NÉEL institut

INTERNSHIP

2021 2022

cnrs

UGA Université Grenoble Alpes

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L'Institut Néel est un grand laboratoire de recherche en physique avec près de 450 membres. Sa force collective s'exprime dans de nombreuses collaborations internationales et nationales, la présence en son sein de plate-formes technologiques aux performances exceptionnelles, et un niveau de production scientifique remarquable.

Vous trouverez dans ce recueil les sujets de stage proposés par les chercheurs de l'Institut Néel. Les domaines scientifiques et technologiques sont extraordinairement variés, à l'image des activités de nos équipes. S'y côtoient en effet magnétisme, fluides quantiques, nouveaux matériaux, cristallographie, science des surfaces, nano-électronique quantique, nano-mécanique, optique nonlinéaire et quantique, spintronique… Par-delà notre cœur de métier qu'est la physique de la matière condensée, nous travaillons aussi aux interfaces avec la chimie, l'ingénierie et la biologie. Dans tous ces domaines, notre activité principalement expérimentale se développe en lien avec de fortes compétences transversales en physique théorique analytique et numérique.

L'Institut Néel développe une expertise technologique au plus niveau, essentielle pour mener à bien de nombreux projets de recherche. Enfin, nous nous impliquons activement dans la valorisation de nos recherches et de nos savoir-faire dans les domaines de l'électronique, de l'énergie, de la santé et aussi des sciences de l'univers.

Cette brochure regroupe les offres de stage de Master proposés pour l'année universitaire 2018-2019. Ce sont principalement des stages de Master 2 avec pour la plupart une possibilité de continuation en thèse. Si vous commencez votre master, vous trouverez aussi des propositions de stage de Master 1. De nombreux sujets de Master 2 peuvent aussi être déclinés en sujets de Master 1. L'Institut Néel vous souhaite la bienvenue, au moins virtuellement par cette brochure et au travers de notre site web www.neel.cnrs.fr ! N'hésitez pas à contacter les chercheurs de l'Institut Néel afin de nous rendre visite.

La direction de l'Institut Néel

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The NÉEL Institute is a major research laboratory in physics, gathering about 450 collaborators. Its collective strength is expressed in numerous national and international collaborative projects, through open technological platforms of exceptional quality, and by a remarkable level of scientific production.

As detailed in this booklet, NÉEL researchers propose a great number of internship topics. These cover a wide range of scientific and technological fields, reflecting the diversity of our teams. Magnetism, quantum fluids, new materials, crystallography and surface science mingle with quantum nanoelectronics, nanomechanics, non-linear and quantum optics, spintronics, etc. Beyond our core expertise in physics of condensed matter, we also work at the interface with chemistry, engineering, astrophysics and biology. In all these fields, our mainly experimental activity benefits from the local presence of many world class experts in theoretical, analytical and computational physics.

The NÉEL Institute fosters a technological expertise that is essential to bring our research projects to the highest level, through often unique house-made or in-house designed instruments. We are also actively involved in creating value from our research in the sectors of electronics, energy, health and space.

This booklet contains the Master internship offers for the 2019-20 academic year. Most of them are Master 2 projects, offering often the possibility of going on as a PhD student. If you are starting your Master degree, you will also find Master 1 project proposals. Many of the Master 2 topics may also be adapted to Master 1 projects.
You are welcome to a virtual visit of NÉEL Institute through this booklet and our website, www.neel.cnrs.fr.
Please get in touch with NÉEL researchers and come around for a real visit!

La direction de l'Institut Néel

LISTE DES SUJETS PROPOSES

2021 -2022

MASTER 1	
Nanomechanics at ultra-low temperatures	Fefferman Andrew
Graphene based superconducting quantum circuits	Renard Julien
Fe Doped tetragonal CuO films as a new ferromagnetic semiconductor	De Santis Maurizio
Optical rotation angles and optical rotatory dispersion of α - GeO_2 crystals	Pena Alexandra Félix Corinne Ménaert Bertrand
MASTER 2	
Measure of a semiconducting qubit chip with embedded control and readout circuits.	Jadot Baptiste Meunier Tristan
Elaboration of epitaxial Rubidium Titanyl Phosphate (RTP) thin films by Pulsed Laser Deposition (PLD)	Mathieu Salaün
Quantum dot arrays control, characterization and automatic tuning	Meunier Tristan
Semiconductor quantum devices controlled with cryo-electronic circuits in high cooling power cryogenic system	Meunier Tristan
Protected superconducting qubits	Roch Nicolas
Ultra-cold Nanomechanics	Collin Eddy
Fermiologie des systèmes non conventionnels	Klein Thierry Marcenat Christophe
Propriétés électroniques de systèmes non conventionnels	Klein Thierry Marcenat Christophe
Machine learning for magnetism	Lepetit Marie-Bernardette
Apprentissage automatique pour le magnétisme	Lepetit Marie-Bernardette
Charge frustration as a route to bad metal behavior in correlated electron systems	Fratini Simone Ralko Arnaud
Erbium doped opto-RF platform for quantum transduction	Chanelière Thierry
Cathodoluminescence-based nano-thermometry	Jacopin Gwénolé
Microwave to optical conversion for quantum networks	Renard Julien Roch Nicolas
Graphene based superconducting quantum circuits	Renard Julien
Quantum foundations : the wave-particle duality on a vibrating string	Poulain Cédric
Acoustic analog of a quantum effect: the Casimir force	Poulain Cédric
Solid-State Electronic Flying Qubits	Bauerle Christopher
Unconventional magnetism and new spin excitations in honeycomb-lattice materials	Songvilay Manila De Brion Sophie Simonet Virginie
Theoretical investigation of novel nickelate superconductors	Cano Andrés Olevano Vaelerio
Convection, Turbulence et Chauffage interne (expérimental)	Roche Philippe
Search for superconductivity under pressure in mono and bi-layer graphene	Núñez-Regueiro Manuel

Monopoles magnétiques et propriétés hors-équilibre des glaces de spins	Lhotel Elsa
Magnetic monopoles and out-of-equilibrium properties of spin ice	Lhotel Elsa
Evolution of the equilibrium morphology of KH2PO4 crystals at different growth conditions	Ménaert Bertrand Zaccaro Julien Pena Revellez Alexandra
Theory of non-perturbative quantum circuits	Florens Serge
Transport quantique non conventionnel dans des systèmes à bandes plates	Bouzerar Georges
Fluorescent Nanorods Optical Trapping in Air	Fick Jochen
Triple photon generation in crystal optical nonlinear waveguides	Boulanger Benoît Boutou Véronique
p-n junction nanowires for solar cells	Den Hertog Martien Monroy Eva
Fe Doped tetragonal CuO films as a new ferromagnetic semiconductor	De Santis Maurizio
Remarkable magnetic behavior of itinerant electrons	Isnard Olivier
Higgs Modes in Superconductors	Measson Marie-Aude
Tailoring superconductivity in two-shells superconductor-semiconductor nanowires	Hocevar Moïra Sacepe Benjamin Belet-Amalric Edith
Integration of a semiconductor quantum dot single photon emitter to a quantum photonic circuit	Nogues Gilles Kheng Kuntheak
Transport properties of an Al/Ge/Al junction	Naud Cécile
Emulating spin qubit on ATOS QLM machine	Meunier Tristan Savin Valentin
III-Nitride nanowire-nanocellulose composites for flexible energy harvesters	Songmuang Rudeesum Jean Bruno
Large scale parametric characterization and test of quantum devices at cryogenic temperatures	Mortemousque Pierre-André Cardoso-Paz Bruna Meunier Tristan
Combinatorial studies of hard magnetic materials	Grenier Stéphane
3D Superconducting Interconnects for Quantum Applications	Meunier Tristan Charbonnier Jean Thomas Candice
Direct studies of TeraHertz emission generated from phase-matched frequency down-conversion in new nonlinear crystals	Segonds Patricia Boulanger Benoît

MASTER 1

NÉEL INSTITUTE Grenoble

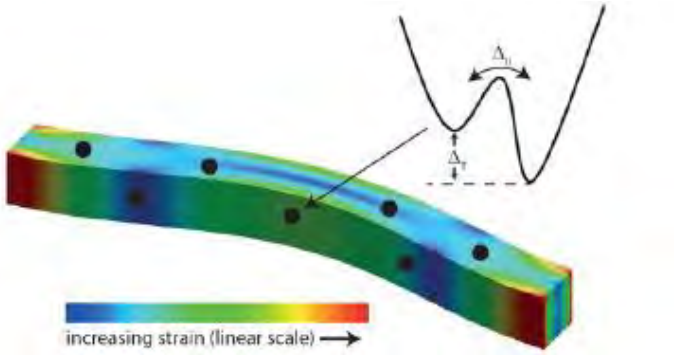
Topic for Master 1 internship – Academic year 2021-2022

Nanomechanics at ultra-low temperatures

General Scope:
The cross-over from atomic-size quantum objects to macroscopic classical systems remains puzzling. We know that macroscopic quantum states exist (e.g. the quantum coherence of the current state in a superconducting loop), but our knowledge is essentially limited to electromagnetic degrees of freedom. Quantum states of moving objects have undergone relatively little experimental study.

Research topic and facilities available:

One of the goals of our research group, to which the intern would contribute, is cooling a glass nanomechanical resonator to the microkelvin range, so that its fundamental mode reaches the quantum ground state. This is essential for probing low energy excitations present in the amorphous lattice of the resonator. New cryogenic technology is required to efficiently carry out this research. In particular, we are developing a continuous nuclear demagnetization refrigerator (CNDR) that will, for the first time, allow measurements below 1 mK on unlimited timescales. Specific activities of the intern will include characterization of nanomechanical resonators at low temperatures, characterization of superconducting microwave resonators at low temperatures and/or tests of CNDR components.



Possible collaboration and networking:
This work may involve collaboration and interactions with researchers at the Institut Néel, elsewhere in Europe, and throughout the world.
Possible extension as a PhD:
Yes
Required skills:
The student should have a strong interest in fundamental research and making challenging measurements at very low temperatures, as well as a thorough understanding of quantum theory at the M1 level.
Starting date: Flexible
Contact:
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More information: https://neel.cnrs.fr/equipes-poles-et-services/ultra-basses-temperatures-ubt

NÉEL INSTITUTE Grenoble

Topic for Master 1 internship – Academic year 2021-2022

Graphene based superconducting quantum circuits

General Scope :

The recent progresses in reproducible fabrication and understanding of quantum systems have brought us to the following situation: it is now possible to build devices that not only present quantum properties but in which quantum states can be initialized, manipulated and readout. The building blocks of quantum circuits are quantum bits and quantum limited amplifiers. Superconducting circuits is the most advanced platform in this context and it has reached several key milestones in the realization of a quantum computer. Despite such celebrated successes, other platforms are studied in order to gain flexibility and compatibility with current semiconductor technologies. In particular, hybrid platforms that couple superconducting and semiconducting properties are expected to bring a decisive advantage by allowing electrical control of the system.

Research topic and facilities available :

In this internship, we will bring electrical tuning at the core of superconducting circuits by introducing a gapless semiconductor graphene, in the key element: the Josephson junction (see Figure). With such electrically tunable Josephson element, we can build the building blocks for a quantum platform: quantum bits and Josephson parametric amplifiers. In the team we have already demonstrated the fabrication of such graphene based Josephson junctions and their use in quantum circuits. The next step, which is the goal of this work is to demonstrate that it can have functionalities and performances to be competitive with other platforms.

A one atom-thick sheet of graphene will thus have to be integrated into superconducting circuits using nanofabrication techniques available at the Institute. Such sample will then be measured at very low temperature (20mK) in a dilution refrigerator using radiofrequency (1-10 GHz) techniques. Measurements will be carried out to extract the figure of merit of the devices: lifetime of the Qubit, noise of the amplifier...

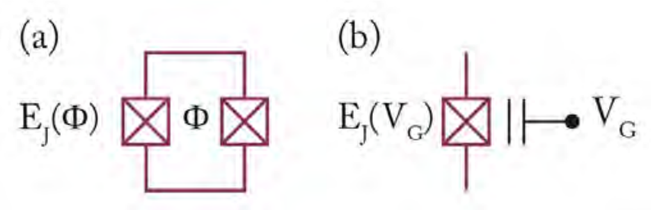

Figure 1: tunability of the Josephson energy E_J in standard Josephson junctions necessitates a loop geometry and a magnetic flux Φ (a). The introduction of a semiconductor allows simple electrical gating with a gate voltage V_G (b). This is the essence of the project.

Possible collaboration and networking : The student will be part of the Hybrid team, which has a multidisciplinary expertise (growth, nanofabrication, electronic transport, spectroscopy...). The team has also several external collaborations worldwide (France, Switzerland, Germany, Canada).

Required skills: The internship will require a solid background in solid state/condensed matter physics. The work will be mainly experimental. The candidate is expected to be strongly motivated to learn the associated techniques (nanofabrication in clean room, radiofrequency electronics, cryogenics...) and engage in a hands-on experimental work.

Starting date : March 2022 (flexible)

Contact :

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NÉEL institut

Title

Fe Doped tetragonal CuO films as a new ferromagnetic semiconductor

General Scope:

Over the past half a century, a considerable research activity has been dedicated to the development of magnetic semiconductors (MSC) that can work at room temperature [Q. Cao and S Yan, *J. Semicond.* **40** 081501 (2019)]. These materials are of primary importance for spintronics applications. At the beginning investigations focused mainly on II–VI MSC and III–V dilute MSC. More recently the attention turned towards oxides like e.g. ZnO-based MSC.
Here we are interested in CuO, which is an antiferromagnetic semiconductor with a gap of about 1.4 eV. Its structure is monoclinic, at odd with the other 3d transition metal monoxides (FeO, CoO, NiO,…) that have a rock-salt structure. However, single-phase tetragonal CuO films were elaborated by epitaxial growth on $SrTiO_3$(001) substrates [W. Siemons *et al*., *Phys. Rev. B* **79**, 195122 (2009)], up to a thickness of about 3 nm. This transition from monoclinic to tetragonal structure is associated with an increase of the oxygen-mediated superexchange interaction *J* and hence of the Néel temperature. Transition metal doped CuO nanocrystals, and in particular $Cu_{1-x}Fe_xO$ ones, have been elaborated by several methods. The iron substitutes copper in the monoclinic structure resulting in a single phase up to x~0.2. Samples are ferromagnetic, but with quite a small remanence and coercive field at room temperature. During this internship, the scope it to grow Fe-doped tetragonal CuO phase with improved magnetic properties, thanks to the larger superexchange interaction characteristic of the tetragonal phase.

Research topic and facilities available:

During the internship, Fe-doped CuO tetragonal thin films will be grown by MBE deposition on $SrTiO_3$(001). The films will be prepared and studied *in-situ* using two interconnected ultra-high-vacuum chambers, the first one dedicated to MBE growth, the second one to the characterization by low energy electron diffraction (LEED), Auger electron spectroscopy and scanning tunnel microscopy (STM) techniques. LEED allows to establish the crystallographic symmetry of the films, Auger is used to study the composition and the presence of contaminants, STM will be performed here to study the surface roughness and for a first investigation of the electronic properties.
After growth, the transport and magnetic properties will be measured *ex situ*, using the devices available at the Néel institute.

Possible collaboration and networking: SIN team at Néel institute

Required skills: A good background in condensed matter physics, dexterity in experimental work.

Possible extension as a PhD: Possible, but no financed up to now

Starting date: March 2022

Contact:
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INSTITUT NÉEL Grenoble

Topic for Master 1 internship – Academic year 2021-2022

Optical rotation angles and optical rotatory dispersion of α - GeO_2 crystals

General Scope:

α - GeO_2 crystals, which are isostructural to quartz (α - SiO_2), are grown at Institut Néel by a high temperature flux method (Figure 1a). It is one of the promising piezoelectric materials to be used for high temperature applications [P. Papet *et al.*, *J. Appl. Phys.* **126**, 144102 (2019)] and in nonlinear optical devices [T. Remark *et al.*, *Opt. Mater. Express*. in press].
Some of the as grown crystals shows optical twins (*Brazil* twins) which are a drawback for the use of α - GeO_2 crystals in some of its applications. These twins have been visualized and characterized by optical microscopy and X-ray topography (figure 1c-d) at Institut Néel in thin slabs. Recently measurements of the optical activity have been used to demonstrate the existence of optical twins in $YAl_3(BO_3)_4$ (YAB) and $K_2Al_2B_2O_7$ (KABO) crystals [J. Buchen *et al.*, *Crystals* **9(1)**, 8 (2019)], and could then be used to assess crystal quality and to select twin-free zones of α - GeO_2 crystals.

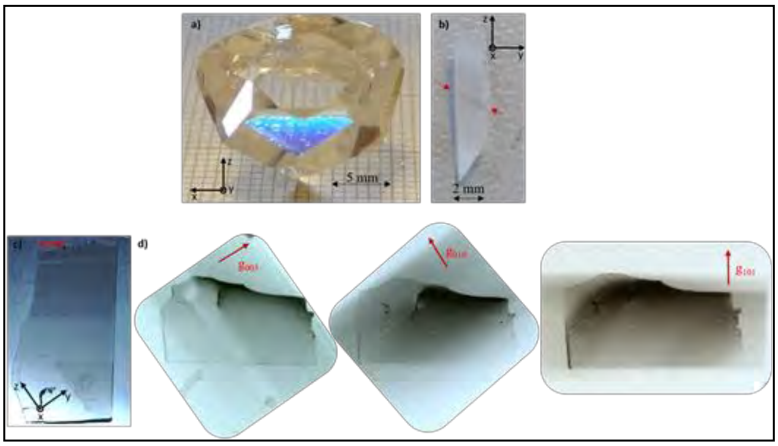

Fig. 1: a) Bulk α-GeO_2 single crystals grown by Top Seeded Solution growth and b) an oriented crystal seed use for crystal growth. Red arrows indicate the position of an optical twin revealed by etching. c) Optical microscopy image of a thin X-slab and d) x-ray traverse topography of different reflections.

