Broadband LWIR and MWIR absorbers by trapezoid multilayered grating and SiO_2 hybrid structures

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***Abstract*—A broadband metamaterial absorber with high absorption simultaneously in the MWIR and LWIR was proposed. In the MWIR, the absorption higher than 0.8 is from 3.26 μm to 4.7 μm, covering the full MWIR transparent window, while the absorption in the LWIR is from 8.46 and 9.9 μm. The broadband absorption in the MWIR results from the slow light effect and the broadband absorption in the LWIR is due to the phonon polariton resonant of trapezoid SiO_2 layer. In the broadband high absorption region, the atmosphere are transparent, which may greatly promote the practical application of absorbers in double-color IR imaging, detecting, infrared stealth and thermal emitting.**

Keywords—metamaterial; broadband absorber; slow-wave effect; phonon polariton resonant; transparent atmosphere window.

I. Introduction

Absorbers have been rapidly developed in a variety area of essential applications especially in infrared wavelength, such as thermal emitting, infrared imaging/stealth and detectors[1-3]. Thermal emitting/cooling can decrease the energy demand by passive radiation. Passive radiation relies on Kirchhoff's law, stating that a good absorber is also a good emitter. So infrared perfect absorbers can be used as passive cooling, which radiates heat through the infrared transparency window of the atmosphere into the cold sink of outer space. The infrared transparency window of atmosphere are from 3 to 5 μm (mid-wave infrared, MWIR), and from 8 to 12 μm (long-wave infrared, LWIR). IR metamaterial absorbers with this spectrally selective absorption bands also have been utilized as imaging and detectors, because the background noise can be significantly reduced. Infrared detectors play significant roles in military reconnaissance, environmental monitoring, fire safety control, night vision, etc. Therefore broadening the selective bands of absorbers to cover the two transparent window is important for these IR applications.

Research on metamaterial absorbers was designed for the first time by Landy et al in 2008[4], who obtained almost perfect narrowband absorption. But the resonant structure restricts the absorption to a narrow resonant wavelength. Hence, in the literature, to broaden the bandwidth of absorbers, a variety of approaches are proposed through integrate several resonators per unit cell horizontally or vertically. However, broaden the absorption band to cover LWIR and MWIR are rare.

In this work, we design a broadband metamaterial absorber with high absorption in the selected wavelength where the atmosphere are transparent. The absorber is composed of trapezoid multilayered grating and trapezoid SiO_2 hybrid structures, lying either hand of the unit cell. The trapezoid multilayered grating consists of flat metal Au and dielectric plate InP. Light of MWIR are trapped by the trapezoid multilayered grating due to slow wave effect, while light of LMIR are trapped by the trapezoid SiO_2 due to phonon polariton resonant. This metamaterial absorbers would find applications in double-color IR imaging, detecting and passive radiative cooling.

II. Numerical investigation

Fig.1 (a) presents the schematic diagram's cross section of a unit cell of the metamaterial absorber, hybrid by trapezoid multilayered grating and trapezoid SiO_2 on each side of the unit cell. A gold film with a thickness (t = 100nm) larger than skin depth is added under the unit cell to block all transmission. The trapezoid multilayered grating consists of flat metal Au and dielectric plate InP, displaying as yellow region and blue region in Fig.1 (a) respectively. The thickness of InP is denoted as l_1, and the thickness of Au is denoted as l_2. The etch width of trapezoid multilayered grating is denoted as G, and the etch width of trapezoid SiO_2 is denoted as P. The number of the layers is denoted as n. The width of the trapezoid multilayered grating is denoted by w and the lattice constant is assumed to be a. So width of the trapezoid SiO_2 is a-w. A plane wave light source is used for illumination with its propagation direction and polarization along the negative y-axis and x-axis, respectively.

The spectral characteristics of the metamaterials absorbers are calculated by performing electromagnetic wave finite difference time domain method (FDTD, available from Lumerical software package [5]). The permittivity of Au is extracted from Palik's work in 1991 [6] and simulated by Drude mode. The permittivity of InP is also extracted from Palik's work [6]. The refractive index can be set as 3.05 for simplicity, which doesn't influence the results. The permittivity of SiO_2 is extracted from Palik's work too [6], and simulated by Lorentz mode. All materials are assumed to be nonmagnetic (i.e., $\mu = \mu_0$). The absorption spectrum (A) of the device is retrieved from scattering parameters as follows: A =1-T-R, where A, R and T denotes the absorption, reflection and transmission, respectively. In this work, the optically thick (100 nm) bottom gold film prevents the light transmission (T = 0) and therefore the absorbance is A =1-R.

As depicted in Fig. 1(b), there are two absorption band with the maximum absorption over 99% in the MWIR and LMIR, where the atmosphere are transparent. The optimal performance of the absorber occurs at the parameters as

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follows: l_1=55 nm, l_2=25 nm, n = 16, a =1.6 µm, w =0.6 µm, G =0.1 µm, and P =0.2 µm. The first absorption band is in the MWIR, with the absorption higher than 0.5 in the region between 3.17 and 5.13 µm. In the region the absorption increases fast to one, so the absorption are higher than 0.8 between 3.26 µm and 4.7 µm. The second absorption band is in the LWIR with the absorption higher than 0.5 in the region between 8.46 and 9.9 µm, and increasing fast in the region. However the bandwidth can be optimized to cover the full LWIR.

