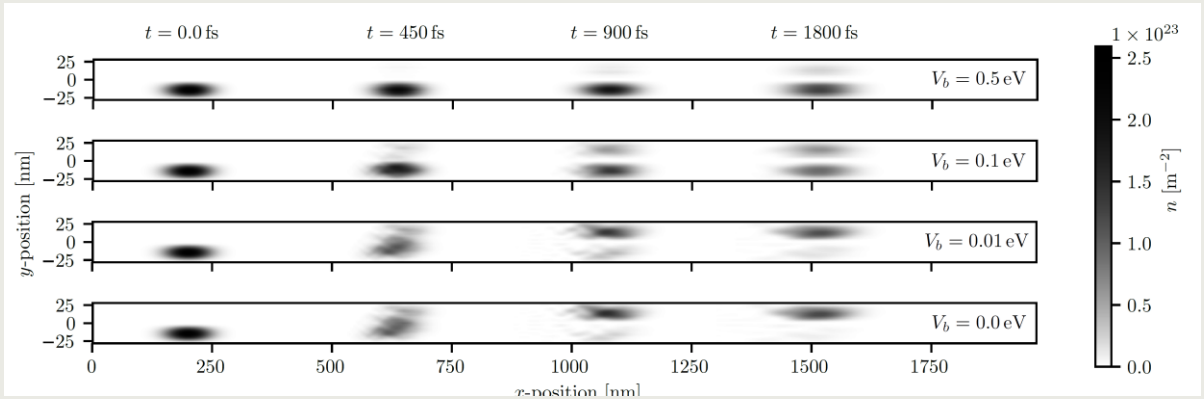
Square nanowire double-barrier resonant-tunneling diode





Flying qubit interferometer

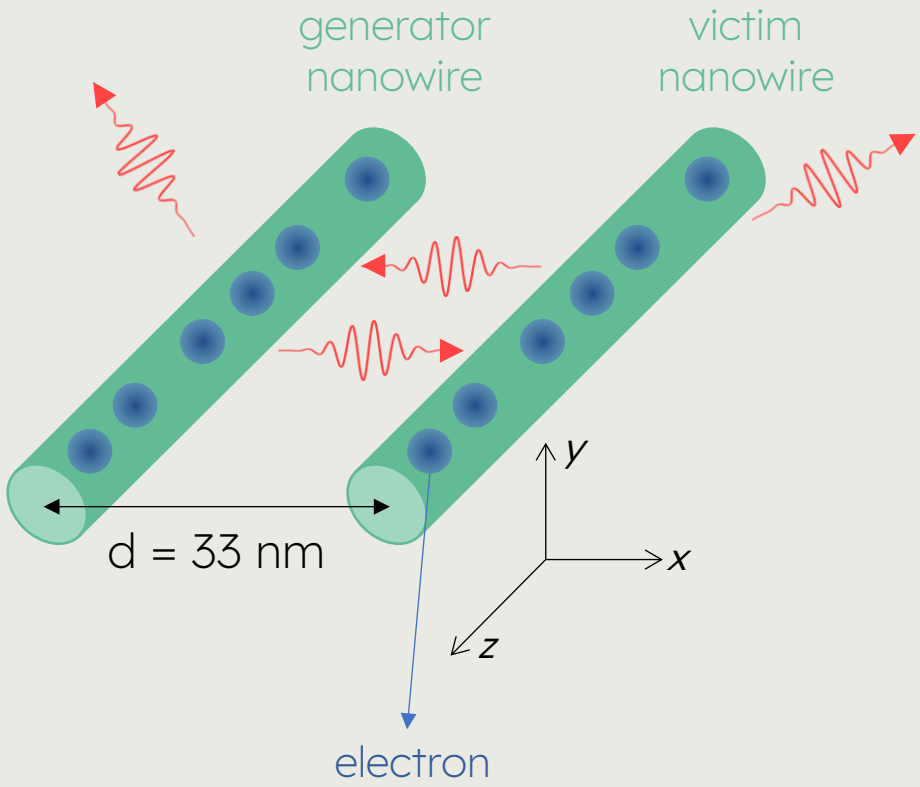




Research @ quest: some results.