Research topic and facilities available:

Changes in the sign and magnitude of optical rotation angles in thick α - GeO_2 slabs oriented along the optical axis could give us information about the presence and extension of optical twins. During the internship the space-resolved measurements of the optical rotation angles, which is known to be of the order of 30 deg/mm at 633 nm, as well as optical rotatory dispersion will be done whether by using a spectrophotometer with rotatable polarizers or by using an accordable laser source available at Institut Néel.

Possible collaboration and networking:
Teams involved in the ANR OVERHEAT project

Required skills:
Strong interest in optical characterizations is needed. Skills in data analysis as well as interest in materials science will be appreciated

Starting date: February/March 2022

Contact:

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MASTER 2

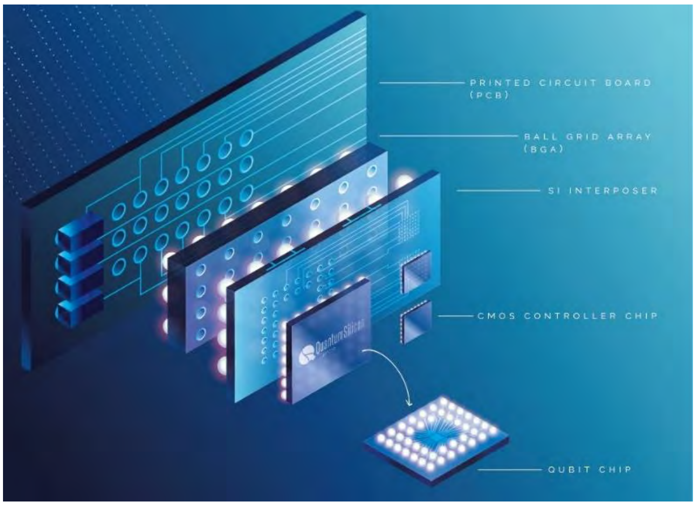
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Measure of a semiconducting qubit chip with embedded control and readout circuits.

General scope:
Quantum computing is a field of growing interest, especially in Grenoble with an exceptional concentration of both research and industrial groups active in this field. The global aim is to develop a new kind of nano-processor, based on quantum properties. Its building brick is a two-level quantum system (the qubit), in our case the spin of an electron trapped in a quantum dot. In this context, the Grenoble Quantum Silicon Group is actively trying to leverage the decades of development of the Silicon industry in Grenoble to realize a network of inter-connected semiconductor spin qubits.

Research topic and facilities available:
The aim of this project is to demonstrate the complete control of a quantum chip via a cryo-electronic circuit operating at low temperature. For this, a demonstrator composed of a silicon interposer, a GaAs quantum circuit, a multiplexed control chip and a trans-impedance amplifier are co-integrated and placed in a cryogenic test environment. Following the recent demonstrations of quantum dot arrays [1] and long-range coupling protocols [2], the GaAs quantum circuit represent a good testbed for the future Si qubits. The control electronics is the third iteration of a cryo-electronic circuit [3] designed to enhance the scalability and performances of the electrostatic control and readout techniques.



Representation of the integrated quantum chip

The candidate will benefit from the extensive knowledge of the Néel group on the control of GaAs nanostructures, and from the resources offered by the technical poles (electronics, cryogenics). The Leti group will support the project with their important effort on the modeling of the control circuits' behavior at low temperatures.

[1] *Coherent control of individual electron spins in a 2D quantum dot array*
P-A Mortemousque et al, Nature Nanotechnology 2020.
[2] *Distant spin entanglement via fast and coherent electron shuttling*
B. Jadot et al, Nature Nanotechnology 2021.
[3] *A 110mK 295µW 28nm FDSOI CMOS Quantum Integrated Circuit with a 2.8GHz Excitation and nA Current Sensing of an On-Chip Double Quantum Dot*, L. Le Guevel et al, ISSCC 2020.

Possible collaboration and networking:
This topic is co-directed by the CEA-Leti and the CNRS-Néel Institute via the "Grenoble Quantum Silicon" group. The circuit is conceived and fabricated by the CEA-Leti, and measured at the Néel Institute, under the supervision of a post-doctorate researcher with a shared affiliation between the two entities. The candidate will have strong interactions with other actors of the QSG project and benefit from their developments.

Required skills: We are looking for a motivated student, with an interest for experimental physics. This internship requires skills in electronics, programming, and a basic understanding of quantum physics. A knowledge of nano-fabrication techniques, cryogenics or electronic circuit design will be appreciated but is not mandatory.

Possible extension as a PhD: Yes, with funding already secured.
Starting date / Duration: Flexible
Contacts: JADOT Baptiste, Institut Néel – CNRS, CEA – LETI, baptiste.jadot@neel.cnrs.fr
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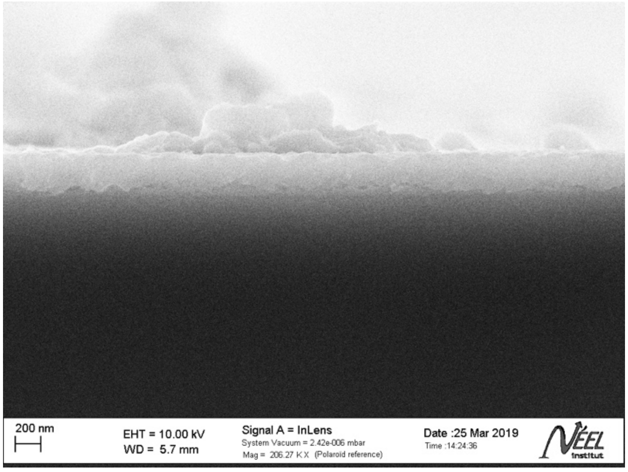
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Elaboration of epitaxial Rubidium Titanyl Phosphate (RTP) thin films by Pulsed Laser Deposition (PLD)

General Scope:

Potassium titanyl phosphate ($KTiOPO_4$, KTP) is a nonlinear optical crystal that is used commercially for second harmonic generation (SHG) of the 1.064 µm Nd:YAG laser for example. Most of its applications are based on bulk KTP crystals. Nevertheless, it was reported [1] that a type-II second-harmonic generation and sum-frequency mixing could be realized in uniform epitaxial $RbTiOPO_4$ (RTP) films over KTP channel waveguides prepared by Pulsed Laser Deposition (PLD). Such waveguides could open the way to efficient low energy nonlinear optical devices for numerous applications in particular in optical Telecom.



[1] *Liu et al., J. Appl. Phys. 76 (12)*

Research topic and facilities available:

RTP single crystals are already grown at the lab by flux method. These massive single crystals will be used as target in a low vacuum chamber in order to deposit thin films by Pulsed Laser Deposition (PLD). The deposition conditions will be optimized to ensure the formation of the right phase, as well as a high crystal quality.

The obtained films will be characterized by X-ray Diffraction (powder and at grazing angle, both available at the Institut Néel), as well as by Scanning Electron Microscopy. The epitaxy quality will be monitored by texture measurements including XRD and EBSD as well as transmission electron microscopy. According to the film quality, SHG will be studied at the Institut Néel.

Possible extension as a PhD:

Yes if funding

Required skills:

Good skills in Materials Sciences (Deposition techniques, vacuum knowledges, characterization techniques: XRD, SEM)

Good writing and oral skills

Starting date: February-March 2022

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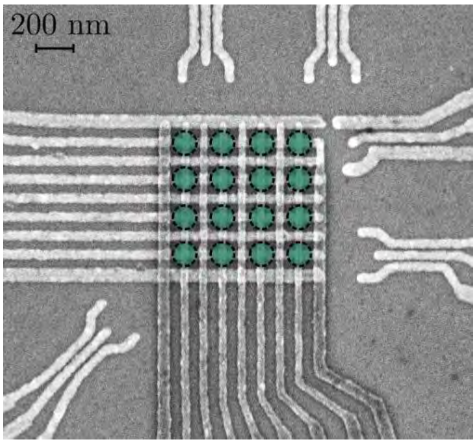
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Quantum dot arrays control, characterization and automatic tuning

Context: Quantum information processing requires to be able to control many qubits with long coherence times. In this context, the electronic spin of a single electron trapped in a Si quantum dot has been identified as a promising platform to both its long coherence time and the possibility to leverage the well-established fabrication of Si foundries. However, quantum dots require to be finely tuned to operate in the right regime which becomes extremely time consuming as the size of the system grows. The QUANTECA team has been a pioneer (PA Mortemousque et al, Nature Nano 2020) in the demonstration and use of the isolated regime in which one or several quantum dots are isolated from the leads allowing to tune the system with a constant number of electrons in the structure hence reducing the dimensionality of the space to explore. The extension of this technique to larger arrays and the exploitation of device symmetries offer interesting perspective to scale systems while keeping the complexity of the tuning under control.

Objectives and means available: The aim of this project is to develop both characterization and automatic tuning procedure for arrays of quantum dots filled with electron spins. The Neel team has extensive knowledge on GaAs dot array devices which are highly tunable and an ongoing collaboration with CEA-LETI to access Si devices fabricated in their industrial foundry. The project will focus on both type of dot array sample. Nowadays, GaAs samples are more mature when it comes to larger arrays and bi-dimensional structures. The idea of the project will eventually be to transfer the demonstrated control to Si quantum devices Si quantum samples. As the project moves forward, some procedures may be optimized with fast electronics in collaboration with CEA-Leti and embedded in custom electronic developed at the Néel institute.



2D array of Quantum dots using 2 layers of gates on GaAs

Interactions and collaborations: This work is part of a collaborative effort between the CEA-IRIG, CEA-LETI and CNRS-Institut Néel to push the technology of spin qubit in silicon and investigate its potential scalability. Therefore, the candidate will work in close collaboration with the LETI's device characterization team to investigate 2D array in Si devices while he will benefit from interaction with the CNRS Institut Néel when it comes to larger devices. A common data acquisition platform shared between the CEA and the CNRS will ensure a smooth collaboration on the automation tools.

Skills and training: The experimental project relies on the knowledge accumulated in the field of few-electron quantum dots and its new implementation in Si devices. All along this project, the candidate will acquire important skills in the field of quantum nanoelectronics: qubit integration, cryoelectronics, cryogenics at mK, low-noise electronics, computer control, characterization of CMOS quantum devices…

Foreseen start for the beginning of the internship: From January to April 2022

Possibility of continuation as a PhD on the same subject with funding already secured.

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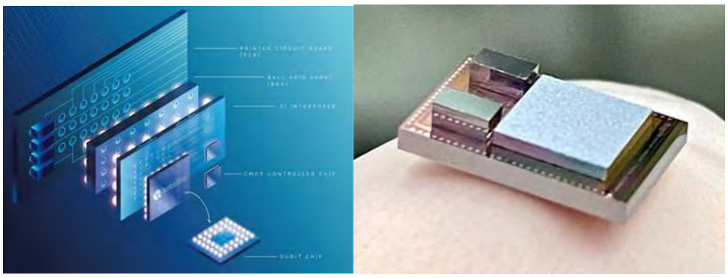
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Semiconductor quantum devices controlled with cryo-electronic circuits in high cooling power cryogenic system

Context: The scaling of quantum nanoprocessors requires the development of integrated electronics as close as possible of the quantum chips. In this context, electron spin qubits in semiconductors have been identified as a promising platform due to both its long coherence time and the possibility to leverage the well-established fabrication of microelectronic foundries for Si based quantum devices. Their direct compatibility with CMOS electronics enables potentially to co-integrate in a compact manner quantum devices and control electronics. This is the purpose of the workplan to investigate such interface between control and quantum systems. It will be important for the integration of larger and larger quantum systems but also for extracting statistical information on the qubit properties.



Schematic and optical picture of CryoCMOS circuits hybridized with a quantum chip on a micro-fabricated interposer. Copyright CEA-LETI

Objectives and means available: The aim of this project is to measure and characterize a spin qubit quantum device integrated with a CryoCMOS control system. As shown on the picture, control and quantum chips will be integrated using tridimensional architecture. The experiment will take place in a dedicated cryostat designed and developed at the Néel institute to deliver enough cooling power to maintain the quantum device at low temperatures while being operated with on-chip cryoelectronics. The candidate will be first responsible for characterizing all the different circuits individually in the new cryogenic environments. She/He finally will test and measure the integrated circuits. At all steps, she/he will benefit from the extensive knowledge of the Néel group and the CEA-LETI in the design and characterization of spin qubit devices and CryoCMOS circuits.

Interactions and collaborations: This work is part of a large collaborative effort between the CEA-IRIG, CEA-LETI and CNRS-Institut Néel to develop and push the technology of spin qubit in silicon and investigate its potential scalability. Therefore, the candidate will work in close collaboration with the LETI's integration and characterization team which is developing fast characterization procedure for the cryo-prober, the electronic team of the CEA-LETI designing the CryoCMOS circuits and the QUANTECA team and cryogeny department of the Néel institute in charge of developing the dedicated cryostat.

Skills and training: The experimental project relies on the knowledge accumulated in the field of few-electron quantum dots and its new implementation in Si devices. All along this project, the candidate will acquire important skills in the field of quantum nanoelectronics: qubit integration, cryoelectronics, cryogenics at mK, low-noise electronics, computer control, characterization of CMOS quantum devices…

Foreseen start for the beginning of the internship: From January to April 2022

Possibility of continuation as a PhD on the same subject with funding already secured.

Contacts: Baptiste jadot CEA Leti baptiste.jadot@cea.fr	**Contacts**: Candice Thomas Cea Leti candice.thomas@cea.fr	**Contacts**: Tristan Meunier Institut Néel/ CNRS-Université Joseph Fourier tristan.meunier@neel.cnrs.fr

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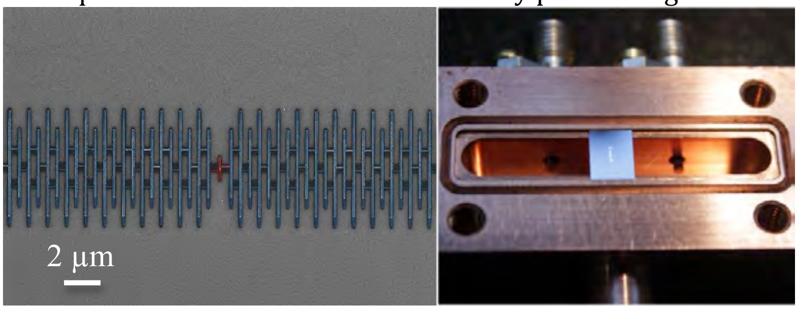
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Protected superconducting qubits

General Scope : During the last decade, it has been demonstrated that superconducting Josephson circuits behave as quantum bits and are very well suited to realize advanced quantum mechanical experiments. These circuits appear as artificial atoms whose properties are defined by their electronic characteristics (capacitance, inductance and tunnel barrier).
Moreover, given their mesoscopic size, these quantum bits couple very strongly to electromagnetic radiations in the microwave range. Thus, it is now possible to perform quantum optics experiments using microwave photons and to unravel light-matter interactions using circuits. This field is dubbed circuit-QED (Quantum Electro-Dynamics).

Research topic and facilities available : The aim of this project is to combine superinductances and innovative circuit geometry to build the next generation superconducting qubits with enhanced quantum coherence and intrinsically protected gates.



Left: example of a Josephson meta-material we engineer in our lab [1]. It is made of thousands of Josephson junctions and behaves as a "superinductance", which is several orders of magnitude larger than what is usually found in standard electronic circuits. Right: superconducting qubit embedding a superinductance (black rectangle) sitting in its copper microwave cavity. In this specific case, the addition of a superinductance enabled a novel readout mechanism.

Our team specializes in the coherent control and manipulation of superconducting quantum circuits. You will benefit from a dedicated, state-of-the-art setup combining very low temperatures (around 10 mK), fast electronics and quantum-limited microwave detection chains. The devices are fabricated in the clean room of the Neel Institute (Nanofab), offering state-of-the-art equipment (100 keV e-beam writer, dedicated Plassys evaporator, ALD and PE-CVD machines…).

[1] Observation of quantum many-body effects due to zero point fluctuations in superconducting circuits, S. Leger, et al. Nature Communications 10, 5259 (2019). [2] Fast high fidelity quantum non-demolition qubit readout via a non-perturbative cross-Kerr coupling, R. Dassonneville, et al. Phys. Rev. X 10, 011045 (2020).

Possible collaboration and networking : Our team is part of several national and international networks.

Possible extension as a PhD : Yes since this position is funded within the ERC project SuperProtected (SUPERinductance for hardware-PROTECTED superconducting qubits).

Required skills: Master 2 or Engineering degree. We are seeking motivated students who want to take part to a state of the art experiment and put some efforts in the theoretical understanding of quantum effects in Josephson parametric amplifiers.

Starting date : Flexible

Contact : Roch Nicolas, Institut Néel - CNRS
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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Ultra-cold Nanomechanics

Keywords: quantum mechanics, nano-mechanics, non-linear phenomena, low temperatures, ground-state cooling

General Scope:
The project is devoted to fundamental research using nanomechanics cooled down to the lowest possible temperatures. It has two facets: a macroscopic approach concerned with the quantum mechanics behavior of the moving device itself, and a microscopic one concerned with elementary excitations in quantum matter and thermodynamics concepts.

Research topic and facilities available:
The project is based on the « brute force » cooling of nanomechanical devices down to temperatures below 1 mK. For devices resonating around 20 MHz in their first flexure, the collective modes describing the motion are in *their quantum ground states*. Experiments probing mechanical quantum coherence are then possible, on a system which is at equilibrium with the environment. These coherence properties are linked to fundamental aspects of quantum theory, with new developments (e.g. stochastic collapse) and old paradoxes (e.g. Schrödinger cat).
Properties of quantum matter are probed by looking at intrinsic mechanical dissipation mechanisms in the constitutive solids, and more specifically at *their fluctuations*. These are characteristic of the thermodynamic baths connected to the mechanics, and tells us about fundamental aspects of thermodynamics.
These experiments rely on cryogenic capabilities of the group: a unique platform allying demagnetization cooling down to 500 µK with microwave optomechanical readout (see Figure).

