Research areas in the Strategic Objectives "Development of new material properties and frontier of information sciences based on the advanced control of quantum states"

6.2.7 Quantum state control and functionalization

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Overview

This research area promotes ingenious, ambitious research that expands investigative frontiers to facilitate the control and functionalization of quantum phenomena, rather than simple observation. By explaining the nature of the quantum phenomena behind the existence and behavior of various atoms, molecules, materials, nano structures, electromagnetic waves, along with the organisms and systems in which these objects interact, and by challenging existing knowledge on the manipulation, control, and measurement of quantum states, this research area will contribute significantly to the creation of novel concepts, innovations, and technology. These seeds will be developed into innovative information processing, measurement, standardization, communication network, and power-saving technology in the future, along with associated applications. Further, this research area aims to produce junior researchers who can lead future quantum physics research and its application on an international level, by exploiting their high-level insight and capabilities based on theoretical development, experimental techniques and calculation techniques.

More specifically, this research area promotes research into a wide range of topics, not only related to quantum physics, information science, chemistry, engineering, and biology, but also having connections with mathematical science, material science, and nano structure science. Thus, this research area works to construct a platform for accelerating cooperation and collaboration between researches in these dissimilar fields.

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

1. Background

Since the initial development of the field of quantum physics in the early 20th century, research has been conducted on quantum optics and band theory in solid states; hence, devices such as lasers, transistors, and light-emitting diodes (LEDs) have been developed. Following the latter part of the 20th century and as a result of rapid progress in the fields of electronics and nano technology, emphasis has been placed on the

finding that single quanta (atoms, electrons, photons, phonons, etc.) and macroscopic quantum phenomena that can be treated as single quanta (superconductor quantum dots, etc.) can be coherently manipulated and controlled. Hence, calculation, communication, measurement, standardization, and power-saving technology will be developed, which allow the applications previously deemed impossible with conventional technologies to be realized, based on the properties of the abovementioned phenomena. There is no end to the growth of quantum science, and research phases are being restructured to move from coherent control of a single quantum to small quantum entanglement, and then onward to the control of large quantum systems.

Thus, this research area promotes pioneering research that expands technological frontiers towards applications in which quantum states are coherently controlled and functionalized.

2. Collection and selection policy

Only ingenious, scientifically engaging projects involving energetic researchers who exhibit considerable conceptual innovation are selected. Proposals that will yield a concrete result within the three-year PRESTO research period only are excluded. On the other hand, proposals initiated under PRESTO research that will contribute significantly to new avenues of research in the field of quantum state control are invited, provided this influence will extend to a period of 10 years after the PRESTO research period has ended. The contributions of such proposed research projects should be anticipated to stimulate a new research era, which should involve the application of quantum functions, over the subsequent 10-year period. From the perspective of fostering young researchers and providing opportunities for many researchers, those who were previously adopted in the PRESTO system are excluded from the public invitation to this research area.

Research proposals may focus on mathematical theory development, computational simulation, experiment, and so on. Special focus will be placed on innovative ideas, executive ability, and the researchers' potential to apply their individual capabilities. Although PRESTO research is individual, some projects with larger grand designs may surpass the limits of a single person. Accordingly, if a proposed scenario is profound and innovative, a research project to which the applicant will contribute a specified portion of work only will be considered. Such cases may include research projects on the creation of materials, substances, or nano structures that can facilitate extraordinary quantum control, along with research aiming to develop eminent quantum control technology or quantum physical measurement technology superior to existing approach. However, in such cases (including proposals involving international research collaborations), in the context of a quantum functionalization base concept, we request that items on which the applicant will work alone and items on which the applicant will work in

collaboration with an associate researcher (or on which the applicant hopes to engage in such a collaboration in the future) are clearly indicated.

Specific examples of research projects that partly engage in cutting-edge research questions are described below. Cutting-edge research questions are naturally expected, which should involve a challenging research question that will be pursued in order to further scientific development. Applicants submitting such research proposals should clarify their current international status and their potential for academic development (e.g., by explaining why the proposed project should be pursued by me). They should also indicate how a significant contribution that stimulates further research will be made following the end of the PRESTO research period. Proposals involving new and challenging techniques and methods that may surprise the judges are expected.

