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Comparative research on characteristics of light absorbers of metal-dielectric and metal photonic crystal transmission grating

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ABSTRACT

Using nanofabricated Si_3N_4 nanohole array photonic crystal grating, an Au metal-dielectric resonance grating by spin-coating Au on the Si_3N_4 nanohole array photonic crystal grating is investigated. Optical properties and related characteristics of metal-dielectric grating light absorber and meal grating light absorber are compared and analyzed. We simulate transmittances corresponding to different grating periods of the metal-dielectric photonic crystal transmission grating in visible-infrared light region and display electric field distributions in the vicinity of nanoholes at different incident wavelengths by using finite-difference time-domain (FDTD) software with broadband light source 400 nm–1100 nm.The mechanism of absorption generation in the metal-dielectric and metal transmission grating is analyzed and discussed in this paper. The Au structure of metal photonic crystal transmission grating is also investigated for light absorber. The metal-dielectric photonic crystal transmission grating structure absorbs more than 90% of the incident light at absorption point wavelength.

1. Introduction

In 1902, R. W. Wood observed anomalous absorption in metal structure [1]. Then, related researches about light absorption in structured metal arise gradually in 1960s, 1970s and 1990s [2–4]. Recently, a multiplexed metal structure light absorber based on the two different size gold square in each unit cell has been proposed [5]. The principle of absorbers and filters in this paper is the excitation of surface Plasmon polaritons [8]. When light is incident to the interface of metal and dielectric, free electrons distributed on the metal surface will be excited and generate oscillation, which results to form surface Plasmas. Large photon energy are transformed to free electrons' oscillation energy due to electronic oscillation generated on the metal surface and the energy of reflectivity declines sharply, which results to strong absorption of incident light power. However, it is rare to propose the transmitted device as an absorber that can absorb optical frequency electromagnetic wave. In many applications, optical absorber has a good prospect that it can be applied in areas such as solar cell, sensor, optical filter, optical waveguide, THz imager and thermal radiation detection [9–14].

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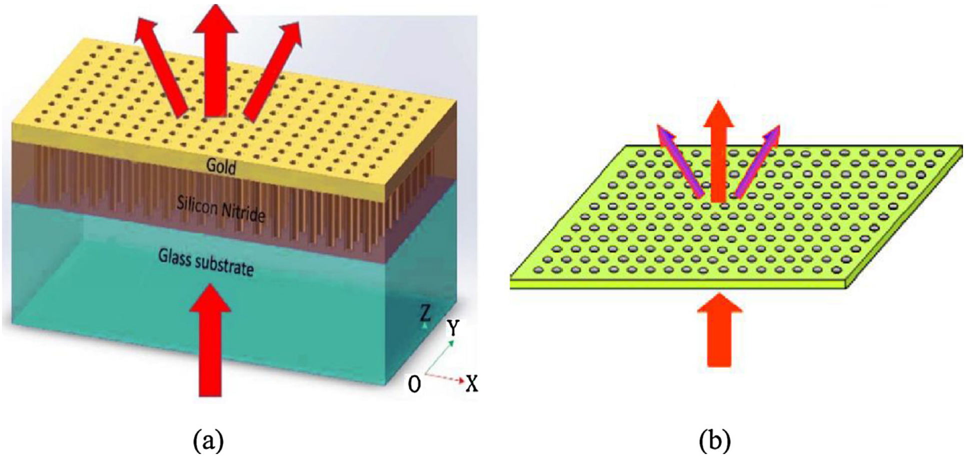

Fig. 1. (a) Light absorber structure of metal-dielectric photonic crystal transmission grating. (b) Light absorber structure of metal (Au) nanohole array transmission grating.

Compared with the traditional absorbers, the characteristic of this structure is transmission grating rather than reflective grating. In this letter, the relationship between wavelength and transmission of the two structures and each electronic field distribution is investigated respectively. Transmittance of this structure is approximately close to zero at a certain wavelength in the range of 600 nm–900 nm, which means light power can be absorbed completely when light is incident through the transmission grating at a certain wavelength. Electric field distribution is simulated to discuss the absorption generation. The intensity of electric field at absorption wavelength in transmission grating is much lower than other wavelength because there is no resonance existing so that much light is reflected and rare light is transmitted. The peak transmission is caused by surface Plasmon resonance. We compare and analyze optical characteristics of the light absorber of metal-dielectric photonic crystal transmission grating and the light absorber of Au nanohole array transmission grating under the incident light source in visible-infrared region.

2. Methods and calculation

The range of incident light wavelength is set as 400–1100 nm due to both of two photonic crystal grating investigation going under visible-infrared light region.

Fig. 1(a) shows the light absorber structure of metal-dielectric photonic crystal transmission grating. The device is made of a nanohole array grating etched through a gold film and a silicon nitride film deposited on a glass substrate. The diameter of the nanoholes is 240 nm. The thickness of silicon nitride is 250 nm and the thickness of gold film is 60 nm [5]. We choose nanohole grating to be convenient for observing obvious surface Plasmon resonance phenomenon by observing the intensity of electronic field. We take a series of examples of different periods of nanohole arrays such as 250 nm, 300 nm, 400 nm, 500 nm, 600 nm respectively, which is suitable for light diffraction. Columns of nanoholes are corresponding to grating lines that provide angular dispersion and diffraction for measuring the resonance spectra of the device.

Fig. 1(b) shows structure of metal (Au) nanohole array transmission grating. The gold film thickness, nanoholes' size, period of nanoholes arrangement and the change of period is the same as the structure of Fig. 1(a) for comparison convenience. Difference of 1(a) and 1(b) is whether silicon nitride layer exists or not. Both of these two fabrications can be accomplished by electron beam lithography.

We use finite-difference time domain (FDTD) software (Lumerical Solutions, Inc.) to simulate and calculate the two structures. Designed light absorber of metal-dielectric photonic crystal transmission grating and Au nanohole array transmission grating is both in the visible and near-infrared wave region. A Johnson-Christy material model based on measurement data is used for the electric permittivity of the gold film [6]. The optical constant of the magnesium fluoride is obtained from [7]. The condition boundary is set as periodic boundary conditions in the lateral direction. In the directions of propagation and transmission, the simulation domain is terminated with perfect matching layers. The incident light is normal incidence from the glass substrate into the device with a broadband light source 400 nm–1100 nm. Fig. 2 shows the calculated power transmittance of metal dielectric structure with different grating periods. Fig. 3 shows the transmittance in Au nanohole array transmission grating structure with periods of 250 nm, 300 nm, 400 nm, 500 nm, 600 nm.

In Fig. 2, it's clearly that the whole transmittance in the nanohole period of 500 nm or 600 nm is obviously lower than the transmittance in the period of 250 nm, 300 nm, 400 nm. There is a peak value and minimum value in every curve. It can be seen that the transmittance minimum value is found at the region of wavelength 600–800 nm. The total trend of transmission is lower. We calculate the minimum value of transmittance is 0.2855 at 602.02 nm, 0.0876 at 642.242 nm, 0.0085 at 804.04 nm, 0.0075 at 783.838 nm and 0.0017 at 682.828 nm corresponding to the grating periods of 250 nm, 300 nm, 400 nm, 500 nm and 600 nm respectively. These values of absorption points are very close to 0 which means rare of light pass through the