Grant-in-Aid for Transformative Research Areas (A) 2022-2027

Revolution ofChiral Materials Science using Helical Light Fields

NEWSLETTER VOL. 4

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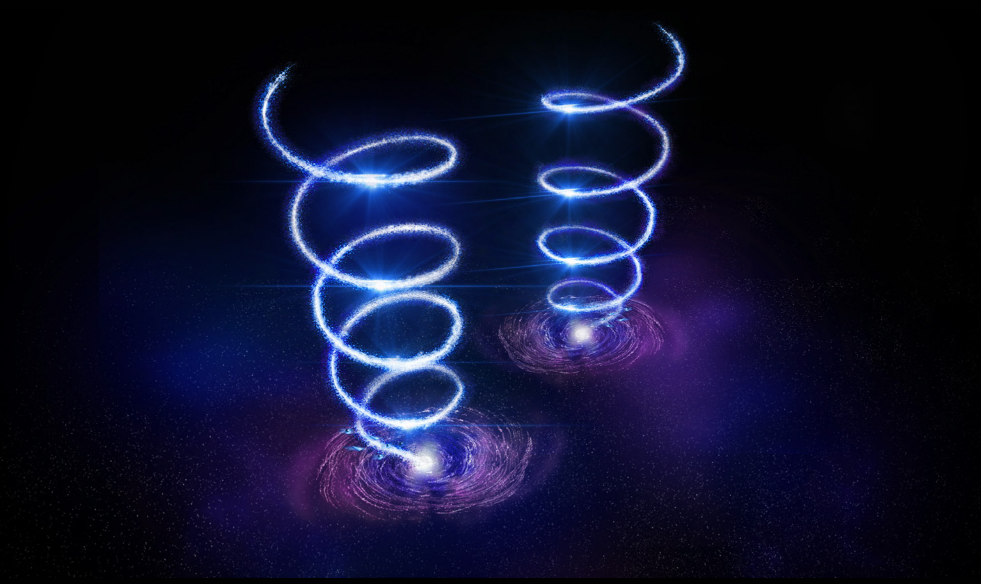
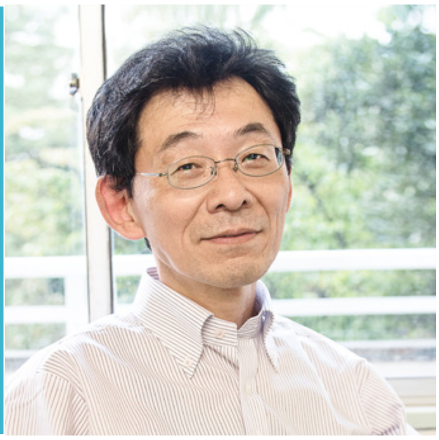




Takashige Omatsu
(Project Representative, Chiba University)

An interim evaluation of the Grant-in-Aid for Transformative Research Areas A, "Revolution of Chiral Materials Science using Helical Light Fields." was conducted. The submission deadline for progress reports was 5th June 2024, and the submission deadline for presentation files was 26th September 2024. The online interview was held on 14th October 2024. We had two questions in advance; "How did you explore the fundamentals?" and "How did you strategically acquire patents?"

The group management, including three collaborative research projects, were well respected. The interviewers mostly gave us several comments concerning scientific fundamentals and strategies for implementing research in society. These comments, which ask how the research results will be further developed, are in line with the questions in advance, and they are valuable to us.

Fortunately, we were able to receive the second highest rating (5-point rating) of "A". I would like to deeply appreciate the project members' cooperations and tireless efforts.

I hope that we will receive the highest rating in the final evaluation and we will also share our fruitful academic results to create a global research area.

Messages from Our Advisors on the Research Area

We have received insightful evaluations and encouraging messages from four advisors regarding the activities and achievements of this Research Area. From their diverse disciplinary perspectives spanning physics, chemistry, and biology, the advisors provide valuable assessments of the scientific significance of the Area, its interdisciplinary framework, and its potential for future development. Their comments highlight both the academic impact of the research conducted to date and the promise of further integration and innovation. The following messages reflect their thoughtful perspectives and generous support for the continued advancement of this Research Area.

Professor Kazue Kurihara Tohoku University

The "Grant-in-Aid for Transformative Research Areas" program aims to pioneer major changes and transformations in the current academic system by creating research fields through the co-creation and integration of diverse researchers. I would like to congratulate the "Super-Helical Light" project for its success achieved through efficient collaboration by talented researchers from diverse fields of physics, chemistry, biology and materials. They have taken on difficult challenges, including understanding the mechanism of optical vortex dichroism and applying this knowledge to chiral crystallization, fabrication of chiral materials with extreme circular dichroism, and other material processing methods. I look forward to seeing further integration of these achievements and new collaborations in the final year of the project.

