Nanomaterials and Advanced Heterostructures (NanoMAT)

Permanent staff **Hubert Renevier, Vincent Consonni,** Estelle Appert, Michel Boudard, Monica Burriel, Odette Chaix, Laurent Jouffret, Françoise Hippert, Roland Madar, Thierry Ouisse, Stéphane Pignard, Eirini Sarigiannidou

Technical support Mikhail Anikin, Isabelle Gélard, Carmen Jiménez, Matthieu Jouvert, Serge Quessada, Laetitia Rapenne, Hervé Roussel, Laurent Terrier, Gilbert Vian

Semiconducting Nanowires & Nanostructures

Context

Semiconducting nanowires: nano-objects with a large surface over volume ratio

Remarkable chemical & physical properties opening the way for next generation devices

Understanding their nucleation, growth, and doping fundamental mechanisms is required for monitoring their morphology and controlling their properties

Objectives

- To develop the spontaneous and selective area growth of semiconducting oxides nanowires by chemical deposition techniques
- To elucidate the nucleation & growth mechanisms by combination with thermodynamic computations
- To explore and control their physical properties: hydrogen, polarity, interface/surface, doping
- To combine nanowires with semiconducting shells to form innovative heterostructures for optoelectronic (self-powered UV photodetectors, LEDs), photovoltaic, and piezoelectric devices

Skills & know-how

Nanowire growth modeling, doping

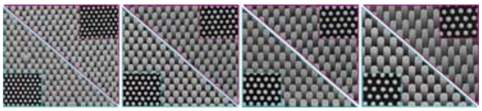
Thermodynamic simulations

Processes: e-beam & nano-imprint lithography

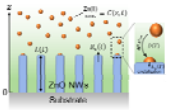
Techniques: sol-gel, chemical bath deposition, SILAR, atomic layer deposition, metal-organic chemical vapour deposition & characterization

Synthesis and Properties of ZnO Nanowires

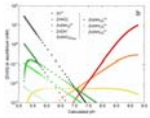
We develop the spontaneous and selective area growth of ZnO nanowires by chemical bath deposition to thoroughly control their morphology and physical properties (hydrogen, polarity, interface/surface, …).



ZnO nanowires selectively grown by chemical bath deposition

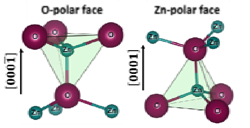


Modeling the nanowire growth

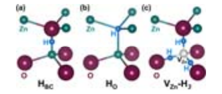


Thermodynamic simulations

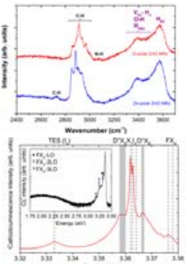
*C. Lausecker et al., **J. Phys. Chem. C** in press (2019)*



*V. Consonni et al., **ACS Nano** 8, 4761 (2014)*



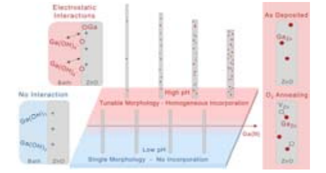
*T. Cossuet et al., **J. Phys. Chem. C** 122, 22767 (2018)*



Polarity effects on the nucleation & growth, surface, physical & contact properties

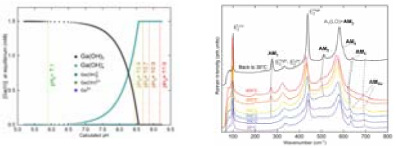
Intentionnal Doping

We explore n- and p-type doping: H, Al, Ga, Cu…



Innovative strategy to make doping in aqueous solution by using attractive electrostatic interactions while monitoring the morphology

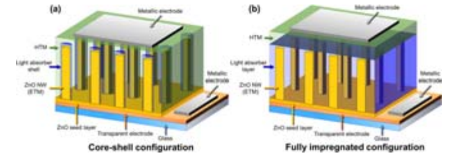
*C. Verrier et al., **Inorg. Chem.** 56, 13111 (2017)*



*P. Gaffuri et al., **Inorg. Chem.** 58, 10269 (2019)*

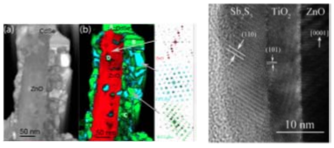
Core-shell Heterostructures & Devices

We develop semiconducting shells for optoelectronic and photovoltaic devices : TiO_2, Sb_2S_3, CuSCN, Ga_2O_3…

