Final report

Marie Curie ERG 239223 – NanoQuantum Devices

Fabrication and transport characterization facilities

The central aim of the present ERC project was to start a new research direction at the host institute: the fabrication and transport characterization of nanoelectronic devices. Since device fabrication facilities were not available before, an **electron beam lithography** (EBL) **system** has been installed. It consist a second-hand scanning electron microscope (Jeol 848) combined with Raith lithography software (see Fig. 1a). After optimizing the system **sub 50nm writing resolution** has been achieved (see Fig. 1b) which opened the way to fabricate various nanostructures. It was widely used to define electric leads to nanoobjects, like semiconductor nanowires, graphene. Furthermore it was also used for other purposes as well, like generating optical lithography masks or template for nanowire growth. The cryogenic infrastructure of the host laboratory has also been extended to enable **low temperate electric characterization** of the fabricated nanocircuits (see Fig. 1c-d): sample holders and computer controlled transport measurement setup has been developed (see Fig. 1c-d).

InAs Nanowire based nanocircuits

Beside the EBL, several fabrication steps are required to produce an InAs Nanowire (NW) based electric circuits (e.g. plasma cleaning, passivation, metallization, bonding), which were all optimized using the available equipments in the home surrounding. Various InAs nanowire based devices were fabricated. We have extensively investigated the possibility to electrically tune the spin-orbit interaction in these circuits by **weak localization** measurements (see Fig. 2a). **Quantum dots** have also been formed in such InAs wires by different fabrication techniques, e.g. local chemical etching of the NW or high resolution bottom gate structures predefined bellow the NW (see. Fig. 2b) [1]. If an InAs NW based quantum dot **coupled to a ferromagnetic (F) lead** the spin ground state of the dot can be gate tunable [2]. We have shown, that this configuration is very promising for efficient **spin injector device**s [3]. First the quantum dot at the ferromagnet normal interface greatly enhances the spin polarization of the current (see Fig. 2c), secondly it allows the change of the orientation of the polarization by electrical means. The quantum dot system is even more exciting, when the F - quantum dot system is coupled to a superconducting lead in addition [4], where the **interplay of ferromagnetism and superconductivity** provides a special subgap feature.

Graphene and single atom based nanojunctions

Beside InAs NW based devices we also stared to develop graphene nanocircuits. Particularly, we explored the fabrication of **graphene nanoribbons** (see Fig. 2) with the combination of a special carbo thermal etching process and EBL [5]. Atomic sized junctions provides an other interesting superconducting hybrid system, when a single atom contact is placed between two superconducting electrode. From the nonlinear subgap I-V characteristics the full **mesoscopic pin code** of the single atom contact can be extracted (see Fig. 2e). We have performed detailed pin code analysis for In nanojunctions [6]. The direct visualization of atomic and single molecular junctions is not possible for most of the experiments, therefore the identification of the precise atomic configuration is based on the transport data and its comparison to simulation. We proposed a **new statistical method** to analyze the transport data, which provides significantly more information than the commonly used conductance histogram technique [7].

Organization and teaching activity

In the framework of the present grant a **new research group** has been established at the host institute focusing on quantum transport in hybrid nanocircuits (http://nano.bme.hu/kvantumtranszport.htm). Beside the PI, 4 master students and 1 BSc has been involved in the research activity. Since 2010, the PI also organizes a **new Nanophysics seminar & Journal Club** on weekly basis, which provides a unique opportunity for the young researchers and students at the host university to get familiar with the recent research results of the field (http://nanowiki.phy.bme.hu/Nanophysics_seminar). In addition a **new course** has been organized **for physics** graduate and undergraduate **students** with the title of Transport in Complex Nanostructures.

References

[1] P.D. Nissen, T.S. Jespersen, K. Grove-Rasmussen, A. Marton, S. Upadhyay, M.H. Madsen, **S. Csonka**, and J. Nygard *Comparison of gate geometries for tunable, local barriers in InAs nanowires,* submitted to Applied Physics Letters (2012).

[2] L. Hofstetter, A. Geresdi, M. Aagesen, J. Nygård, C. Schönenberger, and **S. Csonka** *Ferromagnetic Proximity Effect in a Ferromagnet–Quantum-Dot–Superconductor Device*, Phys. Rev. Lett. 104, 246804 (2010).

[3] **S. Csonka**, I. Weymann and G. Zarand, *An electrically controlled quantum dot based spin current injector*, accepted in RSC Nanoscale (2012).

[4] H. Soller, L. Hofstetter, **S. Csonka**, A. Levy Yeyati, C. Schonenberger, and A. Komnik, *Kondo effect and spin-active scattering in ferromagnet-superconductor junctions,* accepted in PRB (2012).

[5] P. Neumann, E. Tóvári, **S. Csonka**, K. Kamarás, Z. E. Horváth, L. P. Biró, *Large scale nanopatterning of graphene,* Nuclear Instruments&Methods In Physics Research Sec. B 282, 130 (2012).

[6] P. Makk, D. Visontai, L. Oroszlany, D. Zs. Manrique, **S. Csonka**, J. Cserti, C. Lambert, A. Halbritter, *Advanced simulation of conductance histograms validated through channel- sensitive experiments on indium nanojunctions,* Phys. Rev. Lett., 107, 276801 (2011).