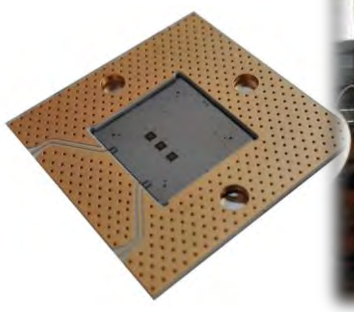

Figure: A PCB board hosting a microwave optomechanics experiment (left) and the nuclear demag. cryostat (right).

Possible collaboration and networking:
This research is carried out at Institut Néel, in collaboration with other researchers from the laboratory. It is performed in the framework of the *European Microkelvin Platform (EMP)*, with contacts to other ultra-low temperature facilities in Europe (UK, Germany, Finland…).

Possible extension as a PhD: yes (funded)

Required skills:
The student should have a strong interest in fundamental research and making challenging measurements at very low temperatures, as well as a thorough understanding of quantum theory at the Master's Degree level.

Starting date: Flexible

Contact:
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INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

"Fermiologie" des systèmes non conventionnels.

Cadre général :
Ce stage expérimental s'inscrit dans le cadre de l'étude des propriétés physiques de systèmes corrélés : supraconducteurs non conventionnels, métaux « exotiques » (semi-métaux de Weyl ou en limite ultra quantique), etc… Les effets de corrélation (interactions électrons-électrons) sont en effet un des ingrédients majeurs à l'origine des propriétés *anormales* de la matière condensée et, étudier, analyser, comprendre ces effets est un enjeu majeur de la physique du solide moderne. Le paramètre essentiel gouvernant les propriétés physiques des solides est leur densité d'états au niveau Fermi et dans ce stage il s'agira essentiellement de déterminer ce paramètre avec la plus grande précision, en utilisant pour cela une approche thermodynamique basée sur une technique de mesure de la chaleur spécifique développée au laboratoire dans des conditions extrêmes de température (jusqu'à 0.3K) et de champs magnétiques (jusqu'à 35T).

Sujet exact, moyens disponibles :
Dans ce stage il s'agira donc d'étudier l'effet de la température et du champ magnétique sur les propriétés physiques de systèmes complexes. En fonction de l'étude en cours au moment du stage et de l'intérêt du candidat, cette étude pourra porter soit :

- sur l'étude de supraconducteurs non conventionnels. Des oscillations anormales de la chaleur spécifique ont par exemple été prédites dans les systèmes présentant un gap supraconducteur non isotropes, tels les supraconducteurs à hautes température critique. Néanmoins ces oscillations n'ont jamais été observées et cela reste un défi important pour la compréhension de ces systèmes. Nos récents développements instrumentaux nous ont permis d'atteindre une résolution suffisante pour effectuer cette étude qui pourra donc faire l'objet du stage.
- Sur l'étude des transitions électroniques (ou magnétiques) dans les systèmes complexes. La chaleur spécifique est là encore un outil particulièrement puissant et il s'agira dans ce cas d'effectuer une étude détaillée de l'évolution de la topologie de la surface de Fermi afin de mieux comprendre les nouvelles phases électroniques (ou magnétiques) pouvant être induite par le champ magnétique ou la température.

Le stagiaire sera amené à se familiariser avec notre technique de mesure et sera impliqué dans l'ensemble des phases de l'étude : montage des échantillons, cryogénie, prise des mesures, analyse des données et confrontation avec les modèles théoriques (s'ils existent).

Interactions et collaborations éventuelles :
Le stagiaire sera intégré au « groupe supraconducteurs » du département matière condensée et basses températures de l'Institut Néel. Il sera amené à interagir des les différents membres du groupe. Par ailleurs il pourrait être amené à effectuer des mesures en champs magnétiques intenses en collaboration avec nos collègues du LNCMI. Enfin il sera amené à interagir avec nos collaborateurs (notamment slovaques et Suédois) pour les différents aspects instrumentaux.

Ce stage pourra se poursuivre par une thèse : Oui, financement sur le concours de l'école doctorale.

Formation / Compétences : inscrit dans un parcours général en physique de la matière condensée avec une bonne maîtrise des concepts fondamentaux en mécanique quantique et physique du solide.

Période envisagée pour le début du stage : Mars à Juin 2022.

Contact : Thierry Klein et Christophe Marcenat
Institut Néel - CNRS : thierry.klein@neel.cnrs.fr , christophe.marcenat@neel.cnrs.fr
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INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

Propriétés électroniques de systèmes non conventionnels

Cadre général :
Ce stage expérimental s'inscrit dans le cadre de l'étude des propriétés physiques de systèmes corrélés : supraconducteurs non conventionnels, métaux « exotiques » (semi-métaux de Weyl ou en limite ultra quantique), etc… Les effets de corrélation (interactions électrons-électrons) sont en effet un des ingrédients majeurs à l'origine des propriétés *anormales* de la matière condensée et, étudier, analyser, comprendre ces effets est un enjeu majeur de la physique du solide moderne. Le paramètre essentiel gouvernant les propriétés physiques des solides est leur densité d'états au niveau Fermi et dans ce stage il s'agira essentiellement de déterminer ce paramètre avec la plus grande précision, en utilisant pour cela une approche thermodynamique basée sur une technique de mesure de la chaleur spécifique développée au laboratoire dans des conditions extrêmes de température (jusqu'à 0.3K) et de champs magnétiques (jusqu'à 35T).

Sujet exact, moyens disponibles :
Dans ce stage il s'agira donc d'étudier l'effet de la température et du champ magnétique sur les propriétés physiques de systèmes complexes. En fonction de l'étude en cours au moment du stage et de l'intérêt du candidat, cette étude pourra porter soit :

- sur l'étude de supraconducteurs non conventionnels. Des oscillations anormales de la chaleur spécifique ont par exemple été prédites dans les systèmes présentant un gap supraconducteur non isotropes, tels les supraconducteurs à hautes température critique. Néanmoins ces oscillations n'ont jamais été observées et cela reste un défi important pour la compréhension de ces systèmes. Nos récents développements instrumentaux nous ont permis d'atteindre une résolution suffisante pour effectuer cette étude qui pourra donc faire l'objet du stage.
- Sur l'étude des transitions électroniques (ou magnétiques) dans les systèmes complexes. La chaleur spécifique est là encore un outil particulièrement puissant et il s'agira dans ce cas d'effectuer une étude détaillée de l'évolution de la topologie de la surface de Fermi afin de mieux comprendre les nouvelles phases électroniques (ou magnétiques) pouvant être induite par le champ magnétique ou la température.

Le stagiaire sera amené à se familiariser avec notre technique de mesure et sera impliqué dans l'ensemble des phases de l'étude : montage des échantillons, cryogénie, prise des mesures, analyse des données et confrontation avec les modèles théoriques (s'ils existent).

Interactions et collaborations éventuelles :
Le stagiaire sera intégré au « groupe supraconducteurs » du département matière condensée et basses températures de l'Institut Néel. Il sera amené à interagir des les différents membres du groupe. Par ailleurs il pourrait être amené à effectuer des mesures en champs magnétiques intenses en collaboration avec nos collègues du LNCMI. Enfin il sera amené à interagir avec nos collaborateurs (notamment slovaques et Suédois) pour les différents aspects instrumentaux.

Ce stage pourra se poursuivre par une thèse : Oui, financement sur le concours de l'école doctorale.

Formation / Compétences : inscrit dans un parcours général en physique de la matière condensée avec une bonne maîtrise des concepts fondamentaux en mécanique quantique et physique du solide.

Période envisagée pour le début du stage : Mars à Juin 2022.

Contact : Thierry Klein et Christophe Marcenat
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NÉEL INSTITUTE Grenoble
Topic for Master 2 internship – Academic year 2021-2022

Machine learning for magnetism

General Scope : Machine learning methods are new tools whose possibilities reserachers are intensively exploring for new scientific domains over the last 2-3 years.
The knowledge of complex magnetic orders is one of the key point in the domain of multiferroics (systems in which magnetic and electric degrees of freedom are coupled) or spintonics. Indeed the manipulation od such orders is one of the challenges for tomorrow computers (low-energy memories, sensors, 4-bits logic, etc.). Those complex ordres are however difficult to decipher as one not only needs the knowledge of precise effective magnetic ineractions, but also the way they induce long range order.

Research topic and facilities available : Machine learning methods have proven very efficient for the determination of phases diagrams, and long-range orders generated from sets of magnetic effective interactions. However the knowledge of the set of magnetic interactions for a give compound still remains a difficult, time-consuming, task.
The main objective of this intership will be to explore the possibility to predict magnetic interactions using deep learing methods.

This is a theoretical subject aiming at exproring the possibilities offered by a new domain. The student will thus have to learn deep learning methods, but also the physics underlying the effective magnetic interacions in a material and the ab-intio methods able to accurately evaluate them (a package have been recently developped for this purpose in our group). The student will be using national and/or regional supercomputer centers during this intership.

Possible collaboration and networking :
The student should work with our collaborators in DL (from SIMAP, Grenoble), in magnetism and ab-initio calculations (from ILL), as well as quantum chemists from Poitiers University and experimental chemists from Lyon whether this internship will foster a PhD.

Possible extension as a PhD : yes

Required skills: master in Physics, Quantum Chemistry or Computer Science (if the student has a good knowledge of deep learning methods). The knowledges needed for this internship are Quantum Mecanics, Machine Learning and the usage of linux computeurs. As this is a interdisciplinary spectrum, the student will have to learn during the internship the part of these domains she/he is not presently familiar with.

Starting date : anytime in the first part of 2022

Contact :
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INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

Apprentissage automatique pour le magnétisme

Cadre général : Les méthodes d'apprentissage automatique (machine learning) constituent de nouveaux outils dont les scientifiques explorent activement les possibilités depuis 2-3 ans.
La connaissance d'ordres magnétiques complexes est un des points clefs dans le domaine des multiferrïques (systèmes dans lesquels les degrésde liberté électriques et megnétiques sont couplés) ou de la spintronique, et leur manipulation un des enjeux des ordinateurs de demain (mémoires à faible consomation énergétique, senseurs, logiques à 4 bits, supraconductivité à haute température, etc.) . Ces ordres sont cependant difficiles à déterminer il faut non seulement connaître précisément les interactions magnétiques effectives, mais aussi la manière donc celles-ci conduisent à un ordre à longue portée.

Sujet exact, moyens disponibles : Les méthodes d'apprentissage automatique se sont révélées très utiles pour la prédiction des diagrammes de phase et des ordres engendrés par des jeux d'interactions magnétiques connues. Déterminer ce jeu d'interactions pour un matériau déterminé reste cependant une tâche difficile et couteuse en tant humain et en temps de calcul.
L'objectif de ce stage sera de tester les méthodes d'apprentissage automatique pour prédire le jeu d'interactions magnétiques effectives d'un matériau réel.

Il s'agit d'un stage théorique visant à explorer les possibilités d'un nouveau domaine. Pour cela l'étudiant devra se former aux méthodes d'apprentissage automatique, à la physique des interactions magnétiques et au calcul de ces dernières par des méthodes ab-initio (un code a récemment été développé dans le groupe à cet effet). Il utilisera les grands centres de calcul nationaux ou régionaux lorsque nécessaire.

Interactions et collaborations éventuelles :
L'étudiant pourra être amené à travailler avec nos collaborateurs spécialistes d'IA (SIMAP Grenoble), de magnétisme et de calcul ab-initio (ILL), ainsi qu'avec des collègues chimistes de Poitiers et expérimentateurs de Lyon si le stage se continuait en thèse.

Ce stage pourra se poursuivre par une thèse.

Formation / Compétences : master de physique, de chimie théorique ou d'informatique (si l'étudiant a une bonne connaissance des méthodes d'apprentissage automatique). Les connaissances nécessaires sont la mécanique quantique, l'apprentissage automatique et l'utilisation de machines de calcul (linux), Il s'agit d'un spectre assez interdisciplinaire aussi seule une partie de ces connaissances seront demandées à l'étudiant, le stage sera pour lui l'occasion de se former dans les autres domaines.

Période envisagée pour le début du stage : 1er semestre 2022.

Contact : LEPETIT Marie-Bernadette
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NÉEL INSTITUTE Grenoble

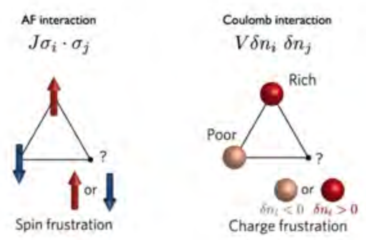
Topic for Master 2 internship – Academic year 2021-2022

Charge frustration as a route to bad metal behavior in correlated electron systems

General Scope:

In condensed matter, *frustration* --- the impossibility to satisfy certain physical constraints imposed to the elementary constituents --- leads to the emergence of original and often complex states: in magnetic systems, for instance, the frustration of spin-spin interactions can lead to spin liquid and spin glass phases, and to the appearance of collective excitations such as magnetic monopoles. In the group we study instead the concept of *charge frustration*, exploring the emergence of new phases and original properties of quantum matter.

Figure: an illustration of the phenomena of spin (left) and charge (right) frustration.



During this internship we intend to tackle an important open question in correlated electron systems: many materials of current interest exhibit a puzzling *bad metal behavior* whose physical origin is still not understood. Our point of view is that such bad metal behavior is caused by emergent low-energy excitations resulting from charge frustration.

Research topic and facilities available:

We propose to study theoretically electronic models with long range Coulomb interactions on low-dimensional lattices. The student will explore the emergence of collective excitations in strongly interacting electron systems and their consequences for charge transport. The models developed to this scope will be analyzed using appropriate many-body approaches, both numerical (exact diagonalization, classical and quantum MonteCarlo simulations) and analytical (perturbation theory in the strong coupling limit, random phase approximation).

The student will have the opportunity of learning important techniques for condensed matter theory, while at the same time getting acquainted with one of the hot topics in current research.

Possible collaboration and networking: University of L'Aquila (Italy), Tallahassee (USA)

Possible extension as a PhD:
YES

Required skills:
Solid basis in condensed matter theory, scientific programming, strong motivation.

Starting date: March 2022

Contact:

Name: Simone Fratini / Arnaud Ralko
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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Erbium doped opto-RF platform for quantum transduction

General Scope :

Rare-earth ions because of their unique 4f electronic configuration form well isolated systems when embedded in solids. They have long coherence time at low temperature making them highly promising qubits for the development of quantum technologies: as solids, they offer perspectives of integration, while keeping atomic properties (narrow lines) when interacting with light (optical or RF). **Erbium** is particularly appealing in this prospect because its optical transition falls in the telecom range, and can naturally be used as a support for optical quantum memories and more generally as a fast and versatile element of control on the qubit. Rare-earth spins also exhibit long coherence times and can be driven efficiently using RF fields. This remarkable combination of optical and spin properties make them ideal for the development of **RF-optical transducers**, and for pushing the performance of optoelectronic devices at the **quantum level**.

Research topic and facilities available :

At Institut Néel, we focus on RF to optical transduction based on a good knowledge of the spin and optical transitions of erbium doped samples which are compatible with the fibered telecom range. Appropriate compound and experimental working conditions (spin and optical transitions of interest, magnetic field orientation, temperature …) still need to be investigated to provide an efficient opto-RF converter. The physical design of the resonator with a prime focus on the RF interaction enhancement is currently under development and will be tested first at moderate **cryogenic temperature (1.5-2K)** to validate the approach before going to ultralow temperature (10-20mK).

During the internship, we propose to focus on an **erbium doped crystal of $CaWO_4$**. Remarkably narrow transitions have been observed for an unexpected orientation of the magnetic field in a symmetry plane of $CaWO_4$. A better understanding of the phenomenon requires advanced **coherent spectroscopy measurements** (optical, RF and a combination of both) and a dedicated decoherence modeling. This **experimental** study will be the basis of an **optimized opto-RF coupling configuration** using this very specific orientation.

Possible collaboration and networking :

- Institut de Recherche de Chimie Paris
- Service de physique de l'état condensé (CEA-Saclay)

Possible extension as a PhD : Yes

Required skills:

Experimental skills in one the domains are highly recommended : optics, laser, atomic spectroscopy, magnetic resonance

Education background in quantum physics and general optics, non-linear optics or light-matter interaction in the optical or RF domain (Electron Paramagnetic Resonance or Nuclear Magnetic Resonance) is demanded.

Starting date : Spring-Summer 2022

Contact :

Name : Thierry Chanelière
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More information : http://neel.cnrs.fr

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Cathodoluminescence-based nano-thermometry

General Scope:

The performance optimization of optoelectronic devices requires a precise knowledge of the semiconductor materials properties at the nanoscale. If temperature is one of the most basic parameters influencing any physical or chemical process, the traditional strategies to measure temperature cannot easily be applied to the nanoscale. Among the different solutions, temperature dependent luminescence properties of nano-diamonds have proven to be good contact-free temperature sensors, with a resolution only limited by the light diffraction. This technique allows to reach a spatial resolution of 500 nm at best.

Research topic and facilities available:

In this context, the aim of this internship is to combine electron and optical microscopy techniques to develop the next generation of temperature nano-sensing (expected spatial resolution: 50 nm).

Indeed, thanks to their reduced wavelength, fast electrons can be used as a highly localized excitation source for luminescence measurements. This technique is called cathodoluminescence (CL) spectroscopy. At Néel, you will benefit from a dedicated, state-of-the-art CL setup combining cryogenic temperatures (4 K-300 K), fast electronics (50 ps) and optical access.

During his/her internship, the student will start by probing the optical properties of nano-diamonds as a function of temperature and monitor the nanoprobe emission characteristics (energy shifts, carrier lifetime...) as a function of the temperature. The developed method will find practical applications as a new tool to investigate nanoscale heat transfer, a process of not only fundamental interest but also technological importance.

