Research area in Strategic Objective "Development of innovative materials and device technologies based on understanding and manipulation of nanoscale thermodynamics"

6.2.3 Thermal Science and Control of Spectral Energy Transport

Research supervisor: Katsunori Hanamura (professor, Tokyo Institute of Technology)

Overview

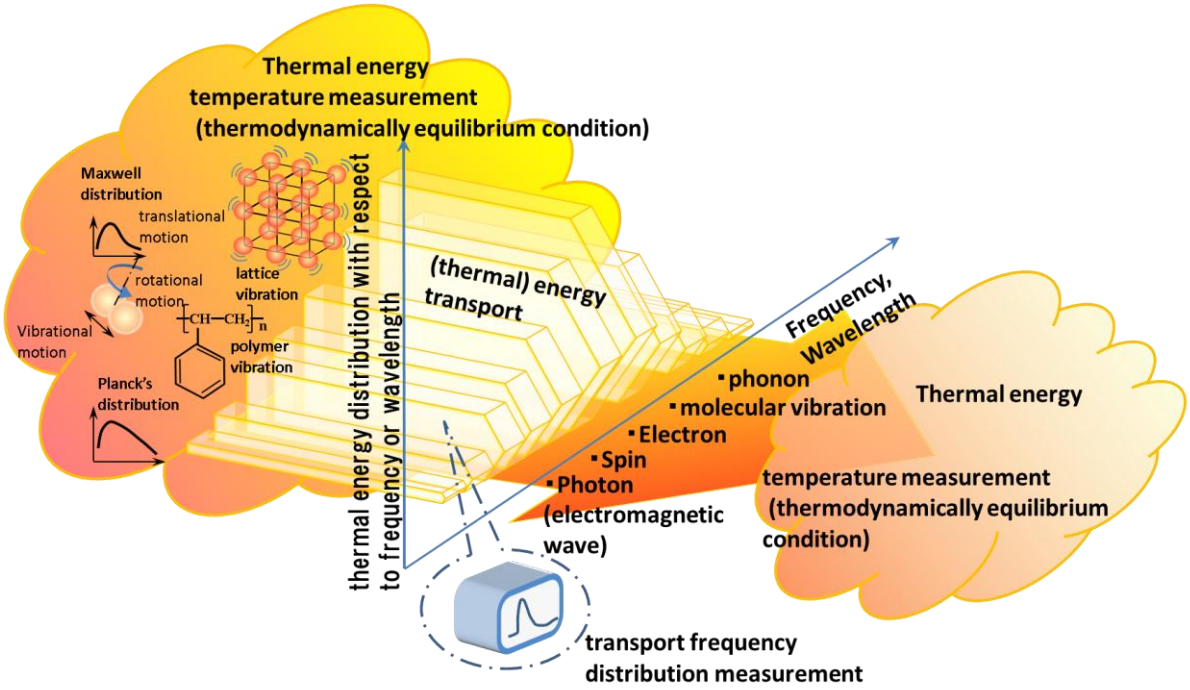
This research area aims to achieve a functional thermal management through such as a spectral control, a directional control and/or an on/off switching of energy transport in nanoscale for contributing to development of epoch-making devices and new materials that lead to a future sustainable society and information-supported industries. Furthermore, it aims to create a new concept or principle of the nanoscale transport of thermal energy by proposing a new measurement technology and a computational procedure for better understanding of fundamentals of the transport phenomena.

For example, a concept of energy transport distribution with respect to frequency or wavelength, i.e., an energy transport spectrum, will be developed, provided that the thermal energy was basically transferred by mechanisms such as phonon, vibrational and rotational modes of molecules or polymers, photon (or electromagnetic wave) and spin. Using a spectral control of energy transport, main part of spectral band will be reflected for insulation, converted into electricity by photovoltaics or phonon-voltaics, or introduced into a different direction for thermal management. Those research approaches will lead to an intrinsic understanding of spectral energy transport and thermal science relating to fundamental technologies for thermal management.

This research area promotes a wide range of specialized research fields, such as mechanical engineering, physics, materials science, chemistry (polymers and inorganics), biology, information technology and mathematics, to encourage interdisciplinary approaches that come from combination, exchange and synergy among various scientific knowledges from different fields.

This research area will be responsible for societal needs, such as significant issues relating global warming, development of renewable energy and use of unutilized energy for protection of global environment, to support a highly information-oriented and sustainable society, and also to promote challenging and creative researches that develop a new approach for thermal science that allows the

control of spectral energy transport.



