

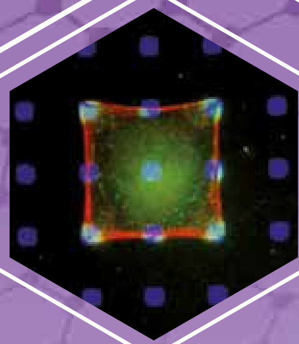

LANEF in 2023

lanef
Laboratoire d'Alliances Nanosciences-Energies du Futur

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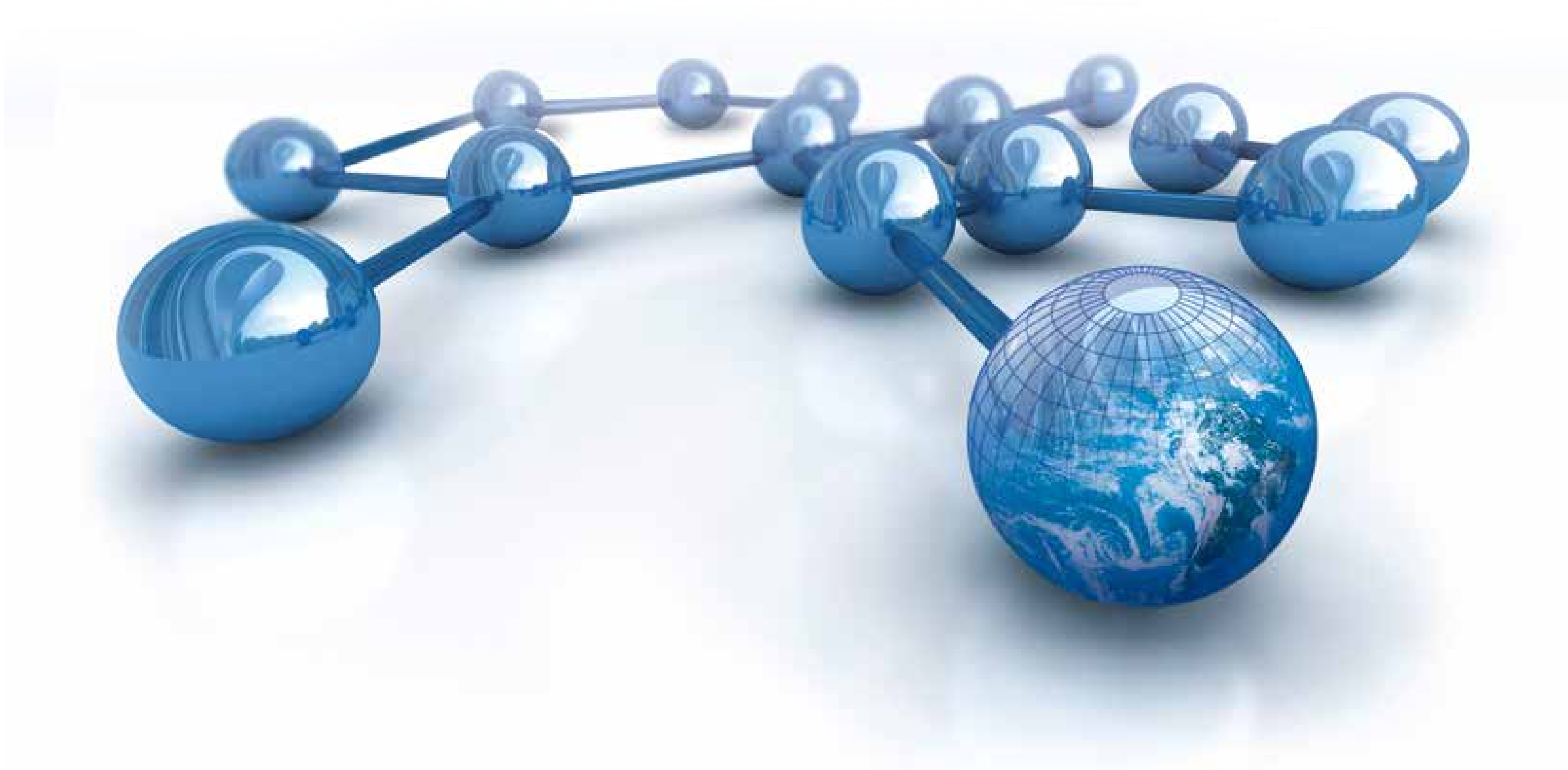


LANEF, Lab Alliances on Nanosciences - Energies for the Future, is a «LabEx» *(Laboratoire d'Excellence)* funded in 2011 in the frame of the French Plan d'*Investissements d'Avenir* and reconducted in 2018. Inside Université Grenoble Alpes (UGA), LANEF associates ten fundamental research labs, and it identifies five scientific and societal Challenges: Nanophysics and Quantum Engineering, Quantum Materials, Electrical Energy, Sensors for Life Science and Health, New frontiers in Cryogenics. It enhances the synergy between the different teams working towards these challenges, and makes connections with R&D.

INTRODUCTION

Fundamental science in physics, materials science and electrical engineering with a sensitivity towards technological developments constitutes an internationally recognized constant strength of the Grenoble community. In addition, it benefits from the Grenoble environment which is particularly suitable to establish links with R&D labs and industry. Grenoble is one of the few places worldwide which combines an expertise in basic cross-disciplinary research, integrated in a larger campus for research and innovation, hosting large-scale European facilities (synchrotron, neutrons, high magnetic fields).

LANEF involves four institutions (UGA, CNRS, CEA, Grenoble-INP) and associates ten fundamental research labs engaged in forefront basic research with an emphasis on physics - condensed matter and nanosciences - and electrical engineering, and supportive of the creation of intellectual property. These are PHELIQS focused on basic research in condensed matter physics and nanosciences, SPINTEC focused on spintronics, Grenoble Electrical Engineering Lab (G2ELab), with a strong focus on electrical energy, Modeling and Exploration of Materials laboratory (MEM), Low Temperature Department (DSBT) focus on cryotechnology, Grenoble High Magnetic Field Lab (LNCMI), which has also a national and European mission for the production and use of high fields, Laboratoire de Physique et Modélisation des Milieux Condensés (LPMMC) dedicated to condensed matter theory, two labs with interdisciplinary strategy between physics, chemistry and biolology/health, Molecular Systems and nanoMaterials for Energy and Health (SYMMES) and Laboratoire Interdisciplinaire de Physique (LiPhy) and finally Institut NEEL with a wide field of research in condensed matter and nanosciences (theory and experiment).

It is a long tradition and a strength of Grenoble to address together scientific and societal challenges. With this strategy in mind, the new LANEF project proposed in 2018 five challenges which underpin the LANEF project:

- **Nanophysics and Quantum Engineering**
- **Quantum Materials**
- **Electrical Energy**
- **Sensors for Life Science and Health**
- **New frontiers in Cryogenics**

Each of these challenges addresses, to various degrees, the idea to go "from scientific to societal objectives". To successfully enforce this strategy, LANEF uses its tools to improve scientific quality, strengthen the links with R&D and industry and spread innovation.

STRUCTURATION

The nanoscience and quantum science and technology development in Grenoble began with condensed matter research. This was initiated in the 80/90s by the developments of mesoscopic physics but also thanks to the new challenges of the microelectronic industry; since the 2000' novel challenges such as energy, health and quantum information contributed to its growth. All through these changes, Grenoble Institutions have accompanied researchers by structuring their scientific environment: the Institute of Physics of Condensed Matter (IPMC) in the 90', the Institute for Nanosciences in the late 90's, the Nanoscience Foundation in the mid-2000's and the *Laboratoire d'Excellence* (LabEx) LANEF since 2011. In 2015, under the aegis of LANEF, an important acceleration of the structuring of quantum science and technology community has taken place. Four "Quantum Engineering Grenoble" programs were successfully funded: the EU-MSCA-COFUND **"GREQUE"** (2017-2022) and **"QUANG"** (2022-2027) projects, the UGA-Cross Disciplinary Project **"QuEnG"** (2017-2022), followed by the UGA-Cross Disciplinary Tools **"TiQua"** (2022-2025) which supports interdisciplinary projects at the interface between humanities and physics, mathematics and computer science.

In addition, the **QuantAlps Federation** was created in January 2022. It is an inclusive federative structure stimulating the emergence of multi-disciplinary and multi-sectoral communities based on internationally recognized expertise. QuantAlps aims in the short term to reinforce Grenoble's role as a major player in quantum technologies at the global level, and in the long term, to function as an innovative ecosystem for quantum sciences. It gathers 18 laboratories of the UGA and involves three additional institutions (CNRS, CEA and Inria).

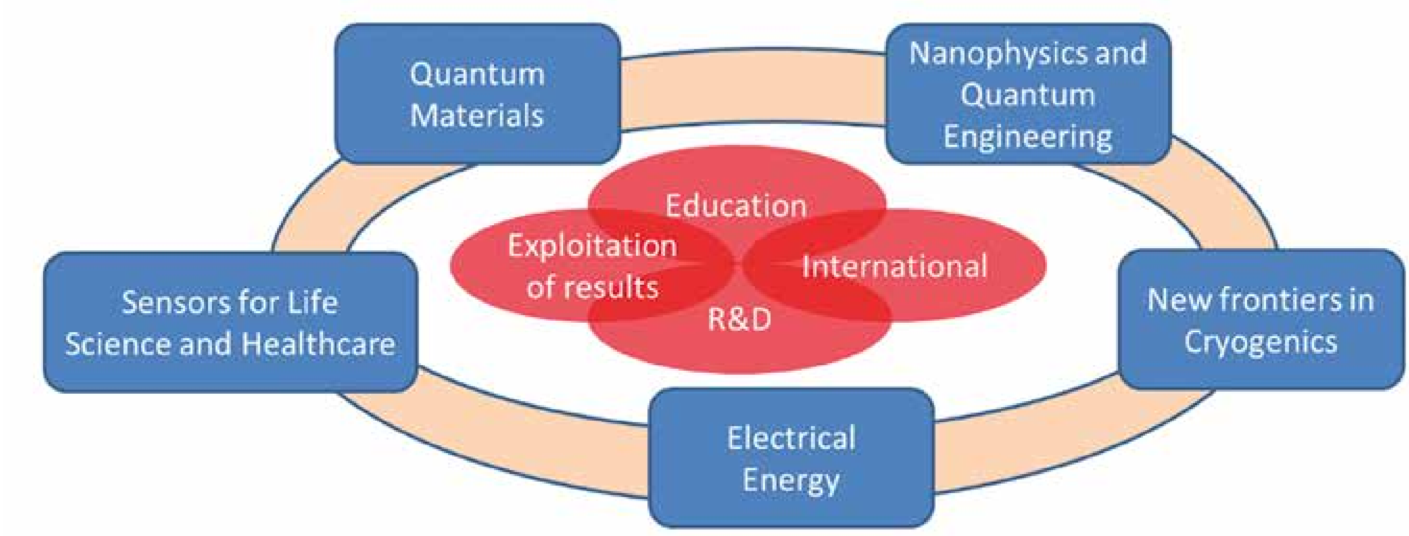


Figure 1: Structuration in five scientific and societal challenges

Through various actions, LANEF, as a trans-laboratory entity, effectively structures a large community of physicists around its five scientific and societal challenges. Its objective is to create and energize synergies between the research teams of the various laboratories, to strengthen education through research, to stimulate links with R&D partners and industries, and to structure international collaborations.

SCIENTIFIC ACTIONS

We detail here only some of the actions funded by LANEF since 2020, which correspond to projects which are still active in 2023. The main scientific achievements have been obtained through three specific calls:

- One call in autumn 2021 allowed the funding or co-funding of **five large research equipment** to strengthen the pool of mutualized equipment and innovative instrumentation. A four-circle X-ray diffractometer, a Brillouin light scattering and a photo-luminescence spectrometers, an MBE for 2D materials elaboration and an UHV-Sionludi prototype were funded or co-funded in 2022.

- **4 international Excellence Chairs** have been awarded in 2022; 4 PhD students / postdoctoral fellows benefit from a common supervision by the chair holder and their Grenoble contact. The chairs strengthen the international collaborations with four sites: Tokyo University, Copenhagen University, the University of California-Davis and the University of Arizona.

- Since 2020 and over five calls, **26 PhD students** have been recruited within the five different Challenges of the LANEF. Synergy within the LabEx is a major criterion, so that all the PhD projects directly involve two laboratories of LANEF.

SCIENTIFIC EVENTS

The LANEF finances scientific animations around the five challenges. Three seminars on Quantum Nano-Electronics, Quantum Materials and Theory take place regularly. These seminars are a good opportunity to gather the respective communities belonging to the different laboratories. A LANEF PhD Day is scheduled every year and gives the opportunity to LANEF funded PhD students to present their projects and to encourage networking. In addition, thematic days and visits of the different laboratories have been organized around the challenges New Frontiers of Cryogenics, Quantum Engineering and Sensors of Life Science and Healthcare to bring the community together or to go into greater depth on specific topics. In order to increase Grenoble visibility, workshops and conferences chaired by members of the LANEF community have also been funded. Finally, specific actions are developed to strengthen links between fundamental research and private companies. Visits, meetings and seminars to and from industry were organized and shared inside the LANEF labs. Contacts have been already established with STMicroelectronics, Air Liquide, Radiall and Thales.

EDUCATION

Together with offering support to research labs, the LANEF has also made an important effort towards the education of students.

Education through research has been a major central action of LANEF with 30 PhD students and postdoc fellows funded or co-funded since 2020. The students are given the opportunity to learn cutting edge techniques over broad experimental fields (optics, cryogenics, nanofabrication, microwave, large scale instruments, very low noise measurements, …) as well as in theoretical modeling, computational physics, applied mathematics and computer science.

International schools received funding from the LabEx LANEF such as ESONN, the Les Houches pre-doctoral school "Frontiers of Quantum Matter", European School of Magnetism, and CryoCourse.

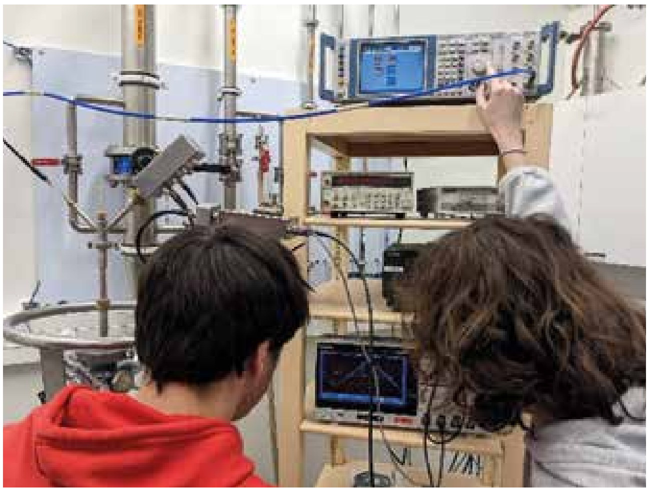


Figure 2: Practicals in labs showing quantum voltage steps in a current biased Josephson junction.

Advanced practicals in laboratories have been developed thanks to the work of an engineer hired by the LabEx LANEF (2 years contract, starting 2016), to equipment funding and to the involvement of technical staff, scientists and academics. More than 20 staff from CNRS and UGA have contributed to the development of the set-ups and the supervision of the students. About 130 Master students per year were given the opportunity to access "state-of the-art" experiments. The sessions were open to small groups of students (generally 4) for a total of more than 300 teaching hours. This platform is now recognized and co-funded by the Education and Research Unit (UFR) PhITEM of the UGA.

INTERNATIONAL ACTIONS

One success in the LANF international actions was to share the international networks of some scientists with the LANEF community. This was particularly the case for the collaborations with **Tsukuba**, led initially by Etienne Gheeraert, which was then extended to various other collaborators in Grenoble. An International Research Laboratory between Grenoble and Tsukuba University has been created in 2020. The relations with **Karlsruhe Institute of Technology** (KIT) were intensified in 2017, with two workshops successively in Grenoble and in Karlsruhe leading in 2018 to the creation of an International Lab (LIA) between CNRS and KIT, led by Serge Florens and Pierre Rodière and now by Marie-Aude Méasson. An interaction with the **Centre for Quantum Technology of National University of Singapore** (CQT-NTU), led by Alexia Auffèves, was initiated with the co-organization of an international summer school on «Strong light-matter coupling» and the successful application of three Merlion projects linked to quantum materials, quantum physics and quantum technologies, involving Grenoble and Singapore with ATOS-Bull as industrial partner for one project. One Chair of Excellence of LANEF, Luigi Amico, was also half-time at the CQT-NTU. In 2022, Alexia Auffèves moved from Grenoble to Singapore to lead the International Laboratory and this opened opportunities to reinforce collaborations and student exchanges. With Barcelona (also a strategic international partner for UGA), we have identified more than 20 permanent researchers on each side, already involved or interested to develop collaborations. They belong to several institutions in **Barcelona** (ICMAB-CSIC, IC2N, UAB, IREC), and to several of the LANEF labs. Two successful preliminary workshops (organized by Grenoble in 2019 and by Barcelona in 2021) have been organized.

ECO-SYSTEM

The four programs on quantum engineering, with initiatives such as the **PhD secondments** in private companies and the **Innovation Board** have created links with industry. The secondments allow the immersion of PhD students, even those working on fundamental aspects, for at least two months, in an industrial plant, a startup or a R&D lab. This has been very well appreciated by the students and helped them to orient their future carrier. The Innovation Board was a fruitful opportunity to gather academics and industrial partners and inform the PhD students of career opportunities in the private sector.

LANEF has also contributed to the creation of several **spin-off companies:** eight startups recently created in Grenoble are in the perimeter of healthcare and quantum technologies (Aryballe, Magia, Diamfab, Grapheal, Antaios, Hprobe, Silent-Waves and Siquance) with five have explicitly acknowledged the direct support of LANEF.

PROSPECTIVE CONCLUSION

Since its creation in 2011, LANEF has succeeded to implement an efficient strategy of synergy and mutualization between the ten laboratories. LANEF was mainly focused on physics - condensed matter and nanoscience - and electrical engineering with a permanent opening and opportunities towards interdisciplinarity (chemistry, life science, health care, …), inter-LabEx collaborations (ARCANE, CEMAM, PERSYVALS, …) and towards startup, private companies or R&D labs. The LANEF dynamic benefits greatly from a **steering committee** constituted by twenty local recognized experts having a collective and proactive attitude, and a deep knowledge of the labs expertise. They coach the projects prior to submission, and generate inside the steering committee a truly open discussion turning the diversity of the ten labs and four institutions to an advantage.

In 2022, under the impulse of the UGA Presidency and through discussions between the different UGA communities, a novel structuration of the fifteen UGA-LabEx has been proposed, taking into account emerging synergies. With the strong development of quantum science and technology in Grenoble, a novel LabEx QuantAlps project has been identified, having the objective to discover and understand new quantum effects at fundamental level, to master them, and to exploit them for new technological applications, remaining attentive to their societal impact within the framework of a sustainable innovation. The QuantAlps ecosystem associates 18 laboratories and four academic organizations (UGA, CNRS, CEA and Inria). This community has recently been structured by the creation of the QuantAlps Federation, focused on animation, communication and coordination of interdisciplinary research on quantum sciences and technologies. Since the Federation and the LabEx will work together with common goals, we decided to name both QuantAlps. In a similar way, the communities of the two Challenges "Electrical Energy" and "Sensors for Lifesciences and Healthcares" are actively participating to the construction of two new LabEx, MateriAlps and EnergyAlps, as well as a Federation between physics and life-science.

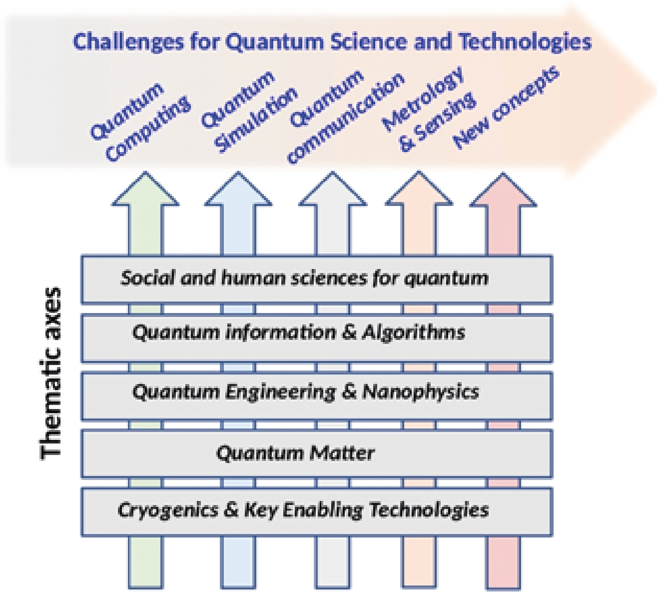


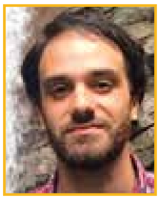
Figure 3: Inside the project LabEx QuantAlps, the consortium is organized through five research axes, from fundamental to applicative, structured around their specific disciplines and the identification of several scientific and societal challenges.

