Kwansei Gakuin University
Report of Research Outcome

2026/03/12

To President

Department : Science and Technology
Position : Postdoctoral fellow
Name : PHAN THANH HUYEN

I report the outcome of the research as follows.

Name of the Fund/Program	□Sabbatical leave with grant □Sabbatical leave with no grant □KGU Joint Research □Individual Special Research ⊠Postdoctoral fellow ※Please report by designated form as for "International Research Collaboration".
Research Theme	Non-Hermitian topology in two-dimensional photonic crystal system
Research Site/Venue	Kwansei Gakuin University – Graduate School of Science and Technology
Research period	2025/04/01 ～ 2026/03/31 （ 12 months）

◆ **Summary of the research outcome** （**approx. 2,500 words**）
Please write down the outcomes in detail regarding the research theme above.

Photonic crystals (PhCs), which are the optical analog of the conventional crystals, are increasingly attractive because of their potential applications in controlling the flow of electromagnetic (EM) waves in telecommunication and devices. Although they are very potential, the energy-loss due to the intrinsic properties and fabrication limits the further development of photonic devices. To overcome this problem, the cross field of "topology" and PhCs come into play. This mathematical concept is used to distinguish the geometry lattice by the topological phase based on whether the wavefunctions can be continuously deformed into each other. It is well-known that wave propagation in periodic media will form the band structure, which is the representation of the allowed or forbidden energy levels of waves. This concept is originally built for Hermitian systems, which follows the energy conservation law. However, in the real world, the energy-loss happens very easily due to the leaking of wave into the environment, leading to the non-Hermitian systems. It is already known that the non-Hermitian systems can offer propagation modes with either real or complex eigenvalues. Moreover, a typical property of a non-Hermitian matrix is that the left and right eigenvectors are completely different. Therefore, the topological band theory for non-Hermitian systems may expose some interesting phenomena distinct from the original band theory. The aim of this research is to theoretically design a 2D photonic system which exhibit non-Hermitian topological properties, examine novel non-Hermitian effects and determine non-Hermitian topological invariants. Our studies are very essential and put a step to experimentally realize non-Hermitian effects.

