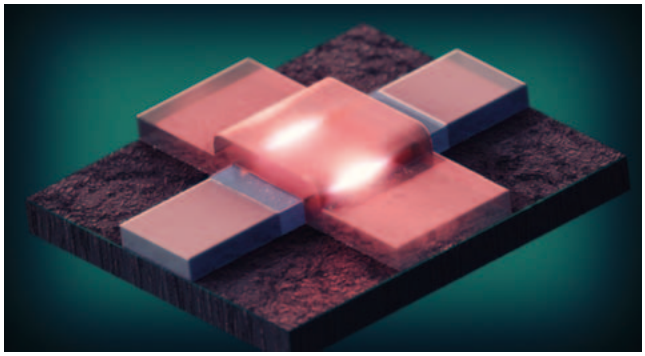
Exploratory Research

1 Highly Sensitive Readout Detector for Si-CMOS-based Quantum Computer

Hitachi Cambridge Laboratory has been researching quantum computing, a technology with the potential for enabling ultra-high-speed computation to help resolve societal challenges that require such complex and high-speed calculations. For reasons of future scalability and the ability to connect to existing circuits, the work has targeted quantum techniques that use silicon-based complementary metal-oxide-semiconductors (CMOS).

Joint research with University of Cambridge, University College London, and Laboratoire d'Electronique des Technologies de l'Information du Commissariat à l'énergie atomique et aux énergies alternatives (CEA-LETI) has demonstrated a readout technique with the highest ever sensitivity achieved using silicon qubits. This brings quantum computing a step closer to reality, with the charge detection sensitivity of 1.3 $\mu e/\sqrt{Hz}$ being five times higher than any other such technique for reading silicon qubits that has been reported previously.

This research was funded by Horizon 2020, the European Union Framework Programme for Research and Innovation, (No 688539: MOS-Quito Project). It was published on July 19, 2018 in the online edition of Physical Review Applied, where it was selected as an Editor's Suggestion (recommended article).



1 Diagram of silicon-based complementary metal-oxide-semiconductor (Si-CMOS) qubit

2 Encrypted Communications Device Making Eavesdropping Practically Impossible

Information security is one of the greatest challenges facing modern society. In response, Hitachi built a prototype encrypted communications device with a level of security such that eavesdropping is practically impossible even if given as much time as the current age of the universe (13.8 billion years) by utilizing the fact that random noise (bit errors) cannot be predicted.

To achieve secure encrypted transmission of a message, the devices exchange random numbers overlaid with noise and generate encryption keys from the transmitted random numbers prior to message transmission. The quantity of the generated encryption keys corresponds to that of the noise. As the system requires that the intended recipient be the only one able to remove the noise, it uses a technique called error correcting coding and a key that is pre-shared between the sender and receiver.

The device can be used over any distance simply by plugging a local-area network cable into it. This usability makes it possible to construct a secure closed network over open networks on a global scale. Potential applications include energy, railway management, defense, finance, and inter-hospital networks.

2 Prototype encrypted communications device (right) and noise generator (left)

3 Regenerative Medicine Research at Hitachi Kobe Laboratory

The Kobe Biomedical Innovation Cluster is Japan's largest medical cluster, also notable for the recent news that Tasuku Honjo, President of the Foundation for Biomedical Research and Innovation at Kobe, was awarded the 2018 Nobel Prize in Physiology or Medicine. The foundation, which celebrated its 20th anniversary in 2017, is continuing to grow as a key center for regenerative medicine, being home to more than 330 companies and other organizations from Japan and overseas.

3 System for the large-scale automatic culturing of iPS cells

Having an existing involvement in the research and development of automatic cell culturing techniques for regenerative medicine, Hitachi shifted its center of operations for this work to Kobe in 2017 when it opened the Hitachi Kobe Laboratory at the cluster. It is currently working with Kyoto University and Sumitomo Dainippon Pharma Co., Ltd. on developing the core cell production technologies for using regenerative medicine to treat Parkinson's disease. To pick up the pace of research, a system developed by Hitachi for the large-scale automatic culturing of induced pluripotent stem (iPS) cells has been installed at a Sumitomo Dainippon Pharma laboratory, and an environment established in which both parties can engage in forthright discussion. The system also won one of the Best 10 New Product Awards at the 60th awards run by Nikkan Kogyo Shimbun, Ltd.

