Even If Facing Difficulties, Create New Value While Building on the Achievements of Your Predecessors

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Abstract

The missions of NTT Basic Research Laboratories are to promote advances in science that will ultimately benefit humankind and contribute to NTT's business. Researchers at the laboratories have published numerous achievements in the fields of materials science, physical science, and optical science. Akira Fujiwara, a senior distinguished researcher, is researching silicon single-electron devices to enable accurate operation and detection of single electrons, which are expected to be applied to quantum electrical standards, high-sensitivity sensors, and quantum qubits. We asked him about the progress of his research activities and attitude as a leading researcher.

Keywords: silicon single-electron device, electric-current standard, quantum metrology triangle

Taking the challenge of applying silicon single-electron devices to high-accuracy electric-current standards

—Could you give an overview of your current research for the readers?

My current research is focused on (i) developing *ultimate electronics* on the basis of high-precision and high-speed charge manipulation, detection, and control of electrons using silicon-based semiconductor nanodevices and (ii) applying this technology to high-accuracy electric-current standards, ultra-low-energy information processing, ultra-sensitive sensing, and quantum technology (**Fig. 1**).

Computers and smartphones, which have become everyday tools, use semiconductor circuits made of silicon. By passing an electric current through a semiconductor circuit or applying a voltage across it, the current can be amplified or switched on/off. The current flowing through the semiconductor circuit consists of moving electrons, which are tiny particles with a negative charge. In my research, I am testing the limits of how far we can control and manipulate each electron in a silicon semiconductor. Such control and manipulation of single electrons will be applicable to ultra-low-energy information processing and ultra-sensitive sensing. Units such as the meter (m) for length and kilogram (kg) for mass are defined as basic international standards for weights and measures. Regarding the ampere (A), which is the unit for electric current, we are aiming to establish

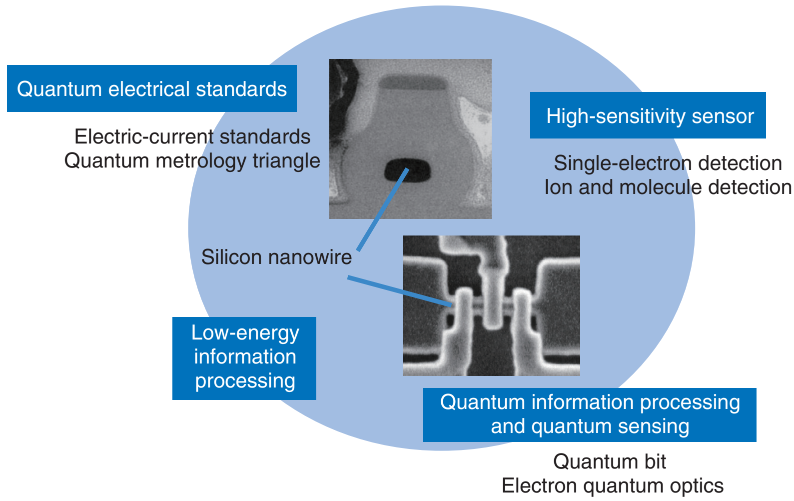

Fig. 1. Ultimate electronics using silicon nanodevices.

a quantum electrical standard on the basis of an accurate current generated by a silicon single-electron device.

—What triggered you to target a new international standard for electric current?

In 2003, when I was a visiting researcher at the National Institute of Standards and Technology (NIST, Gaithersburg, USA) and evaluating the characteristics of a silicon single-electron device developed by NTT, I realized that the field of standards—which pursues extreme accuracy—is the most suitable application of the device. After ten years of persistent research, I began to receive interest from Europe as well.

The technology I am pursuing was not adopted when the International System of Units (SI) was revised in 2019 as well as the definition of the ampere. However, believing that it will be adopted in the future, I am continuing my research while working hard with researchers around the world. Being recognized for such efforts, I was honored to be elevated to an IEEE (Institute of Electrical and Electronics Engineers) Fellow in 2018 and JSAP (Japan Society of Applied Physics) Fellow in 2020. I am glad that I did not give up on my research.

