Jelena Klinovaja 13.11.12

Journal club

The soft superconducting gap in semiconductor Majorana nanowires
So Takei, Benjamin Fregoso, Hoi-Yin Hui, Alejandro M. Lobos, S. Das Sarma
arXiv:1211.1029
We theoretically consider the mysterious topic of the soft gap in the tunneling conductance of the proximity induced superconductivity in a semiconductor-superconductor hybrid structure, where the observation of a zero bias conductance peak has created considerable excitement because it could be connected with the existence of the elusive zero-energy Majorana mode. The observed experimental superconducting tunneling gap in the semiconductor nanowire looks v-shaped with considerable subgap conductance even at very low temperatures in sharp contrast to the theoretically expected hard BCS gap with exponentially suppressed subgap conductance. We systematically study, by solving the appropriate BdG equations both numerically and analytically, a number of physical mechanisms (e.g. magnetic and non-magnetic disorder, finite temperature, dissipative Cooper pair breaking, interface fluctuations), which could, in principle, lead to a soft gap, finding that only the interface fluctuation effect is a quantitatively and qualitatively viable mechanism that is consistent with the experimental observations. Our work indicates that improving the quality of the superconductor-semiconductor interface, so that the proximity tunneling amplitude is uniform along the semiconductor nanowire, would go a long way in enhancing the gap in the hybrid structures being used for studying the Majorana mode.

Tunneling conductance due to discrete spectrum of Andreev states
P. A. Ioselevich, M. V. Feigel'man
arXiv:1211.2722
We study tunneling spectroscopy of discrete subgap Andreev states in a superconducting system. If the tunneling coupling is weak, individual levels are resolved and the conductance $G(V)$ at small temperatures is composed of a set of resonant Lorentz peaks which cannot be described within perturbation theory over tunnelling strength. We establish a general formula for their widths and heights and show that the width of any peak scales as normal-state tunnel conductance, while its height is $\lesssim 2e^2/h$ and depends only on contact geometry and the spatial profile of the resonant Andreev level. We also establish an exact formula for the single-channel conductance that takes the whole Andreev spectrum into account. We use it to study the interference of Andreev reflection processes through different levels. The effect is most pronounced at low voltages, where an Andreev level at E_j and its conjugate at $-E_j$ interfere destructively. This interference leads to the quantization of the zero-bias conductance: G(0) equals $2e^2/h$ (or 0) if there is (there is not) a Majorana fermion in the spectrum, in agreement with previous results from S-matrix theory. We also study $G(eV>0)$ for a system with a pair of almost decoupled Majorana fermions with splitting E_0 and show that at lowest E_0 there is a zero-bias Lorentz peak of width W as expected for a single Majorana fermion (a topological NS-junction) with a narrow dip of width E_0^2/W at zero bias, which ensures $G(0)=0$ (the NS-junction remains trivial on a very small energy scale). As the coupling W gets stronger, the dip becomes narrower, which can be understood as enhanced decoupling of the remote Majorana fermion. Then the zero-bias dip requires extremely low temperatures $T \lesssim E_0^2/W$ to be observed.

Noise Analysis of Qubits Implemented in Triple Quantum Dot Systems in a Davies Master Equation Approach
Sebastian Mehl, David P. DiVincenzo
arXiv:1211.0417
We analyze the influence of noise for qubits implemented using triple quantum dot spin system. We give a detailed description of the physical realization and develop error models for the dominant external noise sources. We use a Davies master equation approach to describe their influence on the qubit. The triple dot system contains two meaningful realizations of a qubit: we consider a subspace and a subsystem of the full Hilbert space to implement the qubit. We test the robustness of these two implementations with respect to the qubit stability. When performing the noise analysis, we extract the initial time evolution of the qubit using a Nakajima-Zwanzig approach. We find that the initial time evolution, which is essential for qubit applications, decouples from the long time dynamics of the system. We extract probabilities for the qubit errors of dephasing, relaxation and leakage. Using the Davies model to describe the environment simplifies the noise analysis. It allows us to construct simple toy models, which closely describe the error probabilities.

Majorana bound states and non-local spin correlations in a quantum wire on an unconventional superconductor
Sho Nakosai, Jan Carl Budich, Yukio Tanaka, Bjrn Trauzettel, Naoto Nagaosa
arXiv:1211.2307
We study theoretically the proximity effect of a one-dimensional metallic quantum wire (in the absence of spin-orbit interaction) lying on top of an unconventional superconductor. Three different material classes are considered as a substrate: (i) a chiral superconductor in class D with broken time-reversal symmetry; a class DIII superconductor (ii) with and (iii) without a nontrivial Z2 number. Interestingly, we find degenerate zero energy Majorana bound states

at both ends of the wire for all three cases. They are unstable against spin-orbit interaction in case (i) while they are topologically protected by time-reversal symmetry in cases (ii) and (iii). Remarkably, we show that non-local spin correlations between the two ends of the wire can be simply controlled by a gate potential in our setup.

