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Investigation of Asymmetric Transmission Properties of 2D Metallic Photonic Crystal for Optical Diode Application

Fulya KARAÇORA NANE[*1,2], Turgut İKİZ[2]

[1]*Hakkari Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Hakkari*
[2]*Çukurova Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Adana*

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Abstract

Current studies combined optics and photonics provide the most promising materials for potential technological and industrial applications, because of their exciting optical and electronic properties. Metals show a lot of optical phenomena associated with their rich dispersion properties, and are widely used in the range from visible to THz frequencies. In this study, asymmetric transmission properties of 2-D photonic crystals have been studied. The effects of different geometric and optical parameters on the transmission are investigated by using MATLAB and freely available MEEP software based on the FDTD method. A novel structure made of silver is used to manipulate electromagnetic propagation of different wave lengths. The simulation results represent transmittance values for the TM mode where the electromagnetic propagation transverse to the same way of incidence wave. As a result, the best comparative asymmetric transmittance values are obtained as 0.75, and 0.15 from top and bottom sides, respectively.

Keywords: 2-D Photonic crystal, Asymmetric transmission, FDTD.

2 Boyutlu Metal Fotonik Kristallerin Asimetrik Özelliklerinin Optik Diyot Uygulaması için Araştırılması

Öz

Optik ve fotoniğin birleştirildiği mevcut araştırmalar, potansiyel teknolojik ve endüstriyel uygulamalar için ilginç optik ve elektronik özellikleri sahip olan yeni malzemeler sunmaktadır. Metaller zengin dispersiyon özelliklerine bağlı olarak birçok optik aykırılık gösterir ve görünür bölgeden terahertz frekansına kadar değişik alanlarda kullanılırlar. Bu çalışmada 2-D fotonik kristallerin asimetrik iletim özellikleri incelenmiştir. Çalışmada farklı geometrik ve optik parametrelerin geçirgenlik üzerindeki etkileri FDTD tabanlı MATLAB ve ücretsiz MEEP programı aracılığı ile araştırılmıştır. Farklı dalga boylarında elektromanyetik yayınımı kontrol etmek için gümüşten tasarlanmış özgün bir yapı kullanılmıştır. Simülasyon sonuçları gelen dalga ile aynı yönde iletilen elektromanyetik yayınım için TM modunda geçirgenlik katsayı değerlerini vermektedir. Çalışma sonucunda en iyi asimetrik geçirgenlik katsayı değerleri 0,75 (üstten gelen) ve 0,15 (alttan gelen) olarak elde edilmiştir.

Anahtar Kelimeler: 2 Boyutlu fotonik kristal, Asimetrik geçiş, FDTD

[*]Sorumlu yazar (Corresponding author): Fulya KARAÇORA NANE, *fulyanane@hakkari.edu.tr*

1. INTRODUCTION

The innovations on information and communication technologies have changed many things in human life. The importance of semiconductor components, integrated circuits and devices has been better understood with the development of human society and technology. The performances of integrated circuits such as microprocessors are now well-suited to the famous Moore's law [1], suggests the electronic devices double in speed and capability about every two years. Although, the integrations of electronic components and devices for information communication and processing are approaching the basic speed and bandwidth limit due to ultra-intensive electrical interconnections. In addition to this, electronics industry has faced another problem, size limit. As a fundamental unit, transistors drive most of electronic parts. When we make the transistors smaller, we can also make them faster and consume less electricity to operate. The problem is: how small can we make transistors? At the moment, companies like Intel are producing silicon transistors with 14 nanometer sizes. They are getting very close to the limit of how small we can make a transistor, because of silicon's 0.2 nm atomic size.

All electronic gadgets like transistors use electrical signals made of electrons moving from one place to another one for communication. Use of light instead of electricity has been considered to be one of the most promising solutions to make electronic components even faster. The main advantage of light is the fastest thing you can use to process and transfer information. Already, fiber optic cables, which simply guide light, are used in current telecommunication technologies.

In recent years, there is widespread research interest in optoelectronics made of optical systems and devices. This area is also called as Photonics, which is a collaborative area of electrical and electronics engineering, material science, physics, and optics. At present, optical integrated circuits using light propagation are being studied and developing intensively. To develop the light based electronic components and devices, it is necessary to create the useful optical materials by giving us a chance to controlling of wave propagation.