I am currently working on establishing high-accuracy single-electron current standards and achieving the quantum metrology triangle, which is an experiment to verify the consistency of quantum electrical standards. Specifically, I am working on (i) the characteristic evaluation of devices fabricated at NTT using a semiconductor-manufacturing line for research purposes and (ii) computational analysis of such devices using a device simulator, which we developed when we were teleworking during the novel coronavirus pandemic (**Fig. 2**). Following the revision of the definition of the ampere in 2019, electric current is now defined as the number of electrons that constitute the current carried per second, and we are currently focusing on how to transfer one electron accurately and quickly while minimizing as much error as possible. Silicon single-electron devices also have the potential to be applied to quantum computers, which is a hot topic of research; however, it is very difficult to produce many identical devices because of their extremely small size. Therefore, I believe that it is important for us to focus on applying such a device in electric-current standards in which one device will be good enough to demonstrate its usefulness.

Collaboration is a vital part of this research. About five years ago, we issued a press release about the results of our joint research with the National Physical Laboratory (NPL) in the UK, announcing that we could generate accurate currents at the world's fastest operating speed [1]. We have also begun joint research with the National Institute of Advanced Industrial Science and Technology (AIST), which manages Japan's national standards.

For practical use of a high-accuracy current standard that will enable the revised "new ampere," we will have to further improve the accuracy of the

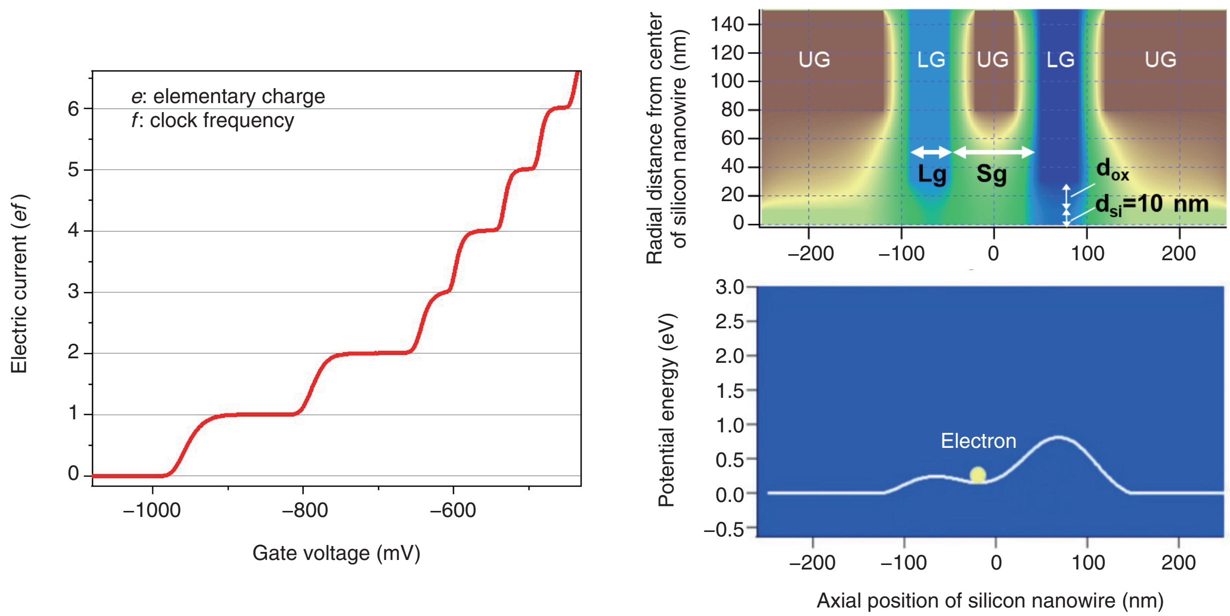

Fig. 2. Characteristics of silicon single-electron current standards (experimental results) and potential analysis using a device simulator.

currents generated by a silicon single-electron device. To break the world record and take the global lead, we are working with AIST and other teams to complete the quantum metrology triangle using single-electron current standards.

Verify your research fairly

—Is it important for researchers to take up the challenge of being the best in the world?

Research, whether basic or applied, is carried out as a community, and in each community, many competitors aim to be the best in the world. I believe that this situation is good for all because by competing together, even if one of us loses, we can all learn. Such friendly rivalry will lead to contributions to the field as well as society. The development of the research community may lead to not only the commercialization and implementation of our products in society but also the creation of new research themes and business.

