Effective Utilization of Organic Resources for Spatiotemporal Control of Materials

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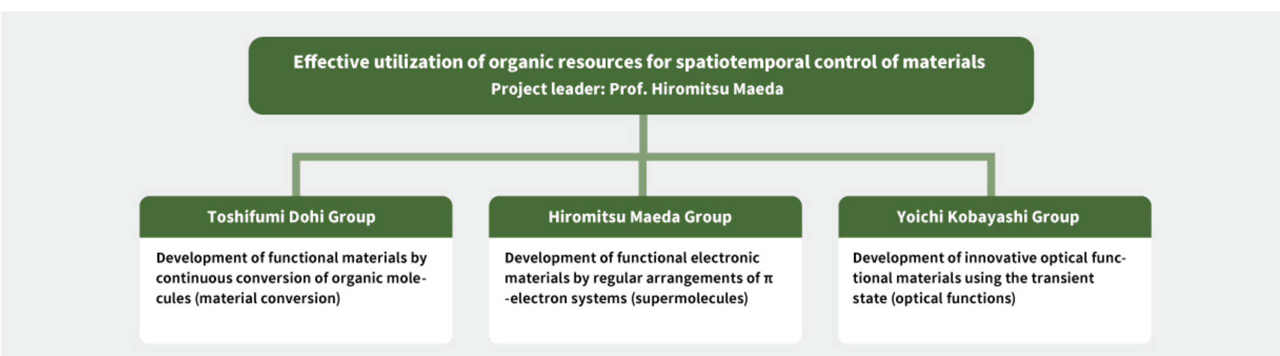
Spatiotemporal control for new functional materials that surpass existing ones

Synthetic organic chemistry for new innovative and functional materials that contribute to protecting the global environment

As the world faces serious problems that threaten the very survival of the earth today, such as climate change and environmental destruction, efforts are being made all over the world to protect the global environment. In this situation, it is becoming increasingly important to develop innovative materials and methods that enable the transportation, transmission, conversion, and storage of materials, energy, information, and many other things with the least possible environmental impact.

The ultimate objective of this research project is to find solutions to many of the problems facing humankind, especially those related to the global natural environment, through synthetic organic chemistry. Concretely, we hope to contribute to the restoration of the natural environment from a totally novel perspective, through the synthesis of new materials that draw out the latent potential of molecules and the creation of new materials that exhibit electronic and optical functionalities.

One essential challenge facing us as we strive for sustainability is how to use limited resources most efficiently. At present, the majority of raw materials for organic functional materials derive from fossil resources, such as petroleum and coal. In addition, they are mostly used as fuel for energy and motive power. In this project, therefore, we aim to develop



new ways to efficiently transform limited resources into functional materials, with a focus on the effective utilization of organic resources.

This project is an extension of our Third Phase R-GIRO project, “Development of Electronic and Photonic Materials Based on Organic and Biotic Resources.” In the Third Phase, we solidified our research foundation with a focus on the spatial control of materials. In the current phase, we expect to expand the possibility of developing even more diverse materials by newly introducing the temporal axis.

Structural organic chemistry, synthetic organic chemistry, and functional solid state chemistry… a powerful alliance of diverse specializations for research in unknown territory

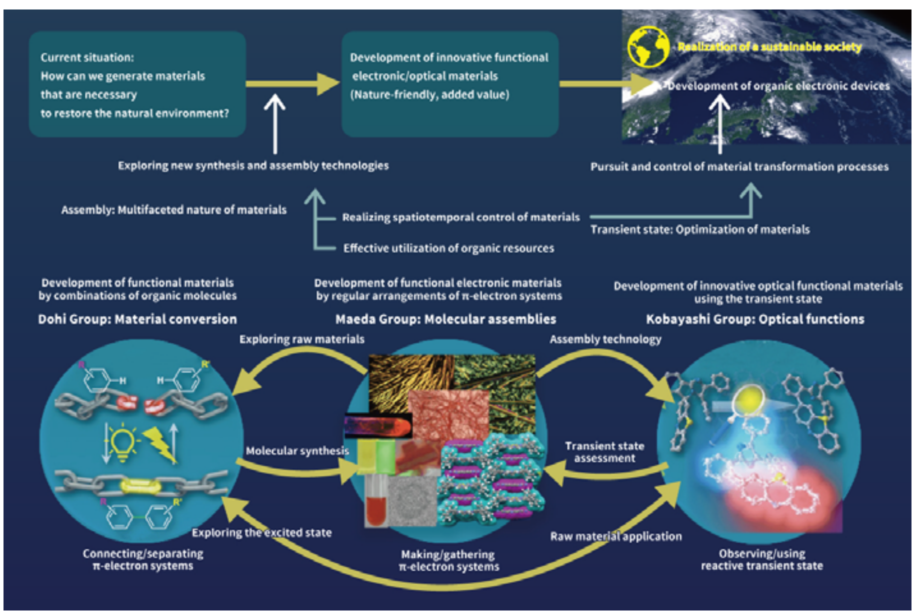
In the project, three groups representing different areas of specialization work on their respective themes while maintaining strong collaboration with one another, fusing their findings to arrive at completely novel research results.

