Integrated Topological Photonic Devices

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Integrated topological photonic devices use light as an information carrier to provide topological protection for the propagation process of light, and have great potential for application in the next generation of on-chip information processing oriented photonic chips. By introducing the concept of topology, integrated photon systems can possess novel characteristics, including unidirectional propagation of boundary states and resistance to structural defects Immunity, etc. With the in-depth study of topological photonics theory, many devices based on topological photonics principles have been proposed and validated, demonstrating the broad prospects of topological photonics in building high-performance optical information processing chips. This article provides a detailed introduction to the research progress of integrated topological photonic devices.

1 Introduction

Topological photonics, as an emerging research field, originated from the concept of topological insulators in condensed matter physics. By introducing topological band theory into photon systems, traditional photon systems have gained new topological properties, Such as boundary states with unidirectional propagation, immunity to structural defects and processing errors, and suppression of backscattering. With the in-depth study of topological optics theory, researchers have proposed and experimentally verified the performance of numerous new devices, demonstrating the enormous potential of topological photonics in the development of high-performance integrated photonic chips. Topology photonics is bringing revolutionary breakthroughs to the development of integrated photonic devices and on-chip optical information processing technology from its unique perspective.

Topology is a branch of mathematics that focuses on the global properties of geometric shapes or parameter spaces that remain invariant during continuous shape changes. In recent years, researchers have introduced topological methods into light In the field of learning systems, a new research area has emerged - topological photonics. The research inspiration of topological photonics comes from the understanding of material topological phases in solid-state physics. The starting point of research in this field can be traced back to In 1980, Klitzing et al. [1] observed the quantum Hall effect through experiments. Subsequently, Thouless et al. [2] and Kohmoto et al. [3] provided theoretical explanations for this phenomenon, pointing out that the integer part of Hall conductivity is related to a topological invariant of the system - the Chern number. In 2008, Haldane and Raghu [4] applied topological theory to optical systems for the first time. They theoretically proposed the quantum Hall effect in photonic crystals, that is, through the periodic changes in the structure of optical materials, photons are regulated in the same way as electrons in solids. This theory pioneered the research in the field of topological photonics. Subsequently, Wang et al. [5,6] achieved unidirectional transmission of topological waveguides in the microwave band and verified the influence of scatterers or obstacles on the robust transmission characteristics of topological boundary states. This series of work has prompted researchers to continuously explore new phenomena and mechanisms in the field of topological photonics, leading to its rapid development in the past decade and widespread attention from researchers.

Driven by the demand for big data and ultra high speed information processing, traditional electronic chips are facing key technological bottlenecks such as high energy consumption and low capacity [7-9]. Integrated photonic chips have the ability to utilize light for information transmission and processing With the advantages of low energy consumption and wide bandwidth, it has become the main solution in application scenarios such as optical interconnection, optical computing, and optical networks. The preparation process of photonic devices inevitably involves processing errors, which often weaken the performance of the devices. Integrated topological photonics devices introduce topological photonics into chip design and fabrication techniques, providing a stable and reliable method for on-chip optical field control. Integrated topological photonic devices utilize the robust transmission characteristics of boundary states [14], which can not only suppress The impact of process errors can still maintain good device performance in the presence of structural defects. At present, researchers have achieved various topological optical phenomena in various optical systems, including photonic crystals [15-16], plasmonic systems [17-20], metamaterials [21-23], and coupled micro ring resonances Device [24-25], waveguide array [26-28], microcavity polariton system [29-31], and synthesis Dimensional resonators [32-33], etc. These topological photon systems utilize various topological phases, topological protection mechanisms, and physical systems, including Zak phase in one-dimensional systems, Floquet topological phase, topological pumping mechanism, artificial gauge field, etc; Quantum Hall phase, quantum spin Hall phase, and quantum valley Hall phase in two-dimensional systems; Various topological optical phenomena in non Hermitian systems, synthetic dimensional systems, nonlinear optical systems, and continuous spectral bound state (BIC) systems.