Professor Yoshie Harada The University of Osaka

When we think of "helices" in the field of biology, the first example that comes to mind is the right-handed double helix of DNA. However, helical structures are also extremely important in proteins. For instance, the α-helix, a representative type of protein secondary structure, forms a right-handed helical conformation. Actin filaments, the major cytoskeletal protein in muscle, are likewise formed by actin molecules polymerizing into a right-handed double-helical structure similar to DNA. Furthermore, collagen found in skin and bone adopts a right-handed triple-helical structure, in which three polypeptide chains wind around one another.

I anticipate that the day when we can manipulate biomolecules and cells using helical light fields to artificially create helical structures at will is not far off.

Messages from Our Advisors on the Research Area

Professor Keiji Sasaki Hokkaido University

This project brings together leading scientists from diverse research fields to explore the fundamental principles governing the interactions between helical light and chiral materials ranging from molecules to biological polymers. Using this understanding to enable controlled formation of helical structures across nano- to macroscopic scales is a challenging and highly promising objective. The collaborative framework connecting theoretical modeling, simulation, experimental demonstration, and application-oriented development is particularly impressive, and positions the project as an emerging global leader in chiral light–matter science. I hope the project team will continue to foster interdisciplinary discussion and cross-cutting research activities, as such efforts have great potential to stimulate unexpected scientific ideas and to give rise to new conceptual paradigms.

Professor Yasushi Inoue The University of Osaka

At the recent Area Meeting held in Kyoto, I once again recognized that this Transformative Research Area—bringing together researchers from diverse fields such as physics, chemistry, and biology under the key concepts of the helicity of light and the chirality of matter—is truly a distinctive research community. In particular, the interdisciplinary research initiatives, guided by the visionary leadership of Professor Omatsu, have successfully integrated the strengths of each participating researcher, resulting in a steady stream of outstanding research achievements. This clearly conveys that a genuine transformation of academic paradigms is in progress. I look forward to the continued development of this Area and to the further success of all participating researchers.

Featured Collaborative Studies across the Research Area

Beyond the research activities carried out within each individual project group, this Transformative Research Area has actively promoted a broad spectrum of collaborative studies that integrate expertise, methodologies, and technologies across group boundaries. Such cross-disciplinary collaborations form a central pillar of the Research Area, enabling the creation of new scientific concepts and research directions that could not be achieved by a single group alone.

Here, we feature recent collaborative research efforts through invited articles contributed by three researchers, each highlighting a distinct example of successful integration across multiple project groups. Professor Homma of Osaka University reports on the fabrication of helical biocompatible fibers by the spiral structure of light, a collaborative achievement realized through close cooperation among Groups C04, C01, and C03. Professor Minowa of Kyoto University presents a theoretical and conceptual correspondence that bridges “vortices” in two seemingly unrelated systems—light and superfluid helium—based on joint research conducted by Groups C02 and A01. Professor Nakashima of Osaka Metropolitan University introduces the mechanism by which modification of silver nanoclusters enhances circularly polarized luminescence of molecular systems, as an outcome of collaborative work between Groups A03 and A02.

Featured Collaborative Studies across the Research Area

Fabrication of Biocompatible Helical Fibers Using an Optical Vortex Beam

K. Homma, Y. Matsumoto, Y. Tanimoto, K. Masui, C. Hosokawa, T. Omatsu, and M. Matsusaki,
Chem. - Asian J. 20, e00361, (2025)

Helical structures are abundant in living systems and appear hierarchically across a wide range of spatial scales. These architectures are essential for proper cellular and tissue functions. Understanding how helical structures influence cellular behavior is therefore important not only from a fundamental biological perspective, but also for applications in cell and tissue engineering. Although many previous studies have employed chiral peptides to investigate how molecular helicity affects cell adhesion, proliferation, and differentiation, how helical structures at the cellular to tissue-scale regulate biological functions remains unclear.