TABLE OF CONTENTS

PHD PROGRAMS, CHAIRS OF EXCELLENCE, EQUIPMENT, SPIN-OFF COMPANIES, EDUCATION

This new edition of the booklet «LANEF 2023» has the objective to show the main progress in the research projects funded by LANEF compared to the previous edition «LANEF 2018». It gathers a collection of short texts describing the scientific projects selected by LANEF since 2017 up to 2022. In addition, we decided to update some of the texts of the previous edition whose outcomes have been substantially enriched. In total, 36 PhD grants, 6 Chairs of Excellence and 5 Equipements are described lanef Laboratoire d'Alliances Nanosciences-Energies du Futur

PHD GRANT



The resource cost of large scale quantum computing

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Marco Fellous Asiani (PhD student), Alexia Auffèves and Robert Whitney (thesis supervisors)

LABORATORIES : NEEL, LPMMC

This thesis studies the question of how to scale up quantum computers in order to reach fault-tolerance. Fault-tolerance uses error correction to protect logical qubits against errors. Logical qubits are composed of many physical qubits here to allow correction to be implemented. In order to implementalgorithms showing a clear advantage compared to classical supercomputers, millions to potentially billions of physical qubits might be required. We focus in particular on the question of the resources (energy, bandwidth,…) required to set up such computers [1]. We provide a method allowing to minimize the amount of resources required in order to implement algorithms.
We apply it to a complete model of quantum computer based on superconducting qubits, which includes error correction, algorithmic but also engineering considerations[2]. Our results (Fig. 1) indicate that for algorithms implemented on thousands of logical qubits, we can reduce the energetic cost by 100, in regimes where, without optimizing, the power consumption could exceed the gigawatt, clearly improving the scaling potential. Finally, we provide general hints about how to make fault-tolerant quantum computers energy efficient.

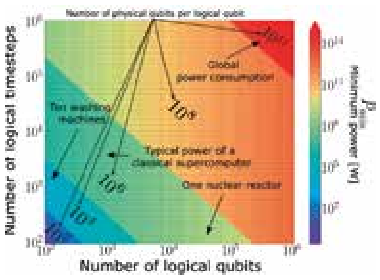

Fig. 1: Minimum power consumption to implement a fault-tolerant quantum memory as a function of its size, for "close" to state of the art values.

OUTCOMES

[1] The energetic cost of work extraction, Phys. Rev. Lett. 124, 130601(2020).
[2] Limitations in quantum computing from resource constraints, PRX Quantum 2, 040335 (2021).
[3] The resource cost of large-scale quantum computing, arXiv:2112.04022.
[4] Comparing the quantum switch and its simulations with energetically-constrained operations, arXiv:2208.01952 (accepted in Physical Review Research)
[5] Optimizing resource efficiencies for scalable full-stack quantum computers, arXiv:2209.05469

Oral presentations: AQIS (2020), GDR IQFA (2020)

Collaborations:

Air Liquide (Company) ; Hui Khoon Ng, Center for quantum technologies, Singapore ; Yvain Thonnart, CEA-Leti

PHD GRANT

Extension of the Randomized measurement toolbox to probe entanglement

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LABORATORIES : NEEL, LPMMC

Characterizing quantum properties related to entanglement in different quantum platforms is lately of significant interest. Existing protocols based on quantum state tomography (QST) offer such a possibility by a reconstruction of the underlying quantum state, but it requires an expensive number of measurements. On the other hand, the randomized measurement (RM) toolbox, offers a method to measure quantities related to entanglement at a much lower measurement cost compared to QST.
This project aims to extend and improve the existing RM toolbox (Fig. 1). As a first task, we developed a more efficient version of the protocol that enables us now to measure entanglement in significantly larger quantum systems [1].
Secondly, we formulate for the first time a protocol to measure the quantum Fisher information using the RM toolbox which allows us to characterize the inherent multipartite entanglement structure of the quantum state [2].
Along with this, we have developed new optimized formalisms to post-process RM data from experiments [3, 4]. These methods are currently being implemented on quantum hardwares to measure interesting entanglement properties.
This thesis is co-funded by the Fondation Nanosciences.

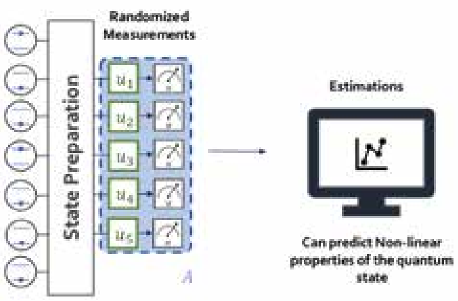

Fig.1: Illustration of the RM protocol to estimate quantities related to entanglement.

OUTCOMES

[1] Importance sampling of randomized measurements to probe entanglement, PRL. 127, 200503 (2021).
[2] Quantum Fisher information from randomized measurements, PRL. 127, 260501, (2021)
[3] Entanglement barrier and its symmetry resolution: theory and experimental observation, PRX Quantum 4, 010318 (2023)
[4] Enhanced estimation of quantum properties with common randomized measurements, arXiv:2304.12292 (2023)

Oral presentations:

CGC 2021 online conference ; CQED workshop (2021)

Collaborations:

Peter Zoller (IQOQI, Innsbruck), Andreas Elben (IQIM and Caltech, USA), Richard Kueng (JKU, Linz), Petar Jurcevic (IBM, New York), Anna Minguzzi (LPMMC, Grenoble)

Brillouin Light Scattering Optical Bench

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LABORATORIES: NEEL, SPINTEC

PRINCIPAL INVESTIGATORS : Laurent Ranno (equipment supervisor), Valérie Reita, Vincent Baltz

In reduced dimensions, new properties of magnetic nano-objects appear, driven by the reduced surface/volume ratio or reduced interface symmetry. Determining some of the intrinsic properties of such objects requires new characterisation tools. For example in multilayers, the chiral exchange interaction (DMI) which may appear when inversion symmetry is lacking cannot be accessed with traditional magnetometry.

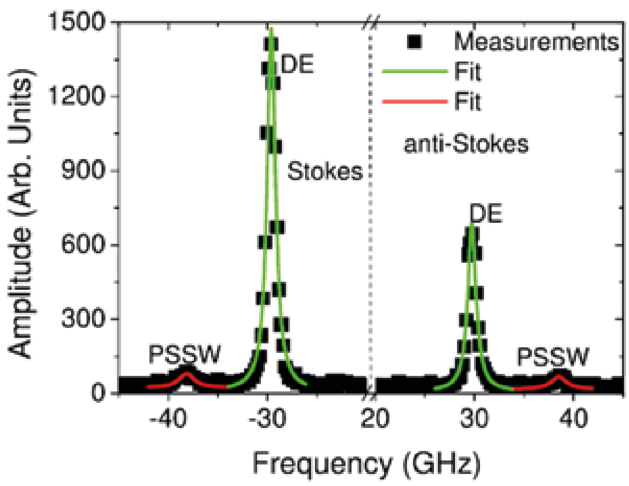


Fig. 1: BLS spectrum recorded on a CoFeB 20nm-thick film (Belmeguenai et al. J. Phys. D 2017). The low energy peaks (Stokes modes, frequency smaller than the laser frequency) represent scattered photons after emission of a spin wave quantum. The higher energy peaks (anti-Stokes modes) represent scattered light after absorption of a spin-wave quantum. The green peaks can be modelled using a Damon-Eshbach (D-E) geometry (surface spin waves propagating perpendicular to magnetisation). The red peaks are due to spin waves propagating along the thickness of the film (Perpendicular Standing Spin Waves PSSW).

Brillouin Light Scattering is an optical technique which allows to determine the dispersion curve of excitations in solids. Fluctuations of atomic positions or magnetic moments can be represented as waves (phonons or magnons). These waves scatter the incident light, reminiscent of diffraction from a grating. Analysing the inelastic scattered light which has emitted (Stokes mode) or absorbed (Anti-Stokes mode) a quantum of excitation allows to determine the dispersion curve and then magnetic quantities (Fig. 1).

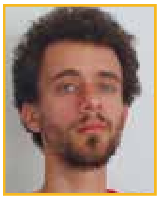
The new optical bench sponsored by LANEF is the third magnetic BLS in France and is located in Institut Néel. It will provide the magnetic community with a dedicated platform which is also open to the phonon community. Extension to higher magnetic fields and low temperature has already been identified as the next development for this tool.

OUTCOMES

PhD grant (LANEF & Fondation Nanoscience) : Georgy Ziborov (nov 2021-2024)

PEPR Spin : extension to low temperatures grant.

PHD GRANT



Topological magnetic solitons in thin epitaxial films with reduced symmetry

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LABORATORIES : NEEL, SPINTEC

In my thesis, I used a combined theoretical and experimental approach to study the relationship between the crystal symmetry, the magnetic interactions and topological solitons in epitaxial thin films. Solitons are field solutions that evolve without perturbing their configurations, to which one can associate particle properties like a charge. For topological magnetic solitons the considered field is the magnetic field and the charge is the topological charge. I studied how the anisotropic magnetic interactions in epitaxial W(110)/Co/AuPt films allow stabilizing domain walls and skyrmions, respectively 1D and 2D magnetic solitons, with different symmetries and topological charges. Theoretically I developed a continuous model to characterize skyrmions [1] and understand the conditions to stabilize anti-skyrmions [2]. Experimentally I grew epitaxial thin films and studied the crystal symmetry and the magnetic properties [3]. I used high-resolution magnetic imaging to reveal self-organized stripe domains and elliptical skyrmions induced by the anisotropy of the magnetic interactions [4].

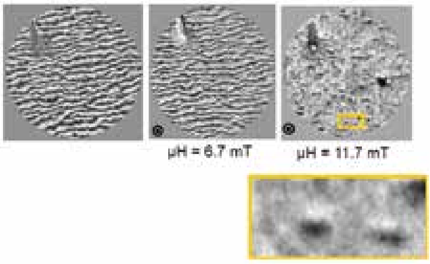

Fig.1 : High-resolution magnetic microscopy (XMCD-PEEM) of self-organized stripe domains in AuPt/Co/W(110) for different applied magnetic fields. For $\mu_0 H = 11.7$ mT, elliptical skyrmions are observed (zoom). The diameter of the full images is 4 µm.

OUTCOMES

[1] The skyrmion-bubble transition in a ferromagnetic thin film, SciPost Phys. 4, 27 (2018)
[2] Micromagnetics of antiskyrmions in ultrathin films, Phys. Rev. B 97, 134404 (2018)
[3] Anisotropic Dzyaloshinskii-Moriya interaction in ultrathin epitaxial Au/Co/W(110), Phys. Rev. B 95, 214422 (2017).
[4] Self-organised stripe domains and elliptical skyrmion bubbles in ultra-thin epitaxial Au0.67Pt0.33/Co/W(110) films, New J. Phys. 23, 013020 (2021).

Oral presentations: JEMS, Glasgow, UK, 2016; INTERMAG, Dublin, Ireland 2017; SKYMAG 2, Paris, France, 2017 ; MAGNET, Assisi, Italy, 2017 ; DPG , Berlin, Germany, 2018.

Collaborations: Stanislas Rohart (LPS, Orsay), Laurent Ranno, Nicolas Rougemaille, Alexis Wartelle, Anne Bernand-Mantel, Maurizio De Santis (NEEL), Mohamed Belmeguenai, Yves Roussigné, Andreï Stachkevitch (LSPM-CNRS-Paris Sorbonne), NIST, ELETTRA.

Leverage: ANR-14-CE26-0012 ULTRASKY, ANR TOPSKY, PhD MCSA-Cofund GREQUE of José Pena Garcia

PHD GRANT

Spectroscopy of parametrically excited spin-waves by NV- magnetometry

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LABORATORIES : SPINTEC, NEEL

Collective spin excitations inside a magnet provide a unique spectroscopic signature on the nature of the magnetic material as well as the magnetic texture present inside. So far, this signature is still uncomplete because most of the spin-wave eigen-modes remain undetected due to the difficulties to either excite or detect them owing to their lack of overlap with spatially averaged quantities. To circumvent these selection rules our project proposes to detect parametrically excited spin-waves using a local detection. The possibility of locally probing the dynamics of magnetization in a nanostructure or an individual spin texture is still very difficult experimentally and this project proposes to exploit for that purpose an in-house developed NV center microscope, whose originality is to fit within the poles of a 1.4T electromagnet.

This instrument uses the photoluminescence measurement of the paramagnetic resonance of a single colored center in a diamond crystal. The colored center consists of a nitrogen atom coupled to a vacancy whose electronic ground state is a spin S = 1. When this defect is swept over a surface by a near-field microscope, the measurement of the disturbance of its relaxation time makes it possible to map with nanometer precision the presence of fluctuators at the Larmor frequency without disturbing the sample. The output of this research is the development of a generic method allowing to obtain a complete spectroscopic signature on the nature of an individual magnetic heterogeneity which can be either static magnetic texture (point defect, skyrmion, buble, vortex, or domain wall) or dynamic magnetic texture (non-linear solitons, bullet modes, spin-wave droplets).

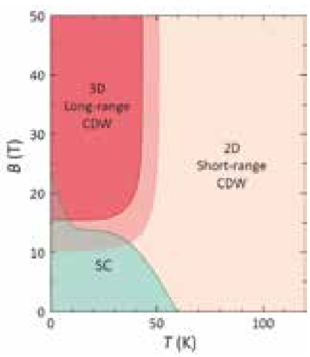

Fig. 1 : Local spectroscopy of the ferromagnetic resonance signal (label FMR) in a YIG slab by NV center microscopy. The contrast is produced by reduction of the relaxation time due to the nearby presence of spin fluctuators oscillating at the Larmor frequency (after [Du, PRL 2017])

OUTCOMES

[1] Coherent transducer with azimuthal spin-wave modes in a magnetic cone state, publication in preparation.

Patent : Diffraction-limited non-chromatic compact lens for Raman microscopy, patent submitted.


QSpin - Quantum Spinconversion in Magnon-Phonon Coupled Systems

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LABORATORIES: SPINTEC, NEEL, LNCMI, ILL, UNIVERSITY OF TOKYO

PRINCIPAL INVESTIGATORS : Yoshichika Otani (Chair of excellence), Olivier Klein (Grenoble contact), Benjamin Pigeau (Grenoble contact), **Giovanni Olivetti** (PhD student), Tim ZIMAN, Anne-Laure BARRA

The recent demonstration of coherent coupling between two magnetic insulators, yttrium iron garnets (YIGs), at millimeter distances in a monolithic device by chiral acoustic phonons represents a significant advancement in magnon-based electronics or magnonics. In addition, since the magnetic insulators lack conduction electrons that can carry the spin information on an atomic scale, these chiral phonons that transfer angular momentum could be a new tool for effectively controlling the magnetization in such materials.

Our project tackles the coherent transfer of angular momentum information between two different quasiparticle waveforms, magnon and phonon, in a nano-patterned geometry.

In this respect, yttrium iron garnet (YIG) holds a unique position in nature for combining the lowest possible magnetic damping, excellent acoustic attenuation (10 times better than quartz), and optical transparency. YIG is thus probably the best possible coherent interlink between magnons, phonons, and both microwave and optical photons, as shown in Fig.1. We focus on realizing the strong magneto-elastic coupling indispensable for developing an integrated magnon-phonon transducer conserving angular momentum and coherence. Observation of the gap opening at the degeneracy point of magnon and phonon energy levels will verify their strong coupling.

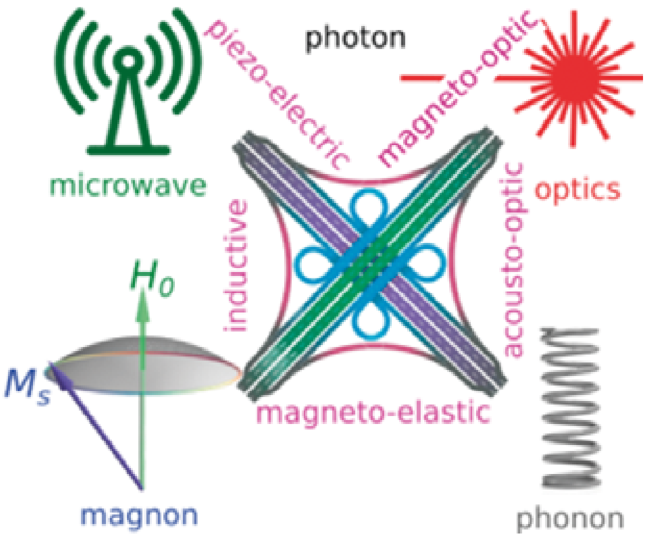

Fig.1: Schematic illustration of the different couplings inside magnetic insulators.

OUTCOMES

[1] "Strong magnon-phonon coupling observed in CoFe/ LiNbO3 bilayer systems in solid state cavity", under preparation.

[2] "Non-local energy decay of ballistic phonons", under preparation.

Subsequent fundings for collaboration:

[1] "Quantum Spintronics and Magnonics for quantum information technologies", International Collaboration Program with Strategic Research Partners, 2022.06 – 2024.12 RIKEN CEMS Japan (21 mil. Yen (about 146 kEuro) for three years.

Conclusion of Memorandum of Understanding for research collaboration and students and researchers exchange between **ISSP University of Tokyo** and **SPINTEC/PHELIQS-CEA and NEEL-CNRS**, under preparation

PHD GRANT

Nanofabrication of hard-soft magnetic nanocomposites

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LABORATORY : NEEL

The study of exchange spring hard-soft magnetic nanocomposites is one of a number of routes being explored to develop high performance permanent magnets. In this thesis e-beam lithography was used to control the size, shape and position of soft magnetic nano-rods (FeCo, Co) embedded in a micro-patterned hard-magnetic matrix (FePt). TEM imaging combined with chemical mapping (collaboration CEA), revealed that diffusion occurred from soft nano-rods into a limited region of the hard matrix in samples with the narrowed (24 nm) nano-rods, leading to the formation of Kirkendall-voids.

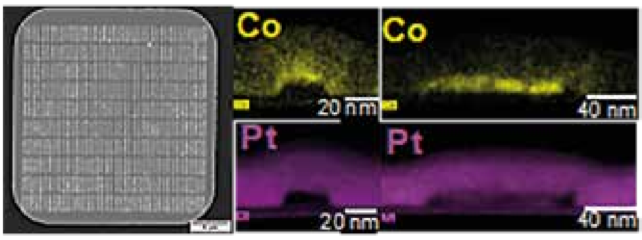


Fig. 1 : SEM top view of soft magnetic FeCo nano-rods embedded in a hard magnetic FePt matrix. TEM cross section image with chemical contrast.

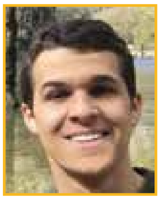
Global (hysteresis loops and First Order Reversal Curves) and local (Magnetic Force Microscopy) experimental magnetic measurements, combined with micromagnetic simulations (collaboration Danube University Krems), allowed us to study the impact of the size and volume content of the nano-rods on magnetisation reversal in our model hard-soft magnetic nanocomposites. A trade-off was found to exist between reducing the width of the soft nano-rods to favour exchange spring behaviour and increasing it to minimize diffusion.
This thesis is co-funded by the Fondation Nanosciences.

OUTCOMES

[1] A High Throughput Study of both Compositionally Graded and Homogeneous Fe-Pt Thin Films, J. Mater. Res. Technol. 18 1245 (2022)
[2]Nanocomposites for Permanent Magnets, in New Trends in Nanoparticle Magnetism Springer (2021)
[3] Nanofabrication, characterisation and modelling of soft-in-hard FeCo-FePt magnetic nanocomposites, submitted

Collaborations: J. Fischbacher & T. Schrefl (DUK, Austria), A. Masseboeuf & H. Okuno (CEA)

PHD GRANT



Magnetic domain-wall dynamics in a curvilinear system

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LABORATORIES : NEEL, SPINTEC

Magnetic domain walls are the boundaries between magnetic domains, i.e. regions with uniform magnetization in a ferromagnetic body. One-dimensional conduits are a prototypical situation to investigate domain walls, reducing the underlying complexity and therefore easing the comparison between theory and experiment. On the applied side, such conduits have been proposed as the building block of low-power logic and memory units.
Whereas most investigations consider thin flat strips made by thin-film technology and patterning, here we considered cylindrical nanowires produced by electrochemical deposition in porous templates. The cylindrical shape has been predicted to allow the motion of domain walls at high speed, up to 1km/s instead of about 100m/s in flat strips. We reported the first current-driven motion of domain walls in such cylindrical nanowires. We confirm that their speed indeed exceeds several hundreds of meters per second. We also evidenced the crucial role of the Œrsted field to stabilize these walls, an aspect that had been disregarded in most theories so far.
This thesis is co-funded by Univ. Erlangen-Nürnberg (Germany).

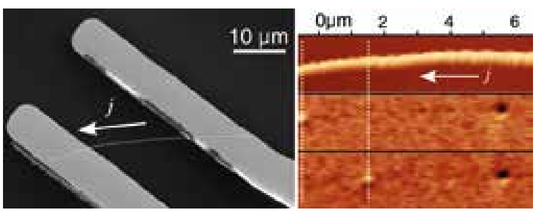

Fig. 1: Nanowire contacted electrically (left) and domain-wall motion induced by a nanosecond pulse of current, monitored by magnetic force microscopy (right).

OUTCOMES

[1] Fast Domain Wall Motion Governed by Topology and Œrsted Fields in Cylindrical Magnetic Nanowires, Phys. Rev. Lett. 123, 217201 (2019)
[2] Mechanism of fast domain wall motion via current-assisted Bloch-point domain wall stabilization, Phys. Rev. B 103, 054430 (2021)
[3] Time-resolved imaging of Œrsted field induced magnetization dynamics in cylindrical magnetic nanowires, Appl. Phys. Lett. 118, 172411 (2021)

Oral Presentations: AUSE Congress and IV ALBA User's meeting, 8-9 Oct 2019 (invited); MMM, Las Vegas, Nov 2019; Intermag, April 2021.