A Majorana smoking gun for the superconductor-semiconductor hybrid topological system
S. Das Sarma, Jay D. Sau, Tudor D. Stanescu
arXiv:1211.0539
Recent observations of a zero bias conductance peak in tunneling transport measurements in superconductor–semiconductor nanowire devices provide evidence for the predicted zero–energy Majorana modes, but not the conclusive proof for their existence. We establish that direct observation of a splitting of the zero bias conductance peak can serve as the smoking gun evidence for the existence of the Majorana mode. We show that the splitting has an oscillatory dependence on the Zeeman field (chemical potential) at fixed chemical potential (Zeeman field). By contrast, when the density is constant rather than the chemical potential – the likely situation in the current experimental set-ups – the splitting oscillations are generically suppressed. Our theory predicts the conditions under which the splitting oscillations can serve as the smoking gun for the experimental confirmation of the elusive Majorana mode.

Majorana states in inhomogeneous spin ladders
Fabio L. Pedrocchi, Stefano Chesi, Suhas Gangadharaiah, and Daniel Loss
Phys. Rev. B 86, 205412 (2012)
We propose an inhomogeneous open spin ladder, related to the Kitaev honeycomb model, which can be tuned between topological and nontopological phases. In extension of Lieb's theorem, we show numerically that the ground state of the spin ladder is either vortex free or vortex full. We study the robustness of Majorana end states (MES) which emerge at the boundary between sections in different topological phases and show that while the MES in the homogeneous ladder are destroyed by single-body perturbations, in the presence of inhomogeneities at least two-body perturbations are required to destabilize MES. Furthermore, we prove that x, y, or z inhomogeneous magnetic fields are not able to destroy the topological degeneracy. Finally, we present a trijunction setup where MES can be braided. A network of such spin ladders provides thus a promising platform for realization and manipulation of MES.

Controllable exchange coupling between two singlet-triplet qubits
Rui Li, Xuedong Hu, and J. Q. You
Phys. Rev. B 86, 205306 (2012)
We study controllable exchange coupling between two singlet-triplet qubits. We start from the original second quantized Hamiltonian of a quadruple quantum dot system and obtain the effective spin-spin interaction between the two qubits using the projection operator method. Under a strong uniform external magnetic field and an inhomogeneous local micromagnetic field, the effective interqubit coupling is of the Ising type, and the coupling strength can be expressed in terms of quantum dot parameters. Finally, we discuss how to generate various two-qubit operations using this controllable coupling, such as entanglement generation, and a controlled-not gate.

Optical Signatures of the Tunable Band Gap and Valley-Spin Coupling in Silicene
Lukas Stille, Calvin J. Tabert, Elisabeth J. Nicol
arXiv:1211.1336
We investigate the optical response of the silicene and similar materials, such as germanene, in the presence of an electrically tunable band gap for variable doping. The interplay of spin orbit coupling, due to the buckled structure of these materials, and a perpendicular electric field gives rise to a rich variety of phases: a topological or quantum spin Hall insulator, a valley-spin-polarized metal and a band insulator. We show that the dynamical conductivity should reveal signatures of these different phases which would allow for their identification along with the determination of parameters such as the spin orbit energy gap. We find an interesting feature where the electric field tuning of the band gap might be used to switch on and off the Drude intraband response. Furthermore, in the presence of spin-valley coupling, the response to circularly polarized light as a function of frequency and electric field tuning of the band gap is examined. Using right- and left-handed circular polarization it is possible to select a particular combination of spin and valley index. The frequency for this effect can be varied by tuning the band gap.

Majorana qubit rotations in microwave cavities
Thomas L. Schmidt, Andreas Nunnenkamp, Christoph Bruder
arXiv:1211.2201
Majorana bound states have been proposed as building blocks for qubits on which certain operations can be performed in a topologically protected way using braiding. However, the set of these protected operations is not sufficient to realize universal quantum computing. We show that the electric field in a microwave cavity can induce Rabi oscillations between adjacent Majorana bound states. These oscillations can be used to implement an additional single-qubit gate. Supplemented with one braiding operation, this gate allows to perform arbitrary single-qubit operations.