The 28th Iranian Conference on Optics and Photonics (ICOP 2022), and the 14th Iranian Conference on Photonics Engineering and Technology (ICPET 2022). Shahid Chamran University, Khuzestan, Iran.
Feb. 1-3, 2022

حسگر مبتنی بر جاذب کامل پلاسمونی با کمترین وابستگی طیفی به قطبش و زاویه پرتو تابش

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چکیده- در این مقاله، یک جاذب کامل پلاسمونی با نانوساختار پایه فلز- عایق- فلز مبتنی بر آرایه تناوبی روزنه ای ارائه شده است. طیف جذب ساختار با استفاده از روش عددی تفاضل محدود - حوزه زمان سه بعدی برای تابش عمود پرتو نور موج صفحه‌ای در محدوده‌ی طول موج ۸۵۰ تا ۱۳۰۰ نانومتر محاسبه گردیده است. طبق نتایج به دست آمده، جاذب پیشنهادی نسبت به قطبش نور در تابش عمود حساس نبوده و در هر دو حالت قطبیدگی الکتریکی عرضی (TE) و مغناطیسی عرضی (TM) طیف جذب یکسانی را با دو پیک تشدید (یکی با جذب ۹۰ درصدی و دیگری با جذب تقریبا کامل) در محدوده‌ی طول موجی مذکور ارائه می دهد. همچنین بر اساس شبیه سازی‌های انجام شده، طیف جذب با انحراف از تابش عمود (تغییر زاویه تابش از ۰ تا۲۰ درجه) تقریبا بدون تغییر خواهد بود. پس از اتمام مدلسازی جاذب، به منظور سنجش قابلیت افزاره بعنوان حسگر ضریب شکست، روزنه‌های تناوبی ساختار به وسیله مایعات آنالیت با ضرایب شکست مختلف پر شدند. با افزایش ضریب شکست آنالیت، هر دو پیک تشدید به طول موج های بالاتر جابه جا گردید، که حساسیت ($\Delta\lambda/\Delta n$) پیک‌ها به ترتیب 103.82 nm/RIU و 189.58 nm/RIU محاسبه شده است.

کلید واژه- جاذب کامل پلاسمونی، غیرحساس به قطبش و زاویه تابش، نانوساختار فلز- عایق- فلز.

A plasmonic perfect absorber-based sensor independent of polarization and incident angle

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Abstract- In this paper, a plasmonic perfect absorber based on metal-insulator-metal nanostructure with a periodic array of specific apertures in its upper metal layer is proposed. The absorption spectrum of the structure is calculated using the three-dimensional finite difference time domain (3D FDTD) numerical method for the vertical incidence of the plane wave beam in the range of 850 nm to 1300 nm. According to the results, the proposed absorber is not sensitive to the polarization of light in vertical radiation, and in both transverse electric (TE) and transverse magnetic (TM) modes, it offers the same absorption spectrum, in which the two resonance peaks with high absorptions are observed. Simulation data have also shown that the absorption spectrum will remain almost constant with a deviation of the radiation angle from 0 to 20 °. The capability of the device as a sensor of the refractive index of analyte solutions has also been measured. Thus by pouring analytes into the apertures of the structure and increasing their refractive index, the displacement of both resonance peaks to higher wavelengths has been observed. The sensitivities of these two resonance peaks ($\Delta\lambda$ / Δn) are obtained 103.82 nm /RIU and 189.58 nm/RIU, respectively.

Keywords: Plasmonic Perfect Absorber, Insensitive to incident angle, Insensitive to polarization, Metal-Insulator-Metal Nanostructure.

1. Introduction

In recent years, plasmonic perfect absorbers based on metal-insulation-metal nanostructures have attracted a lot of attention due to the simplicity of the design and construction processes, and the light confining ability below the diffraction limit using sub-wavelength metal arrays [1]. In these devices, the upper metal layer usually consists of a periodic nano-particles or nano-apertures array, which is separated by a layer of insulator from a continuous flat metal layer at the bottom of the structure [2]. The thickness bottom metal layer will be considered as higher than the penetration depth of incident wavelengths and, it acts as a perfect mirror [3,4]. The perfect light absorption in specific frequency bands is provided by excitation of the localized surface plasmon resonances (LSPRs) at the interface of the upper metal layer and the insulator layer [5]. Currently, plasmonic perfect absorbers based on tiny windows in the upper metal layer due to good contact between the analyte fluids and the absorber surface are mostly used in sensor applications [6]. In this paper, a nanoscale Au-MgF_2-Au structure based on a periodic aperture array is proposed as a perfect absorber whose absorption spectrum in vertical radiation is independent of polarization, and with the deviation of the vertical radiation with a tolerance of 20 degrees, it still achieves full absorption and an almost constant spectrum. For the sensing process, analyte fluids are poured into the apertures of structure. In the following, in sections 2,3, and 4, the absorber structure design, the simulation results, and the research conclusion are presented, respectively.