Firstly, the Maeda Group plays the leading role in the development of new materials. Among organic compounds, Prof. Maeda has been focusing and conducting research on π-electron systems with a double-bond structure. π-electrons are easily movable and have unique properties, such as conductivity and luminescence. In his research so far, Prof. Maeda has already succeeded in forming assemblies of alternately and regularly stacked planar layers of π-electron anions and cations by using the attraction that occurs between oppositely charged ions. He has also formed assemblies of layers of similarly charged ions, which would normally repel each other due to electrostatic repulsion, stacked with strong dispersion force.

In this project, the Maeda Group will work on the synthesis of various π-electronic cations, anions, and ion pairs through detailed examination of molecular structures based on high-precision molecular designs. Furthermore, the group will also attempt to create, by optimally controlling intermolecular interactions, aggregates with properties that largely surpass those of individual molecules (i.e., supermolecules), thereby opening up the previously unexplored research area of function generation using charge-charge interactions.

If the research findings could lead to the establishment of guidelines for synthesizing and assembling organic charged species to control arrangements as desired, it would be possible to develop electronic materials based on totally novel concepts, ranging from aggregates with unique functions and new liquid crystals to soft materials, memory devices, semiconductors, solar cells, and more. The Maeda Group is determined to search for hitherto unknown materials by combining the knowledge obtained using the Dohi Group’s synthesis technologies and the Kobayashi Group’s functional evaluation technologies.

The Dohi Group’s objective is to develop new technologies for organic synthesis by combining catalysts with light and electrons to use them to create new functional compounds. Prof. Dohi has already developed various synthetic reactions, focusing on hypervalent iodine compounds as reagents that replace rare metals. In this research, he and his group are working toward the next step, that is, temporally controlling various reactivities of hypervalent iodine compounds as



Research results envisaged in this project reagents. It involves constructing a reaction system in which multiple different reactions proceed continuously in the same reaction or catalytic system, by temporally controlling the reaction space with external stimuli, such as light and an electric field, by utilizing the mechanism that allows the switching of hypervalent iodine compounds from one to another. Conventional organic synthesis reactions require different reaction vessels and reagents for each reaction. As the number of reactions increases, so do the time and cost required. By incorporating temporal control, the group is trying to build a reaction system that synthesizes complex functional organic molecules rapidly and without generating waste.

In this process, the researchers' special focus is on the development of sustainable synthesis technologies that use biological resources instead of petroleum and other exhaustible resources. Selecting lignin as one such resource, the group will use it in continuous bond-forming reactions combining external stimuli, including light and an electric field, and try to obtain middle molecules, which can enable the creation of functional materials, from small molecules in the same reaction system. The group will also attempt to develop, by using hypervalent iodine reagents as oxidants, new organic synthesis reactions without the use of thermal energy by electrolytic oxidation, with voltage applied to the reaction mixture. The group will provide the π-electronic molecules thus created by spatiotemporal control to the Maeda and Kobayashi Groups and make repeated improvements based on feedback from functional evaluation by the Kobayashi Group for further creation of new useful materials.

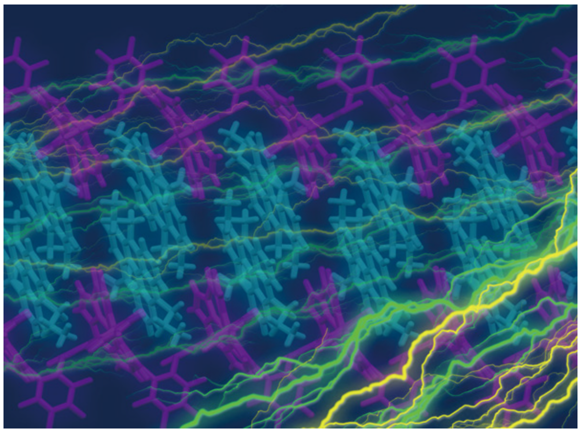
The Kobayashi Group is working on the development of innovative optical functional materials by using the transient state that occurs when light is irradiated. A material exposed to light absorbs the optical energy and shifts to a higher energy level (excited state). This transient state has electronic and optical physical properties completely different from those in the low-energy ground state. The group is trying to discover new functions in materials in connection with this phenomenon. The transient state, during which the energy is retained, is extremely short, lasting only about nanoseconds (one billionth of a second). In his previous research, Prof. Kobayashi succeeded in prolonging the duration of the transient state on the order of several minutes to several tens of minutes.

In this research, the group is developing composite materials that constitute the prolonged transient state through high-precision control of the distance between organic molecules and nanocrystals. With optical irradiation to those materials, the group will aim to develop innovative photochromic composites whose functions can be freely controlled, super-reductants activated by visible light, and next-generation quantum materials.

Nurturing young researchers ready for the world stage
Protecting the future earth, contributing to scientific advances

In this project, we are also making efforts for the training of young researchers, including postdoctoral fellows and doctoral students. We actively support their activities by, for example, inviting them to join pioneering research teams and offering them opportunities to communicate their research results to the whole world through written papers and oral presentations at international conferences. We provide powerful support so that they can make impactful research achievements that can advance their career paths.

Finally, our ultimate research goal is generating totally novel materials and discovering innovative functions, thereby giving birth to new materials that overwhelmingly surpass conventional ones in terms of functionality and new device structures that can be next-generation game changers. Through such research achievements, we hope to contribute to global environmental protection and the advancement of science and technology.



Electronic functions from regular arrangements of π-electron systems

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