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ORIGINAL PAPER

Optical Properties of Planar and Annular Ternary Superconducting Photonic Crystals in Near-Zero-Permittivity Operation Range

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Abstract

Optical properties of ternary superconducting planar/annular photonic crystals composed of a high-temperature superconductor and two dielectrics were theoretically investigated based on transfer matrix methods in Cartesian and cylindrical coordinates. Electrodynamics of superconductor were modelled using two-fluid model. It is of interest to observe that, for a planar structure, there exists an additional high reflectance band termed as superpolariton gap near the superconducting threshold wavelength for the TM wave at oblique incidences and some reflection dips also were found in the TM reflectance. However, the superpolariton gap and reflection dips were seen for an annular geometry at higher order azimuthal number. For an annular structure, the size of superpolariton gap can be controlled by simply adjusting the starting radius. Moreover, the superpolariton gap in both structures strongly depends on the operating temperature, different combinations of dielectric refractive indices, and thicknesses of dielectric materials.

Keywords Photonic crystal · Annular · Superconductor · Superpolariton

1 Introduction

Over the past two decades, the study of photonic crystals (PCs) have attracted considerable attention. The area of PCs stemmed from two important works published by Yablonovitch and John in 1987 [1, 2]. It is known that PCs are characterized by so-called photonic band gaps (PBG) within which electromagnetic (EM) waves cannot propagate through the structure [3]. Thus, PCs are also referred as PBG media. Engineering of PBG in a PC structure has wide applications in the field of photonics [4–6].

Previously, PBG media were mainly fabricated based on usual dielectrics, metals, and semiconductors [7–10]. Recently, one-dimensional (1D) PCs incorporating superconductor and dielectric materials have attracted severe attention [11–22]. Such a 1D superconducting PC has two basic distinctions compared with conventional dielectric-dielectric and metal-dielectric periodic multilayer structures. Firstly, for both TE- and TM-polarized waves, there exists a low-frequency band gap due to the combined effects of the periodicity and of incorporating a superconductor. The second one is that a superpolariton gap is obtained for the TM waves near the threshold wavelength of the bulk superconductor [19]. Further, the optical properties of a superconducting PC are tunable as a function of temperature and static magnetic field. This tunable feature originates from the temperature and field-dependent penetration depth of a superconducting material.

In addition to a planar PC (PPC) structure, wave propagation through an annular (cylindrical or circular) PC has also been a subject of great interest in recent years [23–26]. Such types of structures are called annular or cylindrical Bragg reflector (ABR or CBR). The calculations of PPC were based on Abeles theory for stratified media which is the transfer matrix method (TMM) in Cartesian coordinates [27]. However, the reflection/transmission properties of an annular PC (APC) can be obtained by employing TMM for cylindrical waves developed by Kaliteevski et al. [28]. Recently, annular Bragg lasers have been realized and demonstrated by creating a ring defect into the annular periodic multilayer structure [29, 30]. Such kinds of annular lasers have very important characteristics of vertical emission that makes it of peculiar use in optoelectronics and communications.

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