Spatial Filters Based On EBG Structures With Anisotropic-Like Dispersion

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***Abstract*— Bandpass and bandstop spatial filters based on the dielectric-rod EBG structures are proposed and validated for the frequency range from 18 to 25 GHz. The obtained experimental results are well consistent with the theoretical predictions. The exploited mechanism utilizes, in particular, anisotropic-like dispersion, which can occur in the conventional EBG structures made of isotropic materials.**

I. INTRODUCTION

Spatial filters are widely used for investigation of spatial spectrum, radar data processing, and aerial imaging. They can be realized, for example, via anti-cutoff media [1], resonant grating systems [2], slabs of photonic crystals (also called EBG structures in the microwave frequency range) with and without defects [3,4], and metallic grids [5]. Narrow bandpass and low-pass filters are considered to be simpler obtainable than wide bandpass and bandstop filters. One of the existing problems is related to the obtaining of bandpass spatial filters with strong and nearly constant transmittance T within one or two rather wide pass bands. In this paper, we will demonstrate that such filters can be realized using the finite-thickness EBG structures, which are composed of alumina rods. This can be possible owing to that the anisotropic-like dispersion with (near-)flat isofrequency contours (IFCs) can occur at a proper combination of the lattice characteristics and frequency.

II. THEORETICAL BACKGROUND

It has been shown in [1] that the spatial filtering with the adjacent ranges of variation of the angle of incidence, $\psi>0$, where $T<1$ and reflectance $R=1$, can be obtained at a beam-type excitation by using the anti-cutoff media. On the other hand, for a plane incident wave, the existense of wide adjacent ranges of $T\approx 1$ and $R=1$, and a steep switching between them has been theoretically demonstrated for the two-dimensional, square-lattice, dielectric photonic crystals [3].

In particular, an anti-cutoff-like ψ-domain pass band can appear owing to the anisotropic-like dispersion, which is characterized by (near-) flat IFCs localized near M point. Such a pass band can formally be either bounded or not bounded at large ψ, if the incident wave vector is extended beyond or remaining within the first Brillouin zone, respectively. If these IFCs co-exist with the (near-)flat contours localized near Γ point, low-pass transmission should simultaneously appear, leading to an intermediate-angle stop band. In turn, dual-bandpass filters can then be obtained, that is impossible at $\mathrm{sgn}\psi$=const while using the anti-cutoff media. This should not be considered as a surprising feature if keeping in mind a richness of dispersion types achievable by using photonic crystals. According to our previous results, the required IFC shape can be obtained within a wide range of variation of the lattice parameters, giving one a freedom in selection of the performances for experimental validation.

III. RESULTS AND DISCUSSION

A. Plane-Wave Simulation Results

Extensive numerical simulations have been performed at the plane-wave excitation for the square-lattice finite-thickness EBG structures composed of the dielectric rods, in order to estimate the range of parameter variation, where wide single-bandpass, dual-bandpass, and bandstop filters can be obtained. Consideration was restricted to the case when the electric field vector is parallel to the rod axes. A fast integral equation technique has been used for simulations.

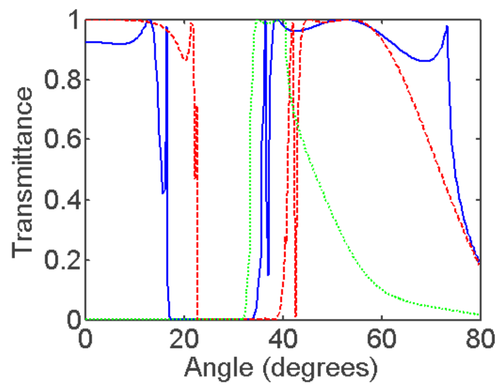

Fig. 1 Zero-order transmittance vs ψ for the eight-layer EBG structure at d/a=0.45 and ka=3.208 – blue solid line, d/a=0.5 and ka=2.964 – red dashed line, and d/a=0.35 and ka=3.808 – green dotted line; a is lattice constant, d is rod diameter, permittivity of the rod material is ε=9.61

For the actual parameters of EBG structures, the obtaining of an ideal wide single- or dual-bandpass filter is a complicated task. However, it is possible to obtain such a filter that has similar basic features. Three typical examples are shown in Fig. 1. The blue solid and red dashed lines correspond to the dual-bandpass and bandstop filters. It is seen that a desired width and location of a ψ-domain pass band can be obtained by adjusting the lattice parameters and frequency. The sharp decrease of the zero-order transmittance takes place at ψ=73.5° due to that the first negative order becomes propagating and successfully competes in transmission with the zero order. The same occurs at ψ=40.5° in the case shown by the dotted line (it corresponds to the single-bandpass filter). Further improvement of the band properties is a subject of optimization.

