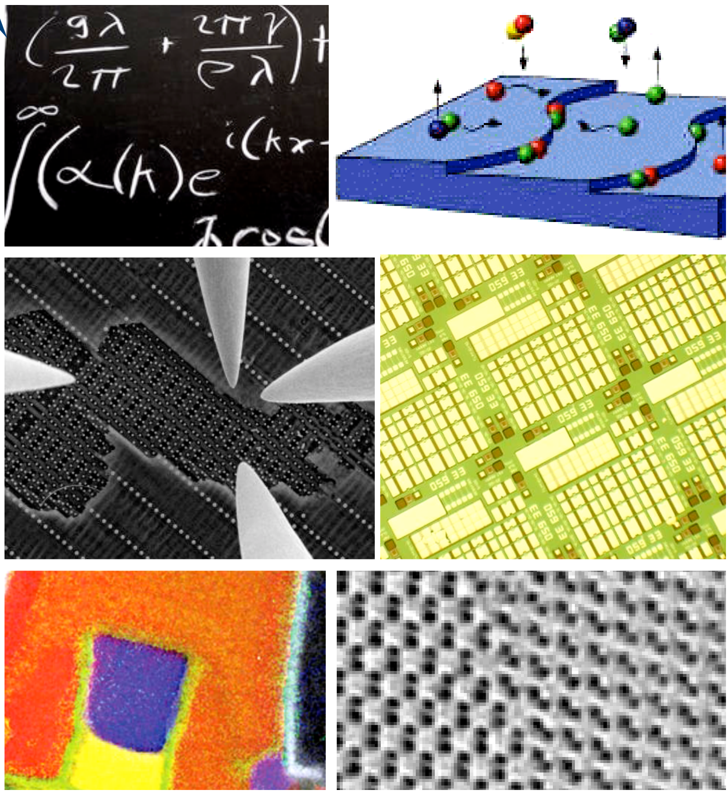
KATHOLIEKE UNIVERSITEIT
LEUVEN

Functional Nanosystems



The **Functional Nanosystems (FuN)** group focuses his research on advanced nanomaterials and their assembly into functional devices and systems. Advanced nanomaterials include nanoparticles, 2D nanostructures, thin film heterostructures and bio-hybrids. We aim at exploring their functional response, which are very important for many applications in fields like electronics, materials science, catalysis, energy production and medicine. Our approach covers experimental and theoretical efforts as well as nanoscale up to macroscale synthesis and characterization.

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Introduction:

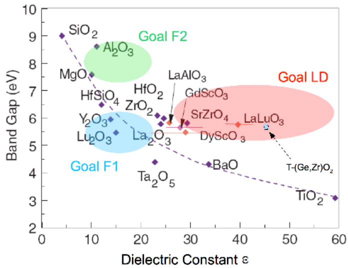
The Functional Nanosystems group of the Laboratory of Solid State Physics and Magnetism works on the elaboration of advanced nanomaterials and their assembly into functional devices and systems. Advanced nanomaterials – such as nanoparticles, heterostructures and bio-hybrids – with a functional response are very useful for many applications in fields like electronics, materials science, catalysis, energy production and medicine. These responses universally originates through a change of a state variable such as a charge or spins density, a spin or dipole orientation, an excited state, a mechanical deformation, a molecular arrangement etc.

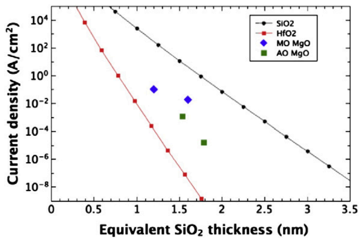
While many artificially tailored nanomaterials offer great potential towards the discovery of novel properties and functions, their practical usefulness depends on the coupling to external forces (such as electric and magnetic fields) and is therefore often limited by unknown and uncontrolled surface and interface details. The preponderant role of those interfaces is perhaps best illustrated by the discovery of novel interface functionality such as the appearance of magnetism between two non-magnetic insulators or the appearance of superconductivity between two insulators.

