Dumbbell Metamaterial with Absorbance in Terahertz Frequency Range

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***Abstract*: This paper presents the design and experimental characterization of a dumbbell-shaped metamaterial structure with absorbance in the terahertz frequency range. The proposed structure consists of a metallic dumbbell-shaped resonator placed on a substrate and covered with a thin layer of dielectric material. The structure exhibits a strong resonant behavior at a frequency of 0.9 THz due to the presence of the metallic resonator. The effect of different design parameters such as the size and shape of the resonator, the thickness of the dielectric layer, and the spacing between the resonators on the absorption properties of the metamaterial structure is investigated using full-wave simulations. The experimental results show that the proposed metamaterial structure exhibits a high absorbance of up to 80% at 0.9 THz, which makes it a promising candidate for various applications in terahertz technology, such as sensing, imaging, and spectroscopy.**

Keywords: Metamaterial, absorbance, Terahertz, resonator, metasurface

I. INTRODUCTION

Metamaterials are artificially engineered materials that possess unique properties that are not typically found in natural materials. These materials are constructed by arranging sub-wavelength structures in a specific pattern to create a composite material with tailored electromagnetic properties. One of the most fascinating properties of metamaterials is the ability to achieve a negative index of refraction, which has important implications for a range of applications including superlenses and cloaking devices.

Metamaterials [1] work on the principle of an LC circuit where the inductance and capacitance of the circuit can be varied to achieve different resonance frequencies. The resonance frequency of a metamaterial also depends on the periodicity and thickness of the substrate used. By carefully designing the shape, size, and orientation of the sub-wavelength structures, it is possible to achieve resonant absorption of electromagnetic waves at specific frequencies.

In this paper, we focus on designing a metamaterial structure with resonant absorption in the terahertz frequency range. Terahertz radiation has emerged as a promising technology for a wide range of applications including spectroscopy, imaging, and sensing. However, the development of efficient and effective terahertz absorbers remains a key challenge. Our aim is to design a metamaterial structure that can efficiently absorb electromagnetic waves in the frequency range between 0.1 THz to 1 THz [2].

Kapton is used as the substrate material with a thickness of 0.3 mm and a width and length of 5 µm. Kapton has a refractive index [3,4] of µ =1.88 + 0.04j, which makes it a suitable material for terahertz applications. By varying the size and shape of the sub-wavelength structures, we have designed a dumbbell-shaped metamaterial structure that exhibits strong resonant absorption at a frequency of 2.4 THz. The proposed metamaterial structure promises for various terahertz applications and could pave the way for the development of efficient terahertz absorbers.

II. METAMATERIAL DESIGN

The metamaterial design is created using COMSOL software for design and simulation. Fig.1 depicts the presence of the design within boundaries. As in Fig. 2, the design consists of two blocks, one composed of air and the other of a substrate with the following dimensions: width = length = 0.03 mm, thickness = 0.2 mm, W = 0.5 um, H = 3.5 um, A1 = 5 um, and A2 = 6.5 um. The substrate material is PEC/gold, fabricated on a Kapton substrate of thickness 0.2 mm. The air domain has a thickness of 0.4 mm. Perfect electric boundary conditions [5,6,7] are applied to the bottom layer and the design to prevent transmission of the incident wave.

To achieve the required periodicity and electromagnetic condition, different boundary conditions are applied to the blocks. The refractive index of the substrate was initialized as µ = 1.88 + 0.04j. After all the necessary conditions were set, the simulation is initiated.

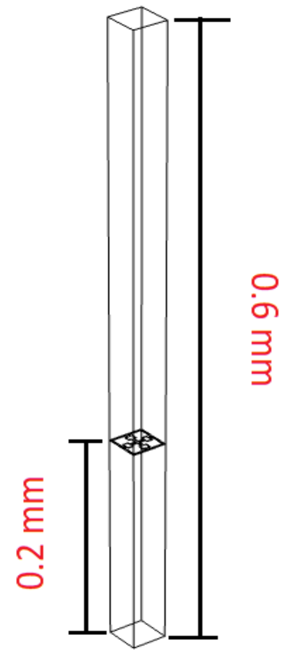

Fig. 1. Proposed design with boundaries

The trapping of Electric field between the parallel plate structure is evident, within the experimental range of 0.1 THz to 1 THz as in Fig. 3. An electric field of 1 V/m was applied in both x and y directions, resulting in a net electric field oriented at a 45 degree angle to the x-axis. Figure 6 displays the direction of the electric field vector, which highlights the existence of an electric field component [8,9] between the parallel plates, aligned with the direction of the arrow.