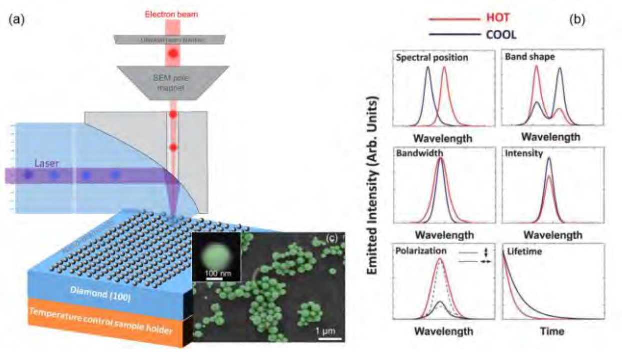

Figure 1. (a) Schematic of the experimental setup coupling electron and light excitation. (b) Schematic representation of the possible effects caused by a temperature increment on the luminescence

Possible collaboration and networking: This research is carried out at Institut Néel, in collaboration with other researchers from the laboratory and from other laboratories (CEA-IRIG, EPFL…)

Possible extension as a PhD: Possibility of continuation as a PhD on the same subject with funding already secured

Required skills: the candidate should have a master 2 in Nanosciences or equivalent, with a marked interest in experimental physics and optics.

Starting date: Flexible, from January to April 2022

Contact : Gwénolé JACOPIN
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More information : http://neel.cnrs.fr

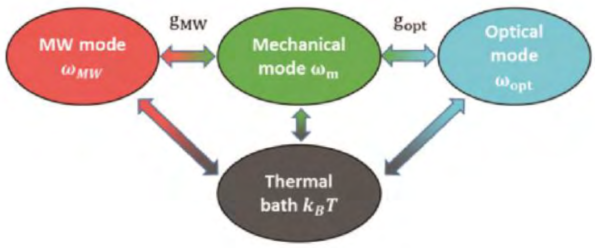
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Microwave to optical conversion for quantum networks

General Scope :
The most promising solid-state implementations of qubits today, *i.e.* superconducting or spin qubits, have typical energy scales corresponding to microwave frequencies of order 10GHz. However, microwave frequency photons are difficult to transmit over long distances without large losses. Typical attenuation in low-loss microwave cables at 10GHz is more than 1 dB.m^{-1}, which compares very poorly with optical fibres with losses below 0.2 dB.km^{-1} at telecom wavelengths ($\lambda \approx 1550$ nm, f $\approx$ 193 THz). In today's classical communication technologies too, the information is processed electronically at MW frequencies and distributed over long distances via optical fibers. In both cases, converters from one frequency range to the other are then required. For classical electronics, the efficiency of the converter is not a limiting issue but for quantum signals, it would destroy any superposition of states. This is why an optical to microwave converter able to conserve quantum signals would be very useful for future quantum networks.

Research topic and facilities available:
In this project, we will develop such a converter using a nanoelectromechanical system (NEMS) as the intermediate between microwaves and optics (see figure). The idea is that it is possible to have a very strong interaction between microwaves/optics and a NEMS and it thus appears as the ideal mediating system for the conversion. The samples are produced by our colleagues at CEA-LETI on a semi-industrial platform. In Néel, we will perform experiments at very low temperatures (20mK). Initially, and this will be the goal of the internship, we will focus on the microwave-NEMS part and demonstrate the cooldown of the NEMS in its ground state using superconducting microwave circuits.



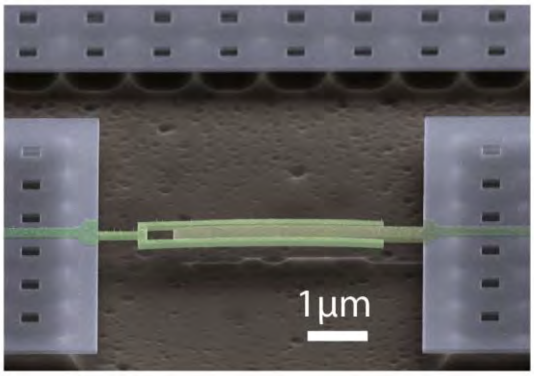


Figure 1: Scheme of the conversion process. A mechanical mode (NEMS) couples the optical and microwaves (MW) modes (coupling terms g_{MW} and g_{opt}). All modes are coupled to a common thermal bath. On the right, a scanning electron microscope image of a fabricated device with a suspended NEMS integrated with a superconducting microwave circuit (green).

Possible collaboration and networking : The student will interact with the other partners of the project: CEA Leti and the LMPQ lab in Paris.
Possible extension as a PhD : Yes
Required skills: The internship (and the PhD thesis) will require a solid background in solid state/condensed matter physics. The work will be mainly experimental. The candidate is expected to be strongly motivated to learn the associated techniques (radiofrequency electronics, optics, cryogenics...) and engage in a hands-on experimental work.
Starting date : March 2022 (flexible)
Contact :
Name: Julien Renard and Nicolas Roch Institut Néel - CNRS
Phone: 0456387176 e-mail: julien.renard@neel.cnrs.fr nicolas.roch@neel.cnrs.fr
More information : http://neel.cnrs.fr

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Graphene based superconducting quantum circuits

General Scope :
The recent progresses in reproducible fabrication and understanding of quantum systems have brought us to the following situation: it is now possible to build devices that not only present quantum properties but in which quantum states can be initialized, manipulated and readout. The building blocks of quantum circuits are quantum bits and quantum limited amplifiers. Superconducting circuits is the most advanced platform in this context and it has reached several key milestones in the realization of a quantum computer. Despite such celebrated successes, other platforms are studied in order to gain flexibility and compatibility with current semiconductor technologies. In particular, hybrid platforms that couple superconducting and semiconducting properties are expected to bring a decisive advantage by allowing electrical control of the system.

Research topic and facilities available :
In this internship, we will bring electrical tuning at the core of superconducting circuits by introducing a gapless semiconductor graphene, in the key element: the Josephson junction (see Figure). With such electrically tunable Josephson element, we can build the building blocks for a quantum platform: quantum bits and Josephson parametric amplifiers. In the team we have already demonstrated the fabrication of such graphene based Josephson junctions and their use in quantum circuits. The next step, which is the goal of this work is to demonstrate that it can have functionalities and performances to be competitive with other platforms.
A one atom-thick sheet of graphene will thus have to be integrated into superconducting circuits using nanofabrication techniques available at the Institute. Such sample will then be measured at very low temperature (20mK) in a dilution refrigerator using radiofrequency (1-10 GHz) techniques. Measurements will be carried out to extract the figure of merit of the devices: lifetime of the Qubit, noise of the amplifier...

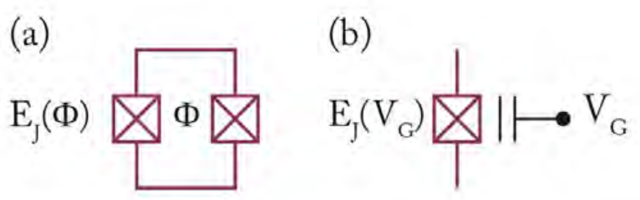


Figure 1: tunability of the Josephson energy E_J in standard Josephson junctions necessitates a loop geometry and a magnetic flux Φ (a). The introduction of a semiconductor allows simple electrical gating with a gate voltage V_G (b). This is the essence of the project.

Possible collaboration and networking : The student will be part of the Hybrid team, which has a multidisciplinary expertise (growth, nanofabrication, electronic transport, spectroscopy...). The team has also several external collaborations worldwide (France, Switzerland, Germany, Canada).
Possible extension as a PhD : Yes
Required skills: The internship (and the PhD thesis) will require a solid background in solid state/condensed matter physics. The work will be mainly experimental. The candidate is expected to be strongly motivated to learn the associated techniques (nanofabrication in clean room, radiofrequency electronics, cryogenics...) and engage in a hands-on experimental work.
Starting date : March 2022 (flexible)

Contact :
Name: Julien Renard Institut Néel - CNRS
Phone: 0456387176 e-mail: julien.renard@neel.cnrs.fr http://perso.neel.cnrs.fr/julien.renard/

More information : http://neel.cnrs.fr

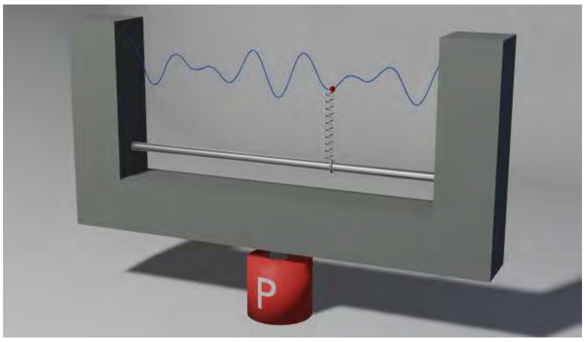
INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

Quantum foundations : the wave-particle duality on a vibrating string

General Scope :

Quantum mechanics is well known for its apparent weirdness. But at the beginning of quantum history, the likes of Einstein, de Broglie, and later Bohm tried to decipher the meaning behind it through the use of classical analogies and mechanisms that were well understood at the time. The aim of our approach is to venture back to this lost realm of clarity in classical physics without renouncing the great achievements of modern quantum mechanics. Works by de Broglie, Bohm, and Einstein will serve as a foundation to study how some (if not all) quantum effects can be experimentally reproduced using adequately locked and fine-tuned mechanical oscillators interacting within a wavy background.



Using classical systems, either oscillating bubbles moved by and within an acoustic field or (in one dimension) a spring-mass particle moved along a vibrating string by the resulting radiation force,we address fundamental issues such as the **wave-particle duality , non-locality and the emergence of of gravitational forces**.

Figure 1: Sketch of the masslet-spring system as proposed in [1]

This approach is based on the crucial role played by the fluctuations of the vacuum energy and its decisive role in key experiments exemplified by the **Casimir effect (see our acoustic Casimir effect proposal for more info.)**An isotropic and random acoustic band-pass noise can indeed be used to mimic the vacuum fluctuations and its associated effects. The main advantage of this setup lies in its flexibility: the sound can be fine-tuned to a certain spectrum, turned on or off (unlike the real Zero Point Field), and can of course be probed, thereby allowing us to address very exciting questions.

As we have recently shown [1], a mass-spring moving along a vibrating string can represent, for some weel-chosen specific conditions a classical analog of a quantum wave-particle object. Furthermore, an acoustic bubble could represent a 3D extension of the masslet on a string,achieving a 3D quantum behaviour, in the spirit of recent works with droplets bouncing on a two-dimentionnal bath and inducing a macroscopic wave-particle duality [2].Ultimately, we are interested in possibly achieving a classical analog of a quantum entanglement and observing non local correlations.

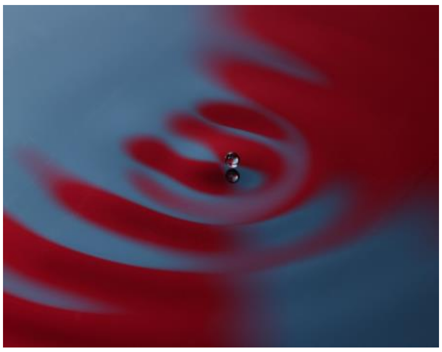


Figure: An oil droplet bouncing on a vibrating bath, generating and interacting with its own wave(see for example: [2] J.W. M. Bush, Annu. Rev. Fluid. Mech. **47**, 269-92 (2015))

INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

The goal of the intership is to work on this subject by a joint theoretical and numerical approach. A Python code was recently developped to simulate various behaviours for the masslet on a string. The objective is to study in more details the quantum regime as well as to start developing the Python code for the 3D case.

Research topic and facilities available :

This work is led within the Nano Optic and Force (NOF) team of Néel institue, see https://neel.cnrs.fr/equipes-poles-et-services/nano-optique-et-forces-nof for more information.

Possible extension as a PhD :

The PhD position will be open in Autumn 2022 and motivated applicants should contact us in advance for further discussions.

Req**uired skills:**

Applicants must have a solid background in physics and mathematics as well as a very god knowledge of the Python langage.

Starting date : January 2022

Contact :
Cedric POULAIN
Institut Néel - CNRS
Phone : 04 76 88 74 30 e-mail : cedric.poulain@neel.cnrs.fr

More information : http://neel.cnrs.fr and

[1] A. Drezet *et al*, Phys. Rev. E. **102**, 052206 (2020) at:

https://journals.aps.org/pre/abstract/10.1103/PhysRevE.102.052206

[2] J.W. M. Bush, Annu. Rev. Fluid. Mech. **47**, 269-92 (2015))

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Acoustic analog of a quantum effect: the Casimir force

General Context:
In 1948, Hendrik Casimir predicted that quantum fluctuations of the vacuum, so-called zero-point fluctuations, could give rise to an attractive force between objects. Casimir's calculations were idealized - he considered two perfectly conducting parallel mirrors facing each other in the vacuum at absolute-zero temperature. Since then, this prediction has been confirmed experimentally but many questions remain, among which the possibility of achieving a repulsive Casimir force. Although the Casimir effect is deeply rooted in the quantum theory of electrodynamics, there are analogous effects in classical physics. A striking example was discussed in 1836, in P. C. Caussée's L'Album du Marin (The Album of the Mariner). Caussée reported a mysteriously strong attractive force that can arise between two ships floating side by side — a force that can lead to disastrous consequences (Boersma, 1996: see Figures 1 and 3). A physical explanation for this force was offered only recently by Boersma, who suggested that it originates in the radiation pressure force of water waves acting differently on the opposite sides of the ships. Analogous arguments can be employed for the Casimir effect itself by invoking a deficit of virtual photon modes of the vacuum between mirrors.

Fig. 1. Two ships roll heavily on a long swell and there is no more wind to damp their rolling. In this situation a strange force, "une certaine force attractive," will pull the two ships toward each other. From P. C. Caussée: "the Mariners Album," early 19th century.

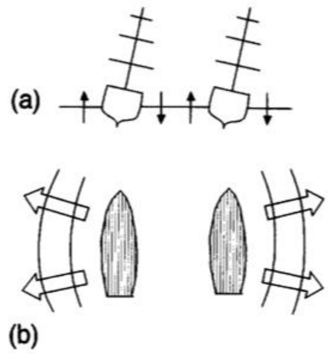


Fig. 3. (a) Two ships at close quarters roll on a long swell. (b) They re-emit the absorbed power as secondary waves.

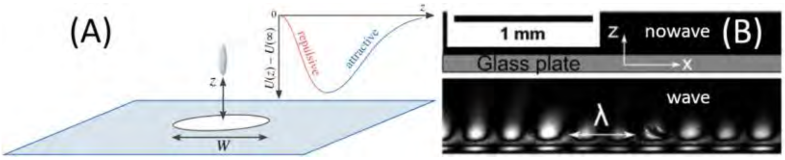
Historically, the Casimir effect was long considered to be an exotic quantum phenomenon, but now it is starting to take on technological importance. Because of its relatively short range, it has only a very small effect on the dynamics of macroscopic mechanical systems. But the Casimir force plays a major role in modern micro and nanoelectromechanical systems (MEMS and NEMS), where the distances between neighboring surfaces are typically far less than 1 μm. In tiny devices such as these, the Casimir force can cause mechanical elements to collapse onto nearby surfaces, resulting in permanent adhesion - an effect called 'stiction', which often proves to be an important factor in the malfunction of NEMS.

Yet the Casimir force can also be repulsive when modifying the properties of the mirrors.
In recent years, several groups have tried to observe such repulsive forces.
One interesting proposal consists of an elongated object floating above a hole in a plate (Levin, 2010: see Fig.1 (A)), but the acting force has not yet been measured.

Indeed, experimental progress is limited by very severe conditions required by the observation of very tiny effects (the typical Casimir pressure is 10^20 weaker than the atmospheric pressure).

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022



(A) Typical configuration of Casimir repulsive: an object facing a micro-hole. The associated force-distance curve is shown. (extract from [1]). (B) Evanescent acoustic field in the vicinity of a non-pierced plate, obtained via Schlieren imaging.

Subject, available means:

In this thesis, we propose to address the Casimir effect with a hydrodynamic approach based on an acoustical analog of the quantum vacuum. Experimentally, an isotropic random acoustic noise in a liquid is used to mimic the quantum fluctuations of the vacuum Zero-point field (ZPF). The advantages of using an analog approach are manyfold: (i) fluctuation spectra can be fine-tuned and shaped at will to match that of the quantum, (ii) the orders of magnitude of the length-scales and forces are larger than their quantum counterparts, (iii) the experiments do not require heavy instrumentation (when compared with cryogenic and vacuum conditions) and (iv) most parameters can therefore easily be varied, allowing for quick exploration of any effect. Most importantly, the (acoustic) field itself can be probed and even imaged, unlike the vacuum field.

At the lab, two promising experiments have recently been set up. The first is the acoustic version of the historical configuration proposed by Casimir, where two acoustic mirrors are immersed in a fluid insonified by ultrasound radiation and an attractive force arises from the difference in acoustic radiation pressures. The second acoustic setup is the pierced hole configuration described above which aims to achieve a repulsive Casimir force and consequently quantum levitation.
During this training period one of both setups will be very carefully examined, both experimentally and theoretically, and confronted with the quantum Casimir experiments running in our lab.
Finally, and probably more for a doctoral pursuit, the ultimate possibility of achieving a Casimir torque effect (by means of either quantum or acoustic chiral structures) will be addressed.

Required skills:

The M2 candidate must have a solid background in physics and maths. A large and healthy dose of curiosity will be appreciated.

Research topic and facilities available :

This work is led within the Nano Optic and Force (NOF) team of Néel institue,
see https://neel.cnrs.fr/equipes-poles-et-services/nano-optique-et-forces-nof for more information.

Possible extension as a PhD :

A PhD position will be open in Autumn 2022 and motivated applicants should contact us in advance for further discussions.

Starting date :
January 2022

Contact :

Cedric POULAIN
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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Solid-State Electronic Flying Qubits

General Scope: Coherent manipulation of single electrons in solid-state devices is attractive for quantum information purposes because they have a high potential for scalability. Depending on the system used, the charge or the spin may code binary qubit information. A particular appealing idea is to use a single flying electron itself as the conveyor of quantum information. Such electronic flying qubits allow performing quantum operations on qubits while they are being coherently transferred. Information processing typically takes place in the nodes of the quantum network on locally controlled qubits, but quantum networking would require flying qubits to exchange information from one location to another. It is therefore of prime interest to develop ways of transferring information from one node to the other. The availability of flying qubits would enable the possibility to develop new non-local architectures for quantum computing with possibly cheaper hardware overhead than e.g. surface codes.

