2019 Master Subjects

Pheliqs
Quantum Physics & Engineering

[1] A predictive simulation stack for the elements of a semiconducting quantum computer

[2] Interaction effects on topological properties of multiterminal Josephson junctions

[3] Theoretical investigation of advanced magnetocaloric materials

[4] Higher-order topological insulators (Theory)

[5] p-wave, spin-triplet, topological superconductivity in the ferromagnetic superconductors

[6] Quantentransport in topological materials

[7] Heterostrain physics in twisted graphene layers

[8] Superconductor / Semiconductor hybrid nanostructures based on Germanium for quantum information

[9] Development of AlGaN nanostructures for electron-pumped UV light emitting devices

[10] Contribution to the fabrication of an electron-pumped UV laser

[11] Molecular beam epitaxy growth and optical characterization of GaN on graphene/GaN substrate

[12] Visible LED realization on polarity controlled substrate

[13] Bacteria analysis and control by optical microcavity

Subject 1

A predictive simulation stack for the elements of a semiconducting quantum computer

Contact: Xavier WAINTAL   DRF//INAC/PHELIQS/GT   xavier.waintal@cea.fr   0438780327

PhD may follow: Yes

Summary :

After being an object of studies for a few decades, quantum nanoelectronics is now moving forward to become the basis on which the first quantum computer could be build. The challenge is immense and even the most basic questions â€“ such as what should be the actual physical implementation of the quantum bits (qubit) â€“ do not have definite answers yet. The Grenoble community is actively following several experimental leads including GaAs/GaAlAs based spin or charge qubits, Silicon CMOS based qubits, superconducting qubits or flying qubits.

The transition from quantum science to quantum technology necessitates the ability to perform predictive simulations of the quantum devices that are reliable enough to be used as a basis for exploring new ideas as well as optimization. The theory group of Pheliqs at CEA Grenoble has been developing numerical tools for this purpose that include the open source Kwant platform , (http://kwant-project.org) and its various extensions to deal with real time dynamics, correlations and electrostatics.

In this internship we will setup a model for predicting the characteristics of semiconducting quantum devices. Our chief concern will be a systematic comparison of our predictions with tailor made experiments that will be performed in the group of C. Bauerle at institute NÃ©el, CNRS Grenoble. We will in particular carefully model the residual disorder present in these samples that, although small, can have a decisive impact on quantum dynamics. If times allows, we will implement machine learning algorithms to optimize the sample behavior.

The work will involve theoretical / formalism aspects (out of equilibrium many-body formalism, Feynman diagramsâ€¦), numerics (using modern approaches based on Python) and the modelisation of concrete physical systems. The internship will take place within the theory group of CEA Grenoble, INAC, PHELIQS (Photonics NanoElectronics and Quantum engineering). Our group contains 15-20 researchers working on nanoelectronics, superconductivity, magnetism and electronic correlations in close collaboration with experimental groups. The project will be done under the direction of Christoph Groth (christoph.groth@cea.fr) and Xavier Waintal (xavier.waintal@cea.fr).

We seek highly motivated students with a strong background in theoretical physics, quantum nanoelectronics and/or numerical simulations.

Full description :

After being an object of studies for a few decades, quantum nanoelectronics is now moving forward to become the basis on which the first quantum computer could be build. The challenge is immense and even the most basic questions â€“ such as what should be the actual physical implementation of the quantum bits (qubit) â€“ do not have definite answers yet. The Grenoble community is actively following several experimental leads including GaAs/GaAlAs based spin or charge qubits, Silicon CMOS based qubits, superconducting qubits or flying qubits.

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nanoelectronics, superconductivity, magnetism and electronic correlations in close collaboration with experimental groups. The project will be done under the direction of Christoph Groth (christoph.groth@cea.fr) and Xavier Waintal (xavier.waintal@cea.fr).
We seek highly motivated students with a strong background in theoretical physics, quantum nanoelectronics and/or numerical simulations.

