2-D Numerical Analysis of Metallic Band-Gap Crystal Waveguide in THz

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***Abstract*— The Finite Element Method (FEM) is used to design a metallic band-gap crystal waveguide operating at THz frequencies. Transmission characteristics have been obtained for two types of patterns, square and triangular arrays.**

I. Introduction And Background

TERAHERTZ (THz) waves refer to electromagnetic (EM) radiation in a frequency band between 0.3 THz and 10 THz, corresponding to wavelengths in the submillimeter range. Recently, growing interest has been focused on THz electromagnetic waves and the subsequent development of a variety of devices for possible applications, such as THz sources, detectors, filters, and cavities etc. A number of waveguides have been developed to guide THz waves, such as metal wires [1], sapphire fiber [2], plastic ribbon waveguide [3], photonic crystals [4],[5] etc. each with their own individual challenges.

The purpose of this presentation is to design photonic band-gap (PBG) crystal waveguides produced in metal rods. The motivation is to guide and manipulate the THz radiation in an efficient way in order to increase the performance of the actual THz devices. Under certain design parameters, such as the refractive index difference between the media composing the PBG crystal or PBG crystal's pattern, the propagation of an electromagnetic wave is forbidden within a frequency range. In the near past, because of their low loss and low dispersion properties, photonic crystals have shown great potential for many applications in THz range, especially for guiding [6]. However, metallic band-gap crystals have demonstrated very important advantages over the dielectric photonic crystals, such as wider band-gaps and smaller sizes [7].

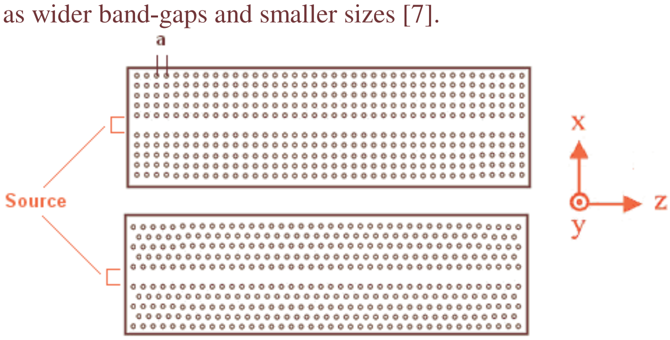

Figure 1 PBG crystal waveguide, square and triangular array, a = lattice constant, L= 25a, Electric field is parallel to the rods in y-direction

A waveguide is formed in a band-gap crystal structure by removing a row of rods. Two types of patterns have been analyzed, square and triangular arrays (Fig.1), using the Finite Element Method (FEM) in 2D. Due to the 2D simulation, this cavity is considered by only allowing light to be transmitted in TE mode in which the electric field is parallel to the rod axis. The electromagnetic wave confinement is provided using the contrast between metal and vacuum permittivities.

II. Results

Before characterizing the band-gap crystal waveguides, it is necessary to determine the transmission properties of the band-gap crystal lattice. Band-gap maps are calculated using FEM for metal rods in square and triangular arranged lattices. Gap map figures show a good agreement with the global gap maps studied in ref [8],[9]. For radius to lattice constant ratio r/a>0.4, a band-gap exists for the whole THz frequency range (Fig.2).

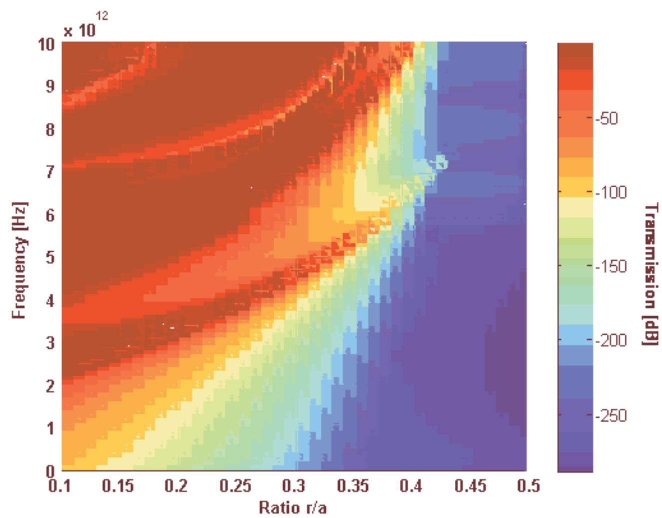

Figure 2 Gap map figure is obtained for gold in square lattice array with lattice constant of 50µm by sweeping THz frequency range for r/a values

In the THz domain, particularly for longer waveguides, the metallic losses are expected to be important with respect to the wavelength of the transmitted signal. This can be attributed to the finite conductivity of metallic materials and their high absorption property in this range [1]. In our structures, materials are characterized by their dielectric properties; moreover, dielectric functions are frequency dependent and have a non-negligible imaginary part. In metal, conductivity and permittivity are determined by using a frequency dependent Drude model [10].

