# ELECTROMAGNETIC WAVES PIER 41

# Progress In Electromagnetics Research

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## Progress In Electromagnetics Research

**Chief Editor: J. A. Kong**

# Electromagnetic Applications of Photonic Band Gap Materials and Structures

**Editors: A. Priou and T. Itoh**

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# ELECTROMAGNETIC APPLICATIONS OF PHOTONIC BAND GAP MATERIALS AND STRUCTURES

## PREFACE

The concept of a photonic band gap material (PBG) was initiated by E. Yablonovitch around 1987. He was the first to build artificial periodic structures playing with the permittivity of materials in order to control totally the propagation of the light. He realized a 3-D diamond hole lattice in plexiglass and demonstrated the capability of PBG material to control the propagation of electromagnetic waves. This 3-D photonic crystal is referred as the Yablonovite illustrating the pioneering researches made by E. Yablonovitch

Since that time many research groups in the world have studied structures more complex than the original dielectric PBG materials. In the microwave range metallo-dielectric configurations are investigated and realized. They are mainly made of periodic metallic rods embedded in a dielectric structure or in free space. Their properties are different from the pure dielectric PBG materials. Controllable PBG materials were also proposed very recently. They are metallic-dielectric materials where electronic devices are inserted such as diodes and transistors. The variation of the current or voltage of the electronic devices changes the impedance of the material so that the properties of the material are shifted to another frequency band. The control of the current or the voltage offers new opportunities to have controllable structures.

Many applications in optics and microwaves are merging by using the concept of PBG materials and structures. This new exciting structures or materials are currently under investigation in many laboratories around the world. Many national and international conferences and workshops are organized on this new subject while many research papers are published on this subject.

The aim of this Special Issue is to present the state-of-the-art on the electromagnetic applications of PBG materials and structures and to give deeper insight in the basic understanding, the modeling of passive and/or active PBG materials, and several microwave and optical applications.

Chapter I organized by G. Guida, A. de Lustrac and A. Priou from Universities of Paris X and XII, France introduces PBG materials explaining the principle of this material and of the complex structures organized with the PBG materials. Passive and active PBG materials are introduced. A review of different numerical methods is provided.

Several optical and microwave applications are underlined.

Chapter II by L. C. Botten in association with co-authors from University of Technology of Sydney, School of Physics, New South Wales, Australia and University of Karlsruhe Germany present a systematic and unified development of the multipole methods. The authors applied this method to a range of scattering problems including finite sets of cylinders, 2-D stacks of grating and the calculation of band diagrams from the scattering matrices of grating layers.

In Chapter III, St. Enoch, G. Tayeb and D. Maystre from Fresnel Institut, France, propose an alternative way to enhance the directivity of an emitting device by using the intrinsic properties of the PBG material. The directional radiation is obtained from new kinds of photonic crystals used near the band-gap edge. A 3-D representation of the dispersion relations of the Bloch modes propagating inside the crystal was utilized as an adequate tool for describing the property of material. This approach was used in the case of a 2-D dielectric structure where both the energy flow inside the crystal and the phase variations of the field could be predicted.

In Chapter IV, organized by Long Gen Zheng and Wen Xun Zhang from Southeast University, Nanjing, China, the characteristics of a 2-D dielectric rod array with square cross-section elements arranged in square lattice were analyzed by using methods based on the eigenvalue equations of vector fields E and H by extending Bloch theorem to the vector field Maxwell equations. They derived a simple formulation for relative bandwidth of frequency band-gap material and the midgap frequency establishing tools in designing PBG structures.

In Chapter V, G. Guida from University of Paris X, France, present research work on numerical studies of disordered photonic crystals that are periodic on the average. Deviations from the periodic structures may arise during a fabrication process and are analogue to extended defects in real crystals. Various numerical methods encountered in the literature are described and limitations are indicated in this chapter.