Requested skills :

theoretical physics, quantum nanoelectronics and/or numerical simulations

Subject 2

Interaction effects on topological properties of multiterminal Josephson junctions

Contact: Manuel HOUZET DRF//INAC/PHELIQS/GT manuel.houzet@cea.fr 0438789044

PhD may follow: Yes

Summary :

There is currently an active search for new phases of matter that admit topologically protected edge states. A promising route to realize them consists in combining conventional materials into appropriate heterostructures. Multiterminal Josephson junctions between conventional superconductors may be considered as topological materials themselves. As an example, 4-terminal junctions can accommodate topologically protected zero-energy bound states, which form so-called Weyl singularities. Their existence may be revealed through a quantized transconductance, like in the quantum Hall effect, but without magnetic field. The aim of the project will be to explore further this recent idea by investigating theoretically the robustness of this prediction in the presence of local Coulomb repulsion within the junction. In particular, the fate of Weyl singularities will be analyzed within an actual quantum-dot model for the junction.

Full description :

Topological phases of matter have attracted much interest in recent years. The existence of topological insulators has been unambiguously demonstrated in a variety of experiments [1]. First reports on the existence of Weyl semimetals have started to appear [2]. However, conclusive evidence for the realization of topological superconductors is still missing. Much of the progress in the field has been fuelled by the insight that, rather than relying on exotic material properties, topological phases may be engineered by combining different more conventional materials [3].

As we have predicted recently, multiterminal Josephson junctions may be considered as topological materials themselves [4]. Indeed, there is an intimate connection between the Josephson effect - a non-dissipative current flowing between two superconductors separated by an interface - and the formation of Andreev bound states localized near that interface and whose energy is below the superconducting gap. Topology teaches that there is more information encoded in the wavefunctions than in the bulk energy spectrum [5]. This is also the case for Andreev states. In particular, we showed that n-terminal Josephson junctions with conventional superconductors may provide a straightforward realization of tunable topological materials in n-1 dimensions. Namely, for n >= 4, the Andreev bound state spectrum of the junction can accommodate Weyl singularities in the space of the n-1 independent superconducting phases, which play the role of band structure quasi-momenta. Such Weyl singularities correspond to topologically protected zero-energy states.

In multiterminal Josephson junctions, the presence of Weyl singularities enables topological transitions that could manifest themselves experimentally as changes of the quantized transconductance, in units of 4e2/h, between two voltage-biased terminals. The quantized transconductance probes the first Chern number of two-dimensional slices through the space of the n-1 phases. Thus, it is similar to the quantum Hall effect.

The aim of the project will be to explore further the theoretical idea introduced in our work and to investigate the conditions for its experimental implementation. In particular, we propose to study the robustness of our prediction in a specific model for a 4-terminal junction, which consists of a small number of discrete levels that are weakly coupled to the leads. The candidate will start by exploring the conditions for the appearance and merging of Weyl points in the absence of interaction. She/he will then consider which modifications of the spectrum may be expected in the presence of local Coulomb repulsion. Following the recent suggestion of the interaction-induced emergence of parafermions in 2-terminal junctions between topological superconductors [6], she/he will study whether a fractional quantum Hall effect could be envisioned in a 4-terminal junction.

In the long-term, the relative simplicity of topological multiterminal Josephson junctions could be important for applications in the growing field of quantum engineering with superconducting devices. Indeed, the topological nature of the investigated effects could lead to applications in the fields of topologically protected quantum computation, as well as metrology.

[1] M.Z. Hasan and C.L. Kane, Rev. Mod. Phys. 82, 3045 (2010), http://arxiv.org/abs/1002.3895

[2] S.Y. Xu et al., Science 349, 613 (2015), http://arxiv.org/abs/1502.03807
[3] J. Alicea, Rep. Prog. Phys. 75, 076501 (2012), http://arxiv.org/abs/1202.1293
[4] R.-P. Riwar, M. Houzet, J.S. Meyer, and Yu. V. Nazarov, Nature Commun. 7, 11167 (2016), http://arxiv.org/abs/1503.06862
[5] M. Nakahara, "Geometry, Topology and Physics", IOP Ed.
[6] Fan Zhang and C.L. Kane, Phys. Rev. Lett. 113, 036401 (2014), http://arxiv.org/abs/1404.1072

see also: http://inac.cea.fr/en/Phocea/Vie_des_labos/Ast/ast.php?t=fait_marquant&id_ast=1173

Requested skills :

The theory project will be performed mainly by using the analytical tools of condensed matter field theory. It may also involve numerical aspects.

Interested candidates should have a good basis in quantum mechanics, statistical physics, and solid state physics.

