 https://doi.org/10.1051/itmconf/20224703033

Topological properties of one-dimensional non-Hermite electromagnetic medium system

Haoze Li*

Kunming University, Kunming, Yunnan, 650000, China

Abstract. In this paper, we establish a one-dimensional periodic dielectric systems based on one-dimensional maxwell's equations, with abundant topological phase. Through the analysis of the system of chiral symmetry, the energy spectrum of the system and topological phase diagram under the influence of various parameters, particularly is a Hermitian topological phase diagram. By further numerical calculation of the energy spectrum and eigenfunction system, found a 0 or a PI energy advantage state borders, and around the edge with the number of boundary value is consistent, indicates that the system meet the volume boundary correspondence principle.

Keywords: Topology, Non Hermite, Electromagnetic medium.

1 Introduction

With the development of the 21st century, put forward higher demands and challenges in the information age preparation and performance of electronic device. The main problem is the electronic equipment heat dissipation. Electronic equipment materials, therefore, the pursuit of low energy consumption, high density and high transmission speed has become a research hotspot [1]. In the process of looking for new materials, materials science and condensed matter physics in the field of integration, make progress together. On the one hand, the development of condensed matter physics, it can provide a direction to find new material according to the progress of the theory. The exploration of new materials and research, on the other hand, provide strong support for understanding, validation, and enrichment of condensed matter physics theory [2]. In recent years, the introduction of the concept of "topology" in math to condensed matter physics has made new breakthroughs in the development of condensed matter physics. At the same time, it also provides a new direction of development of new materials. Combination of quantum hall effect, found that people tend to look for topological phenomenon the electronic structure of material, we can find the electronic materials with novel topological properties and excellent physical properties in these, and provide the support of the revolutionary new design of the electronic equipment, that is, find a new topological quantum materials [3]. At present, the research methods of new topological quantum materials are mainly theoretical calculation and experimental verification. The electronic structure information of some materials, such

* Corresponding author: 1025492095@qq.com

as energy and structure, is calculated and studied, the theoretical prediction is made, and the experimental phenomena are explained and analyzed in order to deeply understand and analyze the topological characteristics of materials. In the study of quantum materials, an important discovery is the quantum effect, that is, under a certain magnetic field, The electrons will move clockwise or counterclockwise along the direction of the sample, and will not be affected by unclean or unstable scattering during the movement, so the long-term resistance in the sample is 0. However, the problem in this phenomenon is that a strong magnetic field is needed in the process of realization [4]. With further research and exploration, the two-dimensional topological insulating layer with time reversal symmetry has been integrated into quantum wells and quantum wells, so as to realize the lossless transmission of electronic signals without the influence of impurities [5]. Then, in the principle calculation of the researchers, Zhong Fang studied bi2se3 group materials. Due to the excellent topological characteristics of power band [6]. During the experiment, the discovery of human deformity by Qikun Xue and others provided a new research hotspot for the research of topological materials [7]. In addition, as a new prediction material, the surface state of semi-metallic materials has also attracted extensive research [8]. In the process of material search and research, many new polar materials have been successfully predicted and found, including topographic semi metals. Their geopolitical, accordion and other characteristics depend on people's continuous exploration and discovery of more new materials and characteristics [9].

Therefore, based on the above background, the main purpose of this paper is to explore the physical phenomena and physical properties of one-dimensional periodic dielectric system through theoretical calculation, so as to provide a new idea for the research and exploration of topological quantum materials.

2 One dimensional periodic dielectric system

The A one-dimensional Schrodinger equation in the form of Maxwell's equations only considers one dimension on the propagation of electromagnetic field in the x direction, $\partial_x E_y = -ik\mu H_z, \partial_x H_z = -ik\varepsilon E_y$. Can construct a one-dimensional periodic system on the x direction:

$$H = \begin{cases} h_x\sigma_x = -\frac{1}{2}k(\mu_1 + \varepsilon_1)\sigma_x, lL \leqslant x < \left(l+\frac{1}{2}\right)L, & \mu_1 - \varepsilon_1 = 0 \\ h_y\sigma_y = i\frac{1}{2}k(\mu_2 - \varepsilon_2 - 2i\gamma)\sigma_y, \left(l+\frac{1}{2}\right)L < x \leqslant (l+1)L, & \mu_2 + \varepsilon_2 = 0 \end{cases} \tag{1}$$

where $l \in Z$, and $k \in [-\pi, \pi)$, σ_x ,σ_y is the Pauli operator, μ is the relative permeability, ε is the relative permittivity and is the dissipation parameter.

