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Comparison of photonic bandgaps of two-dimensional periodic and quasi-periodic photonic crystals with different relative permittivity dielectric

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ABSTRACT

Photonic bandgaps (PBGs) of two-dimensional (2D) triangular-lattice and square-lattice and decagonal quasi-periodic photonic crystals (PCs) have been analyzed, with a given scatterer radius and dielectric relative permittivity changing from 1 to 30 within air-cylinders-in-dielectric and dielectric-cylinders-in-air constructions. The results have shown that 2D quasi-periodic PC is more likely to generate PBG and complete PBG than 2D periodic PC. For the given scatterer radius and two constructions, PBG widths of the two types of 2D PCs vary little, whereas the corresponding center frequencies decrease in smooth "hyperbola-like" curves with dielectric relative permittivity increasing monotonically. The present results will guide the design of PBG-type microstructure photonic devices.

1. Introduction

Since the photonic bandgap (PBG) of two-dimensional (2D) quasi-periodic photonic crystal (PC) (i.e. 2D photonic quasicrystal (PQC)) was found [1], 2D PC [2] was no longer confined to a periodic structure with translational symmetry and was extended to a quasi-periodic structure with rotational symmetry. Further studies showed that the PBG characteristics of 2D PQC have many advantages over 2D periodic PC, such as the defection and localization characteristics is enriched [1], the direction of the incident electromagnetic wave is not sensitive [3,4], the relative permittivity of the substrate materials has lower threshold [6], etc.

The structure parameters and material parameters (e.g. the relative permittivity) of 2D PC affect the PBG characteristics [1–15]. The structure parameters include lattice structure and scatterer parameters (e.g. shape and size). The typical 2D periodic PC lattice structure are triangular lattice [2,7,14,15] and square lattice [2,8,15], and the typical quasi-periodic symmetry folds (i.e., the lattice structure) of 2D PQC are octagonal (8-fold) [1,3–5,9], decagonal (10-fold) [9–12], and dodecagonal (12-fold) [6] rotational symmetry. Compared with other scatterer shape, circular shape is easier to fabricate, so the researchers generally consider circular scatterer in their theoretical study of 2D PC [1–14].

For the same material parameters and scatterer parameters, to the comparative study of PBG characteristics of 2D PQC and 2D periodic PC, we have compared the PBG characteristics of 2D triangular lattice and square lattice and decagonal quasi-periodic PCs in our previous work [11], and those conclusions were drawn from the case of a given substrate material and changing scatterer radius continuously. Until to now, however, the comparison of PBG characteristics of the two types of 2D PCs have not been reported, in the case of a given scatterer radius and changing substrate material or relative permittivity continuously within air-cylinders-in-dielectric and dielectric-cylinders-in-air constructions. In this paper, in order to examine what type of PC is more likely to generate PBG and complete PBG, we give an in-depth investigation in this case. Furthermore, if consult our results, it will be easy to obtain the PBG characteristics of the three kinds of 2D PCs for the given scatterer radius and any given traditional optical materials.

2. Method and model

As is well known, there are three representations for PBG of 2D PC, such as density of states [1], transmission spectra [3,6], and band structure [2,5,7–15]. Because the density of states and the spectral lines depend continuously on frequency (or wavelength), it is difficult to determine the boundary between the PBG and the non-PBG regions. Therefore, the values of the PBG width (or boundary) and

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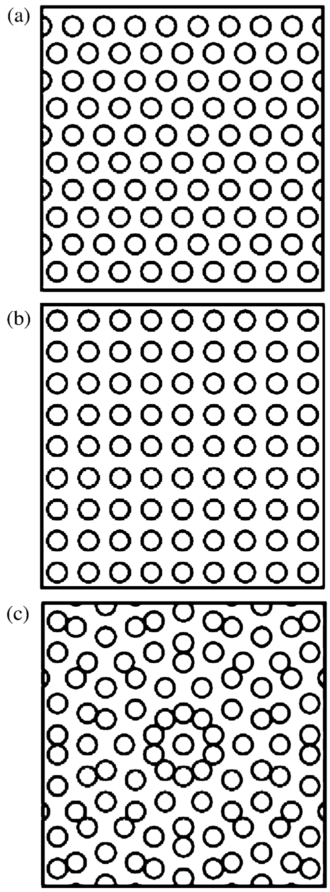

Fig. 1. Structures of the three kinds of 2D PCs: (a) triangular-lattice; (b) square-lattice; (c) decagonal quasi-periodic.

the corresponding frequency range are hard to accurately determine. However, these values are more easily obtained from band structure, which is usually calculated using the plane wave expansion (PWE) method [2,5,7–15]. This method has many advantages, including a simple theoretical analysis, a clear physical conceptual basis, and a research tool in new PCs. For this reason, the PWE method is adopted for our PBG calculations.

