Physica E 90 (2017) 1–6

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Broad-band polarization-independent metamaterial absorber for solar energy harvesting applications

Mehmet Bağmancı[a], Muharrem Karaaslan[a], Emin Ünal[a], Oguzhan Akgol[a], Faruk Karadağ[b], Cumali Sabah[c,d,*]

[a] Department of Electrical and Electronics Engineering, Iskenderun Technical University, Iskenderun, Hatay 31200, Turkey
[b] Department of Physics, Cukurova University, Adana, Turkey
[c] Department of Electrical and Electronics Engineering, Middle East Technical University - Northern Cyprus Campus (METU-NCC), Kalkanli, Guzelyurt 99738, TRNC/Mersin 10, Turkey
[d] Kalkanli Technology Valley (KALTEV), Middle East Technical University - Northern Cyprus Campus (METU-NCC), Kalkanli, Guzelyurt 99738, TRNC/Mersin 10, Turkey

ARTICLE INFO

Keywords:
Metamaterial
Broad band absorber
Solar energy
Energy harvesting

ABSTRACT

A novel broad-band polarization-independent with wide-angle metamaterial absorber(MA) is investigated and demonstrated for solar energy harvesting applications. The proposed MA is composed of two metal layers which have different thickness and a dielectric layer which is sandwiched between these metal layers. By this combination, the proposed MA indicates plasmonic resonance characteristic. Numeric results show that proposed MA has perfect absorption characteristic which is above 88.28% with wide-angle for all visible region. It shows almost perfect absorption of 98.4% at the resonance frequency of 621.76 THz and has also 90% absorption between frequencies of 445 THz and 770 THz which is nearly all visible light region. Besides, numerical results validate that the proposed MA could achieve very high absorption at wide-angles of incidence for both transverse electric (TE) and transverse magnetic (TM) waves.. The proposed MA and its variations enable for solar cell applications due to have upper ratio of 90% in the widest range of visible spectrum comparing to the studies in literature. In order to show additional features of the proposed structure, parametric studies are realized and discussed. Furthermore, the absorption characteristic of proposed MA is investigated for infrared and ultraviolet region. The enhancement of absorption of the structure will provide new type of sensors in these frequency ranges.

1. Introduction

There has been a growing interest in metamaterials (MTMs) which are artificially manufactured by placing small apertures and scatterers periodically providing extraordinary properties that cannot be found in the nature. Russian scientist Veselago first studied on the conditions to obtain negative refractive index and he proposed that having negative permittivity and negative permeability is possible simultaneously [1]. These new unusual materials were put in practice first by Pendry in 1999 [2]. These exciting and interesting properties opened new possibilities for various applications from medical to defence industry. Some of the common applications are super lenses [3,4], super resolutions, invisibility cloaking [5–7], negative refraction [8,9], polarization rotation, source imaging, energy harvesting [10], sensor technology [11], perfect absorption [12–15] and antennas just to name a few.

In the last few decades many perfect absorber studies based on MTM structure are carried out in microwave region and also in very high frequencies covering visible light and ultraviolet spectrum [15–24]. Apart from their perfect absorption values in particular frequency bands, most of them have narrowband which limits the application field of their studies. This drawback is overcome in our study.

In this study, we numerically designed and proposed a novel broad-band perfect metamaterial absorber (MA) with wide-angle for energy harvesting applications in visible frequency region. By a careful design and optimization, plasmonic resonance characteristics are obtained for the proposed structure. Geometrical dimensions and the dielectric constant in the structure are two main parameters affecting the resonant frequency. By tuning these parameters, the optical response of the model is adjusted. In order to obtain optical response of the model, parametric study is realized and discussed. The model has perfect absorption ability in a quite wideband which is above 90%

* Corresponding author.
E-mail address: sabah@metu.edu.tr (C. Sabah).

http://dx.doi.org/10.1016/j.physe.2017.03.001
Received 31 January 2017; Accepted 3 March 2017
Available online 04 March 2017

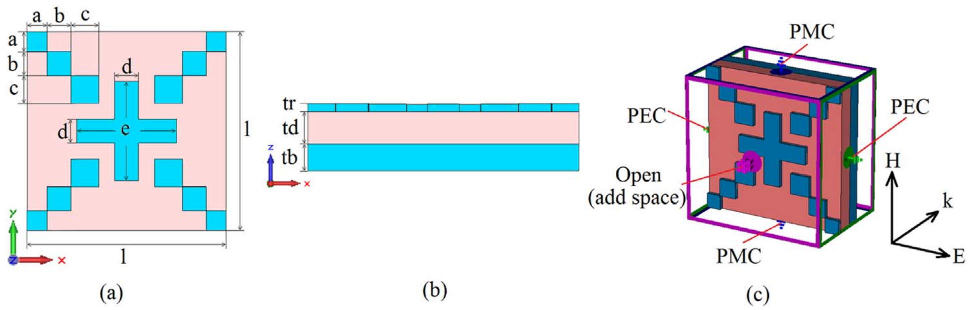

Fig. 1. Unit cell Geometry of proposed structure (a) front view (b) side view and (c) boundary condition. Dimensions of the proposed structure, a=50 nm, b=60 nm, c=70 nm, d=60 nm, e=250 nm, l=500 nm, tr=15 nm, td=60 nm and tb=50 nm.

between frequency of 445 THz and 770 THz. All visible frequency regions are covered and overall absorption is around 88.28%. The structure consists of metallic resonators, dielectric layer and a metallic background in order to prevent reflection so maximize the absorption level. To provide a better understanding the effects of the dimension parameters, parametric studies are realized and discussed. The surface current and electric field distributions in the absorbers are also analysed in order to show and verify the physical operation mechanism of the proposed structure. As a result, the proposed broad-band MA with high quality features will be a good candidate among its counterparts and can be used in solar energy harvesting applications.

