2-D Photonic Crystals as Substrate for THz/Millimeter Wave Microstrip Patch Antennas

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Abstract—**In this paper, we have simulated 2-D photonic crystal (dielectric slab with regular cylindrical periodic lattice of air-gap) as substrate to enhance the electrical performance of the microstrip (rectangular or circular) patch antenna at THz/millimeter wave frequencies. The periodic structures designed to open up frequency bands within which the propagation of electromagnetic waves is forbidden irrespective of the propagation direction. We also simulated the role of depth of the 2-D air gap in the photonic crystal used as substrate materials.**

Index Terms — **Photonic crystal, stop-band, millimeter/sub-millimeter wave, microstrip antenna, beam steering.**

INTRODUCTION

Technology in the millimeter and THz wave regime of the electromagnetic spectrum is currently experiencing an explosive growth. The growth is fuelled in part by the need for faster signal processing and communications, high-resolution spectroscopy, atmospheric and astrophysical remote sensing and medical imaging. Photonic band gap or photonic crystal technology can represent a major breakthrough with respect to the current planar approaches, mainly due to their ability to guide and efficiently control electromagnetic waves [1-4]. Photonic crystal is a new class of periodic dielectric structures in which electromagnetic wave propagating in any direction is completely prohibited for all frequencies within a stop band. In particular, for infinite structures, the local density of states vanishes inside a complete band gap. We propose a broad-band matching technique those incorporate photonic crystal materials into microstrip circuits. Along with opportunities for integration of optical/microwave devices, photonic crystals exhibit a variety of unique physical phenomena [5, 6]. The main reason that has made photonic crystals so popular is their basic feature of having gaps in the energy spectrum that forbid light to travel at certain wavelengths. Such the gaps in the spectra provide very effective confinement of the light within photonic crystals that can be exploited as a basis for a large number of photonic devices. Another unique feature of photonic crystals with certain lattice parameters is the negative refraction index that can be exploited for focusing and non-conventional distribution of light on a microscopic level. In additional, real finite photonic crystals can support surface states on their boundaries, which can also be exploited for different purposes in photonic chips [7-9]. Photonic crystal or photonic band gap based device in the THz/millimeter wave regime are prone to solve numerous problems such as providing planner approaches to minimization beyond the quasi-optical scheme, and functional elements based on particular dispersion feature and/or denser location compact realization of microwave/millimeter wave device such as waveguide filter, mixer, splitter, antenna, become feasible when photonic crystal structure are used as underling core elements.

In this paper we simulated electromagnetic wave propagation phenomenon at millimeter/THz frequencies in a photonic crystal (rectangular dielectric slab with regular cylindrical periodic lattice air gap) surface. The photonic crystal can be used as substrate materials of microstrip antenna for enhance the electrical performance as well as miniaturization. The periodic structures designed to open up frequency bands within which the propagation of electromagnetic waves is forbidden irrespective of the propagation direction. The application fields of these structures include area such as implementation of frequency-selective surface, controlling antenna radiation pattern, filtering of unwanted signals, enhancing broadband power amplification. Communications services are one pertinent example of an increasingly import area. The organization of the paper is as follows. The section II concerns with the basic concept to use photonic crystal as substrate. The section III discusses the simulated results of the photonic crystal as substrate. Finally, section IV concludes the work.

THEORY

The microstrip antennas are known for their many desirable physical characteristics such as, low profile, low cost, low weight, easy of fabrication and conformability. They have found application in communication systems, as well as many other systems that require compact antenna structures. Because of its resonance nature, the microstrip antenna has inherently narrow bandwidth, limiting their widespread applications. However, there are some techniques that may be used to increase the bandwidth, but they all invariably increase the antenna volume by either increasing the patch size or the substrate thickness, while in principle can produce higher bandwidth but

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very less antenna efficiency due to the increased surface wave losses.

The photonic crystal substrate is a simple solution of the problem of surface waves. If a photonic crystal is designed such that the frequencies of the substrate modes fall within the stop band, the excited substrate modes will exponentially decay, hence reducing the energy lost into the substrate and increasing the energy coupled to the radiated field. The point defect in the photonic crystal is used to localize the field within the defected region, hence, confining energy under the patch. The energy confinement leads to a more efficient antenna as well as providing a simpler method of fabrication.

The photonic crystal surfaces have been integrated with patch antennas due to the ability of photonic crystal to suppress surface waves, when certain conditions are fulfilled. An antenna on a photonic crystal would virtually eliminate any power loss into the substrate when the driving frequency is within the stop band, provided there are no evanescent surface modes [4]. Another interesting property of the photonic crystal surfaces relates closely to the reflection phase that is the phase of reflected electric field intensity at the reflecting surface, normalized by the phase of the incident electric field intensity. It is well known that a perfect electric conductor (PEC) presents reflection phase equal to 180^0 when a plane wave is normally incident on it. In contrast to that phenomenon, the reflection phase of perfect magnetic conductor (PMC) which does not exist in nature, is equal to zero degree. Actually, the reflection phase of photonic crystal may vary from $+180^0$ to -180^0 continuously and because of that property, photonic crystal can exhibit both PEC and PMC like behaviour at different frequency. Furthermore, the anisotropic characteristics of photonic crystals [10] structures have been studied and applied to design of microstrip antennas.

