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Metamaterial Fabry–Perot cavity implementation for gain and bandwidth enhancement of THz dipole antenna

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ABSTRACT

In this article, Metamaterial layer is implemented to improve radiation characteristic of dipole antenna at THz domain. Also, cavity back reflector is studied in order to gain enhancement and pattern shaping; in fact, combination of both structures is known as Fabry–Perot cavity. Return loss is modified at 486–654 GHz for less than −10 dB and also *Q* factor is calculated in presence of Metamaterial layer. The absorption and shield factors are simulated and showed at 0.55 THz. Antenna gain is increased more than 120% and bandwidth is amended around 82%. By achieved simulation result, −14.85 dB shield factor is obtained for proposed metamaterial layer. The dipole antenna contains silver line on silicon lossless material with $n = 2.43$ and the plasmonic layer is modeled by deposition of silver wire in silicon. In addition, Glass ($n = 1.65$) and SiN ($n = 1.87$) are used for metamaterial part and it is shown that increase in the permittivity leads to decrease the plasmonic permittivity; thus, more bandwidth of the structure is obtained. Also, effect of change in radius of the metamaterial micro wire on bandwidth of the antenna is considered.

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1. Introduction

Terahertz electromagnetic spectrum is defined for sub millimeter wave applications in the frequency range of 0.1–10 THz. It is an important topic with potential in bio medical sensing and bio imaging [1,2] or designing different devices such as beam splitter and resonators with metamaterial (MTM) such as screw ring structure [3,4]. Nowadays, by developing metamaterial technology, Plasmonic structures have been noticed in nanoscale for THz and optical applications [5]. One of the well-known techniques for sub-wavelength and high *Q* applications in THz and optical systems is Plasmonic. It is used for different applications such as waveguide, antenna, THz absorber and Fabry–Perot cavity [6]. Plasmonic and metamaterial cloak have been used to reduce scattering for making “invisibility” or “low observability” [7]. In addition, plasmonic antenna integration with quantum laser is used. To this end, dipole antenna integration with laser source has been noticed [8,9]. Also, multilayered plasmonic shell for reducing the total scattering cross section [10] and the nanoscale perpendicular dipole antennas with different lengths for changing linear polarization to circular polarization are investigated [11,12]. Recently, nanoscale plasmonic absorbers are also focused on micro bolometer, photodectors, coherent thermal emitters, and solar cells [13]. Combination of Plasmonic antennas with conically tapered waveguides is studied by Schaafsma et al. for THz applications [14]. Plasmonic dipole antenna is attractive for THz applications due to easy fabrication and feeding with Laser or photo mixer. Scattering, efficiency and near field enhancement is noticed in this filed [15]. Also, it is shown that the radiation pattern is controllable with FSS or lens [16]. Bowtie antennas with plasmonic have been studied for THz application as an attractive topic [17,18]. Plasmonic resonators at terahertz frequencies are used to enhance large field for biological and chemical sensors [19] and Fractal Sierpinski is suitable for sensing molecular vibration modes in the near- to mid infrared range [20].

Methods of Plasmonic parallel waveguides are used to improve wave and laser propagation inside of two Plasmonic walls for super focusing [21] or grating plasmonic waveguide for ultra-slow application and wave propagation speed near zero at THz domain [22]. Surface Plasmon polaritons sharp bends based on transformation optics are also noticed for wave reflection at optical range and high reflection coefficient of plasmonic material [23].

By notice to pervious researches for ameliorate of propagation at THz domain, a novel combination between metamaterial and dipole antenna is suggested. Metamaterial is one of the best absorber structures and help to concentrate wave between two

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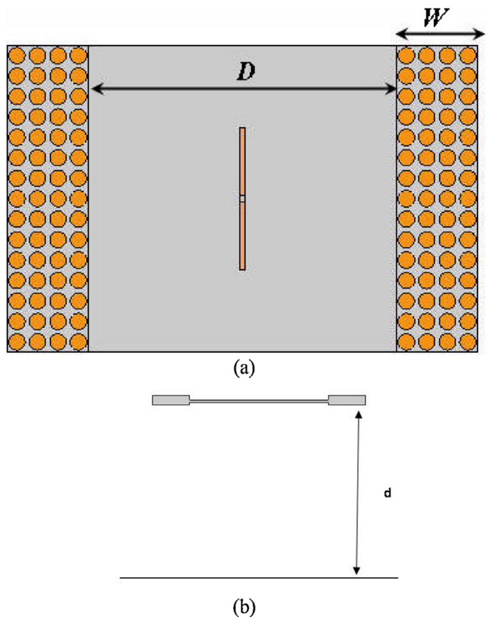

Fig. 1. Antenna and metamaterial layer (a) top view, (b) side view

layers. In other hand, cavity back layer has limited the bottom side; Thus, E-field only be able to scattering from top side. In this article, metamaterial structure is investigated to enhance gain and bandwidth in dipole antenna. Results are compared by HFSS and CST with two different full wave methods of FEM and FDTD, respectively. First, metamaterial absorber are modeled for THz applications and also presented the absorption ratio and shield effective factor. Next, the effect of metamaterial shield layer on antenna bandwidth (BW) is showed. The antenna gain is increased more than 120% and bandwidth is amended around 82%. Final dipole antenna patterns are compared in two different conditions of presence and absence of metamaterial shield.