Subject 3

Theoretical investigation of advanced magnetocaloric materials

Contact: Mike ZHITOMIRSKI DRF//INAC/PHELIQS/GT mike.zhitomirsky@cea.fr 04 38 78 43 30

PhD may follow: Yes

Summary :

An external magnetic field affects the entropy of a magnetic system and provokes temperature variations which can be used for magnetic refrigeration. Such an alternative cooling technology is increasingly important nowadays for space telescopes, particle physics experiments and quantum computing. The existing adiabatic demagnetization refrigerators utilize paramagnetic salts, which have limited capacity for temperatures above 1 K. Recently, two new families of magnetocaloric materials suitable for applications in the 1-4 K temperature range have been proposed: geometrically frustrated spin systems and dipolar magnets. We plan to study the magnetocaloric properties of such materials using large scale Monte Carlo simulations of realistic spin models appropriate for the known, Gd3Ga5O12 and GdLiF4, as well as for the prospective, Yb2Ti2O7 and Yb3Ga5O12, magnetocaloric materials. The theoretical study will benefit from a collaboration with the on-going experimental work at INAC.

Full description :

Computer simulations play an increasingly important role in the way scientists acquire knowledge about Nature. The Monte Carlo methods developed in the past 50 years have revolutionized the field of Statistical Mechanics. Initially used to study ideal simple models, the modern Monte Carlo techniques can be applied to real physical systems. This project is focused on the theoretical investigation of the magnetocaloric properties for a number of magnetic materials. Apart from the fundamental interest, this investigation has an important applied component related to the field of low-temperature magnetic refrigeration.

Actual performance of the adiabatic demagnetization refrigerators is determined by the ordering temperature of a refrigerant material. Therefore, the magnetocaloric properties can be improved by using magnetic materials with so called frustrated lattices, whose geometry precludes a simple magnetic ordering. In the past, we have developed the very efficient hybrid Monte Carlo algorithm and used them to study various properties of geometrically frustrated magnets. The initial task to be carried by student on this project is to develop a computer code for lattices with partial filling of magnetic sites. Such magnetic materials can be prepared by chemical substitution of nonmagnetic impurities. The modified code will be used to investigate the effect of nonmagnetic dilution with the aim to optimize the magnetocaloric properties of real materials. A complementary fundamental study will be devoted to the order from disorder effect in dilute frustrated magnets, which consists in selection of exotic types of magnetic order in degenerate frustrated magnets solely by the structural disorder.

Another class of magnetic solids with suppressed ordering transition includes materials with strongly reduced exchange interactions like in GdLiF4. Still, the dipole-dipole interactions between magnetic ions are always present and affect the material properties. Such materials have a great technological potential for magnetic refrigeration. To uncover this potential one needs to understand their basic physical properties. The student's task will include the analytic computations of the possible magnetic ground states of a dipolar magnet in zero and applied magnetic fields focusing on GdLiF4. In addition, the Monte Carlo codes have to be modified to take account of the long-range nature of the dipole interactions. Those will be used for theoretical investigation of the phase transitions and phase diagrams in two- and three-dimensional of dipolar magnets.

Requested skills :

Basic knowledge of programming and solid state physics

Subject 4

Higher-order topological insulators (Theory)

Contact: Julia MEYER DRF//INAC/PHELIQS/GT julia.meyer@cea.fr 04 38 78 31 46

PhD may follow: Yes

Summary :

Topological insulators are materials that are insulating in the bulk, but host topologically-protected conducting surface states. Much more recently the possibility of higher-order topological insulators has been predicted, where the conducting states live in two dimensions less than the bulk. Experimental evidence for such "hinge" modes has recently been found in Bismuth. Here, we want to explore the differences between the onedimensional edge states of a twodimensional topological insulator and the hinge modes of a threedimensional higher-order topological insulator.

Full description :

Topological insulators are materials that are insulating in the bulk, but host topologically-protected conducting surface states. As such the twodimensional quantum (spin) Hall insulator possesses robust onedimensional edge channels. Much more recently the possibility of higher-order topological insulators has been predicted [1], where the conducting states live in two dimensions less than the bulk. For example, a threedimensional system may have an insulating bulk and surfaces, but topologically-protected onedimensional Â« hinge Â» modes (see picture). Experimental evidence for such hinge modes has recently been found in Bismuth [2]. Here, we want to explore the differences between the onedimensional edge states of a twodimensional topological insulator and the hinge modes of a threedimensional higher-order topological insulator [3]. In particular, we will study their coupling to superconductors in Josephson junctions. Furthermore, we will consider the effect of disorder and a possible coupling to residual bulk/surface states.