Chapter VI organized by A. C. Tarot, S. Collardey and K. Mahdjoubi, University of Rennes France, is related to numerical studies of metallic structures. The authors first present a parametric study using a 3D finite element method allowing them to estimate the role of parameters on the reflection and transmission coefficients and then to design a PBG structure in X band. They also present a numerical analysis of PBG structures using a FDTD method in order to understand the propagation phenomena in these periodic materials.

In Chapter VII, R. Ziolkowski from The University of Arizona, USA, investigates the use of the FDTD approach to model the behavior of electromagnetic band gap (EBG) waveguiding structures for millimeter-wave power splitting, switching and filtering operations. By introducing further defects into the EBG structures, the author has demonstrated that control of the electromagnetic power flow in these EBG waveguides can be achieved and that with such additional defects, defect-based resonators, filters and switches can be realized.

Chapter VIII is related to microwave applications of photonic crystals. E. Ozbay, B. Temelkuran and M. Bayindir from Bilkent University, Turkey present three important applications of PBG materials: waveguides, detectors and antennas. They demonstrate propagation of EM waves through a waveguide built around photonic crystals, show that the sensitivity and selectivity of a detector can be improved by using photonic crystals, and demonstrate that the radiated field from a monopole antenna inserted within the defect volume of a photonic crystal is highly directional and enhanced.

In Chapter IX, Chin-Chang Chang, Y. Qian and T. Itoh from UCLA, USA, describe the recent advancements in the research and development of uniplanar compact photonic bandgap (UC-PBG) structures for microwave and millimeter applications. The structure consists of compact crystals periodically distributed in two dimensions that realize a 2D periodic network of LC circuits without introducing vias. It is the first demonstration for reduction of the physical size of these periodic structures and integration of PBG structures into standard planar circuit technology.

Chapter X organized by R. Gonzalo, G. Nagore from University of Navarra, Spain and P. de Maagt from ESA, The Netherlands, presents the use of photonic crystals structures as substrates in patch configurations in order to mitigate the effect of the surface-wave mode propagation. Comparison between the patch on a conventional substrate based and the one on a photonic crystal substrate has been performed.

In Chapter XI, G. Poilasne from Photonic RF Corp, Los Angeles, USA, shows that one extension of the PBG structures is called High impedance ground planes (High Z). The period of this high Z ground planes is much smaller than that of many PBG structures. These planes exhibit frequency bands in which no surface-wave can propagate. Their EM characteristics make these structures particularly interesting for antenna applications. In the paper the author illustrates such structures for antenna applications.

The last two chapters are associated with optical properties of PBG materials.

In Chapter XII, S. Guenneau, A. Nicolet, F. Zolla and S. Lasquellec, from Fresnel Institut, France present a novel type of optical waveguide whose properties are derived from arrangement of fibers and from a central structural defect along which the light is guided. The authors achieve numerical computations with the help of a new finite element formulation for spectral problems arising in the determination of propagating modes in dielectric and particularly in optical fibers. The software realized is applied to simulation of low index photonic crystal fibers (LPCF) and to high index photonic crystal fibers (HPCF).

In the last chapter, Chapter XIII, T. Maka, D. N. Chigrin, S. G. Romanov and C. M. Sotomayor Torres are studying 3-D PBG structures working in the visible regime. Those structures have possibilities to control, modify or confine EM waves in all three dimensions and have considerable impact on novel passive and active optical devices and systems. In this chapter, the authors show how to use colloidal crystals as templates for photonic crystals and how to monitor the changes of their optical properties in the course of the modification.

This Special Issue illustrates an international character of the research studies carried out on this subject during the past several years. This Special Issue could not be realized without the great help of 40 reviewers on the International Review Board. We would like to thank very much all the reviewers for their effort in reviewing papers with the objective to improve the quality of the papers and select excellent review papers. Also, we would like to thank, especially, G. Guida, Associate Professor of the University of Paris X who has supervised the International Review Board and has produced excellent recommendations. She has worked very hard to read all the papers and has provided remarks and comments to the authors to improve the quality of the final version of their chapters.

Paris and Los Angeles, January 7, 2002
Guest-Editors: A. Priou and T. Itoh

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