Simulation of Metallic and Metallic Dielectric Photonic Structures using the OptiFDTD Software

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Abstract: We have explored the possibilities that metals and metal-dielectrics have in the field of photonic crystals. A systematic theoretical study has to be carried out. In this work we have simulated two-dimensional metallic structures in order to study the photonic properties of nanostructured metals. It is demonstrated that disordered metallic-dielectric photonic crystal provides remarkably high reflection range compared with the corresponding period metallic-dielectric one when the degree of disorder is moderately chosen, and a wider stop band will be obtained with the increasing of periods. The simulations were carried out using Optiwave OptiFDTD software.

1. Introduction

When an electromagnetic (EM) wave propagates in such a structure whose period is comparable to the wavelength of the wave, interesting phenomena occur. Among the most interesting are the possibility of forming a complete photonic band gap (CPBG). Most of the known structures with a CPBG are based on the face-centered cubic (fcc) or diamond symmetry. Photonic crystals are a kind of nanostructures for light, the refractive index of which changes periodically. Photonic crystals are of great interest for optical information processing applications because these crystals provide a common platform to miniaturize a large number of optical components on chip down to single wavelength scale. Many devices are conceived by starting from the perfect crystal with the photonic band gap. Photonic band gap consist of frequency range that prohibit the light to propagate inside the crystal. By applying various types of engineering such as band gap and transmission band in band structure, photons in a variety of way can be manipulated. In band gap engineering, as light with certain frequencies is blocked from the crystal but by introducing an artificial periodic disturbance or defect into the crystal, light can be controlled in number of ways if we introduce a line shape defect, we can construct an ultra small waveguide that allows the transmission of light only along the defect. If we introduce point defect, light can be trapped at certain points. Transmission bands are those that allow propagation of light [5-7]. In different region of electromagnetic spectrum Photonic bandgap have already been demonstrated for semiconductor and dielectric materials. Photonic band gap have a range of applications in optical fibers & sensors. Metallic nanoparticles can be used as building blocks for photonic crystals operating at near IR & optical frequencies. It is not intuitive obvious that metallic nano particles can serve the purpose. First metals are dispersive & can be rather absorbing at IR & optical frequencies. Second, it is very difficult to fabricate metal nanoparticles that are monodispersed spheres with the order of 150 nm, the scale length needed to realize photonic gaps at optical frequencies. But absorption problem can be solved by the careful choice of metal component. On the other hand, metals can be quite lossy at optical frequencies. Nevertheless the absorption can be rather small in a certain frequency range, where the metals behave as a highly dispersive dielectric. We have accounted here that not all metals are affected by absorption in the same way. A theoretical study of the photonic properties of metals is essential for the future development of devices based on metallic photonic materials. Optical elements in the nanoscale are difficult to simulate when they are totally or partially composed by a metal. But finite difference time domain method (FDTD) provides a powerful tool for electromagnetic simulation. Including metals via the Lorentz Drude models [10], the FDTD method can be used for the simulation of different metallic photonic structures. In this work, the results obtained from the simulation of silver two-dimensional photonic structures made of silicon are presented for comparison. All the simulations
have been performed with the Optiwave OptiFDTD 8.0 software [12].

2. Simulation of the structures

A hexagonal structure of air cylinders surrounded by a material is simulated in this study. This structure has been selected because hexagonal patterns in materials can be obtained by self assembly techniques [11] which are attracting the interest of scientist due to their cost effective fabrication process & their potential to scale to mass production. The dimensions of the lattice & radius of the cylinders are varied in order to study the dimensioning effects on the existence, position, & thickness of the band gap. A scheme of the structure & its dimensions can be seen in figure 1(a).

Fig.1(a) Schematic of the simulated structure

Fig.1 (b). Cross-sectional view of simulated structure in Fig1(a) Y dimension is taken as infinity in the simulations

3. Result and Discussion

The silver structure with the largest lattice constant presents a band gap for TM polarized light centered in 1.55μm. Decreasing the dimension of the crystal implies a proportional change in the position and width of the gap similarly to that of dielectric photonic crystal. The simulated band diagram for a structure with \(a = 420\)nm and \(b = 126\)nm is shown in figure 2. Fixing the lattice constant \(a\) to 5μm and 1.5μm results in a thinner band gap. Increasing the value of lattice constant \(a\), the band gap increases correspondingly, but the TE mode remains disappeared.

Fig.2. Bandgap diagrams of the simulated silver structure: \(a=420\)nm, \(b=126\)nm.

There exist band gap for Tm polarized light in the case of silver centered at 227nm for \(a = 420\)nm. While the same structure for \(a = 5\)μm centered at 0.242nm.

4. Conclusions

The metallic structures simulated in this work show a linear behavior similar to that in dielectrics. The reduction in lattice parameter does increase the band gap. Thus by careful doping in silver can be used to control the lattice parameter and thus it is one of potential materials for the fabrication of photonic devices in the visible range of the spectrum.

References