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Scatterer radius dependence of focusing properties in two-dimensional photonic quasicrystal flat lens

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Abstract

The focusing properties of a germanium decagonal photonic quasicrystal flat lens with different scatterer radii have been analyzed. For different wavelengths and polarization modes, the lenses have different scatterer radius thresholds resulting in different focusing properties. For a point source of light in the transverse-electric mode, we found dual-focusing occurs along the symmetry axis within a range of scattering radii. As scatterer radius increases, the dual-focusing image power and far-field-focusing image quality diminish, whereas near-field-focusing image quality, dual-focusing image distance, and the summed object-image distance all increase.

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1. Introduction

Two-dimensional (2D) photonic quasicrystals (PQCs) [1–9], also known as 2D quasi-periodic photonic crystals (QPCs), have attracted much attention because of their better focusing capabilities than left-handed materials [10,11] and 2D periodic photonic crystals (PPCs) [12,13]. Compared with 2D PPCs, 2D PQCs have only rotational symmetry with no translational symmetry [14,15]. Given the substrate material, symmetry degree, and lattice constant, the scatterer size impacts the fill ratio and the effective relative permittivity in 2D PQCs and affects their physical properties, such as the photonic band structure and photonic band gap (PBG) [16–19]. The photonic band structure also has significant influence on focusing of 2D PQCs [8]. Thus, there is importance in investigating the dependence of focusing properties of 2D PQCs with scatterer radius. Moreover, regarding scatterer-size thresholds, providing structure parameters necessary for fabrication of 2D PQCs and their devices is also an important aspect stemming from such investigations.

To date, however, few investigations on the dependence on scatterer size of 2D PQC flat lens properties have been performed. Previous reports [2–6,8,9] have concentrated mainly on the single scatterer radius ($r = 0.3a$ [2,4–6,8,9], $0.35a$ [3]) and have not been concerned with the relationship between focusing properties and the scatterer radius size. Although Ren et al. [7] have studied the influence of radius disorder on

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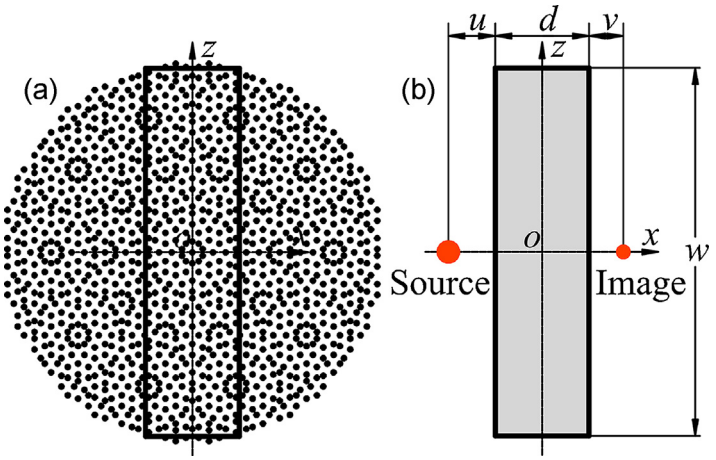

Fig. 1. (a) Decagonal PQC and (b) 2D PQC flat lens model.

the focusing property of 2D PQC slab, they gave no quantitative results between focusing properties and scatterer size.

In our study, we chose a germanium decagonal PQC flat lens as an example. Given the object distance and scatterer refractive index, we analyzed the focusing properties of the flat lens with respect to scatterer radius for two types of point sources in the transverse-electric (TE) and transverse-magnetic (TM) polarization modes. Scatterer radius thresholds for the given point sources and polarization modes are obtained. Dual-focusing is observed along the symmetry axis for the TE-mode point source within a scatterer radius range.

2. Model and method

The 2D PQC flat lens structure is a thin slab of PQC material with dielectric inclusions arranged aperiodically; in Fig. 1, the slab is sketched centered at the origin of the 2D *xoz* plane, which coincides with the symmetry center of the 2D PQC. The lens width and thickness are set to $w = 34a$ and $d = 8.657a$ (a is the lattice constant), with the refractive indices of the scatterer and air given as $n_{Ge} = 4.0$ and $n_{air} = 1$. For the study, the wavelengths for the two point sources of light are $\lambda_{TM} = 2.140a$ for the TM-mode and $\lambda_{TE} = 2.485a$ for the TE-mode. The object distance is set at $u = u_0 + \Delta u$ where $u_0 = d/2 = 4.3285a$, $\Delta u_{\lambda_{TM}} = -0.7a$, and $\Delta u_{\lambda_{TE}} = -1.3a$ [9]. The power peak position in the focus field is established as the image point position x, giving an image distance of $v = x - d/2$. The summed object-image distance is $d_{uv} = u + v = u_0 + \Delta u + x - d/2 = x + \Delta u$.

We employ the finite-difference time-domain (FDTD) method to calculate and analyze focusing

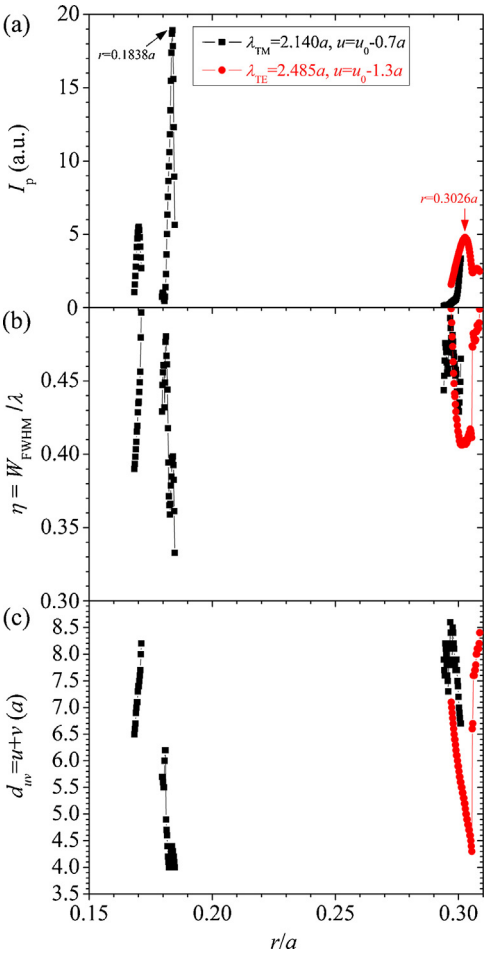

Fig. 2. Scatterer radius dependence of perfect imaging properties of 2D PQC flat lens: (a) for image power I_p, (b) for coefficient η of FWHM (the value is marked by W_{FWHM}), and (c) for summed object-image distance d_{uv}.

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