論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Origin of High Transmission in Photonic Crystal Waveguides with Sharp Bends
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出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第12642号, 授与年月日:2024年3月26日, 学位の種別:課程博士, 審査員:納富 雅也,藤澤 利正,佐藤 琢哉,村上 修一,相川 清隆
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第12642号, Conferred date:2024/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Origin of High Transmission in Photonic Crystal Waveguides with Sharp Bends

Outline

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In this thesis we study two topics: light transmission in triangular lattice photonic crystal waveguides with 120-degree sharp bends and light transmission in square lattice photonic crystal waveguides with 90-degree sharp bends.

Valley photonic crystals, as an optic analog of the valley topological insulators, have attracted much attention in recent years. The valley photonic crystals are created by breaking the inversion-symmetry of a honeycomb or triangular lattice. Their simple design and broadband performance in versatile material platforms has shown great potential in application. One of the novel properties of valley-photonics is the extreme high transmittance via a valley photonic crystal waveguide with a 120-degree bend, which usually causes large scattering in conventional photonic crystal waveguides. Such high bend-transmittance has been widely demonstrated using valley photonic crystal waveguides in various frequency ranges and is commonly considered a direct result of the valley-photonic effects. However, there are ambiguities in previous arguments. Firstly, inter-valley scattering is not strictly prohibited in theory and large backscattering is possible in valley photonic crystal waveguides. Secondly, the conventional verification of valley-photonic effects by demonstrating high bend-transmittance is not rigorous and systematic. We aim to clarify the ambiguities in this topic and explore new methods to produce high bend-transmittance in photonic crystal waveguides.

We firstly adopt a systematic method to examine the high bend-transmittance in triangular lattice photonic crystal waveguides. We use hole-type photonic crystal slabs. The topological property of a triangular lattice photonic crystal can be manipulated by changing the symmetry of the air holes. A circular hole photonic crystal has inversion symmetry and is topologically trivial; a triangular hole photonic crystal has no inversion-symmetry and is topologically non-trivial. We compare the bend-transmittance via valley-topological and trivial photonic crystal waveguides. If valley-photonic effect is present, one should observe evident difference between the topological photonic crystal waveguides and the trivial ones. We also tune the domain-wall types of the waveguides and compare the results among different domain-wall types. We have numerically and experimentally verified that the bend-transmittance is highly dependent on the domain-wall configuration of a photonic crystal waveguide but is not significantly affected by the inversion-symmetry of the bulk lattice. Namely, the valley-topological and trivial photonic crystal waveguides show no significant difference in bend-transmittance. Our findings cast doubt on the conventional understanding of valley-photonics.

A numerical investigation into the polarization singularities inside the waveguides show that the bend-transmittance in triangular lattice waveguides is strongly correlated to the position of and field intensity at the polarization singularities regardless of whether the photonic crystal is topological or not.

We further examined light transmittance in a square lattice photonic crystal waveguide with 90-degree sharp bends. Although the square lattice photonic crystals do not possess valley-dependent properties, extreme high bend-transmittance is observed. In addition, the waveguide possesses glide-symmetry, which gives rise to a degeneracy in the band structure of the waveguide. A large transmittance contrast is observed between frequencies above and below the degeneracy point. A similar phenomenon has previously been reported in valley photonic crystals and is conventionally considered a result of the band topology. Our findings strongly suggest that such transmittance contrast is not related to the valley-photonic effects. Interestingly, we have also found a strong correlation between the bend-transmittance and spatial distribution of polarization singularities in the square lattice photonic crystal waveguides. These findings are consistent with our conclusions for the triangular lattice cases and demonstrate that high bend-transmittance can be achieved in a wide class of photonic crystal waveguides without engineering the band topology. This work can be applied to construct compact photonic routing systems, nanocavities, optical switches and other photonic circuits. We also envisage this work to attract more interest in the transmission phenomena in photonic crystal structures and provide a new understanding of valley-photonics.