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

Dynamical materials science: beyond quantum and classical frameworks

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Project Information	Project Number : 26A202 Keywords : Nonequilibrium physics, soft matter, solid state, quantum physics, hydrodynamics	Project Period (FY) : 2026-2030

Purpose and Background of the Research

●Outline of the Research

Emergence refers to the appearance of collective phenomena resulting from itneractions of constituent particles. While initially established for systems at thermal equilibrium, it has become clear that remarkable emergent phenomena arise in non-equilibrium states (Fig.1). Two streams of research have established this development: one rooted in solid-state and quantum systems and the other in soft matter and other classical systems. This research area, "Dynamical Materials Science," aims to integrate these two streams. By combining the knowledge, techniques, and materials developed in these fields, we will explore novel emergent phenomena in non-equilibrium systems and establish their universal frameworks, with a view not only to understanding these phenomena but also to their design and control. This will open up prospects for the development of innovative technologies and materials that utilize dynamical emergent phenomena.

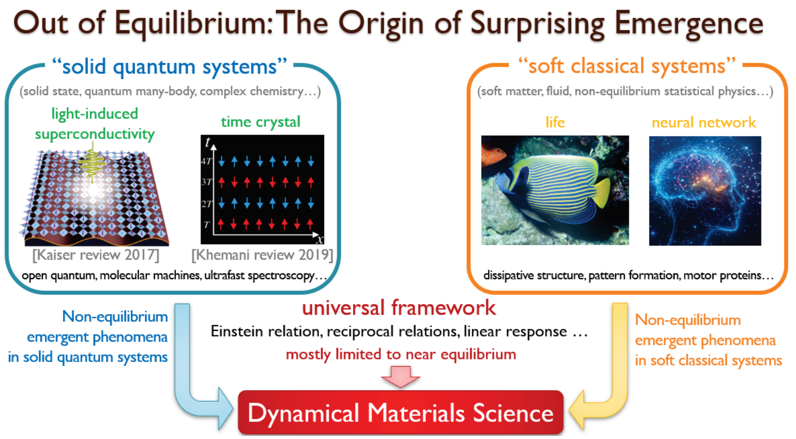


Figure 1. Concept of the Dynamical Materials Science

●Background and the three pillars of the Dynamical Materials Science

While non-equilibrium emergence has been studied for both solid quantum systems and soft classical systems, the two streams rarely interacted until recently, when several remarkable studies began to bridge the two fields. This development hints at three important features, namely, spatiotemporal order, particle activity and nonlinear flow, which form the foundations of the three pillars of the Dynamical Materials Science: "Pattern Materials Science", "Active Materials Science" and "Hydrodynamic Materials Science."

●Planned Research Groups

Figure 2 shows our planned research groups. Each consists of experts of both solid quantum systems and soft classical systems.

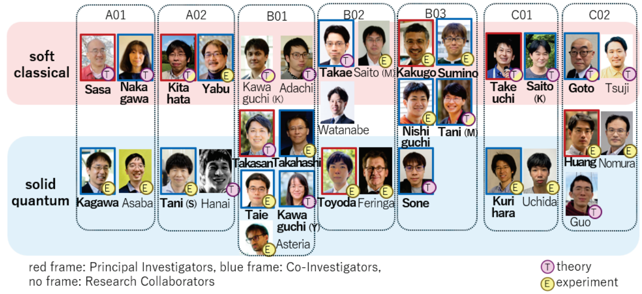


Figure 2. Group members.

<u>A: Pattern Materials Science</u>

A01, Non-equilibrium patterns emerging in strongly correlated materials

A02, Dynamical pattern formation via control of light-induced nonreciprocal interactions

<u>B: Active Materials Science</u>

B01, Developing active matter physics in quantum many-body systems

B02, Design and realization of active solids from artificial molecular motors

B03, Quantum-inspired active matter and function designs

<u>C: Hydrodynamic Materials Science</u>

C01, Universal hydrodynamic laws of non-equilibrium spin fluctuations

C02, Elucidating nonlinear effect of phonon hydrodynamics

Expected Research Achievements

●Example of Pattern Materials Science (A01)

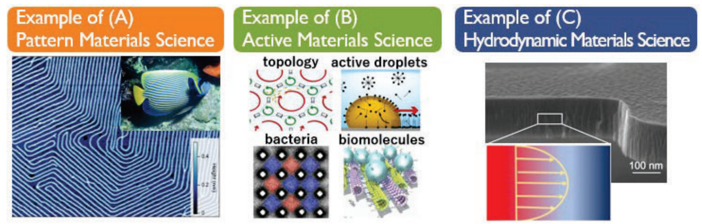
Asaba et al. found the formation of Turing-pattern-like wires in thin-film growth, which were only a few atoms wide (Fig.3 left). We aim to develop a framework of pattern formation for such strongly correlated materials. Besides its fundamental importance, this may pave the way for new fabrication techniques.

●Example of Active Materials Science (B03)

By extending the framework of topological materials to soft classical systems, in particular to various active matter systems (Fig.3 center), we will develop topological science for non-equilibrium non-Hermitian systems including their nonlinear regime.

●Example of Hydrodynamic Materials Science (C02)

Huang and Nomura found hydrodynamic behavior of phonons in graphite (Fig.3 right), which resulted in heat rectification in a device inspired by fluid mechanics. As this is evidence of nonlinearity, we will develop nonlinear phonon hydrodynamics through collaboration with fluid mechanists.



<u>Figure credits</u>

Left: Asaba et al., Sci Adv 2023. Center: Sone and Ashida Phys Rev Lett 2019; Nishiguchi et al., Nat Comm 2018, Akter et al., Sci Robot 2022. Right: Huang et al., Nat Comm 2023.

Figure 3. Examples of Pattern, Active and Hydrodynamic Materials Science.

Website(s)	Official website Official Bluesky account	https://dms.phys.s.u-tokyo.ac.jp/index_en.php https://bsky.app/profile/dyn-mater-sci.bsky.social