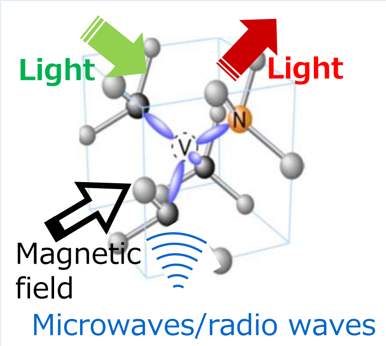
【Flagship Project】 " Quantum metrology & sensing "

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.



Diamond NV center

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.

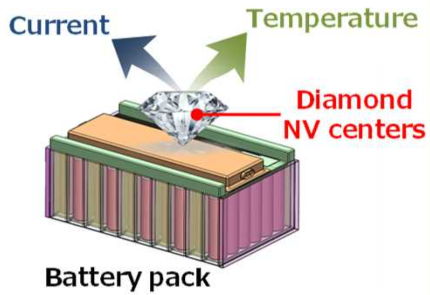
Goals of R&D

- 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

Magnetoencephalography



Battery/power device monitoring

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**

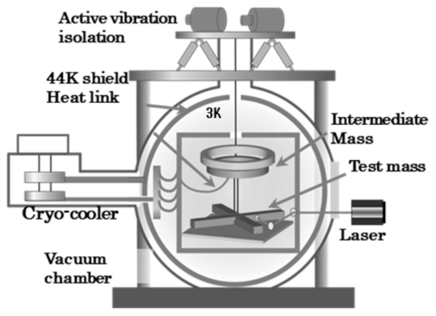
【Basic Foundation Research】 “ Quantum metrology & sensing ” ①

Project Name **Establishment of earthquake early alert methods using high-sensitivity gravity gradiometer**

Project Leader **Associate Prof. Masaki Ando, Graduate School of Science, University of Tokyo**

Overview Detects gravity location change at the time of fault ruptures during large scale earthquakes using a **gravity gradiometer** network and builds systems to dispatch alarms at the early stages in the society

Complementing and synergy effects with the Flagship project:
Development of torsion pendulum-type sensors to contribute to platforms of quantum calculation and sensing



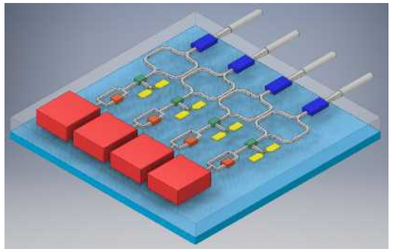
Low temperature torsion Pendulum-type gravity gradiometer

Project Name **Development of photon-number-resolving quantum nano-photonics**

Project Leader **Prof. Keiichi Edamatsu, Research Institute of Electrical Communication, Tohoku University**

Overview Develops quantum light sources with a deterministic photon-number state with high quantum coherence and develops **photon-number-resolving detectors** that identify and detect photon numbers with extremely high accuracy and quantum efficiency, thereby boosting performance of quantum measurement using quantum properties of photons

Complementing and synergy effects with the Flagship project:
Improvement in quantum light sources and detection technologies lead to the development of quantum measurements and sensing using photons



Integration of photon-number- resolving detector and
quantum light circuit

【Basic Foundation Research】 “ Quantum metrology & sensing ” ②

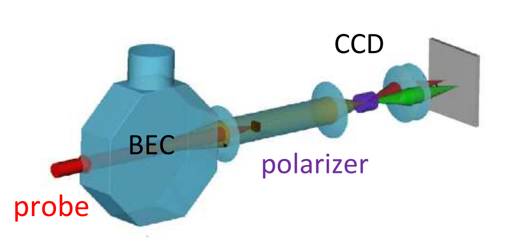
Project Name **Development of quantum atomic magnetometer with dual quantum noise squeezing**

Project Leader **Assistant Prof. Kosuke Shibata, Physics Division, Department of Science, Gakushuin University**

Overview In a magnetometer using a Bose-Einstein condensate, compression of both of atomic spin quantum noise and photon noise is conducted, realizing **magnetic field sensitivity** better than the conventional limit.

Complementing and synergy effects with the Flagship project:

Basic knowledge on quantum magnetic sensors makes a contribution to the improvement of performance of solid quantum sensors.