Research topic: The aim of the proposed M2 internship is to participate in the development of an original flying qubit architecture using ultra-short single-electron charge pulses. In order to generate such ultra-short electron wave packets, we will leverage on the progress made on THz photon production and use photon to electron conversion devices to engineer THz electronic charge pulses that can be used in quantum nanoelectronics. Such single electron wave packets are injected into a quantum interferometer to realize the first electronic flying qubit.

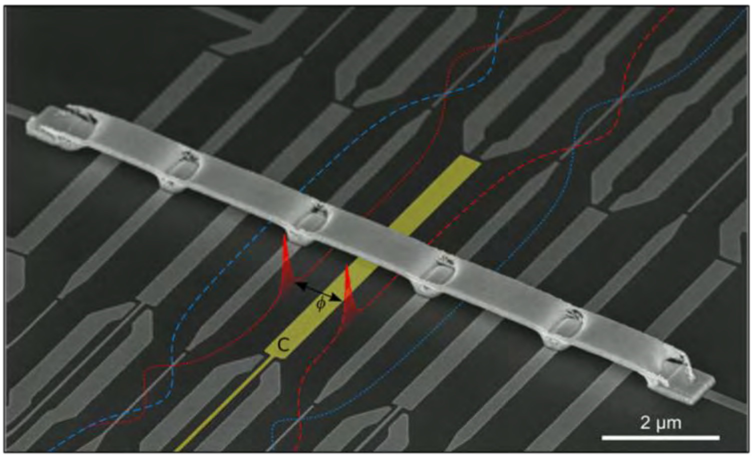

Fig. 1. Scanning electron microscopy image of a multi-qubit flying electron architecture. The image shows four quantum interferometers that can be simultaneously operated owing to a common bridge that connects the islands of each device. The dashed lines schematically indicate the paths of two single-electron wave packets in two neighboring interferometers. The intermediate gate C (highlighted in yellow) allows for controlled Coulomb coupling of the single-electron wave packet and thus in-flight entanglement.

References:

- Roussely et al., Nature Com. **9**, 2811 (2018), Bäuerle et al., Rep. Prog. Phys. **81,** 056503 (2018), Takada et al., Nature Communications **10**, 4557 (2019), Edlbauer et al., Applied Phys. Lett., in print.

Possible collaboration and networking: This project is realized in close collaboration with the nanoelectronics group in Saclay (C. Glattli), the THz laboratory of the Université de Savoie Mont-Blanc (J.F. Roux), the theory group of CEA Grenoble (X. Waintal) as well as the Quantum Metrology group (AIST), Tsukuba, Japan (S. Takada) & the Quantum Device group, RIKEN, Japan (M. Yamamoto)

Possible extension as a PhD: we are looking for a candidate who is motivated to pursue the M2 internship towards a PhD; (PhD fellowship is available)

Required skills:
The candidate should have a good background in quantum mechanics and solid-state physics.

Starting date: preferentially spring 2022 (negotiable)

Contact:

BAUERLE Christopher
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web: http://neel.cnrs.fr
https://neel.cnrs.fr/les-chercheurs-et-techniciens/christopher-bauerle

NÉEL institut

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Unconventional magnetism and new spin excitations in honeycomb-lattice materials

General Scope :

The Kitaev model [1] has been recently proposed to realize a new state of matter, the quantum spin liquid [2,3], which definition goes beyond the conventional Landau formalism. This magnetic state is characterized by a correlated disorder, i.e. the absence of a long-range magnetic order down to T = 0K but the persistence of strong correlations between spins. For the first time, the Kitaev model proposes a solution for realizing a quantum spin liquid in a 2D system with a honeycomb lattice, and provides an exact theoretical framework to describe this system. Furthermore, the excitations associated to this quantum spin liquid display particular statistic properties that are currently generating a lot of interest for applications in quantum computation.

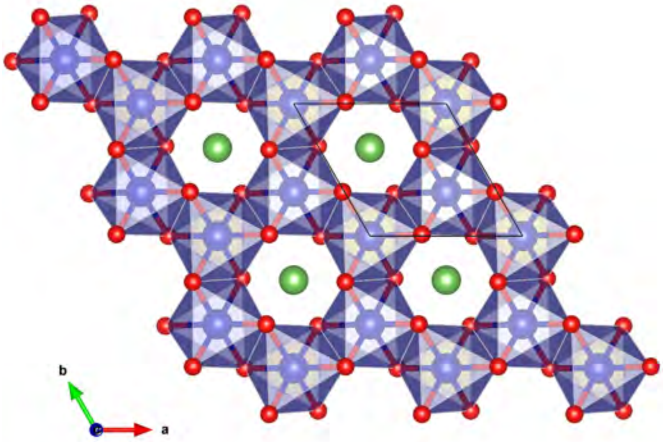

Fig.1 : The honeycomb lattice formed by the magnetic ions represented in blue ($BaCo_2(AsO_4)_2$ compound).

Research topic and facilities available :

It was recently suggested that this theoretical model can be experimentally realized in materials in which the magnetic ions host a large spin-orbit coupling and form a 2D honeycomb lattice. The goal of this internship is to study the structural and magnetic properties of a family of honeycomb-lattice compounds and check if these compounds display the necessary features to realize the Kitaev model.

The student will perform the physical characterization (magnetization, specific heat measurements) using the equipments available at Institut Néel, as well as complementary measurements using optical spectroscopy techniques (infra-red, THz, Raman) to study the dynamical properties of the compounds.

Possible collaboration and networking :

The student will interact with several technical groups and platforms (crystal synthesis, magnetometry platform, X-ray diffraction) and the researchers from the MagSup group. He/She will be able to attend scientific seminars that are regularly organized in the institute.

Possible extension as a PhD : yes (funding already available)

Required skills: solid knowledge in solid state physics and magnetism

Starting date : Spring 2022

Contact : Manila SONGVILAY / Sophie DE BRION / Virginie SIMONET
Institut Néel - CNRS : manila.songvilay@neel.cnrs.fr, sophie.debrion@neel.cnrs.fr, virginie.simonet@neel.cnrs.fr
More information: http://neel.cnrs.fr

[1] A. Kitaev, *Anyons in an exactly solved model and beyond*, Annals of Physics **321**, pp2-111 (2006)
[2] M. Mourigal, *The two faces of a magnetic honeycomb,* Nature **554**, pp 307-308 (2018)
[3] F. Alet, *Exotic quantum phases and phase transitions in correlated matter,* Physica A **369**, pp122-142 (2006)

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Theoretical investigation of novel nickelate superconductors

General Scope

The discovery of superconductivity in nickelates has led to one of the most active topics of research in condensed matter physics in the last two years (see e.g. [1]). These systems open new exciting perspectives to eventually understand the challenge of unconventional superconductivity.

The goal of the internship is the theoretical investigation of novel nickelate superconductors by means of first principles calculations (density functional theory). These calculations will be oriented towards the subsequent incorporation of many-body effects (electronic correlations), which are believed to play a key role in the physics of these unconventional superconductors.

[1] Nickelate superconductors: an ongoing dialog between theory and experiments A. S. Botana, F. Bernardini, and A. Cano, JETP 159, 711 (2021); arXiv:2012.02764

Research topic and facilities available

The internship will be carried out at the Condensed Matter Theory (TMC) group at Institut NEEL. The available facilities include a HPC local cluster for the numerical calculations.

Possible collaboration and networking

The internship will be carried out in the framework of an ongoing national and international collaboration that includes theoreticians from U. Cagliari (Italy) and U. Arizona (USA) and experimentalists (Institut NEEL & ICMCB, CNRS Bordeaux).

Possible extension as a PhD

Yes

Required skills

Theory. Solid state physics. Numerical calculations. Quantum field theory is a plus.

Starting date 1/02/2021 (tentative)

Contact
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More information : http://neel.cnrs.fr

INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

Convection, Turbulence et Chauffage interne (expérimental)

Cadre général :

Les fluides confinés par des parois de températures différentes sont sujets à la convection naturelle. La convection apparaît aussi quand le chauffage est réparti dans sa masse du fluide : on parle alors de convection par *chauffage interne*.

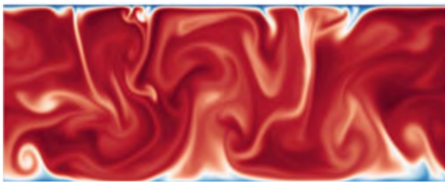


Figure 1 . Simulations de convection par chauffage interne (credit : D. Goluskin)

Un chauffage interne peut être d'origine radiative (dans la couche superficielle de l'océan, dans des lacs froids, dans l'atmosphère de Vénus,,..), nucléaire (magma terrestre, réacteur de centrale,...), chimique (batteries liquides, …), etc.

La convection par chauffage interne est très mal connue lorsque l'écoulement devient turbulent, les dispositifs expérimentaux étant rares et les simulations numériques très gourmandes. Grâce à un dispositif expérimental original exploitant les propriétés extrêmes de l'hélium à très basses températures, nous souhaitons explorer la limite asymptotique (très haut nombre de Rayleigh) de la convection turbulente induite par un chauffage interne.

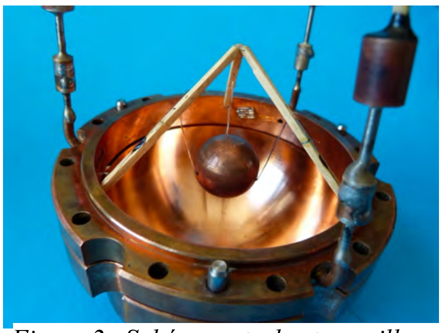


Figure 2 . Sphére centrale et coquille inférieure d'une cellule de convection sphérique

Sujet exact, moyens disponibles :

La turbulence produite par chauffage interne sera caractérisée par sa capacité à transporter la chaleur en géométrie sphérique. La plage de chauffage interne sera la plus étendue possible afin de mettre en évidence d'éventuelles lois de puissance.

Un dispositif expérimental a été fabriqué et partiellement testé. Dans le cadre du stage, il reste à l'assembler, l'instrumenter et mener des premières mesures dans un cryostat à hélium liquide.

Poursuite en thèse :
Le stage pourra se poursuivre par une thèse. Le sujet restera une étude de la convection turbulente à dominante expérimentale, mais il sera plus spécifiquement ciblé sur un enjeu en lien direct ou indirect avec la thématique du changement climatique et/ou de ses conséquences.

Formation / Compétences :

Compétence attendue de l'étudiant:	formation générale en physique
Formation/initiation proposée durant le stage:	convection, physique des basses températures, mesures bas-bruit, instrumentation,

Période envisagée pour le début du stage : 2022

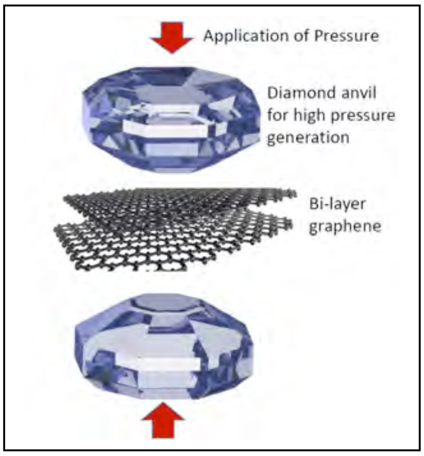
Contact : Philippe Roche, Institut Néel – CNRS/ UGA, per@neel.cnrs.fr   http://hydro.cnrs.me
Pour candidater : merci d'envoyer un bref CV + date du stage (lettre de motivation inutile).

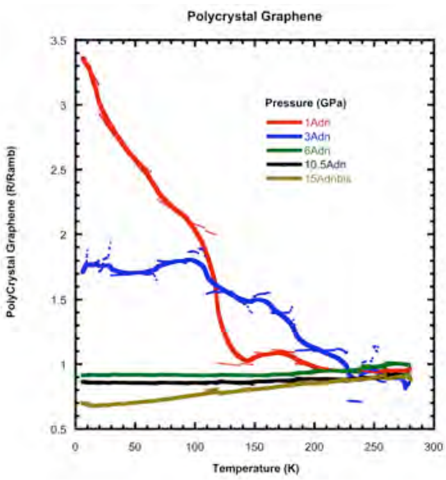
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Search for superconductivity under pressure in mono and bi-layer graphene

General Scope:
The multiplication of the studies on graphene have resulted in a large number of the new applications. However, very few experimental studies have been performed on his electronic properties under pressure. Certainly, few changes are expected under pressure on the graphene mono-layer as it is extremely hard in the basal plane. However, in our preliminary measurements shown in the figure, it is clear that the resistance of the graphene sample changes enormously under pressure due to doping effects. We intend to optimize this doping under pressure to over-dope single layer graphene and attain the level where it has been predicted to be a chiral superconductor [Nature Phys. 8 (2012) 158]. Furthermore, the physics of bi-layers under pressure is certainly very rich. For example, two graphene monolayers, stacked in a Moiré pattern by a small angle rotation, have been recently shown to be superconducting at low temperatures [Nature 556(2018)43]. We plan to study the effect of pressure on the Tc of Moiré bilayers. Finally, Van-der-Waals bonding between two layers of graphene is weak and should be sensitive to pressure, that will deform a bi-layer of graphene towards a diamond symmetry. Theoretical calculations have predicted these structures to be superconductors [PRL 111(2013)066804].





Research topic and facilities available:
The subject of the internship will consist in a first stage in the adaptation, for its assembly in the high-pressure cells, of the graphene single and double layer samples, synthesized in collaboration with L. Marty of the HYBRID Team. The student will thus acquire a solid experience in nanofabrication. He will proceed then to make transport measurements as a function of temperature down to 1K in both piston-cylinder systems (P<2GPa; with P. Rodière, MagSup team) and in Bridgman cells (<30GPa; with M. Nunez-Regueiro and M-A. Measson MagSup Team). These measurements will enrich his knowledge of electronic properties of two-dimensional materials.

Possible collaboration and networking:
Networking: ANR projet obtained in 2019. Teams of the Néel Institute, Institut Lumière Matière (Lyon), Sorbonne University (Paris).
Possible extension as a PhD: YES
Required skills: Good knowledge of condensed matter physics, curiosity, taste for delicate experiments
Starting date:march-april 2022
Contact: Name: Manuel Núñez-Regueiro
Institut Néel - CNRS
e-mail: nunez@neel.cnrs.fr
More information: http://neel.cnrs.fr

INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

Monopoles magnétiques et propriétés hors-équilibre des glaces de spins

Cadre général :

En présence d'énergies en compétition, la matière s'adapte en stabilisant de nouveaux états. En magnétisme, la compétition entre les interactions peut créer des états magnétiques différents des états ferromagnétiques et antiferromagnétiques conventionnels, et qui restent désordonnés jusqu'à la limite de la température nulle. La physique hors-équilibre de tels états à basse température peut être encore plus exotique, même s'il est difficile d'y accéder expérimentalement.

Fig. 1: Echantillon de $Dy_2Ti_2O_7$.

La "glace" de spins est un de ces états. Son état fondamental, gouverné par des règles locales, est dégénéré, et ses excitations sont décrites comme des quasiparticules magnétiques chargées, appelées monopoles magnétiques. Cet état est réalisé dans les composés pyrochlores (=réseau de tétraèdres à sommets partagés) $Dy_2Ti_2O_7$ (Fig. 1) et $Ho_2Ti_2O_7$ en-dessous de 2 K environ.

A très basse température, dans le régime glace de spins (en-dessous de 500 mK), la densité à l'équilibre des monopoles magnétiques tend vers zéro. Le système entre alors dans un état hors-équilibre où la dynamique est pilotée par le déplacement des monopoles (Fig. 2). Nous avons pu montrer que, en piégeant une grande densité de monopoles à basse température, la dynamique est significativement modifiée [2]. Néanmoins, la nature de l'état hors-équilibe reste mal compris.

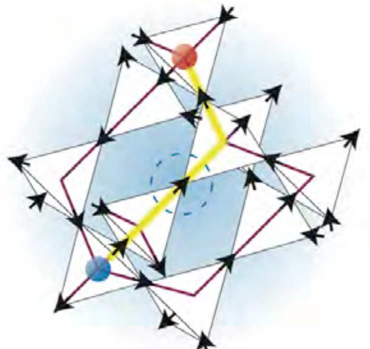


Fig. 2: Glace de spins (flèches noires) sur un réseau pyrochlore avec 2 monopoles magnétiques se déplaçant (sphères rouge / bleue). D'après Moessner, Nature Phys. 5 (2009).

Nous avons récemment développé un dispositif capable de mesurer les fluctuations magnétiques et la susceptibilité ac jusque 100 mK, ce qui permet de tester la relation fluctuation-dissipation et donc de sonder directement l'état hors-équilibre des glaces de spins. Nos résultats préliminaires sont extrêmement prometteurs.

[1] pour une courte introduction: Science **326**, 375 (2009), arXiv: 1005.3557
[2] C. Paulsen *et al.*, Nature Physics **10**, 135 (2014); Nature Physics **12**, 661 (2016); Nature Comm. **10**, 1509 (2019)

Sujet exact, moyens disponibles :

L'objectif du stage est de mesurer le bruit magnétique et la susceptibilité ac dans deux échantillons glaces de spins, $Dy_2Ti_2O_7$ et $Ho_2Ti_2O_7$, et ce en fonction de la température et de la fréquence, avec différents protocoles expérimentaux permettant de varier la densité de monopoles. A partir de ces mesures, l'étudiant pourra déterminer la relation fluctuation-dissipation, et la comparer avec les prédictions théoriques.

Les expériences seront réalisées avec le dispositif de mesure de bruit magnétique récemment développé dans l'équipe et fonctionnant jusque 100 mK grâce à un réfrigétaeur à dilution He^3-He^4.