Collaborations: Univ. Erlangen-Nürnberg, synchrotrons SOLEIL, Elettra and ALBA

Manipulation of magnetic skyrmions in ferrimagnetic oxides

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LABORATORIES : NEEL, SPINTEC

Magnetic skyrmions are magnetic quasiparticles composed of spins that whirl closely to form a very stable and chiral spiral structure (see Figure 1a). Skyrmions have very small dimensions, down to the nm scale and can be manipulated by electric currents, which has led to new concepts of logic devices.

Rare Earth Iron Garnets ($R_3Fe_5O_{12}$) are ferrimagnetic oxides with small saturation magnetisation and magnetic damping, combining key advantages for the high speed (>1km/s) current induced skyrmion manipulation.

$Tm_3Fe_5O_{12}$ thin films (10-100 nm) are deposited on the GGG substrate using sputtering technique, which is advantageous for fast growth of heterostructures and multilayers. X-ray measurements confirmed the heteroepitaxial structure of the grown films and allowed to estimate the sample strain and magnetoelastic coefficient. Polar-magneto-optic Kerr effect (MOKE) experiments show that the sample is perpendicularly magnetized with large magnetic domains, which is explained by a large strain-induced magnetoelastic PMA (see Figure 1b). The next step in the PhD project is to optimize the material and external excitations to stabilize magnetic skyrmions and study their current induced dynamics in tracks.

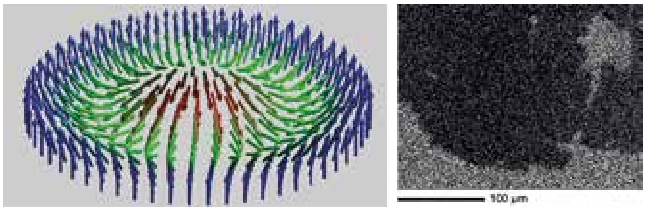

Figure 1. a) Néel-type skyrmion. b) MOKE images of $Tm_3Fe_5O_{12}$ (12nm)/GGG sample.

OUTCOMES

Poster presentation: Optimisation of the growth of iron garnet epitaxial films for skyrmionic spintronics in Colloque Louis Néel, Obernai 2022.

From Sum Frequency Generation and Spontaneous Parametric Down Conversion in hybrid nonlinear plasmonic structures

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LABORATORIES : NEEL, INAC

Nonlinear optical processes are the core of many technologies such as quantum cryptography or non-invasive multiphoton microscopy. However, the intrinsically weak response of bulk nonlinear materials prevents one from directly downsizing components to the nanoscale, making on-chip applications unreachable as is.

To overcome this issue, one way is to combine two complementary nanosized elements with specific properties into one hybrid structure. In my thesis project, I have developed and used a versatile, computer-controlled setup to study home-made optimized hybrid nanostructures composed of plasmonic antennas [1] – for near-field enhancement – and a nonlinear KTP nanocrystal – for nonlinear conversion efficiency. I successfully made and studied these structures, with clear enhancement obtained for Second Harmonic Generation (2 photons merging into 1), and simulations predict enhancement for 1 photon splitting into 2, in line with our goal to produce entangled photon pair with single nanostructures for on-chip systems [3].

An extension of this work is about decision-making strategies based on entangled photon pairs, with applications for resource allocating or deep learning algorithms [2].

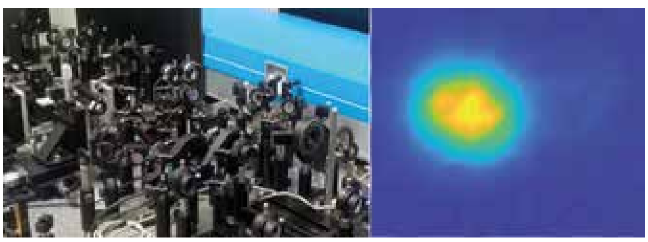


Fig.1 : Left) Experimental setup developed. Right) 2D Second Harmonic Generation cartography of a hybrid nanostructure (inset: corresponding SEM image).

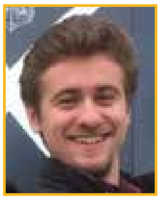
OUTCOMES

[1] Wave-mixing origin and optimization in single and compact aluminum nano-antennas, ACS Photonics 3, 1840-1846 (2016)
[2] Entangled-photon decision maker, Scientific Reports 9, 12229 (2019)
[3] Hybrid KTP–Plasmonic Nanostructures for Enhanced Nonlinear Optics at the Nanoscale, ACS Photonics 7, 665-672 (2020)

Presentations: Invited oral COST NQO – GDR Ondes, Marseille, 2016; C2C symposium, Tokyo, 2018; META 19, Lisbon, 2019.

Collaboration: M. Naruse, University of Tokyo, Tokyo, Japan.

PHD GRANT



Plasmonics and photonics properties of hybrid nanostructures assembled by DNA

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LABORATORIES : SYMMES, PHELIQS, DTBS, NEEL

Semiconductor quantum dots (QDs) are very good light emitters with wavelength tunability from visible to near infrared, and have already found numerous applications in optoelectronic devices or as probes in biological imaging. On another hand, highly fluorescent architectures can be formed by exploiting the plasmonic electric field of a metal nanoparticle to enhance the emitters fluorescence. This local plasmonic field is more particularly amplified at nanorod tips.
The PhD aims at (i) developing the self-assembly of hybrid nano-architectures made of QDs linked in a well-controlled manner to gold nanorods tips by means of DNA strands (Fig. 1), (ii) characterizing and investigating the nano-optical properties of these hybrid structures.
In these studies, we will develop and use original AgInS2 QDs, biocompatible ternary nanoparticles without toxic heavy metal. The great advantage of the targeted hybrid nano-assembly is the precise inter-particles distance control by the rigid DNA linkers, enabling in-depth studies of the plasmon-exciton interaction. It also allows exploring possible applications in bio-sensing exploiting the DNA hybridization.
This thesis is co-funded by Labex ARCANE.

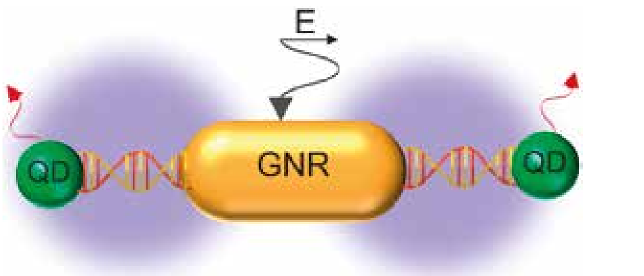

Fig. 1: Assembly of two QD linked to GNR tips by DNA strands. GNR plasmonics effect locally increases the electric field, enhancing QD fluorescence.

OUTCOMES

[1] DNA Mediated Self-Assembly of Fluorescent Emitters to Plasmonic Nanoparticles, Oral presentation at ARCANE Day, Grenoble, 2021.
[2] Propriétés photoniques de nano-architectures assemblées par ADN, Poster at Summer School ERIN2 C'NANO, Bretagne, 2021.
Awards : 1st prize from Graphical Abstract (ARCANE).

PHD GRANT

Ultrasensitive nanowire force sensors in extreme conditions

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LABORATORY : NEEL

An ultrasensitve force field sensor based on the optical readout of suspended vibrating nanowires has been successfully operated at dilution temperatures [1]. The development of measurements techniques operating in the photon counting regime, where less than one photon is detected per oscillation period, enabled to measure the thermal noise of a nanomechanical resonator thermalized to the base temperature of a dilution fridge. Realizing noise thermometry by varying optical readout powers, allows to investigate the unexplored thermal and mechanical properties of the nanowire at dilution temperatures (Fig1.d).

This approach enables unprecedented force readout sensitivities, in the zeptonewton range. In parallel, a novel cavity nano-optomechanical experiment was developed at room temperature, consisting in inserting a nanowire in the middle of a high-finesse fiber-cavity. The combination of dilution temperatures and high-finesse microcavities opens the door towards unexplored regimes in cavity optomechanics, where optical non-linearity arises at the single photon level [2].

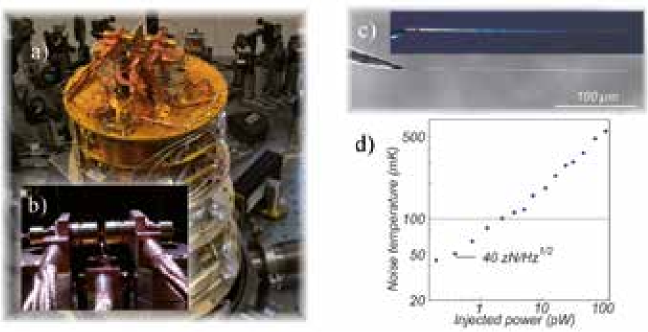

Fig. 1: a) Cryostat CRYOPTICS b) Optical element to inject light and perform the readout c) SiC Nanowire d) Effective temperature and force sensitivity of the sensor.

OUTCOMES

[1] Ultrasensitive nano-optomechanical force field sensor at dilution temperatures, Nature Communications 12, 4124 (2021)
[2] Mapping the cavity optomechanical interaction with subwavelength-sized ultrasensitive nanomechanical force sensors Phys. Rev. X 11, 021009 (2021)
Oral presentation: GDR MecaQ, Paris, France, 2017
Collaborations: W. Wernsdorfer, E. Eyraud, C. Felix, J. Reichel (ENS-Paris)

The G and W colour-centres of Si: artificial atoms for integrated quantum photonics

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PHD GRANT

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LABORATORIES : PHELIQS, LETI

Silicon-on-insulator (SOI) technology is a promising platform for the development of large-scale integrated quantum photonics. However, its applications have been limited until now due to the lack of deterministic sources of single-photons based on silicon. In this context, PHELIQS and coworkers have recently reported a game changing result : the generation of antibunched photons by isolated implantation defects in Si, the so called G and W centers.
The main goal of this PhD thesis will be to demonstrate the first deterministic source of single photons embedded in a SOI chips. We will produce in collaboration with CEA Léti and U. Leipzig dilute ensembles of G centers or W centers, using ion implantation and thermal treatments.
Using nanofabrication tools of the PTA facility, we will define optical microcavities containing a single color centre. By placing the zero-phonon emission (ZPE) line of the centre in resonance with a cavity mode, we expect to observe Purcell-enhancement of the ZPE and the emission of single photons on demand under pulsed excitation.
During the first year, we have integrated ensembles of G-centers in microring cavities as a first step (see Fig.1). The Purcell effect is observed when resonance is achieved between the ZPE and a cavity mode [1].

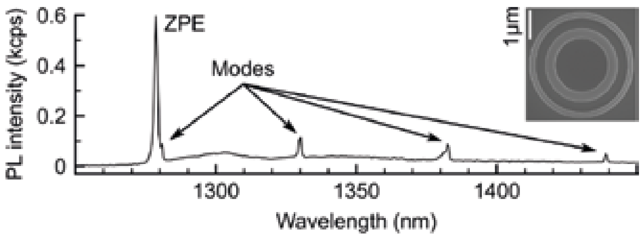

Fig. 1: Photoluminescence spectrum and electron micrograph of a SOI microring containing G color centers.

OUTCOMES

[1] Cavity-enhanced zero-phonon emission from an ensemble of G centers in a silicon-on-insulator microring, B. Lefaucher et al, Appl. Phys. Lett. 122, 061109 (2023)

Collaborations : CEA Léti, L2C Montpellier, U. Leipzig

Differential ultrafast mode switching in micropillar cavities

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PHD GRANT

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LABORATORIES : PHELIQS, NEEL

The injection of free carriers can change the resonance frequency of a semiconductor optical microcavity reversibly within few ps. While cavity switching dynamics is commonly probed using pump-probe spectroscopy, we have introduced a novel approach using quantum dots as a broadband internal light source. The analysis of the cavity emission using a spectrometer and a streak camera (Fig.1) probes the switching dynamics of all cavity modes in a single experiment. We have also studied the effect of a strongly inhomogeneous distribution of the injected electron/ hole pairs. We observe drastically different switching amplitudes and dynamics for different cavity modes, that we quantitatively model through the different overlaps between free carriers and field intensity distributions. Non-uniform free carrier switching appears as a powerful tool to tailor the modal structure of a cavity and the switching dynamics of each mode. This is an interesting novel feature in view of applications of cavity switching in quantum optics. For instance, it provides an additional degree of freedom for controlling in time the interaction between quantum dots and a microcavity mode, and it is currently used in our lab to generate ultrashort non-coherent pulses of spontaneous emission.

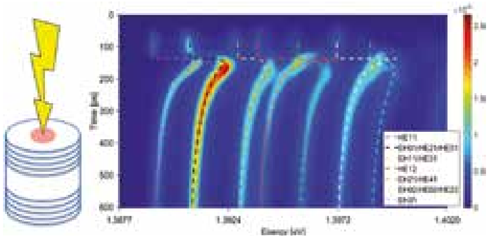


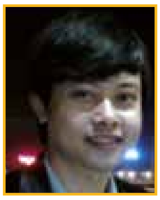
Fig.1 : Streak camera image showing the temporal evolution of various cavity modes frequencies, after the localized injection of free carriers around the axis of a GaAs-AlAs micropillar at 130 ps. The result of numerical simulations is shown by dashed lines

OUTCOMES

[1] Cavity switching: A novel resource for solid-state quantum optics, Proceedings of ICTON 2017, IEEE Book series DOI10.1109/ICTON.2017.8025177
[2] Probing cavity switching events with an internal quantum dot light source, APL Photonics 5, 126104 (2020)
[3] Tailoring the properties of quantum dot-micropillars through ultrafast optical injection of free charge carriers, Light: Physics and Applications 10, 215 (2021)

Invited oral presentations: ICNN, Yokohama (2016); SPIE10111 Photonics West, San Francisco (2017); ICTON, Girona, Spain (2017).

PHD GRANT



Aluminium contact formation on Ge and SiGe nanowires observed by in-situ transmission electron microscopy

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LABORATORIES : NEEL, IRIG, VIENNA UNIVERSITY OF TECHNOLOGY

This PhD studies the thermally induced exchange reaction of Al in Ge and Si_xGe_{1-x} alloy NWs using in-situ heating observations in a transmission electron microscope (TEM), aiming for a better understanding and control of the mechanisms involved in the reaction. Minh Anh first developed a reliable fabrication process to produce sub- 10 nm Ge quantum disks (QDs), using a combination of ex-situ thermal annealing via rapid thermal annealing (RTA) and in-situ Joule heating in a TEM. He demonstrated the influence of an Al_2O_3 protecting shell around the NW on the kinetics of the exchange reaction, allowing to perfectly control the diffusion process, a key for the future production of ultra-scaled devices [1].

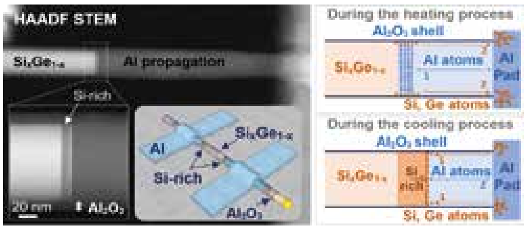

Fig 1: Scanning TEM images of a propagated NW passivated with 20 nm of Al2O3 and an inserted schematic showing the formation of Al/Si-rich/ SixGe1-x heterostructures [2].

He also investigated the thermal diffusion of Al metal in Si_xGe_{1-x} alloy NWs, which presents the formation of Al/Si/Si_xGe_{1-x}/Si/Al heterostructures, a promising structure for near infrared photo-detection applications. For the first time, we show an interesting diffusion phenomenon where the exchange reaction results in the formation of a Si-rich region, sandwiched between the Al reacted part and Si_xGe_{1-x} unreacted part of the NW. Moreover, the reaction can be partially reversed [2].

OUTCOMES

[1] In-Situ Transmission Electron Microscopy Imaging of Aluminum Diffusion in Germanium Nanowires for the Fabrication of Sub-10 nm Ge Quantum Disks. ACS Applied Nano Materials 3, 2, 1891 (2020).

[2] M.A. Luong et al. Reversible Al Propagation in SixGe1−x Nanowires: Implications for Electrical Contact Formation, ACS Applied Nano Materials 3, 10427 (2020).

Oral presentation: IMC conference, Sydney, Australia, 2018.

Leverage: ERC project e-See.

PHD GRANT

Growth and structural characterizations of InAs/GaAs axial nanowires heterostructures

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LABORATORIES : NEEL, PHELIQS

Nanowires can host combinations of materials with very different lattice parameters: the mismatch strain is efficiently relaxed on the sidewalls, enabling the formation of dislocation-free interfaces out of reach with two dimensional thin films. It is important to understand how the strain distributes as it strongly influences the band structure, and consequently the electronic and optical properties of the final device. We grow GaAs-InAs nanowires by molecular beam epitaxy using the vapour-liquid-solid mechanism with gold catalysts. Nanowires diameter, length and density are readily controllable by adjusting the growth parameters and the catalyst diameter. We evaluate the strain and composition distribution by high-resolution scanning transmission electron microscopy (HRSTEM) together with Energy Dispersive X-ray spectroscopy. One of our important results is the observation of a 20 nm long strained region around the interface, where crystal planes bend close the sidewalls. (Fig. 1). Despite a 6% lattice mismatch, our structures show no dislocation when the diameter is less than 40 nm. We are now working on the reverse structure, GaAs on InAs, in order to realize quantum dots integrated in nanowires, positioned on demand, for new photonic emitters.

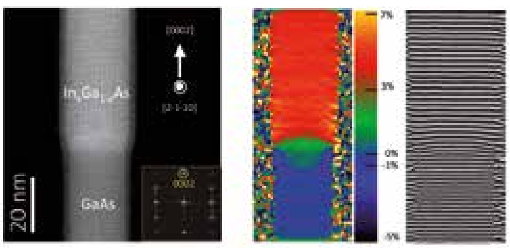


Fig. 1: Left) HRSTEM image of an InAs/GaAs axial heterostructure. Center) Relative change in lattice parameter along the growth axis with respect to unstrained GaAs. Right) HRSTEM image after Fourier filtering of the [0002] Bragg reflection.

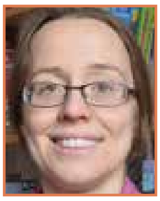
OUTCOMES

[1] Dislocation-free axial InAs-on-GaAs nanowires on silicon, Nanotechnology 28, 365602 (2017).
[2] Full characterization and modeling of graded interfaces in a high lattice-mismatch axial nanowire heterostructure. Phys. Rev. Materials 4, 074607 (2020).

Oral presentations: Journées Nationales du GDR PULSE Paris, 2017 (invited) ; Journée Nationales Nanofils, Grenoble, 2017 ; MRS Fall Meeting, Boston, USA, 2016;Nanowire Week Pisa, 2018; Journées N. ationales du GDR PULSE Paris, 2017 (invited) ; Journée Nationales Nanofils, Grenoble, 2017 ; MRS Fall Meeting, Boston, USA, 2016.

Collaborations: Pierre Verlot, University of Notthingam, UK; Marcel Verheijen, Philips Research, Eindhoven, NL, Nicolas Chauvin, INL, FR; Frank Glas, C2N, FR.

Leverage: AGIR pôle PEM 2015-2016



Quantum technologies with correlated matter at mesoscopic scales

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LABORATORIES: LPMMC, NEEL, INAC

PRINCIPAL INVESTIGATORS : Luigi Amico (Chair of excellence), Anna Minguzzi (Grenoble contact), Denis Feinberg (Neel), **Piero Naldesi** (Post-doc fellow)**, Enrico Compagno** (Post-doc fellow), Juan Polo

In this project, we study key issues in mesoscopic physics inspired both by quantum electronics and by the emerging field provided by atomtronics: ultra-cold atoms manipulated in micro-magnetic or laser-generated micro-optical circuits.

In our research, mesoscopic physics have been studied by integrating quantum electronics and atomtronics in a direct way. With this approach, we could explore physical regimes that are hard, if not impossible to access with more standard views. As starting point, we considered specific ultracold matter-wave-analog of known quantum electronic systems. In line with such a program, bosonic networks confined in ring lattices, the simplest atomtronic circuit perhaps, can define the so-called Atomtronics Quantum Interference Devices (AQUIDs), in analogy with SQUID's (Fig. 1) This way, we have disclosed new aspects of defining issues in quantum science, like interference, entanglement, and macroscopic quantum coherence. In particular, preparation and read-out protocols to study coherent states in AQUID have been devised.

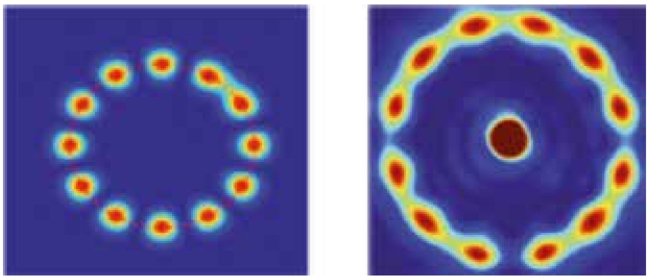

Fig. 1: The Atomtronics Quantum Interference Device (AQUID). Ring-shaped lattice of condensates interrupted by a single weak link mimicking the rf-SQUID (left) or by three weak links with flux qubits dynamics (right). Such systems can sustain macroscopic quantum coherence and quantum phase slips with experimentally feasible protocols [3].

It appears very likely that our integrated approach will trigger breakthroughs both in basic research and technology developments in the years to come. Specifically, the scope of quantum simulators is expected to be considerably enlarged. At the same time, we put the basis for new devices in quantum technology with enhanced coherence, flexibility and control.

