International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.9, No.9, (2016), pp.369-378
http://dx.doi.org/10.14257/ijsip.2016.9.9.34

Design, Simulation and Characteristics Analysis of Wideband Metamaterial Absorber Based on Titanium

Mohammad Belal Hossain[1*] and A B M Hasan Talukder[2]

[1,2]Department of Electrical and Electronic Engineering
University of Dhaka, Dhaka 1000, Bangladesh
[1]belal.hs96@gmail.com, [2]talukder@du.ac.bd

Abstract

Wide range absorption is specially needed for different microtechnological applications along with microbolometers, photodetectors and coherent thermal emitters. Here we report, design of a wideband metamaterial absorber based on Titanium (Ti) and the analysis of its absorption and reflection characteristics. The structure of the absorber consists of two titanium layers spaced by a dielectric layer of refractive index 2. The simulation is done for analyzing its characteristics using finite difference time domain method (FDTD). The results show that the absorption occurs above 90 percent in the range 750 nm to 1200 nm while the reflection occurs below 10 percent. Overall absorption over the range (400 nm to 1500 nm) is found to be almost above 80 percent.

Keywords: *Metamaterial, Negative Index, Dielectric, Power ratio, Absorber, Absorptivity, Reflectivity*

1. Introduction

Metamaterials are engineered composites. The properties of metamaterials are derived from their cellular architecture and chemical composition. Cellular size is smaller or equal to subwavelength. Metamaterials exhibit some exotic properties such as negative refraction, negative permeability and negative permittivity which are unlike conventional materials properties. Those exotic properties are used for many potential applications like perfect lens [1], superlens [2-3], invisibility device [4-5], patch antenna [6], biosensor [7,-8], phase compensator [9]. Metamaterials have been testified in every technological relevant spectrum. Metamaterials can be defined by complex macroscopic parameters electric permittivity and magnetic permeability.

Most of the work on metamaterials has been focused on the real part of complex quantity electric permittivity and magnetic permeability. But overlooked loss components of the imaginary part of complex quantity electric permittivity and magnetic permeability have huge potential for exotic applications [10]. For example, recently there have been different studies demonstrating metamaterials as absorber.

A bilayer unit cell has been used for maximum absorption through independent tuning of the electrical permittivity and magnetic permeability at 1.3 terahertz [11]. A dual band electric-field-coupled (ELC) resonator and a metallic ground plane separated by a dielectric spacer have been used for making a dual band terahertz metamaterial absorber [12]. Periodic arrangement of different scales of electric-field-coupled-LC (ELC) resonators and a metallic background plane, separated by 1 mm dielectric spacer has been designed for absorber [13]. By tuning the scale factor of the ELC unit cells multiple absorptions at different frequencies has been achieved [13]. Metal-dielectric-metal structure has been used for terahertz polarization insensitive dual band metamaterial absorber [14].

2. Method

Here, we present design and simulation of wide band metamaterial absorber based on titanium and analysis of its absorptivity and reflectivity characteristics.

Figure 1, illustrated single unit of wide band metamaterial absorber where two metal layer spaced by dielectric layer used as absorber.

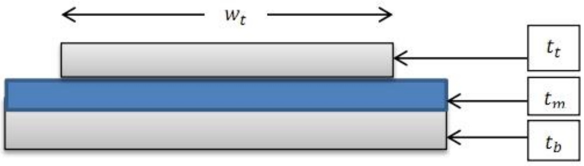

Figure 1. Single Unit Wideband Metamaterial Absorber

The top layer and bottom layer metal can be any metal like Gold, Copper, Silver, Aluminum, Beryllium, Palladium, Platinum, Chromium, Titanium, Tungsten *etc.*, The thickness of the top layer and bottom layer are in the nanometer range. The middle layer is a dielectric layer and the value of refractive index of this layer can be 1.5, 2, 2.5 *etc.*,

The designed wideband metamaterial absorber consists of two titanium layer spaced by a dielectric layer of refractive index 2. The width and thickness of the top titanium layer are denoted by w_t and t_t respectively. The thickness of the middle layer and bottom layer are denoted by t_m and t_b respectively.

In our simulation setup we have used electromagnetic wave source range from 400 nm to 1500 nm. Periodicity of the structure is 300 nm and width of the top titanium layer is 100 nm.

