【Grant-in-Aid for Transformative Research Areas（B）】

Impact of intracellular nano-scale thermal science on life activities: measurements, understandings, and applications

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Project Information	Project Number : 25B201　Project Period (FY) : 2025-2027 Keywords : Transport phenomena, Optical and quantum technologies, Spectroscopy, Reproductive biology

Purpose and Background of the Research

●Outline of the Research

In this research area , we aim to understand local temperature increase" within cells based on heat transfer and thermodynamics through the development of state-of-the-art spectroscopic and thermal measurement techniques, and to build the framework for a new academic field: "intracellular nano-scale thermal science".

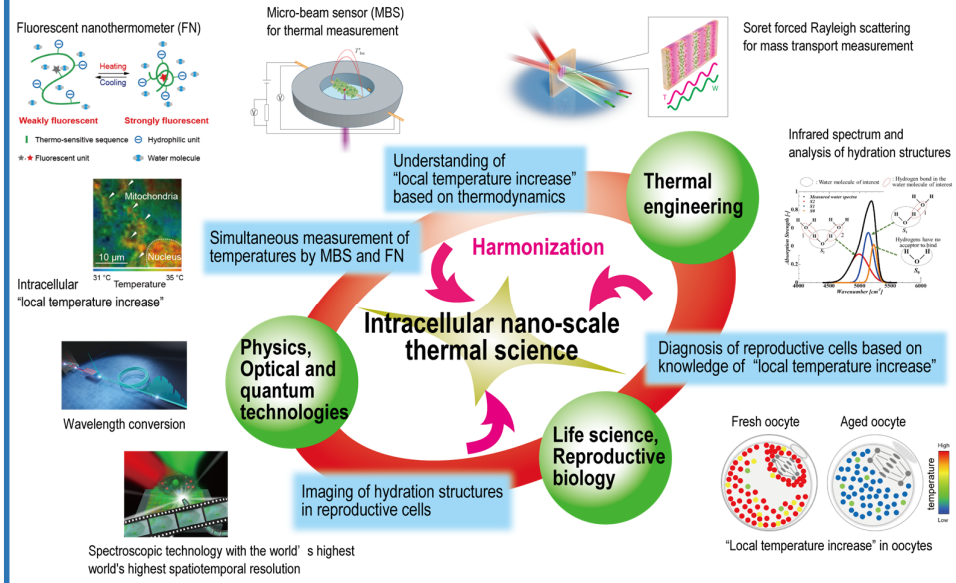

Figure 1. Interdisciplinary collaboration in this research area.

●Background

Intracellular temperature measurements using various temperature probes have revealed nano- and micrometer scale regions within cells that exhibit high temperatures of several °C, but this intracellular "local temperature increase" cannot be explained by Fourier's law of thermal conduction, and many aspects remain unknown. Since a comprehensive approach that is not limited to existing academic fields is important for understanding and applying this phenomenon, collaboration between different fields as shown in Figure 1 will be promoted in our research area.

●Significance of establishing the field of "intracellular nano-scale thermal science"

This new research area will be established through the harmonization of different specialties:

-Measurement and understanding of transport phenomena based on thermodynamics and heat transfer
-Optical and quantum technologies based on physics
-Life science and reproductive biology

Understanding intracellular "local temperature increase" will help to clarify critical aspects of life science, such as the principles that govern the reactions of biomolecules in intracellular nanoscale regions, and the impact of intracellular heat generation on physiological functions. In the process, we aim to pose challenging new questions about nanoscale temperature fields inside living organisms and the life phenomena that are driven by them, and to establish novel fundamental and universal scientific principles.

Expected Research Achievements

●Purpose of this research area

We will develop cutting-edge measurement techniques and integrate specialties from different academic fields in order to better understand the phenomenon of the intracellular "local temperature increase," which will create a framework for the new field of "intracellular nano-scale thermal science". Furthermore, as an application, a non-invasive diagnostic technique to evaluate the healthiness of reproductive cells will be developed based on our elucidation of the "local temperature increases" within cells.

●Research projects

Group A01 will reveal the thermodynamic nature of "local temperature increase" by (1) simultaneous measurement of the temperature obtained by a resistance thermometer and the "local temperature" observed with a fluorescent nanothermometer; (2) measurement of the relaxation time of water, which governs the structural relaxation time of biomacromolecules; and (3) measurement of the mass transport properties of biomacromolecules, which characterize their spatial distribution in cells.

Group A02 will develop an infrared photothermal microscope with the world's highest spatiotemporal resolution to observe intracellular thermal phenomena and the hydration structure of biomolecules.

Group A03 will study the effect of the thermal environment within reproductive cells on fertilization and development to develop a novel diagnostic technique for oocytes based on new findings in "intracellular nano-scale thermal science".

●Expected impacts

Temperature is a fundamental physical quantity that affects the state and activity of molecules. Due to its universality, a fundamental understanding of "local temperature increase" within cells would have a great impact on diverse areas. It is expected that this research area will expand through the further collaboration with researchers from a variety of fields. Examples include:

Theories and calculations: non-equilibrium thermodynamics, hydrogen bonds and hydration structures, molecular dynamics simulations.
Measurement techniques: nanoscale temperature measurement methods, local heating methods, photothermal conversion materials, optical measurements.
Cell diagnosis and cell therapy: neurofunctions, regenerative medicine, cancer medicine, immunology.

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