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A Study of Terahertz Metamaterial Absorber

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ABSTRACT

The objective is to design a single band metamaterial absorber functioning in infrared regime. The novel structure is based on simple circular shape resonator and has not been proposed before. By combining multiple sizes raindrop-shaped resonators on the top layer, a single band absorption in infrared regime can be realized. A structure that can create single absorption band in the terahertz regime is also suggested in order to construct an adjustable high-absorption multiple bands metamaterial absorber that will be useful in many engineering sectors, such as detecting and terahertz imaging. The MIM-based construction has a cross and four circular rings with quarter-sections encircled by square rings in the top layer. The structural configurations can be changed to change the overall number of resonance bands.

Keywords:THz, MTM, Metamaterial, Absorber

INTRODUCTION

Electromagnetic metamaterials are artificially structured materials with subwavelength-sized composite arrays of resonant structures which cannot be found in nature [9]. The geometrical configuration of each individual unit cell controls its electromagnetic properties. By carefully designing the structure, metamaterials can display electric and magnetic resonances at specific frequencies, which has attracted incredible attention. The materials that transform the incident electromagnetic (EM) waves into various types of energy, such as heat or electrical currents, are referred to as electromagnetic (EM) wave absorbers. In other words, they minimise the absorption within the absorber by high inherent loss or appropriate engineering of optical characteristics while suppressing the reflection, transmission, and scattering of the incident waves. Depending on the region of the EM spectrum in which the peak spectral absorption band is located, EM absorbers can be categorized accordingly into different regions of operating wavelengths. The earlier development of EM absorbers has been mostly focused in the RF regime (3kHz ~ 300GHz), due to the large demand in the applications such as communications and military defence. THz absorbers operate in a higher frequency regime (0.3 ~ 3T Hz) and are actively employed the medical applications such as a non-invasive alternative to X-ray imaging as well as in homeland security applications where THz waves are used to detect concealed weapons underneath garments. In visible regime, camouflage technology based on cloaking devices and visible EM absorbers is exciting research of interests to many scientists. This thesis mainly focuses on the applications and the current state of technologies operating in the IR regime. IR radiation (0.3 ~ 400T Hz) absorbers have a very broad application field including thermal imaging, chemical spectroscopy, and energy harvesting. Due to the wide spectrum of IR regime, design of an IR absorber is very application-specific depending on the spectral region of operation. In this thesis, specific kinds of IR absorbers known as metal-insulator-metal IR absorbers are discussed in depth. The proposed absorbers are capable of absorbing MWIR waves with a very high spectral resolution and near-unity absorption. The applications of miniaturized IR spectroscopy and zero-power micromechanical IR digitizers enabled by the unique absorption properties of MIM IR absorbers are also presented.

METAMATERIALS

The field of metamaterials is a research area focusing on developing materials with extraordinary optical characteristics that are not found in nature by tailoring the effective electric and magnetic response of engineered materials. These materials consist of carefully-designed patterns that are usually arranged in a periodic manner much smaller than its working wavelength. The properties of the metamaterials can be tailored precisely to control the impinging electromagnetic waves in different ways such as steering, redirecting, focusing, absorbing, and reflecting. Such precise control of EM waves have been demonstrated for EM clocking, perfect absorbers, energy harvesting, and imaging beyond diffraction limit. Negative refractive index metamaterials, also known as left-handed metamaterials, is one of the most well-known examples of metamaterials which take advantage of artificial electric and magnetic resonance (electric permittivity, $\varepsilon < 0$, and magnetic permeability, $\mu < 0$, respectively) to realize a negative refractive index [3, 4]. Such discovery resulted in a new class of applications such as flat lens, invisibility, and beyond-diffraction imaging. Another type of metamaterials are high impedance surfaces, consisting of layers of metal and dielectric thin films whose geometric shapes and dimensions are precisely controlled to exhibit desired properties such as phase shifting and frequency selective responses. [5]. One can obtain complete absorption at the targeted wavelength, in particular, when the effective surface impedance of a high impedance surface matches the free space impedance [6]. These metamaterials, also known as metamaterial perfect absorbers, have been shown effective throughout a large portion of the electromagnetic spectrum, from microwaves to the optical regime. Because they contain a variety of subwavelength constituents, metamaterials can display amazing electromagnetic phenomena. The resonances of the sub-wavelength constituents produce the special characteristics of metamaterials. The dielectric permittivity, magnetic permeability, and conductivity of a material determine its capacity to propagate waves. Veselago[10] conducted the first theoretical investigation into the plane wave propagation in materials with negative and negative in 1968. In contrast to typical materials, he discovered that in the medium of negative and negative, the group velocity propagates in the opposite direction of the Poynting vector. 1999 saw Smith et al .[11] experimentally demonstrated the first material with both negative ε and μ. Later, Pendry[12] explained the existence of a negative refractive index. After these works, plenty of research has been conducted in this field from microwave to optical spectrum regime of electromagnetic waves[13]. Metamaterials can be characterized by effective complex permittivity $\varepsilon\ (w) = \varepsilon 1\ (w) + i\varepsilon 2\ (w)$ and effective complex permeability $\mu\ (w) = \mu\ (w) + i\mu 2\ (w)$[2]. By carefully adjusting ε (w) and μ (w), it is feasible to construct metamaterials that exhibit properties that do not exist in nature, such as negative index of refraction and backward wave propagation [14]. Typically, metamaterials consist of periodic metallic arrays designed to generate resonances at the desired frequency. Unlike conventional materials that depend on material chemical composition, the electromagnetic properties of metamaterials are strongly determined by the structures themselves.Due to the existence of the ground plane on the bottom layer, with thickness greater than the skin depth, the transmission through the structure can be effectively suppressed, which indicates $S21\ (\omega) = 0$. So, the absorption equation can be altered to the following:

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

RESEARCH OBJECTIVES

The objective is to design a single band metamaterial absorber functioning in infrared regime. The novel structure is based on simple circular shape resonator and has not been proposed before. By combining multiple sizes raindrop-shaped resonators on the top layer, a single band absorption in infrared regime can be realized. A structure that can create single absorption band in the terahertz regime is also suggested in order to construct an adjustable high-absorption multiple bands metamaterial absorber that will be useful in many engineering sectors, such as detecting and terahertz imaging. The MIM-based construction has a cross and four circular rings with quarter-sections encircled by square rings in the top layer. The structural configurations can be changed to change the overall number of resonance bands.The problem here is to investigate and design the narrow-band metamaterial absorbers for the infrared frequency spectrum. In this chapter, we studied and analysed the effects of narrow band metamaterial absorbers for Infrared Frequencies.It is suggested to use a fresh, straightforward design for the top layer based on the most typical shape, the circular one. The absorption band may be narrowed based on our theoretical investigation of adjusting the symmetry and homogeneity of the metallic micron circular disc on top.

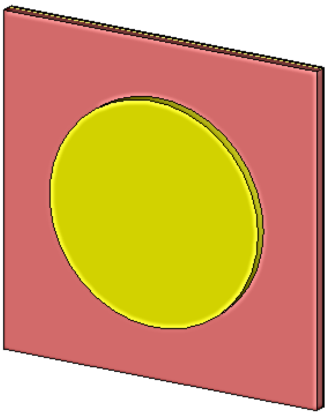

Figure 1. Absorber Structure Design

IMPLEMENTATION

Absorber Structure Design

Only one-unit cell is depicted in Figure 1, which displays the single-band absorber construction that is suggested. Gold arrays on top, a gold ground plane, and a conductive material between two metal layers make up its three functional layers. The periodic gold arrays on top are 45 nm thick, while the gold ground plane on the bottom is 100 nm thick. They are separated by a 60 nm dielectric spacer called SiO2 that has a constant refractive index of 1.45 and is thought to be lossless [8]. The period length p1 of each cell is set to be 1.5 µm. The related structure parameters. A Lorentz-Drude model was used for the gold material [6]. The incident wave was set to be plane waves parallel to the X-Z plane with TE polarized along the Y direction. Periodical boundary conditions were applied on the vertical sides of the structures. Port boundary condition was used between the interference of the PML layer and air layer. The wavelength-dependent reflection parameter R (λ) was obtained from the S-parameter of the port and the absorption of the structure was calculated by A (λ) = 1 - R (λ). Due to the existence of the bottom ground layer, which is thicker than the skin depth at the desired wavelength range, the total transmission is close to zero.The symmetric absorber is not sensitive to TE and TM polarizations because of the four-fold.

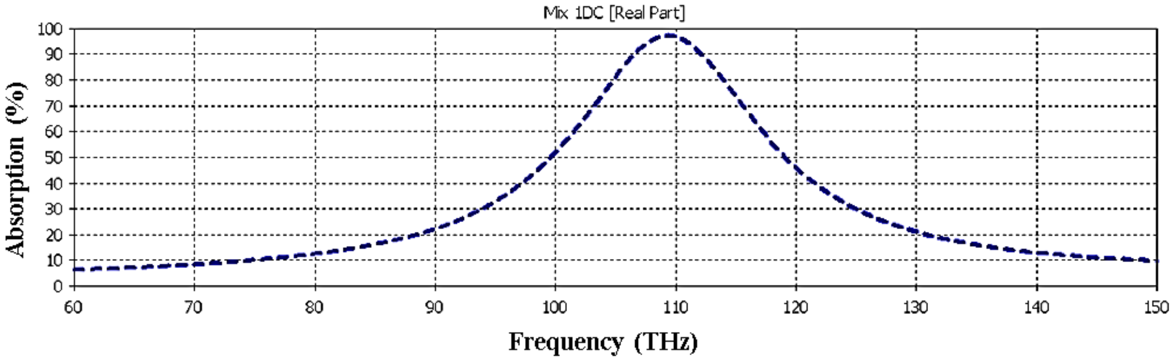

Figure 2. Absorption Plot

Result Analysis

The Investigations have also been done on how parameter changes affect the performance of the intended absorber. Simulations in the CST programme have been run while taking into account different parametric modifications to analyse the performance of the suggested absorber. We are modifying one set of parameters during simulation while holding all other values constant at once. Whenever the height of the substrate was further raised from 0.07 to 2 micrometres, a significant reduction in absorptivity was seen. As a result, it has been determined that 0.07 micrometres is the ideal height for producing near unity absorption.The radius of the graphite disc has a considerable impact on the absorbtivity of the proposed absorber. The absorption increases as the radius increases from 0.1 to 0.6 micro metres, as seen in figure 3.9. The absorptivity is substantially lower for smaller radii. This is because the size of the circular resonator is much smaller at lower radii compared to the unit cell; as a result, there is an impedance mismatch and the absorption is nearly negligible since most of the electromagnetic waves are reflected from the top surface of the device. As the radius increases, the absorption bandwidth likewise increases. Due to its higher than 90-degree absorptivity at the resonant frequencies, the final structure's ideal radius is decided to be r = 0.6 m. Additionally, processing it for sensing demands less bandwidth. Additionally, following modelling, it exhibits reasonably close absorption at the best value.

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