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 (FY2019) and plan (until Mar. 2025)

In the last few years, we have been working on searching for the Majorana zero modes that could have excellent quantum coherence and could be used for the future topological qubit. The Majorana zero mode is predicted to appear in the semiconductor nanowires with large spin-orbit interaction when superconductivity is induced by the proximity effect. It could also appear in the topological insulator coupled with a superconductor. From the point of future device applications, we are interested in these systems. In collaboration with Prof. T. Scheapers group in Julich, Germany, we are trying to measure an energy spectrum of the InAs nanowire Josephson junctions that could host the Majorana zero mode. Similar things are being tried with HgTe Josephson junctions in collaboration with Prof. L. Molenkamp group in Univ. Wurzburg, Germany. In both cases, the topological Josephson junction needs to be embedded in a microwave circuit resonator, device processing techniques for which are being developed. We are also interested in WTe_2 which has been recently reported to be a two-dimensional topological insulator (2DTI) in a monolayer form. We are developing processing technique to fabricate Josephson junctions with the material (Fig.), and got a preliminary result of a supercurrent flow although an expected formation of the helical edge channels has not been confirmed yet.

Our long-term goal is to demonstrate a hybrid quantum system where various quantum objects would be coupled. Each quantum object has pros and cons, so that we could take its advantage in the hybrid system. To realize it, we need to explore and control interactions between each quantum object, especially through microwave photons as many solid state qubits have characteristic energy in that frequency range. The particular interest would be to couple the Majorana based topological qubit with the superconducting qubits to include it in the hybrid quantum system. To exchange quantum information between the hybrid quantum systems, the optical photon should be used, so that the frequency conversion technique between the microwave range and the optical range has to be developed. We are interested in carbon nanotube quantum dots that emit photons in the optical communication frequencies.

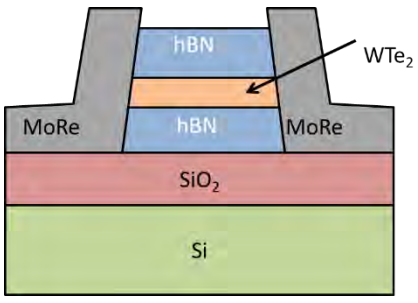

Figure: Schematic structure of the Josephson junction device with WTe_2

(3) Members as of March, 2020

(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

(Student Trainee)
Norizzawati M. Ghazali, Ryunosuke Shima, Masaki Terabayashi, Haruki Inada

(Assistant)
Yoriko Asano, Yoko Sakai

(4) Representative research achievements

1. ”Fabrication of tunnel barriers and single electron transistors in suspended multi-wall carbon nanotubes”, Norizzawati M. Ghazali, Hiroshi Tomizawa, Noriyuki Hagiwara, Katsuya Suzuki, Abdul M. Hashim, Tomohiro Yamaguchi, Seiji Akita, and Koji Ishibashi, AIP Advances, **9**, 105015 (2019).
2. “Thermal Conductivity of a Supported Multi-Walled Carbon Nanotube”, Fabian Könemann, Morten Vollmann, Tino Wagner, Norizzawati Mohd Ghazali, Tomohiro Yamaguchi, Andreas Stemmer, Koji Ishibashi, Bernd Gotsmann, The Journal of Physical Chemistry C**123**, 12460 (2019).
3. “Gate Tunable Hole Charge Qubit Formed in a Ge/Si Nanowire Double Quantum Dot Coupled to Microwave Photons”, Rui Wang, Russell S. Deacon, Jian Sun, Jun Yao, Charles M. Lieber, Koji Ishibashi, Nano Lett. **19**, 1052 (2019).
4. “Quantum structures with carbon nanotubes” (invited), K. Ishibashi, 700. WE-Heraeus-Seminar on One-Dimensional Systems for Quantum Technology, Physikzentrum, Bad Honnef, Germany, June 16th-19th, 2019.

Laboratory Homepage
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