Photopolymerization studies using a photocurable resin have demonstrated that the helical wavefront of an optical vortex beam can twist photopolymerized structures via the transfer of optical angular momentum. Inspired by this concept, we fabricated tissue-scale helical biomaterial fibers by combining photopolymerization of biocompatible poly(ethylene glycol) (PEG) diacrylate with irradiation by optical vortex beams (Figure (a)). The PEG fibers generated with optical vortex beams possessing topological charges of $l = +1$ and $+4$ exhibited well-defined helical structures with minimal branching. Their helical pitches were approximately 400 μm (Figure (b)). In contrast, PEG fibers photopolymerized using a Gaussian beam ($l = 0$), with a planar wavefront, showed significant branching and exhibited a bent structure. Additionally, increasing the photopolymerization duration yielded thicker PEG fibers (Figure (c)). Notably, the handedness of the PEG fibers could be reversed simply by changing the sign of the topological charge.

Overall, our findings demonstrate the potential of optical vortex beams for fabricating tissue-scale helical scaffolds. Because the physical characteristics of the helical PEG fibers, including pitch, length, thickness, and handedness, can be tuned by adjusting beam parameters, this approach offers a promising and versatile method for engineering helical tissue architecture.

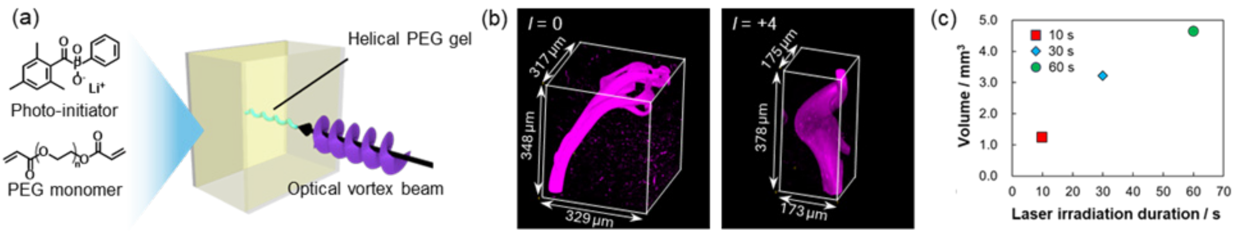


Figure (a) Schematic illustration of the fabrication of helical PEG fibers using an optical vortex beam. (b) Confocal fluorescence images of PEG fibers photopolymerized with either a Gaussian beam ($l = 0$) or an optical vortex beam ($l = +4$). Helical fibers with minimal branching were obtained only under optical vortex beam irradiation. (c) Volume changes of PEG fibers photopolymerized with an optical vortex beam ($l = +4$) as a function of photopolymerization duration, demonstrating that longer irradiation yields thicker fibers.

Featured Collaborative Studies across the Research Area

Kelvin-wave-inspired optical vortex excitation in Kerr nonlinear media

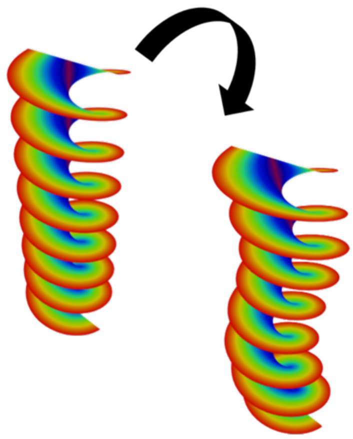
Y. Minowa, N. Yokoshi, and M. Tsubota, *Phys. Rev. B 112, L041501* (2025)

Optical vortices and quantized vortices are key research topics in optical physics and low-temperature physics. Their names suggest similarities, and indeed they share some features—both involve rotational dynamics, for example. However, they also differ in important ways: optical vortices possess chiral (handed) structures, whereas quantized vortices do not. These differences arise from the distinct equations that govern each system.

When we focus on optical vortices in nonlinear Kerr media, the situation becomes more interesting. Their governing equation—the nonlinear optical Schrödinger equation—has a form very similar to the Gross–Pitaevskii equation, which describes quantized vortices. Although this resemblance has long been recognized, the correspondence has remained qualitative, mainly because of fundamental differences such as dimensionality.

In our work, we re-examined the governing equations carefully and re-derived them from first principles. We found that the dynamics of optical vortices and quantized vortices can, in fact, be described by equations of exactly the same form. This correspondence relies on two standard techniques: the slowly varying envelope approximation commonly used in optics, and a transformation to a co-moving frame with the light.

Recognizing this fundamental equivalence allows us to uncover new physical phenomena in both optical and quantized vortex systems by drawing analogies between them. As an illustrative example, we demonstrate Kelvin-wave-like excitations on optical vortices. Kelvin waves are well-known fundamental excitations of quantized and classical vortices, characterized by helical oscillations of the vortex core. We show that optical vortices support two distinct branches of Kelvin-wave-like excitations and that a stationary solution exists in which the helical deformation of the optical vortex core is fixed in space.



