【Grant-in-Aid for Specially Promoted Research】

Non-Hermitian nanophotonics for ultimate photonic devices

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Project Information	Project Number : 22H04915 Project Period (FY) : 2022-2026 Keywords : Photonic crystal, non-Hermitian, semiconductor laser, waveguide

Purpose and Background of the Research

●Outline of the Research

Photonics technologies, represented by lasers and optical integrated circuits, are vital in many fields ranging from telecommunications to manufacturing and medicine. In conventional photonics, it has been considered important to suppress the dissipation of energy caused by the scattering, radiation, and absorption of light. In this project, we aim to employ photonic crystals as the platform to achieve complete control over the dissipation (especially radiation) of optical energy, and, by taking advantage of the non-Hermiticity of these photonic crystals, realize an ultimate class of optical devices capable of unprecedented feats such as ultra-wide-area coherent kW-class lasing and unidirectional light propagation with vertical radiation.

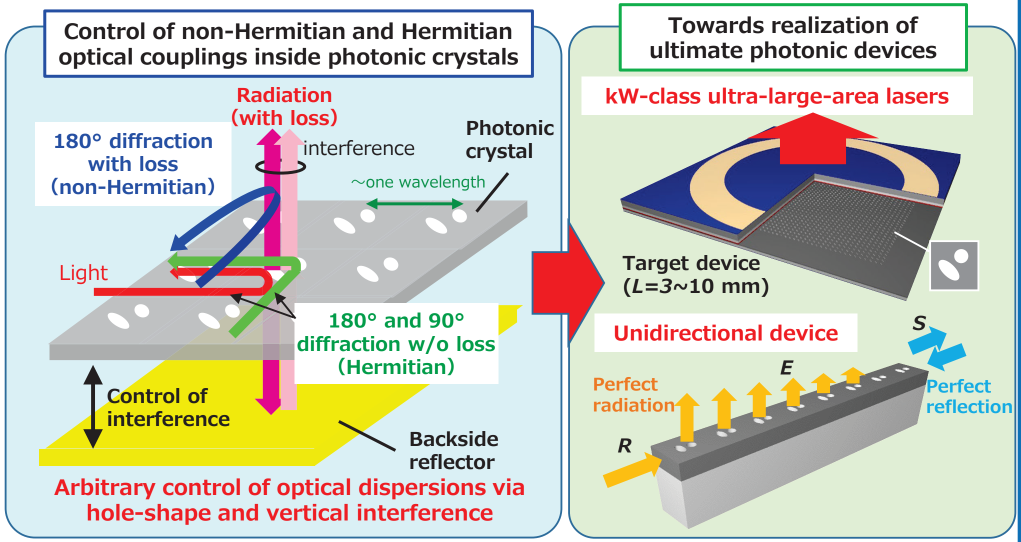

Figure 1. Schematic of non-Hermitian nanophotonics for ultimate photonic devices.

● Originality of the research

Recently, there has been growing interest in non-Hermitian systems in various fields of physics including the field of photonics. However, the previous investigations have been limited to basic research aimed at observing physical phenomena peculiar to non-Hermitian systems, and reports on the utilization of such phenomena for the dramatic improvement of existing optical devices or for the implementation of completely new functionalities have been lacking.

The originality and creativity of this project lies in its aim to realize ultimate optical devices that exploit energy dissipation, which was conventionally considered in the field of photonics to be disadvantageous.

Expected Research Achievements

●Research plan

Specific research targets of this project are outlined below.

(I) Control of non-Hermitian dispersion characteristics inside photonic crystals

Inside photonic crystals, where air holes are periodically arranged with a period of the wavelength of light, the propagating light is diffracted by 180° and 90° without accompanying loss (Hermitian couplings) as well as diffracted vertically with radiation loss (non-Hermitian couplings) as shown in the left panel of Fig. 1. In this study, by controlling the strength of these two types of couplings by changing the hole shapes and the vertical interference condition, we aim to arbitrarily control the frequency and radiation loss (=dispersion characteristics) of the photonic crystal as shown in Fig. 2, which is the basis for realizing the ultimate device discussed in (II) and (III).

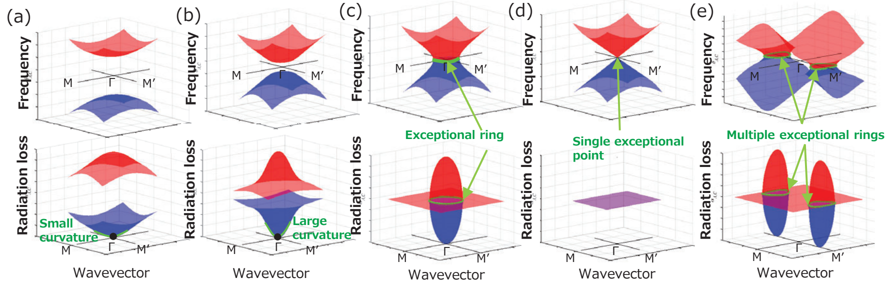

Figure 2. Arbitrary control of non-Hermitian dispersion characteristics inside photonic crystals.

(II) Realization of kW-class coherent photonic-crystal surface-emitting lasers

As an example of an ultimate device that exploits the control of non-Hermitian and Hermitian couplings in photonic crystals investigated in (I), a photonic-crystal surface-emitting laser (PCSEL) whose size is 3-mm to even 10-mm in diameter will be developed. By employing a photonic crystal whose radiation loss drastically increases at the off-Γ point (=at a tilted angle) as shown in Fig. 2(b), stable single-mode lasing in the fundamental mode by cutting off the higher-order modes is expected as shown in Fig. 3.

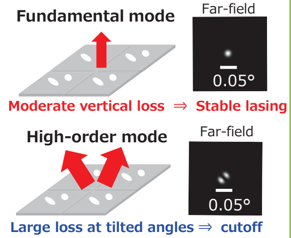

Figure 3. Design principle.

(III) Proposal and demonstration of unidirectional optical devices

As an another example of an ultimate device that exploits the non-Hermiticity in photonic crystals, unidirectional optical devices shown in the lower-right panel of Fig.1 will be investigated. In this device, a linear dispersion relationship shown in Fig. 2(d) of (I) is employed. As shown in Fig. 1, light inserted from the left propagates through this device without reflecting backward, while also radiating in the vertical direction with 100% efficiency. In contrast, light inserted from the right is completely reflected backward. By using such a unique optical property, this project aims to propose and demonstrate optical devices with new functionalities for a wide range of applications.

●Expected Research Achievements and Scientific Significance

This project will light the path to a new academic field, that can be called non-Hermitian nanophotonics. In addition, the impact of this project on broader research fields is expected to be huge. For example, the 3- to 10-mm-diameter, kW-class coherent photonic crystal laser to be realized in research item (II) is anticipated to revolutionize a wide range of laser-based technologies. In addition, the unidirectional device proposed in research item (III) is expected to enable various novel applications.

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