Experiments on Carbon nanotubes with ferromagnetic contacts

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Carbon nanotubes (CNTs) have unique mechanical and electronic properties, which make them a very interesting material for both fundental research and applications. Carbon nanotubes are also characterized by a very low spin-orbit coupling, so they are expected to have a very long spin flip-length, which made them a good candidate for spintronics devices.

The band structure of a SWNT is determined by the indices *(n,m)* or equivalently by the diameter d and the chiral angle θ. The knowledge of these parameters would allow a direct comparison between theoretical prediction and transport measurements. We used the selected area electron diffraction (SAED) technique to characterize the structure of CVD grown CNTs on a Si_3N_4 membranes. The membranes were previously prepared with alignment marks and slits. The first were used to locate the tube while the latter are necessary in order to have partially freestanding nanotubes (fig. 1a). This allows us to perform high resolution nanodiffraction (on the free-standing part) and transport measurements on the same sample. The background stemming from the membrane would cover the weak diffraction pattern produced by the tubes while a support is need in order to contact the CNT. By means of this technique was also possible to distinguish SWNTs, DWNTs and small bundles. Moreover, we could obtain the indices *(n,m)* of an individual CNT. For DWNT it was possible to determine the diameter and the chirality of both shells. The assignment of *(n,m)* for a given tube is done by simulating the diffraction pattern and the equatorial line for different tubes, then searching the best match between measured and calculated data. Because of the small signal (we are doing diffraction on part of a single CNT) it was not always possible to make a unique assignment of the indices, nevertheless it was still possible to restrict the choice to a few possiblities.

In order to investigate spin transport, we have chosen a palladium-iron alloy as contact material. Palladium is known to make transparent contacts to nanotubes and by adding iron it gets ferromagnetic. Two concentrations of $Pd_{0}.8Fe_{0}.2$ and $Pd_{0}.6Fe_{0}.4$ were used. Different shapes for the two contacts lead to different coercive fields, allowing a crossover between parallel and antiparallel magnetization orientations. By sweeping an in-plane magnetic field it was then possible to control the relative magnetization of the contacts.

The magnetic properties of the contacts were studied by SQUID measurements and Lorentz microscopy. From SQUID measurements we obtained the hysteresis curves of arrays of many contacts. Lorentz microscopy allowed to explore the magnetization dynamic of the single contact, i.e. to resolve single domain.

Low temperature magnetoconductance measurements were performed on SWNTs and MWNTs with PdFe contacts. The CNTs was laying on a heavily doped silicon substrate which was used as backgate. The low-field magnetoconductance showed a hysteretic switching (fig.1b) The amplitude of the low-field magnetoconductance was found to be gate and bias dependent. The maximum switching amplitude was 4%, while for certain gate voltages it was completly suppressed. For MWNTs, the high-field magnetoconductance shows weak localization. From weak localization measurements it is possible to get a signature of the band structure and to extract the position of the Fermi energy for a given gate voltage. This should allow to relate band structure and spin transport properties of carbon nanotubes.

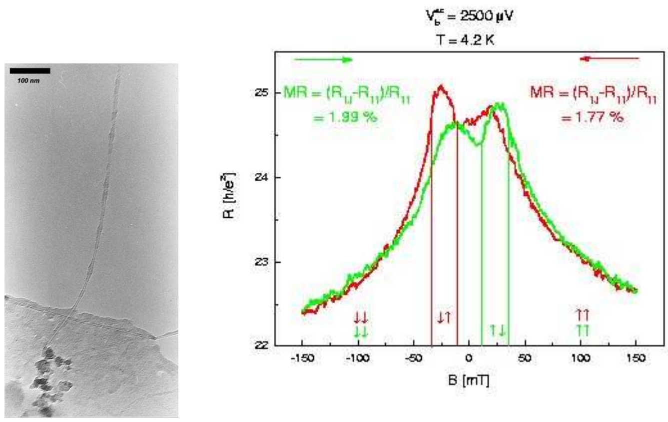

Figure 1: (a) TEM image of a SWNT. (b) Magnetoresitance of a SWNT as a function of the applied in-plane magnetic field, the change from parallel to antiparallel configuration is reflected in the jump in the resistance.