Again inspired by quantum electronics, we have studied transport. The specific features of quantum optical systems allow us to study the problem with a new twist (Fig. 2). At the same time, standard views and methods well established in quantum electronics, like quantum phase dynamics in Josephson junctions arrays, Luttinger liquids effective theories etc., have been employed to study basic questions of atomic and molecular physics of Bose-Einstein condensates.

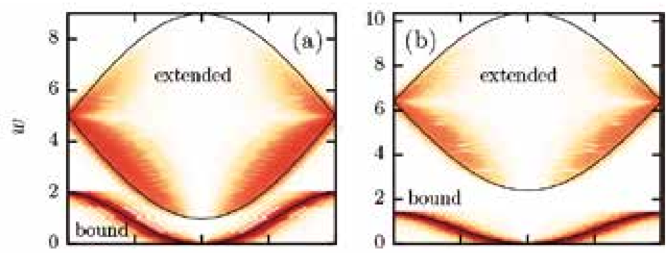

Fig. 2: Quantum solitons in optical lattices. The dynamical structure factor of quantum solitons obtained by a specific microscopic theory with two different system parameters [1].

OUTCOMES

[1] Mesoscopic Vortex-Meissner currents in ring ladders, Quantum Sci. Technol. 3, 035006 (2018)

[2] Readout of the atomtronic quantum interference device, Phys. Rev. A 97, 013633 (2018)

[3] Raise and fall of a bright soliton in an optical lattice', Physical Review Letters 122, 053001 (2019)

[4] Nonclassical states in strongly correlated bosonic ring ladders, Physical Review A 99, 033616 (2019)

[5] Correlated transport in driven atomtronic circuits Physical Review Research 2, 043118 (2020)

[6] Exact results for persistent currents of two bosons in a ring lattice Physical Review A 101, 043418 (2020)

[7] Probing the BCS-BEC crossover with persistent currents, Phys. Rev. Research 3, L032064 (2021)

[8] Enhancing sensitivity to rotations with quantum solitonic currents, SciPost Phys 12, 138 (2022)

[9] Atomtronic circuits: from basic research in many-body physics to applications for quantum technologies, Review of Modern Physics 94, 041001 (2022)

Conferences: 'The many facets of non-equilibrium physics: from many body theory to quantum thermodynamics', Mazara del Vallo, (Italy) 2017. 'Conference on statistical field theory and applications', Trieste 2107. ;'Physics of Quantum, Electronics', USA 2018 ; Frank Hekking Memorial workshop', Les Houches 2018.

PhD: Nicolas Victorin (2015-2019)

Collaborations: R. Dumke, L.-C. Kwek, Centre for quantum technologies (Singapore); C. Miniatura CNRS-MajuLab (Singapore).

PHD GRANT

Heat Management in Silicon based spin qubit network

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LABORATORIES : PHELIQS, NEEL

Worldwide efforts to build the first useful quantum processor are ongoing. Among the possible physical realizations, those based on semiconductor quantum dots are attracting increasing interest owing to their scalability prospects. In this approach, the qubits are encoded in the spin degree of freedom of individual electronic charges localized in gate-defined potential wells (Fig. 1). We anticipate that the heat generated by the manipulation and read-out of qubits will be a bottleneck for the efficient operation of large-scale quantum processors.

This concerns the heat load from massive wiring, the power dissipation of cryogenic control electronics, but also the local heating associated with high-frequency qubit operations (initialization, control, readout). Characterizing and managing heat effects at the quantum chip level is therefore of crucial importance and constitutes the main objective of my PhD.

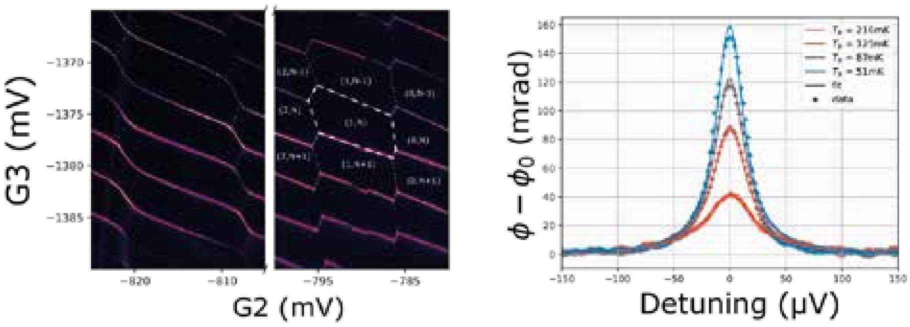
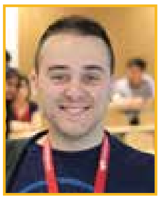


Fig. 1 : Charge stability diagram of a double quantum dot system, the limits between charge stability regions are Coulomb resonances. Right : Temperature dependence of a Coulomb resonance, used here as thermometer at mK temperature

PHD GRANT



Spin-sensitive tunneling in Superconductor - Quantum Dot junctions

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LABORATORIES : NEEL, LPMMC

The magnetic moment of a quantum dot can be screened by its coupling to a superconducting reservoir, depending on the hierarchy of the superconducting gap and other energy scales. The fluctuation between a screened and unscreend state can be triggered by the tunneling of an electron, and is observed as an extremely sharp conductance peak in superconductor-quantum dot-superconductor (S–QD–S) junctions at energies below the superconducting gap. The energy difference between both ground states can be driven by electrostatic gating, tunnel coupling, and, as we demonstrate here, a magnetic field.

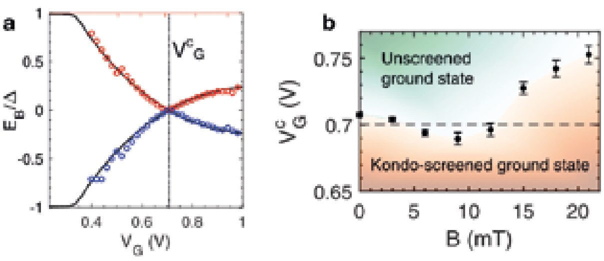

Fig. 1: (a) Gate dependence of the subgap bound state energies at zero applied magnetic field. At the critical gate voltage VGc = 0.709 V, the bound state energies cross zero, indicating the screened-unscreened ground state transition. (b) Magnetic field dependence of the ground state transition, displaying a non-monotonous evolution resulting from the competition of Zeeman splitting and magnetic-field-induced reduction of the superconducting gap.

We perform high-resolution spectroscopy of the subgap excitations near the screening-unscreening transition of S–QD–S junctions. From the subgap conductance peaks, we extract the bound state energies. Wity increasing gate potential, the bound states cross zero energy, indicating the inversion of the ground and excited states (Fig. 1a). With a small applied perpendicular magnetic field, a re-entrant phase boundary between the two ground states is observed (Fig. 1b), resulting from the competition between Zeeman energy and gap reduction and providing direct evidence for a magnetic-field driven ground state transition in S-QD-S hybrids.

OUTCOMES

[1] Magnetic-Field-Induced Transition in a Quantum Dot Coupled to a Super-conductor, Phys. Rev. Research 2, 012065(R) (2020). [2] Direct probe of the Seebeck coefficient in a Kondo-correlated single-quantum-dot transistor, Nano Lett. 19, 506 (2019).

Collaboration: J.P. Pekola, Aalto University, Finland. K.J. Franke, FU Berlin, Germany.

Invited oral presentations: LT28, Gothenborg, Sweden, 2017. Tunneling Through Nanosciences, Ravello, Italy, 2018. MolSpin & Nanocohybri workshop, Lisbon, Portugal, 2019.

Awards: Best thesis presentation prize at Rencontres des Jeunes Physicien-ne-s for A. Garcia Corral, 2017.

Leverage: ANR-DFG PRCI project JOSPEC (2018-2021).

Calorimetry of a Phase Slip in a Josephson Junction

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PHD GRANT

LABORATORIES : NEEL, LPMMC

The magnetic flux threading a superconducting loop is quantized in units of the flux quantum $\Phi_0 = h/2e$, with e the elementary charge and h the Planck constant. The tunneling of a flux quantum in or out of such a loop is associated to a change of 2π in the winding of the phase of the quantum wave function along the loop which contains one or more Josephson junctions. Irreversibility arises from abrupt slips of the gauge-invariant quantum phase difference across the junction and can be visualized as the tunneling of a flux quantum in the transverse direction of the superconducting loop. This is the most elementary dissipative process in superconducting quantum technologies.
Using time-resolved electron thermometry in a nanocalorimeter, we detect the instantaneous heat release caused by a phase slip in a Josephson junction, signaled by an abrupt increase of the local electronic temperature in the weak link and subsequent relaxation back to equilibrium (Fig. 1a). The data are in excellent agreement with a microcopic model of the inhomogeneous superconductivity in the weak link (Fig. 1b). Beyond being an important step in experimental quantum thermodynamics, the observation of the released heat in an elementary quantum process sets the ground the ground for experimentally addressing the ubiquity of dissipation, including that in superconducting quantum sensors and qubits.

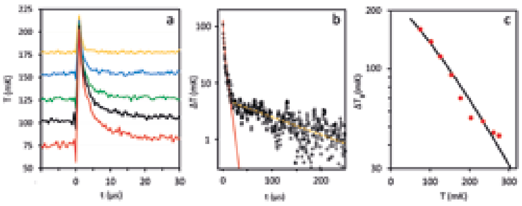


Fig 1: (a) Time-resolved temperature rise in the Josephson junction after a phase slip at t=0, and at different initial device temperatures, and (b) zoom on the beginning of the thermal relaxation on a semi-logarithmic scale, at 75 mK. (c) Experimental amplitude of the initial temperature rise following a phase slip versus starting temperature (bullets). The theoretical model predictss the black solid line.

OUTCOMES

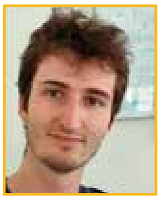
[1] Calorimetry of a phase slip in a Josephson junction, Nat. Phys. 19, 196 (2023).

[2] High-Impedance Surfaces for Above-IC Integration of 2 Cooled Bolometer Arrays at the 350-µm Wavelength, J. Low Temp. Phys. 209, 1258 (2022).

Collaboration: Superconducting bolometers (LETI/CEA) ; MSCA ITN with Aalto and U. Konstanz

Oral presentations: ICTP workshop, Quantum Microwaves, Heat Transfer and Many-Body Physics in Superconducting Devices, Trieste, Italy (2022).

APS March meeting (invited), Chicago, USA (2022).



CMOS compatible Josephson field effect transistor

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PHD GRANT

LABORATORIES : PHELIQS, LETI

Superconducting qubits is nowadays the most advanced platform for quantum computing but the scalability of these circuits remains one of the main challenges. In order to address this question, the scalability of these technologies using classical electronics fabrication processes is a key point.

This work focuses on a CMOS compatible way to build a superconducting qubit. A promising approach seems to be the gatemon geometry in which the Josephson junction is a classical MOSFET with superconducting source and drain and in which a tunable non-disspative current can flow (JoFET). Silicides (CoSi2, V3Si, PtSi) as well as superconducting boron doped silicon and strained germanium quantum well are good candidates for this purpose.

This system should take advantages of years of classical microelectronics development as well as recent breakthroughs in superconducting quantum circuits.

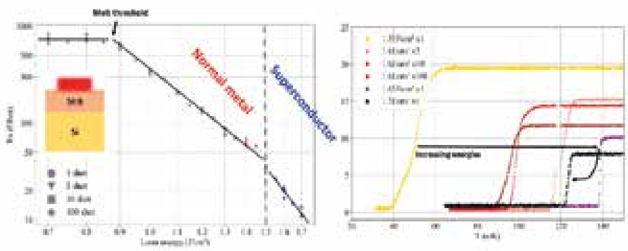

Fig. 1: An in-situ ultra-high boron doped Si CVD followed by nanosecond laser annealing permits to obtain superconducting silicon layer that can be used for the realisation of Josephson junction. (left) Above a certain laser energy we get a superconducting layer. (right) The Si:B superconducting critical temperature depends on the laser annealing energy.

OUTCOMES

Collaborations: F. Chiodi (C2N, CNRS, Univ. Paris-Saclay, France), S. Kerdilès, J.M. Hartmann, P. Dumas (CEA Leti, Grenoble, France)

Communications: Posters at "Frontiers in condensed matter physics" summer school – University of Copenhagen & at "Frontiers of condensed matter" – Les Houches summer school

EQUIPMENT

2DMAT - MBE cluster to grow 2D-MATerials and van der Waals heterostructures

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LABORATORIES : SPINTEC, NEEL, LNCMI, LETI

PRINCIPAL INVESTIGATORS : Matthieu Jamet (equipment supervisor), Isabelle de Moraes, **Hervé Boukari** (equipment supervisor), Céline Vergnaud, Alain Marty, Frédéric Bonell, Yoann Curé, Yann Genuist, Fabien Jourdan

The efforts dedicated to the fabrication of 2D materials, stacks of Van der Waals (VdW) materials and the studies of their original properties have considerably increased these last years worldwide. Coupling different classes of 2D materials with the aim of improving existing properties or investigating new properties is one of the driving force in this very rich research field. One suited technique to fabricate wafer-scale vdW layers and heterostructures is molecular beam epitaxy (MBE).

With the 2D-MAT project, we could build a MBE cluster dedicated to the growth of Selenium (Se) and Tellurium (Te) based vdW materials and stacks combining both classes of material. Such a cluster opens the investigation of new optical/vibrational properties of matter, proximity effects (like 2D ferro/2D semiconductor, 2D ferro/2D superconductor or 2D superconductor/2D semiconductor), new topological and quantum properties (2D topological insulators, Weyl or Dirac semimetals), valleytronic and spintronic effects…

The growth of pure Se or Te based VdW layers requires the use of two MBE systems to avoid the contamination of selenides with Te atoms and vice-versa. Connecting the two MBE chambers through a UHV tunnel specifically funded by LANEF is necessary to develop heterostructures that couple both Se and Te based VdW materials: the transfer of the samples from one MBE to the other one needs to be done in UHV to preserve the chemical purity of the interfaces between the Se and Te based layers. The whole setup is shown in Figure 1.

Figure 1: Photograph of the 2D cluster with Se and Te MBE reactors connected by a UHV transfer tube.

EQUIPMENT

A compact millikelvin ultra-high vacuum scanning tunneling microscope

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LABORATORIES : NEEL, PHELIQS

PRINCIPAL INVESTIGATORS : Vincent Renard, Claude Chapelier and Clemens Winkelmann (equipment supervisors), David Wander (PhD student), Stéphanie Garaudée, Hervé Courtois

Scanning tunneling microscopy and spectroscopy (STM/STS) provides a highly versatile tool for surface science investigations, which not only allows visualizing but also manipulating surfaces at the atomic scale, and measuring their local electronic properties, such as the local density of states. STM/STS has been intensively applied for studying superconducting effects at the nanoscale level. While most commercially available STM setups operate at temperatures above 4 K, the investigation of subtle effects in quantum materials require working at lower temperatures down to tens of mK.

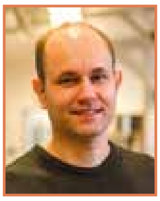
A new STM setup, combining an ultra-high vacuum (UHV) surface preparation chamber with an inverted dilution refrigerator operating below 50 mK, was recently constructed at NEEL (Fig. 1). Presently, the cryogenic part of the STM setup is not fully UHV compatible, which limits the field of applications. Thanks to the LANEF support, we are currently developing, in collaboration with W. Wernsdorfer at the Karlsruhe Institute of Technology (Geramany), a new fully UHV-compatible inverted dilution refrigerator (sionludi), basing on a technology invented in Grenoble. The new instrument will combine a base temperature of 30 mK with uninterrupted UHV, a 3 T magnetic field and microwave drive capabilities.

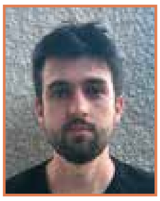
Fig. 1: The present mK STM setup. Within this project, the dilution refrigerator (right part of the setup) will be made fully UHV compatible.

OUTCOMES

[1] Superconductivity of gallium probed on the atomic scale by normal, Andreev and Josephson tunneling processes, in preparation.
[2] A compact ultra-high vacuum millikelvin scanning tunneling microscope, in preparation.

Collaborations: QINU company (Germany) and Prof. W. Wernsdorfer at Karlsruhe Institute of Technology.





Hybrid materials for quantum devices

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LABORATORIES: NEEL, PHELIQS, MEM

PRINCIPAL INVESTIGATORS : Jesper Nygård (Chair of excellence), **Raphael Rousset-Zenou** (PhD student), Moïra Hocevar (Grenoble contact), Zeinab Issa, Julien Renard, Martien den Hertog, Edith Bellet-Amalric, Manuel Houzet, Silvano De Franceschi, Francois Lefloch

The main objective of the project is to develop new hybrid nanowires as well as superconductor-semiconductor quantum devices based on these nanowire materials. The archetypical device is a « superconducting transistor », a so-called gate tunable Josephson junction that has recently been shown to work in different types of qubits (quantum bits, the basic building block for a quantum computer).

Hybrid nanowires are based on a semiconducting core with a superconducting shell that can be processed further into various devices. This class of materials was initially perceived as the ideal platform for creating topologically protected qubits, based on so-called Majorana bound states. It has been realized that this approach is hampered by minute defect densities and device imperfections. However, hybrid nanomaterials are attractive for several types of gate-tunable quantum devices: superconducting qubits (gatemons), Andreev spin qubits, cryogenic switches, quantum limited amplifiers and for fundamental studies of new bound states in superconductors as well as chains of artificial atoms (quantum dots).

The recipient of the chair of excellence, Jesper Nygård, is professor at the Niels Bohr Institute, University of Copenhagen, where hybrid superconducting nanowires were initially developed. Together with research scientist Moïra Hocevar (CNRS), he co-supervises one LANEF PhD student, Raphael Rousset-Zenou.

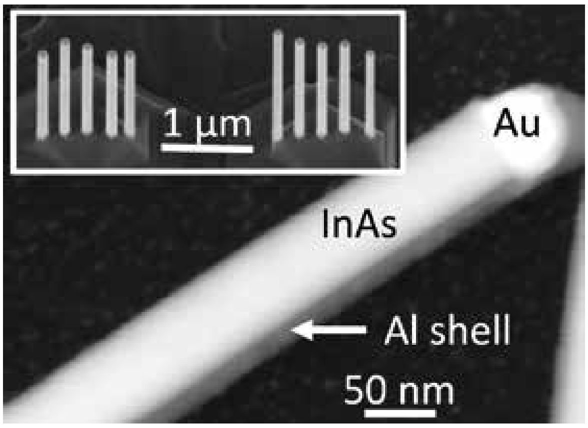

Fig. 1: Hybrid nanowires grown at the NPSC team. The wires have a semiconducting core (InAs) while the shell is a superconductor (Al). Inset: arrays designed for integration of multiple nanowires in devices.

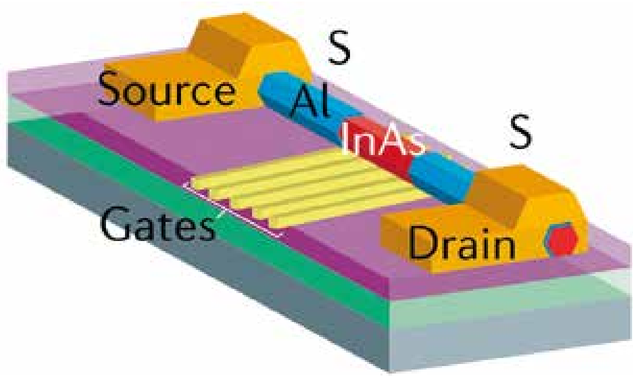

Fig. 2: Schematic of electronic device based on a superconducting core-shell nanowire (InAs/Al), enabling studies of gate-tunable Josephson junctions and hybrid quantum dots. This basic unit can be integrated in more complex quantum circuits.

Materials are synthesized by Molecular Beam Epitaxy in the joint NPSC team of PHELIQS-CEA and Institut Néel-CNRS. The project will in turn engage researchers within quantum devices, nanofabrication, structural studies and theory. The project combines the activities on materials growth with electron microscopy, x-ray diffraction and low-temperature electrical measurements. Initially, Al/InAs core-shell nanowires are developed (Fig. 1) and integrated in superconducting devices such as Josephson junctions (Fig. 2). In turn these can be combined with superconducting resonators, e.g. for applications in quantum limited amplifiers. Materials based on other superconductors and planar structures will also be investigated.

OUTCOMES

Workshop organized by the chair on "Hybrid superconductor-semiconductor materials and devices" at Neel organised by M. Hocevar and J. Nygård (December 2022).

Leverage : Prof. J. Nygård has obtained support from the Carlsberg Foundation and University of Copenhagen to achieve a one-year sabbatical in Grenoble in order to start the chair than runs 2022-25.

Collaborations : Prof. J. Nygård has served on jury committees for QuanG, the ESONN school and regular PhDs/HDRs with LANEF partners.

Conferences: Nanowire week (Atlanta-USA) and Bound States (Budapest-Hungary) in 2023.

PHD GRANT

Many-body quantum optics with superconducting circuits

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LABORATORY : NEEL

The use of superconducting circuits as building blocks for studying light matter interactions at the fundamental level was introduced more than a decade ago and is named Circuit Quantum ElectroDynamics (circuitQED). With this project we push these ideas to the next level and build circuits to explore many-body quantum optics.
The key element of these circuits is the Josephson junction, two superconductors separated by a thin insulating barrier. Thanks to its huge non-linear inductance it can be used for fabricating devices as: quantum two level systems (qubits), quantum limited [1] amplifiers and high impedance transmission lines.
In this project we studied a qubit strongly coupled to an engineered environment containing many degrees of freedom.

