Research area in Strategic Objective ”Innovation of Bio-Sensing , Elucidation of Dynamics and Interactions between Biomolecules by Using Quantum Technology”

6.2.1 Creation of Life Science Basis by Using Quantum Technology

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Overview

The aim of this research area is to apply the knowledge of quantum science and its technologies to biomolecule measurements through the collaboration between quantum science and life science researchers. In recent years, quantum technologies including quantum beams, quantum spin, light quantum sensors and quantum electronic, etc. has progressed markedly based on quantum science. These technologies have also realized quantum computing and time crystals. Japan has cutting-edge quantum technologies, or in a sense, seeds technologies capable of leading the research field in the world. These technologies are expected to advance the development of new biotechnologies for detecting dynamics and interactions of biomolecules, as well as the discovery of quantum phenomena in biological phenomena. At present, however, the application of quantum technologies to life sciences has not so progressed. The program of this research area will encourage applying quantum technologies to biotechnologies to develop new life sciences dramatically.

Research Supervisor's Policy on Call for Application, Selection, and Management of the Research Area

Background

Quantum technologies have progressed markedly in the recent years and have even brought quantum computing into reality. In the current situation, European countries and the U.S. are investing millions of dollars for the applications of quantum technologies to the research field of life sciences. Although Japan has advantage on biosensor production and quantum beam upgradation in the world, it lags far behind advanced nations in the applications of quantum technologies to life sciences.

Recently, Japan has however gradually begun applying the quantum technology seeds to life

sciences. For example, Japanese quantum sensor technologies such as the diamond NV center are noticed in the world because they enable high sensitivity observations of feeble temperature, magnetic fields, electric fields *in vivo*. Combining quantum entanglement photons with super resolution microscopy has enabled to develop new *in vivo* imaging technologies at high spatial resolution, which were difficult to apply to life sciences in the past. Upgraded quantum beam technologies have also established a new era of super precise structural analysis in which quantum level solutions are utilized to capture electron density and hydrogen positions: the key to the expression of biomolecular functions. However, these challenges are not pervasive to life sciences widely due to life science researchers' lack of confidence and resistance to quantum technologies, and the low awareness about the application of quantum science to life sciences.

Policy for proposal invitation and selection

This program will focus on the research area and actively promote the application of quantum technologies to life sciences on the basis of the background and challenges to in prove the current situation described in section 1. Although the specific research issues have been listed below, there is no need to limit proposals to encourage the policy. We will adopt innovative, challenging, and novel proposals that have not been thought of previously by the research supervisor of this program with this policy and the research area advisors who will review the proposals.

The objective of this research area is to develop new life sciences using quantum technologies though it is not aimed at progressing quantum sciences using life science technologies. However, proposals through which quantum science technology makes progress as a result of the mutual interchange between these two research fields are acceptable.

① Issues to be elucidated through the application of quantum technologies for understanding biological phenomena

We recognize that applicants are mainly researchers from the research fields of biology, agriculture, medicine, dentistry and pharmacy, who are studying biological phenomena. The purpose of this thematic scope is not to develop new technologies but to discovery new biological phenomena, principles, substances, and elucidation of disease pathologies, etc. We hope to get a wide range of proposals that quantum technologies can be introduced as a tool to support biological research. The

subjects could be various issues in basic biological research including cytobiological studies of behavior and state changes of biomolecules in cells, biochemical studies of the activity of proteins that control biomolecular functions, neuroscientific or physiological studies of metabolism and brain functions at an individual level, pharmacological studies to elucidate the functions of chemical reactions through the acquisition of chemical bond information for proteins and molecules in blood vessels and in cancer, studies on the relationships between biological responses and diseases, radiological studies to elucidate mutual interactions between molecules *in vivo* through the introduction of behavioral information of hydrogen atoms and water molecules by collaborative utilization of neutron rays and X rays, elucidation and inhibition (leading to the upgradation of therapeutic applications) of protein functions through understanding the behavior of outer electrons or the work of hydrogen bonds, electron transmission in photosynthesis, and cellular functions occurring through membrane potentials.

Examples of quantum technologies: microscopes capable of taking full advantage of light quantum processes, such as multiphoton microscopes, visualization using Qdot (fluorescence quantum fine particles), measurement of temperature and magnetic field using diamond nitrogen-vacancy center, research using quantum sensors such as PET and quantum beams including proton rays, heavy particle rays, and free electron lasers. However, many of the quantum technologies have not been established as methods for practical application to organisms and need to be further improved.

② Issues in developing quantum technologies using measuring techniques applicable to life sciences

We assume that the applicants on this thematic scope would be researchers mainly from applied physics and chemistry. We wish to receive proposals for the development of measuring techniques and probes applicable to life sciences, an issue that has not been dealt with so far. We also welcome proposals by researchers from biological engineering or medical engineering, who are already knowledgeable and experienced in developing measuring techniques and introducing quantum technologies. What we are looking for is research on the *in vivo* applications of techniques that are horizontally developed from techniques with certain levels of achievement records in research fields such as quantum electronics and light quantum. In this scope, it is not necessary to reach a stage to address issues concretely in biological or medical fields during the PRESTO research period.