Interactions et collaborations éventuelles : : S. T. Bramwell et S. R. Giblin (UK), avec le soutien théorique de P. C. W. Holdsworth (ENS Lyon).

Ce stage pourra se poursuivre par une thèse.

Formation / Compétences : Master 2 de Physique

Période envisagée pour le début du stage : à partir de début 2022

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Magnetic monopoles and out-of-equilibrium properties of spin ice

General Scope :

In the presence of competing energies, matter tries to adapt by stabilizing novel states. In magnetism, the competition between magnetic interactions can create magnetic states different from conventional ferromagnetic or antiferromagnetic ordered states, and which remain disordered down to the limit of absolute zero of temperature. The far-from-equilibrium physics of such low temperature states may be even more exotic, yet to access it in the laboratory remains a challenge.

Fig. 1: A $Dy_2Ti_2O_7$ spin ice sample.

"Spin ice" is an example of such a state where the magnetism is governed by local rules giving rise to a ground state degeneracy, and whose excitations can be described as magnetically charged quasiparticles, called magnetic monopoles [1]. It is realized in pyrochlore (=corner sharing tetrahedron lattice) compounds $Dy_2Ti_2O_7$ (Fig. 1) and $Ho_2Ti_2O_7$ below about 2 K.

At very low temperature, deep in the spin ice regime (below 500 mK), the equilibirum density of magnetic monopoles tends towards zero. The system enters an out-of-equilibrium regime where the dynamics are governed by the motion of monopoles (Fig. 2). In particular, we have shown that quenching a high density of monopoles at low temperature significantly modifies the dynamics [2]. Nevertheless, the nature of the out-of-equilibrium state is poorly understood.

We have recently developed a set-up able to measure the magnetic fluctuations and the ac susceptibility down to 100 mK, which allows us to test the fluctuation-dissipation relation, and thus to directly probe the out-of-equilibrium state of spin ice. Our preliminary measurements are extremely promising.

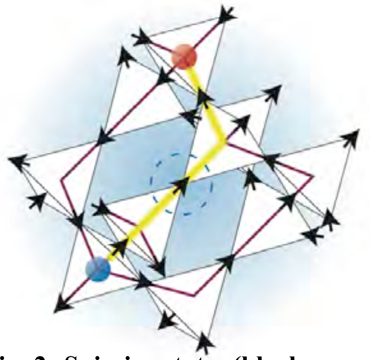

Fig. 2: Spin ice state (black arrows) on a pyrochlore lattice with 2 magnetic monopoles moving around (red / blue spheres). From Moessner, Nature Phys. 5 (2009).

[1] for a brief introduction see Science **326**, 375 (2009), arXiv: 1005.3557

[2] C. Paulsen *et al.*, Nature Physics **10**, 135 (2014); Nature Physics **12**, 661 (2016); Nature Comm. **10**, 1509 (2019)

Research topic and facilities available :

The objective of the internship is to measure the magnetic noise and the ac susceptibility of two spin ice samples $Dy_2Ti_2O_7$ and $Ho_2Ti_2O_7$ as a function of temperature and frequency, using different experimental protocols in order to vary the density of monopoles. From these measurements, the student will determine the fluctuation-dissipation relation, and compare it with theoretical predictions.

Experiments will be performed using the magnetic noise set-up recently developed in the team and equipped with a He^3-He^4 dilution refrigerator to reach subKelvin temperatures.

Possible collaboration and networking : S. T. Bramwell and S. R. Giblin (UK), with the theoretical support of P. C. W. Holdsworth (ENS Lyon).

Possible extension as a PhD : yes

Required skills: Master 2 in Physics

Starting date : from the beginning of 2022

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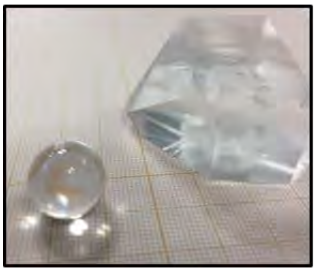
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Evolution of the equilibrium morphology of KH_2PO_4 crystals at different growth conditions

General Scope:
Single crystals, such as KH_2PO_4 (fig. 1a), are central to many fields of science and industry. From all the techniques used to obtain them, growth from solution remains one of the most efficient synthesis route for synthetic crystalline solids in research laboratories and in the related industry. In solution crystals are grown by lowering the temperature and develops flat faces (morphology), so the driving force is the resulting supersaturation in the solution. Depending on several experimental conditions (T, T lowering rate, pH, ...), this morphology can change because growth mechanisms are modified (fig. 1b). Being able to determine the changes in morphology and the growth mechanism for different experimental conditions will lead to a better understanding and an optimization of the crystal growth process.



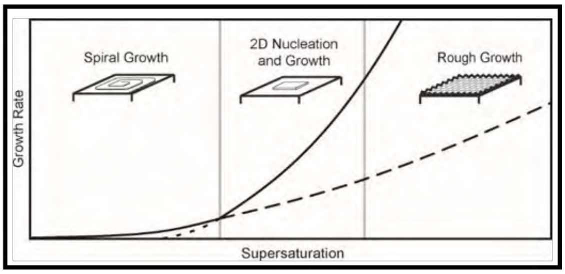


Figure 1: a) KH_2PO_4 bulk crystal and sphere shaped sample obtained from that crystal and b) growth mechanism as a function of supersaturation.

Research topic and facilities available:
The main objective of this internship is to determine the effect of experimental parameters (supersaturation, temperature, crystallization medium and solution viscosity, …) on the crystal habit and morphology and also on the nucleation and growth kinetics. The internship will be made in collaboration between two research laboratories. The experiments concerning low supersaturation conditions will be performed at *Néel Institute* (Grenoble) in an original growth cell and the ones concerning high supersaturation will be performed at *CINaM* (Marseille) in a μ-droplet-based microfluidic platform. All the obtained results will be part of the data that will be used to develop a numerical model able to predict the growth shapes of crystals.

Possible collaboration and networking: Laboratoire de Physique de la Matière Condensée (Paris, France)

Possible extension as a PhD: Possible if any financial support is found.

Required skills: Strong interest in materials science and experimental work is needed. Skills in crystal growth will be appreciate.

Starting date: February/March 2022

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Theory of non-perturbative quantum circuits

General scope :

Hailed as a possible future platform for advanced quantum computations, superconducting circuits also offer a route to design interesting models for many-body physics. Several theoretical challenges need still to be addressed, due to the large number of bosonic degrees of freedom involved. For instance, the strong thermal and quantum fluctuations of the superconducting phase (Fig. 1) result in an enhanced sensitivity to random charges. The development of a general framework to describe reliably these phenomena, possibly under the influence of micro-wave drives used as spectroscopic probes, seems promising thanks to recent progresses in the context of many-body wavefunctions. Working hand in hand with state-of-the-art experiments in the lab (Fig. 2), investigations of novel architectures (dissipative open quantum systems, more resilient qubits,…) will also be addressed.

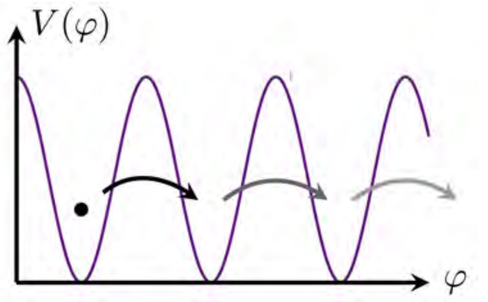

Fig.1 : Quantum tunneling of the superconducting phase

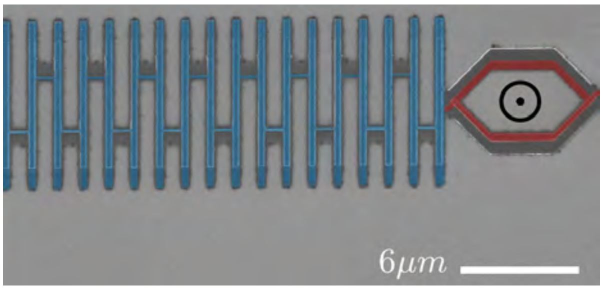

Fig. 2 : Non linear element (red) coupled to bosonic modes (blue)

Research topic and facilities available :

The internship will tackle dissipative quantum phase transitions triggered by the coupling of a single degree of freedom to a macroscopic environment. While a simple cartoon of the transition can be achieved by an effective Gaussian theory, non perturbative effects such as quantum tunneling of the phase do play a role. Taking those into account, the phase diagram for realistic devices will be determined using new many-body variational wavefunctions, combining analytical tools and numerics.

Possible collaboration and networking :

The work will take place within a well established collaboration, both locally and internationally. Experiments related to the project are currently performed by the team of Dr. Nicolas Roch at Néel Institute and by other groups in the USA. The theoretical team involves Dr. Denis Basko (LPMMC), Pr. Soumya Bera (IIT Bombay), Dr. Serge Florens (Néel Institute) and Pr. Izak Snyman (Wits University). If possible, traveling to the partners abroad will be encouraged.

Possible extension as a PhD :

Yes, provided funding can be successfully obtained by the applicant from the doctoral school.

Required skills :

The applicant must have a very solid background in fundamental science, and a training in theoretical physics. Good knowledge in advanced quantum mechanics (path integrals, perturbative Green's functions,...) and in solid state physics (superconductivity, band theory,...) will be also required.

Starting date : Spring 2022

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INSTITUT NEEL Grenoble

Proposition de stage Master 2 - Année universitaire 2021-2022

Transport quantique non conventionnel dans des systèmes à bandes plates

Cadre général :
Depuis plus d'une décennie, de nombreuses études théoriques et expérimentales révèlent le rôle important, essentiel et souvent surprenant de la topologie des états quantiques dans les observables physiques. La topologie est souvent à l'origine de propriétés remarquables, voire inattendues qui viennent défier notre compréhension de la physique.
Parmi les thématiques exotiques de la physique actuelle, celle qui est associée à la présence de bandes plates dans la structure de bande des matériaux a connu, ces dernières années, un essor important. Les bandes plates sont à l'origine de nombreuses propriétés non conventionnelles excitantes, telles que le magnétisme, la supraconductivité, l'existence de phases topologiques et la possibilité de phase super-métallique pour le transport électronique.

Sujet exact, moyens disponibles :
Le but de ce stage théorique est d'étudier à l'aide d'une approche de type de Kubo-Greenwood les effets de la dimensionnalité du système considéré sur la nature du transport quantique électronique dans des systèmes présentant une ou de multiples bandes plates (non dispersives) dans leur structure de bande.
Dans un second temps, on introduira du désordre dans le système (lacunes et potentiels aléatoires sur site) pour évaluer l'impact de ce dernier sur les propriétés de transport. On envisage par ailleurs de relier ces grandeurs physiques étudiées aux propriétés topologiques des états quantiques du système.
Nous précisons qu'afin de réaliser les calculs analytiquement et numériquement, on s'appuiera sur le formalisme des fonctions de Green.
Enfin, en ce qui concerne les systèmes désordonnés, il est important de souligner qu'afin de réaliser les calculs de manière efficace, le candidat pourra profiter de l'existence au sein de l'institut Néel d'un cluster performant de machines de calculs.

Interactions et collaborations éventuelles : L'environnement scientifique permet de nombreuses interactions possibles avec les chercheurs de l'institut Néel.

Ce stage pourra se poursuivre par une thèse.

Formation / Compétences :
Ce stage requiert, de bonnes connaissances en physique quantique, en physique de la matière condensée et/ou physique statistique. Le candidat devra également avoir les capacités d'écrire des codes de calculs (en C,ou C++, Fortran ou Python)

Période envisagée pour le début du stage : Mars-Avril-Mai-Juin 2022

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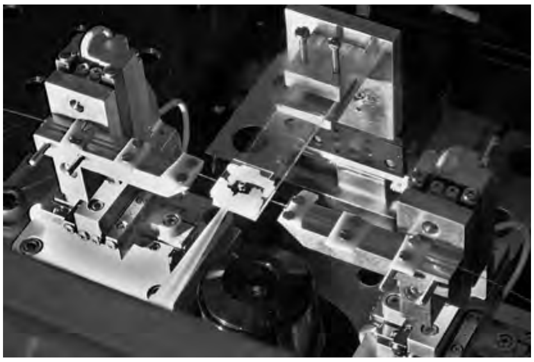
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Fluorescent Nanorods Optical Trapping in Air

General Scope : Since their introduction in 1986, optical tweezers become a standard tool for non-invasive manipulation in microbiology, chemistry, and solid state physics. The importance of this device was underlined by the attribution of the Nobel Prize 2018 to Athur Ashkin, the "Inventor" of the optical tweezers. The great majority of optical tweezers are actually optimized for trapping particles in suspension, allowing for example working with biological cells such as bacteria. Optical trapping of small particles in air is a more challenging task as one has to compensate the stronger Brownian motion and consider the very strong adhesion forces of particles on a surface. Very recently we have succeed to trap efficiently sub-micron sized dielectric particles in air.

The main scope of this internship is to extend the range of trapped particles to fluorescent nanorods and to implement and run a spectroscopic characterization tool for the characterization of these particles. This will be the first spectroscopic srudy of free, only optically trapped, nanorods in air.



Optical Tweezers setup developed at Institut Néel.

Research topic and facilities available :

In a first step the student will optimize the optical tweezers set-up for trapping the fluorescent nanorods. After the investigation of the trapping efficiency, the student will implement the spectroscopic tool already used for Institut Néel's suspension tweezers. Finally the fluorescence emission of the particles will be studied with special interest of the spatial intensity and polarization dependency All the required equipment is available at Institut Néel and the fluorescent nanorods will be provided by our colleagues from Ecole Polytechnique.

Possible extension as a PhD : YES

Required skills: Knowledge in optics/ photonics including integrated optics, fiber optics and optical trapping. The student should also have skills in optics experiments and basic knowledge in LabView-programming would be useful.

Starting date : free, as a function of the students program.

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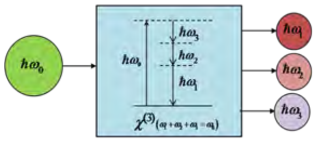
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Title: Triple photon generation in crystal optical nonlinear waveguides

General Scope: This position concerns Triple Photons Generation (TPG). It is based on a third order nonlinear optical interaction is the most direct way to produce pure quantum states of light, called three-photons states. These states exhibit three-body quantum entanglement and their statistics go beyond the usual Gaussian statistics relevant to coherent sources and optical parametric twin-photon generators, offering thus outstanding potential applications in the field of quantum information.

Undoubtedly, three-photons states are new quantum tools to study the non-intuitive properties of quantum mechanics. In 2004, we made the first experimental demonstration of a pure TPG [Opt. Lett. 29, 2794-2796 (2004)], which means that the three photons were created from a single one, using a two-wave stimulation scheme in a phase-matched $KTiOPO_4$ (KTP) bulk crystal. This pioneer work has opened new exciting opportunities in quantum optics. We made the classical and quantum theories of TPG [J. Opt. Soc. Am. B 25(1), 98 – 102 (2008); Phys. Rev. A, 85(4) 02389 1-12 (2012); Phys. Rev. Lett. 120, 043601-1-5 (2018)].



Research topic and facilities available: TPG was first performed in a bulk crystal, which was possible only by stimulated the process using two modes of the field. We have then proposed a novel approach for spontaneous TPG in a guided configuration based on a conventional glass fiber [Opt. Lett. 26(15), 3000-3002 (2011); Opt. Lett., 40(6), 982 (2015) ; invited conference at Non Linear Optics, Hawaii, 27 July 2015]. TPG can benefit from both strong confinement and long interaction length. This result is very important since it indicates that an optical waveguide can enable to achieve a spontaneous TPG, which is completely impossible using a bulk medium. However, because the phase matching is only possible in an optical fiber between two different modes of propagation with a poor spatial and phase overlap, the efficiency of TPG is expected to be very poor (about one triplet/s in a 10 meters long fiber) The work that is proposed in the framework of this internship is to combine the benefit of the high non linearity of bulk crystals such as KTP and the long interaction length and the strong confinement of an optical waveguide [Opt. Express, 24(9), 9932(2016)]. It will be based on a ridge waveguide cut in a KTP bulk crystal (typically, a section of 10x10 μm^2 and a length of about two centimeters). After the first experiments that the group has performed and published recently on second and third harmonic generations in x-cut and y-cut ridge waveguides [Opt. Lett., 43(15) 3770(2018), Opt. Express, 29(14) 22266 (2021)], we are now working on TPG and quantum experiments using CW as well as pulsed laser sources, and nanowires superconductors as photon-counting detectors.

Possible collaboration and networking: FemtoST (Besançon), Centre de Nanosciences et de Nanotechnologies - C2N (Saclay), GAP (Université de Genève), Tel Aviv University (Tel Aviv).

Possible extension as a PhD: It is strongly expected.

Required skills: A background in laser optics, nonlinear optics, quantum mechanics or quantum optics will be useful for the purpose of the project.

Starting date: February or March 2022

Contact:

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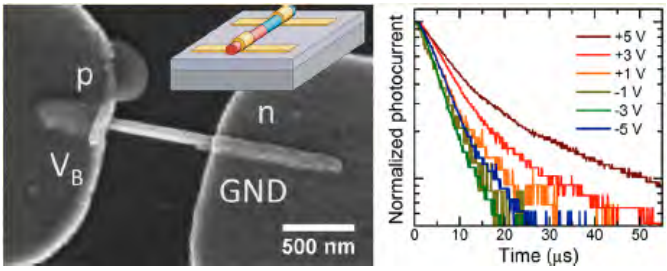
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

p-n junction nanowires for solar cells

General scope:

Semiconductor nanowires (NWs) with controlled composition and dimensions can be fabricated using optimized growth conditions (bottom-up method) or by lithography and etching of a suitably designed substrate (top-down method). Moreover, it is possible to tune the electrical properties by doping, and p-n junctions can be implemented in NWs. These structures are interesting, for example for application as NW solar cells or high-speed photodetectors. Among others, NWs present one major advantage for such applications: they act as antennae and therefore can absorb the light more efficiently using less material. However, challenges remain to control and measure the doping levels in such nano-objects with nm precision. Furthermore, the role of the NW surface on their electrical properties requires further investigation.



