SILPHYDE GROUP

SImuLation PHYsique de Dispositifs Electroniques et optoélectroniques

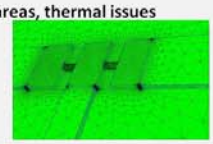
L. BAUDRY, C. DALLE, F. DESSENNE, J.-L. THOBEL, T. SADI

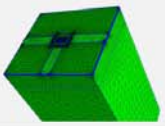
ELECTRONIC DEVICES FOR THz APPLICATIONS : 3D ELECTROTHERMAL MONTE CARLO SIMULATOR

Advanced devices for THz: nanometer scale, complex 3D geometry, importance of access areas, thermal issues

⇨ Needs realistic description of the 3D geometry, Multiscale problem

⇨ Use **Finite Element** techniques (NetGen/Ngsolve, Linz University)





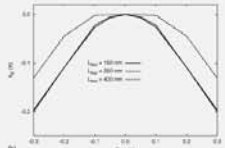
Self consistent electrothermal model

Simulation of Nanoswitches (T or Y shape)

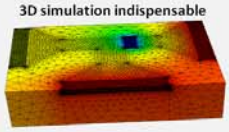
- Based on HEMT structures, realized at IEMN (Anode group)
- Applications: Rectification, Frequency multiplication, Logic switches

Steady-state simulation

Potential at central branch Vc
Push/Pull polarization V/-V



Case of gated (4 terminals) devices
3D simulation indispensable

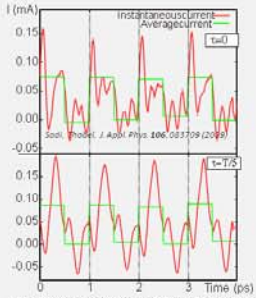


Nonlinear behaviour even at room temperature
⇨ Interplay of non equilibrium transport and surface charge effects

Sadi, Thobel, J.Appl. Phys. 105, 053707 (2009)
Internat. Journ. Num. modeling. 23(3), pp. 200–214. 2010

High frequency simulation

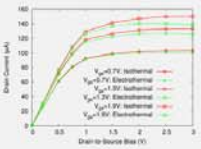
Switching current in a branch by gate bias @ 1 THz.



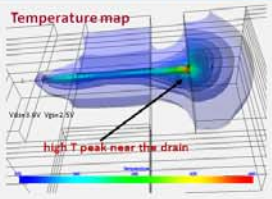
Possible operation at 1 THz depending on surface charge dynamics

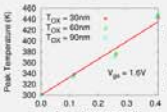
Simulation of InAs nanowire based MISFETs

Electrical characteristics
Lg=1 µm, Lsg=Lgd=0.5 µm, Tox=30nm



Temperature map





- Crucial thermal issues despite low power
- Role of insulator
- Heat parly evacuated through metalizations

T. Sadi, J.-L. Thobel & F. Dessenne, Journ. Appl. Phys. 108, 084506 (2010)
Collab.: TU Ilmenau, Germany

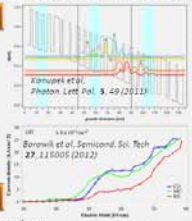
Prospective : nitride based nanodevices

OPTOELECTRONIC DEVICES : SIMULATION OF QUANTUM CASCADE LASERS

Develop and compare models of QCLs (intersubband lasers) emitting from mid-IR to THz

Monte Carlo (MC)

✓Microscopic, e⁻+photons
✓Heating of electron distribution
⇨ space charge ⇨ Band bending
⇨ change in energy levels
⇨ Self-consistency needed
Schrödinger/Poisson/MC



Detailed Rate equations (RE)

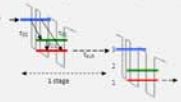
✓Good approximation, less CPU intensive
✓Coulomb scattering ⇨ Thermalization

collabs : Warsaw (Poland)
Sétif (Algeria)

⇨ **Combined RE/MC simulation**

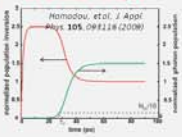
Simplified Rate Equations

✓set of a few equations (4 to 8)

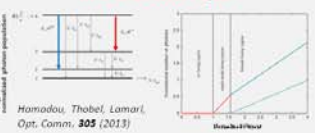


✓explicit solution as often as possible
✓fast computation
✓suitable for circuit applications

o Dynamic behaviour of a mid-IR QCL



o Mode competition in a two-color QCL



o Influence of optical nonlinearities

Stability analysis : Range of optical stability decreases when nonlinearity is enhanced

Hamadou & Thobel, Optics Comm. 284 (2011)

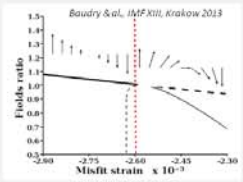
Prospective: What if the QCL structure is no longer periodic?

