A dual-narrow-band near-infrared perfect absorber based on a crossed double nanorods metasurface

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Abstract. Perfect absorbing materials have attracted the attention of researchers because of their wide application in solar photovoltaic industry, biosensor and filter. Here, we report on our numerical work concerning a planar metamaterial absorber, which composed of a crossed double nanorods on a dielectric layer with a gold substrate. Based on the resonance in the crossed nanorods and the similar-Bloch-wave resonance, the planar metamaterial structure can achieve multiple peaks with high absorption and narrow band. There are two nearly perfect absorption peaks obtained at 905 nm and 1161 nm, of which absorptivity and the bandwidth are 99.97%, 99.99% and 18 nm, 19 nm respectively. This peculiar feature may envisage the possible application of the structure in solar photovoltaic industry, biosensor, optical switch and filter.

1. Introduction
Metamaterial absorber is a new type of artificial electromagnetic material, which is widely used in solar photovoltaic industry [1, 2], biosensor [3, 4] and filter [5]. In recent years, more and more attention has been paid to the study of perfect absorbing materials. Multichannel absorption is an important aspect of metamaterial absorber. The first double-channel absorber is designed by Landy et al., they used a double-resonant rings to generate two resonances with different frequencies [6]. Later Tao et al. [7] studied an absorber composed of dual band ELC resonator, and the absorptions of the peaks are 85% and 94% respectively. However, the above two structures can only absorb electromagnetic waves with fixed polarization, which will limit the development and application of metamaterial absorber. It is proved that the polarization sensitivity of metamaterial absorber can be effectively eliminated by the electromagnetic resonance ring with symmetrical structure [8]. In 2018, Lei Zhao et al. proposed a dual-band absorber is designed based on the symmetry-dielectric-dielectric-metal (SDDM) structure and the absorptivity above 99% and 96% respectively [9].

In this study, we propose a planar metamaterial absorber, which composed of a crossed double nanorods on a dielectric layer with a gold substrate. By using the multi-resonances in the crossed nanorods and the similar-Bloch-wave resonance, a high absorption of incident light can be achieve. Using finite-difference time-domain method (FDTD), the simulation is demonstrated that there are absorption peaks at 699nm, 905nm and 1161nm respectively. In particular, the absorption are close to perfect absorption, and the absorption rate can reach 99.97% and 99.99% with bandwidth are 18 nm,
19 nm respectively. The results may be applied peculiar feature may envisage the possible application of the structure in solar photovoltaic industry, biosensor, optical switch and filter.

2. Metamaterial Geometry and Numerical Model

Figure 1. Perspective views of a representative sample of the proposed metamaterial absorber

Here, we designed a dual-narrow-band near-infrared perfect absorber with metamaterial. Figure 1(a) shows the geometrical configuration of a representative sample of the proposed metamaterial absorber composed of two-dimensional germanium grating on a dielectric layer with a gold substrate, in which the period \( P = 850 \text{ nm} \), the nanorods width \( a = 40 \text{ nm} \), the nanorods length \( b = 655 \text{ nm} \), the gap between nanorods \( g = 300 \text{ nm} \), the refractive index of the dielectric layer \( N = 1.5 \), and the height of the nanorods structure is \( 90 \text{ nm} \), and the dielectric layer thickness is \( 185 \text{ nm} \).

In the numerical simulations, the method of finite-difference time-domain (FDTD) was used. The propagation direction of the incident light filed is along the \( z \) axis, perpendicular to the structure. The permittivity of metal is defined by using Drude dispersion. The periodic boundary conditions were applied in the \( x \)-direction, the perfect matching layer conditions were applied in the \( z \)-direction boundaries, and the structure is infinite in \( y \)-direction in the two-dimensional analysis.

3. Results and Discussion

Then, we studied the proposed metamaterial absorber composed of a crossed double nanorods on a dielectric layer with a gold substrate. The absorption spectrum of the proposed structure is shown in Figure 2(a). There are three absorption peaks at 699 nm, 905 nm and 1161 nm in the spectrum of 650 nm–1400 nm. In particular, the absorption at 905 nm and 1161 nm are close to perfect absorption, and the absorption rate can reach 99.97% and 99.99% respectively, which have higher absorptivity compared with the result of Lei Zhao et al. \(^9\). The absorption peak at 699 nm (Peak1) is caused by the higher-order mode in the crossed double nanorods, the electric field distribution is shown in Figure 2(b). It is obvious that the field intensity is mainly distributed in the center of vertical bars and corners of the four bars, the corner parts and the center parts of the vertical bars are antiphase which shows two zero nodes. The absorption peak at 905 nm (Peak2) is caused by the lower-order mode in the crossed double nanorods, the electric field distribution is shown in Figure 2(c). The field intensity is mainly localized in the vertical bars and the corners of all bars, however the phase signs of the corner parts and the center parts of the vertical bars are identical.

For the absorption peak at 1161 nm (Peak 3), it is mainly produced by the resonance of the similar-Bloch-wave resonance, the electric field distribution is shown in Figure 2(d). The field is not only localized in the crossed nanorods, but also in the surrounding medium. It is noted as the similar-Bloch-wave resonance which is formed by the back and forth propagation of the scattered velocity wave.
Figure 2. (a) The absorption spectrum of the proposed metamaterial absorber composed of well-shaped germanium structure on a dielectric layer with a gold substrate. The electric field (Ez) distribution of (b) $\lambda = 699\,nm$, (c) $\lambda = 905\,nm$, and (d) $\lambda = 1156\,nm$.

In metamaterial, the geometric parameters determine the position and properties of spectrum. Therefore, in this part, we studied the effects of the period and geometric parameters ($a$, $b$ and $g$) of the proposed structure of each resonance. Figure 3(a) shows the absorption spectra of the proposed metamaterial when changing the parameter $a$. It can be noted that the geometry parameter $a$ shows a little influence on the FWHM while the intensity of the metamaterial and the location of resonance have noticeable red shift with the increase of $a$. For the geometry parameter $b$, we can see in Figure 3(b) that all absorption spectra has a slight movement. It is worth noting that the intensity of the third peak decreases greatly when $b = 800\,nm$. In Figure 3(c), the absorption spectra of parameter $g$ vary from 240 to 280 are given. Obviously, the third peak has almost no change, which indicates that the change of $g$ has no effect on the similar-Bloch-wave resonance. Figure 3(d) shows the absorption spectrum of the proposed structure with period $p$ varying from 750 nm to 850 nm. Obviously, with the increase of the period $p$, the positions of Peak 2 and Peak 3 are red shifted, while the absorption rate is increased but the FWHM full width at half is almost unchanged. By using the sweep and optimization algorithm, we could find the proper geometric parameters to achieve ultra-narrow FWHM of the resonance, which is beneficial to get better performance absorber.
4. Conclusions
In summary, we propose a novel metamaterial absorber composed of two-dimensional grating on a dielectric layer with a gold substrate which is based on higher order resonance, lower order resonance, and similar-Bloch-wave. There are three absorption peaks formed at 698 nm, 905 nm, and 1161 nm. Especially, the absorption peaks at 905 nm and 1161 nm are closed to perfect absorption, and the absorption rate can reach 99.97% and 99.99% with bandwidth are 18 nm, 19 nm respectively. The results provide a potential application in the peculiar feature may envisage the possible application of the structure in solar photovoltaic industry, biosensor, optical switch and filter.

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