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گیت نوری پلاسمونیکی OR با استفاده از استوانه های طلا و نقره در یک ساختار بلور فوتونی

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چکیده – در این مقاله با استفاده از اثرات تشدید پلاسمون های سطحی در فلزات و در یک بستر بلور فوتونی، گیت نوری *OR* را به نمایش می گذاریم. از دو فلز نقره و طلا، به دلیل اینکه کمترین تلفات را در بین فلزات در رژیم نوری مرئی دارند، برای استفاده از اثرات پلاسمون های سطحی استفاده شده است. ساختار بلور فوتونی استفاده شده، یک ساختار مثلثی متشکل از نانو استوانه های آهنی در هوا، به شعاع *r=50 nm* و ثابت شبکه *a=200 nm*، می باشد. شبیه سازی این ساختار با استفاده از نرم افزار شبیه ساز *COMSOL* انجام شده است.

کلید واژه- پلاسمون سطحی، بلور فوتونی، گیت نوری

A Plasmonic Optical OR Gate Using Gold and Silver Nano Rods in a Photonic Crystal Basis

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Abstract- In this paper, using surface plasmon resonance effect, we demonstrate an optical OR gate. We have used gold and silver because of low losses of silver and gold in visible regime compared to other metals. The photonic crystal structure consists of a hexagonal lattice of iron nano rods, with a radius of r=50 nm and lattice constant of ɑ=200 nm, in a background of air. The designed optical gate, works in the wavelength of λ=0.65 μm with the TM (Hz,Ex,Ey) polarization. Simulation of this structure is done using the COMSOL software package.

Keywords: surface plasmon, photonic crystal, optical gate.

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1 Introduction

In the past years there has been a great interest in photonic crystal based structures and metamaterials because they exhibit novel optical properties such as subwavelength optical imaging using plasmonic effects in metamaterials [1]. Recently surface plasmon resonance in photonic crystals has been demonstrated using 2D FDTD method by W.M.Saj [1]. Also, recently, there has been great interest to exploit subwavelength resonances in metallic structures for creating of artificial materials with unusual effective electromagnetic responses [2].

Photonic crystal waveguides that benefit the surface plasmon resonance, or photonic crystal plasmon waveguides, and also non-photonic crystal based plasmon waveguides are useful in construction of optical metamaterials because of their small size. Plasmons are coupled oscillations of electromagnetic light and oscillations of electrons in the matter excited on a surface of a conductor. Surface plasmons concentrate and locally enhance the intensity of light [3, 4]. This property stimulates investigations on nano scale plasmonic devices because of their possible applications in near field optics, sensing and data storage [5–11].

2 Structure

To design the optical OR gate, we have considered two facts: 1- A photonic crystal structure confines the light and 2- The coupling of the light to surface plasmons of the metallic rods, guides the incoming light to the output branch and prevents it from going backwards to the other input branch. The photonic crystal structure consists of iron nano rods of radius r=50 nm in hexagonal lattice with lattice constant α=200 nm. This structure consists of two input and one output branches. Metallic rods consist of gold and silver nano rods that are devised in the output branch as depicted in figure 1.

Red, yellow and blue dots are representative of iron, gold and silver nano rods respectively in a background of air with radius r=50 nm and lattice constant α=200 nm.

Figure 1 shows the refractive index profile of the simulated structure.

Attention that the yellow colour of gold nano rods is to separate them from silver ones and the true profiling colour is blue.

Size of our proposed optical gate is 5.89 μm × 3.4 μm.

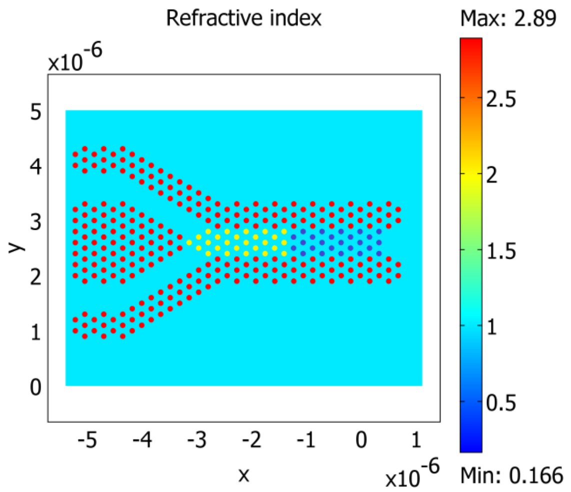
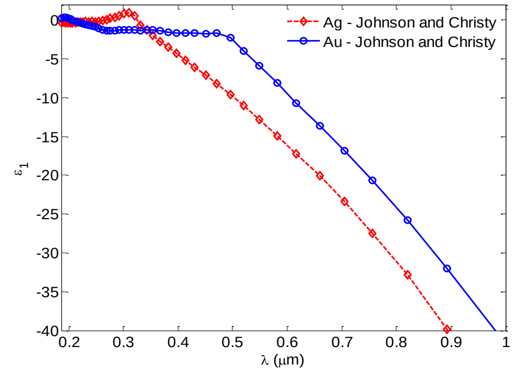


Figure 1: refractive index profile of the simulated optical OR gate. Red, yellow and blue dots are iron, gold and silver nano rods respectively in a background of air.

