Helical state in Ge/Si core/shell nanowire

Recently, in collaboration with Prof. Ishibashi at RIKEN, Japan and Prof. Liber at Harvard University, USA, the research team led by Professor Sun Jian (孙健) at the Hunan Key Laboratory of Super Micro-structure and Ultrafast Process, Central South University, reported the experimental observation of the helical hole state in the Ge/Si core/shell nanowire. The result was published in *Nano Letters* (2018, 18(10): 6144—6149).

A helical state, exhibiting spin momentum locking, is predicted to emerge in 1D ballistic semiconductor nanowires (NWs) possessing strong Rashba spin-orbit interaction under an appropriate applied external magnetic field. Such a helical state is a key ingredient for the realization of Majorana zero modes, and has application for spin filtering, and Cooper pair splitters. A distinct experimental signature of the helical state is a re-entrant conductance gap feature at the $2e^2/h$ conductance plateau as different portions of the band dispersion are probed. Recently the helical state has been experimentally detected in the electron systems, e. g. in the lowest subband of InAs and InSb NWs.

Hole systems offer several potential advantages for spintronics and quantum information processing application, e. g. having an effective spin of 3/2, and strongly coupled momentum and spin, which enable pure electric spin manipulation. Additionally, hole spin lifetimes can be significantly prolonged in the presence of confinement.

Ge/Si core/shell NWs are a promising material system to investigate helical hole states. Owing to a large valance band offset of about 0.5 eV between Ge and Si, holes are naturally accumulated in the Ge core and strongly confined by the interface with the Si shell. The dopant-free growth leads to the high mobility with the mean-free-path up to 500 nm. In addition, both Ge and Si lack nuclear spin which through hyper fine coupling is the typical leading contributor to the limit of spin coherence times for III-IV based qubit devices. More importantly, a strong dipole-coupled Rashba type SOI is predicted in Ge/Si NWs as a result of the quasi-degeneracy in its low energy valence bands. Prof. Sun and his collaborators experimentally detected such helical states in a hole system, i. e. in a quantum point contact formed in a Ge/Si core/shell NW, which has been measured as a re-entrant conductance feature on conductance plateaus observed at integer multiples of $2e^2/h$. The helical spin-gap feature has been further confirmed by both magnetic field dependence and angular dependence, from which they also extracted a strong spin-orbit energy $E_{so}=2.1$ meV and large Landé g-factor of 3.6 for the material. The results showed good agreement with previous theoretical predictions.

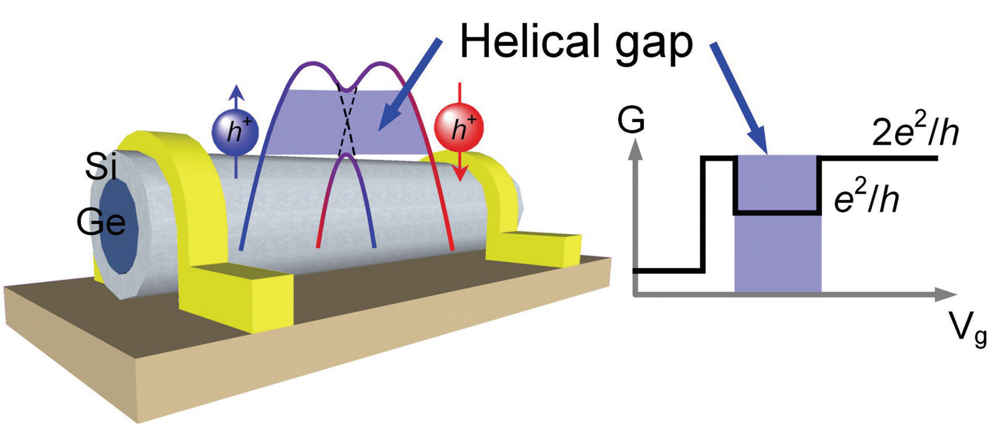

Figure Schematics of the helical hole gap in the band diagram and the corresponding re-entrant conductance feature in the 1-dimensional transport measurement.