Advanced Device Laboratory（2023）
Chief Scientist: Koji Ishibashi (D.Eng.)

(0) Research fields

CPR Subcommittee**:** Engineering, Physics
Keywords: Quantum Nanoscale devices, Carbon nanotube nanostructures, superconductor/topological insulator hybrid structures, Nanofabrication Nanoscale Si-based transistors

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

We explore 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 (FY2023) and plan

1) Nanoscale Si transistors for single spin control

Continuing from last year, we worked on the application of room temperature Pauli spin blockade to magnetic sensors. Room-temperature Pauli spin blockade was confirmed in more than 10 devices, and good agreement with recently published theories was confirmed. To reduce the strong spin-orbit interaction, which is a limiting factor in improving the operating temperature of qubits, we proceeded with the process of a new device incorporating S and Be impurities.

Future plan, We will try to increase device performance at room-temperature as a magnetic sensor and explore a possibility for scaling.

2) Superconductor/semiconductor hybrid structures

Andreev bound states are unique quantum states formed at the interface between a superconductor and a metal. When the metal is replaced by the on-dimensional semiconductor nanowires or topological insulators, even more interesting quantum states, such as Majorana bound states, are predicted to appear. That could be used for the robust topological qubit. In our study, we use InAs based semiconductor nanowires or WTe_2 which is an experimentally demonstrated 2-dimensional topological insulator in a monolayer form.

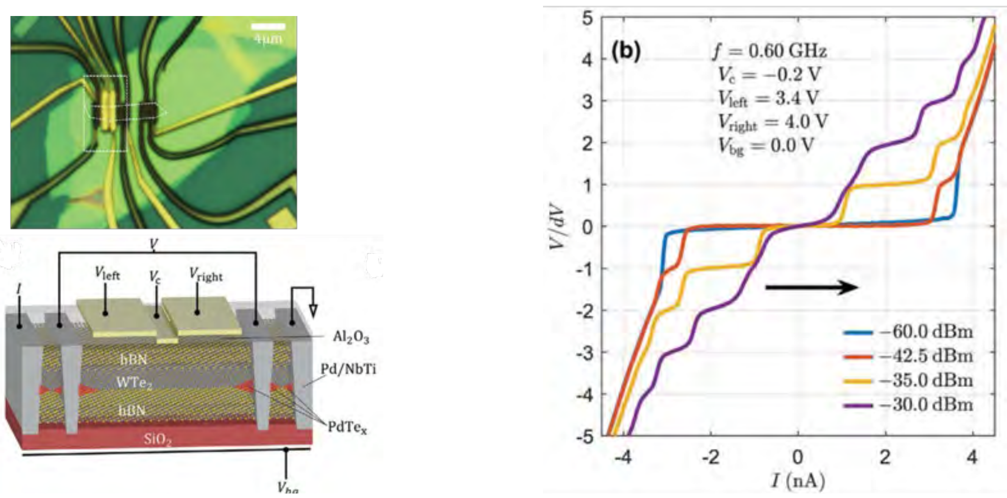

Fig (left): Optical microscope image of the fabricated device (top) and a schematic image of the device structure (bottom) (right): Current-voltage curves under microwave irradiation [1]

In this year, we have succeeded in fabricating a Josephson junction device with mono-layer WTe_2. Superconductivity can be induced in the monolayer WTe_2 by applying positive gate voltage. Taking advantage of this property, we have designed the device structure as shown in the left-hand side of the figure. Josephson junction behaviors were confirmed by observing Schapiro steps that appeared in the current-voltage curves under the microwave irradiation (right-had side of the figure). The behaviors are those of standard Josephson junction devices with no clear indication of topological effects.

The works on the semiconductor nanowires have been carried out in collaboration with Thomas Scheapers's group in Julich Research Center in Germany, and the work on WTe_2 have been carried out in collaboration with Dr. Masayuki Hosoda and Dr. Kenji Kawaguchi of Fujitsu Research.

Future plan, A difficulty in this study lies on the material and device processing as the material easily degrades in air. We still pursue fabricating Josephson junctions with a monolayer WTe_2, as well as search for now material that is more robust in air and easier to handle, to achieve topological Josephson junctions. In the present deice made of the monolayer WTe_2, the parameter region is not clear. More controllable devices have to be designed and fabricated to search for topological effects.

(3) Members

(Chief Scientist)
Koji Ishibashi

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(4) Representative research achievements

1. Michael D. Randle, Masayuki Hosoda, Russell S. Deacon, Manabu Ohtomo, Patrick Zellekens, Kenji Watanabe, Takashi Taniguchi, Shota Okazaki, Takao Sasagawa, Kenichi Kawaguchi, Shintaro Sato, Koji Ishibashi, "Gate-defined Josephson Weak-Links in Monolayer WTe_2", Advanced Materials, **35**, 2301683 (2023)
2. Thomas P. Lyons, Jorge Puebla, Kei Yamamoto, Russell S. Deacon, Yunyoung Hwang, Koji Ishibashi, Sadamichi Maekawa, and Yoshichika Otani, "Acoustically Driven Magnon-Phonon Coupling in a Layered Antiferromagnet", Phys. Rev. Lett. **131**, 196701 (2023)
3. K. Ishibashi (invited), "Josephson Junctions with WTe_2", Workshop on 'Materials for Quantum Electronics' University of Manchester, UK, 28th February – 1st March 2024.

Laboratory Homepage

http://www2.riken.jp/lab/adv_device/en/index.html