Photonic crystals, firstly introduced by Yablonovitch [2] and John [3], opened the new fields in application of optoelectronics. Photonic crystals are defined as a periodic composition of dielectric or metallic materials that are designed to control and manipulate of electromagnetic waves. Photonic crystals are attracting more attention day by day due to their intrinsic electromagnetic properties and possible applications in optical devices.

This study focuses on the investigation of asymmetric transmission properties of a novel dual metallic photonic crystals. The method used in this investigation is FDTD method.

2. NUMERICAL METHOD

In this study, we investigated asymmetric transmission properties of two dimensional metallic gratings for optoelectronic applications. We tried to obtain asymmetric propagation behavior by changing the geometry of metallic grating. According to reference papers [4-7], we have considered a dual metal geometry and studied the transmission spectrum of this structure by freely available MEEP program (MIT Electromagnetic Equation Propagation). We have also compared the MEEP's simulation results by MATLAB. We will use FDTD method in our study. MEEP implements the FDTD method for computational electromagnetism. FDTD algorithm is today's most popular calculation tools [8]. The time and space are divided in a uniform grid for FDTD algorithm which solves time dependent Maxwell equations. For determination of boundary conditions, Perfect matched layer (PML) is embedded in the simulation [9]. Generally, the width of PML layer is equal to a lattice constant in overall simulation area. FDTD solves time-space dependent magnetic and electric fields in different spatial regions by sliding electric and magnetic field components. This idea of grid discretization was first proposed by Yee [10]. Fields in grids can be classified as TM and TE polarization.

2.1. Geometry of Problem

Figure 1 illustrates scheme of the simulation setup for the investigation of the asymmetry of light transmission of our design made by dual metal grating. The unidirectional transmittances of terahertz wave's incidence from top side and bottom side were obtained in TM mode. In this simulation, we use perfectly matched layer (PML) [9] boundary conditions which absorbs electromagnetic waves at the boundaries without reflections. Here, interference waves are sinusoidal wave. The dual metal structures were embedded in free space (ε=μ=1) surrounded by PML. The MEEP simulation results were also checked with snapshots of wave propagation obtained by MATLAB for same design structures. The size of metal grating will be given in result section.

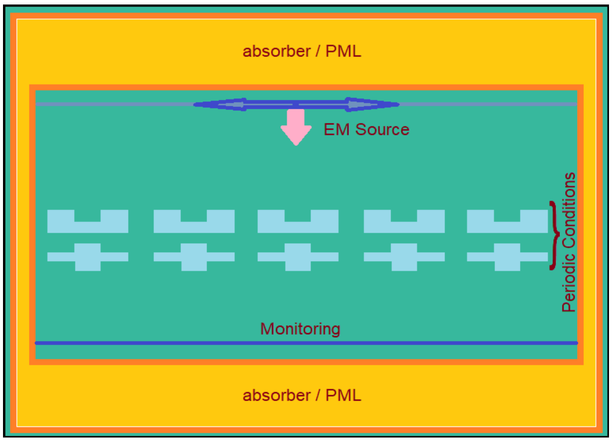

Figure 1. FDTD Simulation setup with perfectly matched layer (PML)

3. RESULTS

The transmission spectrum of our design is calculated for different values of G parameter in TM mode and plotted versus wavelength as shown in Figure 3. It can be clearly seen that an asymmetric transmission behavior can be obtained for a large range of wavelength for all G parameters. When the graphs of the simulation results are compared, it can be said that the most efficient asymmetric characteristic is founded for G=200 nm as 0.75 and 0.15 for top side and bottom side respectively (Figure 2).