The generic approach that is followed here relies on three objectives, namely (1) to explore the synthesis of novel nanomaterials; (2) to precisely control the functionality of these materials by atomic scale engineering and monitoring; and (3) to translate the results into practical devices, tools and systems.

Main Research Topics:

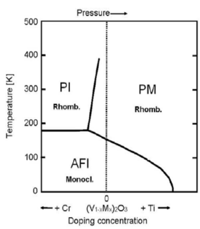
Tailored oxide – semiconductor interfaces
Oxides with a High Dielectric Constant





Oxide-semiconductor interfaces are at the core of any metal-oxide-semiconductor field effect transistor technology (MOSFET). The Si – SiO2 interface is currently the only such interface that shows a low 'electrical' defect density. However, in order to increase this performance further, there is a strong drive to replace the Si – SiO2 system by using a different oxide, a different semiconductor or their combination. The oxides being considered have a higher dielectric constant (10 – 30) while the interesting semiconductors are those which have a high mobility such as Ge (particularly for p-MOSFET) and GaAs/InGaAs (particularly for n-MOSFET). At this stage, there is no interface configuration for these new systems that comes close in electrical quality to that of the Si – SiO2 couple. In the latest 45 nm high performance chips, the gate oxide dielectric consists of ~ 3nm HfO2 (with a dielectric constant k = 25) replace the previously used SiO2 (k = 3.9). For future generations, the goal is to find oxides with an even higher dielectric constant (k = 40-50) while maintain a large band-gap (>5.5 eV).

Electric Field Induced Metal - Insulator - Transition
Theoretical study of strongly correlated electron systems

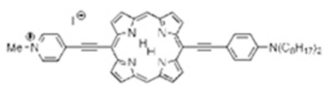


Changes in the electrical resistance are at the basis of most electronic devices. There are many phenomena that lead to variations in the resistance such as changes in the crystal structure, modifications of the composition, oxygen migration etc. In this project, the focus is on oxides displaying purely electronic phase transitions between an insulating and a metallic state and the goal is to demonstrate whether this transition can be induced through the application of an electric field at temperature above room temperature.

The theoretical description of interacting many-particle systems remains one of the grand challenges in condensed-matter physics. The main goal of this project is to study strongly correlated electron systems, and of special interest, materials which show a metal-insulator transition (V2O3, VO2) or multiferroic behavior (BiFeO3, BiMnO3), in connection with the experimental work. This project is performed in collaboration with ETH Zürich (Peter Staar, Prof. Schultess).

Piezoelectric properties of electro-optical materials

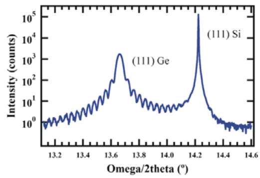
In recent years there has been spectacular progress in the development of novel organic materials for electro-optical applications. These materials have a specific structural construction that induces a permanent charge distribution (a dipole) across the molecule. The goal of the project is evaluation and optimalisation of electro-optical materials for mechanical applications.



Main Research Topics:

High-mobility semiconductor materials

We are investigating semiconductor materials with high carrier mobility compared to silicon. Such layers enable new and improved electronic applications. The main goals of this research are: (1) Developing unique fabrication methods of high mobility semiconductor materials with unique composition, structure and consequently novel physical properties, especially GexSn1-x at the low band gap side and SixC1-x at the wide band gap side. (2) Determining the fundamental physical properties of these unique materials. (3) Integrating high mobility semiconductor materials in novel (opto-)electronic devices and biosensors.

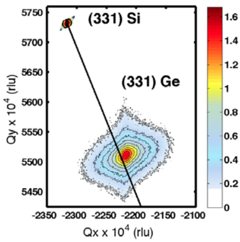


Crystallization of germanium films

We are investigating low cost deposition methods to obtain germanium films on large areas. Such layers enable new and improved large area electronic applications, by using the excellent optical and electrical properties of germanium. We have developed a method consisting of low temperature deposition and annealing, leading to excellent solid phase epitaxial growth of germanium on silicon substrates.