Compared with the common solid lattice, the lattice of electromagnetic medium system has its own strong advantages in the study of problems. Since the lattice of electromagnetic medium system is artificially adjusted by the method of external electromagnetic field, we can realize the lattice parameters that are difficult to realize in solid lattice by adjusting the conditions of electromagnetic field, such as electric field strength and magnetic field strength, so that the lattice constant can be adjusted and the particle interaction strength can be variable, The effect of continuous variation of lattice potential well depth.

Fig. 1. Schematic diagram of one-dimensional electromagnetic field periodic system model. It is arranged periodically along the X direction. In the first half of the cycle, the placement meets the requirements $\mu - \varepsilon = 0$ electromagnetic medium; In the second half of the cycle, the placement meets $\mu + \varepsilon = 0$ electromagnetic medium. Light travels in a medium.

The period of one-dimensional medium is Hamiltonian

$$H = h_x\sigma_x + h_y\sigma_y \tag{2}$$

If the system has chiral symmetry[10], the wave function ψ can be written as $\psi = \psi_R + \psi_L$ and satisfy the following transformation $THT = \lambda^{-1}H$, with $|\lambda|^2 = 1, T^2 = 1$. The Hamiltonian quantity is substituted into the above formula

$$T(h_x\sigma_x + h_y\sigma_y)T = \lambda^{-1}(h_x\sigma_x + h_y\sigma_y) = h_x\lambda^{-1}\sigma_x + h_y\lambda^{-1}\sigma_y \tag{3}$$

It is required that$T\sigma_xT = \lambda^{-1}\sigma_x$, $T\sigma_yT = \lambda^{-1}\sigma_y$.Since the anti commutation relation between Pauli matrices $\sigma_x\sigma_z + \sigma_z\sigma_x = 0, \sigma_y\sigma_z + \sigma_y\sigma_x = 0$ gets $THT = -H$, it shows that the system has chiral symmetry.

3 Topological phase of system

In form, the effective Hamiltonian function can be expressed as

$$H_\alpha(k) = h_{\alpha x}(k)\sigma_x + h_{\alpha y}(k)\sigma_y \qquad (\alpha = 1,2) \tag{4}$$

$h_{\alpha x}(k)\sigma_x$ and $h_{\alpha y}(k)\sigma_x$ are the components of the effective Hamiltonian.

The expression of wave function is

$$\langle\psi_S^\alpha| = \frac{1}{\sqrt{2}E_S(k)}\begin{bmatrix} h_{\alpha x}(k) - ih_{\alpha y}(k) \\ E_S(k) \end{bmatrix} \tag{5}$$

$$\langle\tilde{\psi}_S^\alpha| = \frac{1}{\sqrt{2}E_S(k)}[h_{\alpha x}(k) - ih_{\alpha y}(k) \quad E_S(k)] \tag{6}$$

The energy eigenvalue is

$$E_S(k) = Sh(k), S = \pm, \tag{7}$$

where $h(k) = \sqrt{h^2{}_{\alpha x}(k) + h^2{}_{\alpha y}(k)} = \sqrt{h_{\alpha x}h_{\alpha x} + h_{\alpha y}h_{\alpha y}}, E^2{}_S(k) = h^2{}_{\alpha x}(k) + h^2{}_{\alpha y}(k)$. we can also get

$$\frac{h_{\alpha x}(k)}{h(k)} = \cos\phi_\alpha(k), \frac{h_{\alpha y}(k)}{h(k)} = \sin\phi_\alpha(k), \frac{h_{\alpha y}(k)}{h_{\alpha x}(k)} = \tan\phi_\alpha(k). \tag{8}$$

where $\phi_\alpha(k)$ can be either a real number or a complex number.