2. Absorber Structure Design

The unit cell of the proposed perfect absorber structure is shown in Fig. 1. In this design, a layer of gold with a thickness greater than the penetration depth of the incident wavelength range is placed as the full reflector at the lowest level of the structure and is separated from the other gold layer with a periodic array of apertures on top of the structure by a magnesium fluoride (MgF_2) insulation spacer layer. The thickness of these three layers from bottom to top is t_1=150 nm, t_2=30 nm, and t_3=30 nm, respectively. The periodicity of the unit cell is also considered in the direction of x and y Px=Py=550 nm.

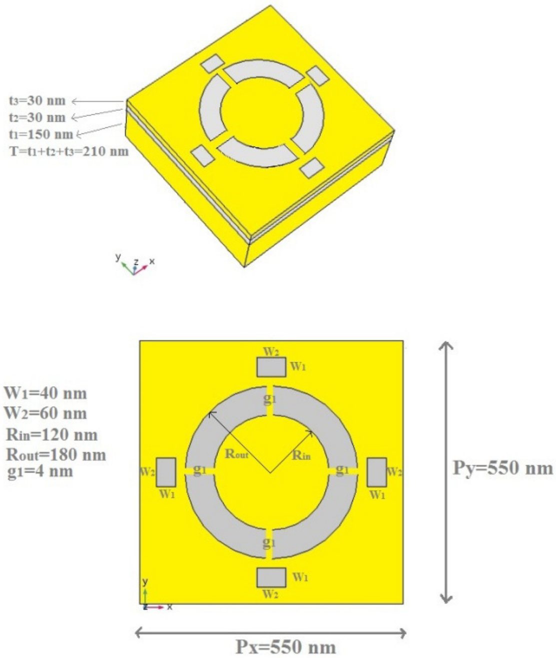

Fig. 1: The unit cell of absorber structure:

(a) The 3D view, (b) The 2D top view.

In the upper gold layer of the structure, a ring-shaped groove is drilled to a depth of t_3=30 nm with internal and external radii of 120 and 180 nm, respectively, in which there are four gold-filled gaps with a distance of 4 nm in the x and y direction of this ring. There are also four rectangular holes with a length and width of W_2=60 and W_1=40 nm and a depth of t_3=30 nm on the sides of x and y and at a distance of 20 nm from the four gaps. The dielectric constant of gold in the incident spectral range is described by the Drude model [7]. The refractive index of the MgF_2 is defined from Ref [8]. If this absorber structure is to be used as a refractive index sensor, analyte liquids (such as water-soluble glucose) are poured into the grooves and holes of the upper gold layer. In the modelling process using the 3D Finite-Difference Time-Domain (FDTD) numerical method, the simulation environment is limited from the upward and downward directions in z to the boundary condition of the perfectly match layer (PML), and in the x and y directions are limited by the periodic boundary condition.

3. Simulation Results

In this step, a plane wave of light within 0.85-1.3 µm wavelength range is incited in z-direction and perpendicular to the structure. The Reflection (R) and Transmission (T) spectra of the absorber are obtained in the incident wavelength range and then the Absorption spectrum (A) is calculated from the relation A = 1-T-R. Note that the reflection spectrum is the reflected power intensity of the sensor structure, and the transmittance spectrum is completely suppressed by the bottom gold mirror (T=0)[3,4]. The absorption spectra of this absorber for polarization of the electric field of radiation in the x (TE) and y (TM) directions is shown in Figure 2 (a). As can be seen, the absorption spectrum of the proposed structure in the vertical incident is independent of polarization, and in both cases, two resonance peaks are observed at wavelengths of 953.771 nm and 1174.29 nm. In another step, to investigate the tolerance of the absorption spectrum relative to the incident angle, we increase the incident plane wave angle from 0 to 20 degrees with 4-degree steps, which the absorption spectrum obtained in Figure 2(b) is shown. According to the observations, the wavelengths of both resonance peaks are independent of the incident angle, and only the bandwidth of both resonances is slightly increased. It should be noted that, in both Figures 2(a) and 2(b), the refractive index inside the apertures of structure n=1.312 is considered.