[1] W.A. Benalcazar et al., Science 357, 61 (2017).
[2] F. Schindler et al., Nat. Phys. 14, 918 (2018).
[3] R. Queiroz and A. Stern, preprint arXiv:1807.04141.

Requested skills :

The theory project will be performed mainly by using the analytical tools of condensed matter field theory. It may also involve numerical aspects. Interested candidates should have a good basis in quantum mechanics, statistical physics, and solid state physics.

Subject 5

p-wave, spin-triplet, topological superconductivity in the ferromagnetic superconductors

Contact: Jean-pascal BRISON DRF//INAC/PHELIQS/IMAPEC jean-pascal.brison@cea.fr 0438785248

PhD may follow: Yes

Summary :

This master project, that should be continued as a PhD project, is focused on a particular class of strongly correlated superconductors, which are â€œspin-triplet/p-waveâ€• type superconductors, a highly sought-after state (e.g. it is necessary to generate Majorana quasiparticles). These p-wave superconductors are uranium-based systems (URhGe or UCoGe for this project), which are also ferromagnetic superconductors: both systems become first ferromagnetic on cooling, at around 9 or 3K respectively, and they remain so when they become superconducting (below 0.25K or 0.5K respectively).

Today, these ferromagnetic superconductors appear as the best ones to explore the rich physics of spin-triplet pairing, as they combine an uncontested p-wave state together with high-purity samples. The aim of the project is to get a much deeper knowledge of the p-wave order parameter (the â€œd-vectorâ€•) in UCoGe. During the M2 internship we will:

- explore the coupling of the d-vector to the magnetic field, which leads to the re-entrant/reinforced superconducting state, through thermal dilatation measurements.

- explore the conditions for the observation of the topological properties of the superconducting state, measuring the thermal Hall effects.

All measurements will be performed in dilution refrigerators, on crystals grown in the group. A strong theoretical support is also available in the laboratory.

Full description :

Superconductivity is one of the liveliest fields in basic research on condensed matter physics, due to the continuous discovery of new families of superconductors challenging our understanding of this phenomena. Most of these new families of superconductors are also strongly correlated electron systems, such as the high-Tc cuprates, iron pnictides, heavy fermionsâ€¦ They share the same key questions concerning their superconducting and normal state properties, and a central one is the origin of the pairing mechanism, which arises dominantly from electron-electron interactions, rather than from electron-phonon interactions. However, recently, it has been realized that the superconducting state of these unconventional superconductors could also have very peculiar topological properties, connected either to the band structure of the material or to the precise nodal structure of the superconducting gap.

This master project, that should be continued as a PhD project, is focused on a particular class of heavy fermion superconductors, which have the appealing feature of being â€œspin-triplet/p-waveâ€• type superconductors, a highly sought-after state (e.g. it is necessary to generate Majorana quasiparticles). These p-wave superconductors are uranium-based systems (URhGe and UCoGe for this project), which are also ferromagnetic superconductors: both systems become first ferromagnetic on cooling, at around 9 or 3K respectively, and they remain so when they become superconducting (below 0.25K or 0.5K respectively).

Moreover, in both systems, superconductivity seems to be reinforced under magnetic field, contrary to the situation of all other known superconductors. Indeed, URhGe shows a spectacular reentrance, and UCoGe a spectacular enhancement of superconductivity, when the ferromagnetic order vanishes as function of the applied magnetic field (see figure).

Today, these ferromagnetic superconductors are probably the best one to explore the rich physics of triplet pairing, as they are the only one combining an uncontested p-wave state together with high-purity samples. The aim of the M2 project is to get a much deeper knowledge of the p-wave order parameter (the â€œd-vectorâ€•) in UCoGe. Two main axes will be started during the M2 internship:

- exploring the coupling of the d-vector to the magnetic field, which leads to the re-entrant/reinforced superconducting state, through thermal dilatation measurements.

- exploring the conditions for the observation of the topological properties of the superconducting state, measuring the thermal Hall effects.

With thermal expansion, we want to explore the superconducting state as function of magnetic field with unequalled precision: most likely, in the region where ferromagnetism collapses inside the superconducting state, the spin-triplet p-wave order parameter has to evolve strongly, and we even expect

the occurrence of phase transitions between different superconducting phases.
UCoGe is predicted to be a â€œWeyl superconductorsâ€•, with nodal chiral excitations along the easy magnetization c-axis. Low energy surface states are then expected, that might concentrate in the chirality domain walls. The thermal Hall effect measurements that will be performed during the M2 internship is a very sensitive and selective probe of the electronic low energy excitations.
All measurements will be performed in dilution refrigerators, on crystals grown in the group. A strong theoretical support is also available in the laboratory.