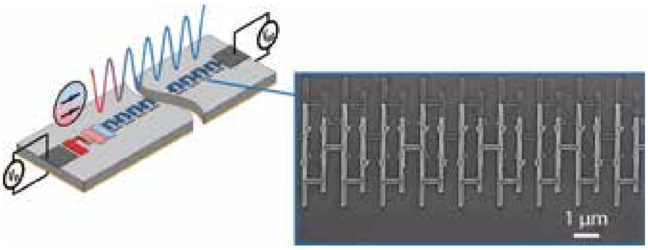

Fig. 1: Left) Artistic representation of the circuit. A transmon qubit (red) coupled to a chain of Josephson junctions (blue). Right) An electronic microscope of the array of Junctions is shown.

To enhance this coupling, we need the impedance of the environment to be high. Using an array of 4700 Josephson junctions (Fig. 1), we can obtain such a high impedance.
We couple the qubit via coupling capacitors to the array and probe the system via microwave transmission measurements. We obtain a strong hybridization of the qubit levels with several modes of the environment obtaining a many-body system[2,3].

OUTCOMES

[1] Understanding the saturation power of Josephson parametric amplifiers made from SQUIDs arrays, Phys. Rev. Appl. 11, 034014 (2019)
[2] A tunable Josephson platform to explore many-body quantum optics in circuit-QED, npj Quantum Information 5 19 (2019).
[3] Observation of quantum many-body effects due to zero point fluctuations in superconducting circuits, Nat Commun 10, 5259 (2019).

Oral presentations: GMD 26 2016 Groningen (Netherlands); APS March Meeting 2017 New Orleans (U.S.A); ICQSIM 2017 Paris (France).

Leverage: CLOUD (ANR-16-CE24-0005)

Start-Up : Silent Waves

START-UP

SILENT WAVES

SILENT WAVES

Ultra-low noise superconducting amplifier for qubit readout

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Founders : Luca Planat (CEO), Nicolas Roch (scientific advisor), Baptiste Planat (strategic advisor)

Silent Waves is a startup that has spun out from the Institut Néel on January 2022. Silent Waves develops, manufactures and commercialises electronic hardware for the quantum industry. Silent Waves is specialized in the readout of microwave signals for superconducting quantum bits (qubits). High fidelity single shot qubit readout is crucial to have a working quantum processor, and given the very low amplitude of signals emited by superconducting qubits, an accurate measurement of these signals require very efficient readout lines.
To that end, Silent Waves develops quantum hardware to increase readout fidelity, while finding solution to improve the scalability of the readout hardware. Improving its scalability will make possible the measurement of hundreds of thousands of superconducting qubits, which is required to have a quantum processor running useful algorithms.
Silent Waves' first product precisely aims at this goal; it is a high gain, broadband, ultra-low noise, superconducting amplifier (Fig. 1). Known as Traveling-Wave Parametric Amplifier, its noise performance allows to reach high fidelity single shot superconducting qubit readout. Its high bandwidth allows to do multiplexed qubit measurement; it means that the amplifier can amplify several microwave signals and thus decrease the total number of readout lines in a quantum computer.
Silent Waves amplifiers benefit from a technology that has been developed during the PhD of Javier Puertas-Martinez, sponsored by LANEF. This technology, an array of thousands of Josephson junctions (superconducting tunnel junctions of few microns squared), with subsequent upgrades, leads to a process allowing the manufacture of these ultra-low noise broadband amplifiers.

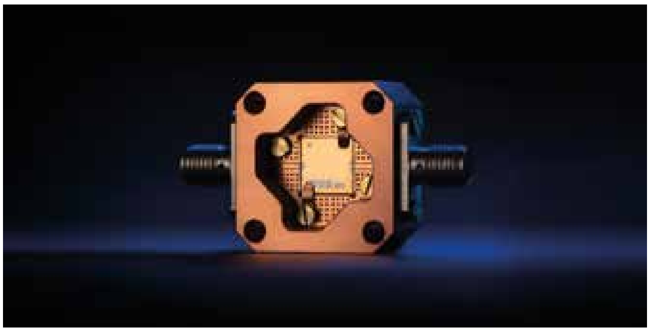
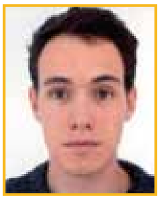


Fig. 1: Picture of a Josephson Traveling-Wave Parametric Amplifier

OUTCOMES

Patent : French patent **FR3093255B1** : Amplificateur paramétrique à onde progressive à basse impédance caractéristique et son procédé de fabrication (CNRS)



Development of Bragg coherent X-ray diffraction and ptychography methods

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PHD GRANT

LABORATORIES : ESRF, MEM

Optimizing the performance of semi-conductor nanostructures, developed for existing and future electronic and optoelectronic devices, relies on a precise control of the strain. This PhD topic focuses on the study and use of Coherent X-ray Imaging techniques, which allow to reconstruct single objects with a resolution of 5 to 10 nm.

Beyond the results in terms of materials knowledge, the main motivation is to develop a technique expected to become a reference metrology method for the study of strained nanostructures, down to objects with a thickness of 10-20 nm.

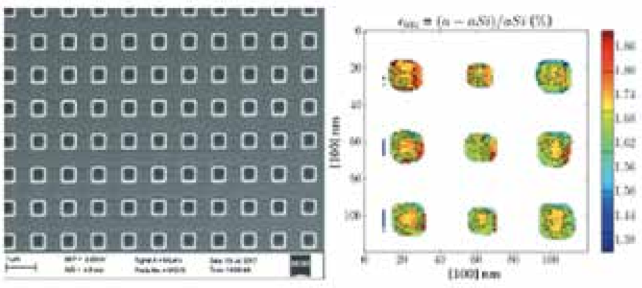


Fig.1 : Left: SEM image of strained SiGe islands; Right: strain map remative to Si lattice parameter on a patterned zone of 2x2 µm² square islands

Therefore, three guidelines are identified: the development of 2D and 3D strain mapping using coherent X-rays, taking into account all the characteristics of the focused X-ray nano-beam; the quantitative study of objects, including non-isolated ones such as in a complex device; the application to axial and radial nanowire heterostructures grown at IRIG and SiGe strained nanostructures, developed by a CEA-LETI/ STMicroelectronics collaboration (Fig. 1).

This PhD is co-financed by the European Synchrotron, with the prospect of the «Extremely Brilliant Source» upgrade, which will provide in 2019 a 100-fold increase of the coherent X-ray flux.

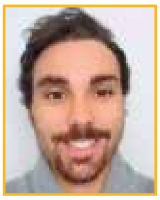
OUTCOMES

[1] Journal of Applied Physics 129, 095302 (2021).

Conference: poster in RX2017, Lille, France.

Software: PyNX python library,http://ftp.esrf.fr/pub/scisoft/PyNX/

Collaboration: ESRF co-financing, XNP group, ID01 beamline.



Chiral magnetic textures in epitaxial thin films with C2v symmetry

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Jose Peña Garcia (PhD student), Stefania Pizzini (thesis supervisor), Jan Vogel, Olivier Fruchart

PHD GRANT

LABORATORIES : NEEL, SPINTEC

In magnetism, chirality emerges naturally due to a chiral anti-symmetric exchange interaction called Dzyaloshinskii-Moriya interaction (DMI), in systems with a breaking inversion symmetry and a large spin-orbit coupling. In competition with other magnetic interactions, the DMI promotes chiral non-collinear magnetic textures whose symmetry depends on the crystal symmetry. In this thesis, we studied the AuPt(111)/Co(0001)/W(110) stack, grown epitaxially. The stack presents an out-of-plane magnetic anisotropy promoted by the spin-orbit-coupling. The crystal has a C2v symmetry, revealed by grazing X-ray diffraction, resulting into an anisotropic DMI, with a Néel and a Bloch component, and an uniaxial strain-induced in-plane anisotropy. Altogether, the magnetic interactions result into an anisotropic environment. The variation of the magnetic properties as a function of the Au-to-Pt ratio is revealed by Brillouin light scattering (BLS). Different chiral magnetic configurations are stabilized in the magnetic stacks: isotropic domain walls [1], self-organized stripes [2], circular skyrmions, elliptical skyrmions [2], and magnetic merons (Figure 1) [3]. Their static and dynamic properties were investigated by X-ray magnetic circular dichroism photoemission electron microscopy (XMCD-PEEM), micromagnetic simulations and analytical models. This PhD was co-funded by MCSA-COFUND GRECQUE and LANEF.

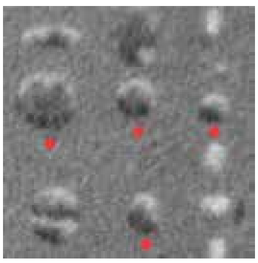


Fig. 1: Magnetic image of micron-sized circular and elliptical dots of Au60Pt40/ Co(0.78nm)/W(110), taken by XMCD-PEEM imaging. The structures marked with a red dot contain merons, with magnetization in the plane of Co layer at the borders (black and white contrast), and magnetization out of the Co plane in the center (dark grey).

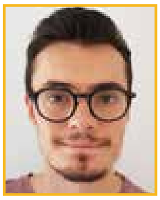
OUTCOMES

[1] Magnetic domain wall dynamics in the precessional regime: Influence of the Dzyaloshinskii-Moriya interaction. Physical Review B, 104, 014405 (2021)
[2] Self-organised stripe domains and elliptical skyrmion bubbles in ultra-thin epitaxial Au0.67Pt0. 33/Co/W (110) films. New Journal of Physics, 23 013020 (2021)
[3] Stabilization and switching of room temperature magnetic merons in epitaxial perpendicularly magnetized nanostructures, In preparation.

Oral presentations: Journées de la Matière Condensée, Grenoble, France (2018) JEMS Porto 2020 (online due to COVID)(2020) ; MMM virtual conference (2020) Collaborations: Stanislas Rohart (LPS, Orsay), André Thiaville (LPS, Orsay), Maurizio De Santis (NEEL), ELETTRA synchrotron (Italy)..

Leverage: ANR-17-CE24-0025 (TOPSKY)

PHD GRANT



Valleytronics in Doubly-Gated Silicon MOSFETs

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Nathan Aubergier (PhD student), Benjamin Piot and Vincent Renard (thesis supervisors)

LABORATORIES : LNCMI, PHELIQS

Electrons in some materials like Silicon or Graphene possess the Valley degree of freedom. This has lead to the rise of "Valleytronics" were valleys can be manipulated in the same ways as spins in Spintronics. Nonetheless, the underlying mechanism of the valley polarisation is only partly understood even if previous studies have demonstrated a crucial role of the interfaces between silicon and the gate oxides. Indeed, contrasting behaviours have been observed at the thermal oxide or implanted oxide interface in SIMOX silicon on insulator (SOI) field effect transistors. We aim at investigating valley polarization exploiting state of the art SOI transistors offering an interface to high-K dielectrics in addition to the thermal oxide. The purpose is multiple: i) determining the magnitude of the valley polarization of these interfaces ii) determining its tunability iii) understanding the physical mechanism behind it. The SOI Si MOSFETS are made by our partner the CEA-LETI.

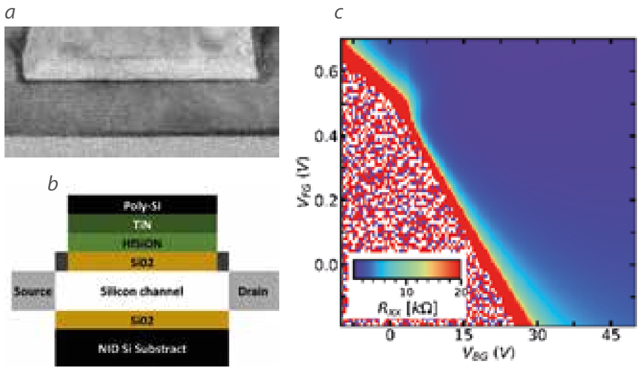
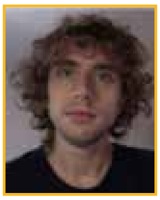


Fig. 1 : a) TEM image of a SIMOX device. b) Schematic of the stacked structure. c) Transistor resistance as function of the two front and back gates VFG , VBG, respectively.

PHD GRANT



Non-equilibrium scaling phenomena and phase transitions in exciton-polariton

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LABORATORIES : LPMMC, NEEL

Exciton-polaritons are hybrid light-matter quasiparticles formed by photons and the electronic excitations of a semiconductor material in a microcavity, where light is confined between two Bragg mirrors. These bosonic-like particles condense into a coherent steady state when the photons escaping the cavity are compensated by the external laser driving, becoming a driven-dissipative quantum fluid, non-equilibrium cousin of thermal Bose-Einstein condensates. A rich variety of physics can be found in these systems: universal properties of the coherence (KPZ universality class), superfluid behavior (quantized vortices, solitons). In this thesis project, we focus on the one-dimensional case.

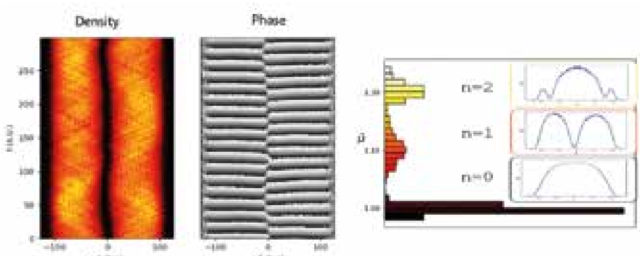


Fig.1 : Left: space-time dynamics of a soliton (from numerical simulation). Right: statistical distribution of energy and correspondent configurations of spatial profile of the condensate.

By means of a generalized Gross-Pitaevskii equation, which models the nonequilibrium dynamics of exciton-polaritons, we investigate its possible regimes. In particular, by tuning quantum and thermal fluctuations and driving intensity, we aim to identify and fully characterize the transition to a disordered state, characterized by proliferation of topological defects, the nucleation of metastable solitons and their proliferation towards a turbulent regime. These regimes are characterized in terms of observables that are accessible for the state-of-art experimental platforms.

This thesis is co-funded by the programme QuantForm-UGA France 2030 (ANR-21-CMAQ-003).

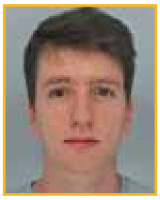
OUTCOMES

[1] The unpredicted scaling of the one-dimensional Kardar-Parisi-Zhang equation, in preparation (2023)

[2] Phase diagram of a one-dimensional exciton-polariton condensate», in preparation (2023)

Conferences: Posters: "Phase diagram of 1d exciton-polariton condensate", Quantum Fluids of Light and Matter, Varenna, Italy 2022; «From Kardar-Parisi-Zhang to Inviscid Burgers universality: a FRG approach», ERG 2022, Berlin, Germany,2022.

Collaborations: J.Bloch, Q.Fontaine, S.Ravets (C2N Paileseau, France).



Interactions between domain walls and vortices in topological triplet superconductors

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PHD GRANT

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LABORATORIES : PHELIQS, NEEL

Unconventional superconductors exhibit exotic properties related to unusual symmetries of the complex order parameter that describes the Cooper pair wave function. In centrosymmetric crystals, pairs have either a spin-singlet or spin-triplet wave function. A further distinction exists between unitary and nonunitary triplet states. In the nonunitary case, the contributions from opposite spins are unequal. Thus, time-reversal symmetry is broken. The spin susceptibility is a common probe of the order parameter symmetry, and can be inferred from Knight shift or polarized neutron scattering measurements.

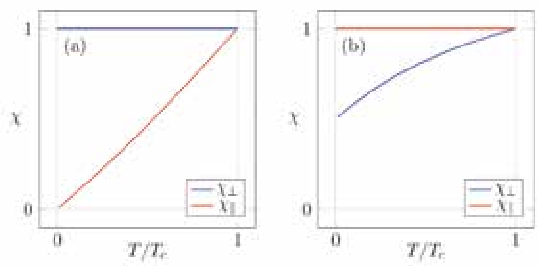

Fig. 1: Examples of in-plane ($\chi_{//}$) and out-of-plane ($\chi_{\perp}$) spin susceptibilities vs the temperature in unitary (a) and nonunitary (b) superconductors.

While it allows for a clear distinction between singlet and unitary triplet states, surprisingly, so far the case of nonunitary states has not been fully explored. Here we provide a theory of the spin susceptibility of triplet superconductors and apply it to group theoretically admissible nonunitary phases of specific crystal symmetries. In the light of our findings, we compare the predicted temperature dependence (see examples Fig. 1) with various experimental results in suspected nonunitary materials, such as UPt3, UBe13, UTe2 or Sr2RuO4. It paves the way for future studies on nonunitary superconductivity, including topological superconductivity characterized by boundary Majorana modes.

This thesis is co-funded by the programme QuantForm-UGA France 2030 (ANR-21-CMAQ-003).

OUTCOMES

[1] Spin susceptibility of nonunitary spin-triplet superconductors, arXiv:12.11226 (2022).

Poster presentation: GDR MEETIC (2022), Summer School Les Houches: Frontiers of Condensed Matter Physics (2022).

Search and study of new FeSi- and FeGe-based superconductors

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Our research concerns a new family of layered Iron based superconductors (IBS), discovered originally in 2008, where pnictogen or chaclogen elements are replaced by Si or Ge. In 2018, we discovered superconductivty below T_c = 10 K in LaFeSiH (Fig.1) thanks to a collaborative work between ICMCB (Bordeaux) and NEEL Institute.
Based on neutron diffraction, we have studied *in-situ* the conventional hydrogention of LaFeSi and shown that it produces a stoichiometric LaFeSiH material [1]. Then, by combining NMR spectroscopy, neutron and synchrotron x ray diffraction, we have proven that LaFeSiH do not order magnetically and do not undergo a lattice distorsion down to 2K.
In addition, by hydrogenation of intermetallic LaFeSi using the decomposition of high hydrogen density materials (anthracene or ammonia borane) in a large volume press (LVP) setup we were able to synthesize polycristalline samples of the tetragonal superconducting LaFeSiH phase but also a new orthorhombic non-superconducting $LaFeSiH_{1+x}$ phase.
Finally, we recently discovered novel LaFeSiX silicides. Among them, $LaFeSiO_{1-\delta}$ (i.e. X = O) is also found superconducting with T_c = 10 K. Its shows very very unique structural and electronic properties among IBS [2].

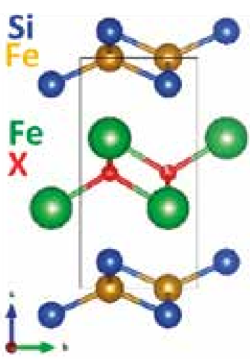


Fig.1 : The crystal structure of the layered $LaFeSiX_{1+x}$ superconducting family.

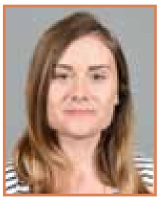
OUTCOMES

[1] In-situ deuteration study of LaFeSi into superconducting LaFeSi(H,D), J. Alloy. Compd. 945 169281 (2023).

[2] Superconductivity in the crystallogenide LaFeSiO1−δ with squeezed FeSi layers, npj Quantum Mater. 7, 86 (2022).

Oral presentation: CSEC-2021, 26-30 July 2021 (online); SCES-2022, 24-29 July 2022, Amsterdam, The Netherlands.

Collaboration: S. Tencé, ICMCB; V. Nassif, ILL.



NICOS : Nickelate Superconductors

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PRINCIPAL INVESTIGATORS : Antia Botana (Chair of excellence), Andrés Cano (Grenoble contact), **Quintin Meier** (Post-doc fellow)

Superconductivity, as discovered by Kamerlingh Onnes 110 years ago, is one of the most important quantum phenomena, from both the fundamental and the applied points of view. Because of the huge economic benefit that can be obtained from the zero electrical resistivity of superconductors, there has always been a consistent push for a better physical understanding of the underlying basic mechanisms as well as for discovering new materials that can be superconducting at practical temperature ranges. Among these efforts, the discovery of high temperature superconductivity in copper oxide superconductors in 1986 triggered an explosion of research in condensed-matter physics.

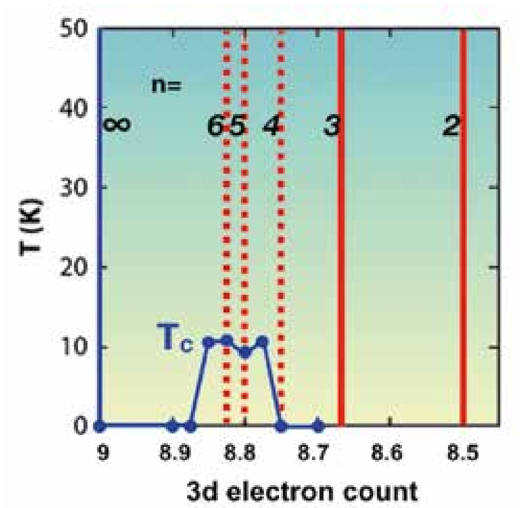

Fig. 1: Layered nickelate phase diagram with respect to 3d electron count. The vertical lines show layered nickelates with different n (n being the number of NiO2 planes along the c-axis).

After a 30-year quest, researchers have recently found the first nickel-based analog of copper oxide superconductors (see e.g. [1] for a review). This discovery motivates the search for other nickelates and should provide new insights into the origin of high-temperature superconductivity (see e.g. [2,3]).