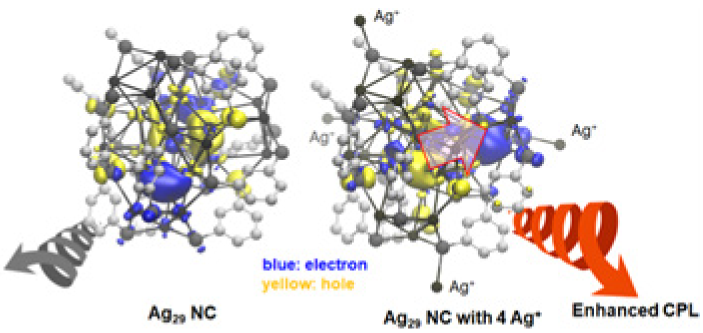
Our theoretical results reveal a previously hidden universality connecting chiral light and quantum matter, offering clear guidance for future studies of both optical vortices and quantized vortices.

Featured Collaborative Studies across the Research Area

Evolution of Circularly Polarized Luminescence in Atomically Precise Silver Nanoclusters with Intrinsic Chirality

W. Ishii, T. Shiraogawa, M. Ehara, H. Sotome, H. Miyasaka, T. Kawai, T. Nakashima, *Angew. Chem. Int. Ed., 64, e202513118* (2025)

Circularly polarized luminescence (CPL) is an impactful method for investigating the chiroptical properties of molecular systems in excited state. In this article, we are looking at how the chiroptical property in silver nanoclusters (NCs) evolves along with the development of excited state. In these experiments, 1,3-benzenedithiol (BDT), a bidentate thiolate ligand, is used, allowing the creation of racemic $[Ag_{29}(BDT)_{12}]^{3-}$ NCs (or simply, Ag_{29} NCs). The Ag_{29} NCs inherently possess chirality in their exterior cages, which consist of a silver(I)-dithiolate coordination framework. The chiral column chromatography method is then used to separate enantiomeric Ag_{29} NCs. When a cationic silver(I) complex is used to modify these negatively charged Ag_{29} NCs on the exterior cage through a post-synthesis treatment, this stabilizes a specific excited state indicative of a triplet character (T_1), which in turn significantly enhances photoluminescence (PL) in the near-infrared (NIR) region. Interestingly, when the same modification is done on separated enantiomeric NCs, the circular dichroism (CD) profile doesn't undergo significant alterations, but the CPL activity is noticeably enhanced—this can be demonstrated by the increase in the anisotropy factor (or $|g_{lum}|$ value), going from $<1 \times 10^{-3}$ to 6×10^{-3}. The role of cationic Ag^+ complex is discussed in detail with the aid of theoretical study in collaboration with Prof. Ehara's group (A02). The cationic Ag^+ complex attached on the NC surface attracts the excited electron towards the chiral exterior cage in the T_1 state. The attraction of excited electron by the surface cationic species effectively delocalizes the excited state (exciton) towards the chiral-structured part of the NC, resulting in the CPL enhancement. The manipulation of exciton localization thus has a great impact on the CPL property.



Event report

Report of Summer Camp at Yatsugatake

Hiroaki Saito (Osaka Metropolitan University)

I had the opportunity to take part in the three-day summer camp for the Chiral Light–Matter Science program, held from July 30 to August 1, 2025, in Yatsugatake, Nagano. The camp was hosted and carefully organized by Professor Okamoto from the Institute for Molecular Science. Over the three days, we had nine talks, group discussions, a poster session, and plenty of time for informal scientific conversations. I also presented my own poster there, which led to a lot of insightful questions and feedback that really helped me think more deeply about my project. Researchers from all over Japan and from a wide range of research fields joined the camp, making it an amazing chance to look at “chiral science” from different angles and broaden my understanding well beyond my usual perspective.

Yatsugatake itself was a beautiful place-the scenery was incredible, the air was clear, and the climate was very comfortable. Walking around the area between sessions became one of my favorite parts of the camp. Sharing meals, chatting late into the night, going on short hikes, and even stargazing together with researchers I had just met created a really memorable atmosphere. Those casual moments outside the official program ended up being just as inspiring as the academic sessions, and they made it much easier to connect with people from completely different backgrounds.

Overall, I’m very grateful for the chance to join this camp and for the financial support that allowed me to participate. The experience gave me new ideas, new connections, and a lot of motivation for my future research.

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Chair : Takashige Omatsu, Chiba University