Left: SEM image of a contacted NW with schematic in the inset. Right: photocurrent time response of the NW.

Research topic and available facilities:

The aim of this internship is to contribute to the study of p-n junction semiconducting NWs regarding their opto-electrical properties. The student will integrate a multi-institute, multi-disciplinary research group. His/her role will be to optimize the etching process of GaN NWs from a bulk substrate containing a planar p-n junction defined during molecular beam epitaxial growth. She/He will use nanosphere lithography followed by a two-step etching process (reactive ion etching + wet chemical etching) to define the NW length and diameter, potentially followed by a high temperature annealing step to further reduce the NW diameter. Then the obtained NWs will be electrically contacted on membrane chips compatible with transmission electron microscopy (TEM) measurements, and the student will be in charge of their electro-optical characterization. This includes current-voltage and complete characterization as a photodetector (responsivity, linearity, spectral selectivity, time response). These results will be correlated to detailed characterization by transmission electron microscopy, performed on exactly the same single NW. Combining in-situ biasing with the 4D Scanning TEM techniques sensitive to the electric field, we may obtain a quantitative description of the electrical properties of this object at the nm scale. Using this combination of techniques, we will improve our understanding of NW solar cells.

The student's work will involve:

- Top-down NW fabrication in cleanroom environment. It implies training in nanosphere lithography, electron beam metalization, reactive ion etching and scanning electron microscopy.
- Current-voltage measurements and electro-optical characterization as a photodetector.
- Nanowire contacting and TEM experiments will be performed by a postdoctoral researcher, but the student will participate in the experiments.
- The student will be involved in the correlation of electro-optical and 4D STEM results.

Possible collaboration and networking: The internship will be in collaboration with Eva Monroy (CEA-IRIG, PHELIQS).
Possible extension as a PhD: Not granted in advance, but we are open to support applications for a PhD grant.
Required skills: Interest in solid-state physics, electrical and optical properties of semiconductors and advanced characterization techniques like transmission electron microscopy.
Starting date: Jan/Feb 2022 or earlier.

Contact: den Hertog Martien & Eva Monroy
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More information at: http://neel.cnrs.fr

Title

Fe Doped tetragonal CuO films as a new ferromagnetic semiconductor

General Scope:

Over the past half a century, a considerable research activity has been dedicated to the development of magnetic semiconductors (MSC) that can work at room temperature [Q. Cao and S Yan, *J. Semicond.* **40** 081501 (2019)]. These materials are of primary importance for spintronics applications. At the beginning investigations focused mainly on II–VI MSC and III–V dilute MSC. More recently the attention turned towards oxides like e.g. ZnO-based MSC.
Here we are interested in CuO, which is an antiferromagnetic semiconductor with a gap of about 1.4 eV. Its structure is monoclinic, at odd with the other 3d transition metal monoxides (FeO, CoO, NiO,…) that have a rock-salt structure. However, single-phase tetragonal CuO films were elaborated by epitaxial growth on $SrTiO_3$(001) substrates [W. Siemons *et al*., *Phys. Rev. B* **79**, 195122 (2009)], up to a thickness of about 3 nm. This transition from monoclinic to tetragonal structure is associated with an increase of the oxygen-mediated superexchange interaction J and hence of the Néel temperature. Transition metal doped CuO nanocrystals, and in particular $Cu_{1-x}Fe_xO$ ones, have been elaborated by several methods. The iron substitutes copper in the monoclinic structure resulting in a single phase up to x~0.2. Samples are ferromagnetic, but with quite a small remanence and coercive field at room temperature. During this internship, the scope it to grow Fe-doped tetragonal CuO phase with improved magnetic properties, thanks to the larger superexchange interaction characteristic of the tetragonal phase.

Research topic and facilities available:

During the internship, Fe-doped CuO tetragonal thin films will be grown by MBE deposition on $SrTiO_3$(001). The films will be prepared and studied *in-situ* using two interconnected ultra-high-vacuum chambers, the first one dedicated to MBE growth, the second one to the characterization by low energy electron diffraction (LEED), Auger electron spectroscopy and scanning tunnel microscopy (STM) techniques. LEED allows to establish the crystallographic symmetry of the films, Auger is used to study the composition and the presence of contaminants, STM will be performed here to study the surface roughness and for a first investigation of the electronic properties.
After growth, the transport and magnetic properties will be measured *ex situ*, using the devices available at the Néel institute.

Possible collaboration and networking: SIN team at Néel institute

Required skills: A good background in condensed matter physics, dexterity in experimental work.

Possible extension as a PhD: Possible, but no financed up to now

Starting date: March 2022

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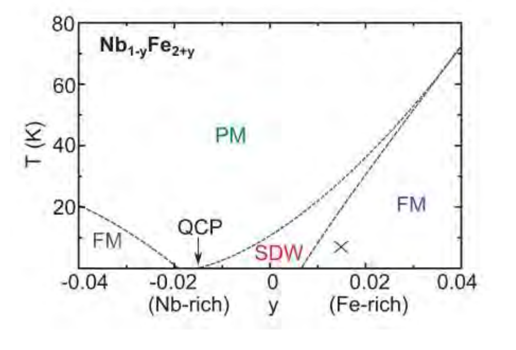
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Remarkable magnetic behavior of itinerant electrons

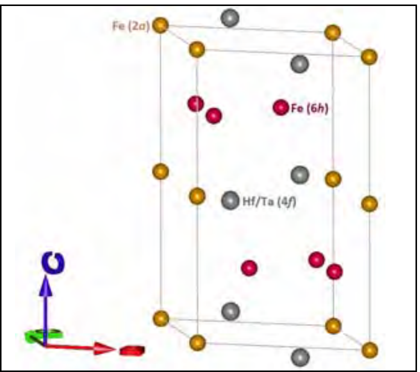
General Scope : The itinerant electron magnetism of 3d electrons of transition elements is a matter of intensive research nowadays [1-4]. When alloying transition metal (Fe, Co..) with rare-earth elements (R) various interesting physical properties can be obtained such as high performance magnetostriction of RFe_2 compounds usefull in actuators and sensors (sonars etc..) or large magnetocaloric properties of RCo_2 materials promising for magnetic refrigeration. Another surprising feature is the magnetically driven negative thermal expansion of materials which do not exhibit the expected contraction but on the contrary expand upon cooling [2]. In addition to the great importance of such remarkable properties for both scientific research and modern technological applications, fundamental research is needed to go deeper in the understanding of the 3d itinerant electron magnetism which can exhibit a wide range of behavior from localized magnetism to pure itinerant electron magnetism. Recent reports showed the complex magnetic phase diagram including quantum critical points (QCP) in $NbFe_2$ [3,4] attracting a large interest from the scientific community from both theoreticians and experimentalists

Research topic and facilities available : The internship is aimed to investigate the magnetic phase diagram of selected R-Fe compounds and analyze their unusual behavior at the crossover between competing interactions of ferro and antiferromagnetic type. In order to modify and probe the magnetic properties, we will use different approaches including insertion of light element and application of presure. This fundamental research will be performed aiming to determine the physical properties ranging from crystal structure to magnetic, thermal and transport properties. The research will involve experimental investigations at Néel laboratory as well as study of data from large scale facilities like neutron diffraction (to determine the arrangement of the magnetic moments) and/or synchrotron radiation. Most of the experiments will be performed at cryogenic temperatures down to 2K. The internship will include preparation of samples, measurements of their interesting physical properties and analysis of the observed behavior. This will be done in a research team using equipments already available. **This internship is aimed to be followed by a PhD Thesis**



Left : Magnetic phase diagram of $Nb_{1-y}Fe_{2+y}$ compound Paramagnetic : PM, Ferromagnetic :FM, Quantum critical point QCP

Right : Typical crystal structure of RFe_2 compounds



Possible collaboration and networking : We currently have several national and international collaborations on this research topic. collaboration in France with the CNRS, the Institute Laue Langevin and synchrotron SOLEIL, and with foreign laboratories in Germany, Czech republic (collaborators specialists of magnetic measurements at high pressure) and Brazilian colleagues.

Required skills: sciences Interest for experiments and wish to broaden its knowledge in fundamental sciences. Master 2 in Condensed Matter Physics or Engineer in Materials wanted.

Starting date : February or march 2021

Contact : Olivier ISNARD Institut Néel - CNRS

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Higgs Modes in Superconductors

General Scope :

When a spontaneous breaking of a continuous symmetry takes place, for instance when crossing the normal to **superconducting** transition, collective excitations of the order parameter emerge:
They are the phase modes and the massive **amplitude Higgs mode,** as illustrated Fig.1 in red.
There is growing interest in the search and the study of the fundamental collective Higgs mode, as an analogous in quantum many body systems of the particle physics Higgs boson and as a fingerprint of the properties of the superconducting state. Indeed, even if theoretically always here in any superconductors and even if presented as a textbook excitation, this 'dark' mode remains very elusive. In principle, it does not couple to any external probe. Our purpose is to identify this Higgs mode in various compounds, with different type of superconductivity (symmetry, mechanism, coupled electronic orders).

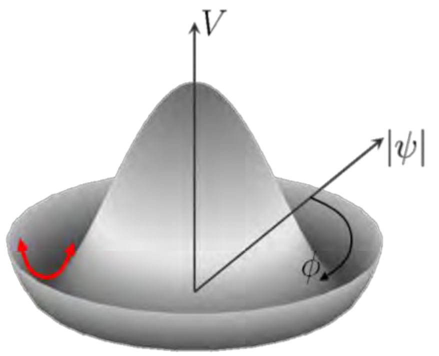

Fig. 1: Mexican-hat-shaped potential of the free as a function of the complex order parameter There are two types of fundamental collectiv around the new equilibrium state taken spontane the line of minima. One, the amplitude mode ir known as a "dark" mode and is the analogou Higgs boson. In superconductor, it correspo coherent oscillatory pairings and depairings of the Cooper pairs of electrons.

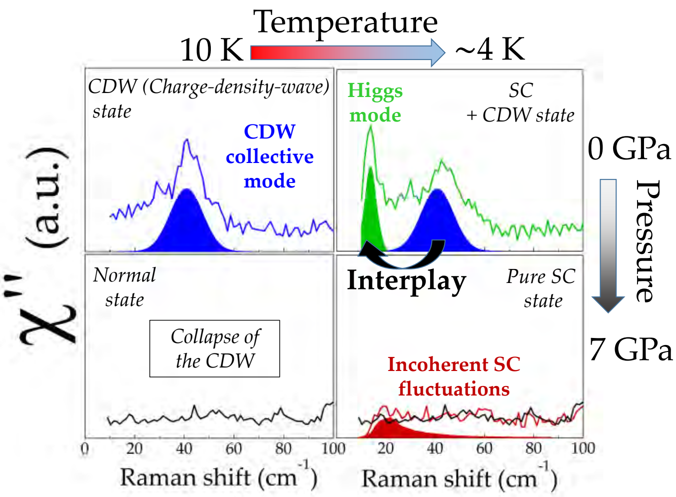

Fig. 2: Raman spectra of 2H-$NbSe_2$ under high pressure and at low temperature. Evidence of the requisite of the adjacent CDW state (in blue) for the Higgs mode (in green) observability: Pressure-induced concomitant collapse of the Higgs mode and CDW state.

Research topic and facilities available:

The compounds where a superconducting Higgs mode has been claimed to be present are the ones where superconductivity coexists with another type of electronic order, such as charge density wave (CDW). In these systems, like in $NbSe_2$ (see Fig. 2), the amplitude oscillations of the CDW order parameter (CDW mode) can be detected by Raman spectroscopy. When the system becomes superconductor, a new Raman peak emerges. It has been attributed to the Higgs mode. This is one of the very few examples of such Higgs mode measurements. The student will explore a new family of compounds to discover new Higgs mode which, as fingerprint of its underlying quantum order, may give access to properties of the electronic orders and their interplay. The student will perform symmetry dependent electronic Raman scattering experiment under extreme conditions, at low temperature and under high pressure, on a chosen family of superconductors.

Possible collaboration and networking: We already have a close theoretical collaboration with Lara Benfatto (Roma) on this topic. Collaborations with samples' growers (France and abroad), high

magnetic field facilities (Nijmegen), High pressure labs (Paris), Optics (Germany) is also established.
Networking: ERC project.

Possible extension as a PhD: YES. This study will be done in the context of a financed European ERC project.

Required skills: knowledge of condensed matter physics, curiosity, taste for delicate experiments.

Starting date: march-april 2022

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Tailoring superconductivity in two-shells superconductor-semiconductor nanowires

General Scope : Controlling and manipulating topological superconductivity[1] can lead to the creation of a new generation of quantum bits, called topological quantum bits, that are more robust to decoherence than traditional quantum bits. One solution to create topological superconductivity is to combine a superconductor with a one-dimensional semiconductor having a large spin-orbit coupling. Superconductivity in the semiconductor appears via the proximity effect and so far, the most studied systems have been Al/InAs and Al/InSb core-shell nanowires. Yet, magnetic fields are necessary to create topological quantum bits and because of its low critical field, Al is not a good choice. New combinations of materials[2] are currently emerging including Sn and Pb. Yet, induced superconductivity in the semiconductor can be too strong with Sn and Pb. In order to mitigate this effect, high quality tunnel barriers are envisaged, preferentially lattice matched with the semiconductor nanowire.

Research topic and facilities available : The objective of the internship is to explore the properties of two-shells superconductor-semiconductor nanowires using the InAs-ZnTe(CdSe)-superconductor system. Two-shells nanowires are very novel, as previously only one-shell nanowires were explored. This will be realized through (1) the preparation of InAs nanowires wrapped with ZnTe(CdSe) shells using a molecular beam epitaxy reactor and (2) the fabrication and transport characterization of two-shells nanowire devices in a low temperature setup. The work consisting in growing the nanowires will take place at CEA-IRIG where molecular beam epitaxy reactors are available within the joint CEA/CNRS NPSC team. Fabrication of the devices will take place at Institut Néel at the Epitaxy platform and the Nanofab cleanroom facility. Transport measurements in a dilution fridge will take place in collaboration with the QNES team at Institut Néel.

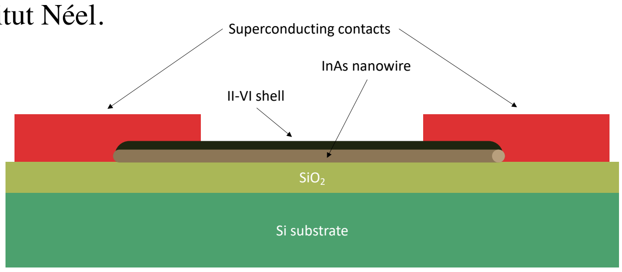

Figure1. Example of a two-shells nanowire device designed for the study of topological superconductivity

[1]S.M. Frolov, M.J. Manfra, J.D. Sau *Topological superconductivity in hybrid devices* Nat. Phys. 16, 718–724 (2020)
[2]M. Pendharkar, B. Zhang, H. Wu, A. Zarassi, P. Zhang, C. P. Dempsey, J. S. Lee, S. D. Harrington, G. Badawy, M. Rossi, R. op het Veld, S. Gazibegovic, J. Jung, A. -H. Chen, M. A. Verheijen, M. Hocevar, E. P. A. M. Bakkers, C. J. Palmstrøm, S. M. Frolov. *Parity-preserving and magnetic field resilient superconductivity in indium antimonide nanowires with tin shells* Science 372 508 (2021)

Possible collaboration and networking : Collaboration with USA (University of Pittsburgh, Carnegie Mellon University, UCSB) and The Netherlands (TU/Eindhoven) via the NSF/ANR HYBRID project. The intern will work closely with the PhD students of the international collaboration through his/her participation in regular meetings and discussions.

Possible extension as a PhD : Yes

Required skills: Interest in performing experiments in the lab (materials growth, fabrication of devices and measurement), background in solid-state physics and nanotechnologies.
Starting date : Beginning of 2022

Contacts :

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Integration of a semiconductor quantum dot single photon emitter to a quantum photonic circuit

General Scope:

Single-photons as flying quantum bits (qubits) are required for ultimately secure communication or quantum computing. Integration of quantum sources with photonic waveguides is crucial for the development of “plug and play” sources for secure quantum communication as well as for experiments requiring complex photonic circuits such as linear optics quantum computing. Single-photon sources based on semiconductor quantum dots (QDs) are particularly interesting because of their possibility of integration into conventional optoelectronics devices.

Research topic and facilities available:

Our group develops the growth of CdSe QDs inserted in ZnSe nanowires (NWs), covered by a thick ZnMgSe shell acting as a photonic wire helping to guide photons emitted by the QD. These NW-QDs emit single-photons in the visible domain and have shown the possibility of single-photon emission up to room temperature. The NW-QD geometry offers several advantages, such as the control of the optical dipole orientation and nano-maniplulation of single emitters. In this internship, we propose to explore the integration of a NW-QD single-photon emitter to a waveguide and a photonic circuit. The goal of the internship will be: (i) to optically characterize the NW-QDs grown in our group, (ii) to design, fabricate and characterize waveguides for the optimal guiding of single photons, (iii) to study the coupling of the NW-QD to the waveguide.

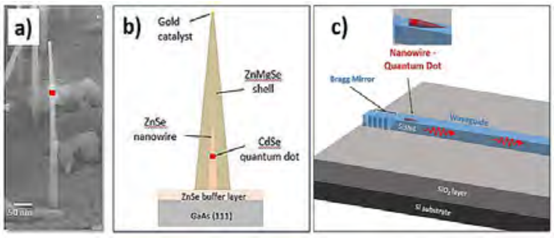

Figure: a) a ZnSe/CdSe NW-QD on the as-grown sample; b) a similar NW-QD in a photonic wire ; c) Evanescent coupling of a NW-QD to a wave guide.

Possible collaboration and networking:

Our group “NanoPhysics and Semiconductors” is a joint CEA/CNRS team and the internship will take place both in CEA-IRIG and CNRS-NEEL, with collaboration with LETI-DOPT. This internship will allow tackling different topics in nanociences and optics: NW-QD grown by Molecular Beam Epitaxy, nano-fabrication in clean room, spectroscopic (micro-photoluminescence) studies, light-matter interaction at the nanometer scale studies supported by numerical simulations.