I sometimes naturally feel disappointed when I am competing with overseas researchers. Although Japan is excellent in the field of science, the United States and Europe, the birthplace of modern science, are even better and have more resources, including a deeper pool of researchers. I even have moments when I feel that Japan is losing and accept that fact with humility, but I am also sometimes frustrated with my lack of ability.

Under these circumstances, I try to evaluate and verify my own research fairly. For example, you can judge the quality of your research results, their significance, and their contribution to the community by the response from the community and leading researchers. Of course, it is important to have your own beliefs, but I try not to be complacent and evaluate myself objectively so that I can grow further.

I have been active as a researcher for a long time and feel that the environment surrounding research is becoming more difficult every year. In Europe and the United States, the competition is very fierce, and it is a tough environment in which you have to keep producing outstanding results to survive under severe competition for acquiring research funds and human resources. In quite a few cases, people leave their home countries in search of a research environment and place in which they can be themselves and live their lives as researchers. China is producing good results with its large organizations and resources; even so, I have heard that in some cases, young researchers are only allowed to work as research assistants. Compared with those countries, Japan is a good environment for creating new ideas in a harmonious relationship among researchers but lacks the intensity as in other countries. Still, it is difficult to obtain employment as a researcher in Japan, and, as has been reported in the media, it is also difficult for young researchers to find an academic post at a university.

Under these circumstances, the choice of a research theme can be a fork in the road for researchers. For example, research in a popular field is, in a sense, secured by the fact that it is needed by society, so a certain number of posts are available. Working on research in such a field that is currently needed or popular is one meaningful choice; however, you run the risk of being carried away by superficial trends and your research not becoming significant enough. In the case of basic research, it is important to take a more long-term perspective and read the trends. If you find a field in which you can use your strengths or a theme that only you can tackle and has the potential to make you a leading researcher, you should compete in that field, even if it is a narrow one.

I am conducting research on electric-current standards with this mindset, and striving to make the most of my skills, one step at a time. For the rest of my research life, I want to pursue what only I can do while evaluating my research fairly from time to time so that I do not become complacent.

—You have been pursuing the issues that will impact future society rather than the issues facing us today, right?

Science is a process of knowledge accumulation, so even if my research is not useful right now, I want to conduct research that prompts people to say things like, "This is really new." and "This is one step forward." I believe that it is very important to aim for research that is valued by the research community.

I think that my research has been successful to some extent by having this attitude, therefore I cherish the research community and colleagues. If you understand what has been done in the community by your predecessors, you will come to respect them. If you focus on adding something new to the community, the community will grow and the researchers who belong to the community will be able to continue their research, creating a virtuous cycle. It is important to build up the community and become a valued member so that you can exchange useful information and obtain the cooperation of other researchers. To that end, I want to continue to engage in friendly rivalry with world-class researchers. It is vital to have people around you with whom you can have serious discussions about your research and continue learning from the results of those discussions, and I am happy to have such a community around me now. I work in an environment in which I can form collaborative teams with my colleagues and have come to realize the importance of collaborative research.

I think that the culture of Japanese companies and the mindset of researchers still have a strong tendency to do everything on their own. Japanese researchers have a strong respect for craftsmanship and are willing to do work with their hands in every aspect, including everyday maintenance of experimental equipment. Although I think that mindset is commendable, in Europe, the work of technicians is separate from that of researchers, and many companies seem to think that what they don't have in-house, they can obtain from outside. Partly due to cultural differences, international companies are probably more accustomed to doing things collaboratively. Both domestic and international companies have advantages and disadvantages, but if you can produce good results and new value by complementing what you don't have with what others do have, I think joint research is essential.

I used to be less than enthusiastic about collaborating. It was the advice from Tetsuomi Sogawa, head of the NTT Science and Core Technology Laboratory Group (who was then head of NTT Basic Research Laboratories), that changed my mind. Regarding the joint research with NPL on electric-current standards I mentioned earlier, he encouraged me to, "Not only work within our lab but also collaborate with outside parties to give your research a visible presence." I am also encouraging mid-career and young researchers to follow that advice. Joint research involves a lot of tasks due to intellectual property issues and piles of paperwork, but I transfer the necessary skills to these researchers and assure them that they can go ahead and form collaborations without hesitation if they need to. That said, I try not to say too much or be too forceful so as not to put too much pressure on our young researchers; in other words, I just try to make sure that my advice is one of their options.

