Advanced Device Laboratory
Chief Scientist: Koji Ishibashi (D.Eng.)

(0) Research field

CPR Subcommittee: Engineering, Physics

Keywords:
Quantum devices, nanofabrication, coherent manipulation of spins, carbon nanotubes, topological insulator/superconductor hybrid structures

(1) Long-term goal of laboratory and research background

We are exploring functional nanoelectronics that is complementary to the Silicon electronics. We try to make use of various quantum objects such as an electron charge/spin, an exciton, Cooper pairs et al. that can be controlled in a single particle level and could be used in quantum computing devices and other functional quantum devices. To realize these devices in nanoscale dimensions, we not only use conventional semiconducting materials (such as Si-MOS structures), but also use carbon nanotubes and semiconductor nanowires that have extremely small dimensions which are difficult to realize with conventional lithography technique. Topological insulators could be explored by combining them with superconductors, where a unique quantum state of the Majorana zero mode is expected. We also study atom manipulation techniques for the ultimate small structures as well as inspection techniques for functional nanostructures. New physics or new functionalities that appear in the nanoscale devices and new functional materials are also our interests.

(2) Current research activities (FY2020) and plan (until Mar. 2025)

Among various quantum objects we are studying, electron spin would be most fundamental. In this year, we have carried out an interesting experiment with spin-based qubit (quantum bit) in Si-based small-transistors where we can take full advantage of sophisticated nanofabrication technology. Another advantage would work at higher temperatures because extremely small qubits could be fabricated. Tunnel transistor structures were fabricated, and single trap states were used as a qubit. With it, the quantum thermal cycle was simulated. When a qubit that is square wave-modulated to two types of energy (large and small) is irradiated with a microwave that is square wave-modulated to two types of frequencies (large and small), the qubit takes the following four states. i) 0 state with large qubit energy, ii) 1 state with large qubit energy, iii) 1 state with small qubit energy, and iv) 0 state with small qubit energy. The cyclical transition of these four states mimics the quantum thermal cycle. i) → ii) → iii) → iv) → i)⋯ is an "engine" cycle that takes work out of heat. The reverse cycle i) → iv) → iii) → ii) → i) is a "refrigerator" cycle that removes heat from the environment by a given work. In the experiment, the quantum interference effect between these two cycles could be confirmed. This experimental system does not include the heat bath essential for the heat engine. However, the observed interference effect itself is expected for the actual quantum heat engine. We believe that the findings obtained in this experiment can be applied to quantum heat engines including heat baths.

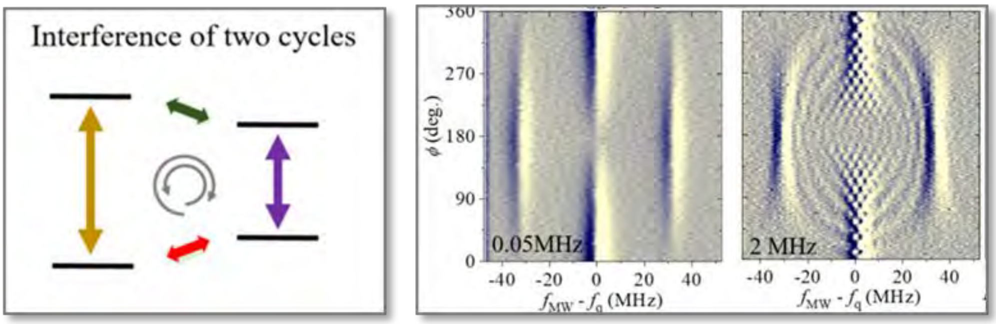

Fig: Schematic image of the heat cycle process (left) and their interference (right)

(3) Members as of March, 2021

(Chief Scientist)
Koji Ishibashi
(Senior research scientist)
Masashi Nantoh, Tomohiro Yamaguchi, Keiji Ono, Russell S. Deacon,
(Research scientist)
Akira Hida
(Postdoctral researcher)
Yoshisuke Ban
(Special Temporary Research Scientist)
Takayuki Okamoto
(Visiting researcher)
Masayuki Hosoda
(Assistant)
Yoriko Asano, Yoko Sakai

(4) Representative research achievements

1. “Analog of a Quantum Heat Engine Using a Single-Spin Qubit”, K. Ono, S. N. Shevchenko, T. Mori, S. Moriyama, Franco Nori, Phys. Lev. Lett. 125, 166802 (2020)
2. “Hard-Gap Spectroscopy in a Self-Defined Mesoscopic InAs/Al Nanowire Josephson Junction”, Patrick Zellekens, Russell Deacon, Pujitha Perla, H. Aruni Fonseka, Timm Mörstedt, Steven A. Hindmarsh, Benjamin Bennemann, Florian Lentz, Mihail I. Lepsa, Ana M. Sanchez, Detlev Grützmacher, Koji Ishibashi, and Thomas Schäpers, Phys. Rev. Applied 14, 054019 (2020)
3. "Spin filtering in germanium/silicon core/shell nanowires with pseudo-helical gap", Jian Sun, Russell S. Deacon, Xiaochi Liu, Jun Yao, and Koji Ishibashi, Appl. Phys. Lett. 117, 052403 (2020)
4. “Directly Probing Effective-Mass Anisotropy of Two-Dimensional $ReSe_2$ in Schottky Tunnel Transistors”, Liu, Xiaochi, Yuan, Yahua, Wang, Zhongwang, Deacon, Russell S., Yoo, Won Jong, Sun, Jian; Ishibashi, Koji, Phys. Rev. Appl. 13, 044056 (2020)
5. Rui Wang, Jian Sun, Russell S. Deacon, Koji Ishibashi (invited), ”Spin-Orbit Interaction in a Hole Nanowire and its Applications for Hybrid Quantum Systems”, 2020 International Conference on Solid State Devices and Materials (SSDM2020), Online, Sep. 27th-30th, 2020

Laboratory Homepage
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