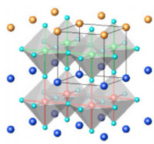
The advantages of this method are:

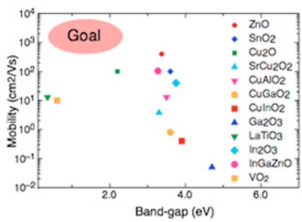
- low thermal budget (400 °C is sufficient)
- Plasma-enhanced chemical vapor deposition (PECVD) can be used
- ideal for large scale applications
- fast overall process (extreme fast deposition and RTA)
- easily scalable to large areas (> 8 inch)
- excellent structural quality
- high electrical quality (carrier mobilities of more than 80 % higher than Si(001) demonstrated)
- smooth interface (< 1 nm RMS roughness, no mixing)
- smooth surface (0.4 nm RMS roughness obtained)



Oxides semiconductors
Magnetoelectricity in oxide heterostructures

Understanding and controlling the physical properties of thin films and heterostructures inspires many of today's research activities in condensed matter physics. Of particular interest are magnetoelectric materials, where an intimate coupling between electrical polarization and magnetization exists and can be used for instance to switch a magnetization with an electric field. Apart from single-phase films, heterostructures are intensively investigated, where different materials are brought together, resulting in multifunctionality through coupling at the interfaces. Striking examples are the emergence of magnetism at the interface between two non-magnetic insulators and the creation of a high mobility electron gas at the interface between two insulators.

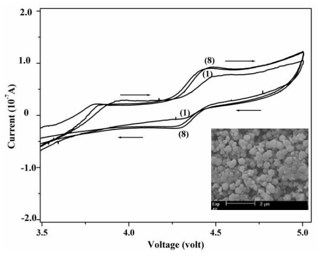




Currently, semiconductor technology combines two very different and often incompatible materials, namely simple semiconductors and oxides Developing oxide semiconductors with propeties comparable to those of the simple semiconductors is our task. One of potential applications of these oxide semiconductors is solar cells.

Main Research Topics:

Synthesis and characterization of Li_2MPO_4F (M=Co, Ni, Mn), Cathode materials for Lithium Rechargeable batteries



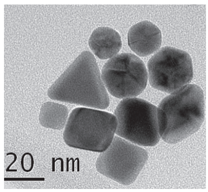
Research in the field of lithium rechargeable batteries has progressed with the active chemistry of electrodes and electrolytes to synthesize materials with high performance in terms of energy, power, lifetime and safety. The structure of materials commonly used to prepare positive electrodes generally consists of two-dimensional or three-dimensional frameworks and their rate capability is governed by the diffusion of lithium ions within the bulk electrode.

Proton Exchange Membrane Fuel Cells

The PEM (proton exchange membrane)fuel cell promises to deliver clean and efficient power by combining hydrogen and oxygen in a simple electrochemical device that directly converts chemical energy to electrical energy. We aim at finding a polymer membrane with high proton conductivity, good mechanical, chemical and thermal strength and low gas permeability as well as to improve the electrical performance of polymer membranes at T>100°C and low relative humidity by preparing new complexes with the ionic liquids.

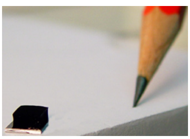
Nanoparticles for Electron Emission Tumor Treatment

Many different chemical and physical routes are currently followed of the treatment of tumor cells. An alternative method is to use an external x-ray photon source to excite photoelectrons and Auger electrons from selected materials. In this case, the energy of the photo-emitted electrons can be chosen quasi-continuously by changing the photon energy and the materials while also the discrete Auger electron energies remain available.



This research is carried in collaboration with several other groups at the KULeuven including the department of Radiation Oncology as well as the department of Biosystems.

Synthesis of carbon nanotubes and graphene

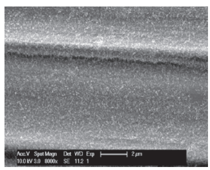


Carbon nanomaterials such as carbon nanotubes and graphene are grown using the catalytic chemical vapour deposition technique. We also explore their potential use in various applications, such as for Li-batteries, sensors, fibers, nanocomposites etc.

This research is conducted in collaboration with EPFL, Switzerland.