The expressions of the Hamiltonian parameters of the system are

$$h_{1x}(k) = E(k)\frac{\sin h_x \cos h_y}{\sin E}, h_{1y}(k) = E(k)\frac{\sin h_y}{\sin E}, \tag{9}$$

https://doi.org/10.1051/itmconf/20224703033

$$h_{2x}(k) = E(k)\frac{\sin h_x}{\sin E}, h_{2y}(k) = E(k)\frac{\cos h_x \sin h_y}{\sin E}, \tag{10}$$

$$\cos E = \cos h_x \cos h_y. \tag{11}$$

Equation 11 is the dispersion relation of the system, as shown in the figure[11].

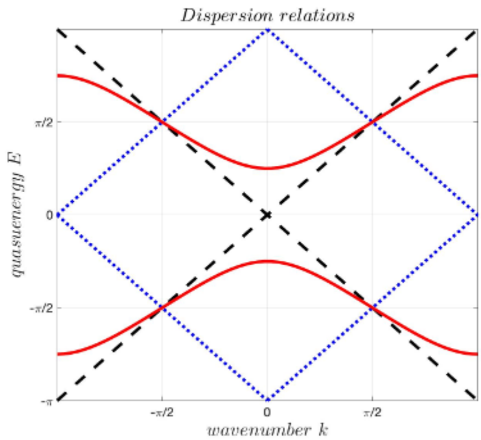

Fig. 2. (Color online)Dispersion relation of one-dimensional quantum walk. The continuous line shows a typical gap phase, where $h_y = \pm\pi/4, h_x = -k\varepsilon$. The two gapless dispersion relations are $h_y = 0$ (slash) and $\pm\pi$ (point). In both cases, the gap at $E = 0$ and $\pm\pi$ is closed.

Figure 2 shows the dispersion relationship between the general value of h_y and the special values of $h_y = 0$ and $h_y = \pi$. Note that for the general rotation angle h_y, the dispersion relationship has a gap around $E = 0$ and $E = \pi$. For the special value, when the system energy is E = 0, the system has no energy gap, so the system is in the edge state.

According to the chiral symmetry of its Hamiltonian, a pair of topological winding numbers [12] can be introduced.

$$\nu_\alpha \pi = \oint dxi \left\langle \tilde{\psi}_s^\alpha \middle| \frac{\partial}{\partial x} \middle| \psi_s^\alpha \right\rangle \qquad (\alpha = 1,2) \tag{12}$$

Through numerical calculation, we can get

$$\nu_1 = \begin{cases} \frac{\alpha}{2}, & l = 2\alpha, \qquad \alpha = 0, \pm 1, \pm 2 \cdots \\ \frac{\beta}{2}, & l = 2\beta + 1, \quad \beta = 0, \pm 1, \pm 2 \cdots \end{cases} \tag{13}$$

Equation (13) represents the winding number increased by H_1 system after l length period. Whether l is even or odd, the expression of winding number increased by H_1 system is the same.

$$\nu_{12} = \begin{cases} \frac{\alpha}{2}, & l = 2\alpha, \qquad \alpha = 0, \pm 1, \pm 2 \cdots \\ -\frac{\beta}{2}, & l = 2\beta + 1, \quad \beta = 0, \pm 1, \pm 2 \cdots \end{cases} \tag{14}$$

Equation (14) represents the winding number increased by H_2 system after l length period. Whether l is even or odd , the expression of winding number increased by H_2 system has a negative sign difference. Therefore, there are two kinds of edge states in the system. When l is an even number, it belongs to the first kind of edge state $E_0 = 2S\pi$, represented by $E_0 = 0$; When l is odd, it belongs to the second kind of edge state $E_0 = 2S\pi + \pi$, represented by $E_0 = \pi$. When there is no gap in the system, that is, when $E = 0$ or π, the topological phase transition occurs. When the imaginary phase does not exist, it belongs to Hermite system, then the system satisfies the following formula

$$\frac{\varepsilon}{\gamma} = -\frac{2n}{l}, l = \begin{cases} 2\alpha \\ 2\beta + 1 \end{cases}. \tag{15}$$

It shows that $\frac{\varepsilon}{\gamma}$ as long as there is topological phase transition in the range of rational number, that is, the existence of imaginary number term does not affect the existence of topological phase.