RESULTS

Photonic crystals are artificial structures, which forbid propagation of light in particular ranges of frequencies and remaining transparent for others. The goal that is being pursued is to implement an electromagnetic photonic crystal structure in conventional planar circuit technology, operating in the microwave and millimeter wave range. The simplest way to do so is to embed the periodic arrangement within a substrate board, with two clear advantages [11]:

- approach could be low cost and simple to fabricate, and
- resulting device could be compatible with conventional planar circuit technology.

A straightforward approach is to drill an array of air cylinders in a planar circuit board. This would emulate a lattice topology, such as a square lattice. The photonic band gap crystal has immense potential in improving the performance of antennas and antenna arrays especially millimeter and THz wave frequencies. The perfectly reflecting and dissipation less properties of the photonic crystal eliminates the problem of the radiation losses of a planer antenna mounted on dielectric substrate, and provides an enhancement of the radiation intensity of directional antennas and antenna arrays [12-14]. The initial design consideration start from an ideal infinite 2-D photonic crystal made of an array of air-gap cylinders imbedded in a dielectric.

We consider the 2-D dielectric slab of total length of the dielectric slab is 6.0mm. The height of the dielectric slab is 1.0mm and width is 3mm. In the dielectric slab, $\varepsilon = 2.2$ and 5×11 air gap cylinders. The radius of the air gap cylinder is 0.2mm and the distance between the two consecutive air gap cylinders is 0.20mm. The depth of the air gap is 1.0mm. It is shown in Fig. 1. The stop-band frequency lies between 212.8GHz to 260.85GHz.

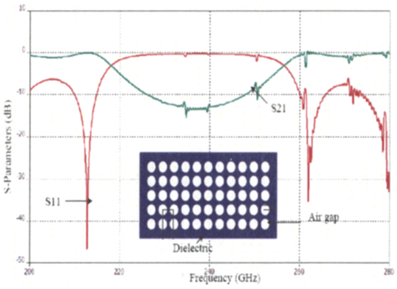

Fig. 1 The reflection and transmission coefficient of dielectric slab, it also regular intervals air gap of distance is 1.0mm.

The 2-D dielectric slab of total length of the dielectric slab is 6.0mm. The height of the dielectric slab is 1.0mm and width is 3mm. In the dielectric slab, $\varepsilon = 2.2$ and 5×11 air gap cylinders. In Fig. 2, if the depth of the air gap is varies 0.25mm the stop-band frequency is also varies. In Fig. 3 and Fig. 4, the depth of the air gap is varies 0.50mm and 0.75mm and corresponding stop-band frequency changes. The stop-band frequency is used to design of microstrip antennas in communication systems. If we design the antenna at that frequency region then it works so well. As the depth of the air gap decreases the, the stop band become complicated.

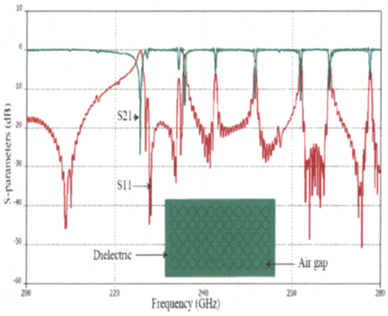

Fig. 2 The reflection and transmission coefficient of dielectric slab, it also regular intervals air gap distance is 0.25mm.

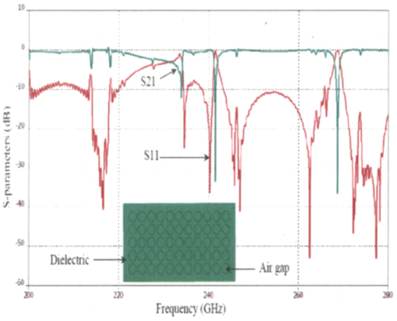

Fig. 3 The reflection and transmission coefficient of dielectric slab, it also regular intervals air gap distance is 0.50mm.

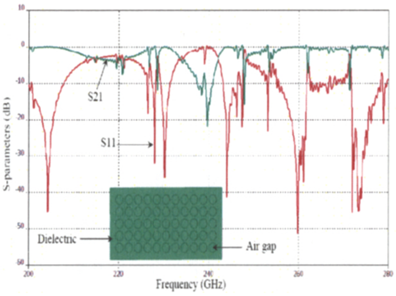

Fig. 4 The reflection and transmission coefficient of dielectric slab, it also regular intervals air gap distance is 0.75mm.

IV. CONCLUSION

In conclusion, the 2-D photonic band gap crystals are becoming promising for THz/millimeter waves, nanophotonic and optoelectronic applications such as detecting, sensing and broadband communication. We have simulated the photonic crystal for different depth of the air gaps and study the stop band frequency characteristics to design of microstrip antenna. Finally at the depth of air gap is 1.00 mm stop band frequency is broader and interesting. Consequently, we can design microstrip antenna in the frequency range 212.8GHz to 260.85GHz will provide interesting results. To realm of photonic the increase of operating frequency posses a challenge to the fabrication technology, as well as prior design procedure, because small sub-wavelength feature have to be handled in material systems that are subject to both, losses and material dispersion. Photonic crystal based antenna are prone to prove to provide pure electric (or optical) beam steering schemes without involving mechanical motion is highly desirable

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