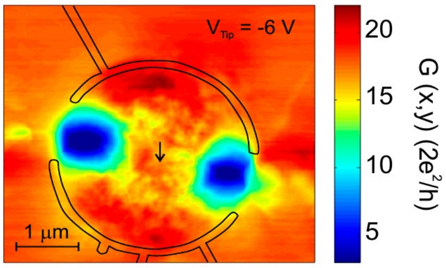
Theory of Scanning Gate Microscopy in two-dimensional Materials

Directeur de thèse : Dietmar Weinmann
Institut de Physique et Chimie des Matériaux de Strasbourg
23 rue du Loess, 67034 Strasbourg cedex 2
Tel : 03 88 10 72 17 ; e-mail : dietmar.weinmann@ipcms.unistra.fr



The investigation of electronic transport through nanostructures is crucial for the development of modern electronic devices. In parallel, the influence of quantum coherent processes places the problem at the fundamentally interesting interface between classical and quantum physics. While transport experiments traditionally measure the conductance, and its dependence on parameters like an applied magnetic field, Scanning Gate Microscopy (SGM) [1,2] adds spatial resolution. It consists of measuring the conductance changes induced by a local potential perturbation created by a charged AFM tip scanning the surface of the sample. The resulting maps of conductance as a function of the tip position (see the figure for an example from Ref. [3]) yield rich information about the transport through the sample. In order to exploit the potential of those data for improving our understanding of quantum transport, a theoretical analysis of the situation is essential. Our group has developed a systematic perturbative approach [4,5] that proved useful to describe the weak tip regime in recent experiments on ballistic cavities [6]. For the case of invasive tips, we have used numerical quantum calculations [3,6] and a semiclassical approach based on electron trajectories [3] to describe the tip-induced conductance changes.

While most experiments have been performed on semiconductor heterostructures, very recent experimental developments show interesting features in the SGM of strictly two-dimensional materials [7]. The present project is to generalize our theoretical approaches towards the situation of such materials, in particular single- and bilayer graphene and transition metal dichalcogenide (TMD) monolayers, by taking into account the effects of the corresponding electronic dispersion relations. We will then investigate the particularities of SGM in those materials. Furthermore, we plan an attempt to extract details of the typically weak disorder potential in a sample from SGM maps. An approach to this problem could be to calculate the SGM-response for different disorder realizations and to use machine-learning methods to solve the inverse problem.

The theoretical tools and concepts to be used are the basic ones of quantum transport through mesoscopic systems, including analytical (semiclassical expansions) and numerical (quantum transport and classical trajectories) methods. The student will work in the Mesoscopic Quantum Physics Team at IPCMS, in close contact with experimentalists, in particular with the group of K. Ensslin at the ETH in Zürich.

References:

[1] M.A. Topinka *et al.*, *Science* **289**, 2323 (2000); *Nature* **410**, 183 (2001)
[2] H. Sellier *et al.*, *Semicond. Sci. Technol.* **26**, 064008 (2011); and references therein
[3] C. Pöltl, A. Kozikov, K. Ensslin, T. Ihn, R.A. Jalabert, C. Reichl, W. Wegscheider, D. Weinmann, *Phys. Rev. B* **94**, 195304 (2016)
[4] R.A. Jalabert, W. Szewc, S. Tomsovic, and D. Weinmann, *Phys. Rev. Lett.* **105**, 166802 (2010)
[5] C. Gorini, R. A. Jalabert, W. Szewc, S. Tomsovic, D. Weinmann, *Phys. Rev. B* **88**, 035406 (2013)
[6] R. Steinacher, C. Pöltl, T. Krähenmann, A. Hofmann, C. Reichl, W. Zwerger, W. Wegscheider, R. A. Jalabert, K. Ensslin, D. Weinmann, T. Ihn, *Phys. Rev. B* **98**, 075426 (2018)
[7] B. Brun et al., arXiv:1811.02929