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Quantum transport in coupled resonators enclosed synthetic magnetic flux

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HIGHLIGHTS

- The light transport is investigated through ring array of coupled resonators enclosed synthetic magnetic field.
- Aharonov–Bohm ring interferometer of arbitrary configuration is investigated.
- The half-integer magnetic flux quantum leads to destructive interference and transmission zeros for two-arm at equal length.
- Complete transmission is available via tuning synthetic magnetic flux.

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ABSTRACT

Quantum transport properties are instrumental to understanding quantum coherent transport processes. Potential applications of quantum transport are widespread, in areas ranging from quantum information science to quantum engineering, and not restricted to quantum state transfer, control and manipulation. Here, we study light transport in a ring array of coupled resonators enclosed synthetic magnetic flux. The ring configuration, with an arbitrary number of resonators embedded, forms a two-arm Aharonov–Bohm interferometer. The influence of magnetic flux on light transport is investigated. Tuning the magnetic flux can lead to resonant transmission, while half-integer magnetic flux quantum leads to completely destructive interference and transmission zeros in an interferometer with two equal arms.

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1. Introduction

Coherent transport in discrete low-dimensional mesoscopic quantum systems has attracted much attentions for fundamental physics as well as applications due to persistent technique progress in nanofabrication [1–4]. Quantum interference phenomena and quantum coherent transport properties are extensively investigated in various quantum devices [5], interesting effects including Fano resonance [6–8], Kondo effect [9,10], Aharonov–Bohm (AB) effect [11,12], have been theoretically predicted and experimentally verified in one-dimensional nanostructures system, such as photonic nanocrystals [13–15], nanowires [16,17], quantum dots array [18,19]. Much effort has been devoted to investigate coherent electron transport properties of various types of interferometers oriented at different geometries [20–24]. Among these, quantum dots embedded two-arm electron wave interferometers are mostly studied, in particular, the AB interferometer [2,24,25]. The AB interferometer is composed by a two-terminal structure with single or double quantum dots embedded. The two-terminal configuration forms a close ring shape quantum system threading by magnetic flux that is tunable via externally applied magnetic field. Studying transport properties of a quantum system is beneficial for understanding quantum processes concerning energy transfer. The applications include quantum state transfer, quantum control and manipulation in quantum information science.

The engineered and modulated optical systems mimic a great deal of quantum systems including atomic, molecular in condensed matter physics. For example, the dynamic localization [26] and Bloch oscillation [27] of electron under static external field are demonstrated in periodically modulated coupled optical waveguides. The optical systems of coupled waveguides and coupled resonators are successfully employed to investigate parity-time symmetry [28–31]. In recent years, quantum optical analogue is a fruitful platform for studying coherent mechanics in quantum realm due to the simplicity and flexibility of photons. Photons, as neutral particles, although proved not directly interact with magnetic field, the photonic analogy of AB effect is proposed [32,33] and verified based on dynamic modulation of material permittivity [34,35], and based on photon–phonon interaction [36]. The key point is to realize nonreciprocal photon tunneling. Thereafter, the study of quantum phenomena from solids to their artificial electromagnetic counterparts in optics has become a hot topic in quantum physics, quantum information and quantum optics [35–40]. The synthetic artificial gauge field is introduced to simulate and investigate phenomena usually found in electronic systems [38], investigations include the quantum topology in photonic system [41–44] and the photonic analogue of quantum (anomalous) Hall effect in photonic crystals [45–48].

Here, we study light transport in the presence of synthetic magnetic flux in a ring array of coupled resonators. In the presence of artificial gauge field, photons mimic electrons in magnetic field, a coupled resonators system provides an optical platform for investigating quantum phenomena. The ring array of coupled resonators enclosed synthetic magnetic field acts as a two-arm AB interferometer. As interference is sensitive to the relative phase between light waves propagating in its arms, thus light transmission probability is relevant to the connection positions of the input and output leads, and depends on the enclosed synthetic magnetic flux. The interference and phase sensitive feature reveal the quantum nature of photons. We employ the Bethe ansatz method to study the light transport properties. We focus on the influence of a synthetic gauge field on light transport in a ring shaped array with arbitrary number of coupled resonators. The transmission zeros and the resonant transmissions are further discussed.

2. Coupled resonators enclosed synthetic magnetic flux

We begin with two coupled passive resonators [49], using coupled mode theory, the dynamics of field amplitudes inside the resonators give

$$\frac{\mathrm{d}a_1}{\mathrm{d}t} = -i\omega_c a_1 + iJa_2, \tag{1}$$

$$\frac{\mathrm{d}a_2}{\mathrm{d}t} = -i\omega_c a_2 + iJa_1, \tag{2}$$