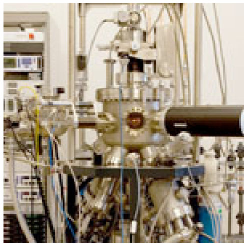
Grafting carbon nanotubes on carbon fibers for nano-engineered composites

We elaborate a process to grow carbon nanotubes directly on carbon fibers without damaging their initial structure and without reduxcing their mechanical properties. These carbon nanotubes grafted carbon fibers are used for carbon fiber reinforced polymer composites which find currently tremendous applications where light-weight and strong materials are required.

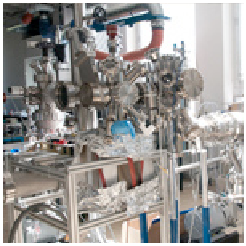


Main Research Equipments:

Molecular Beam Epitaxy Systems
Atomic Layer Deposition
Chemical Vapour Deposition
Semiconductor Parameter Analyser
Ferroelectric Parameter Tester
Variable Temperature Probe Station (8-inch)
Impedance Analyser / Cyclic Voltammetry
Auto-Claves and Ovens
Planetary Ball Milling
Spin coater
Glove Box
X-Ray Photoemssion Spectroscopy (soon available)

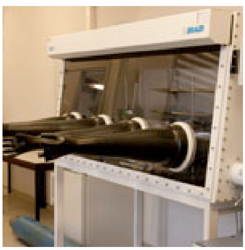


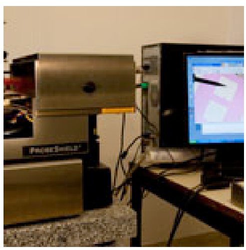
The activities of FuN take place in several laboratories and collaborations. This includes NanoFuN, a joint laboratory with the Nanomaterials and Nanoscale Characterisation group of Prof. J.W. Seo of the Metallurgy and Materials Engineering Department. This also includes the Ion and Molecular Beam Laboratory (IMBL) a joint laboratory between the Section Solid State Physics and Magnetism and the Section Nuclear Solid State Physics of the Physics Department.



IMBL:
Molecular Beam Epitaxy
X-Ray Diffraction
Scanning Tunneling microscope
Auger-Electron Spectroscopy

MTM:
Transmission Electron Microscopy
Scanning Electron Microscopy
Focused Ion Beam





Main Projects:

FP7 EU-projects:
- Integrated Real-Time Measurement Platforms for Nanoparticles and Nanpaticle Thin Films (Snowcontrol), Coordinator, 2011-2015
- Laboratory Compact Light Sources (LabSync), Coordinator, 2007-2013
- Dual-channel CMOS for (sub)-22 nm high performance logic (DualLogic), 2007-2011

National projects:
- Odysseus
  Nanomaterials with Controlled Functionality
- Hercules:
  Near Atmospheric Pressure Characterization and Processing Station (NAPCAP)
  Nanoscale Manipulation and Characterization Inside a Transmission Electron Microscope
- FWO Research Foundation Flanders:
  Magnetoelectric properties of tailored oxide heterostructures
  Metal-insulator transitions in electron correlated systems
  Design of metal oxide semiconductors with a low bandgap and high mobility
- Strategic Initiative Materials in Flanders (SIM), Nanoforce

KUL projects:
- IDO: Evaluation and optimalisation of electro- optical materials for mechanical applications
- START: Tailoring 1D complex oxide nanostructures for integrated electronic and electromagnetic systems
- GOA:
  Genesis of electrical and magnetic properties in condensed matter
  New model-based concepts for nano-engineered polymer composites

Main Collaborations:

IBM Zurich Research Laboratory
ETH Zurich
EPF Lausanne
IMEC
University of Szeged (HU)
University of Antwerp
University of Hasselt

Main Recent Publications of year 2011:

Preparation and characterization of composite membranes based on sulfonated PEEK and $AlPO_4$ for PEMFCs
V. S. Rangasamy, S. Thayumanasundaram and J.-P. Locquet
Solid State Ionics in print (2011)