The aim should be to develop: detection systems for interactions among biomolecules using quantum sensors, a method for the quantitative measurement of temperature, magnetic fields, and electrical fields in cells using nanometer spatial resolution through improvement of quantum sensor sensitivity, a multimodal imaging modality for a localized physical field within cells, applications for measurement with magnetocardiograms or magnetoencephalograms in industries and therapy, NMR and MRI for single molecules using electron spin resonance, a minimally invasive deep *in vivo* imaging technique by introducing quantum entanglement into a fluorescence super resolution microscope, a new in vivo imaging technique using light and quantum technologies including multiphotons, a technique for observing the internal wall of blood vessels using quantum entanglement and light, etc. and to conduct basic research to upgrade the therapeutic applications of quantum dot.

③ Issues in understanding biological phenomena in terms of quantum science

We assume that the applicants on this thematic scope are quantum researchers from the departments of science, structural scientists using Spring-8, cryoelectron microscope, NMR, etc., theoretical biologists, computational scientists, quantum biologists in a so-called narrow sense, etc. The purpose of this research project is not invention but understanding, or understanding organisms in terms of quantum science. Tools for this purpose do not need to be quantum technologies. For example, an approach from calculation simulation is conceivable, phenomena that quantum coherence and electron correlation are closely and directly related to biological functions, i.e., cases with no incorporated classical macro (coarse visualization) model exists at the forefront of the discussion. The understanding covers a wide range, including whether such a model does indeed exist. Specific examples include: research on light absorption and response by visual substances on the basis of crystal structure analysis at super resolution, research on electron transmission and energy transfer involved in photosynthesis by plants and respiration by mitochondria, magnetoreception by migrating birds, etc.

Selection of proposals

Joint research by researchers sharing their research themes is acceptable for applying to this program

of the research area. That is, a proposal can be made by a quantum science researcher teaming up with a researcher or a business firm from life sciences. However, please note that the research fund will be granted only to the individual researcher whose proposal is accepted for PRESTO. In the case of joint research, the paired applications are acceptable if such a situation has been clearly stated. In such a case, it is not necessary that both proposals should pass for adoption; there is a possibility that either one of the pair is accepted. Of course, an individual researcher who is knowledgeable in both life sciences and quantum science can apply in the same manner as in the past. It is suggested to cooperate with other individual researchers or the research advisors after the proposal is adopted. The selection will be conducted through the cooperation with the research advisors. Instructors in chemistry or spectroscopy who link quantum science and biology are deployed as research area advisors in good balance in order to cope with the process of selection of various research proposals. Quantum science researchers interested in life science analysis and life science researchers who aim to utilize quantum technologies for the elucidation of biological phenomena are accepted even though they have no joint research partner at present. They will be able to find partners through in this research area in the near future after their proposals are adopted by the program.

"PRESTO" is a program that allows full-time participation. We welcome innovative proposals that are free from research themes of presently affiliated research laboratories (JST performs an internal review for full-time employment).

Operational policies

This research area is operated to emphasize on exchange among researchers from different fields, set up a "core for technology and analysis" as a platform, and to establish a research system in which researchers of life science technologies and those of quantum science technologies work in a single area. We aim to contrive a system that allows advisors from different research areas to guide individual researchers for acquiring diverse knowledge and to allow researchers of life science technologies to collaborate with those of quantum science technologies for flexibly teaming with researchers inside and outside of their research areas.

In this research area, we do not perform evaluations based on the number of papers or presentations at meetings of academic associations during the three and a half years of the PRESTO research

period. We do not expect immediate achievements. It inevitably takes more time to apply the achievement of a research in the society. Please feel secure in actively challenging high-risk themes. We firmly believe that achievements far beyond our present imagination will come out of this research area sometime in the future. It would be a great pleasure for this research area supervisor to see a large number of researchers responsible for the achievements that are applied in the future.

*A session for proposal invitation and explanation is scheduled as follows. We await the participation of many interested candidates.

	Date	Venue
Kanto	14:00 to 16:20 April 18 (Tuesday) (a joint session for the CREST research area "Creation of the base of innovative quantum technology based on high level control of quantum state" and PRESTO research area "Control of quantum state and functionalization")	Hall on the first floor of the annex to the JST Tokyo head office 7K's Gobancho, Gobancho, Chiyoda-Ku, Tokyo
Kansai	14:00 to 15:30 April 21 (Friday)	Shin Osaka Learning Square Building 1-3-12 Nishi Awaji, Higashi Yodogaya-Ku, Osaka Shi, Osaka

See the following website for details:

http://www.senryaku.jst.go.jp/teian.html