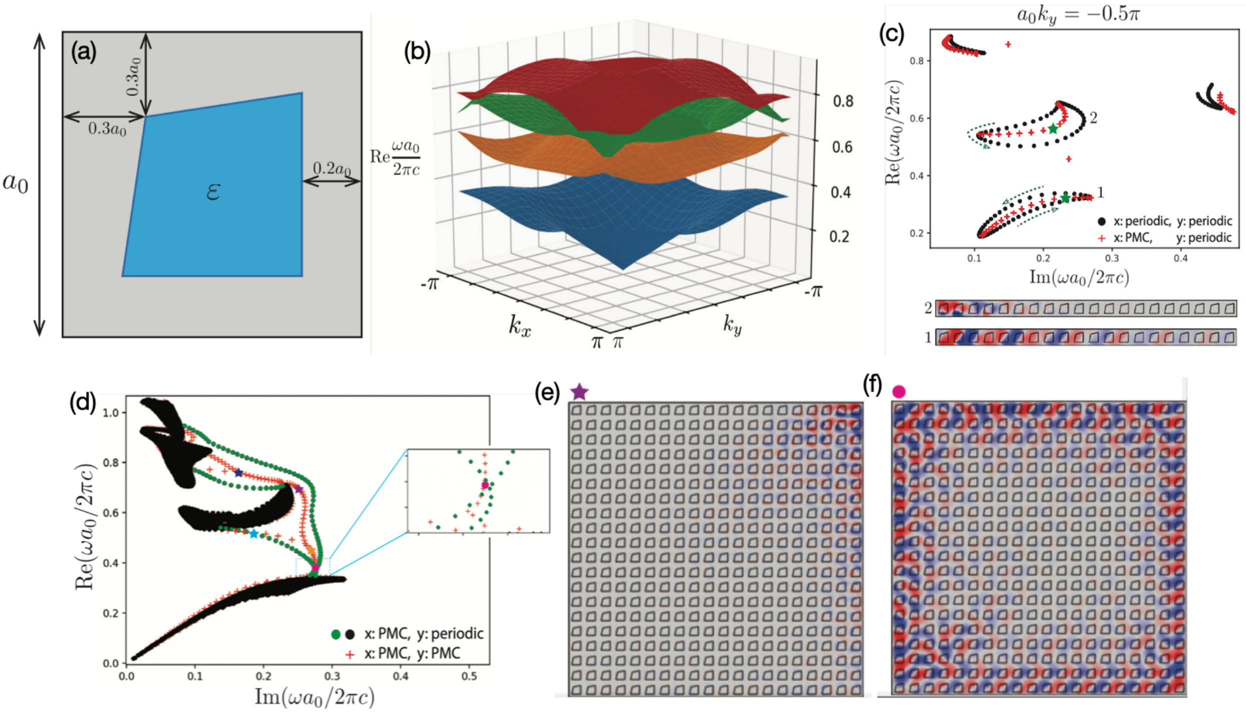

Figure 1: (a) A schematic of a unit cell of a 2D non-Hermitian PhC made of magneto-optical material, which is in broken of mirror symmetry. (b) k-dependent dispersion of real part of eigenfrequencies, showing a complete band gap between the first and the second bands. (c) Photonic dispersion in the complex plane for the infinite structure (black) and ribbon structure (red) at $a_0k_y = -0.5\pi$. The green arrows denote the winding direction (clockwise or anti-clockwise) when kx is varied from $-\pi/a_0$ to π/a_0. Number 1 and 2 indicate band indices.The lower panels are field profile of the states labeled by green stars in the corresponding band structures. The states enclosed by the point gap exhibit skin effect, where EM waves are highly localized at the boundaries of structures. (d) Photonic dispersion in the complex plane of the finite structure (red) and semi-infinite (black). The inset shows enlarged figure of the region enclosed by the blue dot line. The topological edge states form loop in complex plane and encloses the complex eigenfrequencies of the corner skin modes. (e) Field profile of the corner skin modes labeled by the stars in (d) and the extended topological edge states labeled by the magenta circle in (d).

Based on the theoretical background, we have theoretically designed a 2D non-Hermitian PhC and numerically investigated the skin effect and topological states of electromagnetic waves. Owing to the absence of inversion and mirror symmetries as well as broken reciprocity, complex eigenfrequencies exhibit point gaps in the complex plane, which protect the emergence of the non-Hermitian skin effect at the edges of truncated structures. Furthermore, we demonstrated that topological edge states arising from a nonzero Chern number also form point gaps in their complex eigenfrequency spectra. These point gaps give rise to a second-order non-Hermitian skin effect, where electromagnetic waves become localized at the corners of finite structures. Unlike conventional topological edge or corner states, the skin modes appear over a broad frequency range and scale with system size. We confirm that the emergence of a point gap in the edge-state spectrum is the condition for the corner skin effect, as double truncation causes these edge states to collapse and accumulate at the corner.

Our results provide a realistic photonic platform for exploring higher-order non-Hermitian topology and may stimulate future experimental studies.

Beside the study of non-Hermitian PhC, we also parallelly provide the theory and simulation for the observation of hinge modes in 3D woodpile PhC.

