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جاذب پلاسمونیک باند باریک قابل تنظیم بر اساس کریستال مایع و ساختارهای مربعی از جنس طلا

رضا رشیدی‌تبار و نجمه نزهت

دانشکده مهندسی برق، دانشگاه صنعتی شیراز، شیراز، ایران

چکیده - در این مقاله جذب آرایه‌هایی از اجرام مربعی شکل از جنس طلا با اندازه‌های متفاوت در ناحیه فرو سرخ نزدیک مورد بررسی قرار می‌گیرد. در این ساختار، اجرام مربعی شکل طلا درون کریستال مایع قرار دارند. کریستال مایع از نوع 5CB است که منجر به قابل تنظیم شدن ساختار می‌شود. نقش کریستال مایع و اندازه مربع‌های طلا برروی جذب ساختار بررسی می‌شود. در ساختاری که مربع‌های طلا با دو اندازه متفاوت وجود دارد، دو قله جذب باریک بالای ٪۹۵ بدست می‌آید. برای بدست آوردن سه قله جذب، مربع های طلا با سه اندازه متفاوت درون کریستال مایع قرار داده شده است. در این صورت سه قله جذب بالای ٪۸۵ به وجود می‌آید. در ساختارهای پیشنهادی، با تغییر ضریب شکست کریستال مایع ناشی از تغییر ولتاژ در حالت‌هایی که محور اپتیکی با محور z زاویه ۰^o یا ۹۰^o دارد، میزان جذب درحدود ۳۰nm تغییر می‌کند.

کلید واژه- پلاسمون سطحی، جاذب، کریستال مایع

Tunable Narrow Band Plasmonic Absorber Based on Liquid Crystal and Gold Squares

R. Rashiditabar and N. Nozhat

Department of Electrical Engineering, Shiraz University of Technology, Shiraz, Iran

Abstract- In this paper, the absorption of gold square arrays with different sizes is investigated in near infrared regime. The gold squares are dispersed in 5CB type of liquid crystal to make the proposed absorber tunable. It is shown that the size of gold squares plays a great role in the absorption behavior of the proposed absorber. The obtained absorptions by two different sizes of gold squares are narrow band which are more than 95%. As three different gold squares are utilized in the structure, three more than 85% absorption peaks are created. The tunability of the proposed structures is about 30 nm as the optical angle varies between 0^o and 90^o by the applied voltage.

Keywords: Surface plasmon, Absorber, Liquid Crystal

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R. Rashiditabar

r.rashiditabar@sutech.ac.ir

N. Nozhat

nozhat@sutech.ac.ir

1 Introduction

Surface plasmons (SPs) are caused by the interaction of light and electrons near the surface of metals leading to an evanescent wave along the metal surface. SPs can be excited in sub-wavelength metallic structures leading to photonic circuit miniaturization. In this case, a branch of photonics called plasmonics is introduced to study and develop the SP devices. There are different plasmonic devices to be used in photonic circuits such as waveguides, couplers and absorbers [1,2].

Plasmonic absorbers are utilized in different applications such as solar cells [3]. In [4] a plasmonic dual and triple narrow band absorber has been designed that an array of gold squares has been fabricated to create three near perfect absorption peaks in near and intermediate infrared regions. Chen *et al.* have fabricated plasmonic dual band perfect absorber based on gold cross-shaped patterns at near infrared frequencies [5]. The mentioned structures suffered from post fabrication tunability. In this case, materials such as liquid crystals (LCs) have been investigated to fabricate active devices with post fabrication tunability [6]. LC is an anisotropic material with interesting optoelectronic features. The interaction of LC and plasmonic structures has been studied by many researchers. There are various plasmonic structures such as plasmonic LC colour filters [7] and absorbers [8,9] that LC made them tunable. In [8], two tunable narrowband absorption peaks are created by nanodisks. Su *et al.* have proposed a tunable wideband plasmonic absorber which is sensitive to the angle and size of nanorods dispersed in LC [9]. In the mentioned tunable absorbers, localized surface plasmon resonance (LSPR) gave rise the absorption in the structures. Therefore, tunable plasmonic absorbers which are less complicated to fabricate are of great interest to plasmonic researchers.

In this paper, two tunable narrow band plasmonic absorbers are proposed that consist of gold squares dispersed in 5CB type of LC. The investigated absorbers are tunable by LC while different square sizes create different absorption peaks.

The rest of the paper is as follows. In Section 2, the materials and structures of the proposed absorbers are described. The simulation method is investigated in Section 3. In Section 4, the paper is concluded.