2. Antenna design

Fig. 1 shows the two top and side views of dipole antenna with Metamaterial absorber. The antenna is containing a dipole structure on silicon thin film substrate with ε of 11.9 (n = 2.43) and thickness of 5 μm. The length of dipole is 140 μm with 6 μm gap for feeding. The metamaterial layers are placed in two sides of the dipole structure with radius of 8 μm and 20 μm height for each via. Also, a thin metal reflector (Ag) is used here as a cavity back with distance of d = 250 μm from dipole structure. The total dimensions are 460 μm × 300 μm × 20 μm. Here, four metamaterial layers are used as an absorber. λ_g can be obtained by $\lambda/\sqrt{\varepsilon_r}$. In fact, λ is 600 μm at 0.5 THz and λ_g for silicone substrate is around 174 μm. Dipole is designed for 0.80 λ_g. The metamaterial layer in both side and thin metal reflector is making a Fabry–Perot as similar as modeled in previous researches [6,9]. But here, W = 80 μm is assumed for width of metamaterial layer or $D/4$ or around $\lambda_g/2$.

3. Simulation results

Transmission through an anisotropic zero-epsilon metamaterial slab is noticed because of its importance [24] so at first step, the scattering characteristics of metamaterial absorber have been studied by incident a wave to waveguide and simulate the plasmonic transmission wave. Simulation shows high rate of absorption by metamaterial layer. Time domain simulation is used for calculation.

Fig. 2 shows the metamaterial Layer and Wave port. Here, the incident wave is modified for 0.45 THz cut off frequency.

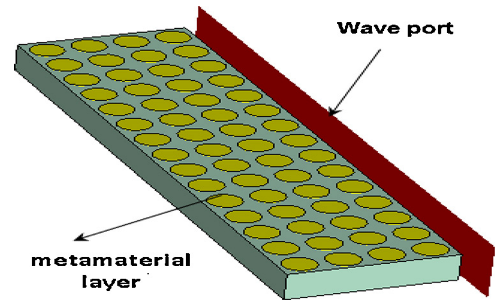

Fig. 2. Metamaterial layer and wave port

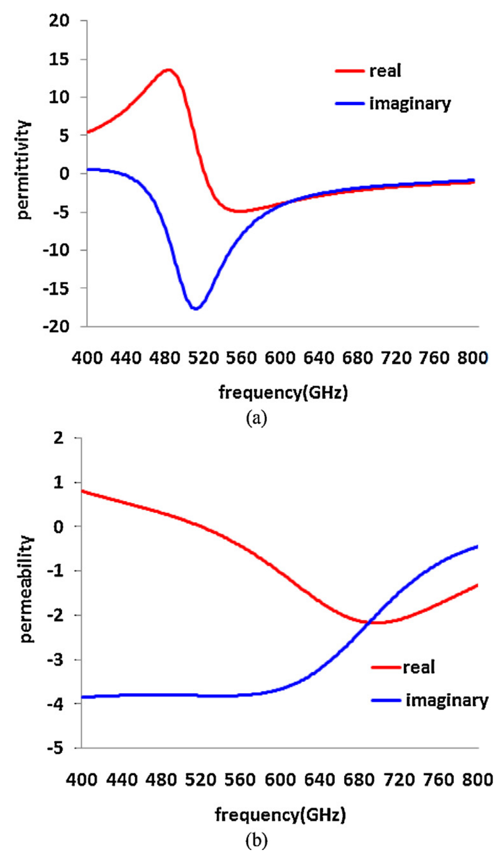

Fig. 3. Metamaterial parameter for real and imaginary (a) permittivity (b) permeability

When the THz wave incidents to metamaterial layer, the metamaterial Left-Handed Characteristics improve the scattering from plasmonic layer, so E and H ratio in another side are decreased too much.

Studies about calculation of permittivity and permeability in Double Negative Metamaterial have been done by Ziolkowski [25]. Nicolson–Rose method as shows in Eqs. (1) to (4) is a conventional mathematical method for calculation of Metamaterials parameters. Here, this method has been executed in Matlab by numerical calculation. $V_1 = S_{21} + S_{11}$, $V_2 = S_{21} - S_{11}$, $k_0 = \omega/c$ and d is the thickness of the layer [25,26].

$$\Gamma = \frac{\sqrt{(\mu_r/\varepsilon_r)} - 1}{\sqrt{(\mu_r/\varepsilon_r)} + 1} = \frac{\eta - 1}{\eta + 1} \tag{1}$$

$$\varepsilon_r \approx \frac{2}{jk_0 d}\frac{1 - V_1}{1 + V_1} \tag{2}$$

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