Hitachi has also, since 2017, been participating in the open laboratory of the Kobe Eye Center, which supplies integrated ophthalmological care, and where it is seeking new approaches to regenerative medicine and care for the vision-impaired. It is also pursuing joint research with the Institute of Physical and Chemical Research (RIKEN), seeking to contribute to regenerative medicine through open innovation with key opinion leaders. Some of this work has been supported by the "Evaluation for Industrialization in the Field of Regenerative Medicine" project of the Japan Agency for Medical Research and Development (AMED).

4 Use of Tumor Marker in Urine to Test for Cancer

Competition to develop the next generation of cancer testing techniques is taking place around the world, focusing mainly on blood tests. An issue with blood testing is that it requires the patient to visit a clinic to have a sample taken. However, given that one of the main reasons why so few people have cancer tests done in Japan is that they lack time to go to a clinic, one way of resolving the problem is to switch to a type of sample that people can collect for themselves. This is why Hitachi has been working on the development of a new test for cancer that uses the metabolites in urine.

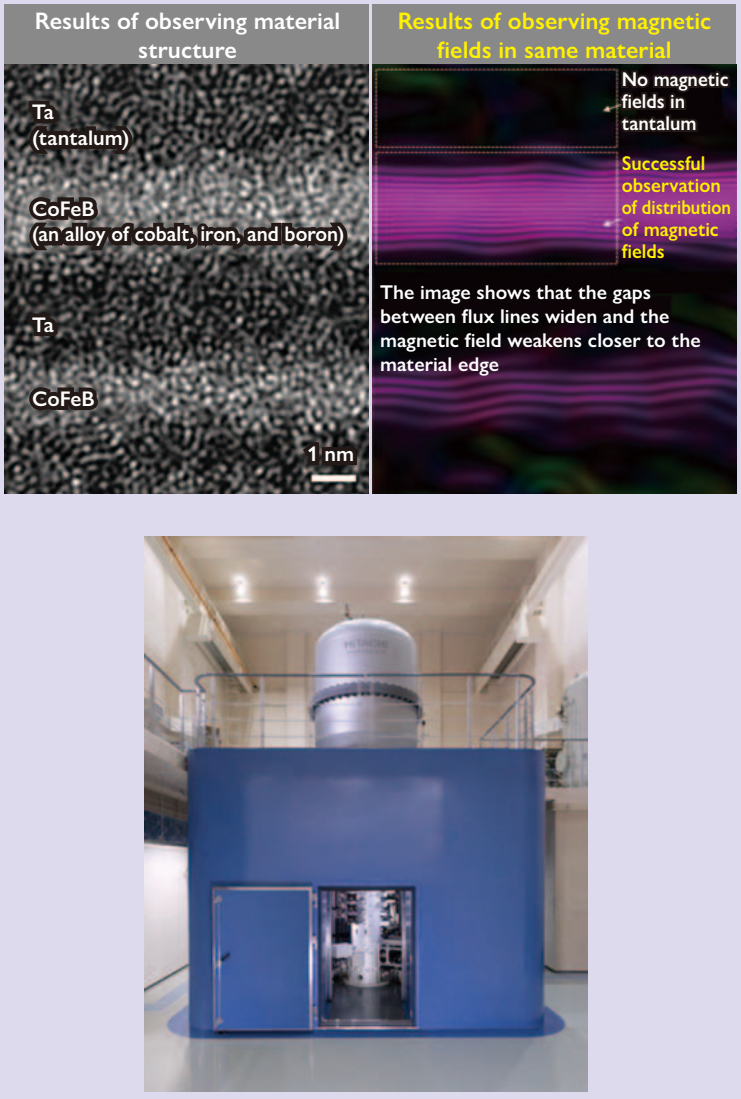
Developing such a test requires the ability to detect as many as possible of the metabolites in urine, and the identification of which of these metabolites are present in cancer sufferers in higher or lower quantities than in healthy subjects. To achieve this, Hitachi has established a new cancer testing model that uses tumor markers found in urine,

4 Work on identifying tumor marker in urine

having developed an analysis sequence in which the comprehensive analysis of metabolites using a liquid chromatograph mass spectrometer with a number of different separation modes is accompanied by the use of statistical analysis, machine learning, and multi-variable analysis to identify the tumor markers. The validity of the proposed cancer testing model has been demonstrated by its use on pediatric cancers and bile duct carcinoma, where the test was able to clearly distinguish sufferers from healthy subjects.