Requested skills :

A strong tatse for instrumentation, experimental physics, quantum physics, ability to discuss with theorists and face complex problems.

Subject 6

Quantentransport in topological materials

Contact: Georg KNEBEL DRF//INAC/PHELIQS/IMAPEC georg.knebel@cea.fr 0438783951

PhD may follow: Yes

Summary :

The main purpose of the internship is to understand at the fundamental level the different unconventional phenomena that are present in newly discovered 3D topological semimetals using original experimental studies. Thus, the trainee will be involved in characterization measurements (resistivity, thermoelectric power, specific heat ...) at very low temperature and high magnetic field, the analysis of the data, and in the improvement of the experimental device. It will also be able to collaborate with the other people of the laboratory who make complementary measurements on these same compounds and it will be possible to carry out to carry out experiments on large instruments (LNCMI ...).

Full description :

Conventionally, band theory classifies materials as insulators, semiconductors or metals based on the presence (or not) and the size of an energy gap between the conduction band and the valence band. The semimetals are metals that are between semiconductors and metals. They are characterized by a weak overlap in energy between the valence band and the conduction band at particular points of the Brillouin zone, the most famous example being the graphene (2D). The 3D equivalent of graphene is the topological semi-metal grouping Dirac semimetal (Cd3As2, Na3Bi...) and Weyl semi-metal (TaAs, NbAs ...). The particular points of the Brillouin zone, for which the conduction and valence bands are touching, are called nodes Weyl (or Dirac points). Near these points, the energy dispersion as function of the electronic wave vector k is linear in the three directions of space forming Dirac cones. The richness of these materials comes from the presence of these Weyl nodes around which the electron wave function will acquire an exotic topological phase or Berry phase. Topological aspects are eagerly looked for such because they produce new phenomena such as topological surface states and could be used for future applications in spintronic and quantum transport. The main objective of the project is to understand at a fundamental level the various unconventional phenomena that are present in the topological 3D semimetals with original experimental studies. The PhD student will have the possibility to participate in crystal growth. We will also try to grow thin films of these materials and to performed detailed studies depending on the geometry of the samples. Uniaxial and hydrostatic pressure will be used to fine-tune the Fermi level. The candidat will have to perform various kinds of measurements (resistivity, thermoelectric power, specific heat...) at very low temperature and high magnetic field, data analysis, and improving the experimental device. To attend the quantum limit of these materials, experiments will be performed at the high magnetic field laboratories in Grenoble and Toulouse.

Requested skills :

instrumentation, experimental physics, solid state physics

Subject 7

Heterostrain physics in twisted graphene layers

Contact: Vincent RENARD DRF//INAC/PHELIQS/LATEQS vincent.renard@cea.fr 0438786225

PhD may follow: Yes

Summary :

The study of twisted graphene layers (graphene layers stacked with a rotation between the layers) has been recently boosted by the discovery of new correlated states of matter (superconductivity and Mott insulator) in this full carbon system. Such new physics occurs due to electron-electron interactions boosted at peculiar rotation angles between the layers. We have recently shown that the electronic properties of such not only depend on the rotation between the layers but also on relative deformations of the layers which we have called heterostrain. The aim of the present project is to control and study heterostrain, hunting for potential new states of matter.

Full description :

We are looking for a motivated candidate for a Phd project preceded by a master's training on heterostrain in twisted graphene layers.

A moirÃ© appears in twisted graphene layers which results from the superposition of the two atomic lattices with a rotation angle (See figure below). The resulting moirÃ© potential has been shown to lead to a pletora of new physical phenomena. From van Hove singulatities which energy is tunable by the twist angle [1], to electron localization by the moirÃ© potential [2] and the creation of topologically protected one-dimensional states in systems with very low rotation angle [3]. Year 2018, was very fruitful for this system with the report of three important resultsÂ :

1) Superconductivity was demonstrated to emerge in twisted graphene layers when the rotation angle is carefully adjusted to a precise â€˜magic' value [4].

2) The system was reported to be a quasi-cristal (system with rotational symetry but no translationnal symmetry) when the rotation angle is 30Â° [5]

3) The electronic properties of the system were shown to be determined not only by the rotation angle between the layers but also by relative deformations of the layersÂ : heterostrain [6].