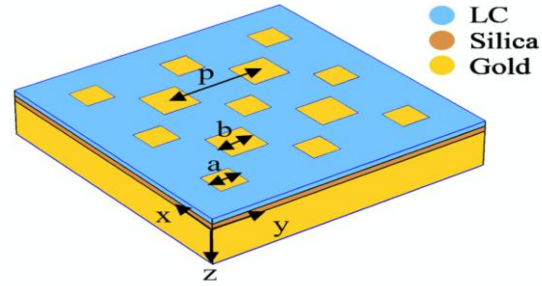
2 The structures of the proposed absorbers

The schematic view of the proposed absorber by two gold squares is depicted in Fig. 1. The gold squares with a thickness of h=30 nm are dispersed in LC with a thickness of t_1=30 nm and both are placed on a silica layer with a thickness of t_2=30 nm. There is a gold substrate with a thickness of t_3=200 nm to block any wave leakage under the silica layer. The lengths of the gold squares are a=150 nm and b=200 nm. The distance of adjacent gold squares is denoted by p=500 nm.

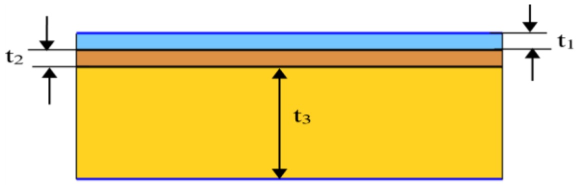
The permittivity of gold is described by Johnson and Christy [10] data while Lemarchand data is used to simulate the SiO_2 [11]. The refractive index of LC is described by a second ranked tensor as [12]:

$$\varepsilon=\begin{pmatrix} n_o^2\cos^2\phi+n_e^2\sin^2\phi & 0 & (n_o^2-n_e^2)\sin\phi\cos\phi \\ 0 & n_o^2 & 0 \\ (n_o^2-n_e^2)\sin\phi\cos\phi & 0 & n_e^2\cos^2\phi+n_o^2\sin^2\phi \end{pmatrix} \quad (1)$$

where n_e and n_o are ordinary and extraordinary refractive indices, and ϕ is the angle between the optical and z-axes.



(a)



(b)

Fig. 1. (a) The schematic view and (b) side view of the proposed absorber when 2 different square sizes are utilized in the structure.

Furthermore, if LC is illuminated by a linearly polarized plane wave, the effective refractive index is defined as [12]:

$$n_{eff} = \frac{n_e n_o}{\sqrt{n_e^2 \cos^2\phi + n_o^2 \sin^2\phi}} \qquad (2)$$

The refractive indices of LC are chosen according to data in [13].

3 The Simulation procedure

The finite element method (FEM) is used to simulate our proposed absorbers. The structure, shown in Fig. 1, is illuminated by an x-polarized plane wave. In our simulations, the absorption is calculated by A=1-R-T, where A, R and T are the absorption, the reflectance and the transmittance, respectively. The transmittance of the structure is zero due to the thickness of the gold substrate. The absorption spectra of the mentioned structure are depicted in Fig. 2 for $\phi = 0^o$ and $\phi = 90^o$.

The LSPRs occur at the peak absorption wavelengths of λ_1=1.124 μm and λ_2=1.35 μm as $\phi = 0^o$, $\lambda_1^{'}$ =1.155 μm and $\lambda_2^{'}$ =1.39 μm as $\phi = 90^o$. The electric field amplitude $(|\mathbf{E}|)$ distributions of the LSPRs at the resonance wavelengths of λ_1 and λ_2 are shown in Fig. 3 when $\phi = 0^o$.

The variation of the applied voltage to the LC by the substrate leads to the change of ϕ (optical axis) of the LC molecules that gives rise to the LC refractive indices adjustability and makes the structure tunable.

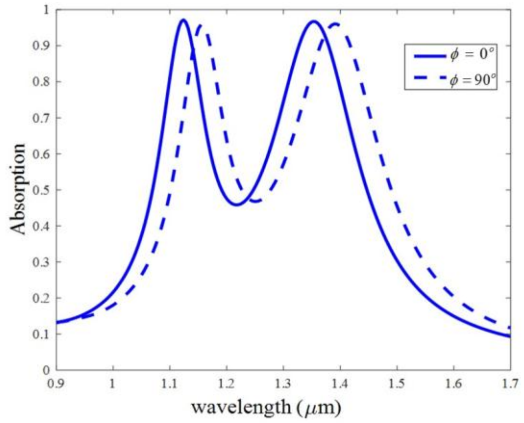
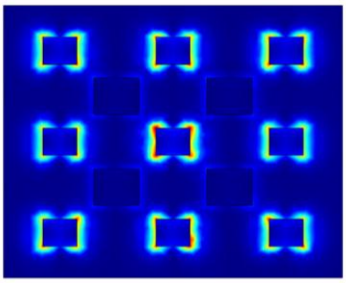
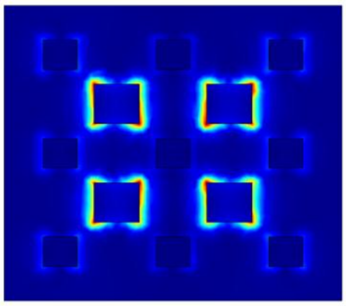