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

Background

In recent years, various electronic equipments are being integrated. Consequently, heat generation density in electronic devices is increasing. The conventional heat transfer method, in which heat is transported through the side-walls of packaged chips, is considered to be approaching its limit. If, for example, heat at a generation point is directly transferred to an internal heat pipe with a directional control, overcoming the limit of the conventional technology is not impossible. In the case of smartphones, heat is transferred through the outer surface into the environment for cooling. However, the heat transport process from the generation point to the outer surface must be fundamentally reviewed on the basis of structure, material, and principles resulting from energy transport mechanisms. In addition, energy-saving technologies are being developed based on the optimization of thermal management by producing high heat fluxes or switching the heat flow off, as required. If the heat flow can be redirected to the right and left, in addition to the on/off switching control of heat

transport, the conventional passive insulation method can be transformed to a more active method, which provides directional heat transport, and achieve effective heat utilization. Furthermore, a large volume of unutilized thermal energy exists in manufacturing industries, many automobiles, and many houses, although its amount per automobile or house is small. If the thermal energy was basically transferred bymechanisms, such as phonons, molecular vibrations, electrons, photons (electromagnetic waves), and spins, an energy transport spectrum with respect to frequency or wavelength will be developed. As a result, provided that the monochromatic energy transport was switched ON/OFF depending on the frequency, this thermal energy may lead to power generation by phonovoltaics or photovoltaics using an active range of component of frequency. That is, heat transport itself becomes functional in addition to gaining directional control.

So far, research has been conducted on topics like “heat dissipation (heat removal)”, “heat transport”, “heat generation”, “thermal insulation”, “heat storage”, and “thermal energy conversion”. However, to address the new societal and industrial needs introduced by a highly information-supported society and energy saving requirements, this research area is based on the marked development of fine processing technologies and upgraded measurement and computational technologies to examine topics from the new viewpoints described above and connect them to the creation of science and technology, as well as innovation.

Policies for proposal invitation and selection

In practical systems, the amount of thermal energy is estimated from temperature measurement under thermodynamically equilibrium condition. However, no existing method can directly measure the physical quantity of heat transport. As represented by measurement of heat flux, the temperature is essential for the estimation of heat flux, that is, the temperature difference between two points of a substance with known thermal conductivity should be measured. This temperature is defined as a thermodynamically equilibrium temperature. On the other hand, if the thermal energy was basically transferred by mechanisms such as phonons, molecular vibrations, electrons, photons (electromagnetic waves), and spins, the energy transport spectrum with respect to frequency or wavelength will be developed, and then, there is no concept of thermal energy at equilibrium in the monochromatic energy transport. Instead, some functional characteristics may be provided to each monochromatic transporting mode.

This research area does not follow conventional research, which aims to understand heat transport

macroscopically, but uses new concepts, ideas, and technologies to understand the characteristics of the (thermal) energy transport spectrum, which has a distribution with respect to frequency or wavelength to understand the essence of heat transport and undertake groundbreaking research. In addition, it aims at developing new ideas and technologies that allow switching energy transport with each frequency (or wavelength), for example, to the right or left. Furthermore, it is possible to add characteristics or functions to the transported (thermal) energy in this transfer process. Various research approaches are possible, such as measurement and directional control, on/off switching, energy conversion, heat transport in polymers, and heat transport in freezing biological tissues and cells. The proposal invitation is expected to attract the participation of researchers from a wide range of specialized fields, including chemistry, biology, information technology, and mathematics, in addition to mechanical engineering, physics, and materials science.

This research area expects a wide range of proposals related to basic research aimed at understanding and controlling the characteristic (thermal) energy transport spectrum with respect to frequency or wavelength in each system, including the definition and direct measurement of physical quantities in the energy transport process.

Although emphasis is given on research at the nano- (micro-)scale levels, a wide range of themes are expected from some fields, considering systems in which a mechanism confirmed at the nanoscale level becomes effective when scaled up to a practical system. Emphasis is also given to energy transport phenomena on surfaces, which could control a practical system.

Topics that have been actively promoted are not excluded if they fit the purpose of this research area or involve the concept of energy transport spectrum with respect to frequency or wavelength.

This area covers research that may expand to a new science derived from the mechanism of heat transport, including research on the interactions of controlling mechanisms such as phonons, molecular vibrations, electrons, photons (electromagnetic waves), or spins.

Policies for research area management

This research area not only promotes creative research proposals by individual researchers but also emphasizes the viewpoint of human resource development concerning whether they can break their own shells through interaction with researchers in other fields or make new “associate” who may work together for future research related to thermal science. In the 2017 fiscal year, this PRESTO research is expected to utilize the opportunities of collaborations with researchers inside and outside

the research area, including those in the CREST research area “Creation of nanoscale thermal management technologies”, which is undertaken under the same strategic objective, to become an important step to assist the participants’ advancement in research. In this regard, we invite researchers to explain in their proposal how they would like to develop thermal research in the future.

This research area expects that researchers with accepted proposals firmly understand the social background of the research and advance their own PRESTO research to support collaborations with industries in the future. For this purpose, researchers who participate in this research area are requested to actively study intellectual property rights during the research period.

Collaboration and cooperation with research organizations and research frameworks, including the nanotechnology platform of the Ministry of Education, Culture, Sports, Science, and Technology are promoted nationwide, depending on the research progress.

*A proposal invitation and explanation session for this research area is scheduled as below. We expect many interested people to participate.

	date	Venue
Kanto	10:00 – 12:00 April 24 (Monday)	Hall on the 1st floor JST Tokyo Head Office, Annex

See the following for details:

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