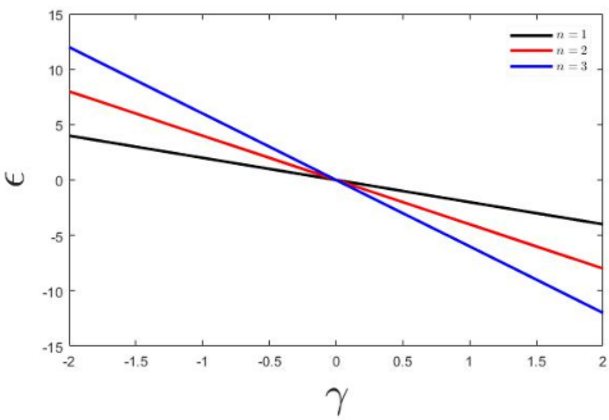

Fig. 3. Topological phase diagram in Hermite system. Let $l = 1$, when $n = 1,2,3$, the relationship between dielectric constant a and dissipation parameter B is shown in the figure.

When the imaginary number phase exists, it belongs to the case of non Hermite system. The self consistent equation of phase diagram is

$$\exp\left(-\frac{\mu}{\gamma}\pi\alpha\right) = \sec\left(\frac{\varepsilon}{\gamma}\pi\alpha\right) + \sqrt{\sec^2\left(\frac{\varepsilon}{\gamma}\pi\alpha\right) - 1}, \qquad l = 2\alpha. \tag{16}$$

We make the module of $\frac{\pi\alpha}{\gamma}$ equal to 1, and due to the construction of one-dimensional system $\mu - \varepsilon = 0$and $\mu + \varepsilon = 0$, so these two equations need to be satisfied at the same time. So when μ and ε Only when these three conditions are met can there be topological phase [13-16]. The topological phase diagram is shown in the figure.

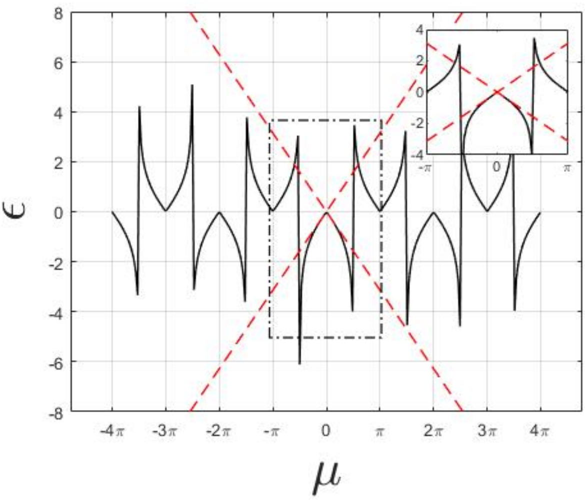

Fig. 4. Topological phase diagram in the case of non Hermite system. Dielectric constant ε And permeability μ The relationship is shown by the black solid line, and the images of $\mu - \varepsilon = 0$ and $\mu + \varepsilon = 0$ are shown by the red dotted line μ and ε Only when the conditions of intersection are met can the topological phase be generated.

Bulk-boundary correspondence [17,18] is a topological characteristics of the material, this is a one-to-one correspondence between express topology status system and the number of peripheral countries. System, we studied the existence of the laps of the condition that accords with a condition of the edge of the zero state, this suggests that there is a corresponding relationship between them. Within the system is a topology of mediocre stage and external system is a topology of mediocre stage.System topological phase transition occurs at the border, lead to the existence of zero energy or energy bound state in the phase interface, and the value of the winding is in line with the matching the number of peripheral countries have the same probability distribution, indicates the boundary of the territory's energy 0 and protection by the topological characteristics of the system, the chiral non Hermitian symmetrical one-dimensional electromagnetic medium system meet the bulk - a boundary correspondence principle.