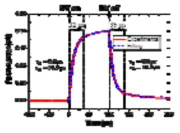


Core-shell heterostructures: light trapping, charge carrier management, passivation…

*V. Consonni et al., **Nanotechnology** 30, 362001 (2019)*



*R. Parize et al., **J. Phys. Chem. C** 121, 9672 (2017)*



*T. Cossuet et al., **Adv. Funct. Mater.** 28, 1803142 (2018)*

Oxides for Nanoionic Devices

Context

We study **ion conducting and mixed ionic-electronic conducting (MIEC) oxides** for their use in several microelectronics applications:

- ✓ **Valence change memories (VCMs) and neuromorphic computing systems**
- ✓ **Micro Solid Oxide Fuel Cells and Electrolysers (μ-SOCs)**

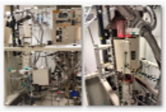
Objectives

- Design and optimization of oxide heterostructures for applications in the nanoionics field
- Understanding of the relationship between the structural, physico-chemical and functional properties
- Tuning of the microstructure, ion transport, electrochemical and resistive switching (RS) properties

Skills & know-how

- Deposition of **perovskite** and **fluorite-type oxides** by Metal Organic Chemical Vapour Deposition (**MOCVD**) and Atomic Layer Deposition (**ALD**)
- Characterization by a large number of chemical, structural and electrochemical techniques

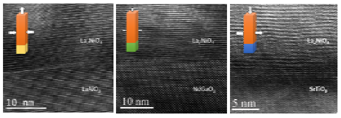
Chemical Vapour Deposition Techniques: MOCVD and ALD



Pulsed Injection MOCVD reactor

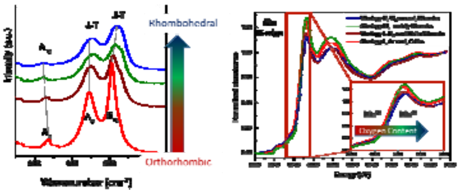
ALD reactor

Epitaxial $La_2NiO_{4+\delta}$ thin films by MOCVD



$La_2NiO_{4+\delta}$ epitaxial thin films deposited on 3 different single crystal substrates

Polycrystalline $LaMnO_{3+\delta}$ thin films grown by MOCVD

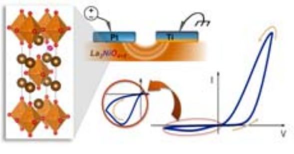


***Three growth strategies** to:*

- ✓ *integrate $LaMnO_{3+\delta}$ on a Si-based substrate*
- ✓ *tune the oxygen content and Mn oxidation state*

*R. Rodríguez-Lamas et al., **Belstein J. Nanotechnol.** 10, 389 (2019)*

Perovskite-Based Resistive Switching Devices



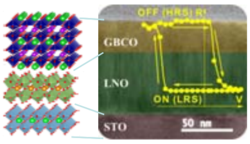
*K. Maas et al., **J. Mater. Chem. C** in press (2019) DOI: 10.1039/C9TC03972D*

Pt/$La_2NiO_{4+\delta}$/Ti for Artificial Synapse Applications

- ✓ Analog, highly multilevel
- ✓ Gradual SET and RESET
- ✓ No electroforming required
- ✓ Transience behaviour
- ✓ R is history-dependant

Bipolar RS in epitaxial $GdBaCoO_{5+x}$ heterostructures

- ✓ Clockwise hysteretic R(V) switching
- ✓ Up to 2 orders of magnitude HRS/LRS

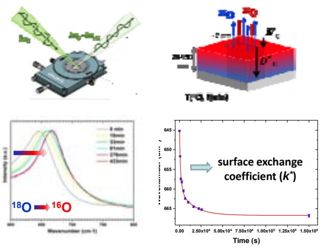


*S. Bagdzevicius et al., **J. Mater. Chem. C** 7, 7580 (2019)*

*S. Bagdzevicius et al., **Solid State Ionics** 29, 334 (2019)*

Functional Characterization by *in-situ* Raman Scattering

New methodology for isotopic oxygen exchange measurements



Rapid, cost-efficient non-destructive method to measure the surface exchange coefficient

D. Pla et al., in preparation