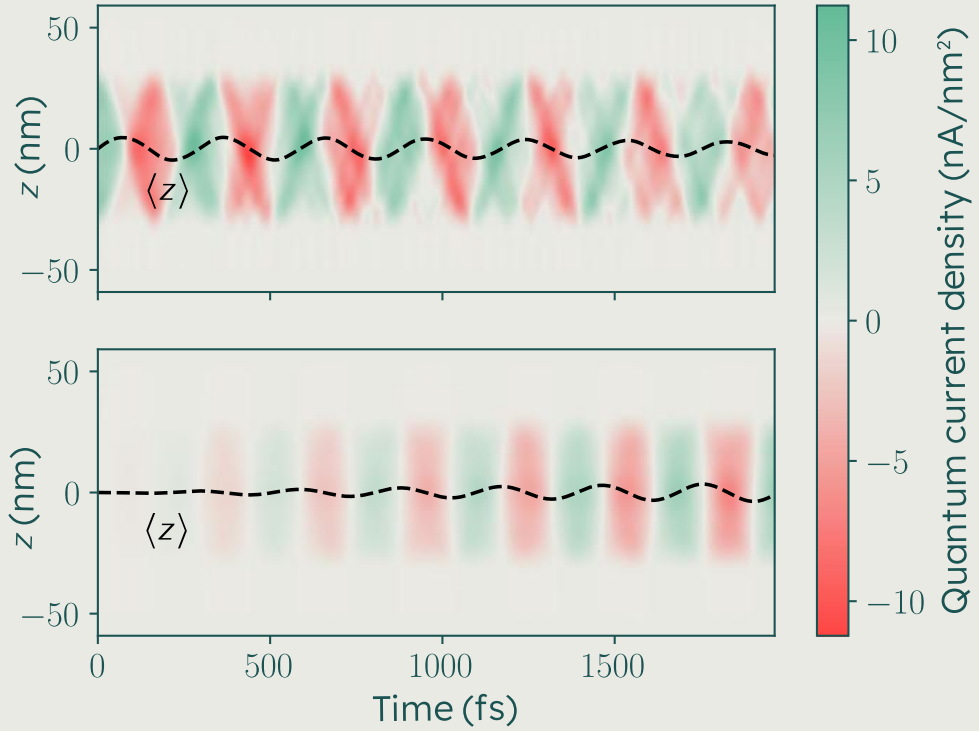
Maxwell-Kohn-Sham system.

***Ab initio* modelling of crosstalk between nanowires**



generator wire

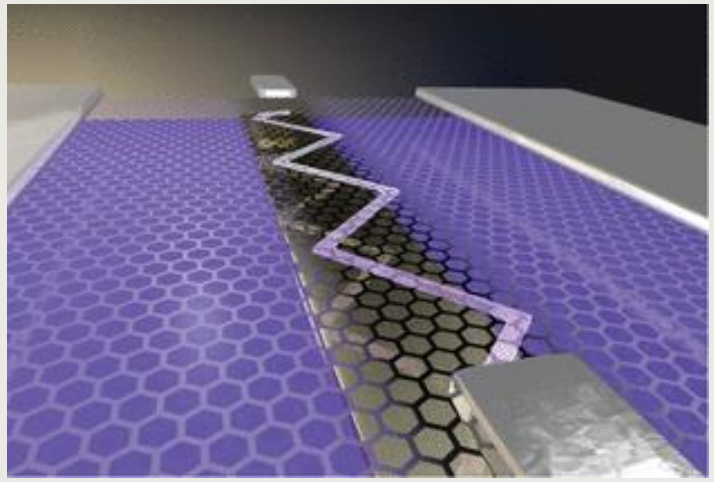
victim wire

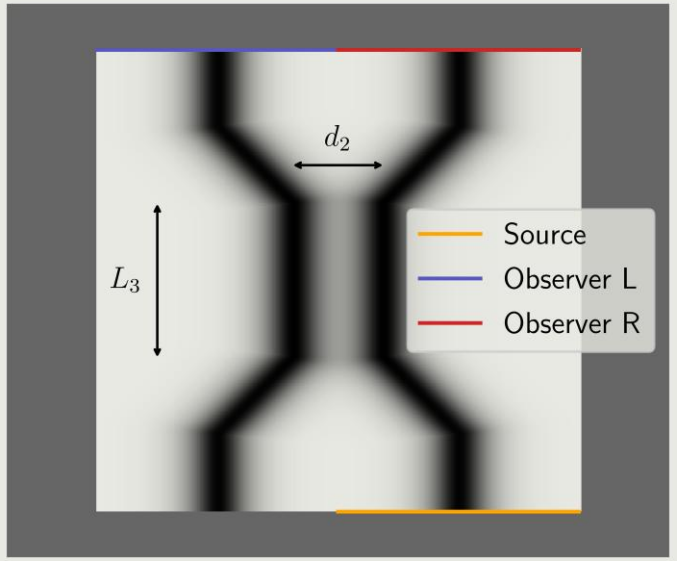


Research @ quest: some results.