Examples of particular research projects

- A research project evaluating and controlling unbalanced dynamics and large-scale quantum entanglement in a quantitative manner, using a quantum many-body system with high parameter controllability. Examples include cooled atoms in a photonic lattice, ions in a two-dimensional Penning trap, a light circuit integrated on a chip, or a solid material and device in which multiple spins are regularly arranged.
- A research project aiming to realize an extremely large nonlinear effect via photon-material interaction in a light and microwave resonator using quantum opto-electro-nanomechanics mechanisms. Using this result, the development of an ultra-high-efficiency, ultra-high-sensitivity quantum functional device that can yield coherent wavelength or coherent media conversion, etc., will be pursued.
- A theoretical research project that will establish a new framework for a research topic currently under investigation, such as micro-economy thermodynamics or unbalanced statistical mechanics, using knowledge of quantum information science. In addition, an experimental research project related to quantum feedback control and dynamics in an open system involving atoms and molecules, or in optical and biological systems, will be pursued. The examined systems may act as stages for validating the developed theories.
- A research project related to a new framework that mitigates and eliminates requirements and restrictions in conventional digital quantum calculations, e.g., for quantum state control incorporating dispersion, quantum information processing techniques based on so-called reservoir engineering, and systems capable of error correction without measuring individual quantum dots.
- A research project elucidating the role of quantum coherence in chemical reactions in organisms, such as for photosynthesis in plants, magnetic compasses in birds, and enzyme reaction.
- The development of a new quantum algorithm that renders some previous impossibility possible, by utilizing information theory and quantum physics.

- The development of cutting-edge technology essential for the practical application of quantum information technology by exploiting the researcher's particular research interest. The development of, for example, a unique material and nano structure, an interface specific to the parallel control of multiple quantum dots, a field-programmable gate array (FPGA) circuit and Josephson computer operable at extremely low temperature, or a radio-frequency (RF) waveguide enabling coherent movement of captured ions. In such cases, a grand design concept should be proposed and an intimate collaboration with a specific digital-quantum-computer research group suggested.

Many of researchers slected last year were physicists. This year, while we cantinute to encourage strong applications from physicists, we also seeks for strong applications by non-physicists, e. g., information scientists, chemists, material scientists, electrical engineers, control engineers, applied mathematicians, biology-related scientists, and others. The proposals must include research plans that can achieve the ultimate goal of surpassing the performance limit of classical devices with quantum functions, i. e., demonstration of quantum supremacy.

The fact that research phases in quantum information science have shifted focus from coherent control of single quanta to small quantum entanglement, and onward to the development of a quantum calculator based on the control of a large quantum system, has already been mentioned. In this year's call, we invite proposals aimed at unique and ambitious demonstrations of quantum functions utilizing diversified approaches. We actively seeks the candidacy of women.

3. Operation policy

Proposals that will begin under PRESTO research and that will contribute to the stimulation of new research avenues in quantum state control in the 10-year period after the PRESTO research period has been ended are expected, rather than proposals that will yield a compact result within the three-year PRESTO research period only. The research area will provide an environment in which associated researchers can conduct in-depth discussion and proceed to large-scale research projects vigorously and cooperatively. The research area aims to produce research results that will become sources of scientific and technological innovation by allowing researchers to interact with each other within the research area. This will overcome the problem of cross-field partnership and collaboration and produce junior researchers that will lead future research in quantum science and associated applications on an international level.

The management of the research area not only cooperates with the CREST "Creation of an innovative quantum technology platform based on the advanced control of quantum states", having the same strategic objective, but also promotes cooperation between research areas through the CREST "Advanced core technology for creation and practical utilization of innovative properties and functions based upon optics

and photonics” , PRESTO “Fully controlled photons and their proactive usage for new era creation” and PRESTO” Creation of Life Science Basis by Using Quantum Technology”. The research area will also facilitate cooperative conferences and workshops as required. Moreover, the research area manages outreach activities and public awareness campaigns with the cooperation of the affiliated researchers. On a needs basis, the sharing of certain items of research equipment and apparatus, such as existing apparatus in common national utilities (e.g., the Tsukuba Innovation Arena and the MEXT Nanotechnology Platform) and apparatus in the applicant’s research institute, is requested.

Briefings on the call for proposals in this research area will be held according to the following schedule. We hope to see many interested parties in attendance. Both briefings listed below will be held jointly for the CREST research area “The creation of innovative quantum technology platform based on the advanced control of the quantum state,” and the PRESTO research area “Quantum state control and functionalization.”

Date & Time	Venue
April 18 (Tue) 14:00-16:20	JST Tokyo Headquarters Annex 1st Floor Hall K’s Gobancho,7,Chiyoda-ku

For more information, please visit the following site: http://senryaku.jst.go.jp/teian-en.html.