5 Performance Improvement for Atomic-resolution Holography Electron Microscope and New Double-slit Experiment

Creating a sustainable society calls for advances in high-function materials, such as magnets that revolutionize energy efficiency or catalysts that boost the productivity of chemical plants that process natural gas. This has led to hopes that electron microscopes will be able to provide clear high-resolution images of reaction processes down to the atomic level. Using its ultra-high-voltage holography electron microscope with atomic-resolution*,



5 Successful observation of distribution of magnetic fields inside a material with world-leading resolution (top) and the atomic-resolution holography electron microscope used for the observations (bottom)

Hitachi has succeeded in achieving a world-leading resolution of 0.67 nm for observations of the distribution of magnetic fields inside materials. It has also achieved a brightness of $3x10^{14}A/m^2sr$, the highest ever ("brightness" represents the directivity and intensity of the electron beam directed at the specimen). This provides clearer atomic-level imaging of the magnetic fields and structures present during reaction processes in materials.

Meanwhile, in joint work with the Institute of Physical and Chemical Research (RIKEN) and Osaka Prefecture University aimed at exploring the fundamentals of quantum mechanics, this high-brightness electron beam is being utilized to undertake a new double-slit experiment to deepen understanding of the wave-particle duality of electrons by providing an experimental demonstration of the relationship between the uncertainty principle and interference.

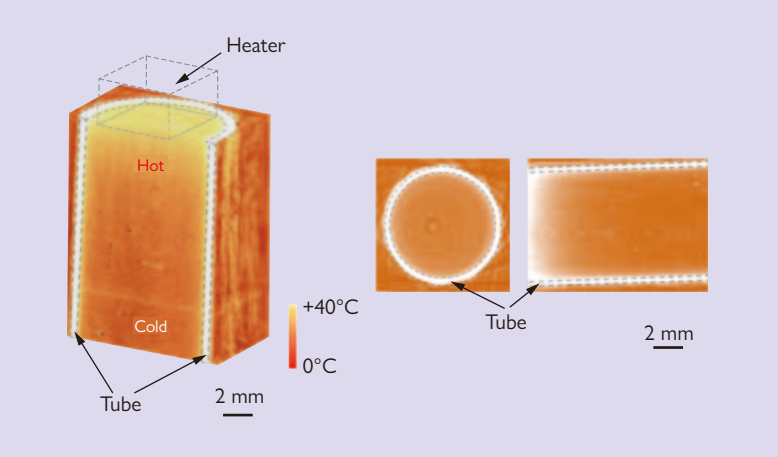
* Developed with assistance from the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST)

6 Three-dimensional X-ray Thermography

Thermal management is a key technology to desterilize unused energy sources for building sustainable societies. For non-destructive observations of the inner thermal distribution of objects, Hitachi has developed a novel three-dimensional X-ray thermography using a phase-contrast X-ray imaging technique.

The high-sensitivity of phase-contrast X-ray imaging provides a way to detect temperature changes by using density changes caused by thermal expansion. In addition, the high-transparency of objects to X-ray enables the detection of temperature inside objects. Time-resolved two-dimensional observation of heated water was performed using a phase-contrast imaging system with synchrotron radiation, and dynamic thermal flow was successfully visualized. Moreover, by combining the novel technique with computed tomography (CT), three-dimensional observation of the temperature of heated water in a tube was also performed successfully.

The novel technique is expected to be used not only for the real-time operand measurement of temperature in batteries and other power devices, but also for biochemical and biomedical applications.



