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# Article / Book Information

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# 論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）


Photonic crystals are periodic dielectric structures with periodic modulation of the refractive index. The periodicity ensures that the dispersion of photons in photonic crystals is described by the photonic band structure. The photonic band offers many attractive optical phenomena, and thus photonic crystals are versatile platforms for controlling light. Because the photonic band structure is an optical analog of the electronic band structure, photons in photonic crystals sometimes display phenomena similar to electrons in electronic crystals. In this thesis, we mainly deal with two topics: valley-dependent optical physics and topological singularities of far-field polarization vectors.

First, we investigate valley-dependent optical physics in photonic crystals with triangular lattice. Recently, valleyphotonics, which is an analogy with valleytronics in electronic systems, has been extensively studied. Previous works focus on valley photonic crystal slabs with honeycomb lattice structures because the lowest two bands form Dirac cones at the K and K' points in their photonic crystals. When perturbations breaking the inversion symmetry is introduced, the degenerate two states at the K and K' points split, and it has been known that the gapped states display valley-dependent optical phenomena. All of the previous works rely on this mechanism because this scheme is just analogous to graphene with a staggered sublattice potential. However, the Berry curvature and angular momentum are general properties in systems without inversion symmetry, and thus it is not clear whether the presence of Dirac cones is essential. In this thesis, we propose another scheme to create valley photonic crystals. We focus on triangular-lattice photonic crystals with circular and triangular holes. In triangular-lattice photonic crystals with circular holes, the first band is not degenerate, and the second and third band form Dirac cones at the K and K' points. Here we focus on the lowest band. We numerically demonstrate that the lowest band exhibits valley-dependent phenomena such as angular momentum, Berry curvature, and interface states by breaking the inversion symmetry. We introduce the inversion asymmetry by deforming circular holes into triangular holes. The structural asymmetry induces the asymmetry of the mode profiles at the K and K' points, which generates the finite angular momentum and the Berry curvature at the K and K' points. They are opposite for the modes at the K and K' points due to the time-reversal symmetry. We also find that the localized interface states appear at the interfaces between two inverted valley photonic crystals. We numerically confirm that some of these interface states are robust against the backscattering at corners of a sharp bend.

Second, we investigate far-field polarization vectors radiated from photonic crystals with or without two-fold rotational symmetry. We first propose a new scheme to generate off-Γ bound states in the continuum (BICs) by using an at-Γ BIC with higher-order topological charges. We start with a photonic crystal with six-fold rotational symmetry because it can carry at-Γ BICs with charge -2. We numerically confirm that the at-Γ BIC with charge -2 splits into two off-Γ BICs with charge -1 by perturbations breaking six-fold rotational symmetry but preserving two-fold rotational symmetry. The mechanism of this scheme relies on charge conservation and crystalline symmetry. These results suggest that we can deterministically generate off-Γ BICs by an infinitesimal perturbation without fine-tuning of system parameters.

We also demonstrate a wide variety of pair-creation and annihilation processes of circularly-polarized states with opposite charge and same handedness. Two circularly-polarized states with opposite charge and same handedness are annihilated by the collision between them. To fully describe the topological nature of BICs and circularly-polarized states, we introduce the handedness-wise topological charge. The handedness-wise topological charge consistently explains the creation and annihilation of circularly-polarized states, and guarantees the topological protection of these polarization singularities.

Finally, we experimentally confirm the splitting of an at-Γ BIC with charge -2 into two off-Γ BICs with charge -1. To demonstrate the splitting of an at-Γ BIC, we fabricate three types of photonic crystals: one is a photonic crystal with six-fold rotational symmetry, and the others are perturbed photonic crystals without six-fold rotational symmetry. We perform two angle-resolved reflection measurements to characterize the band structure, quality factor, and far-field polarization vector of the fabricated photonic crystals. In the first measurement, we measure the reflection spectra of the fabricated photonic crystals, and determine the band structure and quality factor of the modes from the reflection spectra. We observe that the perturbation destroys the at-Γ BIC and that resonant peaks vanish at finite wavevectors in the perturbed photonic crystals. These results show the splitting of the at-Γ BIC into two off-Γ BICs by the perturbation. In the second measurement, we measure isofrequency contours of the photonic crystals by using two orthogonal polarizers. We first confirm that the measured isofrequency contours are good agreement with the numerical results. Next, we determine the charge of the BICs by rotating the two polarizers. When the perturbation is absent, the reflected signals vanish at the Γ point. When the perturbation is introduced, the disappearance of the reflected signal shifts to finite wavevectors. Combining the two reflection measurements, we experimentally confirm the splitting from an at-Γ BIC with charge -2 into two off-Γ BIC with charge -1.