The simulation has been done using finite difference time domain method. We have total 5 different designs for different thickness of top and bottom titanium layer by fixing middle dielectric layer at 35 nm. Thickness of the top and bottom titanium layer for different design is given below:

Table 1. Thickness of the Top and Bottom Titanium Layer for Five Different Designs

Design No.	Top titanium layer thickness(nm)	Bottom titanium layer thickness(nm)
1	150	150
2	150	200
3	160	200
4	170	220
5	150	250

3. Results and Discussion

The spectral absorptivity curve for design 1 is shown in Figure 2.1. It has been observed from the curve that at wavelength 656.41 nm absorptivity is 90.3% and at wavelength 1256.84 nm absorptivity is 90.45%. For wavelength 656.41 nm to 1256.84 nm absorptivity has been found above 90%. Over the range absorptivity has been found almost above 80%.

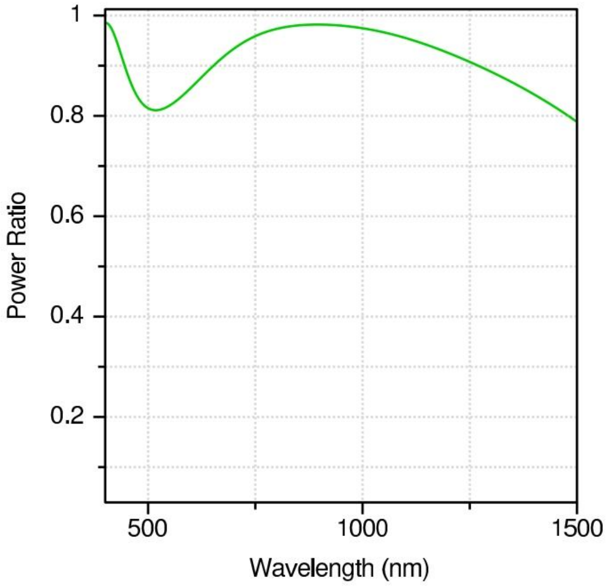

Figure 2.1. Spectral Absorptivity for Design 1

The spectral reflectivity curve for design 1 is shown in Figure 2.2. It has been observed from the curve that at wavelength 656.41 nm reflectivity is 9.69% and at wavelength 1256.84 nm reflectivity is 9.61%. For wavelength 656.41 nm to 1256.84 nm reflectivity has been found below 10%. Over the range reflectivity has been found almost below 20%.

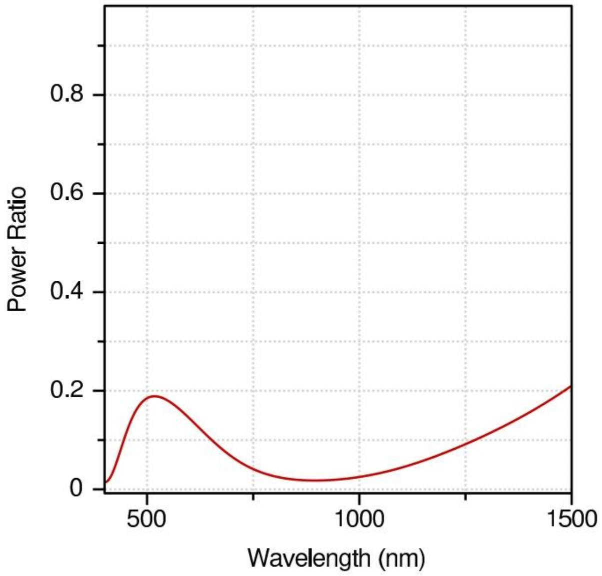

Figure 2.2. Spectral Reflectivity for Design 1

The spectral absorptivity curve for design 2 is shown in Figure 3.1. It has been observed from the curve that at wavelength 656.405 nm absorptivity is 90.3% and at wavelength 1256.84 nm absorptivity is 90.4%. For wavelength 656.405 nm to 1256.84

nm absorptivity has been found above 90%. Over the range absorptivity has been found almost above 80%.