B. Experiment

Based on the comparative analysis of several tens of theoretical performances, for which the plane-wave simulations were performed, we selected the set of parameters for experimental validation. The finite-size square-lattice EBG structure was designed, which represents an 8x100 array of alumina rods having d=3.15mm, length of 15.4cm, and ε=9.61, while a=7mm. The angle of incidence was varied from 0° to 80°. The experimental set-up used in the frequency range from 18 to 25 GHz is schematically shown in Fig. 2.

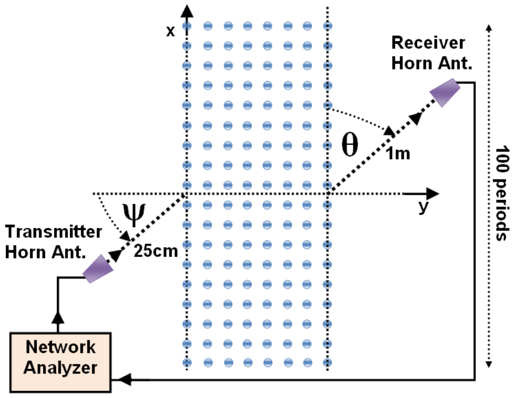

Fig. 2 Experimental set-up

Before starting the experiment, the FDTD simulations have been done for estimating possible effects of a non-plane wave excitation. The Gaussian beam with a width of 15a at the distance 20 cm from the front-side interface has been used instead of a horn antenna because of the code restrictions. The angular distribution of the field has been analysed at the distance of 1 m from the back-side interface, according to Fig. 2. Then, the experiment has been carried out within the same frequency range by using a pair of horn antennas, see Fig. 2.

Figures 3(a) and 3(b) present an example of the comparison of the simulation and experimental results. Despite of the difference in the source type, the basic features are the same in the both plots. The two pass bands and the stop band in between are seen in Figs. 3(a) and 3(b) within nearly the same (θ,ψ)-domains. The stronger blurring in Fig. 3(b) is connected, in particular, with the wider angular spectrum. The dashed lines correspond to θ=π/2-ψ. The dotted lines correspond to max$T$ at every ψ. Hence, the deviation of the dotted line from the dashed one characterizes the deviation from the collimation regime, in which all the beams propagate inside the EBG structure along the y axis shown in Fig. 2.

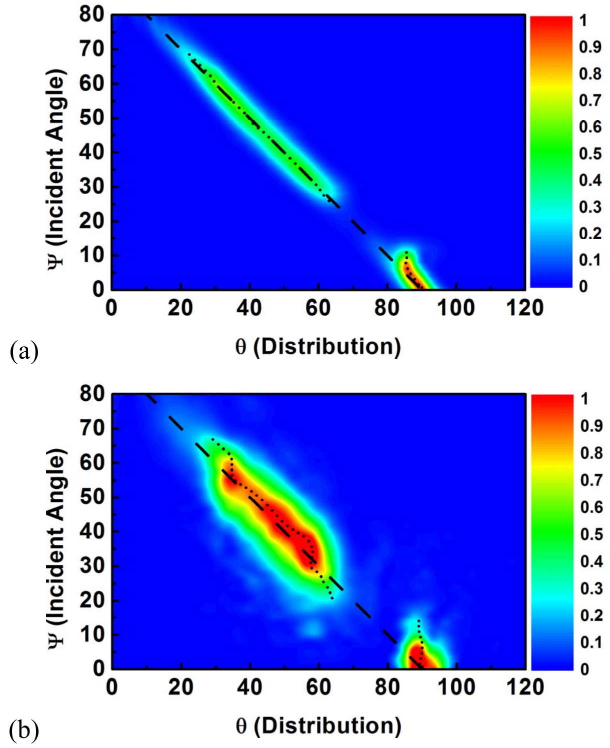

Fig. 3 Transmission maps obtained for the eight-layer EBG structure from FDTD simulations – plot (a) and experiment – plot (b) at f=22.55GHz; transmission values are shown in arbitrary units

IV. Conclusions

Dual-bandpass and bandstop spatial filters can be obtained using dielectric EBG structures with the properly chosen parameters. Both simulation and experimental results show that this possibility exists at a non-plane wave excitation.

Acknowledgment

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