6 Three-dimensional measurement of temperature distribution in water being heated by a heater

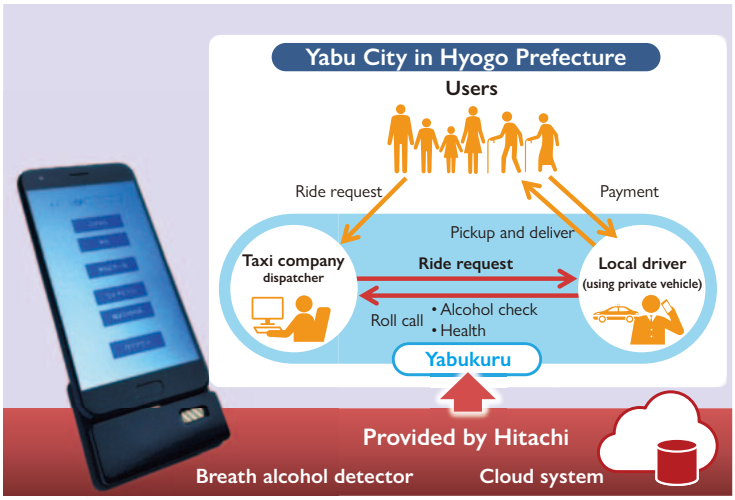
7 Practical Trial of Cloud-linked Breath Alcohol Detector with Anti-impersonation Function

The Yabukuru ride-hailing initiative that commenced in the National Strategic Special Zone of Yabu City in Hyogo Prefecture on May 26, 2018 has started trialing a cloud-linked breath alcohol detector.

The Yabukuru initiative is a transportation service for short trips within designated parts of the city in which local drivers use private vehicles to provide rides to both locals and visitors. Hitachi has loaned alcohol detectors to the drivers and is providing a cloud system that assists administrators in the allocation of rides to drivers and also checks the results of driver breath tests. The alcohol detectors are equipped with the ability to prevent

abuse such as having another person take the breath test, using a proprietary breath recognition function and the recording of facial images for this purpose.

Along with using the results of the trial to further enhance the detectors, Hitachi also intends to continue with the development of systems that will help establish safe transportation services with a view also to reforming working practices for drivers at freight and other transportation operators as well as at providers of passenger services such as buses and taxis, and also for other local governments with similar requirements to Yabu City.



7 Breath alcohol detector and details of trial

8 Happiness Planet: Personalized Support for Working Style Reform

Happiness Planet is an initiative aimed at combining technology with human capabilities to make the world a livelier place. A public trial in September 2018 that attracted 1,623 participants split into 175 teams from across approximately 100 companies demonstrated that work style reform can proceed in a positive and enjoyable manner.

The trial provided a virtual space in which people's enthusiasm could spread by using a smartphone app to bring together people with an interest in working practices and present them with daily challenges on that topic. It also used a technique for measuring happiness level to provide an objective indicator of the extent to which the working practice challenges improved happiness.

Happiness level in this context is an objective indicator calculated from the rhythms of bodily movement as captured by an accelerometer. Activities such as engaging actively in discussion with other people or becoming engrossed in writing tend to lift a person's happiness score. Using this in much the same way as a thermometer might be used to record a person's temperature on a daily basis allows individuals to find the ways of working that play to their strengths and helps energize organizations or entire society.

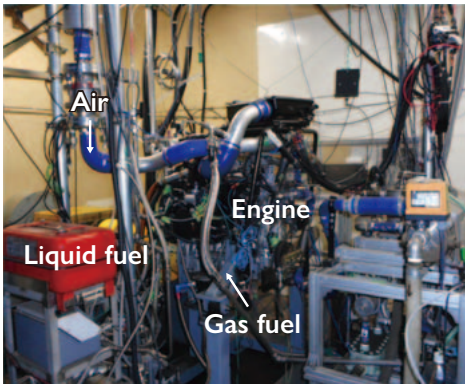
8 Happiness Planet cloud service screens and how it is used for work style reform

9 AI Engine Control Based on Type and Mix of Fuel

Recognizing that biofuel (including ethanol and methane) and hydrogen will increasingly be used to help achieve a low-carbon society, Hitachi has developed an artificial intelligence (AI) combustion control technique for generator engines based on the type and mix of fuel.