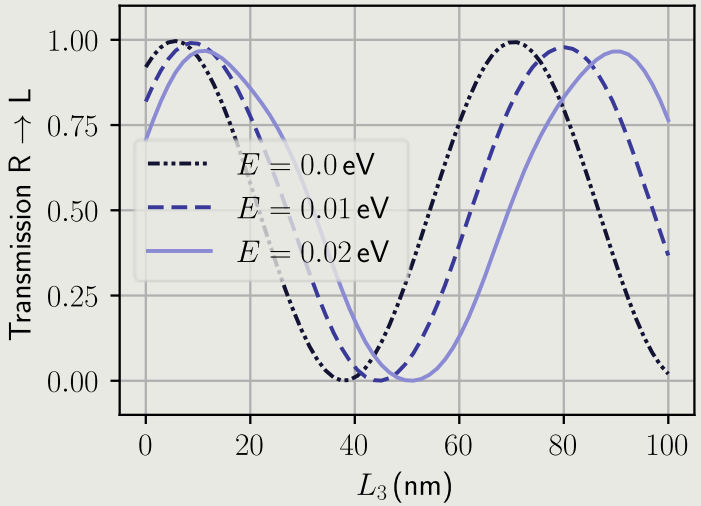
Maxwell-Dirac system.

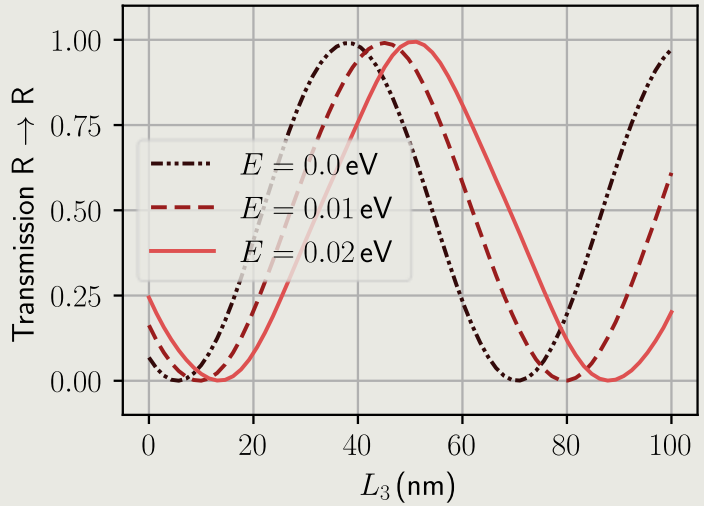
Electrostatically induced interconnects in graphene





- Electrons are guided by an electrostatic potential
- **No scattering** at the boundaries of graphene ribbon
- **Properties can be tuned** by varying shape and amplitude of the potential

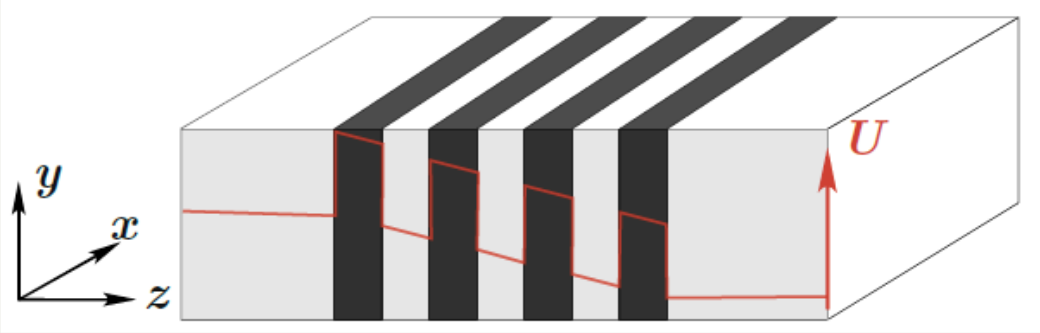




Research @ quest: some results.

Quantum transport modelling.

Multi-quantum well device

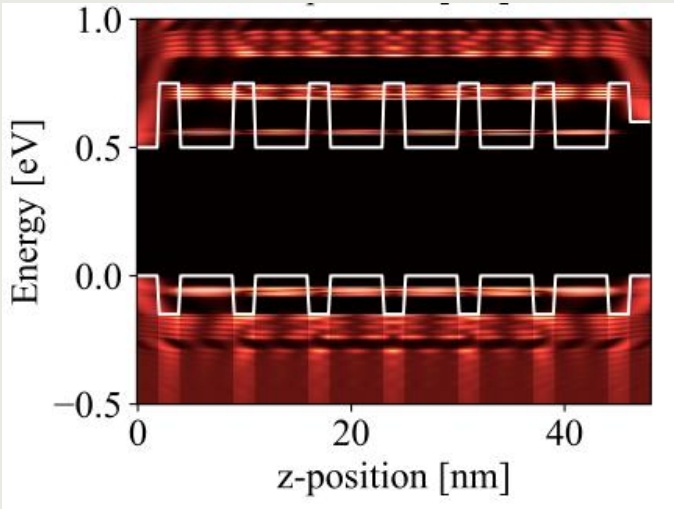


Layered structure of distinct semiconductors with multi-barrier potential energy profile U