This last discovery was made in our group using a formalism developed by a former PhD student to quantify heterostrain and performing scanning tunneling microscopy measurements on samples where the heterostrain was native (resulting from the growth). While these have opened a new area of research by demonstrating the impact of heterostrain we have at present no control of this parameter. The Phd project therefore aims at developing ways to control heterostrain to be able to study its influence on the electronic properties by low temperature STM and possibly discover new states of matter. The attendee with a strong background in condensed matter physic will be involved at all steps: sample preparation, design and fabrication of the system allowing to tune heterostrain, STM measurements and analysis. The analysis will be done in collaboration with the Theoretical team of Cergy Pontoise which has a long experience in twisted graphene layers.

References

[1] G. Lucian et al. Nature Physics 6, 109 (2010)

[2] G. T. de LaissardiÃ¨re et al. Nanoletters 10, 804 (2010)

[3] S. Huang et al. Phys Rev. Lett. 121, 037702 (2018)

[4] Y. Cao et al. Nature 556, 43 (2018)

[5] S. J. Ahn et al. Science 361,782 (2018)

[6] Huder et al. Phys Rev. Lett. 120, 156405 (2018)

Requested skills :

Condensed matter physics, experiments

Subject 8

Superconductor / Semiconductor hybrid nanostructures based on Germanium for quantum information

Contact: Francois LEFLOCH   DRF//INAC/PHELIQS/LATEQS   francois.lefloch@cea.fr   0438784822

PhD may follow: Yes

Summary :

Holes in germanium have the advantage to possess a strong spin-orbit coupling enabling fast electrical control of their spin. In addition, p-type germanium has the tendency to form low-Schottky-barrier contacts with several metals, including superconducting ones. This opens the opportunity to realize novel hybrid superconductor-semiconductor devices relying on the superconducting proximity effect in germanium.

The goal of this project is to fabricate and study nano-devices embedding a 2D hole gas confined to a germanium well. More specifically, we aim at realizing quantum-dot and quantum-wire nanostructures in which individual hole spins are electrically controlled by means of electrostatic gates. Then we plan to connect such nanostructures to superconducting electrodes to obtain novel types of high-quality hybrid devices such as gate-tunable transmons, i.e. â€œgatemonsâ€•.

Two types of germanium layers will be studied: high-mobility, strained-Ge quantum wells in Ge/Ge0.8Si0.2 heterostructures), and Ge layers on insulator (GeOI).

The strong spin-orbit coupling in combination with the superconducting proximity effect will be exploited to reach topological superconductor states hosting Majorana-fermion edge quasi-particles.

This internship can naturally evolve into a longer-term PhD project. The student will take active part in device fabrication at the PTA cleanroom and low-temperature transport measurements in dedicated cryostats equipped with superconducting vector magnets.

Full description :

Holes in germanium have the advantage to possess a strong spin-orbit coupling enabling fast electrical control of their spin. In addition, p-type germanium has the tendency to form low-Schottky-barrier contacts with several metals, including superconducting ones. This opens the opportunity to realize novel hybrid superconductor-semiconductor devices relying on the superconducting proximity effect in germanium.

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The strong spin-orbit coupling in combination with the superconducting proximity effect will be exploited to reach topological superconductor states hosting Majorana-fermion edge quasi-particles.

This internship can naturally evolve into a longer-term PhD project. The student will take active part in device fabrication at the PTA cleanroom and low-temperature transport measurements in dedicated cryostats equipped with superconducting vector magnets.

Requested skills :

Master in Physics

Subject 9

Development of AlGaN nanostructures for electron-pumped UV light emitting devices

Contact: Eva MONROY DRF//INAC/PHELIQS/NPSC eva.monroy@cea.fr 0438789068

PhD may follow: Yes

Summary :

The student will participate in a project to develop a new concept of UV lamp based on electron pumping of AlGaN nanostructres. Within this project, the master student will be in charge of the fabrication of AlGaN-based nanowires emitting in the UV-B and UV-C ranges, their structural and optical characterization, comparison of the results with theoretical calculations using a commercial software, and finally comparison of the performance of such nanowire structures with quantum wells and quantum dots available in our laboratory.

