Activities on Quantum Information Technology in Japan

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- Japanese government’s basic plan on science and technology
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National Projects -2015

- Basic studies, Proof of principles, Feasibility studies


JST
- Quantum magneto flux logic
- Quantum fluctuation
- Quantum computation and information
- Innovative space-time

CREST:
- Function Evolution

CAO
- Q Inf. Processing

NICT
- FIRST Q Inf. Tech.
- QKD & Q Network
National Projects 2015-

- Aimed for social deployment
  - **CAO**
    - ImPACT: *Advanced information society infrastructure linking quantum artificial brains in quantum network* (FY2014-2018; US$30M)
      - Quantum Neural Network, Quantum Simulation, Quantum Secure Network
    - SIP: *Photonics and Quantum Technology for Society 5.0* (FY2018-2022; US$20M@2018)
      - Laser Processing, Quantum Cryptography, Photo-electronic Information Processing
  - **MEXT**
    - Q-LEAP (2018-2028; US$200M)
      - Superconducting QC, Q solis state sensors, Advanced laser
  - **MIAC**
    - Satellite Quantum Crypto-technology
  - **NEDO**
    - Next generation computer technology (FY2018-2022; US$4.5M/project/year)
      - Quantum annealing (HW/SW)
  - **JST**
    - CREST: *Advanced control of quantum states* (FY2016-)
    - PRESTO: Quantum functionalization (FY2016-), Quantum software (2019-)
    - R&D Future Creation: Gyroscopes with matter waves (FY2017-2027; US$37M), Cloud of optical lattice clocks (FY2018-2028; US$37M)
The 5th Science and Technology Basic Plan (2016-2022)

- Advances in ICT, etc. have ushered in an “era of drastic change”
  - Increasing scale and complexity of domestic and global-scale challenges (such as energy restrictions, the declining national birth rate and aging population, regional impoverishment, natural disasters, changes in security environment, and deepening global-scale challenges, etc.)

- Acting to Create New Value for the Development of Future Industry and Social Transformation
  - Realizing “Society 5.0” (“Super Smart Society”)
  - Enhancing Competitiveness and Consolidating Fundamental Technologies in Society 5.0
    - Focus on the fundamental technologies needed for the service platform (such as cyber security, IoT system development, “bigdata” analysis, AI, and devices etc.) and strive to enhance technologies that represent core strengths for new value creation (such as robots, sensors, biotechnology, materials and nanotechnology, and Light/quantum technology etc.), by setting ambitious targets from a medium-term perspective.
What is Society 5.0

- Realize the advanced **fusion of cyberspace and physical space**, to balance economic advancement with the resolution of social problems, bringing about a human-centered society.

[https://www8.cao.go.jp/cstp/english/basic/5thbasicplan_outline.pdf](https://www8.cao.go.jp/cstp/english/basic/5thbasicplan_outline.pdf)
Quantum technology and Society 5.0

Society 5.0 highly integrates cyberspace and physical space

- Large scale computing
- Secure data storage
- Navigation: Optical clock gyroscope
- Optimization
- Secure communication
- Quantum sensing/measurement
Cross-ministerial **Strategic Innovation Promotion Program**

- Allocating budgets that cross the traditional framework of government ministries and disciplines
- Innovation along the entire path from basic research to effective exit strategies (practical application/commercialization)
- For quantum technology, *Photonics and Quantum Technology for Society 5.0*
  - Laser Processing
  - **Quantum secure cloud**
    (NICT, Toshiba, NEC, Zenmtech, Gakushuin-U, U. Tokyo, Hokkaido U.)
  - Photonic-electronic information processing
Quantum secure cloud

- Basic idea:
  secret sharing (secure storage)+QKD (secure communication)

- Advantages:
  - Information theoretically secure storage
  - Data recovery
  - Secret arithmetic
  - Long term secret communication with shared key by QKD
  - Integration with post-quantum crypto
R&D items for quantum secure cloud

- Social deployment
  - Development of Applications
    - Medical data, Genome, ...
  - Contribution to Standardization

- System technologies
  - Secret sharing, secret arithmetic
  - Key management, API
  - Random number generation

- QKD technologies
  - High speed, low cost system development (BB84/CV)
  - Implementation security
Q-LEAP: Quantum Leap Flagship Program