This article provides a detailed introduction to integrated photonic devices corresponding to different dimensions of topology, as well as new types of photonic devices that combine topological photonics with synthetic dimensions and non Hermitian physics. Firstly, from the perspective of one-dimensional topological photons Starting from learning, the one-dimensional topological optical model, different topological phases and topological protection mechanisms,

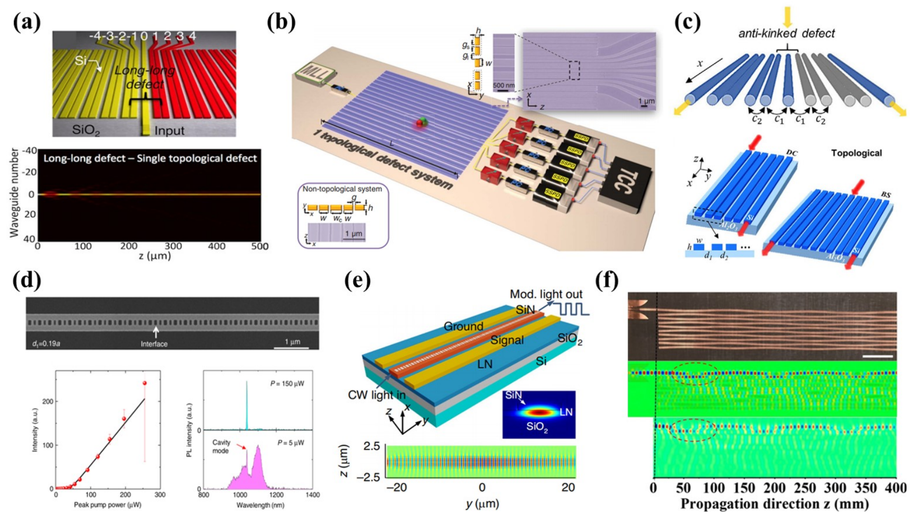

Figure 1: Enter Caption

and their corresponding on-chip topological photonic devices were introduced in detail; Secondly, the topological phases corresponding to the two-dimensional topological photonic crystal structure and the topological photonic devices composed of them were introduced in detail; Once again, the topological photonic devices combined with non Hermitian physics, synthetic dimensions, nonlinear optics, and BIC were introduced; Finally, the future development direction of integrated topological photonic devices was discussed.

2 Result

3 Summary and Outlook

In recent years, with the rise of topological photonics and the development trend of device miniaturization and integration, researchers have theoretically proposed and experimentally implemented numerous integrated topological photonics devices. This article reviews the research progress of various integrated topological photonic devices for on-chip information processing, analyzes their advantages compared to traditional integrated optical devices, and explores their potential applications in the next generation of optical information processing chips. By introducing topological concepts, photon systems have acquired many unique properties, such as unidirectional propagation of boundary states and insensitivity to structural defects. Starting from different device dimensions, this article first introduces one-dimensional topological photonic devices based on Zak phase, Floquet phase, and topological pumping mechanisms, and explores their applications in optical communication, optical computing, and quantum information processing. Subsequently, the two-dimensional topological photonic crystal devices were introduced from the perspectives of quantum Hall phase, quantum spin Hall phase, and quantum valley Hall phase, with a focus on analyzing them The advantages and disadvantages of these types of devices when applied in on-chip information processing scenarios. Finally, based on the current research hotspots in the field of topological photonics, a detailed introduction was given to four types of devices: non Hermitian topological photonics devices, synthetic dimensional topological photonics devices, nonlinear topological photonics devices, and BIC based topological photonics devices. The new on-chip optical field control methods and on-chip information processing functions brought about by the combination of topological photonics with non Hermitian physics, synthetic dimension, nonlinear optics, BIC and other technologies were discussed.