4 Conclusions

The energy spectrum of the system and the number of turns calculation theory. The results showed that the upper and lower band gap energy band can be 0 to close or open the energy and the energy change of PI under the adjustable parameters. System through phase change topology, the topological mediocre and topology of mediocrity. Each topology stage by a couple of laps, meet the volume boundary correspondence principle. There is a topological phase topological edge protection of the state of the phase interface. By changing the parameters, the topological phase will appear in the value system of the circle, which enriched the topological phase diagram of the system.

The Graduate Program of Scientific Research Foundation of Yunnan Education Department (Grant No.2021Y708).

References

1. Hasan M Z, Kane C L. Colloquium: topological insulators[J]. Reviews of modern physics, 2010, 82(4): 3045.
2. Qi X L, Zhang S C. Topological insulators and superconductors[J]. Reviews of Modern Physics, 2011, 83(4): 1057.
3. Qi X L, Zhang S C. The quantum spin Hall effect and topological insulators[J]. arXiv preprint arXiv:1001.1602, 2010.
4. Yan B, Zhang S C. Topological materials[J]. Reports on Progress in Physics, 2012, 75(9): 096501.
5. Bernevig B A, Hughes T L, Zhang S C. Quantum spin Hall effect and topological phase transition in HgTe quantum wells[J]. science, 2006, 314(5806): 1757-1761.
6. Zhang W, Yu R, Zhang H J, et al. First-principles studies of the three-dimensional strong topological insulators Bi2Te3, Bi2Se3 and Sb2Te3[J]. New Journal of Physics, 2010, 12(6): 065013.
7. Chang C Z, Zhang J, Feng X, et al. Experimental observation of the quantum anomalous Hall effect in a magnetic topological insulator[J]. Science, 2013, 340(6129): 167-170.
8. Wang S, Lin B C, Wang A Q, et al. Quantum transport in Dirac and Weyl semimetals: a review[J]. Advances in Physics: X, 2017, 2(3): 518-544.
9. Ma J C, Deng K, Zheng L, et al. Experimental progress on layered topological semimetals. 2D Mater[J]. 2019.
10. Wu H, Nance J, Razavi S A, et al. Chiral Symmetry Breaking for Deterministic Switching of Perpendicular Magnetization by Spin–Orbit Torque[J]. Nano letters, 2020, 21(1): 515-521.
11. Asbóth J K. Symmetries, topological phases, and bound states in the one-dimensional quantum walk[J]. Physical Review B, 2012, 86(19): 195414.
12. Zhou L. Dynamical characterization of non-Hermitian Floquet topological phases in one dimension[J]. Physical Review B, 2019, 100(18): 184314.
13. Zhou L, Gong J. Non-Hermitian Floquet topological phases with arbitrarily many real-quasienergy edge states[J]. Physical Review B, 2018, 98(20): 205417.
14. Zhou L, Gong J. Floquet topological phases in a spin-1/2 double kicked rotor[J]. Physical Review A, 2018, 97(6): 063603.
15. Zhou L, Pan J. Non-Hermitian Floquet topological phases in the double-kicked rotor[J]. Physical Review A, 2019, 100(5): 053608.
16. Asbóth J K. Symmetries, topological phases, and bound states in the one-dimensional quantum walk[J]. Physical Review B, 2012, 86(19): 195414.
17. Wang C, Wang X R, Guo C X, et al. Defective edge states and anomalous bulk-boundary correspondence for topological insulators under non-Hermitian similarity transformation[J]. International Journal of Modern Physics B, 2020, 34(09): 2050146.
18. Asbóth J K, Obuse H. Bulk-boundary correspondence for chiral symmetric quantum walks[J]. Physical review b, 2013, 88(12): 121406.