Possible extension as a PhD: Yes

Required skills: Semiconductor physics, optics, photonics, nanotechnology, with strong interest for experiment.

Starting date: February 2022

Contact:

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Transport properties of an Al/Ge/Al junction

General Scope :
The internship is motivated by our recent investigations of ultra-scaled hybrid Al/Ge devices that we achieved using bottom-up grown Germanium nanowires and a selective thermal induced Al/Ge exchange reaction. It leads to pure and remarkable atomically sharp interfaces between Al and Ge as shown on the figure1. Integrating such structures in a Josephson field-effect transistor (FET) we were able to demonstrate highly transparent interfaces and superconducting proximity effect through a pure Ge segment. These results imposed already such Al/Ge devices as promising candidates for superconducting qubits.

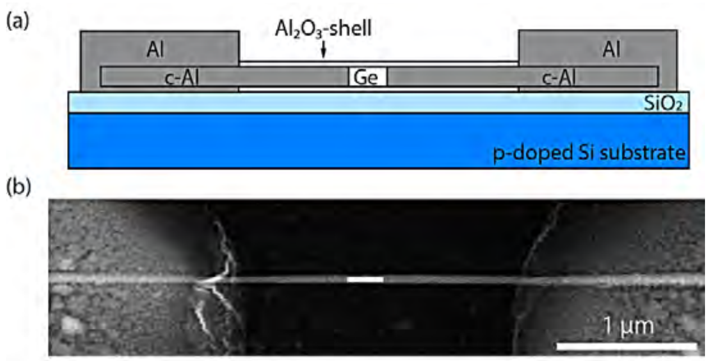

Figure 1: (a) Schematic illustration of the passivated Al-Ge-Al NW heterostructure comprising one-dimensional self-aligned Al leads contacting a Ge segment. (b) TEM image showing an Al-Ge-Al heterostructure device

Research topic and facilities available :
Our research aims at exploring superconductor/semiconductor hybrid devices based on ultra-scaled Al/Ge heterostructures and their integration in functional quantum circuits. The transport properties of such Al/Ge hybrid devices demonstrated a rich variety of promising properties ranging from a supercurrent through the junction to Coulomb diamonds related to the germanium quantum dot. We will explore these properties in a homemade He3 cryostat which allows to measure at 350 mK.

Possible collaboration and networking : The internship proposal is related to a joint proposal between the Neel institute and the Technical University of Vienna (Austria).

Possible extension as a PhD : Not funded

Required skills: Master in condensed physics

Starting date : **March or April 2022**

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INSTITUT NEEL Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Emulating spin qubit on ATOS QLM machine

Context : In quantum nanoelectronics, one of the major goals is the use of quantum mechanics for the development of nanoprocessors that are more and more efficient. This requires the ability to control quantum phenomena at the single electron scale within nanostructures. In this context, the degree of freedom of the electron spin has been identified as a potential candidate for the support of quantum information. We can define the elementary block of the nanoprocessor by capturing a single electron (and therefore its spin) inside a quantum dot. The development of a quantum circuit will follow the same methods of microelectronic circuits conception, by connecting the elementary bricks, while respecting the constraints of controlling the individual spins. Nowadays, in quantum dots systems, all the elementary operations required for the functioning of a quantum processor have been demonstrated and characterized in trapped spins of AsGa heterostructures. The effort of the spin qubits community turns to the transposition of these demonstrations for trapped spins in silicon structures, whose fabrication is compatible with CMOS industrial processes. An important question still on debate is the precise architecture of the quantum processor. This is the purpose of the internship to evaluate on a classical computer different spin qubit architectures.

The ATOS QLM machine is able to emulate up to 40 qubits and is suitable to incorporate decoherence mechanisms and quantum operation errors.

Objectives and means available: The candidate will develop research on the simulation of electron spin qubits. The tasks will be to model precisely the decoherence properties and the characteristic of the quantum operations in order to emulate specific algorithms on QLM type of computers. Such a program will aim to test various architectures of quantum processors based on spin qubits.

Interactions and collaborations: This work is part of a large collaborative effort between the CEA-IRIG, CEA-LETI and CNRS-Institut Néel to develop and push the technology of spin qubit in silicon and investigate its potential scalability. This consortium is collaborating with ATOS for simulating spin qubits.

Skills and training: The project relies on the knowledge accumulated in the field of few-electron quantum dots and its new implementation in Si devices. All along this project, the candidate will acquire important skills in the field of condensed matter physics: spin qubit basic operations, emulation of quantum systems, quantum algorithms, …

Foreseen start for the beginning of the internship: From January to April 2022

Possibility of continuation as a PhD on the same subject with funding already secured.

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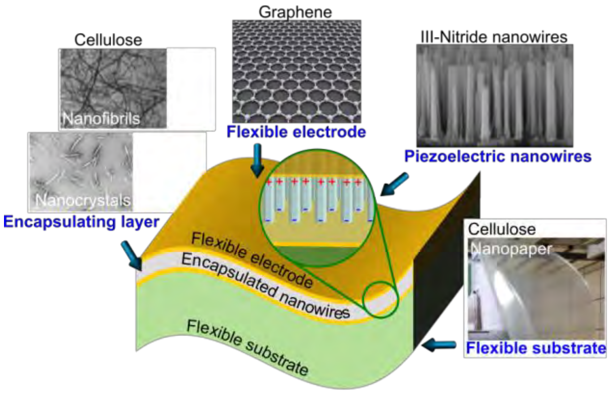
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

III-Nitride nanowire-nanocellulose composites for flexible energy harvesters

General Scope:

A large number of small-scale smart electronics have been progressively integrated into our everyday lives in various sectors (healthcare, energy, security, etc). Such systems require sustainable, maintenance-free, and self-powered devices that can harvest the energy from their surrounding. Lately, there is a significant increasing research interest in piezoelectric nanowire nanogenerators which can scavenge mechanical energy from natural or biomechanical origin to drive small-scale devices. A typical way of fabricating nanowire nanogenerators is to embed the nanowires in synthetic polymers to improve their stability and processability while preserving their mechanical compliance. These encapsulated nanowires are transferred on top of soft materials such as plastic sheets which are easier to be integrated with various surfaces than rigid substrates. The common plastic substrates could cause ecological problems since they are based on non-renewable petrochemical products and cannot be decomposed through biodegradation as organic materials. This work aims at developing inorganic-organic composites for eco-friendly flexible energy harvesters.



Research topic and facilities available:

The targets of the project are (1) to use piezoelectric semiconductor III-Nitride nanowires to convert green energy into usable electrical energy and (2) to replace eco-unfavorable device components with eco-friendly materials, *i.e.* using plant-based cellulose nanopapers instead of plastic substrates and using graphene to substitute metallic electrodes for electrical contacts.

Two internships will participate in the process development of inorganic-organic composite fabrication and characterization. They will intensively explore cellulose nanopapers as a flexible substrate and test the nanowire encapsulation by nanocelluloses in different forms (nanofibrils, nanocrystals). The study also includes the fabrication of graphene electrical contact for nanowire nanogenerator devices on nanopapers. Together with the team, both students will contribute to the large-scale characterization of electrical and electromechanical properties to gain essential information associated with the device's key parameters such as output power, sensitivity, detection limit, linearity, response time, stability, etc. The fabrication process of each component will be readjusted according to the effective output signal. The interns will join regular meetings with the staff involved in the project.

The experiments will be performed at CERMAV and Néel/Grenoble. The students will have an opportunity to access the facilities of both laboratories for necessary experiments such as nanofabrications facilities (metal evaporation, chemical bench, lithography, etc.), characterization tools for electrical, structural, and optical properties (scanning electron microscopy, atomic force microscopy, etc).

Possible collaboration and networking: Nanophysics and semiconductors/ Néel, Quantic electronics, surfaces and spintronics/Néel, Optic and Material/Néel, CTP, and CERMAV

Possible extension as a PhD: No funding is currently available but we support the applications for the grant.

Required skills: Nanofabrications, Semiconductors, Nanomaterials, Solid State Physics, Chemistry

Starting date: February/March 2022 for 4 to 6 months

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

M2 Internship in Si spin qubits, academic year 2021/2022

Large scale parametric characterization and test of quantum devices at cryogenic temperatures

Context: A natural way to address the scalability of quantum devices is to design and realise arrays of individual quantum objects with nearest-neighbor interaction. In large-scale semiconductor quantum processors, a quantum bit is encoded in the spin of an isolated electron, trapped in an array of quantum dots (QDs) [1]. Over the years, we have studied devices with an increasing number of QDs, in designs that allow for the coherent control of individual spin. **However, there is a pre-requisite for a precise control of spin qubits: a deep knowledge of the quantum dots used to confine the electrons in arrays [2]. Therefore, demonstrating the extensive and scalable characterization and calibration of QD systems is crucial for the development of our quantum processor.** Last year CEA-Leti has acquired a unique automatised measurement tool for 300-mm wafers at cryogenic temperature, which gives us a new way to develop intelligent and efficient characterization techniques (Figure 1).

Objectives and means available: The systematic characterization of the QD control parameters scales with the number of control knobs and QDs. The dense exploration of the parameter space to determine the array's charge state limits the experimental throughput of relevant data points. During his/her internship, the student will develop QD characterization algorithms, like adaptive meshing or feature recognition using signal and image processing algorithms to optimise the parameter space exploration. Consequently, within this project, the student will develop feedback loop in the computer software fast real-time processing to optimise the characterization speed and allow for statistical analyses. Parallel to this, the student will work on the development, based on existing works, of optimized experimental characterization protocols. Indeed, the characterization of quantum devices at large scale will build up a statistical knowledge of the structures that can enhance the measurement protocols. As such, they will be embedded in the automated characterization workflow for arrays of quantum dots and will progressively enrich the physical modelling and understanding of the QD arrays.

Figure 1: Photograph of the cryogenic 300mm-wafer prober

Interactions and collaborations: This work is part of a large collaborative effort to develop and push the technology of spin qubit in silicon and investigate its potential scalability. Therefore, the candidate will work in close collaboration with the LETI's characterization and integration team designing the quantum devices, with the CEA-IRIG where the quantum devices are characterized at mK temperatures and used as qubit platforms.

Skills and training: We are looking for a motivated student, with an interest for experimental physics. This internship requires skills in semiconductor physics. A strong interest in algorithm programming and quantum physics is required. A knowledge of nano-fabrication techniques, low-temperature physics and/or spintronics will be appreciated but is not mandatory.

[1] Vinet, M. et al. Towards scalable silicon quantum computing, IEDM (2018).

[2] Mortemousque, P.-A. *et al.* Coherent control of individual electron spins in a two-dimensional quantum dot array. *Nat. Nanotechnol.* (2020) doi:10.1038/s41565-020-00816-w

Possible extension as a PhD: Yes. **Starting date / Duration**: Flexible

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MEUNIER Tristan, CNRS, Institut Néel, Tristan.meunier@neel.cnrs.fr

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Combinatorial studies of hard magnetic materials

General Scope:
The demand for high performance rare earth transition metal (RE-TM) hard magnets (Nd-Fe-B, Sm-Co) is continuously growing, in particular for use in power transformation (windmills, (hybrid)-electric-vehicles, electric bicycles) and robotics. The elements at the origin of magnetocrystalline anisotropy and thus coercivity in today's best magnets (Nd, Pr, Dy, Tb, Sm) are from the family of strategically important rare earth elements. To address the growing demand for magnets but the limited supply of REs, much effort is now going into developing magnets in which the most critical REs are partially substituted by under-used and thus much cheaper REs (e.g. Ce, La). Partial substitution of the main transition metal (e.g. Fe in $Nd_2Fe_{14}B$ and Co in $SmCo_5$ based magnets) is also being studied. The thin film combinatorial approach is ideally adapted to study the tuning of both intrinsic and extrinsic magnetic properties in model samples, and can guide the subsequent development of bulk magnets. Beyond optimising known hard magnetic phases, it can also be used to explore for new phases. The experimental data sets can serve as input in the emerging field of machine-learning-led magnet development.

Research topic and facilities available:
This internship concerns the high throughput fabrication and characterization of thin film libraries of hard magnetic materials. Compositionally graded RE-TM based films will be fabricated by sputtering. The influence of composition and post-deposition annealing on both structural and magnetic properties will be explored using high throughput scanning characterization techniques. Composition will be characterized by Energy Dispersive X-Ray analysis in a scanning electron microscope, crystal structure by X-Ray Diffraction and magnetic properties will be probed using an in-house developed scanning polar Magneto-Optic Kerr effect system. Particular emphasis will be placed on the development of automated analysis of XRD data sets.

Possible collaboration and networking:
This internship will be carried out in the framework of a collaboration with the group of Prof. Thomas Schrefl at the Christian Doppler Laboratory for magnet design by machine learning (Danube University Krems, Austria).

Possible extension as a PhD: Yes

Required skills: Materials science / condensed matter physics, coding (python) for data analysis.

Starting date : Spring 2022

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NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

3D Superconducting Interconnects for Quantum Applications.

General Scope :

As part of Quantum Silicon Grenoble project, teams at CEA-LETI, CEA-IRIG and Néel Institute aim at building a quantum accelerator with silicon spin quantum bits (qubits). Compatible with large-scale production, existing integration processes on Si are a real advantage for the scalability of these qubits. However, the extreme qubit operating conditions (cryogenic temperatures ≤1K, high frequencies in the range of a few GHz, high signal density) require the development of adapted technological building blocks as well as multi-chip module platforms (see Fig.1), designed to bring control electronics circuits closer to the qubits in the cryostat.

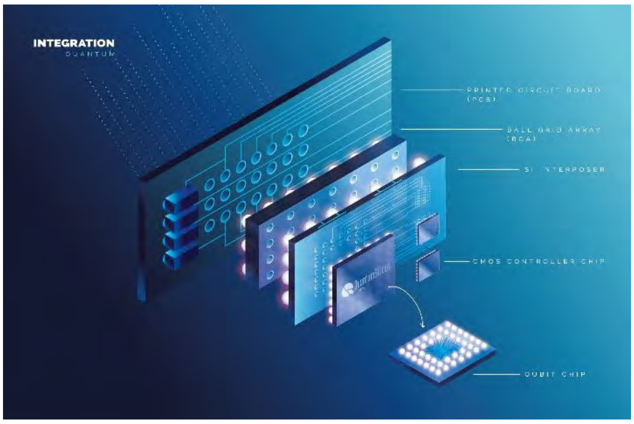

Figure 1- Example of multi-chip platform developed at Quantum Silicon Grenoble (credit: CEA).

Research topic and facilities available:
The integration of superconductors is promising to optimize the coupling between the qubits and their control electronics. Indeed, their vanishing resistance at low temperatures adds flexibility to the design and sizing of the interconnects (e.g. microbumps or routing tracks) located between the qubits and control electronics circuits. The low thermal conductivity of superconductors can be used to protect the qubits from the heat generated by the control electronics circuits integrated close-by. Finally, the low dispersion of superconductors favors high frequency signal transmission needed to encode and read the information stored in the qubits. This internship will focus on the fabrication (in CEA-LETI clean-room facilities) and characterization (electrical, structural and thermal) of superconducting interconnects.

Possible collaboration and networking:
This work is part of a large collaborative effort to develop and push the technology of spin qubit in silicon and investigate its potential scalability. The candidate will work in a consortium made of CEA-LETI, CEA-IRIG and Néel Institute researchers, at the interface between the integration, the characterization and the design teams.

Required skills:
We are looking for a motivated student, with a background in microelectronics, nanofabrication and/or condensed matter physics.

Possible extension as a PhD : Yes
Starting date: in between January and April 2022

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NÉEL institut

NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Direct studies of TeraHertz emission generated from phase-matched frequency down-conversion in new nonlinear crystals

General Scope : The scope of this internship is to determine the potentiality of eight nonlinear crystals for generating a coherent and continuously tuneable Terahertz (THz) light. Such an emission is of prime importance for many applications as spectroscopy, biomedical and imaging for example. Our interest is in the frequency range 0,1 - 20 THz corresponding to the wavelength range 3000 - 15 µm.

Research topic and facilities available : The eight selected nonlinear crystals belong to uniaxial or biaxial optical classes and their optical properties are well known in their Mid-infrared (MIR) transparency range. We aim to generate second-order frequency down-conversion processes under birefringent phase-matching (BPM) conditions in these crystals of two incoming beams emitting very close wavelengths located in their MIR transparency range. We will take advantage of our recent calculations that provided a new database for THz emission in all these nonlinear crystals [1].
We will directly generate a continuously tuneable Thz light by using difference frequency generation (DFG) between two incoming monochromatic and tuneable wavelengths interacting collinearly in each nonlinear crystal. They will be provided by a commercial source emitting pulses in the picosecond regime. We will also consider what is also called Optical Rectification between the two Fourier components of the same single pulse of a commercial tuneable femtosecond source. All incoming beams will propagate at normal incidence on the input face of each nonlinear crystal that has been shaped as an oriented slab polished to optical quality. The orientation of their linear polarization will be adjusted by using achromatic half-wave plates. They will be removed after the sample to record the Thz emitted light only using a bolometer detector.

[1] Cyril Bernerd, Patricia Segonds, Jérôme Debray, Jean-François Roux, Emilie Hérault, et al.. Evaluation of eight nonlinear crystals for phase-matched Terahertz second-order difference-frequency generation at room temperature. *Optical Materials Express*, OSA pub, 2020, 10 (2), pp.561. ⟨10.1364/OME.383548⟩. ⟨hal-02450500⟩

Possible collaboration and networking : All the studied nonlinear crystals were provided thanks to many collaborations with leader groups in crystal growth over the world as BAE Systems, Shandong & Tianjin Universities, Kuban State University, Riken, Chimie ParisTech.

Application to a PhD position is not requested

Required skills: A background in laser optics and non-linear optics will be appreciated.

Starting date: starting from February 2021

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