- Quantum information technology (Q comp., Q sim.)
  - Flagship Project: Superconducting Quantum Computers (Y. Nakamura)
  - Basic Foundation Research:
    - cold-atom based quantum simulators
    - Multi-degree-of-freedom complex quantum simulator using cooled ions
    - Architecture and applications for small to large scale quantum computation
    - quantum software applications by fast classical simulator of quantum computers
    - Large scale integration of silicon qubits to realize quantum computer
    - Quantum software

- Quantum metrology & sensing
  - Flagship Project: highly sophisticated control of solid quantum sensors (M.Hatano)
  - Basic Foundation Research:
    - earthquake early alert methods using high-sensitivity gravity gradiometer
    - photon-number-resolving quantum nano-photonics
    - quantum atomic magnetometer with dual quantum noise squeezing
    - Spectroscopic techniques toward elucidating functions of complex molecular systems
    - quantum sensing devices using quantum entangled photons
    - Material science of complex defects for highly-sensitive quantum sensors
    - high-performance inertial quantum sensors

**Project Name**
Research and Development of Superconducting Quantum Computers

**Head quarter**:
Center for Emergent Matter Science, RIKEN (Project leader: Yasunobu Nakamura)

**Collaborators**:
The University of Tokyo, National Institute of Advanced Industrial Science and Technology, National Institute of Information and Communications Technology, QunaSys, MDR, Toshiba, NEC, NTT, Kyoto University, Osaka University, Nagoya University, Tokyo Medical and Dental University

**Overview**
1. **Construction of a superconducting quantum computing platform** outperforming classical devices
2. Integration of **100 or more quantum bits (qubits)** with novel 3D packaging techniques
3. Development of **quantum applications** accessible via a **cloud-based service**

**Goals of R&D**
- Integration of **100 or more qubits** into a three-dimensional package
- Readily accessible **applications** available on a **cloud-based service**

**Milestones**
- **5 Year Plan**:
  - Implementation of a 50-qubit system with high-fidelity control and readout
  - Creation of a cloud service for the 50-qubit device
- **10 Year Plan**:
  - Growth to a 100-qubit system with higher-fidelity control and readout
  - Expansion of the cloud service for a 100-qubit device, applications for **practical use**
    - (1-qubit gates > 99.9%, 2-qubit gates > 99%, Readout > 99%)
    - (2-qubit gates > 99.95%, 2-qubit gates > 99.9%, Readout > 99.9%)

**Exit Strategies**
- Construction & operation of a cloud system in **collaboration with partners in the private sector**
- Development of **practical quantum computers** through an academic-industrial alliance

**Strengthening of the research infrastructure & development of human resources of the next generation**
- Recruitment of young **Principal Investigators** as leaders in the next generation
- Employment of **PhD students** as researchers in the next generation
- Close collaborations with **worldwide research groups** for the **exchange of international talents** to jointly spread quantum technologies across the globe
- **Foundation of a consortium** for quantum information research and development
- Support for the procurement and establishment of **career paths** for researchers and students

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Project Name: Development of innovative sensor systems by highly sophisticated control of solid quantum sensors

Project Leader: Prof. Mutsuko Hatano, School of Engineering, Department of Electrical and Electronic Engineering, Tokyo Institute of Technology

(Joint Research Institutes) Kyoto University, University of Tokyo, National Institute of Advanced Industrial Science and Technology, National Institutes for Quantum and Radiological Science and Technology, DENSO, Hitachi, YAZAKI, etc.

Overview: Building a “solid quantum hub” to conduct research and development continuously from physics to applications of sensor co-development. Developing prototypes of quantum sensors by utilizing diamond NV center (nitrogen-vacancy pair), whose spin coherence is superior even at room temperature in the atmosphere and whose quantum states can be initialized and read out by light.

Goals of R&D:
- Development of prototypes for magnetoencephalography with high sensitivity and high spatial resolution
- Development of prototypes for systems that monitor the current and the temperature in batteries and power devices

Milestones:
- Magnetoencephalography
  4th to 5th year: Sensitivity of 5pT; Imaging of nerve issues, and magnetoencephalography of small animals
  10th year: Sensitivity of 10fT; Measurement of human magnetoencephalogram
- Monitoring systems of batteries and power devices
  4th to 5th year: Implementation of quantum sensors inside batteries and power devices; Simultaneous measurement of current and temperature
  10th year: Small prototypes that measure current and temperature

Future strategy:
Form a consortium of corporations that have interest in the development of materials and devices of solid quantum sensors and the development of systems employing such sensors. Aim at efficient and smooth social implementation by collaborative development that distinguishes between the cooperative area for joint development of basic technologies common to the member companies and the competitive area according to the individual applications and needs.