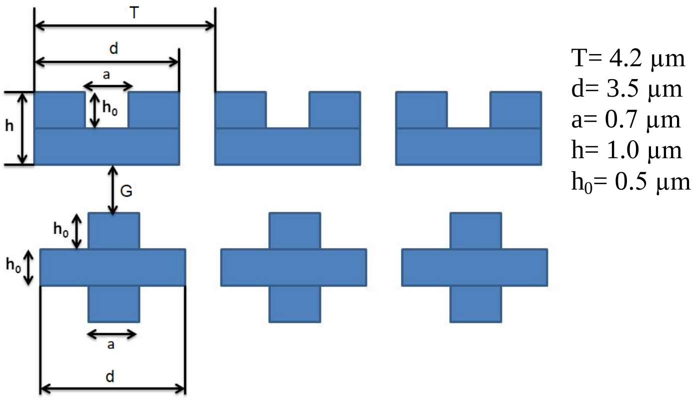

Figure 2. Schema of metallic periodic condition for our design

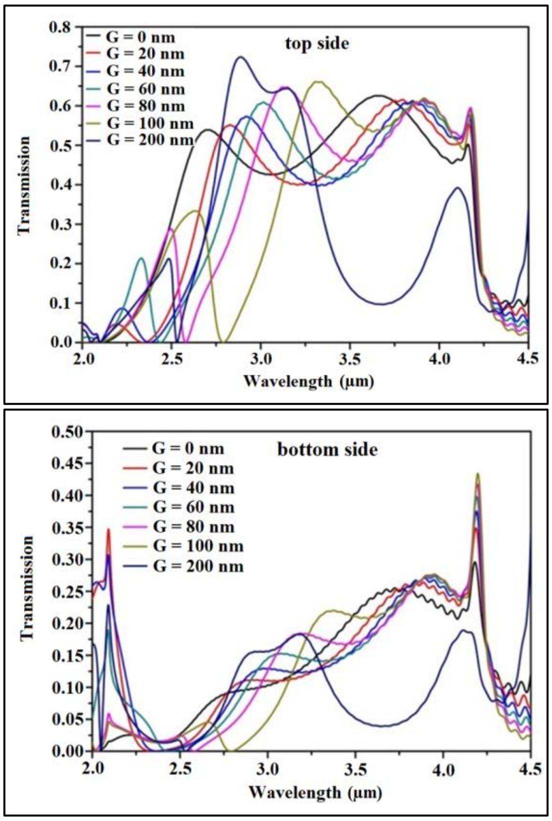

Figure 3. All G parameter (distance between dual metallic layers) dependent FDTD simulation results for our design

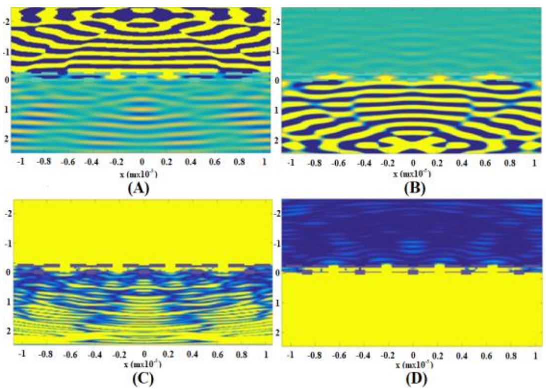

Figure 4. Ez field (TM) mode propagation (a) incidence from top side, (b) incidence from bottom side. Poynting vector distribution (c) incidence from top side, (d) incidence from bottom side for our design (G=200 nm, λ= 2.9 µm)

The wave propagations and Poynting vector distributions from top side and bottom side are obtained by MATLAB and shown in Figure 4. According to these simulation results, the intensities of field distribution and Poynting vector in the transmission region confirm the transmittance result is calculated for our design with G=200 nm, λ= 2.9 µm by using the MEEP program.

4. CONLUSION

The aim of this study was to obtain an asymmetric transmission behavior in the 2-D dual metallic photonic crystals. For this purpose, we designed a novel dual metallic structure and analyzed the numerical results of electromagnetic wave propagation for TM mode. Firstly, the distance between dual metallic layers was modified to obtain the asymmetric transmission. We have carried out an asymmetric transmission behavior in our design for a large range of wavelength for all G values. We have also checked the most effective parameters of our design (G=200 nm, λ= 2.9 µm) by MATLAB simulations. The MATLAB results are consistent with the MEEP results. The asymmetric transmission means that an electromagnetic propagation is completely transmitted in one direction, but blocked in other direction. This feature may be utilized to design the optical diodes [11] for light based integrated circuits. Consequently, the transmission spectrum of our design may reveal the optical diode like transmission behavior around 3 µm. There can be found many studies on such optical diodes in literature [4,12-14].

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