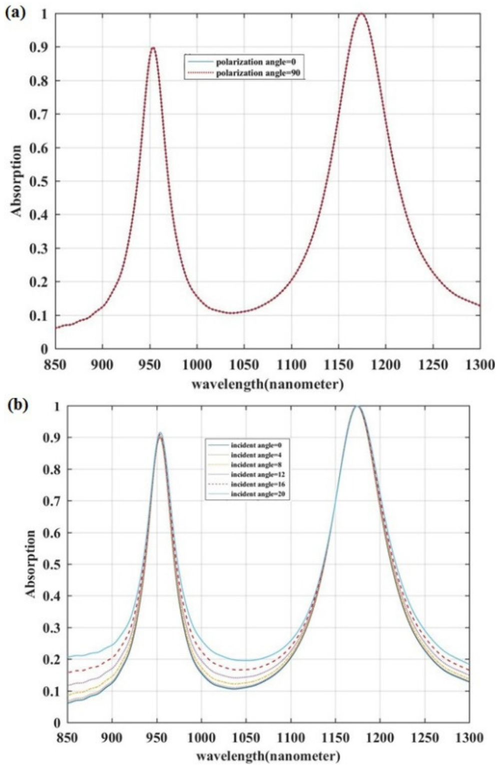

Fig. 2: The absorption spectra for;(a)TE and TM modes, (b) different incident angles (0,4,8,12,16,20°).

In order to evaluate the sensing capability of the proposed absorber, analytes with different refractive indices are poured one after the other into the apertures of the structure and the output absorption spectrum is measured for each of them. According to the results obtained in Figure 3, as the analyte refractive index increases, both resonance peaks shift to higher wavelengths. We can calculate the sensitivity of the sensor using relation $S=\Delta\lambda_p/\Delta n$. Where $\Delta\lambda_p$ is the resonance peak shift, and Δn is a refractive index unit (RIU) variations [3,4]. The sensitivity of the first and second resonance peaks were obtained 103.82 nm/RIU, and 189.58 nm/RIU, respectively.

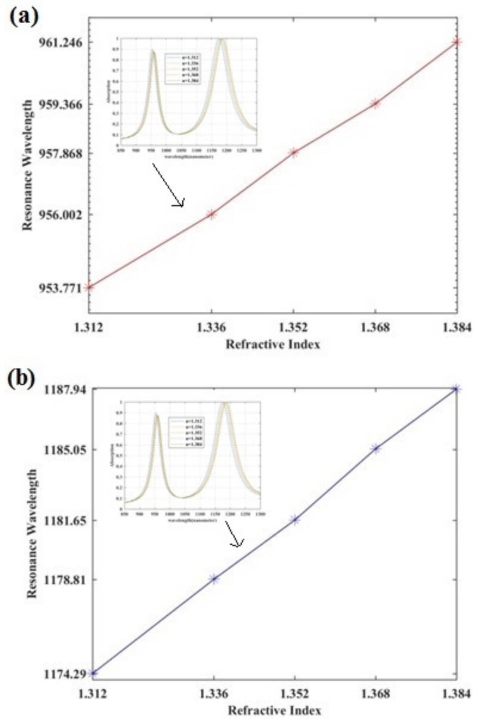

Fig. 3: The curve of the resonance wavelength versus refractive indices for (a)peak 1 , (b) peak 2.

4. Conclusion

In this paper, a plasmonic perfect absorber based on metal-insulator-metal nanostructure with a periodic array of specific apertures in its upper metal layer has been presented. The absorption spectrum of the structure has been calculated for the vertical incidence of the plane wave beam in the range of 850 nm to 1300 nm. According to the simulations, the proposed absorber is not sensitive to the polarization of light in vertical radiation, and in both TE and TM modes, the two resonance peaks with high absorptions (one 90% and the other complete absorption) have been observed. The absorption spectrum also has been remained almost constant with a deviation of the vertical radiation angle from 0 to 20 °.

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