PhD Thesis Awards - Abstract

Fundamental research

William LEGRAND

« Crafting magnetic skyrmions at room temperature : size, stability and dynamics in multilayers »

This Ph.D. thesis focuses on magnetic skyrmions, small magnetic “particles” being a few nanometres in size only. The skyrmions studied in this work are obtained at ambient conditions and observed in sandwiches made of a few tens of metallic layers, alternating between different magnetic and non-magnetic metals, each being around one nanometre thick. Different physical properties of skyrmions such as their size, shape, stability, etc., are studied and modelled. This work also deals with the creation and the displacement of skyrmions induced by electronic currents, and aims at enhancing the achieved velocities by optimising the combinations of layers. This thesis finally pushes forwards the reduction of the size of the skyrmions, by developing a novel type of chiral magnetic system coupling vertically “opposed” skyrmions with reversed polarities. These advances find applications in next-generation electronics.

Ida LUCCI

« Surface and interface contributions to III-V/Si hetero-epitaxial growth: Theory and Experiments »

This thesis context is related to the development of components for integrated photonics (less power loss) and «green» energy applications (photovoltaics or solar hydrogen production).

It aims to clarify the initial phase of the monolithic growth of III-V semiconductors on Si from experimental analysis and theory. In particular, the purpose of this thesis is threefold: i) to study the thermodynamic properties by simulations based on density functional theory (DFT), ii) to clarify the very first steps of heterogeneous GaP growth on Si and finally iii) to generalize to III-V materials on Si. Pioneering theoretical and experimental work was required to analyze these structures.

The study demonstrated that the total wetting is never achieved in this system, regardless of the chemical potential, and that this effect is enhanced by the passivation of the Si surface. These results are generalized to all III-V/Si systems. A III-V/Si growth mechanism is proposed to clarify the early stages of growth and to explain the generation of defects such as antiphase domains, which is related to the partial wetting properties of the system.

Finally, surface energy engineering is used to produce a textured GaP surface, integrated on silicon, for applications in the energy field.

Benjamin VERLHAC

« Atomic-scale spin-sensing with a single molecule at the apex of a scanning tunneling microscope »

This thesis is placed in the context of the study of surface magnetism, which knew great developments these last years thanks to the scanning tunneling microscope (STM). The purpose of the thesis was to demonstrate that a simple molecule, the nickelocene [Ni(C5H5)2], can be attached to the STM tip apex to produce a molecular and magnetic probe-tip.

We show that, compared to other systems studied by STM, the magnetic properties of nickelocene in gas phase are preserved upon adsorption on a metallic electrode, when it is adsorbed either on a copper surface or on the copper terminated STM tip apex. We’ve shown also that the value of its spin can be tuned by contacting the tip adsorbed molecule onto the Cu(100) surface, triggering a controllable Kondo resonance. However, the main result of the thesis is the use of the tip adsorbed nickelocene as a probe of the magnetism of a single atom on Cu(100) and a ferromagnetic surface. Indeed, nickelocene presents spin excitations which correspond to a change of spin momentum and are sensible to neighboring magnetism. The magnetic sensibility of our technique is due to the exchange coupling between the molecule on the tip and the magnetic object. Due to a traceable variation of this coupling by only a few picometers movement of the tip, we are able to achieve atomic and subsurface resolution on the ferromagnetic surface. Another aspect is that spin excitations allow also to discriminate the two electron spin populations in the tunnel junction transport, permitting an atomically resolved mapping of spin polarized transport.

This work has been published recently (Verlhac et al., Science 366, 6465 (2019)), and is already cited as interesting results by pioneers of STM related surface magnetism research (Czap et al., Science 364, 670 (2019) ; Yang et al., Phys.Rev. Lett. 122, 227203 (2019)).

PhD Thesis Awards - Abstract

Applied research

Claire DAZON

« Workplace exposure to nanomaterials during powder handling: Relationships between powder properties and airborne particle characteristics »

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Interdisciplinary research

Noémie DANNÉ

« Single carbon nanotubes tracking to measure the rheological properties of complex environments: application in neuroscience »

The brain is mainly composed of neurons and glial cells. The extracellular space (ECS) corresponds to the space which exists between all these cells (~ 20% of the volume of the whole brain). Its organization is complex and the neurotransmitters and many other molecules necessary for the proper functioning of the brain circulate there. Thus, the ECS changes during age, learning or during neurodegenerative diseases. However, its local dimensions and viscosity are still poorly known due to certain limitations (optical resolution, opacity / tissue thickness, macroscopic diffusion models). To understand these parameters, we have developed a strategy based on the tracking of single luminescent carbon nanotubes. To super-localize the nanotubes within thick tissues, we optimized i) the encapsulation of nanotubes to limit their non-specific interactions with tissues, ii) the excitation wavelength of nanotubes taking into account the ratio signal on background and photo-toxicity. The analysis of the diffusion properties of nanotubes in complex spaces made it possible to extract two local properties: a structure-specific complexity parameter (tortuosity) and the viscosity of the fluid seen by the nanotubes. This methodology allows to model the viscosity that would be seen by any molecule of arbitrary sizes to simulate those intrinsically present or administered in the brain for pharmacological treatments. Finally, we present a strategy to make ultra-short carbon nanotubes luminescent which are not intrinsically so and which could be a complementary approach to measure the local viscosity of the ECS.