Actually, a QCL is never periodic due to
➢ Contacts
➢ Field nonuniformities in the operating device ⇨ domain formation and propagation ⇨ rich nonlinear physics

FERROELECTRIC NANODEVICES

Theoretical studies of polarization switching mechanisms in low dimensional ferroelectric systems

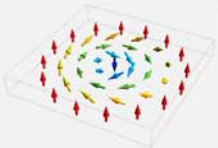
In thin films :
Different switching regimes



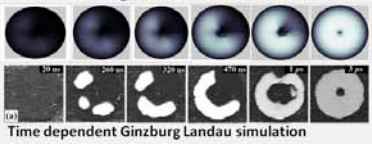
Depend on temperature, strain ...

In nanostructures: (e;g. thin film with circular electrodes)
New switching mechanisms involving 'vortice'

Collabs (PHC Alliance): Cambridge, Amiens, Belfast



Nucleation and growth of vortice in PZT thin films



Time dependent Ginzburg Landau simulation

Boudry et al., Thin solid Films (2011)

Good agreement/ Piezoresponse Force Microscopy experiments

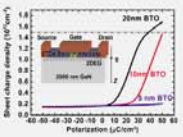
(Gruverman et al., J. Phys. C: Condens. Matter 20 342201 (2008))

Device applications

Non volatile memories

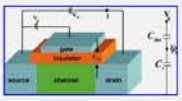
➢...High integration
➢Reduce energy consumption

Prospective : FETs with Ferroelectric Gate



'Non volatil' Transistors
(e.g. on nitride-based devices)

Zhang & al, J. Appl. Phys. 108, 084501 (2010)



Si-MOS devices
Reduction of gate stack capacitance ⇨ overcome the 60mV/dec V_T limit

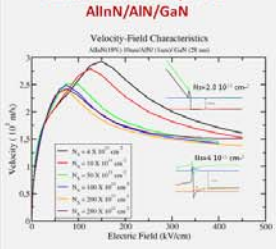
Salahuddin, Datta.Nano Letters 8(2), (2008)
Jimenez, Miranda & Godoy, IEEE TED, 57(10) 2405 (2010)

NITRIDE BASED ELECTRONICS ... ... TOWARDS MULTIPHYSICS GLOBAL SIMULATION

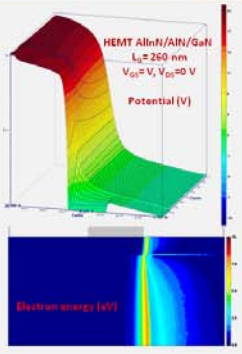
From electron transport ... to device simulation

ANR Satellite, Collab. PUISSANCE group

Monte Carlo simulation of multivalley-multisubband transport in AlInN/AlN/GaN

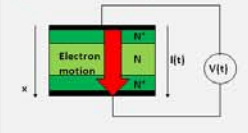


Density dependence of of peak velocity
high densities ⇨ reduced effective intervalley spacing

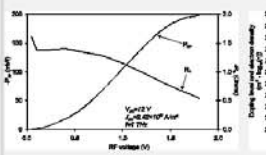


Transferred electron devices (TEDs) for THz operation

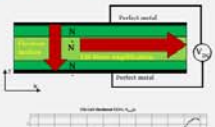
Mesa Gunn diode : 1D time-domain quasi-electrostatic/electron transport model

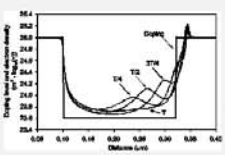


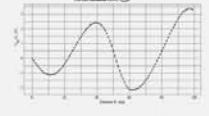
Using GaN operation @1THZ possible but close to the maximum achievable mainly due to thermal limitations
Dalle et al. IEEE Electron. Dev. Lett., 59, p3321 (2012)



Distributed GaN TED : 2D time-domain electromagnetic/transport model







Transversal RF voltage $V_{RF}(x,t)$ amplification in THz oscillations operating mode

Prospective 3D electromagnetic/energy -momentum modeling

➢ active line/ load circuit interaction

➢ Thermal Issues

➢ 3D
- Electron Transport
- Maxwell
- Heat propagation
- ...

Multiphysics simulators

(parallel computing needed)

iemn
Institut d'Electronique, de Microélectronique et de Nanotechnologie
UMR CNRS 8520

cnrs · Université Lille1 · Université de Valenciennes et du Hainaut-Cambresis · ISEN école d'ingénieurs · RENATECH