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Location and web-site *(LNCMI-T or G)*	LNCMI-T (http://www.toulouse.lncmi.cnrs.fr/)
Level required *(M1-M2 ...)* **Year**	Master 2 2013
Title of the subject	Dirac Fermion under Extreme Experimental Conditions

Summary*(5 lines maxi)*

Dirac fermions in condensed matter are quasi-particles presenting very peculiar properties opening innovative routes for emerging nanoelectronics. The goal of the Master Internship is to study the electronic properties of Dirac fermions in new 1D and 2D materials taking advantage of the unique experimental conditions available at the LNCMI-T. The candidate will be in charge of devices preparation and electronic transport measurements to reveal the quantum states of Dirac fermions.

Detailed subject

When a new material or physical system is discovered, scientists naturally envision a myriad of experiments dedicated to understand its fundamental electronic or optical properties and hope for some new and exciting applications that may result. Very often, many of these new "objects" never fulfill such expectations, but sometimes a material with outstanding properties is discovered and focuses the attention of the scientists worldwide. Graphene is one of these wonderful examples [1]. In large part, the interest in graphene is driven by the unique properties of its quasi-particles, called Dirac fermions.

Dirac fermions in condensed matter are charge carriers that mimic relativistic particles with zero rest mass. Very peculiar electronic properties have been unveiled recently [2], such as the non-zero minimum of graphene's conductivity at evanescent charge carrier concentration and the tunnelling with unit probability through classically forbidden electrostatic barriers (the so-called Klein paradox). The presence of 2D Dirac fermions has also been recently demonstrated in 3D topological insulators. Indeed, while the bulk states in these materials are fully gapped, there is a topologically protected surface state consisting of massless Dirac fermions [3]. Such surface states are robust against disorder and promising for dissipationless electron transport in absence of high magnetic field.

These exceptional electronic properties open promising routes for the emerging of nanoelectronics devices relying on Dirac fermions. Two challenges are currently addressed and constitutes the heart of this Master internship : The first one is a deep understanding of the fundamental electronic properties by taking advantage of extreme experimental conditions available at the LNCMI-T. The second one consists in structuring the 2D fermions into a one-dimensional electronic wave guide useful for nanoelectronics devices. New quantum phenomena are expected to emerge depending on the strength of the confinement [4].

The Laboratoire National des Champs Magnétiques Intenses (LNCMI) of Toulouse benefits from the powerful combination of both nanoscience oriented research, and the generation of very high magnetic field up to 80T. Dedicated magneto-transport experiments are specially

designed to probe the electronic properties of individually connected nano-objects down to 300mK. The control of technological processes for home-made high quality 2D and 1D nano-devices (Fig.1) along with the extreme experimental conditions described above provide a unique scientific environment. Ground-breaking results have recently been obtained at the LNCMI, such as the giant Aharonov-Bohm conductance modulation and the onset of propagative Landau states in ballistic carbon nanotubes [5], the IQHE in trilayer graphene which highlights the importance of the stacking order of the layers (Fig.2) [6] and the unusual Landau quantization in graphene nanoribbons driven by valley degeneracy lifting effects [7].

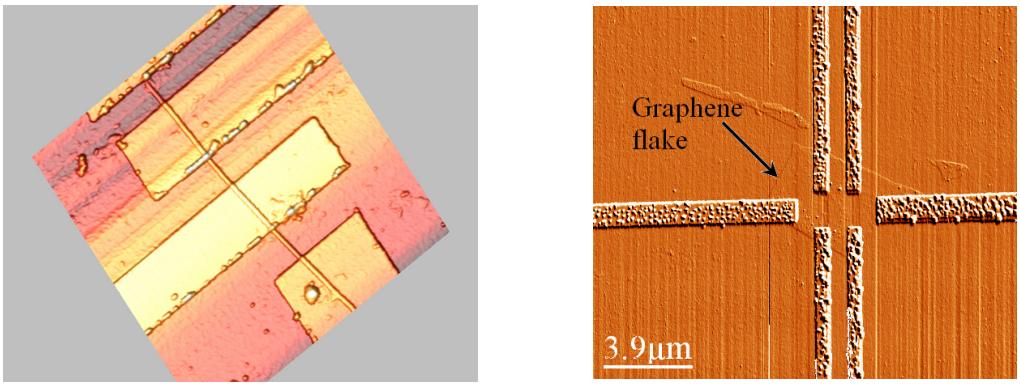

Fig.1 : On the left, AFM observation of a multi-wall carbon nanotube connected to Pd-electrodes and presenting a quasi-ballistic behaviour. On the right, AFM image of a graphene flake connected in a Hall bar configuration. Both devices were fabricated at the LNCMI.

The successful candidate will take part in the activities of the "*Nano-object and semiconducting Nanostructures"* group at the LNCMI-Toulouse. He will be mostly in charge of :

- the graphene nanoribbon and topological insulator devices preparation including nanotechnology processes in clean room,
- the electronic transport measurements under extreme experimental conditions (62T, 300mK) to unveil the unusual properties of these new materials.

The candidate will benefit to fruitful and longstanding collaborations with international theoreticians. He also will take part to a collaborative Egide program (YuanPie) between the "*Nano-object and semiconducting Nanostructures"* group and the university of Nanjing (China). This includes working visits at the National Laboratory of Microstructures, School of Electronic Science and Engineering, Nanjing University to explore the electronic properties of ultra-narrow graphene ribbons synthesized by unzipping carbon nanotubes.

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Publications linked to the theme	
- [1] A. K. Geim and K. S. Novoselov, Nature Materials 6, 183-191 (2007). - [2] A. H. Castro Neto et al., Reviews of Modern Physics 81, 109–162 (2009). - [3] M.Z. Hasan and C.L. Kane, Rev Mod Phys **82**, 3045 (2010). - [4] K. Wakabayashi et al, Carbon 47, 124 (2009). - [5] B. Raquet & al, Phys. Rev. Lett. **101**, 046803 (2008). - [6] A. Kumar & al, Phys. Rev. Lett. **107**, 126806 (2011). - [7] R. Ribeiro & al, Phys. Rev. Lett. **107**, 086601(2011).	
This Master training could be extended into a PhD within the same research subject.	
Education/skills expected : Master in Physics (condensed matter) is required.	
Salary [1]:	700€/month
Supervisor :	Pr. Bertrand Raquet and XX
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[1] M1 = 436€/month
M2 = 700€/month