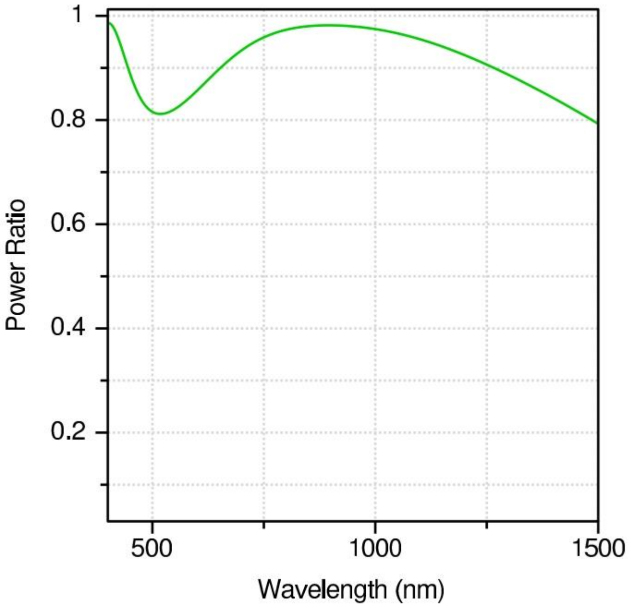

Figure 3.1. Spectral Absorptivity for Design 2

The spectral reflectivity curve for design 2 is shown in Figure 3.2. It has been observed from the curve that at wavelength 656.405 nm reflectivity is 9.69% and at wavelength 1256.84 nm reflectivity is 9.62%. For wavelength 656.405 nm to 1256.84 nm reflectivity has been found below 10%. Over the range reflectivity has been found almost below 20%.

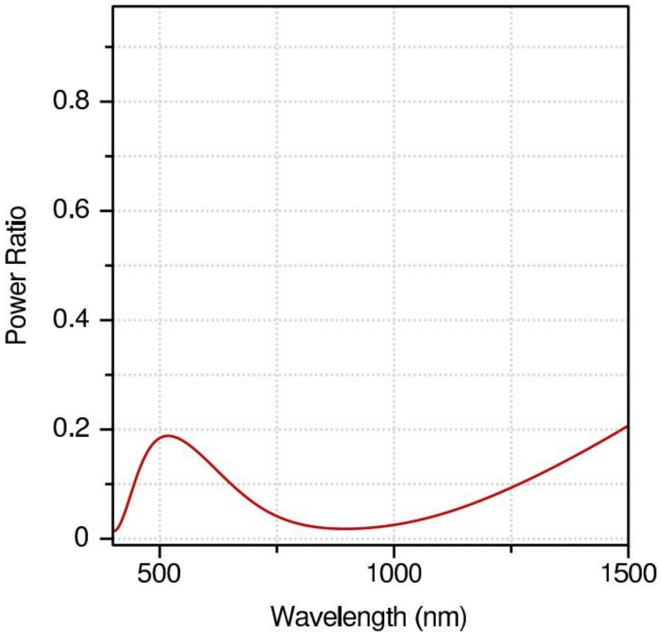

Figure 3.2. Spectral Reflectivity for Design 2

The spectral absorptivity curve for design 3 is shown in Figure 4.1. It has been observed from the curve that at wavelength 685.42 nm absorptivity is 90.6% and at wavelength 1271.57 nm absorptivity is 90.12%. For wavelength 685.42 nm to 1271.57 nm absorptivity has been found above 90%. Over the range absorptivity has been found above 80%.

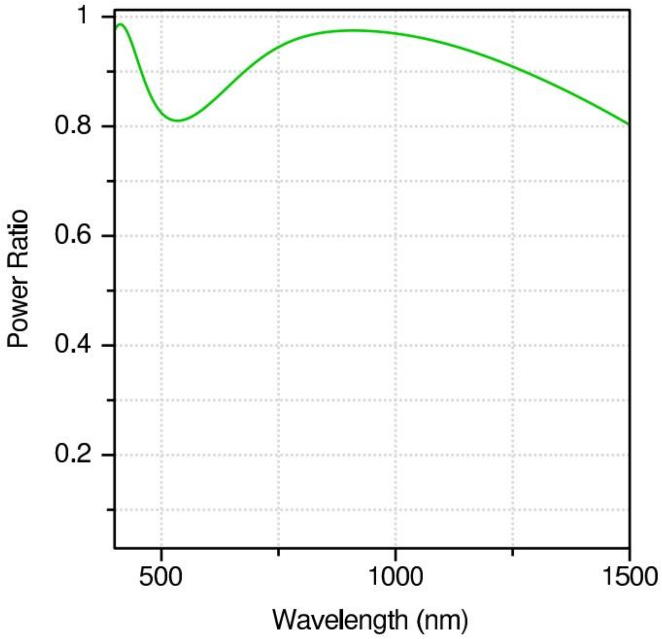

Figure 4.1. Spectral Absorptivity for Design 3

The spectral reflectivity curve for design 3 is shown in Figure 4.2. It has been observed from the curve that at wavelength 685.42 nm reflectivity is 9.06% and at wavelength 1271.57 nm reflectivity is 9.01%. For wavelength 685.42 nm to 1271.57 nm reflectivity has been found below 10%. Over the range reflectivity has been found below 20%.