Bertille MARTINEZ

« Electronic properties of narrow band gap colloidal nanocrystals : application to infrared nano-crystals »

Infrared detectors are useful in many fields such as military surveillance or obstacle detection for self-driving car cameras. However, these devices are very expensive and so, their use in day to day applications is limited. Colloidal nanocrystals are cheap to synthetize and are now quite mature in the visible range: they can be employed as light emitters in QLED displays or as active material in perovskite solar cells. The aim of my PhD work was to study the potential of such nanocrystals as infrared sensors.

I studied mercury chalcogenide nanocrystals. These objects absorb in the infrared range and are photoconductive: they generate free carriers, holes or electrons, after they absorbed photons. Once synthetized, their electronic structure is characterized experimentally. This allows us to determine the nature and the density of free carriers. These two parameters are tunable by changing the nanocrystal size or surface chemistry. My work showed the great tunability of these objects optoelectronic properties, which is of utmost importance to design an efficient infrared sensor.

I then applied these results to propose a sensor architecture working with nanocrystal absorbing above 2.5 µm. The development of a surface chemistry leading to high carrier mobility combined to the use of transport and barrier layers increasing signal to noise ratio led to a high dynamics, efficient and room temperature operable sensor.

Nanomedicine research

Alexandre BORDAT

« Alternative strategies for the delivery of anticancer drugs by physical encapsulation in thermores-ponsive polymer nanoparticles or chemical coupling as polymer prodrugs »

The project is based on two innovative anti-cancer drug delivery systems to (i) enable the physical targeting of the tumor by mild hyperthermia and (ii) enable the subcutaneous administration of anticancer drugs while improving their efficacy.

(i) We synthesized a thermosensitive UCST-type copolymer to formulate nanoparticles physically encapsulating doxorubicin. The idea being to heat the tumor by mild hyperthermia to release doxorubicin in a controlled manner. Our work highlights the essential parameters (hitherto neglected) to take into account in order to obtain an optimal system: to use a polymer with a UCST stable upon dilution and to anticipate the impact of the encapsulation of the drug on the thermoresponsiveness.

(ii) We opted for a chemical coupling approach between an anticancer drug, paclitaxel, and a hydrophilic polymer to allow its subcutaneous administration. This route of administration is seldom used for anticancer drugs because they can induce irritation and even necrosis at the injection site. Our studies have shown that we are able to eliminate this local toxicity and improve the pharmacokinetics of paclitaxel. This is the first time that an innocuous subcutaneous administration of paclitaxel has been described for systemic exposure and not for local use. Further studies in mice performed after the thesis demonstrated that this approach improves the efficacy of the treatment compared to the traditional intravenous administration used in the clinic. Our goal is to bring the technology to the clinic through IMESCIA, a start-up that we co-founded in June 2019.

Finally, surface energy engineering is used to produce a textured GaP surface, integrated on silicon, for applications in the energy field.

PhD Thesis Awards - Abstract

C'Nano - SFNano

Max PIFFOUX

« Physical and interdisciplinary approaches of the extracellular vesicle field : new tools and techniques toward clinical translation in regenerative medicine and drug delivery »

Extracellular Vesicles are nanosized vesicles secreted by most cells of the organism that demonstrated physiologic roles via information transfer through biological macromolecules. Therapeutic use of these EVs as drug delivery systems or regeneration triggering agent is of a major interest, e.g. the use Mesenchymal Stem Cells derived EVs after myocardial infarction or stroke. EV recapitulate their parental cell and benefit from unique opportunities like off-the-shelf availability, low immunogenicity and no anarchic differentiation or pulmonary embolism. Major obstacles like the EV drug loading, engineering, targeting, characterization, delivery method and GMP high yield production still limit clinical translation. We developed new methods to respond to these needs at the crossroad of biology, physics, pharmacy and medicine. A new liquid cell transmission electron microscopy labeling method was developed to investigate live in-situ at the nanoscale EVs behavior that can be used for other "soft" materials like liposomes. The PEG induced liposome/EV fusion method was designed to produce biological/synthetic hybrids with engineered membrane properties and drug loading. We designed a microfluidic chip allowing shear stress application to trigger EV production and a 2nd generation system for high yield scalable and compliant with Good Manufacturing Practice EV production method. These EVs were tested in regenerative medicine models of fistula healing and chronic heart insufficiency with a new local delivery method using thermosensitive gels and compared to their parental cells. We now explore the scale-up, immunogenicity, and stability of these EVs and benchmarking their cost/efficiency in a company supported by C'Nano : Everzom.