The Examination Of Finite Dimensions Impact On The Sensing Performance Of Terahertz Metamaterial Absorber

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Summary

This research investigates the impact of finite number of unit cells on the sensing performance of chosen THz metamaterial absorber. Sensor models with different number of unit cells varying from 16 to infinite have been created using WIPL-D software. The results of comparison show that as the sensor's size increases, its absorption response becomes more similar to the one of an infinite sensor structure. Metamaterial absorber with 50 unit cells expresses the similar behavior in terms of the corresponding frequency and amplitude shifts as the infinite absorber when the H9N2 virus sample of variable thickness is uniformly deposited on the top of the sensors' surface. The uneven distribution of sample affects the sensor's absorption response which has been proven on the example of sensor with 50 unit cells.

1. Introduction

Metamaterial absorbers (MA) are devices that can minimize the reflection and theoretically eliminate transmission of the incident EM wave [1]. They are typically designed as metal-dielectric-metal structures [2–3], but other possible designs include dielectric grating-based structures [1], integrated microfluidic structures [4] and dielectric-metal structures [5]. MAs can be used in solar power harvesting, material detection, thermal imaging and sensing [1]. MAs that work in terahertz (THz) domain are crucial for bio-sensing applications since the vibration resonances of biomolecules coincide with the THz range. Besides that, THz technology has several different advantages relevant for the field of bio-sensing such as non-ionizing property and strong penetration capability [6]. Sensors based on THz MA can be used to detect various virus subtypes with wide range of particle size [7]. Since the physically realizable sensor has finite dimensions and therefore its structure cannot be fully periodical, we wanted to investigate the impact of finite number of unit cells on the sensing performance. First, we had to come up with proper modelling technique for both the infinite and finite sensor structure in WIPL-D software.

2. Sensor Design And Modeling Process

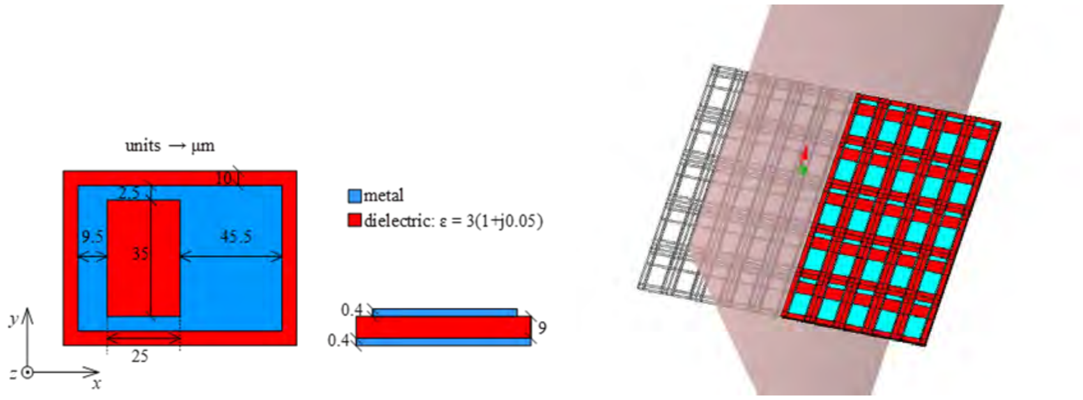
For the purpose of investigating the impact of finite dimensions on sensing performance, we have selected quad-band metamaterial absorber presented in [3]. The chosen MA is a typical planar metal-dielectric-metal structure whose quad-band absorption is achieved by introducing slight deformation to the traditional rectangular metallic resonator rather than using multiple single-band resonators of different sizes. Although there are four resonant frequencies, we will focus our analysis on the range of the first resonant frequency which is below 1 THz, but the concept can be broadened to the higher frequencies.

2 1. Unit Cell and Modelling of Infinite Sensor Structure

The unit cell structure is composed of metallic ground layer and perforated metallic resonator separated by a polyimide lossy dielectric spacer. The dimensions of interest are given in Figure 1 *a*. Both metallic layers are made of gold whose conductivity varies with the increase of frequency, but since the frequency range of interest is below 1 THz, the fixed value of 40.9 MS/m used in [3] is sufficient for obtaining good-quality results. If the analysis is to be extended to the range of higher frequencies, variation of conductivity can be taken into account by using Drude model. In addition, the ground layer is thicker than the skin depth in the whole frequency range of interest which is essential for proper isolation between the substrate and the sensor itself.