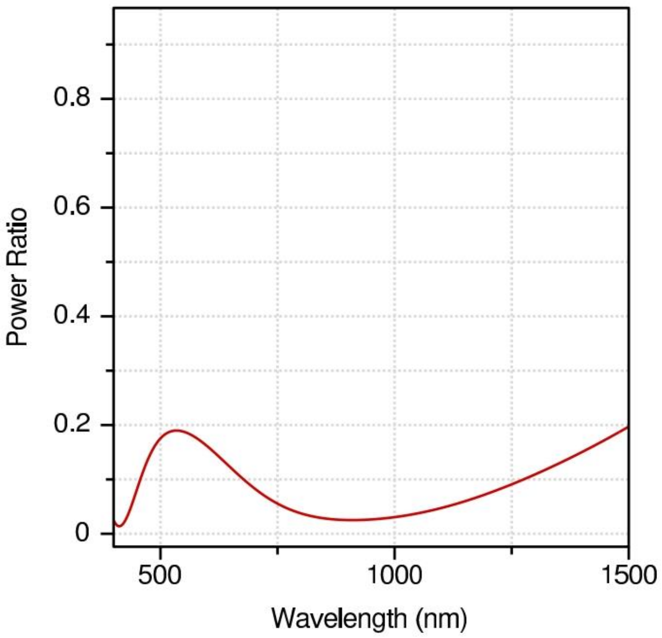

Figure 4.2. Spectral Reflectivity for Design 3

The spectral absorptivity curve for design 4 is shown in Figure 5.1. It has been observed from the curve that at wavelength 707.71 nm absorptivity is 90.4% and at wavelength 1271.57 nm absorptivity is 90.4%. For wavelength 707.71 nm to 1271.57 nm absorptivity has been found above 90%. Over the range absorptivity has been found above 80%.

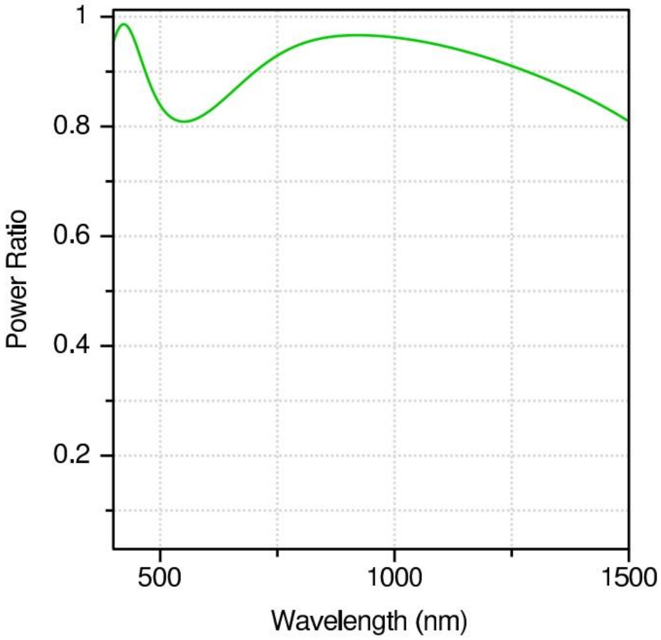

Figure 5.1. Spectral Absorptivity for Design 4

The spectral reflectivity curve for design 4 is shown in Figure 5.2. It has been observed from the curve that at wavelength 707.71 nm reflectivity is 9.62% and at wavelength 1271.57 nm reflectivity is 9.63%. For wavelength 707.71 nm to 1271.57 nm reflectivity has been found below 10%. Over the range reflectivity has been found below 20%.

