Research area in Strategic Objective *"Opening up technological frontiers by synergy between photonics and informatics, materials science, etc., to support a sustainable society"*

Pioneering the Synergy of Information and Physics connected by Optics and Photonics

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Overview

In this research area, we combine Japanese predominant optics and photonics with information, materials and other fields to promote innovative pioneering frontier that push the boundaries of conventional technology, with the aim of creating a sustainable information and communications system. Research on information processing using the characteristics of optics and photonics has been conducted for many years, but practical applications have not progressed due to insufficient integration with existing information processing technologies and utilization of accumulated knowledge. On the other hand, in some cases, the properties of light have not been fully exploited in an attempt to replace existing information processing methods with optics and photonics. Therefore, by promoting inter-hierarchical synergy across the development of exploitation technologies, in addition to in-depth research into basic technologies related to fundamental science, devices and systems, the aim is to create a virtuous cycle of innovative technology creation and expanded expectations.

We promote research from two perspectives: "principles and elemental technologies that demonstrate the true value of optics and photonics" and "hybrid technologies between optics/photonics and other fields". Specifically, by developing fundamental technologies that maximise the potential of optics and photonics, by introducing new theories and materials, and by exploring the fundamental principles and new phenomena of optics and photonics, we aim to pioneer technologies that improve the efficiency of entire systems by using optics and photonics in the right place at the right time. In addition, through the synergy of optics and photonics, information and other sciences, we aim to develop hybrid technologies that overcome conventional performance limits that cannot be overcome by optics and photonics or electrons alone, and to demonstrate systems that go beyond conventional limits.

We will thus contribute to the realisation of a sustainable information systems society by promoting the synergy of advanced understanding of the physical properties of hardware and system design based on information technology, and by striving for a world where information and physics are directly connected by fully exploiting the advantages of optics and photonics, such as high efficiency and high speed.

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

1. Background

Research on photonic computing, leveraging the wave nature and multiplicity of light, has been underway for several decades. The anticipation that the performance improvement of conventional computers based on electronics would eventually reach its limits began around the time when research on optical computing commenced. However, the progress in CMOS integrated circuit technology has been remarkable, leading to continuous performance enhancements up to the present day. Conventional integrated electronic circuits have relied on classical electric currents, but further miniaturization faces limitations imposed by quantum mechanics, particularly the tunnel length. Currently, circuit fabrication processes being developed for mass production are aimed at the 2nm generation, which approaches the tunnel length limit. Beyond this lies the ultimate limit imposed by atomic distances. While discussions about the proximity of the limits of integrated electronic circuit processes have persisted, it is undeniable that the ultimate boundaries dictated by physical laws are drawing near. Since the development of CPUs half a century ago, there has been a consistent demand for precise and high-speed logic-circuit devices. However, recent attention has shifted toward generative AI and machine learning, leading to significant changes in required functionalities. In this research area, we aim to establish information and communication technologies utilizing light, bringing together knowledge from diverse scientific fields such as optics, informatics, and materials science, to achieve a revolutionary transformation of functionalities required for information processing and overcome the physical limits of existing devices.

Cyber-physical systems that connect real-world information to cyberspace have gained attention for addressing societal issues. For the advanced integration of such real-world and cyber-integrated information systems, the current systems significantly lack input-output functions with the real world. Innovation in technology leveraging the characteristics of light, such as its ability for high-capacity, long-distance, and low-latency data transmission, is essential.

2. Principle of invitation project and selection

In this research area, we are soliciting research proposals related to fundamental research in optics, information science, materials science, and their interdisciplinary fusion fields aimed at realizing information systems utilizing light. In addition to proposals based on groundbreaking ideas leading to innovation in information systems, we expect research proposals that aim to bridge the gap between fundamental research and technology development. While specific research topics are provided below

as examples, proposals may encompass multiple themes.

1. Principles and Essential Technologies to Unleash the True Potential of Light
   Research focused on essential technologies such as ultimate photon-electron conversion and control, which can fully harness the latent capabilities of light for future information systems. This involves introducing new theories, materials, and investigating fundamental principles and novel phenomena related to light, including its various degrees of freedom (amplitude, phase, spatial distribution, polarization, frequency). The goal is to create theoretical foundations and technological advancements that enhance the scalability, controllability, and efficiency of light devices. As an application of these essential technologies, proposing concepts for solving societal challenges in various fields (such as environment, food, healthcare, and manufacturing) using information systems based on light would be desirable. Pioneering technologies that strategically utilize light throughout the system are crucial for efficiency optimization.
2. Hybrid Technologies Bridging Photonics and Diverse Disciplines
   Development of hybrid technologies based on optics, electronics and quantum technology, which are integrating photonics with diverse disciplines such as information science, in order to exceed the performance limits of conventional photonics and electronics. Complementary coordination and fusion of research on photonic devices based on condensed matter physics, materials science, etc., and research on mathematical models, network architectures, and software based on information science are essential. Through the fusion of diverse disciplines, comprehensive design principles and implementation methods for hybrid systems based on optics, electronics and quantum technology are established for demonstrating systems that break through conventional limits. Examples of such hybrid technologies include:

   Computer technologies surpassing power efficiency and processing speed through collaboration of photonic and other computational resources.

   Seamless integration of wired and wireless communication through flexible photon-electron conversion.

   Sensing technologies that combine previously untapped properties and wavelength ranges of light with novel devices and algorithms.

   These research endeavors aim to revolutionize information communication systems by leveraging the unique features of light and bridging disciplines to address real-world challenges.

3. Research periods and research funds

The budget for one research project at the beginning is 40 million yen at the maximum (direct expenses). The research period begins in fiscal year 2024 and ends in fiscal year 2027 (three and a half

years or lesser).

4. Principle of research-area management

In this research area, the research supervisor and advisors will work together to provide an environment where the PRESTO researchers can spend three and a half years working on their original research without being preoccupied with short-term outcomes. In addition, we strongly encourage collaborative and cross-disciplinary research exchanges by creating an atmosphere in which new research seeds can be discovered and nurtured through interactions with researchers in different fields in the related CREST and PRESTO research areas. In addition, through the organisation of workshops, symposia and other events, we will actively promote collaboration with CREST “Frontier exploration via the synergy of photonics/optics with information, communication, sensing, and material technologies”, which is being implemented under the same strategic objectives, as well as academic exchange with overseas research institutions.