Schematic diagram of a Bose-Einstein condensate spatial magnetometer

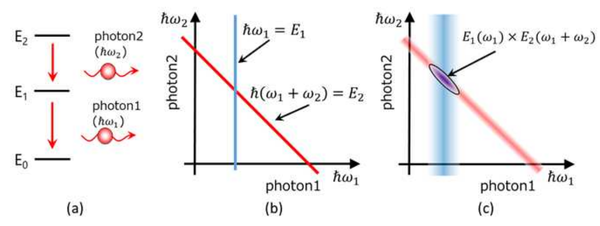
Project Name **Development of Spectroscopic techniques based on cutting-edge quantum optics toward elucidating functions of complex molecular systems**

Project Leader **Associate Prof. Ryosuke Shimizu, Graduate School of Informatics and Engineering, The University of Electro-Communications**

Overview In addition to the proposal and proof of principle of 2D quantum spectroscopy to extract **quantum entanglement** information in time-frequency regions of two photons, clarification of the physical functions of useful complicated molecular systems such as photosynthesis is conducted

Complementing and synergy effects with the Flagship project:

Substantiates 2D quantum spectroscopy, new quantum measurement technologies, thereby contributing to the platforms of quantum measurement and sensing



Principles of 2D quantum spectroscopy

Project Name **Research on quantum sensing devices using quantum entangled photons**

Project Leader **Prof. Shigeki Takeuchi, Graduate School of Engineering, Kyoto University**

Overview Develops quantum sensing devices using frequency-correlated **quantum entangled photons**. In particular, the realization of high-sensitivity infrared absorption spectrometers just using visible light detectors based on the infrared quantum absorption spectroscopy using quantum entangled light.

Complementing and synergy effects with the Flagship project:

Development of new sensor technologies using quantum entangled light to make a contribution to platforms of quantum measurement and sensing

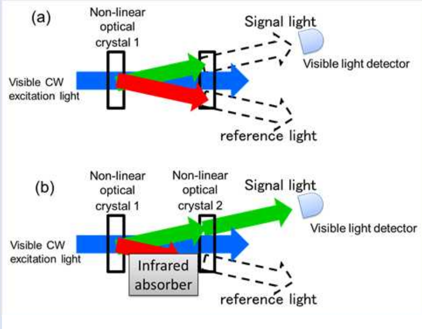


Image of infrared quantum absorption spectroscopy

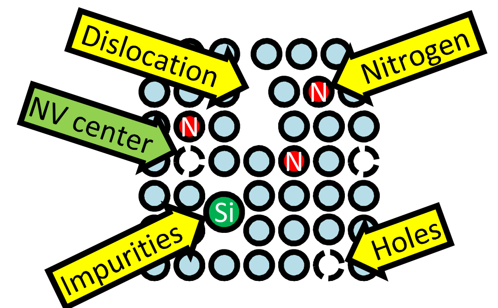
Project Name **Material science of complex defects for highly-sensitive quantum sensors**

Project Leader **Tokuyuki Teraji, Chief Researcher, Research Center for Functional Materials, National Institutes for Materials Science**

Overview **Development of single-crystal diamond formulation methods** that contribute to quantum sensing, building of defect formation scientific principles for high-density high-quality complex defects formation, and creation of diamond NV centers with high-magnetic sensitivity

Complementing and synergy effects with the Flagship project:

Advanced crystal growth and evaluation technologies are implemented to obtain high-quality diamond NV centers and improve the fabrication technologies of solid quantum sensors



Defects which disturb formation of high-quality NV centers

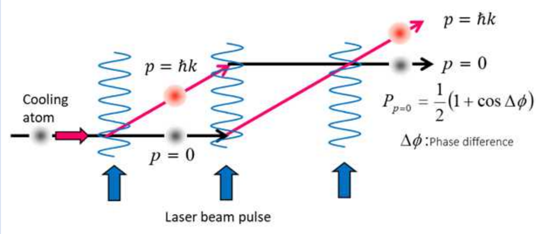
【Basic Foundation Research】 " Quantum metrology & sensing " ④

Project Name **Development of next generation high-performance inertial quantum sensors**

Project Leader **Prof. Ken'ichi Nakagawa, Institute for Laser Science, University of Electro-Communications**

Overview We develop the basic technologies to improve the sensitivity of atomic interferometers by using quantum controls of external motion of atoms, and realize substantial miniaturization of existing **inertial quantum sensor** systems

Complementing and synergy effects with the Flagship project:
Knowledge relating to the improvement of sensitivity of inertial quantum sensors makes a contribution to platforms of quantum measurement and sensing



