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Design Guidelines for Gap Waveguide Technology Based on Glide-Symmetric Holey Structures

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***Abstract*—The behaviour of a glide-symmetric holey periodic structure as electromagnetic band gap (EBG) is here studied. A number of numerical simulations have been carried out in order to define the importance of each constituent parameter of the unit cell. Our proposed structure finds potential application in antennas and circuits based on gap waveguide technology for the millimeter band. Experimental verifications confirm the effects previously analysed with the numerical studies.**

***Index Terms*—Glide symmetry, parallel plate mode, gap waveguide, holey EBG, metasurfaces.**

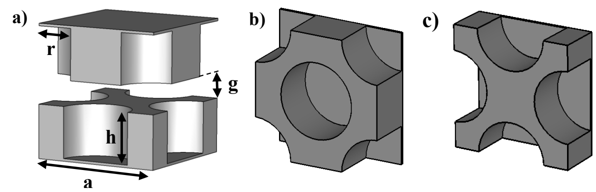

Fig. 1. Description of the main parameters of the unit cell: a) Complete glide-symmetric unit cell. b) Upper layer. c) Lower layer. The two layers are separated by an air gap g.

I. Introduction

The interest about gap waveguide technology has rapidly raised since its definition in 2009 [1] and the first experimental demonstration in 2011 [2]. The key aspect of this technology is that metallic contact is not required. This represents a clear advantage for high frequency circuits and antennas. The commonest band gap periodic structure used to implement gap waveguide technology is the bed of nails [3], although other options have been considered [4]. The bed of nails may be difficult to manufacture when the frequency is extremely high as pins become very thin. To overcome this limitation, glide-symmetric holes have been recently proposed [5], [6]. A glide-symmetric structure is a periodic structure obtained by two geometrical transformations: a translation and a reflection [7]. In the case of holey EBGs, glide symmetry provides advantages in terms of manufacturing: the periodicity is larger with holes than with pins; and drilling holes is easier than milling pins. In this letter, we introduce a glide-symmetric holey structure, and study its stop-band performance when varying its constituent parameters. The idea is to provide a clear vision on how to use it to prevent propagation of parallel plate modes and consequently to use it for gap waveguide designs, especially in the groove version [8] that is the most promising for the millimeter band. An example of glide-symmetric groove gap-waveguide has already been introduced in [6].

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II. Description of the glide-symmetric unit cell

The structure under study is composed of two layers of periodic holes shifted half a period and separated by a very small gap of air (Fig. 1). Structures based on holes instead of pins have been already proposed for packaging purposes (see [9]). However, the use of only one layer of holes in front of a smooth metallic lid separated by an air gap, with a squared lattice, only has a stop-band for certain directions and with a relatively narrow bandwidth. However, when the upper metal layer is replaced by second layer of holes and this layer is shifted with respect to the bottom layer, the band-gap covers all directions. If the shift is half of the unit cell (glide-symmetric configuration), a bandwidth of almost 2 to 1 may be achieved. A dispersion diagram demonstrating this bandwidth is represented in Fig. 2.

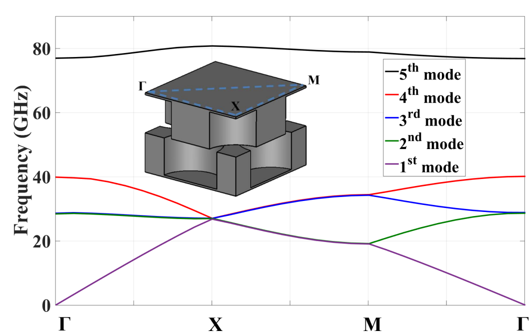

Fig. 2. Dispersion diagram for the glide-symmetric holey structure with dimensions a = 5 mm, r = 1.4 mm, h = 2 mm, g = 0.05 mm.

Here, we will study this glide-symmetric unit cell in terms of starting and end frequencies of the stop-band as a function of its constituent parameters. The graphs will be normalized to the distance between two consecutive holes as typically done in photonic crystals [10]. This means that each pair of points in the following graphs correspond to the result of the calculation of a full dispersion diagram.

III. Parametric study

We consider the structure simulated in Fig. 2 as the reference case (parameters: a = 5 mm, r = 1.4 mm, h = 2 mm, g = 0.05 mm). We study initially the effect of the radius of the holes on the stop-band for a number of periodicities (see results in Fig. 3). In analogy with photonic crystals [10], these results demonstrate that the center of the stop-band is related to the periodicity a, which fixes the central frequency. As stated in [11], [7] for one dimensional cases, for a glide-symmetric configuration, the effective periodicity is half of the unit cell, since there is a double periodicity inside of a single unit cell.

