Fantastic Focusing Direction of Luneburg Lens with Gradient Photonic Crystals Structure in Metamaterial Regime

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Gradient Photonic Crystals (GPCs) are attractive optical structures for manipulating and controlling the propagation of light. In long-wavelength limit (operating wavelength is much larger than the lattice period of structure), GPCs can be homogenized and served as gradient index (GRIN) effective medium. Here, a Luneburg lens is designed with ten layers of GRIN square GPCs structure in metamaterial regime based on the effective medium approximation. Inside the lens, the local effective refractive index is controlled via the filling fraction. Simulation results demonstrate excellent performance of the Luneburg lens for different incident light over a broad frequency band using the COMSOL finite-element package. When the operating wavelength is greater than the three times of the lattice spacing (it is treated as the threshold wavelength), the designed Luneburg lens with GRIN square PCs structure is expected to lead to nearly isotropic optical properties and not affected by the complex spatial dispersion relations. The designed Luneburg lens will show the anisotropy features-fantastic anisotropy focusing direction once the operating wavelength is less than the threshold wavelength.

What wavelengths for the square PCs structure can be treated as homogeneous and isotropic effective medium? We find that the equi-frequency contours(EFCs) calculated by COMSOL are very nearly circle in the long-wavelength limit. Fig. 1(a) shows the photonic band structure for the lowest-frequency modes of a square photonic crystals about the high-symmetry points at the corners of the first Brillouin zone. The dispersion relation in vacuum is that $\omega/k=c/n$, and it has a same form in square photonic crystals, whose dispersion relation is:$\omega(k)=(c/n_{eff})\cdot k$, where c is the velocity of light in vacuum, n_{eff} is the effective refractive index obtained from dispersion curves of square PCs and k is the modulus of wave vector in free-space air.

The equi-frequency contours of GRIN square PCs structure are very nearly circle when the operating wavelength is greater than the three times of the lattice spacing. But the operating wavelength is less than the threshold wavelength such as 2.75 times (a/lambda=0.36, green line as shown in Fig. 1(b)), the designed Luneburg lens will have different focusing direction under the different incidence because of the complex spatial dispersion . In such a Luneburg lens, rays incident from infinity only at incidence of 45 degree not 0 degree will focus on a perfect geometrical point without aberration. Rays incident from infinity at incidence of 0 degree will not focus because of bragg diffraction, as shown in Fig.2 (a) and (b).

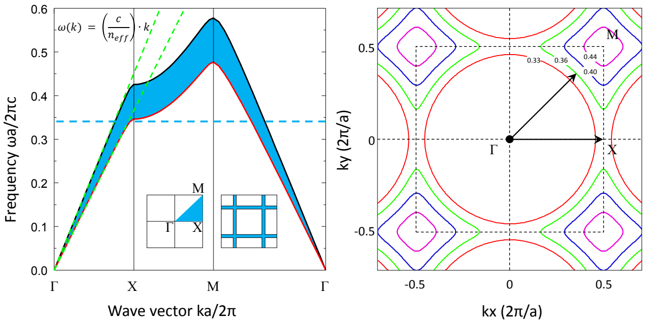

Fig.1(a)The photonic band structure for the lowest-frequency modes of a square photonic crystals. The left inset shows the high-symmetry points at the corners of the first brillouin zone (shaded light blue). The right inset shows the basic unit of square PCs in virtual space.(b) Equi-frequency diagrams: contour plots of ω(kx, ky) for the first bands of a square lattice of width 0.4a dielectric rods (n_1=1.52,n_0=1) in air.

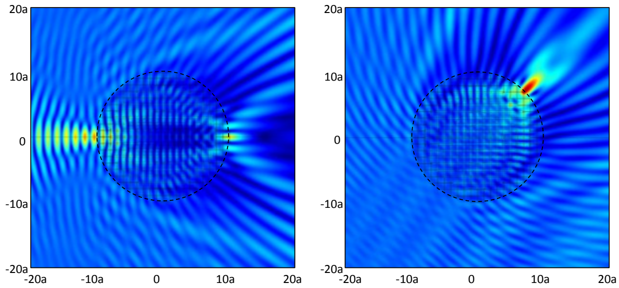

Fig.2 Simulation results of electric field distribution for the designed Luneburg lens at the incident angle of (a) 0 degree and (b)45 degree.

Acknowledgements

The research was supported by the National Natural Science Foundation of China (Grant Nos. 61275171, 91323301, 91123032, 61275048, 61205185, 61205194)

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