Project **P1408 Clean Zigzag and Armchair Graphene Nanoribbons**

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Abstract We are looking for an excellent and highly motivated graduate student who would like to join our team in Basel working on the fabrication of graphene nanoribbons and quantum transport measurements. In the envisioned experiments, we will develop new fabrication techniques aimed at creating ultra-clean graphene nanoribbons with high-quality zigzag or armchair edge termination. We will perform low-noise electronic transport measurement at low temperatures in magnetic fields in order to investigate novel quantum states of matter such as graphene ballistic 1D modes, edge antiferromagnetism, helical states and Majorana fermions.

Motivation Graphene has developed into a very fertile and exciting playground for the study of novel electronic states [1]. Confining graphene in form of a nanoribbon opens up an electronic gap which is otherwise absent in bulk graphene. Furthermore, if the nanoribbon is terminated with well defined edges, great opportunities arise for exploring intriguing novel quantum states such as antiferromagnetic electron spin order [2–6], helical states [7], and topological phases sustaining Majorana fermions with non-Abelian braiding statistics [7]. Such quantum states have recently attracted a lot of attention due to the fascinating new physics as well as the potential for applications in sensing, spintronics, and topological quantum computation. However, fabrication of clean ribbons with well defined crystallographic edges is very challenging.

This Project, will be a hands-on experimental effort to develop an anisotropic etching technique based on a cold, remote plasma [8–10] towards fabrication of clean zigzag and armchair ribbons with low disorder (see Fig. 1). Following the proposal of Klinovaja et al. [7], will pattern nanomagnets along the ribbon to create a giant spin-orbit coupling and helical states (see Fig. 1b). We will add an s-wave superconductor to induce proximity effect and a topological transition in presence of a magnetic field. After each step, we will employ quantum transport spectroscopy at low temperatures to study the ribbon devices. Graphene nanoribbons are a great playground for novel quantum states, offering very large subband splittings, giant SO coupling, and facile proximity effect.

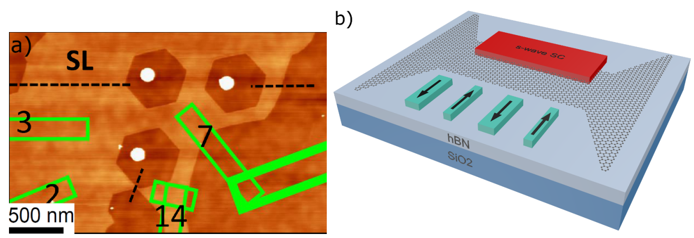

Figure 1: a) Remote plasma fabricated zigzag graphene nanoribbons b) sketch of devices for helical states and majorana Fermions: *armchair* ribbon with nanmagnets (cyan) and s-wave superconductor (SC, red) on hexagonal Boron Nitride.

Candidates need to hold a masters (or equivalent) degree, preferably in physics. Prior experience in (experimental) condensed matter/mesoscopic physics and nanofabrication would be helpful. German language proficiency is not necessary. Graduate students are expected to work with postdocs as well as graduate and undergraduate students. The Department requires assumption of teaching assistant responsibilities (about one day per week effort during semesters). Starting date: early 2015. Duration of Ph. D. research: 4 years.

The **Department of Physics in Basel** offers a highly stimulating and collaborative environment with active and internationally recognized research groups in both experimental and theoretical condensed matter physics. Our group is part of
- Swiss Nanoscience Institute (SNI), sponsor of this fellowship
- Quantum Science and Technology NCCR QSIT (Swiss NSF)
- Basel QC2 Center for Quantum Computing and Quantum Coherence

To apply, please submit
- curriculum vitae
- publications and/or a thesis, if available
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- short description of interests and skills might be helpful
Please contact Dominik.Zumbuhl@unibas.ch with any questions.

References

[1] S. Das Sarma, S. Adam, E. H. Hwang, and E. Rossi, Rev. Mod. Phys. **83**, 407 (2011).

[2] M. Fujita, K. Wakabayashi, K. Nakada, and K. Kusakabe, J. Phys. Soc. Jap. **65**, 1920 (1996).

[3] K. Nakada, M. Fujita, G. Dresselhaus, and M. S. Dresselhaus, Phys. Rev. B **54**, 17954 (1996).

[4] Y.-W. Son, M. L. Cohen, and S. G. Louie, Nature **444**, 347 (2006).

[5] Y.-W. Son, M. L. Cohen, and S. G. Louie, Phys. Rev. Lett. **97**, 216803 (2006).

[6] O. V. Yazyev, Rep. Prog. Phys. **73**, 056501 (2010).

[7] J. Klinovaja and D. Loss, Phys. Rev. X **3**, 011008 (2013).

[8] B. McCarrol and D. W. McKee, Carbon **9**, 301 (1971).

[9] R. Yang et al., Advanced Materials **22**, 4014 (2010).

[10] Z. Shi et al., Advanced Materials **23**, 3061 (2011).