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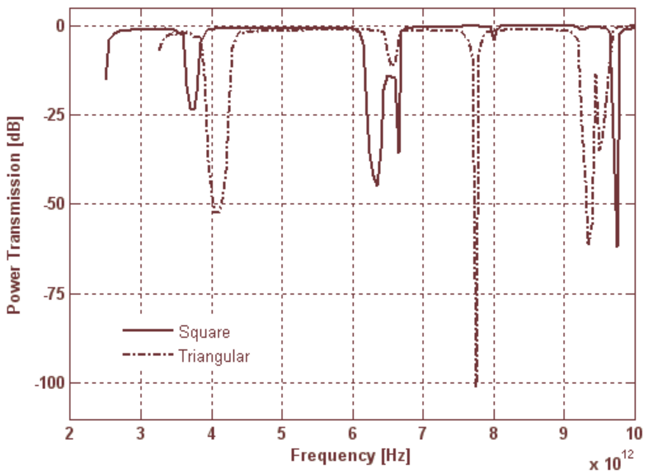

Figure 3 Power transmissions in dB for square and triangular lattice waveguides with copper rods.

In this study it is found that the behaviour of high conductivity materials i.e. noble metals is reflective rather than absorptive. The effect of metallic losses in photonic crystal structure is lower than expected. It is also observed that among four metals (gold, silver, copper and aluminium) there is a slight difference in their transmission figures. However, copper shows better transmission in both square lattice and triangular lattice waveguides.

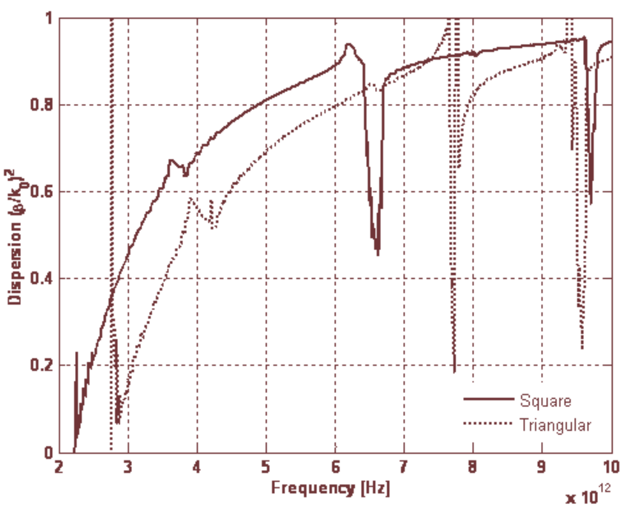

Figure 4 Dispersion curves for square and triangular lattice waveguides with copper rods**.**

Transmission and dispersion are calculated with lattice constant of 50µm and the r/a ratio of 0.4. Power transmission and dispersion characteristics of THz metallic band-gap crystal waveguide have been shown in Fig.3 and Fig.4, respectively, for square lattice waveguides and triangular waveguide. As it seen from Fig.3, very good transmission has been obtained at frequencies between 2.7-3.45, 4-6 and 6.85-9.15 THz for square array and 4.4-6.45, 6.7-7.5 and 7.95-9.2 THz for triangular array.

Guided modes also exist in 2D metallic band-gap waveguides. Only TE mode operation is considered in this study because, for metallic band-gap material it is possible to see an angle independent band-gap for a TE polarized waveguide from zero frequencies to the cut-off frequency while for TM crystal has a small band-gap region [11]. Cut-off frequencies can be seen from the power transmission figure (Fig. 3). For the square lattice the waveguide cut-off frequency is 2.5 while the cut-off frequency of the triangular waveguide is 3.25. These are very close to the cut-off frequency of a metallic rectangular waveguide with a similar width. These values are related to the width of the waveguide created by removing one row of rods.

III. Conclusion

We simulated 2-D metallic photonic crystal waveguide based on two configurations for THz frequency range. Four metals (gold, copper, aluminium and silver) have been studied. A good agreement has been achieved with band–gap maps of metallic lattices and guided modes of metallic PBG crystal waveguides. Over wide frequency ranges consistently high transmission characteristics are obtained in both square and triangular waveguides.

Acknowledgements

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