2. Designing and numerical setup of the proposed broad-band MA

The proposed MA is consisting of two metal layer which are Ni(Nickel) spaced by SiO_2(silicon dioxide) layer as a dielectric which are demonstrated in Fig. 1(b). Geometry of unit-cell is demonstrated in Fig. 1. Background Ni layer thickness is significant for it serves as an optical mirror to zero transmittance. This thick of background Ni layer also couples with resonator-top Ni layer which is seen in Fig. 1(b)- to create electric and magnetic dipole, which drastically concentrated electromagnetic energy into the absorber. Geometry of the proposed resonator and thickness of the sandwich layers are chosen for both impedance matching and high absorptivity while the resonator is expected to provide polarization independent excitation of resonance [25]. Complex dielectric parameters of Ni and SiO_2 are taken from [26], and [27], correspondingly.

3. Brief theory about perfect metamaterial absorber design

Absorption response of MTM structure described by two basic parameters; its transmittance (T(ω)) and reflectance (R(ω)) which are frequency dependent quantities,

$$A(\omega) = 1 - R(\omega) - T(\omega)$$

Reflectance and transmittance rate on the other hand depend on the scattering parameters $R(\omega)=S_{11}^2$ and $T(\omega)=S_{12}^2$ which are given at bottom,

$$S_{11} = \frac{\sqrt{Reflectedpower}}{\sqrt{IncidentPower}} S_{12} = \frac{\sqrt{Transmittedpower}}{\sqrt{IncidentPower}}$$

In order to optimize the absorptivity of MTM structure, reflection and transmission coefficients must be minimized to obtain minimum feasible values. Commonly using technique for this process is to employ a combination of period arrangement of metal-dielectric layers and resonator on top of dielectric. So, through the geometric optimization of a MTM design, its impedance can be matched with free space which is 377 Ω at the resonance frequency where $Z(\omega)=Z_0$.This origins a striking decreasing in the total reflected radiation by the MTM structure's surface (reflection rate decrease to zero). Likewise, by arrangement the ground plane of MA to a metal with the thickness much larger than its skin depth at the operation frequency, the transmission rate completely exterminate (T(ω)≌0). The absorption response of structure takes this form,

$$A(\omega) = 1 - R(\omega)$$

This method is known as 'coupled system' [28], and it has also been used in this working with the ground plane being assigned to be nickel with thickness larger than the skin depth of the proposed MA in visible light region which is operation frequency, infrared and ultraviolet regions.

4. Numerical simulations and results

Numerical simulations are realized by finite integration technique based electromagnetic solver software to explore the absorption mechanism of proposed MA. Boundary conditions of proposed structure are chosen as electric boundaries for x- direction, magnetic boundaries for y- direction and open boundaries (add space) for z-direction. For numerical analyses electric and magnetic field components of incident wave are supposed to be polarized x- and y- direction, respectively and the direction of propagation is along the z- direction which are demonstrated in Fig. 1(c).

Reflectance and absorbance curve of the proposed structure for visible region are shown in Fig. 2(a). While other proposed structures

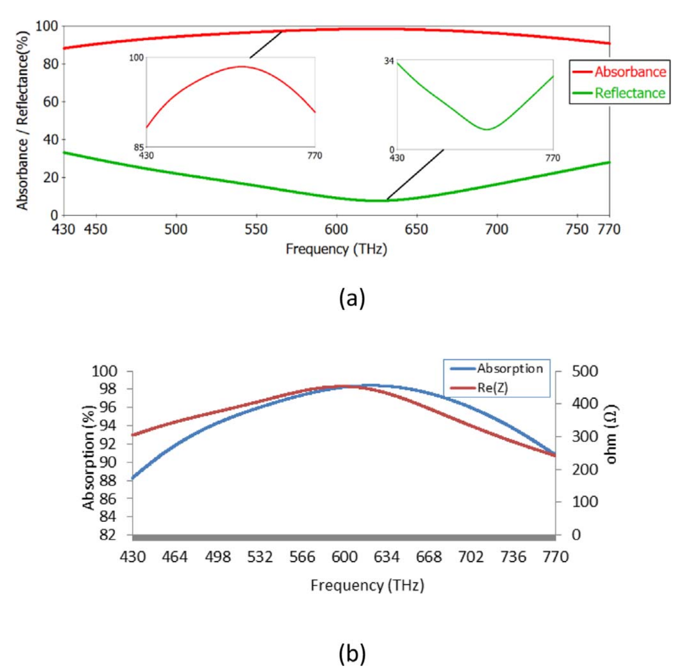

Fig. 2. (a) Simulated absorption and reflection characteristic of proposed MA at visible region and zoomed graph and (b) absorptivity and real impedance of proposed MA.