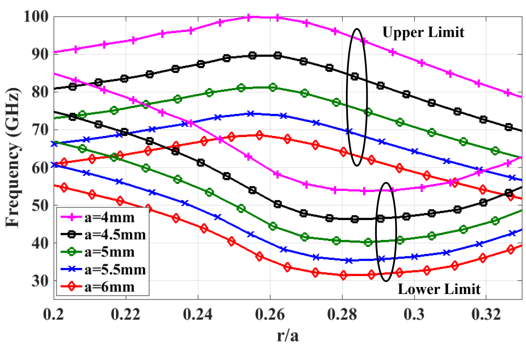

Fig. 3. Effect of the radius versus period ratio (r/a) in the stop-band for a number of periodicities a with h = 2 mm, g = 0.05 mm.

On the other hand, for each periodicity there is a clear maximum in the bandwidth for a particular value of r/a. A new representation of the same results in terms of relative bandwidth (Fig. 4) demonstrates that the optimum happens around r/a=0.275, i.e., when the diameter of the hole is half the periodicity.

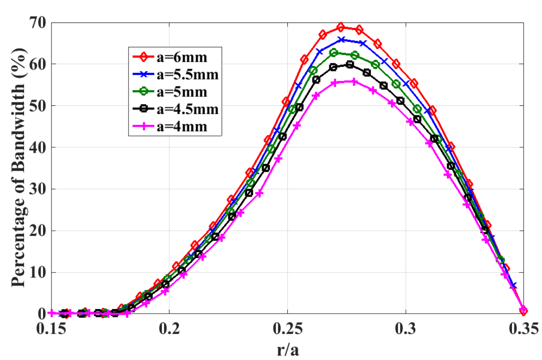

Fig. 4. Bandwidth of the stop-band as a function of r/a for a number of periods a with h = 2 mm, g = 0.05 mm.

The influence of the depth of the holes h is also analyzed and represented in Fig. 5. There is a minimum required depth for the holes, but after that value, a change in this parameter does not affect the stop-band. Also, the non sensitivity of the stop-band to the shape or flatness of the bottom of the hole has been also verified. This important flexibility simplifies the manufacturing.

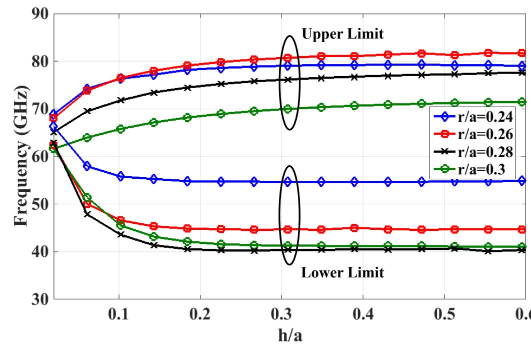

Fig. 5. Effect of the depth of the holes h in the stop-band for different r/a, a = 5 mm, g = 0.05 mm.

Finally, the effect of the gap size is also studied. As it happened with the pin structure, the smaller the gap, the broader the stop-band. The lower limit is the one that is more affected by this parameter, and when the gap is not small enough, the stop-band does not longer exist. Also, when the holes are large with respect to the period, the effect of the gap is reduced as there is less capacitive effect between upper and lower layer.

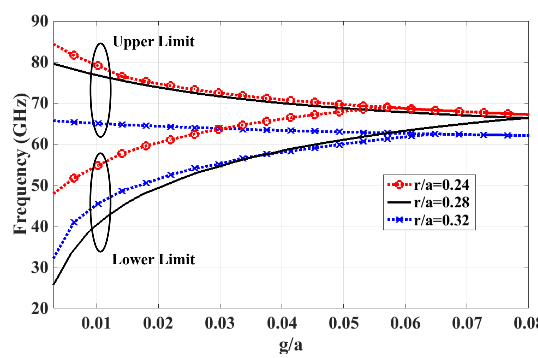

Fig. 6. Effect of the gap g in the stop-band for a number of r/a values, h = 2 mm, a = 5mm.

The combined effect of gap and depth of the holes h has also been studied and it is presented in the Fig. 7. The stop-band always increases when the gap decreases independently of the depth of the holes.