The new technique uses pressure data from inside the cylinder of the generator engine to achieve stable combustion using a variety of different fuel types. This controls the engine based on the type and mix of fuel through a repeated cycle of self-learning, involving the use of a neural network to learn how to adjust control values to suit the fuel being used, and data collection of the pressure and other information needed for this learning. The new AI technique can achieve stable engine combustion with variation of less than 3% when running on a mixed fuel, such as a combination of biofuel and hydrogen.

Hitachi intends to use this technique to work towards a low-carbon society by bringing forward the implementation of regional energy systems.



9 Engine system for testing

10 Hitachi-UTokyo Laboratory: Habitat Innovation

Developed nations in particular are facing emerging societal issues that include the environment, older demographics, and aging infrastructure. To achieve Society 5.0, which seeks to use data to resolve these issues, Hitachi, too, is seeking to resolve societal challenges based on a vision developed through collaborative creation with the University of Tokyo.

At the Hitachi-UTokyo Laboratory, solutions are being developed along with ongoing debate that transcends the boundaries between science and the humanities based on a three-pronged approach to creating the cities of the future that draws on the changing structure of society, technical innovation, and the wellbeing of individuals to address societal challenges (habitat innovation).

The open forum that commenced in June 2018 provides a venue both for reporting progress on the technologies being developed and for holding debates about the wider world and challenges opened up by the use of data by inviting experts to participate in panel discussions. It has also published books that have been put together based on the results of joint research and the discussions.

Along with the continued publishing of information, Hitachi also intends to proceed with practical implementations of future urban scenarios and services that incorporate the knowledge acquired, and with sharing the issues. Hitachi will also be working with interested parties inside and outside the company on proposals and business developments aimed at a data-driven approach to putting these into practice.

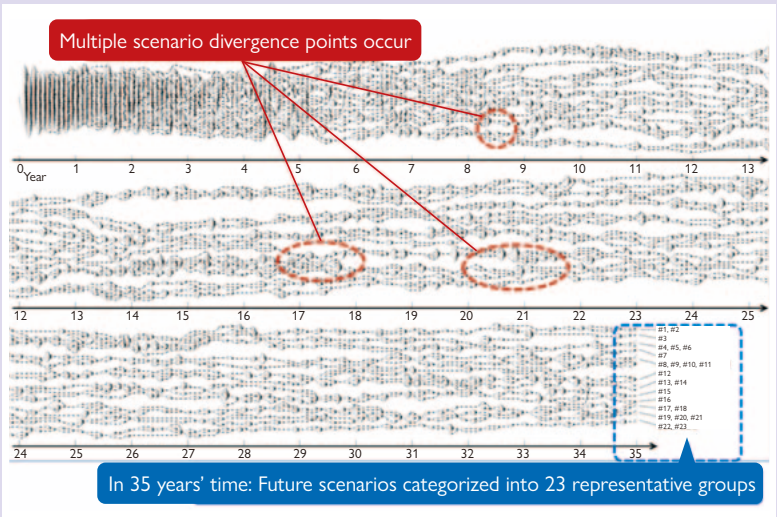

10 Forum for collaborative creation between industry and academia held on June 13, 2018

11 Hitachi Kyoto University Laboratory: Development of "AI Policy Proposal" Scenarios for the Future

With its aging population, low birthrate, and a changing industrial structure, Japan is going through a paradigm shift from a past of growth and expansion to a post-growth era (with neither growth nor expansion), bringing with it major challenges for society: (1) Population and birth rate, (2) Public finances and social security, (3) Cities and regions, (4) Sustainability of resources, the environment, and so on, (5) Maintaining employment, (6) Overcoming disparities, (7) The consequences of this for people's wellbeing, and (8) Health maintenance and improvement.

Now, Hitachi has developed the "Policy Proposal AI" based on a model of society in which a divergence tree is used to represent a wide variety of possible future scenarios, and to indicate the factors influencing each divergence point. From the results of the sustainability analysis of Japan in 2050 undertaken in cooperation with experts from Kyoto University, the AI presented two different possibilities for the future of Japan, one in which the population is concentrated in major cities and another in which it is regionally dispersed, and that the point at which these two scenarios diverge from one another will occur in about a decade's time.