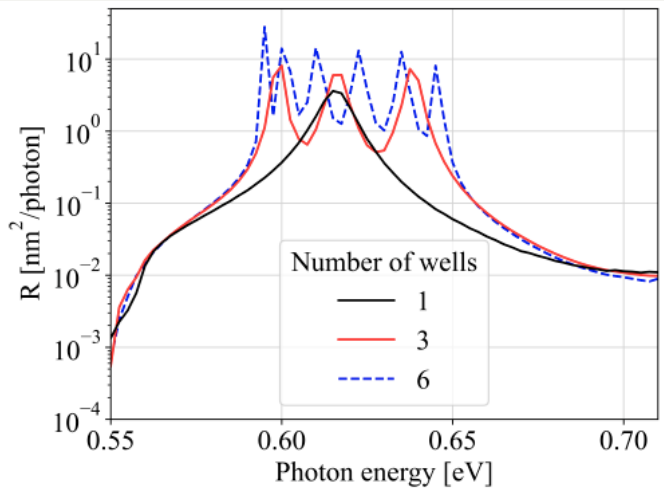
Application, e.g., **photodetector**

Strong light-matter interplay requires rigorous second-quantized description of **electron-photon interaction**

local density of states (LDOS) of a six-well device



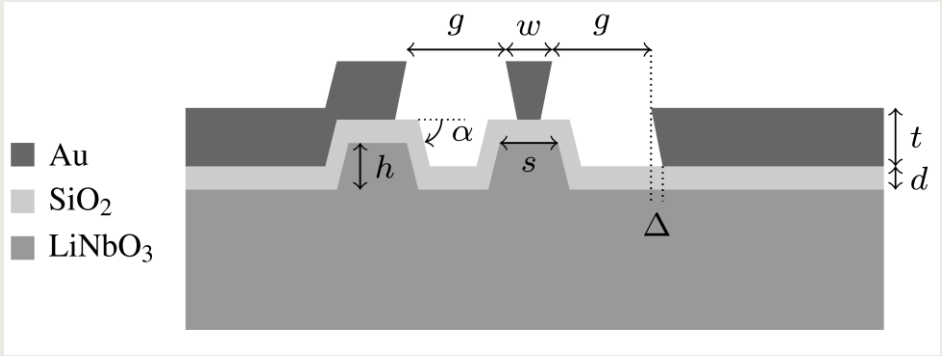
photocurrent response R of one-, three- and six-well devices

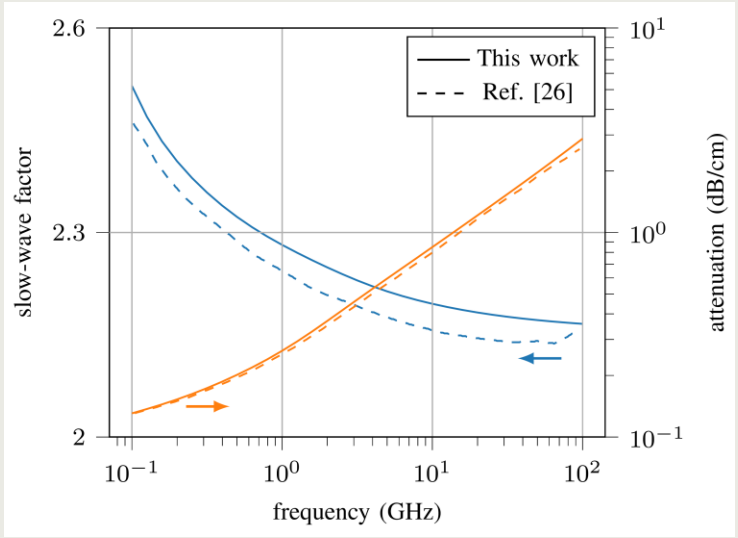


Research @ quest: some results.

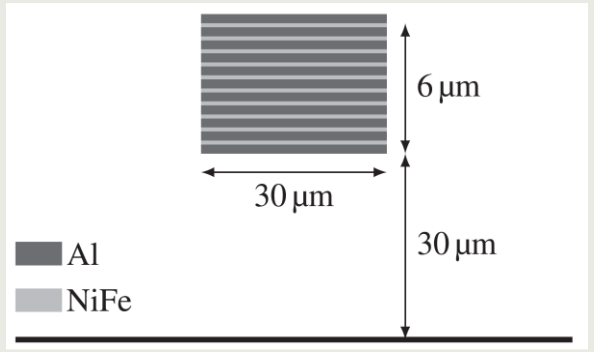
EM modelling novel, emerging interconnect topologies.