2.2. Modelling of Finite Sensor Structure

In order to create a model of finite sensor structure in WIPL-D, whole modelling process has to be done manually since the PBC option is no longer suitable which results in significantly higher time-consumption. Despite the introduced difficulties, The finite sensor modelling has some significant advantages such as the ability to analyze the impact of the end effects which are inevitably present in the physically realizable structure and the possibility of modelling the uneven distribution of the sample across the sensor's surface. To fully investigate the impact of dimensions on sensor performance, we have created models for different numbers of unit cells (16, 50, 100 and 400). The example of modelling a sensor of finite dimensions is given for structure made of 50 cells in Figure 1 *b*.



a) *b*)

Figure 1. *a*) THz MA unit cell with given dimensions , *b*) Modelling of the sensor with 50 unit cells (the pink plane represents the used symmetry plane).

2.3. Virus Sample and Results

To investigate the sensing capabilities of both infinite and finite sensor structures, we have chosen the sample of H9N2 subtype of Influenza A virus (IAV). IAVs are respiratory viruses with RNA genome and a serious possibility of causing human epidemics or pandemics [8]. Virus sample has been modeled as a continuous dielectric layer that completely covers the top of the MA structure. The resonant peak amplitude varies with the modification of sample properties as shown in Figure 2. Additionally, the amplitude shifts are more dynamic for the finite structure.

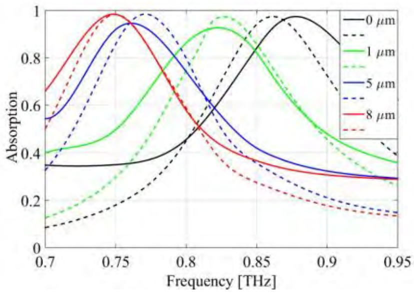


Figure 2. Comparison between the absorption responses of the finite sensor made of 50 unit cells with different thicknesses of H9N2 sample (full line) and the results for the infinite model (dashed line).

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References

[1]. F. Yan, Q. Li, H. Tian, Z. Wang and L. Li, “Ultrahigh Q-factor dual-band terahertz perfect absorber with dielectric grating slit waveguide for sensing”, *Journal of Physics D: Applied Physics*, vol. 53, pp. (235103) 1–9, 2020.

[2]. B. X. Wang, W. Q. Huang and L. L. Wang, “Ultra-narrow terahertz perfect light absorber based on surface lattice resonance of a sandwich resonator for sensing applications”, *RSC Advances*, vol. 7, pp. 42956–42963, 2017

[3]. Q. Xie, G. Dong, B. Wang and W. Huang, “Design of Quad-Band Terahertz Metamaterial Absorber Using a Perforated Rectangular Resonator for Sensing Applications”, *Nanoscale Research Letters*, vol. 13, pp. (137) 1–8, 2018.

[4] X. Hu, G. Xu, L. Wen, H. Wang, Y. Zhao, Y. Zhang, D. R. S. Cumming and Q. Chen, “Metamaterial absorber integrated microfluidic terahertz sensors”, *Laser and Photonics Reviews*, vol. 10, pp. 962–969, 2016.

[5]. D. Hu, T. Meng, H. Wang, Y. Ma and Q. Zhu, “Ultra-narrow-band terahertz perfect metamaterial absorber for refractive index sensing application”, *Results in Physics*, vol. 19, pp. (103567) 1–5, 2020.

[6]. A. Kovačević, M. Potrebić and D. Tošić, “Sensitivity Analysis of Possible THz Virus Detection Using Quad-Band Metamaterial Sensor”, *In Proceedings of the IEEE 32nd International Conference on Microelectronics* (*MIEL*), Niš, Serbia, 2021, pp 107–110.

[7]. N. Akter, M. M. Hasan and N. Pala, “A Review of THz Technologies for Rapid Sensing and Detection of Viruses including SARS-CoV-2”, *MDPI Biosensors*, vol. 11, pp. (349) 1–21, 2021.

[8] B. Dadonaite, B. Gilbertson, M. L. Knight, S. Trifković, S. Rockman, A. Laederach, L. E. Brown, E. Fodor, D. L. V. Bauer, “The Structure of the Influenza A Virus Genome”, *Nature Microbiology*, vol. 4, no.11, pp. 1781 – 1789, 2019.