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 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 (FY2021) and plan (until Mar. 2025)

This year we highlight a research activity on the topological insulator/superconductor hybrid structures. We are working on InAs nanowires and monolayer films of WTe_2 to which superconductivity is induced. They are predicted to show the topological transition in the induced superconducting channel. At this moment, we are developing technologies to fabricate high quality Josephson junctions with the materials, and microwave measurement setup in a dilution refrigerator to perform spectroscopic measurements of the bound states formed in the junction.

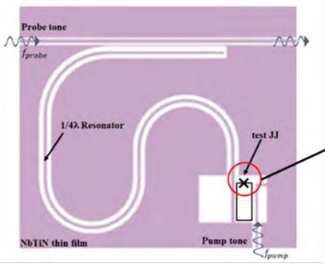
- **Josephson junctions with WTe_2**

This is one of a few 2-dimensional (2D) materials that are experimentally demonstrated to be a 2D topological insulator. The difficulty of the material is its device fabrication processes as the material is easily degraded in air. We have developed fabrication process in a glove box that avoids exposing the material to air and enables sandwiching the WTe_2 with hBN films. Until now, we have succeeded in realizing the Josephson junction with a multilayer WTe_2. Fabrication yield is not high enough, but we are trying to extend it to the monolayer WTe_2.

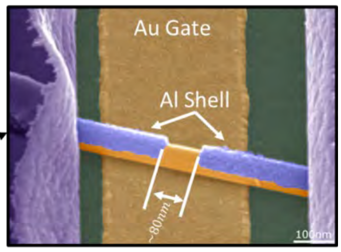
- **Josephson junctions with InAs nanowires**

This work is carried out in collaboration with Prof. Thomas Schapers's group in Julich research center in Germany. They can grow high quality InAs nanowires with molecular beam epitaxy and can deposit superconducting materials of Al or Nb without breaking vacuum. With the material, we fabricate Josephson junction devices, and demonstrated high quality junction properties. The RF-SQUID stricture was fabricated with the device, which was coupled with a coplanar microwave resonator. We could measure the Andreev bound state spectrum using the dispersive readout technique (See Fig.). We have recently developed the flip-chip technique in which the junction device and the resonator device were fabricated in different chips and combined face-to-face to realize the coupling between them. The technique can be used for other materials such as WTe_2.

A plan is to study the expected topological transition by measuring the bound state spectrum, AC Josephson effects and other properties.



Schematic design of the RF-SQUID with a nanowire junction coupled with a coplanar waveguide resonator



False color image of the InAs nanowire Josephson junction

(3) Members

(Chief Scientist)
Koji Ishibashi

(Senior research scientist)
Masashi Nantoh, Tomohiro Yamaguchi, Keiji Ono, Russell S. Deacon,

(Research scientist)
Akira Hida

(Postdoctral researcher)
Yoshisuke Ban
Michael Randle

(Special Temporary Research Scientist)
Takayuki Okamoto

(Assistant)
Yoriko Asano, Yoko Sakai

(4) Representative research achievements

1. P. Perla, A. Faustmann, S. Kölling, P. Zellekens, R. Deacon, H. Aruni Fonseka, J. Kölzer, Y. Sato, A. M. Sanchez, O. Moutanabbir, K. Ishibashi, D. Grützmacher, M. I. Lepsa, and T. Schäpers, "Te-doped selective-area grown InAs nanowires for superconducting hybrid devices", Phys. Rev. Materials. **6**, 024602 (2022)
2. P. Perla, H. A.Fonseka, P. Zellekens, R. Deacon, Y. Han, J. Koelzer, T. Mörstedt, B. Bennemann, A. Espiari, K. Ishibashi, D. Gruetzmacher, A. Sanchez, M. I. Lepsa and T. Schäpers, "Fully in situ Nb/InAs-nanowire Josephson junctions by selective-area growth and shadow evaporation", Nanoscale, Adv., **3**, 1413 (2021)
3. Daichi Suzuki, Kou Li, Koji Ishibashi, and Yukio Kawano, "A Terahertz Video Camera Patch Sheet with an Adjustable Design based on Self-Aligned, 2D, Suspended Sensor Array Patterning", Adv. Func. Mat. **31**, 2008931 (2021)
4. Yoshisuke Ban, Kimihiko Kato, Shota Iizuka, Satoshi Moriyama, Koji Ishibashi, Keiji Ono, and Takahiro Mori, "ON current enhancement and variability suppression in tunnel FETs by the isoelectronic trap impurity of beryllium", Jpn. J. Appl. Phys. 60, SBBA01 (2021)
5. Joseph Hillier, Keiji Ono, Kouta Ibukuro, Fayong Liu, Zuo Li, Muhammad Husain, Harvey Rutt, Isao Tomita, Yoshishige Tsuchiya, Koji Ishibashi, Shinichi Saito, "Probing hole spin transport of disorder quantum dots via Pauli spin-blockade in standard silicon transistors", Nanotechnology, 32 260001 (2021)

Laboratory Homepage
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