The models of 2D triangular-lattice PC and 2D square-lattice PC and 2D decagonal PQC structures are shown in Fig. 1a–c, respectively.

The lattice constant and scatterer radius are set at a and r. According to Fig. 1, the maximum scatterer radius in the three kinds of 2D PCs is $r_{tmax} = 0.5a$, $r_{smax} = 0.5a$, $r_{dmax} \approx 0.3a$, respectively. The relative permittivity of dielectric material is set at ε_r. Without loss of generality, two constructions considered are air-cylinders-in-dielectric ($\varepsilon_{ra} = 1$, $\varepsilon_{rb} = \varepsilon_r$) and dielectric-cylinders-in-air ($\varepsilon_{ra} = \varepsilon_r$, $\varepsilon_{rb} = 1$). The relative permittivity ε_r of the dielectric material is allowed to vary in the range 1–30 (this range contains the relative permittivity of all the traditional optical materials), the scatterer radius is set at $r = 0.3a$ for all the three kinds of 2D PCs, and the calculation step of the relative permittivity is set at $\Delta\varepsilon_r = 0.001$.

3. Results and discussion

3.1. Photonic bandgaps within air-cylinders-in-dielectric construction

Firstly, the PBGs of the three kinds of 2D PCs within the air-cylinders-in-dielectric construction were obtained as shown in Fig. 2a–c, and the complete PBGs of 2D decagonal PQC were shown in Fig. 2d.

According to Fig. 2, for the structure of air cylinders ($r = 0.3a$) arranged in dielectric and the dielectric relative permittivity ε_{rb}

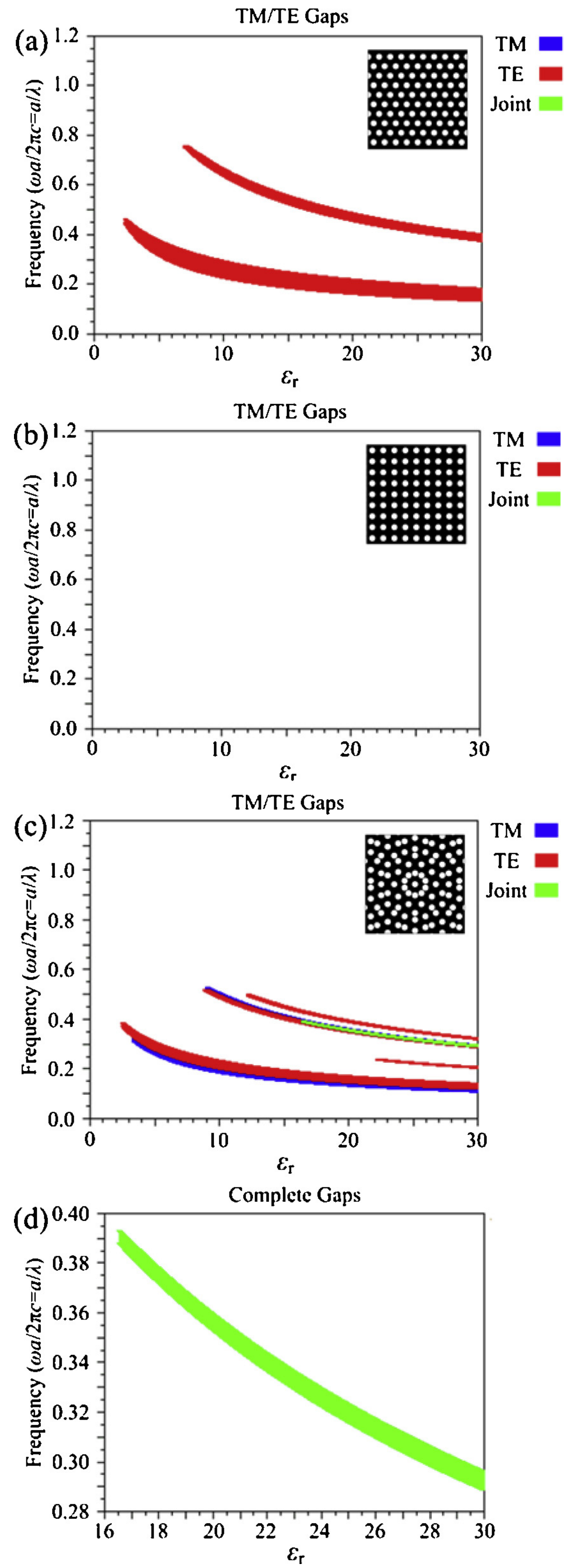

Fig. 2. PBGs of the three kinds of 2D PCs within the air-cylinders-in-dielectric construction and with dielectric relative permittivity changing from 1 to 30: (a) triangular-lattice; (b) square-lattice; (c) decagonal quasi-periodic-lattice; (d) complete PBGs of 2D decagonal PQC.