[7] P. Makk, D. Tomaszewski, J. Martinek, Z. Balogh, **S. Csonka**, M. Wawrzyniak, M. Frei, L. Venkataraman, A. Halbritter, *Correlation Analysis of Atomic and Single-Molecule Junction Conductance*, accepted in ACS Nano (2012).

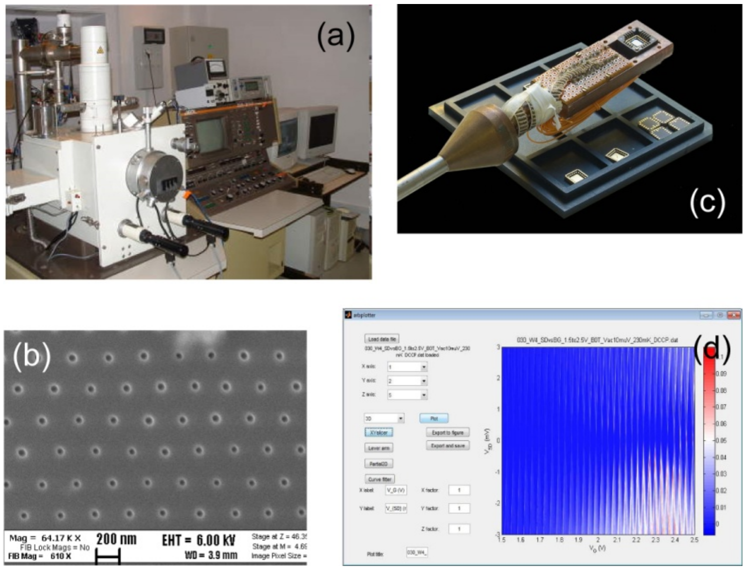

Fig. 1 *Fabrication and transport measurement facilities a) E-beam lithography system (EBL). A second hand Jeol 848 SEM with Raith e-beam unit, which was installed in the framework of ERG project. b) Structure defined by the EBL demonstrating resolution bellow 50nm. c) One of the developed cryogenic sample holder which allows the investigation of electronic properties of the nanocircuits at low temperatures. d) Computer controlled measurement interface, which suitable for quantum dot spectroscopy.*

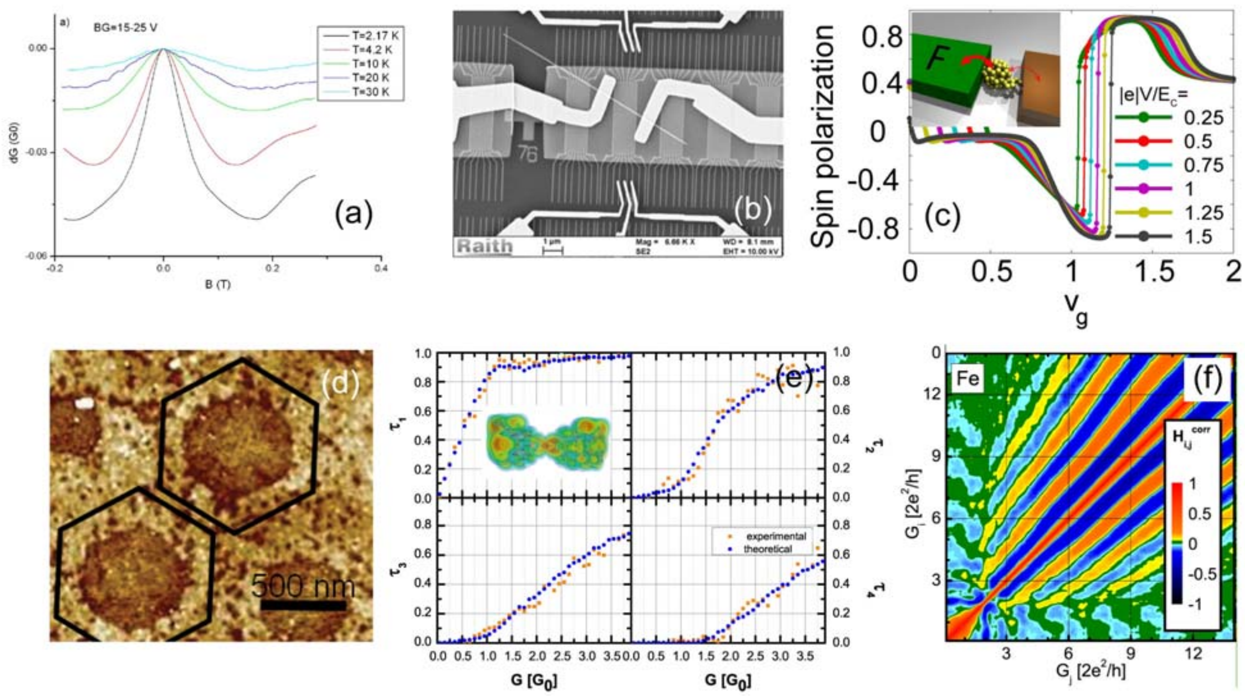

Fig. 2 *a) Weak antilocalization measurement demonstrating the strong spin-orbit interaction in InAs nanowires. b) SEM image of InAs nanowire based device with local bottom gate network. c) Quantum dot based spin filter geometry which enhances the polarization of the ferromagnetic lead (F) and provides gate controlled spin reversal. d) Formation of graphene nanoribbons by carbothermal etching. e) Transmission channel analysis of single atom In junctions. f) Novel correlation technique, which allows the investigation of atomic and molecular nanojuctions.*