Light-pulse atom interferometry

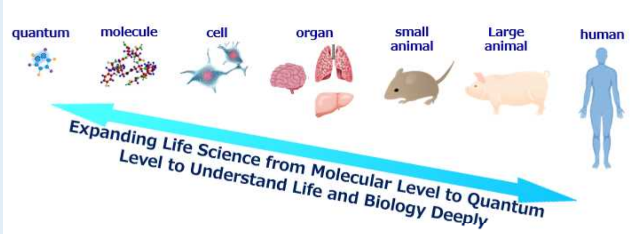
【Flagship project】 "Quantum metrology & sensing (quantum life science)"

Project Name | **Innovating Medicine and Life Science through the Application of Quantum Technology**

Project Leader | **Yoshinobu Baba, Director General of Institute for Quantum Life Science (iQLS), National Institutes for Quantum and Radiological Science and Technology (QST)**
Collaborators: University of Tokyo, Osaka University, Kobe University, Kyoto University, Taiyo Nippon Sanso, Toray Research Center, Inc., etc.

Overview

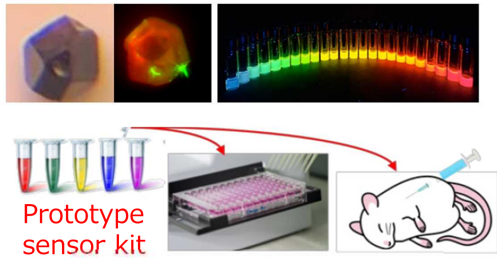
- Creation of **<u>quantum technology</u>** that leads the world in innovating medicine and life science and engenders social change
- Implementation of research and development relating to **<u>nanoscale biosensors, ultrasensitive MRI/NMR,</u>** and the **<u>clarification and imitation of quantum-theoretical life phenomena,</u>** as well as the **<u>realization of prototype measurement technology to be utilized in medical and life science research</u>**



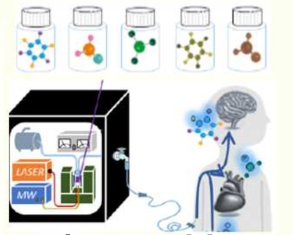
Quantum Life Science

Goals of R&D

- **Development of nanoscale biosensor systems** with the ability to make simultaneous measurements over a wide field-of-view at high resolution
- **Development of ultrasensitive MRI/NMR equipment** based on quantum technology such as hyperpolarization and quantum coding, and novel long-life **hyperpolarized molecular probes of low toxicity**
- **Explication of the quantum-theoretical mechanisms of biological functions** that have not been clarified to date; to be achieved through the development of high-precision quantum-coherence measurement and spectrographic analysis technologies that enable us to explore quantum effects (eg. photosynthesis, magnetoreception) in living creatures



Nanoscale/quantum biosensors (image)



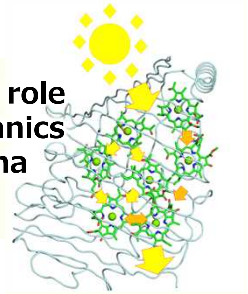
Ultrasensitive MRI/NMR (image)

Milestones

5 Year Plan: **Measurement of at least three quantities, such as pH and temperature,** within each target organ
Realization of metabolic imaging using room-temperature hyperpolarized pyruvic acid and the **development of room temperature hyperpolarization equipment**
Observation of quantum coherence in photosynthesis proteins using an ultrashort-pulsed laser and other advanced technology.

10 Year Plan: **<u>Realization of simultaneous measurement & imaging of three quantities, such as pH and temperature,</u>** <u>within small animals</u>
Realization of room-temperature hyperpolarized metabolic imaging in large animals and **<u>preparation for a clinical trial of long-life sensor molecules</u>** that will make new diagnostics possible
<u>Application of the developed measurement systems to research goals such as clarifying the mechanisms of artificial photosynthesis photoreceptor proteins</u>

Clarification of the role of quantum mechanics in life phenomena (image)



Exit Strategies

- **Formation of a consortium** to enable long-term, active collaboration that transcends conventional medical-engineering and industry-academia relations, and works towards the application of quantum technology to life science research
- Promote rigorous exchanges of opinion to enable industry-academia-government product development, accelerate the bridge to industry and **drive the creation of new business ventures**
- Based on the extensive track record of QST, **<u>construct a preclinical to clinical research system</u>** <u>that will accelerate the practical application of research and development to medical treatment</u>

Strengthening research infrastructure & developing human resources for the next generation

- **Establish a system encouraging collaboration** between young researchers who have obtained their doctorate within the last a decade and prominent researchers with internationally recognized achievements in medicine and/or life science
- **<u>Foster world leaders</u>** <u>who are willing and able to see the big picture from the foundations of quantum technology to the development of medical and life science to social implementation</u>