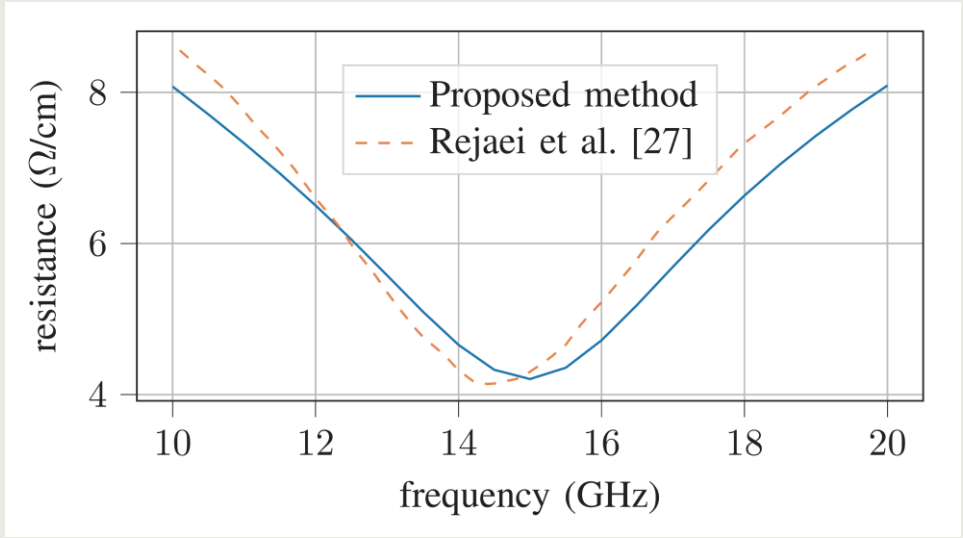
Mach-Zehnder modulator with a ridge-type CPW gold electrode





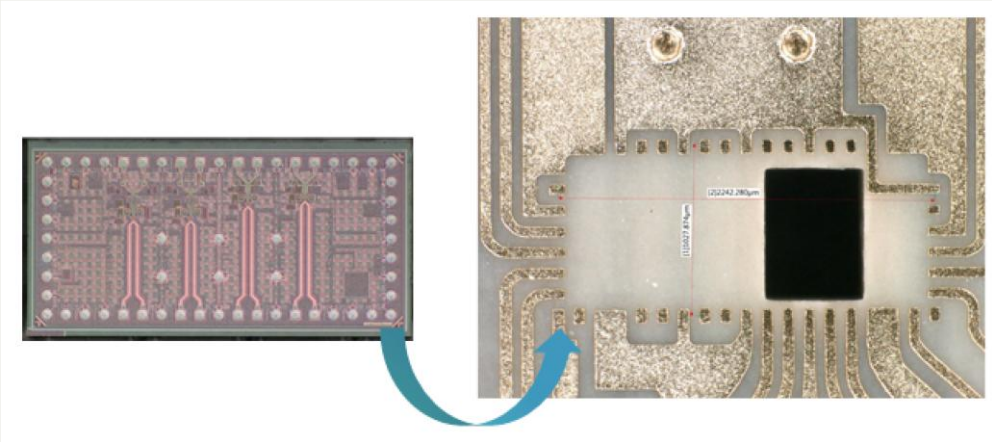
Superlattice metaconductor





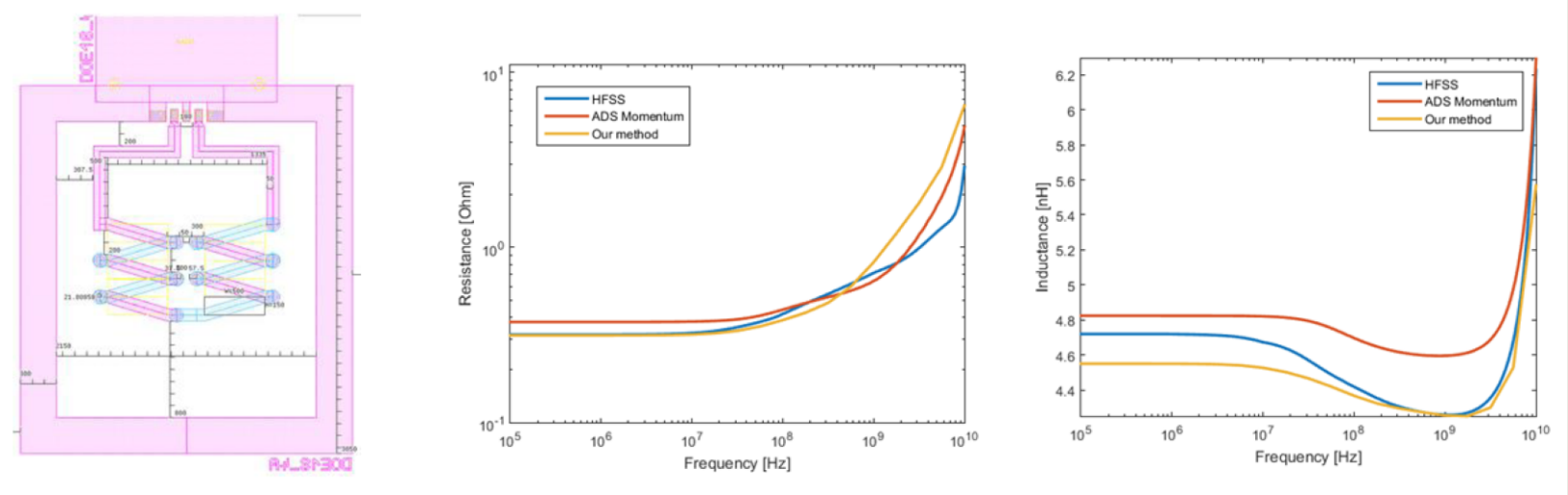
Research @ quest: some results.

