DIRECTIVE EMISSION FROM PHOTONIC QUASICRYSTALS WITH 12-FOLD SYMMETRY

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Abstract: This paper deals with the study of the electromagnetic radiation from electric line sources embedded in two-dimensional photonic "quasicrystal" slabs made of dielectric rods arranged according to a 12-fold symmetric aperiodic tiling. Preliminary numerical results, based on a rigorous full-wave method, seem to indicate significant improvements, in terms of sidelobe levels, as compared to previous studies (restricted to 5-fold-symmetric Penrose-type geometries).

INTRODUCTION AND BACKGROUND

During the last two decades, there has been a growing interest in the study of the physical properties and applications of *aperiodically-ordered* structures, related to the concept of "quasicrystals" in solid-state physics, in many fields of science and technology (see [1] for a recent review on the subject, and [2] for an up-to-date bibliography database). In electromagnetic (EM) engineering, use of *photonic quasicrystals* (PQCs) has been proposed in several applications, involving lasers, negative refraction and superlensing, high-impedance substrates etc. (see [3-6], and the references therein, for a sparse sampling).

In [7], we presented a comparative study of two-dimensional (2-D) QPCs made of dielectric rods arranged according to selected *aperiodic tiling* geometries, featuring different types and degrees of order and symmetry. In particular, we studied in detail the radiation from a line source embedded in a PQC slab with Penrose-type (5-fold symmetry) lattice. Results showed the possibility of achieving *moderate* directivity at three frequencies located nearby the (main and secondary) bandgaps, with the lowest frequency smaller (~68%) than the (single) value observed for a periodic photonic crystal slab with comparable size and filling factor. However, the sidelobe level (~-5dB) was still rather high.

In this paper, we show that significant improvements can be obtained by using PQCs with 12-fold symmetry, similar to those considered in [6] for negative refraction and superlensing applications.

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Geometry and Parameters. As in [7], we consider a 2-D (z-invariant) geometry (see Fig. 1) involving a slab of 435 dielectric rods located at the vertexes of a 12-fold-symmetric aperiodic tiling (see the inset in Fig. 1) generated combining square and equilateral triangles according to the Stampfli rules [6,8]. The total size of the slab is $107a \times 4.3a$, with a being the period of an equivalent periodic crystal slab having the same total size and filling factor. The rods have radius $r = 0.15a$ and relative permittivity $\varepsilon_r = 12$. A time-harmonic electric line source is located at

$(x = 0, y = -0.52a)$, with a slight vertical displacement from the symmetry center of the tiling (at $x = y = 0$), so as to avoid the placement inside a dielectric rod.

Preliminary Results. Figure 2 shows the EM response of the PQC of interest computed via a well-established full-wave numerical technique based on a multipolar Fourier-Bessel expansion [9]. Specifically, Fig. 2(a) shows the normalized *radiativity* (cf. [7, Eq. (2)]) from a 257-rod square-shaped PQC slab as a function of the normalized frequency a/λ_0 (with λ_0 denoting the free-space wavelength), from which at least three bandgap regions can readily be identified as pronounced dips. Figure 2(b) shows the normalized radiation patterns in the top halfspace, for a line source embedded in the 435-rod PQC slab shown in Fig. 1, at three representative frequencies $(a/\lambda_0 = 0.220, 0.292, 0.678)$ for which some moderate-to-high directive behavior is achieved. It is observed that the two lowest operational frequencies turn out to be smaller than the lowest one in [7]. Moreover, while the sidelobel level at the lowest frequency $(a/\lambda_0 = 0.220)$ is comparable with those in [7], it is *considerably lower* (~-10dB) at the other two frequencies $(a/\lambda_0 = 0.292, 0.678)$.