In the future, Hitachi hopes to see this "Policy Proposal AI" being used in actual policy making processes, using collaboration with Kyoto University as a starting point for working with national and local government agencies.



11 Processes by which scenarios for the future diverge from one another (2018 to 2052)

12 Hitachi Hokkaido University Laboratory: Collaborative Creation to Build a "Health-centered Community" in Order to Eventually Achieve a Society Friendly to Women, Children, and the Elderly

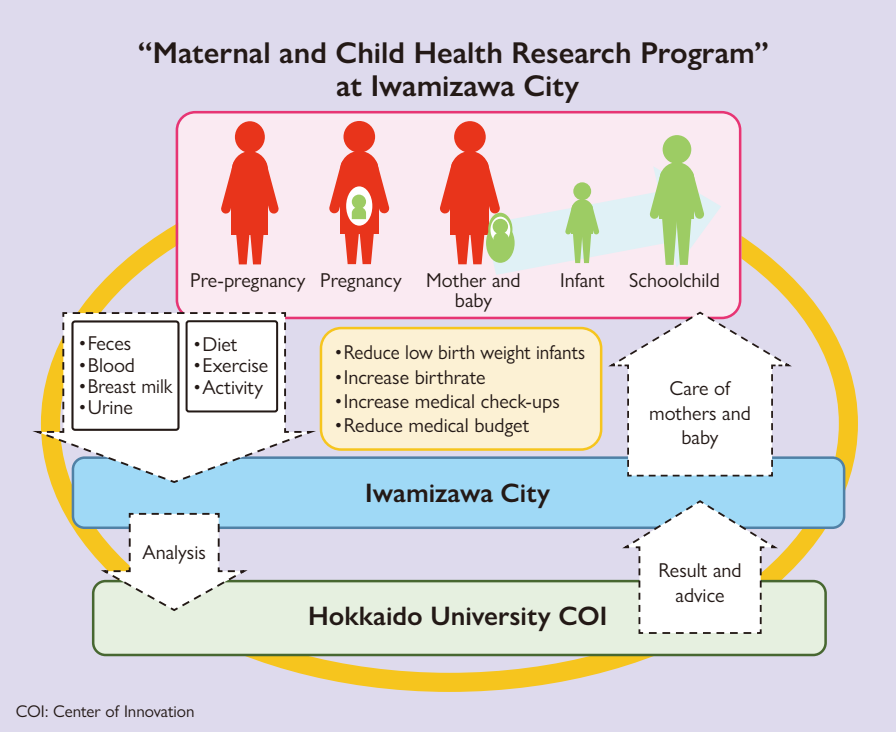
Japan's falling population, with a low birth rate and demographic aging, is raising serious concerns about the restructuring of social security and about regional revitalization and development. Working with corporate research partners among others, Hitachi is cooperating with the "Maternal and Child Health Research Program" at Iwamizawa City, the objective of which is the healthy growth and development of the children who will inherit the future.

Led by Iwamizawa City in Hokkaido, the survey is being planned and undertaken jointly with the Hokkaido University "Innovative Food and Healthcare MASTER." The survey is a type never before undertaken anywhere in the world, with pregnant mothers and their children as its subjects and involving monitoring of their circumstances during pregnancy followed by ongoing monitoring of the lifestyle habits and health of the children from birth to school age. The aims are to identify the factors that influence child growth and development and the causes of various types of ill-health, with the hope that this will contribute to increasing the birth rate and reducing the number of babies with low birth weight.

Along with promoting their individual wellbeing and longer health lifespans, support for child health can underpin child rearing assistance and healthcare cost reduction.

Hitachi intends to continue engaging in collaborative creation with industry and academia as well as central and local government aimed at the restructuring of social systems.

This research was undertaken under the Center of Innovation (COI) Program of the Ministry of Education, Culture, Sports, Science and Technology and the Japan Science and Technology Agency.



12 Overview of health survey of mothers and children in Iwamizawa City