【Grant-in-Aid for Scientific Research (S)】

Broad Section B

Title of Project： Reconfigurable topological nanophotonics

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Keyword：topological photonics, nanophotonics, non-Hermitian optics, photonic crystal

【Purpose and Background of the Research】

Electronic wavefunctions of solid-state materials exhibit intriguing topological properties in the momentum space, leading to various novel phenomena and materials. The topological physics is now a very active area. The Nobel Prize in physics 2016 was given to three theorists initiating this field. Recently, this concept is being applied to photonic crystals, which are artificial structures having a periodic refractive index modulation, and various intriguing optical properties have been found. This field called topological photonics is extensively studied. However, topological properties in optics are created by the pre-fabricated structure, and therefore one cannot control or change externally. In this study, we develop novel ways to dynamically control topological properties in specially-arranged nanophotonic structures, and aim for proposing novel forms of photonic processing using reconfigurable topological properties.

【Research Methods】

In this study, we explore two methods for realizing reconfigurable topological nanophotonics: loading tunable nanomaterials and use of non-Hermitian optics.

In the first approach, we load a nano-scale material whose refractive index is largely tunable, for example, a phase-change material, on a photonic crystal, and explore the possibility of photonic topological phase transition. Figure 1 (a) shows a typical example of our idea. Here we assume to employ $Ge_2Se_2Te_5$ (GST), a well-known phase change material exhibiting a large index contrast at the structural phase transition. We theoretically found that when we deliberately arrange the pattern of GST, this particular photonic crystal exhibits photonic topological phase transition by the phase transition of GST. In the present project, we explore a variety of combinations of structures and materials, and experimentally demonstrate to control various photonic topological properties with this method.

In the second approach, we employ non-Hermitian photonic periodic systems which have a periodicity in both real and imaginary parts of refractive index. Recently, it has been clarified that non-Hermitian periodic systems posses so-called exceptional points at which the band structure becomes discontinuous. Around the exceptional points, one can largely alter the band structure by changing the imaginary part (that is, absorption or gain) of the index. Recently, we have theoretically found that one can create and control the topological insulating phase solely by the variation of gain/absorption shown in Fig. 1(b). In this project, we experimentally demonstrate reconfigurable non-Hermitian topological structures with this method.

In addition, with these tuning methods, we plan to control various topological singular points appearing due to a vectorial nature of photonic topological properties.

This project is performed under a collaboration with NTT Basic Research Laboratories.

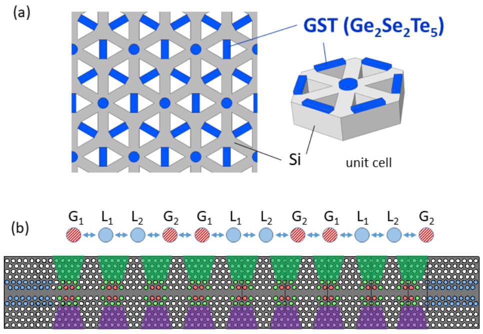

Figure 1 Reconfigurable topological nanophotonics structures. (a) GST tuning, (b) Non-Hermitian tuning.

【Expected Research Achievements and Scientific Significance】

Currently, a large number of novel properties are being found in topological photonics. Reconfigurable topological nanophotonic systems will enable us to employ these intriguing properties dynamically. We believe this will lead to a new degree of freedom to realize a novel form of photonic processing.

【Publications Relevant to the Project】

- K. Takata, and M. Notomi, "Photonic topological insulating phase induced solely by gain and loss," *Phys. Rev. Lett.* 121, 213902 (2018).
- T. Yoda and M. Notomi, “Generation and annihilation of topologically protected bound states in the continuum and circularly polarized states by symmetry breaking”, *Phys. Rev. Lett.* 125, 053902 (2020)

【Term of Project】 FY2020-2024

【Budget Allocation】 141,300 Thousand Yen

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