Research mottos: "friendly rivalry," "take advantage of every opportunity," and "dig deep"

—What has been important to you in your research activities?

I believe that basic research is not immediately useful or helpful to anyone; however, even if you face difficulties, create something new and valuable while building on the achievements of your predecessors.

With that belief in mind, I continue my research activities with the mottos of "friendly rivalry," which I have mentioned several times already, as well as "take advantage of every opportunity," and "dig deep." I believe that research is about learning from your failures, and even though I have had many failures, I have tried to learn from them. When I was young, sometimes the devices I created did not work as expected, but as I searched for the cause of the problem, I discovered new phenomena. At that time, I remember how happy I was when one of my senior colleagues said to me, "Mr. Fujiwara, even if you fall, you get up and learn from your failure."

Research is often described as "digging deep and wide." It is important to dig deeper and deeper into your topic. You need to understand more about the topic than anyone else to come up with new ideas. It is also very important to dig horizontally and cultivate the area surrounding your research topic. Doing so will help you understand the position of the research you are working on, and you will learn that it actually has a close relationship with unknown fields. That's why I often tell young researchers to take both approaches. If you only dig deep, you will become complacent, and if you only dig horizontally, you will end up with research without depth. I'm also trying to find a good balance between digging deep and digging horizontally.

—Finally, do you have any advice for young researchers on how to interact with leading researchers?

I think it is quite intimidating for a young researcher to suddenly meet a "big name" in their field. It may sound like a cliché, but the first thing you should do is try to get people to remember your face. It is also important to ask questions and make impactful presentations at international conferences. When you get the opportunity to make a presentation, I hope you will practice hard and impress the audience in such a manner that they will think, "What an impressive young person!"

If you feel uncomfortable asking a leading researcher a question, ask a talented person of your generation first or someone who is more approachable. In that sense, coffee breaks at a conference are valuable times to meet and ask questions. In fact, quite important information about research is exchanged at such meetings, so don't drink coffee alone because you are tired; instead, listen to the detailed stories that you couldn't hear at the presentations and the stories about the presenters' difficulties. All top researchers have such lively exchanges of information during coffee breaks.

At times, I feel that I am not yet part of that circle, even though I am saying things that sound great. At other times, I find it difficult having conversations with native speakers of English and feel that I am still in the process of learning. Therefore, let's take the challenge and get into such conversations without hesitation. You tend to be hesitant if you think you're not good enough or don't understand what's being said. Well, that's just the way I am. Instead of hesitating, it's okay to say, "I don't really understand the topic, but may I join the conversation anyway?" You don't have to pretend to know more than you do.

Reference

[1] Press release issued by NTT, "World-record accuracy of gigahertz high-speed single-electron transfer – An important step toward a high-accuracy current standard –," July 5, 2016. https://group.ntt/en/newsrelease/2016/07/05/160705a.html

■ Interviewee profile

Akira Fujiwara received a B.E., M.E., and Ph.D. in applied physics from The University of Tokyo in 1989, 1991, and 1994. He joined NTT LSI Laboratories in 1994 and moved to NTT Basic Research Laboratories in 1996. Since 1994, he has been engaged in research on silicon nanostructures and their application to single-electron devices. He was a guest researcher at the National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA from 2003 to 2004. He was a director of the Japanese Society of Applied Physics (JSAP) in 2010 and 2011 and a visiting professor of Hokkaido University in 2013. He was appointed as a distinguished scientist of NTT in 2007 and senior distinguished scientist of NTT in 2015. He received the International Conference on Solid State Devices and Materials (SSDM) Young Researcher Award in 1998, SSDM Paper Award in 1999, and Japanese Journal of Applied Physics (JJAP) Paper Awards in 2003, 2006, and 2013. He was awarded the Young Scientist Award in 2006 and Prizes for Science and Technology in 2017 from the Minister of the Ministry of Education, Culture, Sports, Science, and Technology. He was supported by the funding program for Next Generation World-Leading Researchers (NEXT Program), Japan Society for the Promotion of Science (JSPS) from 2011 to 2014. He is now a principal investigator of the 2018–2022 JSPS KAKENHI S (Quantum Standards and Ultimate Precision Measurements Based on Single Electrons). He is a JSAP Fellow, a member of Science Council of Japan, and an IEEE Fellow.