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

Chimera Quasiparticles for Novel Condensed-Matter Science

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Purpose and Background of the Research

●Outline of the Research

The functions of electronic devices that support modern society originate from “**quasiparticles**” (quantum mechanical entities that behave like particles) in materials. The discovery of a wide variety of quasiparticles is one of the most important achievements in condensed-matter physics, which has enabled us to understand complex physical phenomena as the motion of a small number of quasiparticles. For example, phenomena related to crystal lattice vibration, light, magnetism, dielectric polarization, and plasma can be described by phonons, photons, magnons, polaritons, and plasmons, respectively. If we can create a new species by combining such a wide variety of quasiparticles, we can realize desired physical properties and functions, which will bring about new developments in materials science.

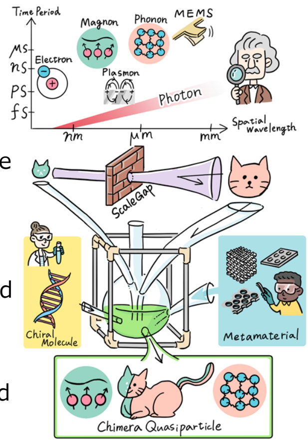

Figure 1. Schematic of chimera quasiparticle scienee

However, in most cases, quasiparticles behave independently due to differences in time and space scales. Therefore, in this research field, we will create “**chimeras**” by introducing various schemes, such as artificial structures, material and molecular design, and symmetry design, to surpass the **scale gap** and create “chemical reactions” between quasiparticles that have been studied independently (Fig. 1). This will revolutionize the fundamentals of condensed-matter science and form a new foundation for the realization of highly functional electronic, optical, quantum, and energy devices. The goal of this research field is to construct “**chimera quasiparticle science**”.

● Surpassing the Scale Gap

In most cases, quasiparticles behave independently, and in order to make two quasiparticles to interact, the time period (i.e., time scale), and the spatial wavelength (i.e., spatial scale), must match. For example, for phonons, which are responsible for thermal conduction, and magnons, which are responsible for magnetism, the two lines showing the relationship between wavelength and time period do not intersect (Figure 2, left panel), so they behave independently. This scale difference has led to the formation of separate academic and technological fields for each of the different scales. However, by adding an artificial length scale, multiple quasiparticles can be combined to freely manipulate functionality. As shown in the right panel of Fig. 2, the fabrication of a thin-film heterostructure creates intersections between quasiparticle scales and enables interactions.

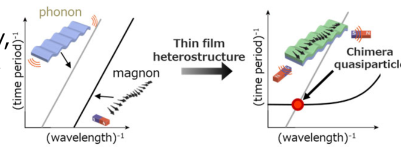

Figure 2. Generation of chimera quasiparticle of phonons and magnons

●Guideline for Achievement of Chimera Quasiparticle Science

1. Chimera quasiparticles by **artificial structure**

(a) We use metamaterials. By introducing an artificial scale through spatial patterns, a quasiparticle with a different wavenumber from that of the original one is created, causing chimerizations with quasiparticles that would not normally interact. (b) We utilize resonators, where the quasiparticles are confined in space, and the wavelength matching condition is relaxed. The confinement effect causes a strong hybridization of quasiparticles. (c) Temporal control of the artificial structure also connects quasiparticles with different time periods.

2. Chimera quasiparticles by **designing materials and molecules**

In addition to various inorganic materials, organic molecules are introduced to take advantage of their properties such as pronounced symmetry breaking and tendency to non-equilibrium phenomena. We use organic molecules, combinations of organic molecules and inorganic materials, and organic-inorganic hybrid materials.

3. Chimera quasiparticles by **symmetry design**

For example, lowering of the symmetry of the system results in a phonon-magnon coupling. In addition, by extending the lifetime of quasiparticles through conservation laws ensured by symmetries, the quasiparticle coupling is increased, resulting in chimera quasiparticles.

Expected Research Achievements

●Chimera Quasiparticles Open Up New Material Properties and Functions

Chimera quasiparticles can provide new functions and properties to quasiparticles (Figure 3), such as **cross-correlated responses**. For example, through the chimerization of phonons, and magnons with photons, optical control of electrons, phonons, and magnons becomes possible. Moreover, quasiparticles with short time and length scales are difficult to observe, but by combining with quasiparticles with longer scales, they can be easily observed and utilized. Furthermore, the chimera quasiparticles can lead to **nonreciprocity**, enabling e.g. rectification of heat flow and unidirectional sound control technology. In addition, chimerization with quasiparticles that are controllable by external fields enables **selective excitations** of various quasiparticles. One can also create chimera quasiparticles using **nonlinearity** and realize giant nonlinear phenomena.

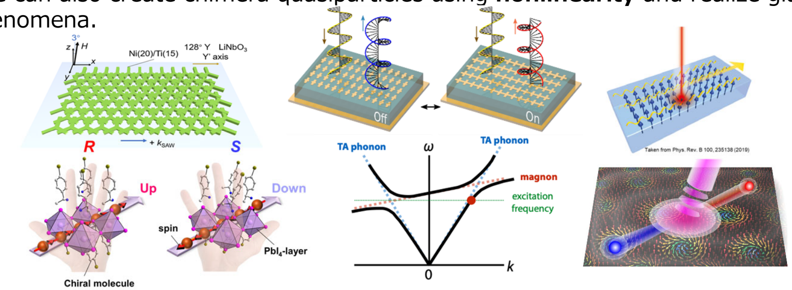

Figure 3. Various research developments in chimera quasiparticle science

●Fusion of Fields in Chimera Quasiparticle Science

The above framework to surpass the scale differences is being discovered separately in the three fields of **spintronics**, **chiral molecule science**, and **metamaterials** , and it is the time to integrate these findings and establish a new research area of chimera quasiparticles. This is the first project in the world to combine these fields, and the integration of such knowledge will lead to a revolution in the science of quasiparticles and provide opportunities for young researchers to be involved in this field.

Homepage Address, etc.	https://chimera-qp.ee.es.osaka-u.ac.jp