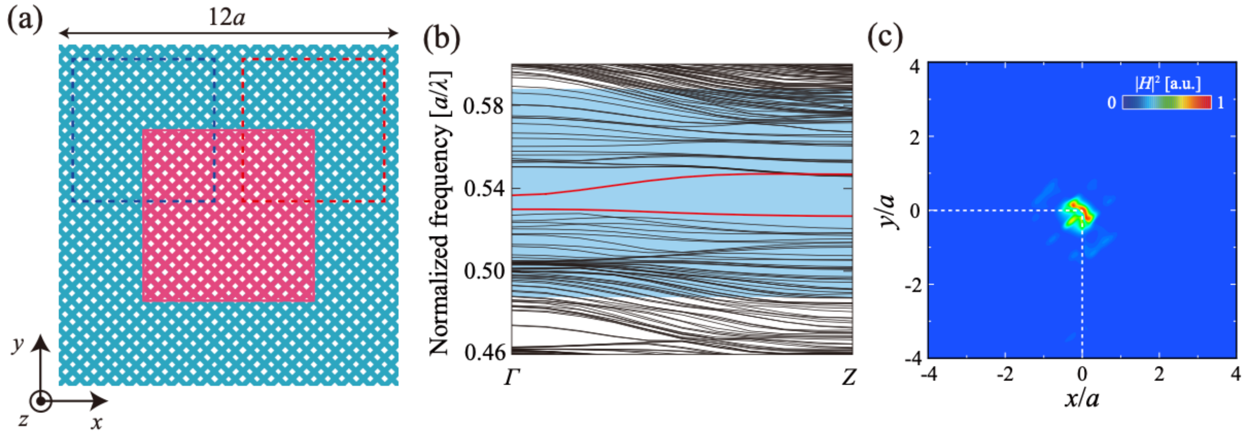

Figure 2: (a) Schematic diagram of a supercell. Topological invariants are different in the magenta and cyan colored region. Hinge states appear in the red-dotted square, whereas they are absent in the blue-dottedsquare. (b)Numerically obtained photonic band structure for the supercell in (a). (c) Numerically obtained spacial distribution of $|H|^2$ at a normalized frequency of 0.526.

Following our previous theoretical study on the Wilson loop and topological properties of a 3D woodpile PhC [3], we collaborated with an experimental group to measure the hinge states in both the microwave and near-infrared regimes. To make the PhC structure self-suspended during the fabrication process, frames were added surrounding the structure, and supporting beams were introduced at the interface between two types of PhCs where the dislocation appears (in the 2nd and 4th layers). We calculated the photonic band structure of the modified system using the finite element method. Figure 2(b) shows the projected band structure along the Γ–Z direction around the band-gap frequency. Compared with the original structure reported in [3], the hinge states (red lines) are still observed, although they are slightly shifted. The structural modulation alters the frequency and dispersion of the hinge modes but does not eliminate them. In this sense, the hinge modes exhibit a certain degree of robustness.

Based on the numerical results, the experimental group fabricated the woodpile structure with a lattice constant of 12.8 mm and measured the hinge modes in the microwave region. The hinge modes in the near-infrared regime were also observed by scaling the woodpile structure down to a lattice constant of 620 nm. The obtained hinge states, particularly in the near-infrared region, provide a promising alternative for waveguiding without modifying the local refractive index, which could be applied in three-dimensional photonic circuits.

For future perspectives, we will extend our studies of non-Hermitian topology to systems with exceptional points. We plan to develop a computational method to evaluate non-Hermitian topological invariants in the presence of exceptional points. Furthermore, we aim to leverage topological modes in PhC structures to investigate interactions between photons and quantum emitters, as strong light–matter coupling plays a crucial role in the field of nanophotonics.

References

[1] D. S. Borgnia, et al., Phys. Rev. Lett. **124**, 056802 (2020).
[2] N. Okuma et al., Phys. Rev. Lett. **124**, 086801 (2020).
[3] H.T. Phan, S. Takahashi, et el., Phys. Rev. B **110** 235429 (2024).

Papers

[4] **H. T. Phan** and K. Wakabayashi, "Non-Hermitian corner skin effect in a two-dimensional photonic crystal," Phys. Rev. B, under review.
[5] S. Takahashi, S. Kawabata, **H. T. Phan**, et al., "Near-Infrared hinge states in a three-dimensional photonic crystal," in preparation.

Academic conferences

[1] **H. T. Phan**, and K. Wakabayashi, "Non-Hermitian topological properties in 2D photonic crystals," in the 14th International Symposium on Photonic and Electromagnetic Crystal Structures (PECS-XIV), Glasgow, UK (Nov. 2025).
[2] **H. T. Phan**, and K. Wakabayashi, "Non-Hermitian skin effects in two-dimensional photonic crystals," in TACT 2025 International Thin Films Conference, Taipei, Taiwan (Oct. 2025).
[3] **H. T. Phan**, and K. Wakabayashi, "Numerical simulation of skin effect in a non-Hermitian photonic crystal," in JSAP Autumn Meeting 2025 (Sep. 2025).
[4] **H. T. Phan**, and K. Wakabayashi, "Non-Hermitian topological properties in a 2D photonic crystal," in JST CREST Joint Area Seminar (Jun. 2025).

Deadline : Within two months after finishing the research period.
Sabbatical leave with grant: Submit this report to President with confirmation by the dean of school you belong to.
※Postdoctoral fellow is required to submit this report with confirmation by the dean of graduate school before the end of employment period.
Where to submit : Organization for Research and Development and Outreach (NUC)
◆We put this report on the web of KGU. If there is any problem about it because of difficulties on your research, please let us know.