Strengthening of the research infrastructure & development of human resources of the next generation
- Allows young leaders to promote these activities so that they can become world leaders of each area in the 10 years
- Hiring of competent doctoral students as researchers, to nurture young leaders in next generation
- Promotion of fluidity of human resources and fusion of different fields at the co-development hub to formulate positions in new interdisciplinary fields
- Formulate career paths for postdocs and doctoral students through industry-government-academia collaboration
- Cultivation of human resources who comprehend solid quantum sensors from fundamental theories to overall systems

NEDO: Project for Innovative AI Chips and Next-Generation Computing Technology Development

- Project for Innovative AI Chips and Next-Generation Computing Technology Development

- Two projects related to quantum technology
  - Research and Development of quantum annealing with super conductor parametrons
  - Research and Development of a Common Software Platform for Ising Machines
Quantum annealing with super conductor parametrons

- Highly **coherent super conductor parametron** annealing devices (NEC,AIST)
- **3D multibit** implantation (NEC, AIST)
- **Efficient representation** of many body interaction (TIT)
- Optimal design of quantum annealing mechanism (Waseda U.)
- Magnetic flux circuits for **control and read-out** of qubits (YNU)
- High speed parallel **simulation** on quantum dynamics for performance estimation of quantum annealing (NEC, Kyoto U.)
Research and Development of a Common Software Platform for Ising Machines

- Common software platform as an intermediate layer between Ising machine hardware and real problems
- Algorithms (Waseda)
- Quantum annealing theories (TIT)
- Security and material design applications (AIST)
- Extraction and formulation of problems, applications (Toyota Tusho)
- Libraries and APIs (Fixter)
- Hardware (NEC)
Technological Foundation of Advanced Quantum Computing and Information Processing

A PRESTO research area starts in 2019

Aim
Creation of technological foundation to realize scalable quantum computing through overcoming or exploiting the restrictions that quantum systems provide.

Term & budget
Three year project. US$0.3M/project/year

Remarks
- PRESTO seeks original and challenging proposals
- PRESTO offers a chance for a young researcher to conduct his own project with advices from experienced researchers
Quantum-related funding and studies

**Sensing**
- Diamond NV
  - Brain, heart magneto sensors
  - Real time monitoring of power devices
- Optical lattice clock
  - Gravitational potential
  - Relativistic space-time probe
  - Gravitational accelerometer
  - Gyroscope
- Matter wave interferometer
- Entangled photons
  - Quantum OCT
  - IR spectroscopy
- Quantum memory • repeater
  - Long distance quantum communication
  - Photonic qubits
- Photonic crystal
- Topological QC
- Topological materials

**Communication/cryptography**
- QKD
  - Secure storage cloud
- Photonic qubits
- Quantum memory • repeater
  - Long distance quantum communication
  - Authentication, secret sharing
  - Secure cloud computing
  - Quantum annealing
  - Quantum supremacy
  - Qubit implementation
  - Quantum control
  - Nonlinear optics
  - Photon generation/detection

**Computing**
- Super conductor qubits
- Super conductor qubits
- NMR
- Imaging
- Network
- Teleportation
- Quantum control
- Quantum simulation
- Quantum computer science
  - Complexity, algorithm
  - Programming, compilers
  - Architecture, QECC
  - Implementation, interconnection

**Simulation**
- Quantum computer science
  - Complexity, algorithm
  - Programming, compilers
  - Architecture, QECC
  - Implementation, interconnection
- Coherent control
  - Chemical reaction
  - Trapping molecules
  - High speed optical switch
- Macroscopic quantum control

**Materials**
- Spintronics
- Multiferroics
- Topological materials
- LT-CMOS
- SC circuit

**Foundation of quantum science and technology**

**10 years • ~US$36M**

**5(-10) years US$4.6M/Y**
Summary

- Japan has continued funding on quantum science for more than 30 years, and contributed to develop quantum information science and technology.
  - Such as super conductor qbits, high speed QKD networks, AQIS conference,...

- Since 2015, several national projects have been launched to promote R&D for social deployment of the quantum information technology in the areas of sensing, communication/cryptography, computing, and simulation.

- At the same time, small projects are funded under PSESTO to encourage young researchers.