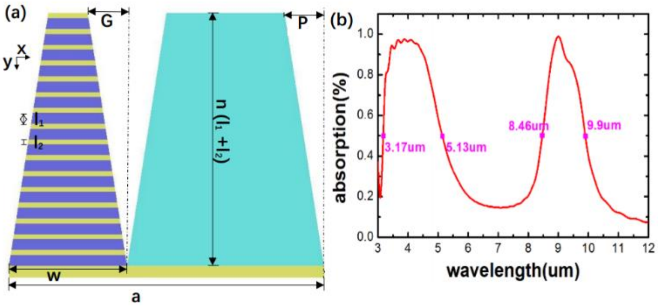

Fig.1. (a) The cross section of a unit cell of the metamaterial absorber. The yellow region is gold, the blue region is InP, and the green region is SiO_2. The thickness of InP is denoted as l_1, and the thickness of Au is denoted as l_2. The etch width of trapezoid multilayered grating is denoted as G, and the etch width of trapezoid SiO_2 is denoted as P. The number of the layers is denoted as n. The width of the trapezoid multilayered grating is denoted by w and the lattice constant is assumed to be a. So width of the trapezoid SiO_2 is a-w, and hight of the SiO_2 is $n*(l_1+l_2)$. A plane wave light source is used for illumination with its propagation direction and polarization along the negative y-axis and x-axis, respectively. (b) The absorption spectrum of the metamaterial absorber with the parameters setting as follows: l_1=55 nm, l_2=25 nm, n = 16, a =1.6 µm, w =0.6 µm, G =0.1 µm, and P =0.2 µm.

To better understand the underlying mechanism of the two broadband absorption, the electric and magnetic fields were extracted from the simulated wavelength at 3.75 µm, 4.25 µm, 4.75 µm in the MWIR and 8.75 µm in the LWIR. Fig. 2 shows the distribution on the x-y plane of the metamaterial absorber. Figures 2(a) and 2(b) are the electric and magnetic intensity distribution, respectively, extracted from wavelength 3.75 µm, focusing on the top of the trapezoid multilayered grating.

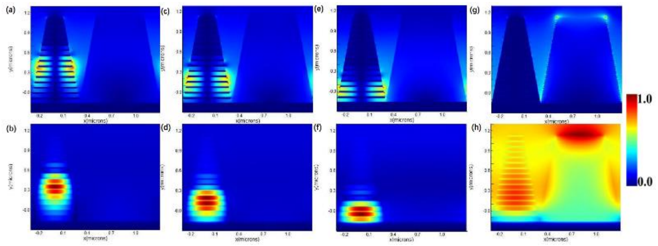

Fig.2. The electric and magnetic field intensity distribution at four wavelength on the x-y plane of the absorber. (a) and (b) are the electricand magnetic intensity distribution extracted from wavelength 3.75 µm, respectively. (c) and (d) are the electric and magnetic intensity distribution extracted from wavelength 4.25 µm respectively. (e) and (f) are extracted from wavelength 4.75 µm, while (g) and (h) are extracted from wavelength 8.75 µm.

Figures 2(c) and 2(d) are the electric and magnetic intensity distribution, respectively, extracted from wavelength 4.25 µm, focusing on the middle of the trapezoid multilayered grating. Figures 2(e) and 2(f) are the electric and magnetic intensity distribution, respectively, extracted from wavelength 4.75 µm, focusing on the bottom of the trapezoid multilayered grating. In the MWIR high absorption region, the electric and magnetic intensity resonant positions go deep into trapezoid multilayered grating of the absorber, as the incident light wavelength increases. This phenomenon can be explained as slowlight effect in anisotropic metamaterial waveguide[7]. Figures 2(g) and 2(h) are the electric and magnetic intensity distribution, respectively, extracted from wavelength 8.75 µm in the LWIR, focusing on the region of the trapezoid SiO_2 layer. The absorption in the LWIR will disappear, if we get rid of the trapezoid SiO_2 layer. So the absorption in the LWIR is due to the trapezoid SiO_2 layer, which results from resonant of phonon polariton[8].

III. Conclusion

In summary, we proposed a broadband metamaterial absorber with high absorption simultaneously in the MWIR and LWIR where the atmosphere are transparent. The absorption band in the MWIR with the absorption higher than 0.5 is from 3.17 to 5.13 µm, and higher than 0.8 is from 3.26 µm to 4.7 µm, covering the full MWIR transparent window. The absorption band in the LWIR with the absorption higher than 0.5 is from 8.46 and 9.9 µm. The broadband high absorption in MWIR is due to slow wave effect of the trapezoid multilayered grating, while the broadband high absorption in LWIR is due to the phonon polariton resonant in the trapezoid SiO_2 layer. This wok may greatly promote the practical application of absorbers in double-color IR imaging, detecting, infrared stealth and passive radiative cooling.

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