Full description :

Our project is a contribution to the development of high-brightness, mercury-free, 100% recyclable and high-gloss UV lamps. UV disinfection is usually carried out using discharge lamps containing large quantities of mercury, a highly toxic substance strictly regulated by EU directives. The currently explored alternative consists of UV (LED UV) light emitting diodes based on AlGaN semiconductors. However, after more than 15 years of R&D, the UV LED technology is progressing very slowly, and comparative studies show that it is still far from rivaling the mercury lamp. The performance of UV LEDs remains limited by two major problems: the high activation energy of the dopants in the AlGaN and the diffusion length of the holes in these materials, extremely smaller than that of the electrons.

To circumvent the problems associated to the UV LED technology, we propose to pump an active region based on AlGaN nanostructures with an electron beam. In such a configuration, electrons and holes are generated throughout the active medium with the same spatial distribution, without the need for doping or electrical contacts.

Within this project, the master student will be in charge of (i) fabrication of AlGaN-based nanowires emitting in the UV-B and UV-C ranges, (ii) structural and optical charterization, (iii) comparison of the results with theoretical calculations using a commercial software, and (iv) comparison of the performance of such nanowire structures with quantum wells and quantum dots (available in our laboratory).

The strudent will be trained in the use of molecular-beam epitaxy, scanning electron microscopy, photoluminescence, cathodoluminescence and modeling of the electronic structure using the Nextnano commercial software.

Requested skills :

Knowledge of semiconductor physics and taste for experimental work.

Subject 10

Contribution to the fabrication of an electron-pumped UV laser

Contact: Eva MONROY DRF//INAC/PHELIQS/NPSC eva.monroy@cea.fr 0438789068

PhD may follow: Yes

Summary :

During the internship, the student will contribute to the design of the active region of a semiconductor laser structure emitting at 350 nm. He/she will participate to the growth of test structures containing quantum wells and quantum dots as active media. He will characterize the structure by x-ray diffraction, photoluminescence and cathodoluminescence. In view of the results in terms of internal quantum efficiency and linewidth, a decision will be made on the optimum structure for the fabrication of optimized laser structures.

Full description :

There is a strong demand for deep-UV lasers for applications such as Lidar remote detection, non-line-of sight communication, chem-bio sensing, 3D printing, etc. This spectral range is currently covered by gas lasers or lasers based on frequency conversion, which are bulky, inefficient, and inflexible in wavelength. Laser diodes should provide an alternative solution, but their implementation is held back by the difficulties to fabricate highly-conductive p-AlGaN cladding layers. In this project, we will develop a new compact UV-laser technology based on the excitation of AlGaN nanostructures by a highly energetic electron beam from a carbon nanotube cathode. We target Peltier-cooled quasi-continuous-wave devices at 350 nm and 265 nm, with an average output power > 50 mW. The choice of wavelengths aims at a direct comparison with the Nd-YAG technology.

During the internship, the student will contribute to the design of the active region of the laser structure emitting at 350 nm, from the electronic and optical viewpoints. He/she will participate to the growth of test structures containing quantum wells and quantum dots as active media. He will characterize the structure by x-ray diffraction, photoluminescence and cathodoluminescence. In view of the results in terms of internal quantum efficiency and linewidth, a decision will be made on the optimum structure for the fabrication of the laser.

The strudent will be trained in molecular beam epitaxy, photoluminescence, cathodoluminescence, x-ray diffraction, and modelling using nextnano and comsol.

Requested skills :

Knowledge of semiconductor physics. Taste for experimental work on optoelectronics.

Subject 11

Molecular beam epitaxy growth and optical characterization of GaN on graphene/GaN substrate

Contact: Bruno DAUDIN DRF//INAC/PHELIQS/NPSC bruno.daudin@cea.fr 0438783750

PhD may follow: Yes

Summary :

Among the multiple advantages of graphene, its use as a substrate for nitride semiconductors is particularly attractive: besides allowing the epitaxial growth of these technologically important materials on any substrate, graphene promotes an elastic decoupling of the epitaxial layer from the substrate with the subsequent advantage of minimizing or even suppressing the crystalline defect formation (for instance dislocations) associated with the lattice mismatch with the substrate and concomitant elastic strain relaxation. This is particularly true for nitride semiconductors (GaN and alloys) which are the building block of white LEDs, more and more used those days in the context of energetic transition. Along these lines, we propose to use the concept of â€œremote epitaxyâ€• to grow high quality GaN layers. For this purpose a layer of graphene will be deposited on a thick GaN substrate (in collaboration with the SystÃ¨mes Hybrides de basse dimensionalitÃ© team of Institute NÃ©el). Next, GaN will be grown on this substrate by molecular beam epitaxy (in the laboratory INAC/PHELIQS/NPSC of CEA-Grenoble). Due to the very small thickness of graphene (one monolayer), we expect that the epitaxiated layer will keep the â€œmemoryâ€• of the substrate and grow in monocristalline form. But we also expect that this monolayer of graphene will ensure a sufficient elastic decoupling from the substrate to avoid the transfer of the dislocations from the substrate to the epitaxiated layer. Then, our goal is to finally obtain a material of excellent crystalline and optical qualities and contribute to overcome an enduring problem inherent to nitride materials, which has still to be solved in spite of the international progress registered in the field.