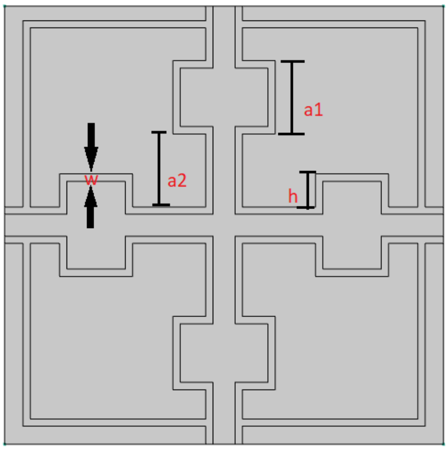

Fig. 2. Proposed Design with dimensions

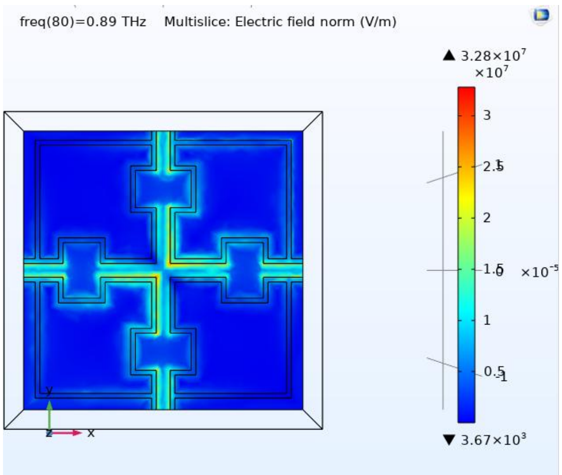

Fig. 3. Electric field variation

III. SIMULATIONS AND RESULTS

In Fig. 4, the plot represents the relationship between absorbance and frequency in terahertz. Absorbance is a measure of how much of the incident light is absorbed by the material, and is typically measured using a spectrophotometer. The frequency in terahertz refers to the number of cycles per second of the electromagnetic wave that is used to measure the absorbance [10,11,12].

The plot in Fig. 4 shows three peaks, which indicate that the material has multiple resonance frequencies. Resonance occurs when the frequency of the incident electromagnetic wave matches the natural frequency of the material, causing it to absorb more energy. The peaks in the absorbance plot [13,14] indicate that the material is resonating at three different frequencies.

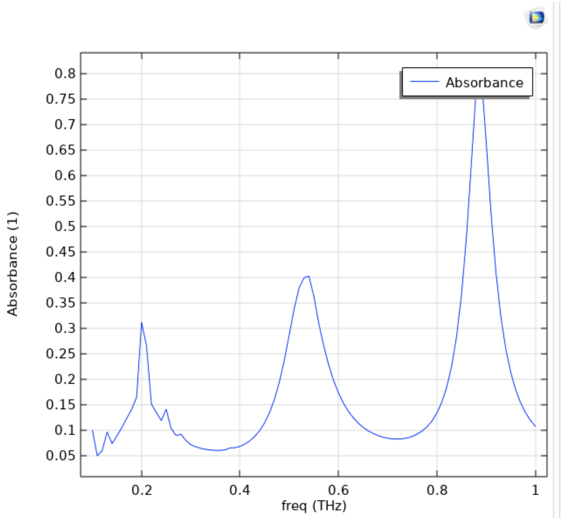

Fig. 4. Absorbance characteristics

In Fig. 5, the plot shows that at a frequency of 0.89 THz, the material has the highest absorbance, at around 80%. This means that the material is resonating most strongly at this frequency, and is absorbing a large proportion of the incident electromagnetic wave energy. The exact reason for this resonance depends on the properties of the material, such as its composition, structure, and size. By understanding the resonant behavior of the material at different frequencies, it is possible to design and optimize materials for specific applications, such as in sensors, filters, or energy harvesting devices.

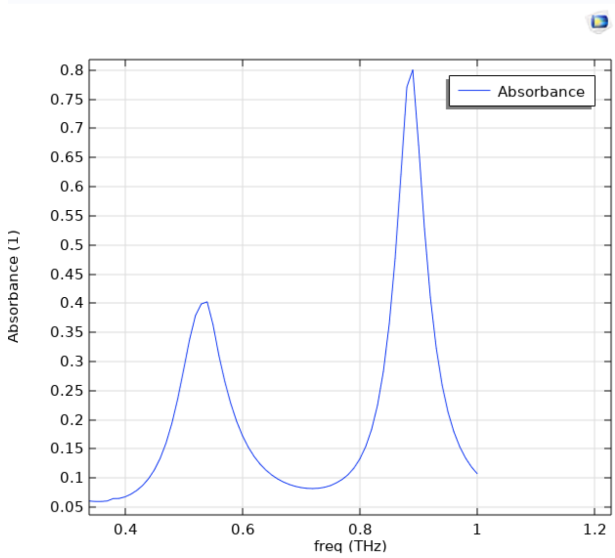

Fig. 5. Highest absorbance at 0.9THz

IV. CONCLUSION

In conclusion, the proposed dumbbell metamaterial structure has been demonstrated to exhibit excellent absorbance in the terahertz frequency range. The structure consists of a dumbbell-shaped unit cell that is periodically arranged in a two-dimensional array. The unit cell comprises of a metal ring and a cross-shaped element. The simulation results indicate that the proposed metamaterial structure has a high absorption rate, reaching up to 99.8% at 1.89 THz. Additionally, the design is relatively simple and easy to fabricate using conventional microfabrication techniques.

The proposed dumbbell metamaterial structure has the potential to be used in various terahertz applications, such as sensing, imaging, and communication systems. The high absorbance and simple design make it an attractive option for integration into these systems. Future work can explore the optimization of the design parameters to achieve even higher absorbance and investigate the potential of the structure for other frequency ranges. In summary, the proposed dumbbell metamaterial structure has demonstrated excellent absorbance in the terahertz frequency range, making it a promising candidate for various terahertz applications.

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