The scientific ambition of the project is twofold. On one hand, we aim at developing further the theory of the new superconducting nickelates to gain fundamental insight about the physics of these intriguing systems. On the other hand, we aim at performing theoretical predictions of new nickel-based materials with potential for superconductivity that can be experimentally realized. Thus, the project is expected to promote also new synergies between theory and experiments in the realm of quantum materials. This includes different research teams at NEEL and LNCMI as well as international collaborators.

OUTCOMES

[1] Nickelate superconductors: an ongoing dialog between theory and experiments, JETP 159, 711 (2021); arXiv:2012.02764

[2] Superconductivity in a quintuple-layer square-planar nickelate, Nature Mater. 21, 160-164 (2022).

[3] Single-Layer T' Nickelates: Synthesis of the La and Pr Members and Electronic Properties across the Rare-Earth Series, Chem. Mater. 34 (16), 7201-7209 (2022).

C4QM: CryoCrystallography for Quantum Materials

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Precise knowledge of the structure of materials is essential to understand and control their physical properties. This is particularly important for materials in which new properties emerge, associated with macroscopic quantum states such as superconductivity or unconventional magnetic and electronic phases. These states stabilize at critical temperatures below which thermal excitations no longer disturb their order. It is therefore essential to be able to study them down to low temperatures, typically below 20K. This problem represents a real challenge for current laboratory X-ray diffraction experiments, in particular on single crystals. On the other hand, the disorder and order at short distance linked for example to pre-transitional fluctuations or to frustration, visible in diffuse scattering, is an important factor for the understanding of these systems.

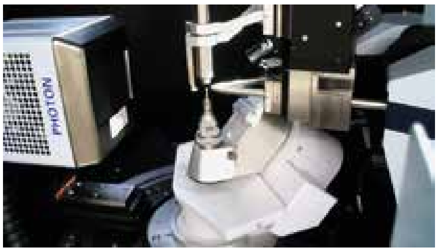


Fig. 1: The 4-circle diffractometer Bruker D8 venture

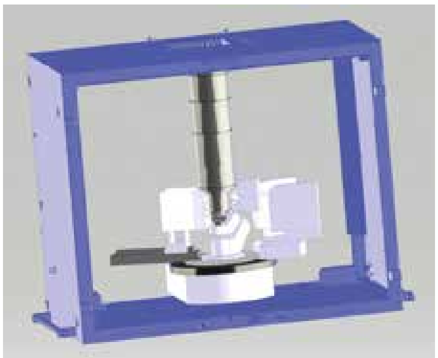
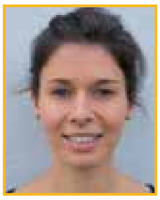


Fig. 2: Design of the cryostat inserted in the diffractometer cabinet (Courtesy G. Garde)

To this end we have acquired, with the help of CNRS and LANEF funds, a state-of-the-art 4-circle diffractometer equipped with a dual (Mo, Ag) microsource (Fig. 1). Using liquid nitrogen refrigeration, data can be measured down to 100K.

At the same time, we are developing, in collaboration with the NEEL cryogenics team (G. Donnier-Valentin, G. Garde, M. Calvo), a cryostat to go below 10 K. The design of the cryostat is now completed, as shown in Fig. 2. This cryogenic development is entirely funded by LANEF.



Structure and superconductivity of gold-intercalated graphene grown on Re

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Graphene-based hybrid structures are promising platforms for testing a variety of phenomena, especially related to proximity effects. One can induce superconductivity in graphene by growing it directly onto a superconducting material. Rhenium is an appealing substrate, as demonstrated at IRIG, NEEL and SIMAP, since it has desirable catalytic properties and hosts a superconducting state up to 1.6-1.9 K. During this thesis, we first optimised the synthesis of high quality graphene. Along this path, the structure of a carbon phase (a carbide), forming in competition with graphene, and of ubiquitous graphene defects appearing as topographic depressions and observed for a decade, were resolved at atomic scale.
Starting with graphene on Re, we next restored the pristine electronic properties of graphene (which are altered due to the strong interaction with Re) via intercalation of atomic layers of gold. We showed that the intercalated layer is highly transparent to the proximity effect, inducing a superconducting state in graphene much resembling that in Re.
Provided that we bring magnetic impurities on such a truly-two-dimensional superconductor, we expect much sought-for Yu-Shiba-Rusinov states, extending as far as few 10 nm. Preliminary results involving an original magnetic verdazyl compound deposited on Cu(111) were obtained.

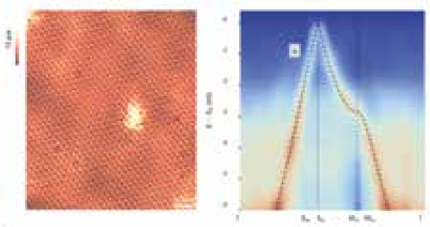

Fig. 1 : Structure (left: STM image) and electronic band structure (right: ARPES data) of graphene/Au/Re

OUTCOMES

[1] Depressions by stacking faults in nanorippled graphene on metals, 2D Materials, 7, 025016 (2020)

[2] How to induce superconductivity in epitaxial graphene via remote proximity effect through an intercalated gold layer, 2D Mater. 8 015002 (2020)

[3] Structure of graphene and a surface carbide grown on the (0001) surface of rhenium, Physical Review Materials 4, 124002 (2020)

Poster presentations: IOT workshop, Grenoble, France, 2017; RJP, Grenoble, France, 2017; 2D@Grenoble, Grenoble, France, 2017; GDR graphene & co, Aussois, France, 2017; Journée ARC6, Grenoble, France, 2017.

PHD GRANT

Helical Superconductivity and the Anomalous Josephson Effect

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LABORATORY : PHELIQS

The interplay of spin-orbit coupling (SOC) and the Zeeman effect due to a magnetic field plays an important role in spintronics and in the realization of so-called topological superconductivity. The aim of our project is to theoretically study this interplay in novel materials such as transition metal dichalcogenide monolayers (TMDC) – two-dimensional systems similar to graphene but with two different atoms in the unit cell. They host a strong intrinsic SOC, often called Ising SOC, which acts as an effective Zeeman field perpendicular to the plane of the material and having opposite orientations at the two corners of the Brillouin zone, K and K'=-K (Fig.1).

The Ising SOC plays a very important role in TMDC superconductors, where it causes unconventional pairing of Cooper pairs and, as a consequence, a great enhancement of the upper critical field [1]. We are interested in the properties of these "Ising superconductors" and their Josephson junctions, the effect of disorder on those properties, as well as possible topological superconducting phases that might appear and the ways to probe them.

Fig. 1: Left: Crystal lattice of TMDC monolayers. Right: Schematic representation of the Ising spin-orbit coupling.

OUTCOMES

[1] Enhancement of the upper critical field in disordered transition metal dichalcogenide monolayers, Phys. Rev. Lett 119, 117001 (2017).
[2] Weak localization in transition metal dichalcogenide monolayers and their heterostructures with graphene, Phys. Rev. B 99, 205407 (2019).
[3] Tunneling spectroscopy of few-monolayer NbSe2 in high magnetic field: Ising protection and triplet superconductivity, Phys. Rev. B 106, 184514 (2022).

Oral presentations:

Workshop "Superconductivity, spintronics and beyond", Grenoble, 14.11.2017
GDR meeting "Physique Quantique Mesoscopique", Aussois, 05.12.2017
Spring school "Transport in Nanostructures", Capri, 19.04.2018

PHD GRANT

Competing orders in cuprate superconductors

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Understanding the origin of high-T_c superconductivity in cuprates is one of the greatest challenges of condensed-matter physics. Recently, it has been realized that superconductivity in these materials is in competition with several electronic phases, the understanding of which is crucial for cracking the high-T_c mystery. Igor Vinograd has used four complementary parameters (temperature, magnetic field, carrier density and hydrostatic pressure) to tune the competition between superconductivity and electronic-ordering phenomena, which he has then probed with NMR measurements.

His work in $YBa_2Cu_3O_y$ has shown that superconductivity and charge-density waves compete fiercely [2,4] but also coexist in a way that suggests that the two phases may be intertwined [3].

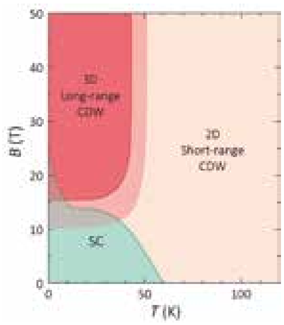


Fig. 1: Field - temperature phase diagram illustrating the interplay between CDW and superconductivity in YBa2Cu3Oy

In $La_{2-x}Sr_xCuO_4$, after quenching superconductivity with high fields, his measurements have revealed that the same antiferromagnetic groundstate found at low doping actually persists up to, but not beyond, the critical doping of the infamous pseudogap phase [1]. This suggests a connection between the physics of the doped Mott insulator, known to govern properties at low doping, and the existence of the pseudogap.

OUTCOMES

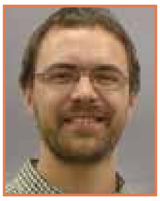
[1] Hidden magnetism at the pseudogap critical point of a high temperature superconductor, Nat. Phys. 16, 1604 (2020).
[2] Nuclear magnetic resonance study of charge density waves under hydrostatic pressure in YBa2Cu3Oy, Phys. Rev. B 100, 094502 (2019).
[3] Unusual interplay between superconductivity and charge order in underdoped YBa2Cu3Oy, Phys. Rev. Lett. 121, 167002 (2018).
[4] Spin susceptibility across the upper critical field in charge ordered YBa2Cu3Oy, PNAS 114, 13148 (2017).

Oral presentation: M2S conference (2018, Beijing)

Leverage: ANR-19-CE30-0019 (Neptun)

Main collaborations: D. Leboeuf (LNCMI), C. Marcenat (PHELIQS), T. Klein (NEEL), S. Ono (CRIEPI, Tokyo), A. Reyes (NHMFL, Tallahassee).

CHAIR OF EXCELLENCE



SyDcoM – Symmetry guided discovery of topological materials

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PRINCIPAL INVESTIGATORS : Midori Amano Patino (Post-Doc fellow), Elise Pachoud and Gerard Lapertot (Grenoble contacts), Jean-Pascal Brison, Klaus Hasselbach.

When superconductivity is combined with topology in a material, unconventional properties often arise, providing new challenges for our current understanding of materials. Artificially engineered nanostructures with conventional superconductors and topological materials have been proposed. However, intrinsic topological superconductivity can also exist in bulk unconventional superconductors such as p-wave or chiral superconductors. Among these, uranium-based systems like UPt_3, URu_2Si_2, UCoGe, UTe_2 are prominent cases where topological superconductivity is most likely to occur. Another recently discovered candidate is the time-reversal symmetry breaking superconductor $LaNiGa_2$ [1,2].

Fig.1: Crystals of $LaNiGa_2$ next to the alumina crucible in which they were synthesized.

Our project tackles the synthesis of high quality single crytals of these materials, and also aims at discovering new ones. The Grenoble teams of LANEF and Prof. Taufour have a strong record in the discovery and exploration of unconventional superconducting properties.

Based on this combined expertise, we will develop a new approach for the discovery of other topological superconductors. Using the recent progress in symmetry indicator techniques to identify topological materials, we will identify unconventional superconductors with topolgical band-structure similar to the one of $LaNiGa_2$.

OUTCOMES

[1] "Dirac lines and loop at the Fermi level in the time-reversal symmetry breaking superconductor LaNiGa2", Communications Physics 5, 22 (2022)

[2] "Nonsymmorphic band sticking in a topological superconductor", Phys. Rev. B 105, 064517 (2022).

PHD GRANT

Next step toward the miniaturisation of space cryocoolers

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LABORATORIES : NEEL, LEGI, DSBT

An experimental and numerical study of Darcy – Weisbach friction factor and Nusselt number at moderate Reynolds numbers (1<Re<100) in a well-controlled microstructure for regenerators of pulse tube cryocoolers has been performed.

The microstructure consists in convoluted channels of width 10, 20 or 40 µm and depth 150-300 µm, generated by rhombic-or sinusoidal-shaped staggered pillars (bottom of Fig.1).

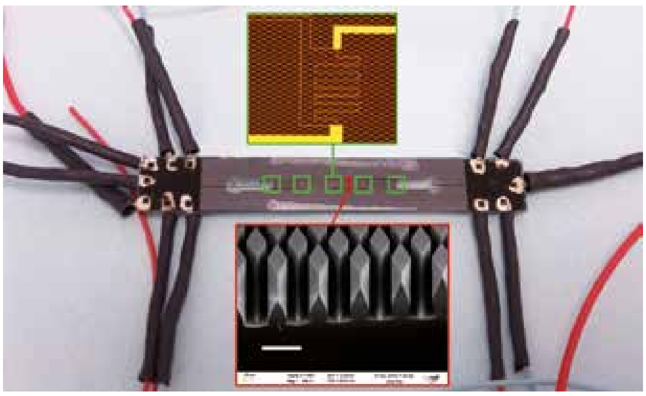

Fig. 1: Sample of micro-machined regenerator. Zoom on: thermometer (up) and bunch of micro-pillars (down), the scale bar is 100 µm.

The channels are etched in silicon wafers using the deep reactive ion etching of MEMS technology. The wall temperature is locally measured by thermometers lithographed on the Pyrex cap of the regenerator (top of Fig. 1). The influence of the porosity, from 40 to 70%, and that of the geometry parameters have been studied. The possible integration of such passive modules in pulse-tube cryocoolers is also considered.

OUTCOMES

[1] Hydrodynamic Experimental and Numerical Study of Micro-Fabricated Regenerator, Proceedings of the 5th European Conference on Microfluidics, 85 (2018).
[2] Flow and heat transfer around a diamond-shaped cylinder at moderate Reynolds number, Int. J. Heat Mass Transf. 142, 118435 (2019)
[3] Pressure losses at moderate Reynolds numbers in diamond-shaped cylinders arrays: application to micro-regenerators, Journal of Fluids Engineering 143(6), 061203 (2021)

Oral presentation: joined conference MicroFlu'18 NEGF'18, Strasbourg, France, 2018

Collaboration: NanoFab-NEEL.

Leverage: reflexion about the technology readiness level of these products.

 

Multipoint statistics and large scale structures of turbulence

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The main focus of the work is to apply comprehensive stochastic analysis methods, yielding to multipoint characterizations of turbulence. This stochastic approach is set in the context on non-equilibrium thermodynamics, to achieve a new understanding of turbulent fluctuations, intermittency and extreme events. Moreover, thanks to the collaboration built around this project, our vision is to extend this comprehensive approach for ideal isotropic turbulence to non-classical fluids in low temperature helium flows, where quantum effects emerge in the Eulerian and Lagrangian framework as well as non-ideal turbulence like for instationary conditions which is important for example for real life wind conditions.

The Eulerian framework : To apply this highly demanding analysis in the Eulerian framework, we used the SHREK (Superfluid à Haut Reynolds en Ecoulement de von Karman) experiment at INAC. This extreme experiment (3000 L of liquid He) is able to generate unprecedented high Reynolds numbers in stable laboratory conditions in various conditions. By changing the rotation speeds a continuous transition to a pulsing (instationary) turbulent state can be achieved. We used micron-sized hot wires (Fig. 1) in order to acquire turbulent fluctuations for hours and converge the high order statistics in the signal (rare events). The preliminary results obtained [1] indicate that the Integral Fluctuation Theorem is a new fundmental law for turbulence and holds even for highest Reynolds numbers achievable in laboratory conditions.

The Lagrangian framework : In this framework we used the Cryogenic Lagrangian Exploration Module (CryoLEM) at the Néel Institute. This cryostat is equipped with multiple angle optical access in order to perform 3D Lagrangian Particle Tracking (3D-LPT) on micron-sized particles evolving in turbulent helium-4 fluid or superfluid flow. Moreover, this experiment is entirely setup on a spinning table (up to 2 revolution per second) to study the influence of rotation on the different turbulent flows generated and control their anisotropy. We have obtained in early 2018 the first Lagrangian particle trajectories in a rotating cryogenic turbulent flow (Fig. 2). Our aim is now to adapt our stochastic analysis to this moving frame of reference [2].

Within a cooperation with Martin Obligado (LEGI) a new characterization of the turbulent structure of wind turbines could be worked out.

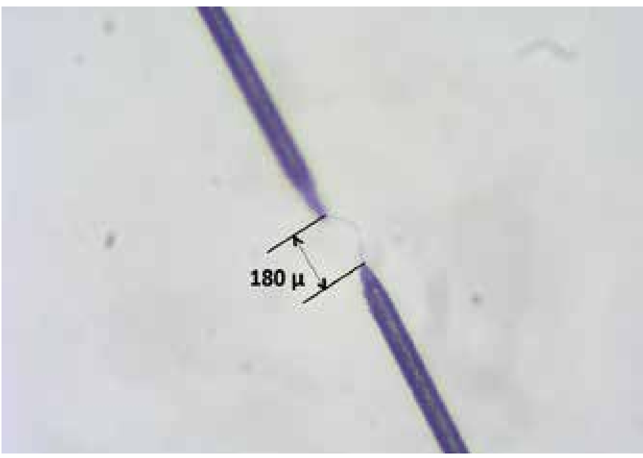

Fig. 1: Micron size (180 µm long) Wollaston hot wire

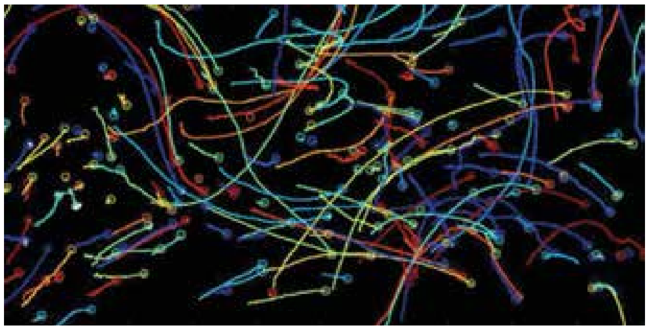

Fig. 2: Lagrangian trajectories obtained in the CryoLEM

OUTCOMES

[1] Small scale structures of turbulence in terms of entropy and fluctuation theorems, Phys. Rev. Fluids 5, 034602 (2020)

[2] Markov property of Lagrangian turbulence, EPL, 137(5), 53001 (2022)

[3] An open source package to perform basic and advanced statistical analysis of turbulence data and other complex systems, Physics of Fluids 34 (10), 101801 (2022).

[4] Direct visualization of the quantum vortex density law in rotating 4He, arXiv:2212.12250 (2023)

Oral presentations:

Quantum Turbulence Workshop, Tallahassee, United States (2017); ETC Conference, Stockholm (2017) and Torino (2019) ; 73rd Annual Meeting of the APS Division of Fluid Dynamics, Chicago (2020); iTi 2021 (interdisciplinary Turbulence initiative), Bertinoro, Italy, (2021); EGU 2021 (interdisciplinary Turbulence initiative), Vienna, Austria (2021); APS DFD 2022 75th Annual Meeting, Indianapolis, United States (2022)

Collaboration:

- The European EUHIT program supported part of the Work
- Extension of collaboration to LEGI, Grenoble. LANEF

Workshops organised by the chair:

« Different states of turbulence », Grenoble, 13. – 14. Feb. 2019, « Turbulence in the context of Eulerian and Lagrangian views », Grenoble, 29. – 30. Aug. 2019

Non-equilibrium quantum modeling of nano-structure based solar cells

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Kevin-Davis Richler (PhD student), Didier Mayou (thesis supervisor), Simone Fratini

LABORATORIES : NEEL, MEM

The development of solar photovoltaic systems has been essentially related to inorganic semiconductors. However, solar cells based on organic materials have emerged, showing many advantages compared to their inorganic counterparts. One important difference is that light absorption does not lead instantaneously to free charge carriers but instead to an exciton (see Fig. 1) The efficiency of organic cells therefore relies on a good charge separation of the exciton at the donor-acceptor interface.
Understanding the influence of the electron phonon interaction in this process is crucial because in organic systems it may lead to the formation of a polaron. In this project we studied the influence of polaron formation on the electron transfer process as well as its effect on photocurrent efficiency. We have first developed and benchmarked a new numerical method to take into account the role of polarons [1]. We then applied this new formalism to study charge injection at the donor-acceptor interface [2]. This allowed to analyze the combined roles of disorder and polaronic states on the charge separation process. Since then, this first work has opened the way for more detailed studies of this fundamental problem.

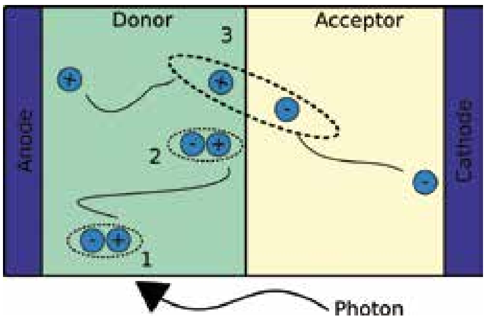

Fig. 1: Generation of a photocurrent in a bulk-heterojunction organic solar cell.

OUTCOMES

[1] Inhomogeneous Dynamical Mean Field Theory of the Small Polaron Problem. K.D. Richler, S.Fratini, S.Ciuchi,and D.Mayou J.Phys.: Condens. Matter 30, 465902 (2018).
[2] Influence of static disorder and polaronic band formation on the interfacial electron transfer in organic photovoltaic devices. K.D. Richler and D.Mayou Phys.Rev.B 99, 195151 (2019)

Collaborations: S. Ciuchi, University of L'Aquila, Italy.