Electrochemical investigation on Li_2CoSiO_4 as cathode and carbon nanotubes as anodes for Lithium Battery
S. Thayumanasundaram, V. S. Rangasamy, E. Couteau, N. De Greef, J.W. Seo and J.-P. Locquet
Journal of Power Sources in print (2011)

Correlation between strain and the metal-insulator transition in epitaxial V_2O_3 thin films grown by MBE
L. Dillemans, R. R. Lieten, M. Menghini, T. Smets, J. W. Seo and J.-P. Locquet
Thin Solid Films in print (2011)

Deposition and characterization of MgO/Si gate stacks grown by MBE
C.-Y. Su, M. Frederickx, M. Menghini, L. Dillemans, R. R. Lieten, T. Smets, J. W. Seo and J.-P. Locquet
Thin Solid Films in print (2011)

Solid phase epitaxy of Germanium on Silicon substrates
R.R. Lieten , Q.-B. Ma, J. Guzman, J.W. Ager III, E.E. Haller, J.-P. Locquet
Mater. Res. Soc. Symp. Proc. Vol. 1339 © 2011 Materials Research Society pp. 1-6

Indium Rich III-Nitrides on Germanium by Molecular Beam Epitaxy
R.R. Lieten, W.-J. Tseng, M. Leys, J.-P. Locquet, J. Dekoster
Mater. Res. Soc. Symp. Proc. Vol. 1324 © 2011 Materials Research Society pp. 1-6

Unexpected optical response of single ZnO nanowires probed using controllable electrical contacts
Y. J. Zeng, M. Menghini, D. Y. Li, S. S. Lin, Z. Z. Ye, J. Hadermann, T. Moorkens, J.W. Seo, J.P. Locquet and C. Van Haesendonck
Phys. Chem. Chem. Phys., 2011, Advance Article, 13, 6931-6935

Solid phase epitaxial growth of Dy-Germanide films on Ge(100) substrates
Md. N. K. Bhuiyan, Mariela Menghini, J.W. Seo and J.P. Locquet
Microelectronic Engineering, 88 (8), 423-426, (2011)

Epitaxial growth of Dy_2O_3 films on $SrTiO_3$ (001) substrates by molecular beam epitaxy
Md N. K. Bhuiyan, M Menghini, J.W. Seo, Ch Dieker, W Jaeger, C Marchiori and J.P. Locquet
J. Vacuum Science & Technology B, Microelectronics and Nanometer Structures, 29 (1), art.nr. 01A801, 1-4, (2011)

High quality epitaxial Dy_3Ge_5 films grown on Ge (001) substrates
Md N. K. Bhuiyan, M Menghini, J. W. Seo, C Marchiori and J.P. Locquet
J. Vacuum Science & Technology B, Microelectronics and Nanometer Structures, 29 (1) art.nr. 01A805, 1-4, (2011).

Epitaxial growth of Dy_2O_3 thin films on epitaxial Dy-germanide films on Ge(001) substrates.
Md N. K. Bhuiyan, M. Menghini, J.W. Seo and J.P. Locquet
Microelectronic Engineering, 88 (4), 411-414, (2011).

Epitaxial growth of V_2O_3 on Al_2O_3 by reactive MBE
L. Dillemans, T. Tran, Md. N. K. Bhuiyan, T. Smets, M. Menghini, R. Lieten, J.W. Seo and J. P. Locquet
Mater. Res. Soc. Symp. Proc. Vol. 1292 © 2011 Materials Research Society pp. 1-6, (2011).

Growth of sputter-deposited gold nanoparticles in ionic liquids.
E. Vanecht, K. Binnemans, J.W. Seo, L. Stappers, J. Fransaer
Physical Chemistry Chemical Physics, 13 (30), 13565-13571, (2011).

Striking influence of the catalyst support and its acid-base properties: New insight into the growth mechanism of carbon nanotubes.
A. Magrez, R. Smajda, J.W., Seo, E. Horvath, P. Ribic, J. Andresen, D. Acquaviva, A. Olariu, G. Laurenczy, L. Forro, .
ACS Nano, 5 (5), 3428-3437, (2011).

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