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A broadband polarization-independent perfect absorber with tapered cylinder structures

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A B S T R A C T

A broadband, polarization-independent, and wide angle metamaterial absorber (MA) with tapered cylinder structures is investigated with finite difference time domain simulations. The titanium nitride (TiN) and indium tin oxide (ITO) thin film are introduced as the tapered cylinder structures. The unit cell structure is mainly composed of two pairs of TiN/ITO layers and one TiN base layer. The absorption is higher than 99% between the wavelength 700 nm and 1000 nm. The broadband, polarization independent average absorption remains above 95% between 400 nm and 1200 nm with a wide range of incident angles from 0° to 40°. The electrical field intensity distributions are studied to disclose the broadband absorption mechanism. This designed broadband absorber appears to be very promising applications in the plasmonic sensing and photovoltaic devices.

1. Introduction

Metamaterials are a kind of artificially structured material with extraordinary electromagnetic properties invisible in nature. Metamaterial absorption is one of the interesting properties in artificially engineered metamaterials [1–5]. Metamaterial absorbers based on the structure of metal-dielectric-metal thin film were widely applied for the perfect absorber design [6,7]. Plasmonic absorption Au, Ag, also called localized surface plasmonic resonance, has been extensively investigated [8–11]. Aydin et al. demonstrated that the absorber yields broadband and polarization-independent resonant light absorption over the entire visible spectrum (400–700 nm) with an average measured absorption of 0.71 and simulated absorption of 0.85 with a nanostructured top silver film composed of crossed trapezoidal arrays [10]. Hyungduk Ko proposed a broadband visible light absorber composed of multiple metal-dielectric-metal layers, and an average simulated absorption of 93% was obtained over the entire visible spectrum of 400–700 nm by controlling the geometric parameters [11]. Nielsen et al. [12] demonstrated a periodic array of differently-sized and circularly-shaped gap plasmonic resonators in the entire visible wavelength range. Song et al. [13] proposed a harvesting system by combining a broadband absorber with a perfect selective emitter in the opposite surface separated by a tungsten cylinder contained in a silica substrate. The inorganic ceramic materials, such as semiconductor-based oxides and transition-metal nitrides are proposed as the alternative plasmonic materials [14–16]. These semiconductor oxides have low loss in the near-IR range, and metal-nitrides provide alternatives to gold and silver in the visible frequencies. A broadband metamaterial absorber with square ring structure had been reported by Li et al. [17]. A perfect absorber with TiN nano-disk array was theoretically proposed by Wang et al. [18]. The absorber shows a average absorbance larger than 95% from 400 nm to 1100 nm by numerical simulation. The transparent conducting oxides are greatly used for optoelectronic device applications and solar cells. The ITO material provides wide opportunities for realizing surface plasmon polariton excitations in IR wavelength window [19,20]. In this paper, A broadband, polarization-independent, and wide angle metamaterial absorber with tapered cylinder structures is investigated with finite difference time domain simulations.

2. Structure model and simulation

The unit cell schematic of the proposed broadband absorber is shown in Fig. 1. There are four tapered cylinder layers and one TiN base layer. The structure parameters are denoted as follows: p is the side length of square unit cell, r_1 is the radius of the top TiN tapered

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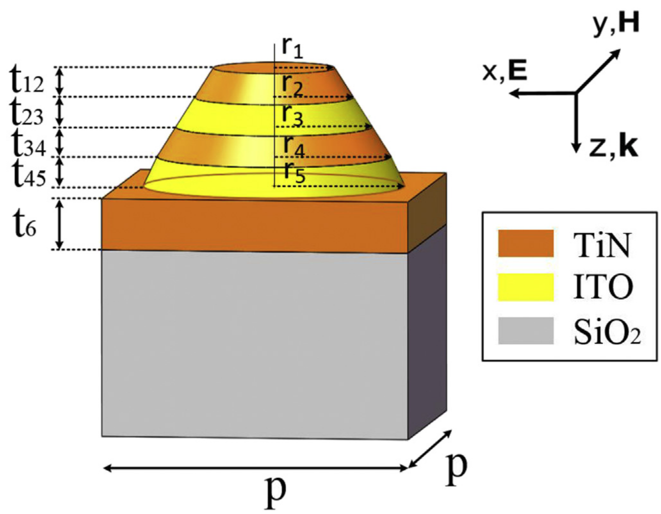

Fig. 1. Unit cell schematic of the proposed broadband absorber, the overall structure is a periodic array of the unit cell.

cylinder, r_2, r_4 are the bottom radiuses of the two TiN tapered cylinder, r_3, r_5 are the bottom radiuses of the two ITO tapered cylinder, t_{12} , t_{23}, t_{34} and t_{45} are the thickness of TiN and ITO tapered cylinder, t_6 is the thickness of the base TiN film. Quartz is employed as the device substrate, and its thickness is 200 μm.