Fig. 2. The absorption spectra of the plasmonic absorber of Fig. 1 for $\phi = 0^o$ and $\phi = 90^o$.



(a)



(b)

Fig. 3. The electric field amplitude distributions at the resonance wavelengths of (a) λ_1=1.124 μm and (b) λ_2=1.35 μm for $\phi = 0^o$.

It is possible to have three narrow band absorption peaks by three different sizes of gold squares. Therefore, a structure with three gold squares is proposed with the same thickness of gold squares (h=30 nm) and a=120 nm, b=140 nm and c=160 nm. The distance between adjacent gold squares is denoted by p=610 nm. The scheme of the absorber is depicted in Fig. 4.

The absorption spectra of the structure with three gold squares are shown in Fig. 5.

As it is clear, there are three absorption peaks at λ_1=1.005 μm, λ_2=1.064 μm and λ_3=1.125 μm wavelengths when $\phi = 0^o$.

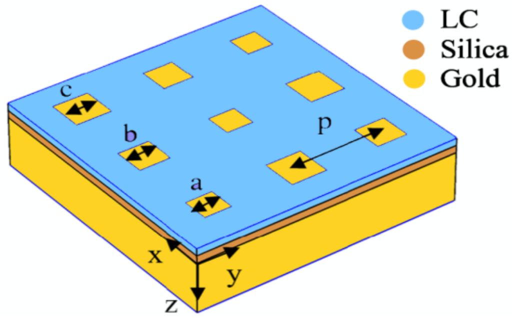


Fig. 4. The schematic view of the proposed structure when 3 different square sizes are utilized in the structure.

Also, the absorption peaks are $\lambda_1^{'}=1.035\ \mu$m, $\lambda_2^{'}=1.09\ \mu$m and $\lambda_3^{'}=1.155\ \mu$m as $\phi=90^o$. The structures have a tunability of about 30 nm which is caused by LC.

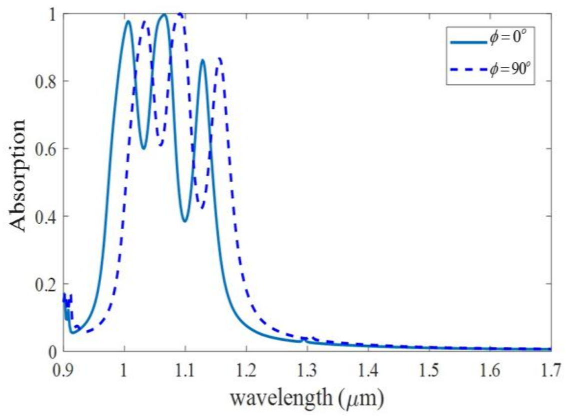


Fig. 5. The absorption spectra of the plasmonic absorber of Fig. 4 for $\phi=0^o$ and 90^o.

As an example, the corresponding LSPRs of the gold squares at λ_1=1.005 μm when $\phi=0^o$ is illustrated in Fig. 6. It is obvious that the smaller squares resonate at shorter wavelength.

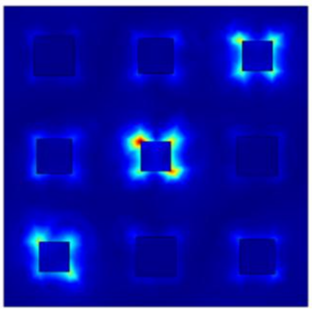


Fig. 6. The electric field amplitude distribution at the resonance wavelength of λ_1=1.005 μm for $\phi=0^o$.

4 Conclusion

In this paper, two narrow band tunable plasmonic absorbers are proposed. The absorbers are proposed by two and three different sizes of gold squares. The absorption of the structures is due to the plasmon resonances of the gold squares dispersed in the LC. In this case, there are two and three absorption peaks while they are tunable due to the tunability of the LC by applied voltage. The absorption spectra for the structure with two and three gold squares are above 95% and 85%, respectively.

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