Requested skills :

interest in experimental science. Curiosity. Interest in material science

Subject 12

Visible LED realization on polarity controlled substrate

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PhD may follow: Yes

Summary :

The exceptional structural and optical properties of III-V semiconductor nanowires (GaN, AlN, InN and their alloys) make them attractive candidates for a future generation of visible and ultraviolet light emitting diodes (LEDs). The crystallographic phase of these materials (wurtzite) is not centrosymmetric: as a result, the epitaxial layers â€“or the nanowires- are terminated either by a nitrogen plane or by a metal one. The nitrogen polarity being associated with point defects incorporation, the realization of efficient, nanowire-based, devices implies to use metal polarity and to control it. Considering that GaN nanowires spontaneously nucleated on Si or numerous alternative substrates exhibit nitrogen polarity, their conversion to metal polarity is essential to realize optimized LEDs. Preliminary experiments have demonstrated that such a conversion can be achieved by way of oxygen plasma treatment of nitrogen polar GaN nanowires. The goal of the internship will be to confirm these preliminary results and next realize GaN/InGaN LED structures to compare their properties to their nitrogen polar counterparts. The internship will be focused on experiment and will provide training to molecular beam epitaxy (MBE) of GaN nanowires, to plasma treatment, scanning electron microscopy (SEM) and cathodoluminescence. The application ultimately targeted deals about the realization of nanowire LEDs on large silicon substrates. Prolongation in PhD is possible.

Requested skills :

interest in experimental science

Subject 13

Bacteria analysis and control by optical microcavity

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PhD may follow: Yes

Summary :

Silicon nanophotonic structures can strongly focus light. This results in a very intense electromagnetic field capable of attracting and trapping a bacterium. The latter is then identified by analyzing the fluctuations of the light intensity transmitted by the optical structure. This device still in the development phase has made it possible to distinguish three types of bacteria in a few seconds. This internship is part of the continuity of this study, where we want to study, not only other bacteria, but also the behavior of these bacteria according to external agents (life and death of the cell, effect of an antibiotic effect of temperature).

Full description :

Radiation pressure is the force exerted by the light when it meets or crosses an object. This small force can move or manipulate, in the manner of a mini clamp, objects of micrometric size. Generally implemented through a microscope, it is called optical tweezing.

The laboratory has a long experience in the study of photonic crystal microcavities. It has been demonstrated that optical microcavities manufactured on Silicon On Insulator (SOI) substrate make it possible to achieve extremely efficient confinement of the electromagnetic field, both from the spectral and spatial point of view. The detection and quantification of the optical forces (radiation pressure and gradient) generated by these microcavities was obtained by observing the movement of micrometric particles placed in solution nearby the structures. It has thus been demonstrated that these optofluidic systems allow the trapping, assembly, manipulation and sorting of micro-nano objects in suspension. We went one step further by successfully identifying a bacterium trapped through its optical signature.

As part of this master's subject, we plan to continue these studies by evaluating the potential of these optofluidic technologies in the field of cell biology. A first step will be to evolve the components to an integrated system able to maintain cell viability and compatible with the constraints of spectroscopic measurements. The final objective of this internship will be to propose an optofluidic silicon system allowing to analyze and / or dynamically control the response of a cell to external agent (antibiotic, heat, food). The work will be conducted in collaboration with teams specialized in of life and health technologies.

Recent publications:

R. Therisod, M. Tardif. et al. â€œGram-type differentiation of bacteria with 2D hollow photonic crystal cavitiesâ€•, Appl. Phys. Lett. 113, 111101 (2018)

Tardif, M. et al. â€œSingle-cell bacterium identification with a SOI optical microcavityâ€•, Appl. Phys. Lett. 133510, (2016).