The finite difference time domain method [21,22] is used for the plasmonic modelling. The dielectric functions and optical constants of TiN and ITO were obtained from Refs. [23] and [24], respectively. The plane wave is incident to the absorber along the z direction, and the z direction has a perfectly matched layer in this simulation. A s-polarization (electric field parallel to y-direction) and a p-polarization (magnetic field parallel to y-direction) plane waves incident from the air. The reflection (R) was detected with a power monitor located behind the radiation source of the plane waves, and the transmission (T) was detected with a power monitor located at −450 nm relative to the bottom of the base TiN layer. The gap between the light source and the base TiN layer is 1 μm, and the gap between the reflection monitor and the bottom of the base TiN layer is 1.1 μm. Bloch's periodic boundary conditions are applied to model periodic structures at the oblique incidence angle [25]. The absorbance spectrum A(λ) can be calculated from the corresponding reflection spectrum R(λ) reflectance and transmission spectrum T(λ), as $A(\lambda) = 1 - R(\lambda) - T(\lambda)$. In all of the simulations, a cubic mesh with a size of 2.5 nm was employed.

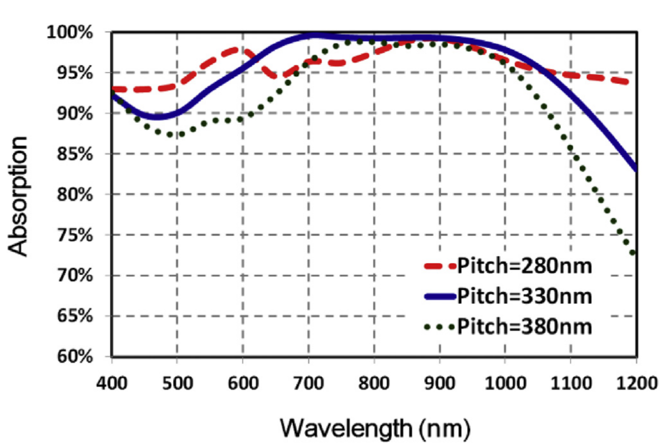

Fig. 2. Absorption spectrum of the broadband absorber for normal incident light with the pitch 280 nm, 330 nm and 380 nm.

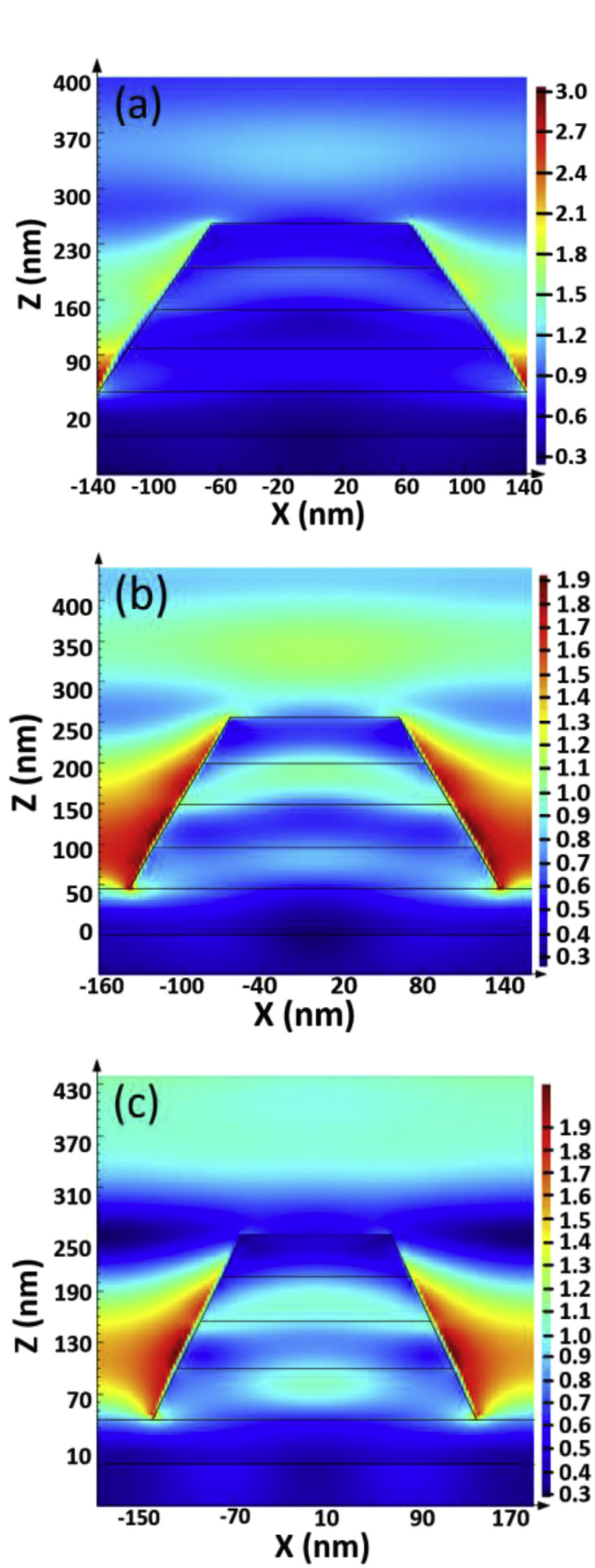

Fig. 3. Electrical intensity distribution the broadband absorber for normal incident light for the different unit cell pitch: (a) 280 nm, (b) 330 nm, (c) 380 nm.