IV. Experimental results

Two different prototypes have been manufactured to experimentally verify the conclusions achieved in the last section (see Fig. 8). The two of them have holes with the same diameter $2r$ = 4.5 mm and height h = 2 mm, but with different periodicities: one of them has a periodicity a = 8.25 mm whilst the second one as a periodicity of a = 9.25 mm. The first one is optimum in terms of bandwidth as r/a = 0.27, whilst the

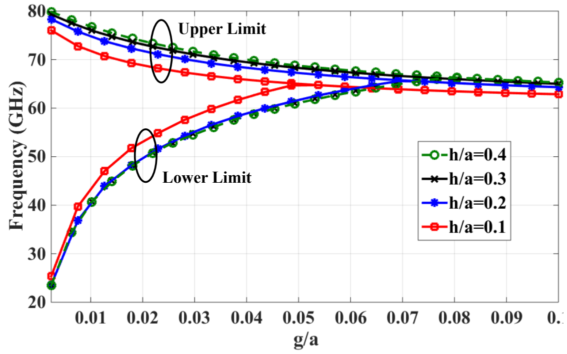

Fig. 7. Effect of the gap g in the stop-band for a number of h/a values, r= 1.4 mm, a= 5mm.

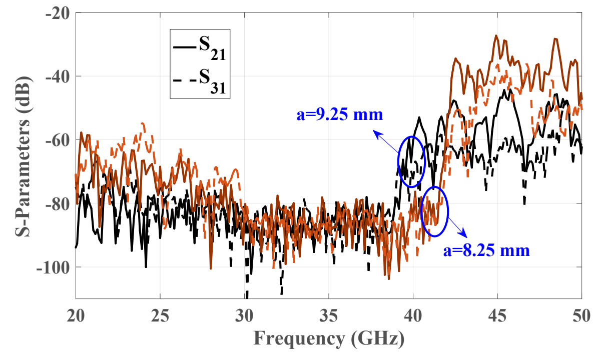

Fig. 9. Measured S-parameters. For all the prototypes: $2r$ = 4.5 mm, h = 2 mm, g = 0.18 mm. The are two values of the periodicity: a = 8.25 mm and a = 9.25 mm.

second one is not. The total size of both prototypes is 130 mm x 130 mm and three vertical connectors have been screwed in three positions to measure the main directions of the dispersion diagram: straight (ports 1-2), and diagonal (ports 1-3). The number of unit cells is 15.5 x 15.5 when a = 8.25 mm, and 14.5 x 14.5 when a = 9.25 mm.

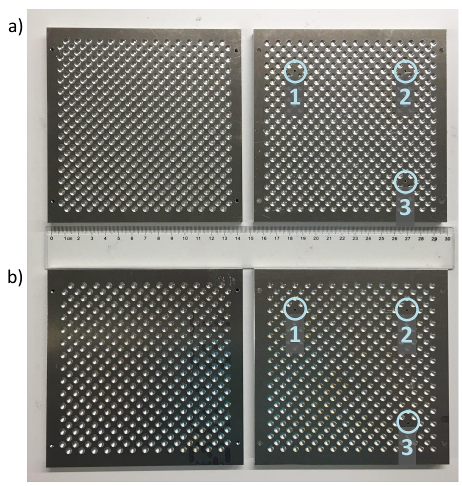

Fig. 8. Photo of the manufactured prototypes. On the top, the shifted layers for a = 8.25 mm, on the bottom, the shifted layers for a = 9.25 mm.

The measurements of the S-parameters for these prototypes are shown in Fig. 9. In both cases, there is a stop band in both directions, straight (ports 1-2) and diagonal (ports 1-3). For the case of a = 8.25 mm, the stop-band is at higher frequencies than for the case of a = 9.25 mm, as predicted in the numerical analyses. This demonstrates that the periodicity is a key parameter in this type of EBG. Since the case of a = 8.25 mm is optimum, the stop-band is broader than in the case of a = 9.25 mm.

V. Conclusions

A complete analysis of the structure named as glide-symmetric holey EBG has been presented. This structure presents a broad stop-band for parallel plate modes, and finds potential application in gap waveguide technology. The periodicity of the holes determines the center of the stop-band and the bandwidth can be optimized with the ratio radii of holes versus period. The reduction on the gap increases the stop-band and the effect of the depth of holes is negligible after a minimum value. These conclusions have been experimentally verified in the millimeter band. The structure provides a simple manufacturing specially for high frequencies when compared to structures based on pins.

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