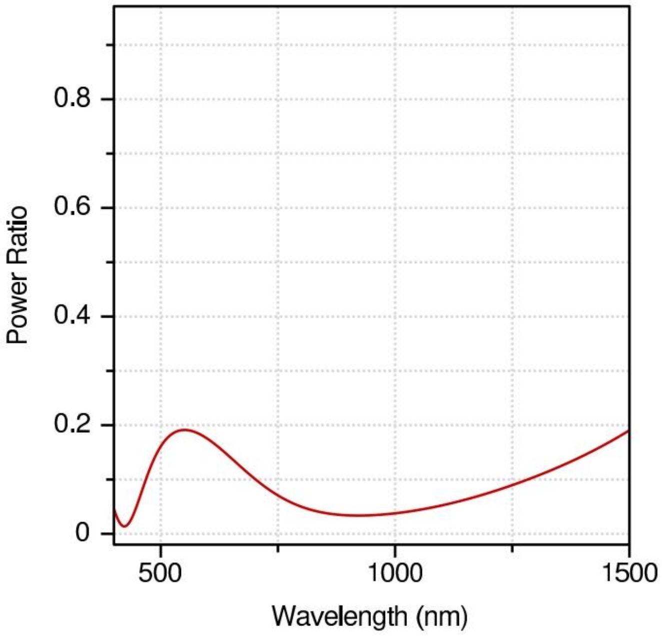

Figure 5.2. Spectral Reflectivity for Design 4

The spectral absorptivity curve for design 5 is shown in Figure 6.1. It has been observed from the curve that at wavelength 656.405 nm absorptivity is 90.3% and at wavelength 1242.46 nm absorptivity is 91.07%. For wavelength 656.405 nm to 1242.46 nm absorptivity has been found above 90%. Over the range absorptivity has been found almost above 80%.

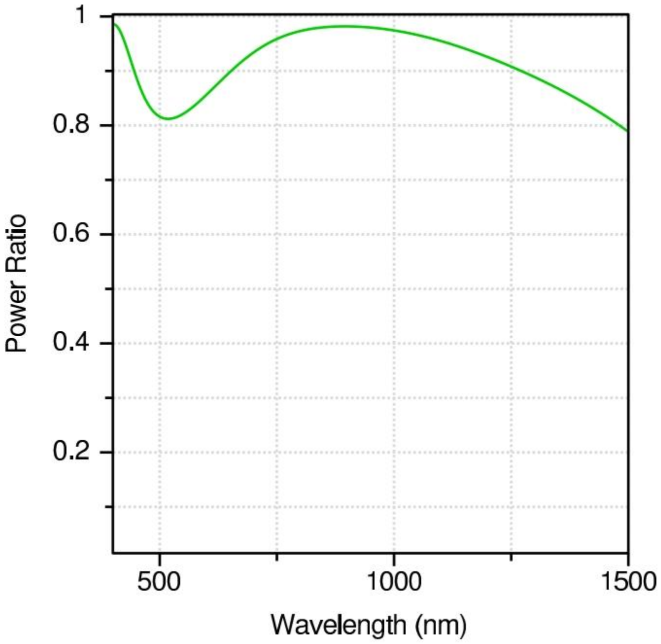

Figure 6.1. Spectral Absorptivity for Design 5

The spectral reflectivity curve for design 5 is shown in Figure 6.2. It has been observed from the curve that at wavelength 656.405 nm reflectivity is 9.68% and at wavelength 1242.46 nm reflectivity is 8.93%. For wavelength 656.405 nm to 1242.46 nm reflectivity has been found below 10%. Over the range reflectivity has been found almost below 20%.

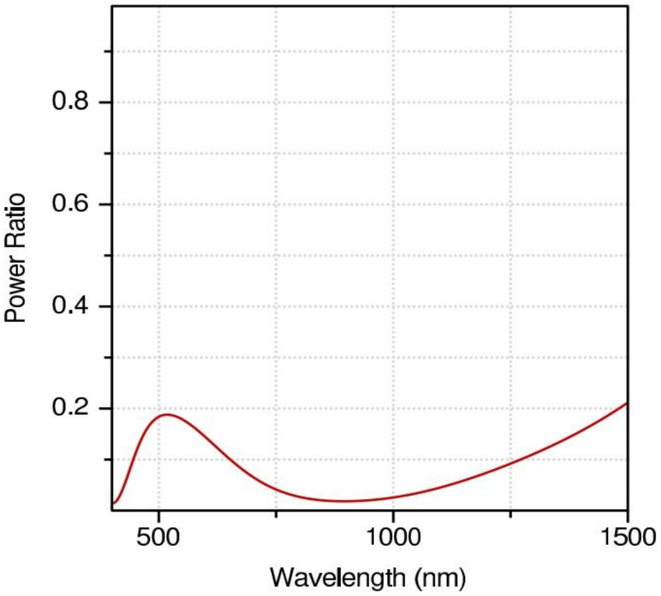

Figure 6.2. Spectral Reflectivity for Design 5

4. Conclusion

Absorption range is different for different design but it is found after analyzing above five designs that absorption above 90 percent occurs in the range 750 nm to 1200 nm and reflection below 10 percent occurs in the same range for each design. It is also found that for each design overall absorption above 80 percent occurs over the range (400 nm to 1200 nm) and reflection below 20 percent occurs in the same range. The designed wideband absorber can be used for various applications like microbolometers, photodetectors, coherent thermal emitters, microantena and solar cells.