EM modelling of mmWave ICs and 3-D interconnect structures.



Confidential results / cooperation with

HUAWEI

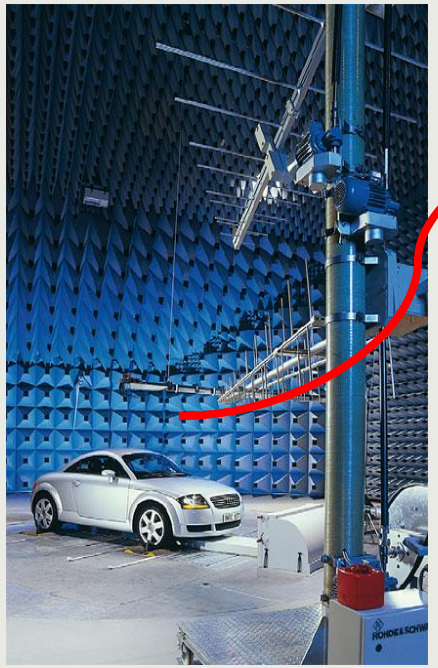


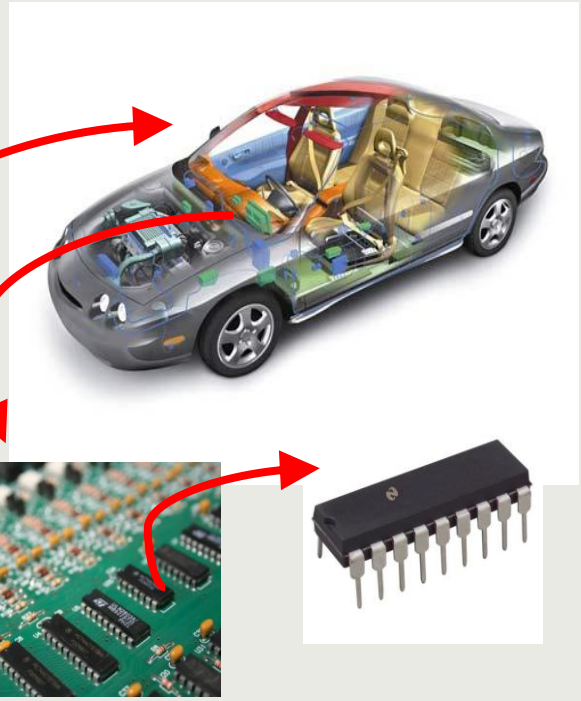
Cooperation with

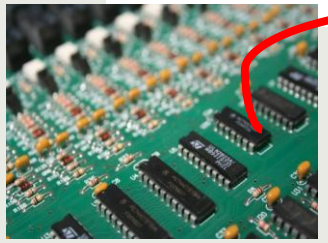
imec

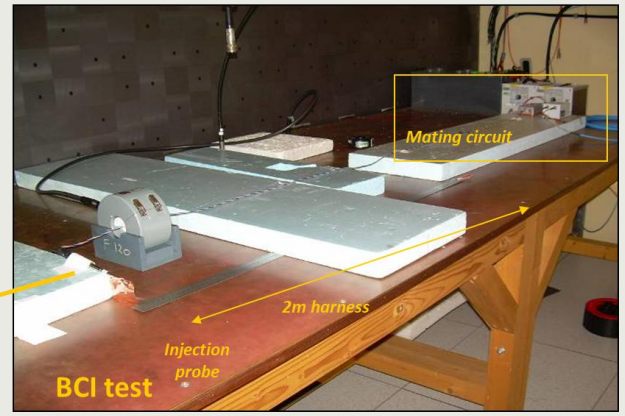
Research @ quest: some results.