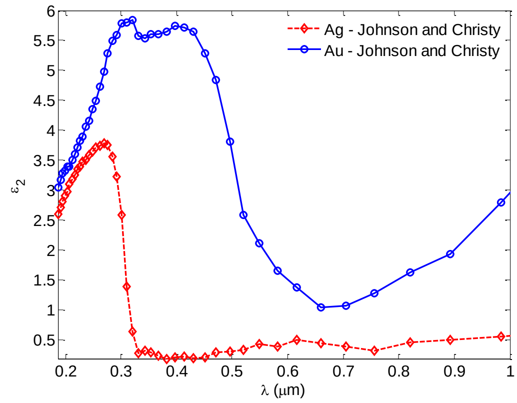
3 Simulation results

To satisfy the resonance condition of the metallic nano rods, we have used the TM (H_z,E_x,E_y) polarization as the polarization of the input light [1]. The TM polarized input light has the wavelength of λ=0.65 μm because of a good surface plasmon resonance condition (minimum loss) in metallic nano rods of silver and gold in this wavelength according to figure 2. In figure 2, experimental data [14] for real and imaginary parts of the relative permittivity of gold and silver are shown.

As we can see in the figure 2 b, imaginary part of the permittivity of gold has a minimum in the wavelength of λ=0.65 μm and silver is its minimum range. Silver has a smaller imaginary part in the wavelength of 0.65 μm and is a better choice for wave-guiding purposes but gold, instead, has a smaller real part that results in less reflectance from the surface. So, we choose the gold and silver in the first and second part of the output branch to have a minimum reflectivity and minimum loss accordingly.



(a)



(b)

Figure2: (a) Real and (b) imaginary parts of the relative permittivity of gold and silver [15].

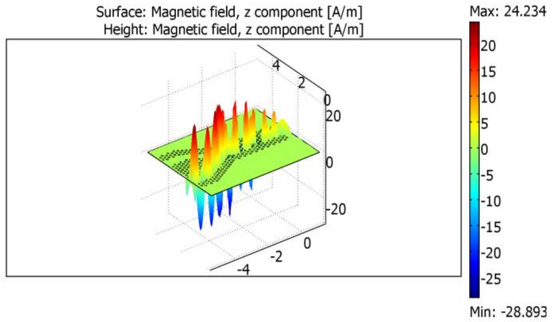
A minimum reflectivity in the first section of the output branch will result in a minimum reflecting light that goes through the other input branch and a minimum loss in the second section, will cause in a minimum propagation loss that is caused by surface plasmon resonances of metallic rods.

Real and imaginary parts of the permittivity of iron, silver and gold, at the wavelength of λ=0.65 μm, are shown in table 1.

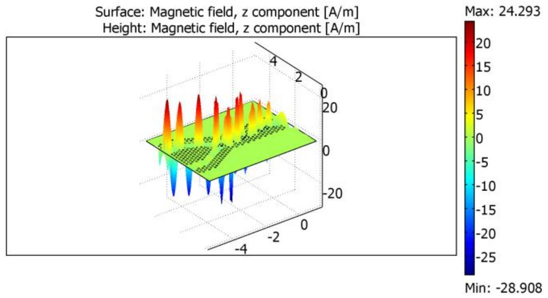
Table 1: Experimental data for real and imaginary parts of the permittivity of iron [14], gold and silver [15].

Permittivity / Material	ε_1	ε_2
Iron	-11.36	19.48
Au	-13.64	1.03
Ag	-20.09	0.4483

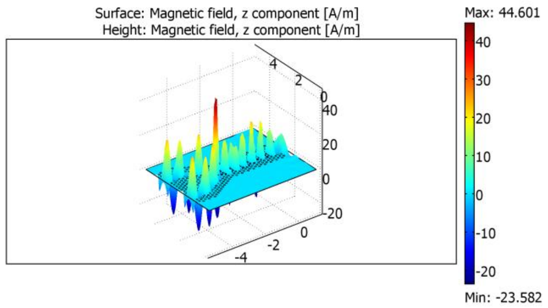
To simulate our structure, we have used finite element method (FE) using the COMSOL multiphysics software package. The z component of magnetic field, propagating in the structure, is shown in figures 3.



(a)



(b)



(c)

Figure3: 3D plot of the z component of magnetic field [A/m] of three operating states of the optical OR gate, a) 0-1 b) 1-0 c) 1-1.

As we can see three operating steps of the optical OR gate are results of the surface plasmon resonance effect of the silver and gold nano rods that couples the incoming light to the output branch. The photonic crystal has the duty of confining the light in the gate and guides it to the output branch.

4 Conclusion

The COMSOL Multiphysics simulation package based on the FE method is used to simulate the optical OR gate depicted in figure 1. Hexagonal photonic crystal structure with lattice constant ɑ=200 nm and r=50 nm, confines the incoming TM (H_z, E_x, E_y) beam inside the optical gate. Since gold and silver Nano rods have the minimum loss among the metals in the visible rage, we have devised them in the first and second section of the output branch to have a minimum loss and reflectivity. These Nano rods guide the light to the output because the surface plasmons of these rodes couple to the incoming light and prevent the incoming light from going backwards to the other input branch. Since our proposed optical gate is compact (5.89 µm × 3.4 µm), it can be used in integrated optical circuits.

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