CONCLUSIONS AND PERSPECTIVES

We presented a study of directive emission from line source embedded in PQC slabs with 12-fold symmetry. Preliminary results turn out to be significantly better, in terms of sidelobe level, than those presented in [7] for the Penrose (5-fold symmetry) case. It should be noticed that the PQC slab in [7] was randomly extracted from the Penrose tiling, whereas the QPC slab here was extracted from the 12-fold-symmetric tiling preserving the (local) center of symmetry. Moreover, we cannot rule out the possibility that the improvement stems from a better matched choice of the slab size and/or filling factor. Accordingly, current and future investigations are aimed at better understanding the role of *local* vs. *global* symmetry, as well as the slab geometrical parameters, in the directive emission properties. Preliminary results, for 12-fold-symmetric PQCs, seem to indicate a general degradation of the directivity when the line source is horizontally displaced from the $x = 0$ symmetry axis. On the other hand, vertical displacements along the *y*-axis seem to yield, in certain cases, *lower* sidelobe levels. Similar parametric studies are being carried out for other (Penrose, 8-fold) PQC geometries. Also of interest is the development of leaky-wave-based analytic parameterizations of the radiated field.

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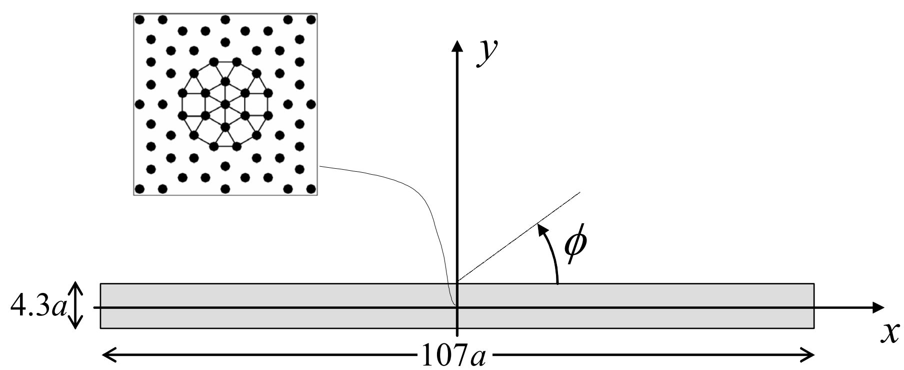

Figure 1 – Problem geometry (explained in the text).

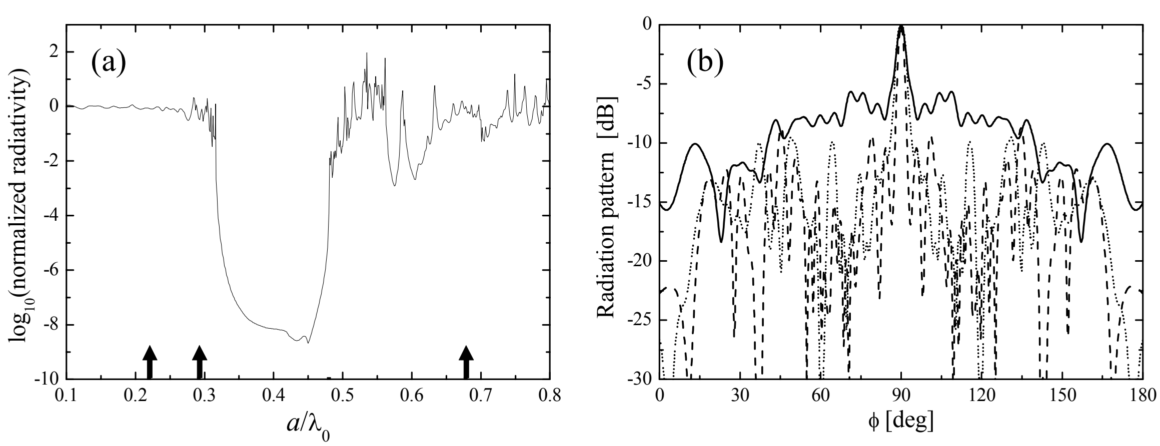

Figure 2 – Electromagnetic response. (a) Normalized radiativity, as a function of normalized frequency, for a 257-rod square-shaped PQC slab. (b) Radiation patterns from a line source (at x=0, y=-0.52a) embedded in the 435-rod PQC slab shown in Fig. 1, at three representative frequencies (marked as arrows in (a)). Solid curve: a/λ_0=0.220; dashed curve: a/λ_0=0.292; dotted curve: a/λ_0=0.678.