EMC of automotive ICs.









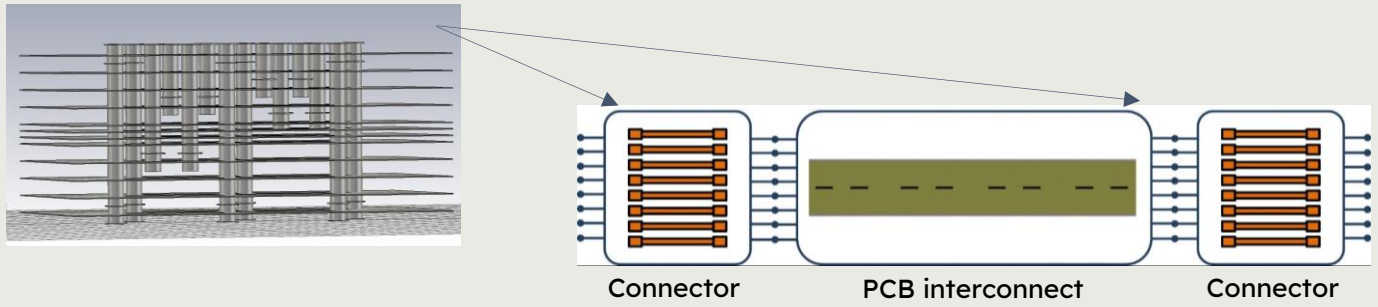
BCI/DPI and transient (e.g., ESD) test setups

Cooperation with Melexis

Research @ quest: some results.

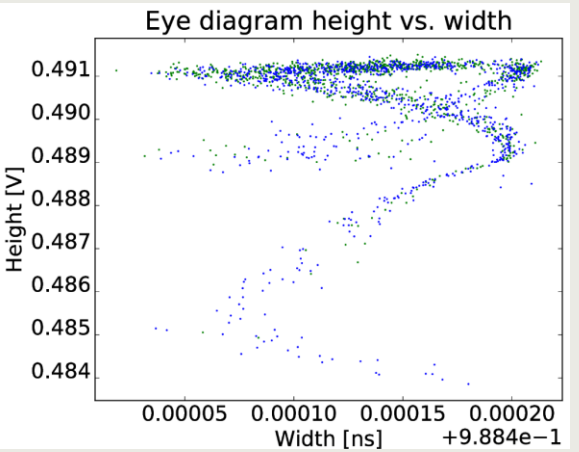
SI-aware modelling and design.

Stochastic link analysis: connector footprint + on-PCB interconnect

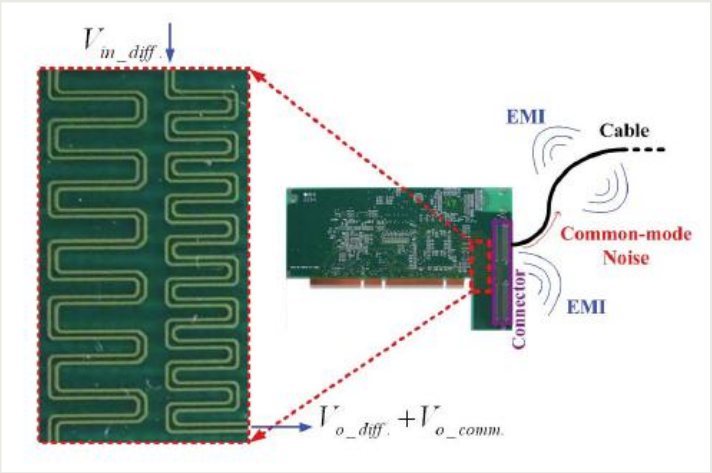


Machine Learning

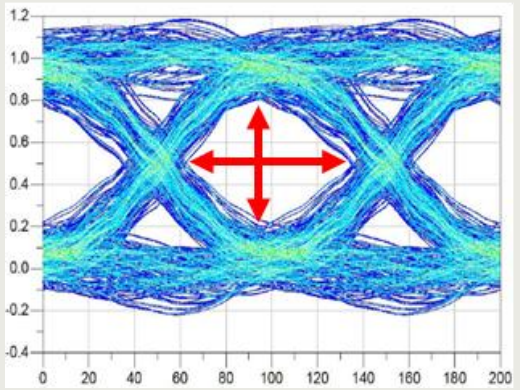
Variability of eye diagram



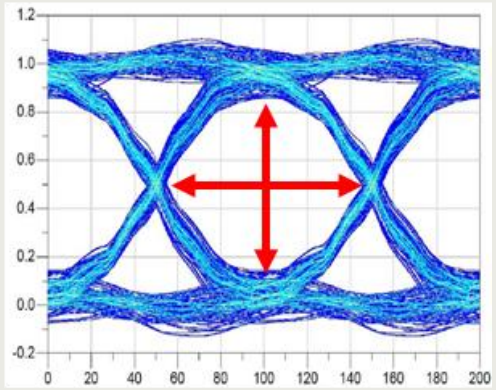
Design for differential signaling and common-mode noise reduction



classic design



improved design



Research @ quest: mission and strategy.