PHD GRANT

Pathway towards improved efficiency of kesterite based solar cell

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Md Abdul Aziz SUZON (Ph.D. student), Louis Grenet and Henri Mariette (thesis supervisors)

LABORATORIES : LITEN, NEEL

CdTe and Cu(In,Ga)Se2 (CIGS) materials are used in commercial thin-film solar cell technologies. However, both of them contain critical raw material (toxic and/or scarce elements). Kesterite Cu2ZnSn(S,Se)4, (CZTSSe) absorbers are very attractive to replace these materials since they are only made of abundant and non-toxic constituents. However, despite very similar optoelectronic properties, CZTSSe-based solar cells exhibit half of the CIGS-based devices efficiency.
In order to improve carrier collection and to increase efficiencies in kesterite solar cells, we aimed at introducing a band gap gradient in the device absorber. It was successfully implemented by varying the [S]/([S]+[Se]) ratio in the depth of the absorber as demonstrated by material characterization. In parallel, improving efficiencies of Cu2ZnSnSe4 (pure Se) and Cu2ZnSnS4 (pure S) devices was necessary to fabricate efficient devices with bandgap gradient. In the latter case (pure S devices), it was done through the incorporation of Na (Sodium) and Sb (Antimony) into the kesterite absorber : this was found to be beneficial in terms of defect passivation (Na) and morphology quality (Na+Sb). Particularly, best efficiency with optimized Na content is doubled (> 4.5%) compared to the sample without Na. Maximum efficiencies of 6.5% and 9.4% have been obtained for CZTS and CZTSe solar cells respectively.
After the PhD thesis, further improvement in kesterite material and devices have been explored. Particularly, the concept of bandgap engineering with cationic Cu/Ag alloying has been studied jointly by LITEN and IRIG (INAC). Additionnaly, optimization of absorber surfaces allowed to fabricate solar cells with power conversion efficiencies exceeding 10%.

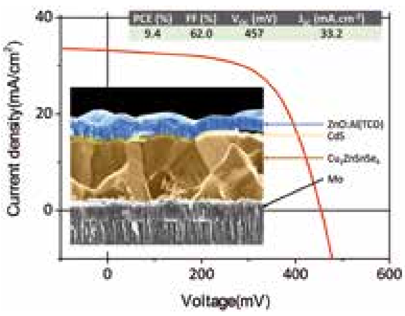

Fig. : I-V curve under AM 1.5G illumination and SEM cross section of our best experimental kesterite based device

OUTCOMES

[1] Analysis of failure modes in Kesterite solar cells, ACS Applied Energy Materials 1 (5), 2103 (2018)
[2] Na and Sb doping in CuZnSnS4 solar cells, physica status solidi (a) 216 (11), 1900070 (2019)
[3] Optical determination of the band gap and band tail of epitaxial at low temperature, Physical Review B 102 (19), 195205 (2020)
[4] Homogeneous and Graded Ag Alloying in (Cu1xAgx)2ZnSnSe4 Solar Cells, physica status solidi (a) 217 (9), 2000040 (2020)
[5] Surface preparation for 10% efficient CZTSe solar cells, Progress in Photovoltaics: Research and Applications 29 (2), 188-199 (2021)

Oral presentation:
- 8th EU Kesterite Workshop, Barcelona, Spain 2017
- JNPV, Dourdan, France, 2017

PHD GRANT

EQUIPMENT

SpectroLumi - High resolution luminescence spectrometer from UV to IR for stationary characterizations between 10 K and 300 K

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LABORATORIES : NEEL, SYMMES, LMGP

PRINCIPAL INVESTIGATORS : Mathieu Salaün, Thierry Chanelière and Vincent Maurel (equipment supervisors), Corinne Félix

Several research teams are working on the development and characterisation of new luminescent materials for applications in the fields of energy, laser optics, biophotonics, quantum computing or photo-catalysis. As the research efforts of these teams are guided and conditioned by an understanding of the mechanisms governing luminescence (presence of crystalline defects in materials, surface traps in the context of the study of nanomaterials, energy transfers between luminescent ions, etc.), it is essential to have access to an apparatus that allows for fine spectroscopic analyses of luminescence (Figure 1).

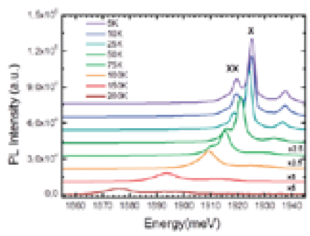

Figure 1: Temperature evolution of the excitonic lines of a CdTe quantum box inserted in ZnTe nanowires

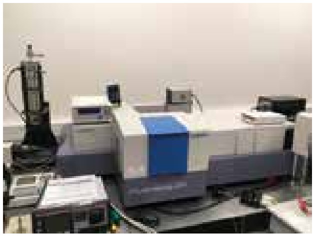

Figure 2: Image of the FLQM with l-He cryostat beside.

In November 2022, thanks to a co-funding with LMGP and LANEF, we received from Horiba the last generation fluorimeter FLQM which is equiped to perform experiments with the specifications presented below:

Excitation (resolution <0,1nm):

- Continuous Xe Lamp with extension in UV (200 nm to NIR)
- Flash Xe Lamp
- OPO pulsed laser (400-2000 nm)
- Pulsed (25 ps, 25 MHz) Diode Laser (375 nm and 450 nm)

Emission (resolution <0,1 nm):

- PMT (200 nm to 950 nm) for steady state and photon counting
- InGaAs detector (850 nm to 1550 nm (1700 nm at RT)

Accessories:

- L-He or N2 cryostat for analysis 4K to 350K
- Livetimes measurments (300 ps to 100 ms)
- Fibered inverted microscope (1µm resol.)
- Solid and liquid sample holder
- Linkam for deported experiments

START-UP

DIAMFAB

High value-added wafer for electronics and quantum applications

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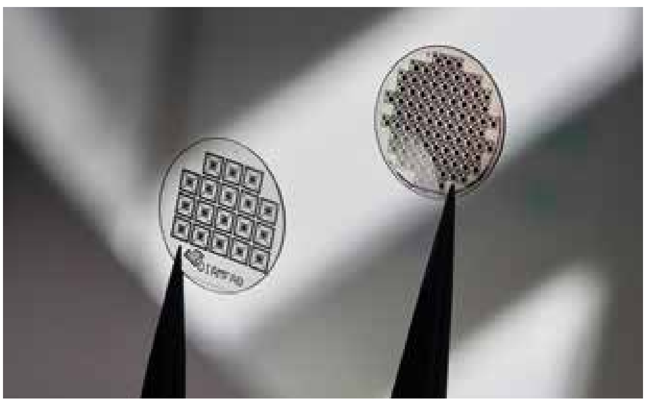
Founders : Gauthier Chicot (CEO), Khaled Driche (CTO), David Eon (Scientific Advisor), Julien Pernot (Scientific Advisor) and Etienne Gheeraert (Scientific Advisor)

At DIAMFAB we synthesize and dope diamond for the semiconductor industry. Our high value-added wafers will be at the heart of the energy transition thanks to their superior electrical performance, record efficiency and high compactness. From the electric car to the future high voltage network, from hybrid aircraft to batteries for connected objects, diamond will be the key to the electrification of our society.



Thanks to its unique know-how in synthetic diamond growth and doping, based on 30 years of CNRS R&D, DIAMFAB is today the only one to offer high value-added diamond wafers to manufacture the electronic components that will revolutionize the management of electrical energy. Our innovative technology is placed at a key stage in the diamond component manufacturing chain which is decisive for the final performance of the component. Moreover, thanks to the very high quality of our material and the latest developments of our technology, we also offer nitrogen doped layers for quantum applications like magnetometers or other very accurate sensors.

https://diamfab.com

Shaping and characterisation of molecular ionic ferroelectrics for electrical applications

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PHD GRANT

Gwenn Morvezen (PhD student), Alain Sylvestre and Hervé Guillou (thesis supervisors), Nicolas Bréfuel, Daniel Bourgault

LABORATORIES : NEEL, G2ELAB

Molecular ionic materials are hybrid or organic compounds made of pre existant molecular units. Their optical, electrical and magnetic properties are sought after and suitable to envisaged applications. Ferroelectrics are materials exhibiting a spontaneous electrical polarisation that can be switched under electric field. Among most used are PZT and PMN-PT. Both contain lead (Pb) and therefore need an health-compatible alternative.

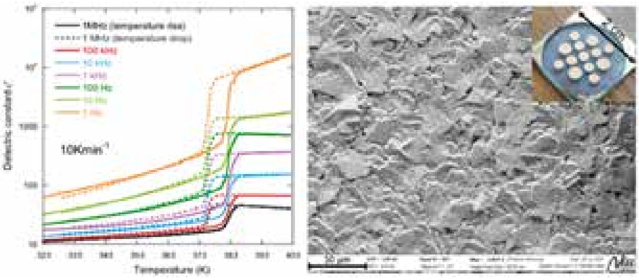

Fig.1: (left) DabcoHBF4 dielectric constant measurements at Curie temperature [1]. (right) SEM image of a deposited film (full sample in insert)

DabcoHBF4 is studied in this thesis. It combines molecular tunability and ferroelectric properties while being lead-free and synthetised by low energy processes.The first aim of this work is to investigate the phase transition and conduction mechanisms of the bulk dabcoHBF4 from dielectric spectroscopy and calorimetry (Fig. 1). The second is to overcome one of the restricting challenges for electronic applications : its thickness. Thus, we are developping novel processes of thermal deposition to obtain thin films of dabcoHBF4 and exploit its ferroelectric properties at its maximum. Our work is now to optimise the deposition process on thin films to then assess its performance as ferroelectric memories (FeRAM), capacitors or energy storage devices.

OUTCOMES

[1] Significance of considering pellet molding pressure and dielectric conditions for switchable dielectric molecular materials, J. Mat. Science, 56, 18582 (2021)

Conference: Poster, ISAF Tours 2022

Thermal conductivity of Semi-conducting Nanowires for Thermoelectrics

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PHD GRANT

Dhruv Singhal (PhD student), Denis Buttard and Olivier Bourgeois (thesis supervisors), Dimitri Tainoff (thesis co-supervisor)

LABORATORIES : PHELIQS, NEEL

For high thermoelectric efficiency, materials with high electrical conductivity and low thermal conductivity are needed. The thermal conductivity of semiconductors is dominated by phonon transport, implying that the electrical and thermal conductivities can be decoupled. For instance, the mean free path of phonons in a silicon nanowire is strongly reduced by surface scattering if the diameter of the nanowire is reduced.

We grow forests of doped silicon nanowires using Chemical Vapor Deposition with gold droplets to induce the Vapor-Liquid-Solid mechanism. The nanowires undergo guided growth in alumina templates formed by anodizing aluminum. The nanowire profile follows the internal geometry of the pores, which is tuned by changing the parameters of the anodization. We measure the thermal conductivity of the forest of nanowires embedded in the template (using the 3ω method and Raman thermometry) and the electrical conductivity of single nanowire; we use SEM and TEM for structural characterization. The thermal conductivity of silicon nanowires of diameter equal to 65 nm was measured to be 10 Wm-1K-1 at 300K, an order of magnitude below that of bulk silicon. Optimizing the thermal conductivity through the nanowire morphology and the electrical conductivity through doping should allow us to obtain large values of the power factor and realize a cost-effective thermoelectric device.

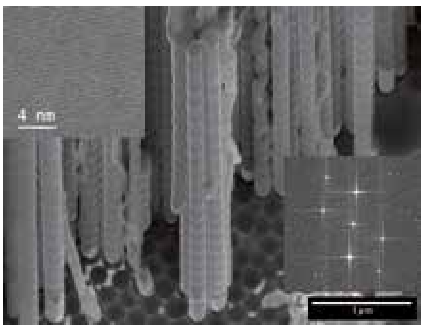

Fig. 1 : SEM image of the diameter-modulated silicon nanowires. (Insets) High-resolution TEM image and its FFT showing the crystal structure of the nanowires.

OUTCOMES

[1] Measurement of anisotropic thermal conductivity of a dense forest of nanowires using the 3ω method, Rev. Sci. Instrum. 89, 084902 (2018).
[2] Nanowire forest of pnictogen-chalcogenide alloys for thermos-electricity, Nanoscale 11, 13423 – 13430 (2019).

Collaboration: Institut Català de Nanociència i Nanotecnologia, Barcelona

Others: InnoEnergy PhD School.

Rapid immunoassays exploiting magnetic nanoparticles and micro-magnets

Sarah Delshadi (PhD student), Orphée Cugat and Patrice Marche (Thesis supervisors), Guillaume Blaire, Paul Kauffmann, Nora Dempsey, Franz Bruckert, Marianne Weidenhaupt

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LABORATORIES : G2ELAB, IAB, NEEL, LMGP

Magnetic attraction is widely used in-*in vitro* diagnostics, as it provides non-contact forces able to capture the objects of interest. Down-scaling the particle size allows diffusion-based transport for much faster reactions; however, due to their high Brownian motion, sub-micrometric superparamagnetic nanoparticles are not efficiently trapped by conventional macro-magnets. We exploit high local gradients from micro-magnets to manipulate and locally capture the nanoparticles. We first developed a colorimetric magnetic immunoassay (MagIA), performed in multi-well plates. We then developed a radically innovative, magnetically localized fluorescent detection immunoassay (MLFIA) which allows rapid molecule quantification, without any fluid handling (see Fig.1). We optimized MagIA and MLFIA with ovalbumin model, then transferred MLFIA to the detection of clinical parameters (Toxoplasma gondii IgG and IgM) and C reactive protein in human samples. MLFIA presents several key advantages: it is compatible with biological media, uses a small volume and requires little energy. It is also highly versatile. Since my PhD we developed a portable reader for point-of-care diagnostics and founded the startup MafiA-Diagnostics. Our results are opening the way to a new generation of sensitive immunological lab-on-chip.

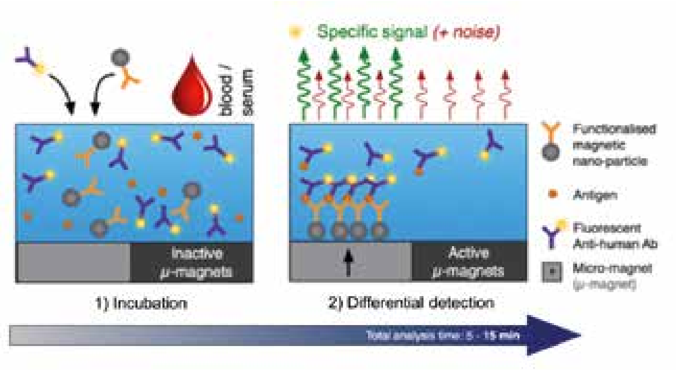

Fig.1: Principle of MagiA-Diagnostics magnetically localized fluorescent

OUTCOMES

[1] Rapid immunoassay exploiting nanoparticles and micro-magnets, Bioanalysis 9, 517 (2017).

Conference: Poster, Innovative no-wash immunoassay, Intermag, Dublin, Ireland, 2017.

Start-up: Co-founder of MagIA Diagnostics (2017)

MAGIA-DIAGNOSTICS

Multi-analysis « Point-of-Care »

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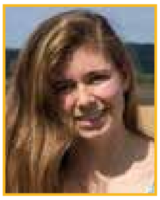
MagIA-Diagnostics was founded in Grenoble in July 2017 after a period of incubation at Linksium. The operational founders Paul Kauffmann (Phelma engineer / physicist), Sarah Delshadi (UGA biologist), Cedric Bruix (ESSEC, finances), and Mario Fratzl (Phelma/Darmstadt, mechatronics engineer) collaborate with the scientific support of Franz Bruckert (LMGP/Phelma, biochemistry), Orphée Cugat (G2Elab/CNRS, magnetic MEMS), Patrice Marche (IAB/INSERM, immunologist) and Nora Dempsey (Néel/CNRS, magnetic materials).

MagIA is developing a multi-analyis «Point-of-Care» solution delivering up to 8 immunoassay within 20 minutes that can be used outside of any clinical environment.

With a first focus on infectious diseases MagIA is providing a syndromic testing approach at the Point of Care outside of traditional clinical environment. With the motto «a better screening for a better care», MagIA focuses first on the rapid detection of infectious diseases, starting with an HIV-Viral Hepatitis combo, to link to care Key « high-risk » populations. MagIA's innovation is a one-step no-wash immunoassay method which brings unique characteristics:

(1) laboratory quality on a portable device, usable indoor, outdoor,
(2) 8 analyses in parallel with 1 single fingerpick, for a syndromic diagnostic approach
(3) secured analysis and traceable results.

MagIA expects CE marking by 2024
https:// www.magia-diagnostics.com



Fabrication & magnetic actuation of 3D-printed micro-structures

Roxane Pétrot (PhD student), Thibaut Devillers, Orphée Cugat, Olivier Stéphan (PhD supervisors)

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LABORATORIES : NEEL, G2ELAB, LIPHY

3D microprinting by 2-photon polymerization (2PP) is a technique allowing fabrication of objects of any shape at the scale of tens of µm, with nanometric resolution. Controlling the motion of such structures is crucial for some advanced applications. For magnetic actuation, we build the structures, attach them to NdFeB magnet microbeads, and actuate them with an external magnetic field.

During my PhD, I'm looking to improve the original fabrication method to make it simpler and reproducible. First we trapped the microbeads on thermo-magnetically patterned micromagnets (TMP), to be able to locate them easily and print next to them (Fig.1.a). Then, we developped microprinting onto TMP (Fig.1.b).

Simultaneously, I am working on the design and fabrication of a structure that mimics intestinal villi, in order to grow cells onto them. The inner structure is composed of a usual photoresist lattice, covered by an envelope made of a gelatin/collagen based photoresist (Fig. 1.c), and a magnetic bead at its end so as to deform the structure and apply mechanical stimuli to the cells which are cultured on the surface.

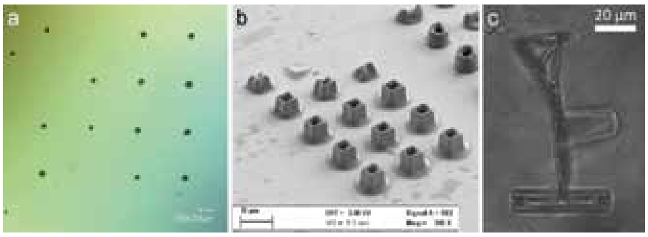

Fig. 1. a) 20 µm magnetic beads trapped on TMP substrate.
b) 10 µm cubes printed on TMP at various powers.
c) Flexible hybrid structure for cell culture

OUTCOMES

[1] Fabrication and Magnetic Actuation of 3D-Microprinted Multifunctional Hybrid Microstructures. Adv. Mater. Technol. 5, 2000535 (2020).

Collaboration: C. Tomba, INL

GRAPHEAL

Connected biosensors for Wearables and Field Diagnostics

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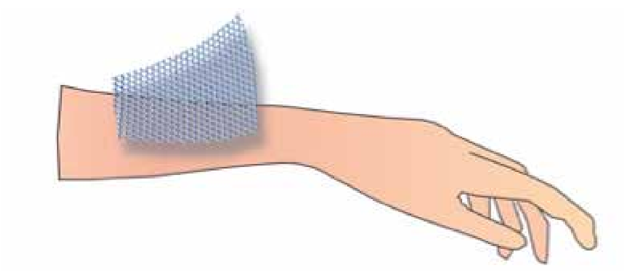
Founders : Vincent Bouchiat (CEO) and Behnaz Djoharian (CDO)

Grapheal is a medical device company, spin-off from Hybrid team at Neel Institute incorporated in April 2019. Grapheal introduces a novel digital biosensing technology into embedded systems to enable diagnostics test and remote patient monitoring in the field (Hospital at home, telemedicine) . It features flexible sensing technology based on Field effect transistors implemented using proprietary graphene on polymer material. The devices are combining novel electronic nanomaterials, embedded wireless electronics, software data analysis and medical cloud IoT technologies. First applications focus on skin patches to monitor and improve the treatment of chronic wounds that require long-term care.

The transparent and ultra-thin patch enables the acquisition of biomedical data from the wounds. The stored data is transmitted to a dedicated Cloud platform using a simple smartphone. The collected data will be processed and effectively analyzed for better decision making. The patch enables the analysis of the exudate of the wound and send alert in case of infection. Grapheal has also developed diagnostic test kits during the pandemic which are based on a similar technology. They provide in a few minutes a digital tamper-proof sanitary passport.



https://www.grapheal.com

PHD GRANT

Odorant binding proteins-based biomimetic optoelectronic nose

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yanxia.hou-broutin@cea.fr

Marielle El Kazzy (PhD student), Yanxia Hou-Broutin (thesis supervisor)

LABORATORIES : SYMMES, ARYBALLE (COMPANY)

Today, there is a growing demand for efficient detection of volatile organic compounds (VOCs) in various domains. For this purpose, electronic noses have emerged as promising analytical tools. In this thesis, we aim to improve the performances (sensitivity, selectivity and specificity) of a biomimetic optoelectronic nose using novel sensing materials (Fig. 1): odorant binding proteins (OBPs) with cross-reactivity to VOCs. Moreover, based on molecular docking and protein engineering, we design a set of selective OBPs for some target VOCs. All cross-reactive and specific OBPs are combined on the same chip for the development of the optoelectronic nose. Finally, the studied biomaterials will be coupled with the handheld optoelectronic nose (NeOse Pro) developed by the local company Aryballe.

This thesis is co-funded by the project OBP-Optinose, ANR-18-CE42-0012-01.

