【Grant-in-Aid for Scientific Research (S)】

Broad Section D

Title of Project : Quantum Standards and Ultimate Precision Measurements Based on Single Electrons

Akira Fujiwara
(NTT Basic Research Laboratories, Physical Science Laboratory, Senior Distinguished Scientist)

Research Project Number : 18H05258 Researcher Number : 70393759
Keyword : single electron, quantum metrology triangle, quantum Hall, quantum electrical standards

【Purpose and Background of the Research】

One by one transfer and detection of electrons based on the single-electron charging effect in nanostructures enable us to build ultimate electronic devices such as quantum current standards and high sensitivity sensors, which will be applicable to ultimate precession measurements. This project is dedicated to the development of high speed single-electron transfer and detection devices, high-resistance quantum Hall arrays and current multiplication devices for high-accuracy current measurements. We aim at realizing the quantum metrology triangle (QMT) (Fig. 1), which is an experiment for the consistency check of three quantum electrical standards, with the best accuracy in the world.

【Research Methods】

In the 5 years project, NTT, AIST, and UEC will develop component devices and measurement techniques and combine them to perform high-accuracy QMT experiments cooperatively.

NTT will develop sub-10-GHz clocked silicon single-electron devices, which are key devices for quantum current standards generating a high (nanoampere level) current. Electron dynamics and error mechanism related to the single-electron transfer are intensively investigated to realize a high precision current source.

In order to convert the generated current to a voltage comparable to the Josephson voltage standard, AIST will develop 10-MΩ quantum Hall array resistance standards. Towards the final goal of QMT experiments, AIST will build a unified measurement system in a refrigerator including all quantum electrical standards (Fig. 1).

UEC will develop quantum current mirrors for precise current multiplication based on coupled arrays of Josephson tunnel junction. A novel scheme of single-electron detection in a sub-10-GHz regime is also studied utilizing single magnetic flux quantum (SFQ) circuits, which will be applied to absolute evaluation of the accuracy of single-electron current standards.

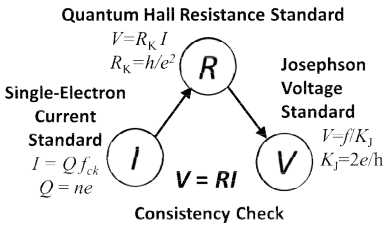

Fig. 1 Quantum metrology triangle (QMT)

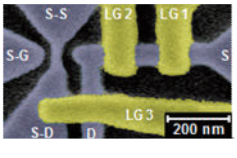

Fig. 2 Silicon single-electron devices

【Expected Research Achievements and Scientific Significance】

QMT has been perused for decades towards consistency check of the fundamental constants of nature such as the Planck constant and the elementary charge. Scientific impact of the QMT realization with the world-best accuracy will be significantly high. Furthermore, developed devices and techniques in the project are expected to lead to portable standards/calibration systems, real-time sensors for chemical and biological applications, and ultimate precision measurement apparatuses, which are all beneficial in various engineering and industrial fields.

【Publications Relevant to the Project】

・G. Yamahata, K. Nishiguchi, and A. Fujiwara, Gigahertz single-trap electron pumps in silicon, Nat. Commun. **5**, 5038 (2014).
・G. Yamahata et al., Gigahertz single-electron pumping in silicon with an accuracy better than 9.2 parts in 107, Appl. Phys. Lett. **109**, 013101 (2016).
・N. Kaneko, Review of Quantum Electrical Standards and Benefits and Effects of the Implementation of the 'Revised SI', IEEJ Trans. **12** 627 (2017).

【Term of Project】 FY2018-2022

【Budget Allocation】 151,400 Thousand Yen

【Homepage Address and Other Contact Information】

NTT : http://www.brl.ntt.co.jp/people/afuji/
http://www.brl.ntt.co.jp/e/group_004/group_004.html
AIST :
https:// https://unit.aist.go.jp/ripm/qelec-std/
UEC : http://inaho.pc.uec.ac.jp/