Modelling of nano- and quantumdevices + EMC/SI/PI-aware modelling and design of electronic devices

- Modelling tools are not only indispensable for design, but also help to understand the physics
- Nanodevices require multiphysics (Maxwell, Schrödinger, Dirac, Kohn-Sham, ...) and multiscale modelling!
- EMC/SI/PI-aware modelling tools are validated by designs and measurements
- New QM/EM and EMC/SI/PI research domain:
    - Many challenges but also many opportunities (academic / industrial)
    - Various application domains + potential strategic partners:
      (nano)electronics, (quantum) photonics, solid-state physics,
      spintronics, quantum computing, ...

Thesis @ quest.

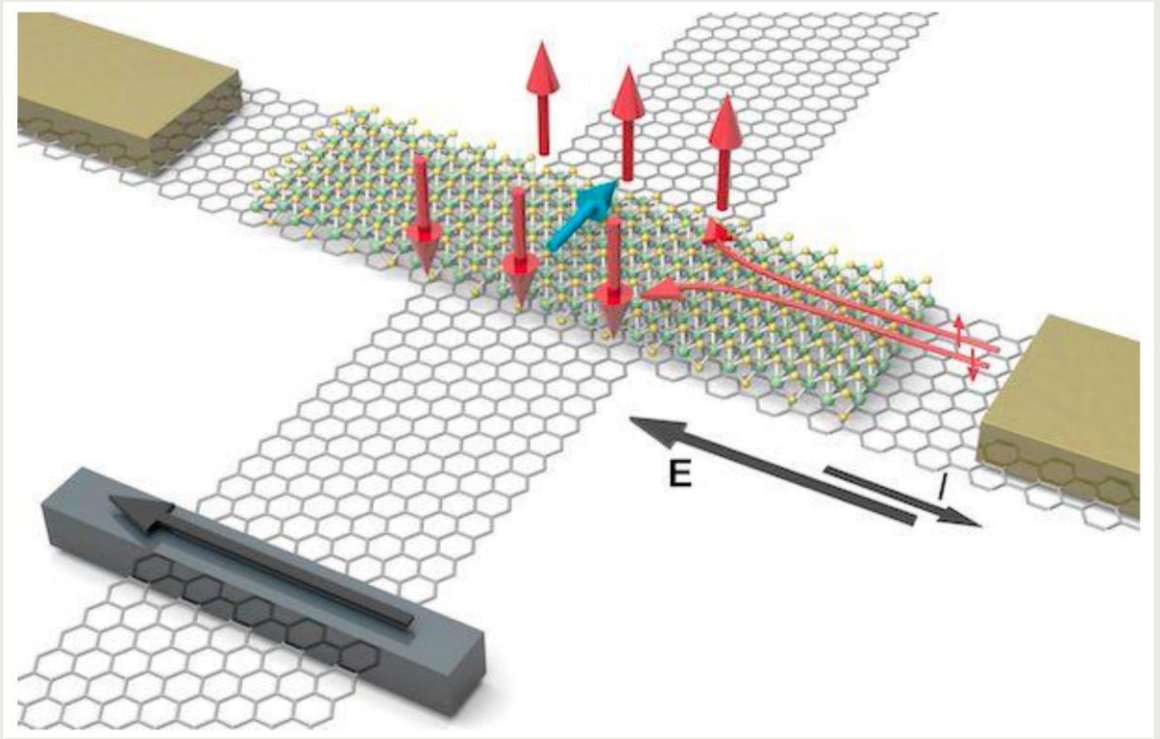
Domain: (nano)electronic and quantum devices and systems

- EM modelling topics and hybrid QM/EM modelling topics
- EMC/SI/PI-aware modelling and design topics
- Concrete topics:
  - will be posted on Plato in April
  - can be chosen as such or can be tailored to student's interest
  - detailed discussion with quest (preferably personal appointment)

Thesis topics vs quest's strategic research agenda

- Useful for the student: knowledge / skills / future opportunities
- Useful for quest: building knowledge + tools

Conclusion.



Modelling of nano- and quantumdevices

+ EM-aware design of electronic systems and (nano)devices

- New domain => groundbreaking research
- Academic and industrial need

Thesis @ quest

- Research freedom
- Close counselling by highly motivated team
- Prospect: relevant to student (academic or industrial career) and to research lab

quest.

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Electromagnetic Systems
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GHENT UNIVERSITY

imec

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