References

[1] J. B. Pendry, "Negative Refraction Makes a Perfect Lens", Phys. Rev. Lett. vol. 85, no. 18, **(2000)**, pp. 3966-3969.
[2] X. Zhang and Z. Liu, "Superlenses to overcome the diffraction limit", Nature Materials, vol. 7, no. 6, (2008), pp. 435 - 441.
[3] Koray Aydin, Irfan Bulu1 and Ekmel Ozbay, "Subwavelength resolution with a negative-index metamaterial superlens", Appl. Phys. Lett. vol. 90, no. 25, **(2007)**, pp. 254102.
[4] U. Leonhardt, "Optical conformal mapping", Science, vol. 312, no. 5781, **(2006)**, pp. 1777-1780.
[5] J. B. Pendry, D. Schurig and D. R. Smith, "Controlling electromagnetic fields", Science, vol. 312, no. 5781, **(2006)**, pp. 1780-1782.
[6] F. Bilotti, A. Alu and L. Vegni, "Design of Miniaturized Metamaterial Patch Antennas with µ Negative Loading", IEEE Transactions on Antennas and Propagation, vol. 56, no. 6, **(2008)**, pp. 1640-1647.
[7] L. L. Spada, F. Bilotti and L. Vegni, "Metamaterial biosensor for cancer detection", IEEE Sensors", **(2011)**.
[8] A.V. Kabashin,P. Evans, S. Pastkovsky, W. Hendren, G. A.Wurtz, R. Atkinson, R. Pollard, V. A. Podolskiy and A. V. Zayats, "Plasmonic nanorod metamaterials for biosensing", Nature Materials, vol. 8, no. 11, **(2009)**, pp. 867 – 871.
[9] I. S. Nefedov and S.A. Tretyakov, "On potential applications of metamaterials for the design of broadband phase shifters", Microwave and Optical Technology Letters, vol. 45, no. 2, **(2005)**, pp. 98-102.
[10] N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith and W. J. Padilla,"Perfect Metamaterial Absorber", Phys. Rev. Lett. vol. 100, no. 20, **(2008)**, pp. 207402.
[11] H. Tao, N. I. Landy, C. M. Bingham, X. Zhang, R. D. Averitt and W.J. Padilla, "A metamaterial absorber for the terahertz regime:Design, fabrication and characterization", Optics Express, vol. 16, no. 10, **(2008)** , pp. 7181.
[12] H. Tao1, C. M. Bingham, D. Pilon, K. Fan, A. C. Strikwerda, D. Shrekenhamer, W. J. Padilla, Xin Zhang and R. D. Averitt, "A dual band terahertz metamaterial absorber", Journal of Physics D: Applied Physics, vol. 43, no. 22, **(2010)**, pp. 225102.
[13] H. Li, L. H. Yuan, B. Zhou, X. P. Shen, Q. Cheng and T. J. Cui, "Ultrathin multiband gigahertz metamaterial absorbers", J. Appl. Phys. vol. 110, no. 1, **(2011)**, pp. 014909.
[14] Y. Ma, Q. Chen, J. Grant, S. C. Saha, A. Khalid and D. R. S. Cumming, "A terahertz polarization insensitive dual band metamaterial absorber", Optics Letters, vol. 36, no. 6, **(2011)**. pp. 945.

Authors

Mohammed Belal Hossain completed his MSc (Specialization in applied physics and material science) & BSc degrees from the department of Electrical and Electronic Engineering (former name Department of Applied Physics, Electronics & Communication Engineering), University of Dhaka, Bangladesh. His research interest focuses on nanotechnology, semiconductor, material science and plasmonics.

A. B. M Hasan Talukder is working as a Lecturer in the Department of Electrical and Electronic Engineering at the University of Dhaka, Bangladesh. He completed his MSc & BSc from the same department which was formerly known as the Department of Applied Physics, Electronics & Communication Engineering. He is doing researches in the field of Nanotechnology and Photonics. Few of his works are published in different journals. He can be contacted through email: talukder@du.ac.bd.