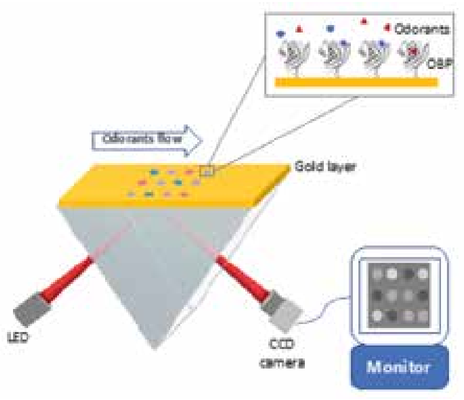

Fig. 1: Schematic representation of the OBP-based optoelectronic nose.

OUTCOMES

[1] An Overview of Artificial Olfaction Systems with a Focus on Surface Plasmon Resonance for the Analysis of VOCs, Biosensors, 11, 244 (2021).
[2] Biomimetic Olfactory Biosensors and Bioelectronic Noses, Advances in Biosensors: Reviews, Book Series, Vol. 3, Chapter 1, 15 (2020) .

Oral presentation: "Odorant binding protein based biomimetic optoelectronic nose", GDR BIOMIM 1st Annual Meeting, October 2020, Nice, France.

Collaboration: Aryballe, Centre des Sciences du Goût et de l'Alimentation (Dijon), Université Nice Sophia Antipolis.

START-UP

aryballe

ARYBALLE

Simple odor analytics

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Founders : Tristan Rousselle (CEO), Thierry Livache (Scientific director), Yanxia Hou-Broutin (Scientific advisor)

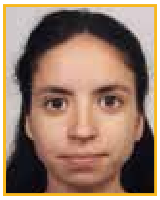
Aryballe was created in 2014 in Grenoble, based on an exclusively licensed patent by the IRIG laboratory SyMMES (UMR 5819 CEA-CNRS-UGA). The company combines biochemical sensors, advanced optics, and machine learning in a single objective solution to collect, display and analyze odor data so companies can make better decisions. With technological transfer from IRIG, in 2018, Aryballe has successfully miniaturized their first portable and universal odor detection device (NeOse Pro™) (Fig. 1a) using surface plasmon resonance imaging as detection system.
Today, Aryballe focuses on the development of a novel generation of low-cost portable devices, NeOse Advance (Fig. 1b), based on silicon photonics such as Mach Zehnder Interferometers. Such systems are very efficient for odor analysis related to various market segments including automotive industry, flavor & fragrances, food and beverage industry, home automation, etc. **To learn more, please visit https://aryballe.com.**

Figure 1: a) NeOse Pro (on the left) and b) NeOse Advance (on the right) developed by Aryballe.

OUTCOMES

Four patents in common IRIG/Aryballe (three with license): FR1751751, FR1758547, FR1907884, FR2200324

Leverage: Two collaborative ANR projects coordinated by Y. Hou-Broutin with Aryballe as partner: OBP Optinose (ANR-18-CE42-0012), eSPRi (ANR-22-CE42-0008-01)



Correlative microscopy for multiphysics sensing within neuron networks

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Océane Terral (PhD student), Cécile Delacour and Aurélie Dupont (thesis supervisors)

LABORATORIES : NEEL, LIPHY

Electronic devices have been used to interface neurons since the beginning of bioelectricity because they can both stimulate and record electrical activity of cells. However, they are still limited in term of spatial resolution to sense weak (<100µV) and localized (few micrometers) signals. To overcome this issue, the project's approach is to combine advanced electrical and optical techniques to extract multiple features regarding neurons activity and metabolism. In particular, multisite spike recording will be performed with microelectrode and field effect transistor arrays. Graphene bioelectronics is ideal for electrical biosensing, thanks to its optical transparency, biocompatibility and the presence of readily accessible surface charges which give the unprecedented possibility to realize a direct coupling with cells. In addition, fluorescence imaging method will be applied to map and identify ion inward flow and small variations of temperature related to specific active states of neurons. Together, the electrical and optical addressing will provide highly complementary information on the metabolism and power consumption associated with voltage activity diagrams of neuron networks.

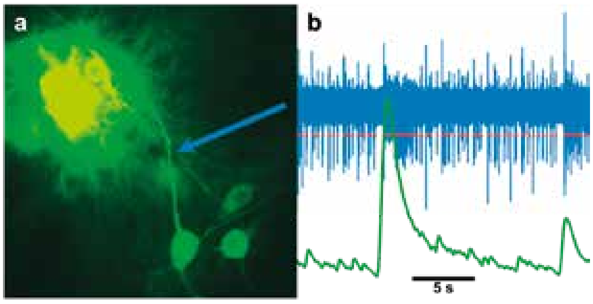

Fig.1 : (a) Fluorescence image of DIV19 neurons transfected with Ca2+ indicator. (b) Time traces of electrical signal (blue) and Ca2+ optical signal (green) measured at the arrow position.

OUTCOMES

Publications :

[1] A Multifunctional Hybrid Graphene and Microfluidic Platform to Interface Topological Neuron Networks, Advanced Functional Materials, 2207001 (2022)

Eleven more PhD students have been hired recently

- **AKAR Elçin:** "GaN-based single-nanowire resonant photo-detectors using quantum confined states", co-supervisors E. Monroy and M. Den Hertog,(collaboration PHELIQS and NEEL)
- **GRANGER Francis:** "Non-cryogenic on-chip single photon source based on semiconductor quantum dot", co-supervisors K. Kheng and G. Nogues (collaboration PHELIQS and NEEL)
- **HELLUIN Félix:** "Universal properties of two-dimensional exciton-polariton condensates", co-supervisors Anna Minguzzi and Michele Filippone (collaboration LPMMC and MEM)
- **KHVALYUK Anton:** "Low-energy theory of strongly disordered superconductors", co-supervisors Denis Basko and Benjamin Sacépé (collaboration LPMMC and NEEL)
- **LE Khan Linh :** « 2D Dilute Magnetic Perovskites», co supervisors David Ferrand and Thuat Nguyen Tran cofunding with QuanG (MSCA Cofund 2021), (collaboration Vietnam National University, NEEL and LNCMI)
- **MARQUARDT Nils:** "Enlightening Spin-triplet Superconductivity in UTe2", co-supervisors G. Knebel and D. Le Boeuf (collaboration PHELIQS and LNCMI)
- **MORINEAU Félix:** "Magnetic monopole noise and fluctuation dissipation relation", co-supervisors E. Lhotel and M. Zhitomiirsky (collaboration NEEL and PHELIQS)
- **SARRADE Jeremy :** "Superconductivity, magnetism and quantum criticality in CeRh1-xIrxIn5", co-supervisors I. Sheikin and T. Klein (collaboration LNCMI and NEEL)
- **TSUCHIDA NOGUEIRA Camila:** "Development and investigation of new lanthanide doped nanocrystals for nanothermometry", co-supervisors Alain Ibanez and J. Carvalho cofunding with CAPES (Brazil), (collaboration University of Goias- Brazil and NEEL)
- **VASSELON Thomas:** "Electronic Flying qubits with ultrashort electronic wave packets", co-supervisors C. Bauerle and X. Waintal (collaboration NEEL and PHELIQS)
- **BAJOUK Ola:** «Reducing CO2 from the air by trapping it in a foaming concentrator" co-supervisors Pascale Chenevier and Elise Lorenceau and co-funding with the UGA-Cross Disciplinary Project «CDP DefiCO2» (collaboration SYMMES and LiPhy)

The in-Lab practicals program provides a platform of physics experiments for MASTER/Engineer students

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Panayotis Spathis, Benoit Chabaud, Thierry Klein, Julien Pernot, Alexandre Pourret, Hervé Guillou, David Ferrand, and Patricia Segonds

Students : M1 Physics, M1 Nanophysics-Quantum Physics, 2A-IPHY Engineer track, M2 Quantum Matter, M2 Photonics and Semi-conductors, M2 Energy, M2 Nuclear Energy, M2 Nanobiotechnologies, M2 Science Trading in Physics…

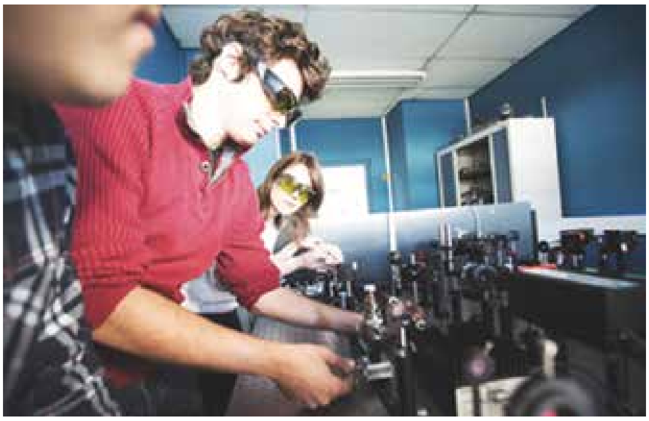
This program has been co-funded by the LANEF, IDEX Université Grenoble-Alpes, the Education and Research Department (UFR) PHITEM of the University Grenoble Alpes (UGA) and the NEEL UGA-CNRS Institute, where the platform of physics experiments is set up. It provides students the opportunity to run experiments during their training by using equipments of our labworks on cryophysics, nonlinear optics and quantum optics, solid state physics and biophysics.

Among half a dozen experiments of Cryophysics labwork, one is about the characterization of a Josephson junction. The students fabricate a junction consisting of a niobium wire tip ($T_c \approx 9$ K) that is precisely positioned opposite a solid niobium cylinder. The insulator is obtained by natural oxidation of the tip. The system is inserted into a liquid Helium bath (T= 4.2 K). The current-voltage characteristic of the junction and its dependence on both the magnetic field and radiofrequency waves are measured showing quantum effects (flux and voltage quantization).

Another experiment concerns the measurement of the second sound velocity in superfluid Helium ($T \leq 2.17$ K). The students connect a heating resistor and a thermal sensor placed at an adjustable distance. The resistor generates a heat wave characterized by a cross-motion of superfluid and normal fluid. The thermometer detects the passage of the heat wave and the speed of the second sound is deduced from the time of flight.

Cryophysics labwork also provides the measurement of the specific heat and latent heat of Helium. The students size a cupronickel capillary tube equipped with a resistor and several thermometers. This system is inserted into a calorimeter and a flow of liquid Helium under controlled pressure is imposed in the capillary. The resistor heats the Helium. The flow rate and the upstream and downstream temperatures are used to determine Helium specific heat and latent heat.

The nonlinear optics labwork learns polarization and propagation of light in nonlinear crystals, with a highlight on the double refraction phenomenon. Then invisible light emitted by a high-power pulsed laser is converted into visible from Second Harmonic Generation (SHG). Phase-matching conditions are studied for maximal conversion efficiency. Quantum optics labwork aims the students to produce pairs of entangled photons in polarization from spontaneous down-conversion and then to demonstrate the entanglement of photon pairs previously generated by the observation of the Bell inequality violation.



Solid-state Physics labwork deals with the metal-insulator transition in low dimensional compounds as the magnetic behavior (flux penetration) in superconductors, i.e. the highlighting of a fundamental particularity of this state of matter. It also concerns the electronic properties of 2D gases illustrating the temperature dependence of the mobility of these compounds but also the existence of the quantum Hall effect.

In biophysics labwork, the students try to trap polystyrene microparticles in a liquid medium. They acquire knowledge about the interaction between light and matter and measure the Brownian motion of these particles.

OUTCOMES

The sessions were open to small groups of students (generally 2 to 4 per experiment) for a total per year of more than 300 teaching hours and about 130 Master or 2nd year Engineer Phelma students.

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PhD student	Call	Supervisors	start	defense	page
Nathan AUBERGIER	2020	Benjamin PIOT & Vincent RENARD	01/10/2020		**26**
Thomas BERNAT	2021	Manuel HOUZET, Julia MEYER, Klaus HASSELBACH	01/10/2021		**27**
Daria BEZNASYUK	2014	Moïra HOCEVAR & Julien CLAUDON	01/03/2015	24/09/2018	**18**
Lorenzo CAMOSI	2014	Jan VOGEL	01/03/2015	30/05/2018	**12**
Victor CHAMPAIN	2021	Silvano DE FRANCESCHI & Clemens WINKELMANN	01/10/2021		**20**
Nicolas CHAUVET	2015	Guillaume BACHELIER	01/10/2015	05/03/2019	**15**
Eric CLOT	2020	Olivier KLEIN & Benjamin PIGEAU	01/10/2020		**12**
Nicolas DAVEAU	2020	Didier GASPARUTTO & Kuntheak KHENG	01/10/2020		**16**
Sarah DELSHADI	2014	Orphée CUGAT & Patrice MARCHE	01/10/2014	17/10/2017	**36**
Isabelle DE MORAES	2017	Nora DEMPSEY	01/10/2017	06/11/2020	**14**
Marielle EL KAZZY	2019	Yanxia HOU-BROUTIN	01/10/2019		**38**
Marco FELLOUS ASIANI	2018	Alexia AUFFEVES & Robert WHITNEY	01/01/2018	09/11/2021	**10**
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Alvaro GARCIA CORRAL	2016	Clemens WINKELMANN	01/10/2016	16/10/2020	**20**
Gaetan GIRARD	2017	Vincent FAVRE-NICOLIN & Joël EYMERY	01/10/2017	04/03/2020	**25**
Efe GUMUS	2018	Clemens WINKELMANN	01/01/2018	28/04/2023	**21**
Mads HANSEN	2019	Andre SULPICE & Pierre TOULEMONDE	01/10/2019	16/12/2022	**27**
Stefan ILIC	2016	Julia MEYER & Manuel HOUZET	01/10/2016	04/10/2019	**30**
Axel LEBLANC	2021	François LEFLOCH & Fabrice NEMOUCHI	01/10/2021	04/03/2020	**21**
Baptiste LEFAUCHER	2021	Jean-Michel GERARD	01/10/2021		**17**
Minh Anh LUONG	2016	Martien DEN HERTOG & Eric ROBIN	01/11/2016	16/10/2019	**18**
Estelle MAZALEYRAT	2016	Claude CHAPELIER & Johann CORAUX	01/10/2016	18/12/2019	**29**
Gwenn MORVEZEN	2021	Alain SYLVESTRE & Hervé GUILLOU	01/10/2021		**35**
Jose PENA GARCIA	2017	Stefania PIZZINI	01/02/2018	12/07/2021	**25**
Roxane PETROT	2019	Thibaut DEVILLERS, Orphée CUGAT, Olivier STEPHAN	01/10/2019	19/01/2023	**37**
Javier PUERTAS MARTINEZ	2014	Nicolas ROCH	01/04/2015	22/08/2018	**24**
Aniket RATH	2020	Benoit VERMERSCH & Cyril BRANCIARD	01/10/2020		**10**
Kevin-Davis RICHLER	2016	Didier MAYOU	01/09/2016	23/10/2019	**33**
Tobias SATTLER	2014	Jean-Michel GERARD	01/09/2014	28/11/2017	**17**
Michaël SCHOBITZ	2017	Olivier FRUCHART	01/04/2018	02/07/2021	**14**
Dhruv SINGHAL	2015	Denis BUTTARD & Olivier BOURGEOIS	01/11/2015	20/05/2019	**35**
Arkadii SOCHINSKII	2015	Nicolas LUCHIER & Frederic AYELA	01/10/2015	24/10/2018	**31**
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Georgy ZIBOROV	2021	Laurent RANNO	01/10/2021		**15**

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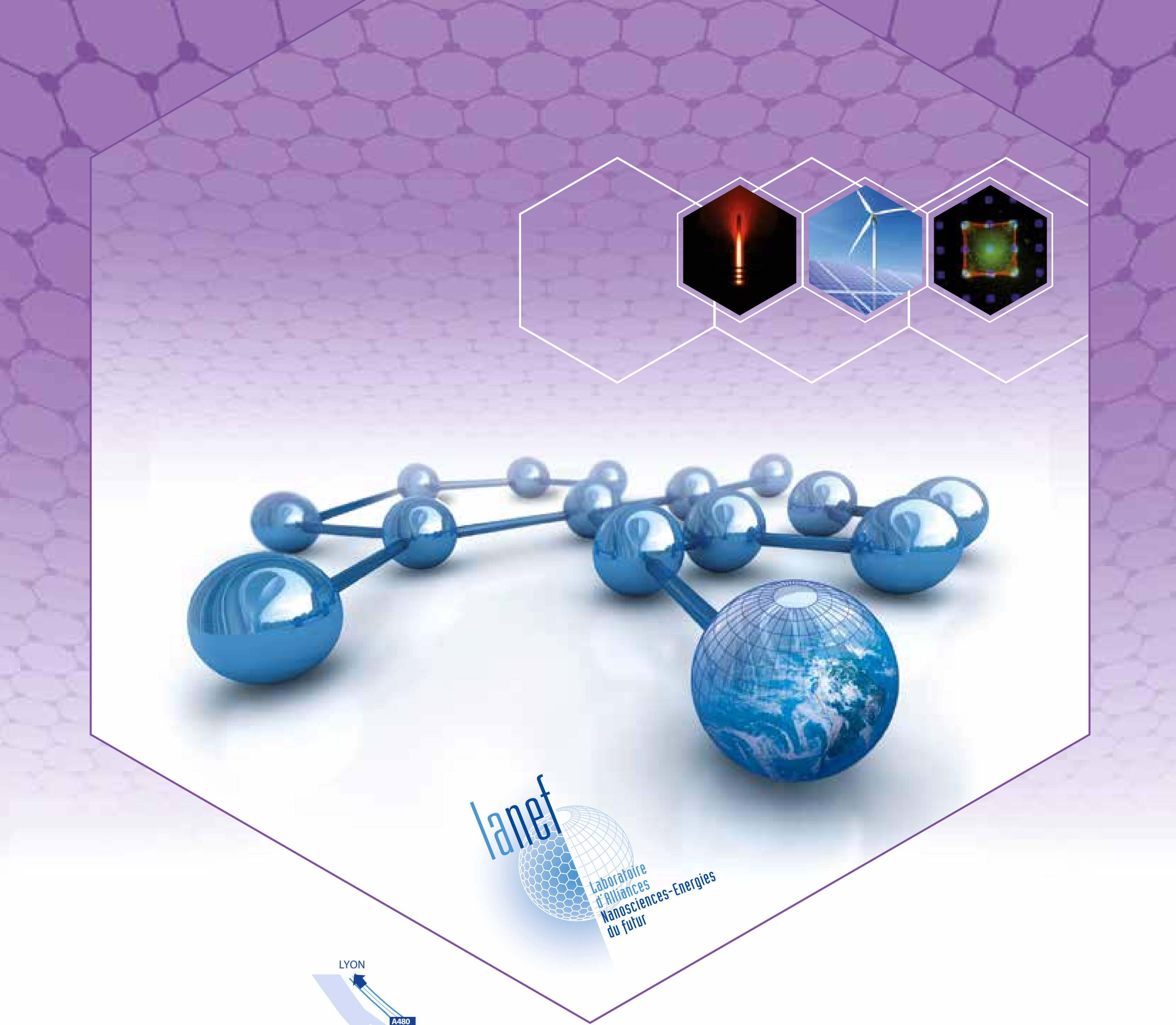
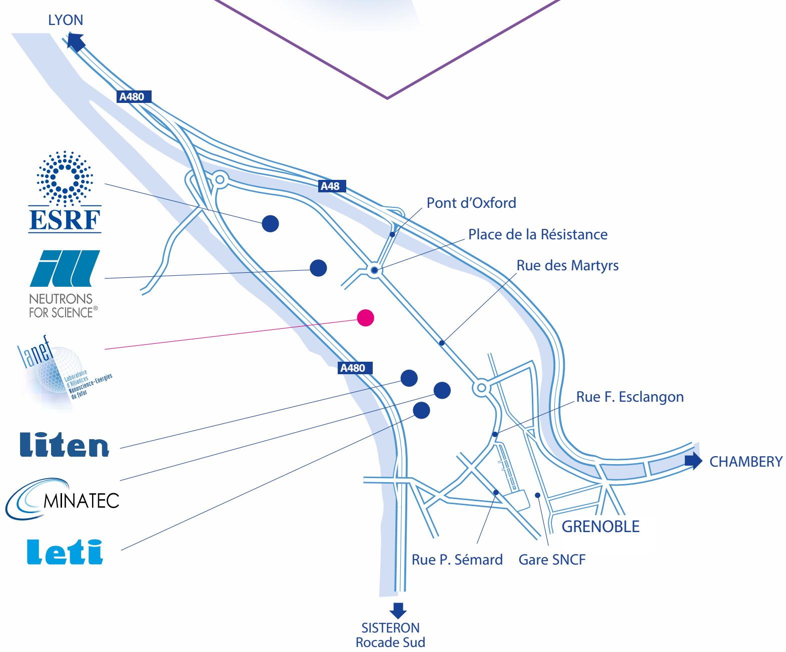
LANEF – Laboratoire d'Alliances Nanosciences - Energies du Futur – est un des laboratoires d'excellence dont le financement a été annoncé le 24 mars 2011 par Monsieur François Fillon, premier ministre, et Madame Valérie Pécresse, ministre de l'Enseignement supérieur et de la Recherche, suite à l'évaluation menée par un jury international dans le cadre des investissements d'avenir.
Le projet a été porté par le PRES Université de Grenoble, avec le soutien de l'Université Joseph Fourier, de Grenoble - Institut National Polytechnique, du Centre National de la Recherche Scientifique, et du Commissariat à l'Energie Atomique et aux Energies Renouvelables.
Il est maintenant porté par l'IDEX Université Grenoble-Alpes.





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