Usage Report for Fiscal Year 2018

Project Title:

Spinorbitronics in polygonal mesoscopic rings

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Background and purpose

Spin interferometry focuses on electron spin interference phenomena conducted in solid-state mesoscopic devices. This involves usually low-dimensional quantum ring structures under the influence of spin-orbit fields. In contrast to many other interferometric methods in physics spin interferometry is not intended to be a high-precision measurement method. Instead, it can be employed to directly observe and measure dynamic and geometric (Berry) phases of electron spin. These phases are otherwise difficult to observe and give only indirect effects in measurements. Spin-interferometry has been employed to measure adiabatic and nonadiabatic spin geometric and spin dynamic phases via Aharonov-Casher effect where the spin is manipulated via the spin-orbit fields. The Rashba and Dresselhaus type of spin-orbit fields give their characteristics imprints in the interference patterns. Especially the Rashba type of spin-orbit interaction may be very strong in semiconductor-based quantum wells.

Spin interferometry is often conducted in circular interference devices. However, in polygonal rings electron propagation direction is discontinuous at the vertices and, as a consequence, nonadiabatic spin dynamics emerge. Polygonal quantum rings therefore serve as test beds of nonadiabatic spin phenomena including large geometric phases, transport anisotropies, and topological transitions of the geometric phase. Moreover, calculations show intricate mixing of geometric and dynamic phases that can be tested in future devices [H. Saarikoski *et al.*, PRB **91**, 241406(R) (2015)]. On-going and future experiments in polygonal devices include square quantum ring arrays in InGaAs in the Nitta group at Tohoku University as well as rings on BiSbTe topological insulators with Dr. Kawamura at RIKEN (see Fig. 1). Quantum rings in topological insulars involve *k*-linear Hamiltonians and spin-momentum locking which may offer high disorder tolerance.

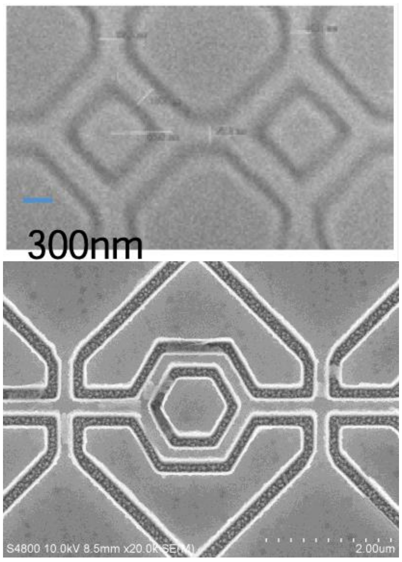

Figure 1 Micrograph of an array of square shaped mesoscopic rings in InGaAs semiconductor quantum wells (left) as well as a single hexagonal quantum ring on BiSbTe topological insulator (right). Courtesy of Nitta group at Tohoku University and of Dr. Minoru Kawamura at RIKEN Center for Emergent Matter Science, respectively.

Specific usage and calculations method

We studied signatures of nonadiabatic effects in square and hexagonal quantum rings in semiconductor materials as well as topological insulators. Simulation results were compared to planned and on-going experiments at Tohoku University and at RIKEN. Calculations were done in **square quantum ring arrays** with the **Kwant code.**

Results

Calculations showed novel features such as reversal of resistance amplitude phase as a function of a magnetic flux through the ring (Fig. 2). This is tentatively attributed to the topological change in the spin rotation path in the ring giving rise to **geometric phase switching**. Analogous Berry phase switching was recently demonstrated in graphene resonators for momentum-locked pseudospins [F. Ghahari et al., Science **356**, 845–849 (2017)]. However, the same idea is applicable for any system involving geometric phases including spin devices and even classical systems [H. Saarikoski *et al.*, Journal of Physics: Condensed Matter **28**, 166002 (2016)]. However, the geometric phase switching was associated with an *effective* geometric phase instead of the usual Aharonov-Anandan geometric phase. We plan to study further the connection of the novel effective geometric phases to mathematics of **differential geometry**. Investigations into the emergence of the effective geometric phase should yield its the mathematical origins in both classical and quantum systems.

With the Nitta group we worked on the problem of how to **achieve and detect inversion of the renormalized Dresselhaus interaction in InGaAs quantum wells**. We demonstrated detection of it via an unexpected phase shift of spin interference anisotropy (manuscript submitted to PRL).

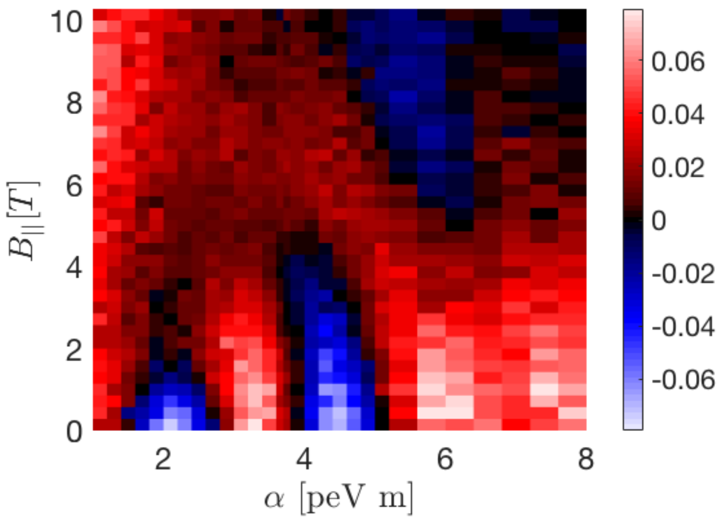

Figure 2 Simulated resistance oscillation amplitude in a square quantum ring array as a function of Rashba spin-orbit interaction α and in-plane magnetic field $B_{||}$ shows phase a checkerboard-like change in pattern, i.e. a change from negative (blue) to positive (red) and from positive to negative in high $B_{||}$. Unpublished data calculated using the Kwant code in the Hokusai system.

Conclusions

The Hokusai system was extensively used to calculate spin transport in quantum rings. Very promising results were obtained during the project resulting in one publication, one preprint and some preliminary unpublished data. The project was terminated prematurely in August due to end of employment contract at RIKEN.

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Fiscal Year 2017 List of Publications Resulting from the Use of the supercomputer

[Publication]

Publication
H. Saarikoski, A. A. Reynoso, J. P. Baltánas, D. Frustaglia, and J. Nitta, Spin interferometry in anisotropic spin-orbit fields, Physical Review B 97, 125423 (2018)

Preprint
Fumiya Nagasawa, Andrés A. Reynoso, José-Pablo Baltánas, Diego Frustaglia, Henri Saarikoski, and Junsaku Nitta, Gate-controlled anisotropy in Aharonov-Casher spin interference, arXiv:1803.11371 (2018).

[Oral presentation at an international symposium]

"Gate controlled anisotropy of Aharonov-Casher spin interference", PASPS 10 conference, Johannes Kepler University, Linz, Austria, August 2018. (contributed talk).