HNUE JOURNAL OF SCIENCE DOI: 10.18173/2354-1059.2019-0037
Natural Sciences, 2019, Volume 64, Issue 6, pp. 108-114
This paper is available online at http://stdb.hnue.edu.vn

ELECTROMAGNETIC PROPERTIES OF MULTI-CONFIGURATION OF GOLD NANO CLUSTER ABSORBER IN INFRARED REGIME

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Abstract. Nanotechnology plays an increasingly important role in research as well as the advancement of science and technology. Current studies of nanoparticle or nanocluster are mainly concentrated due to important electromagnetic properties emerged in this domain. This study presents the investigations on the nature of electromagnetic wave absorption in the Infrared regime (IR) that is comparable with the metamaterial absorber of the gold-nano-particle nanocluster structure with different single-particle forms and configurations. Research shows that the electromagnetic response appears to be good for optical sensor or energy harvesting application.

Keywords: Gold nanoparticle, absorber metamaterial, reflection coefficient, THz, Infrared.

1. Introduction

Absorber metamaterial is a new kind of metamaterial that could totally absorb all energy impinges on its surface [1]. The word "meta" means beyond therefore the term "metamaterial" refers to beyond conventional materials. Since their first design, absorber metamaterials have become the topic of many emerging research directions [2-6]. The unusual dispersion characteristics of metamaterials are typically achieved using carefully designed the geometry and shape of structure. These engineered metamaterials can manipulate electromagnetic fields as desired [1]. Through the clever design of meta-molecules, metamaterials could exhibit a wide interesting range of physic properties, such as negative index, cloaking, perfect absorption and many more. Usually, unit cells (UC) of many metamaterials that are designed to operate at optical frequencies are made

Received June 18, 2019. Revised June 22, 2019. Accepted June 29, 2019.
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of nano unit cell metals such as gold, silver, copper, etc. [7, 8]. By exciting thesestructure with an external EM field, Surface Plasmon Polaritons (SPPs) are generated in the metal or metal/dielectric surfaces. These SPPs are the collective oscillations of conduction electrons in response to the field incident on the structure. This can generate the resonance of the absorber to the incoming wave then perform the perfect absorption peak at some frequency ranges [9, 10].

The study of electromagnetic and chemical properties of nanoparticles has been concentrated long time ago by many groups worldwide [7-10]. However, the collection of these particles, which is also named nanocluster, has not been widely studied on this topic. In this article, we examine nanoclusters formed by a group of 5 particles of 100-300 nm radius range and the interaction of these clusters with electromagnetic waves at the IR regime reaching their surface. The cluster with 5 particles is chosen for the ease and convenience of investigating compared to other configuration when we study about the distance between the nanoparticle. The results of the investigation of the change of the particle radius, the distance of particles, and the defect of particle position are also given and discussed in the report. The results of the study are important in applications of nano IR optical sensor, plasmonic resonator and so on [9, 10]. The calculation in this study was performed by using Finite-Integration Technique based on CST Microwave Studio.

2. Content

2.1. Result and discussion

In our study, nanoparticle clusters were placed with concordant boundary conditions in the simulation setup. For the sake of simplicity and reasonable symmetric degree, a model of 5-gold-nanoparticle with the radius of 100-300 nm is used. The output of the stimulation contains scatting parameters including transmission coefficient S_{12} and reflection coefficient S_{11}. From these data, the absorption coefficient can be determined by the following equation:

$$A = 1 - |S_{11}|^2 - |S_{12}|^2$$

In the part below, we discuss the absorption property of different configurations of the nanogold cluster.

2.2. Different inter-particle distance

First, the distance between five particles is alternately 10 nm, 20 nm, 30 nm in cluster configurations as shown in Figure 1. The radius of each particle is 100 nm. The absorbing boundary condition is placed surrounding the cluster, a plane wave with a definite frequency range in the IR (Infrared) regime is sent along the axis perpendicular to the nano-cluster surface. From the simulation results, the reflection and transmission coefficients of the structure are determined. These results are shown in Figure 2 below. One can see that the absorption response depends on different configurations of nano-cluster. Three clusters have different absorption responses in the IR frequency range. Three main resonance points are observed at 260 THz, 245.30 THz, and 220.66 THz (respectively for 10 nm, 20 nm, 30 nm distance particle cluster). When the distance increases, the region of absorption is larger and the frequency is redshifted. The negative value of the absorption response is also observed and this could be due to some errors occurring when extracting the parameters from the scattering coefficients in the calculation. This does not affect our absorption results.

Figure 1. Nano-cluster of (a) 10 nm-distance, (b) 20 nm-distance, (c) 30 nm-distance

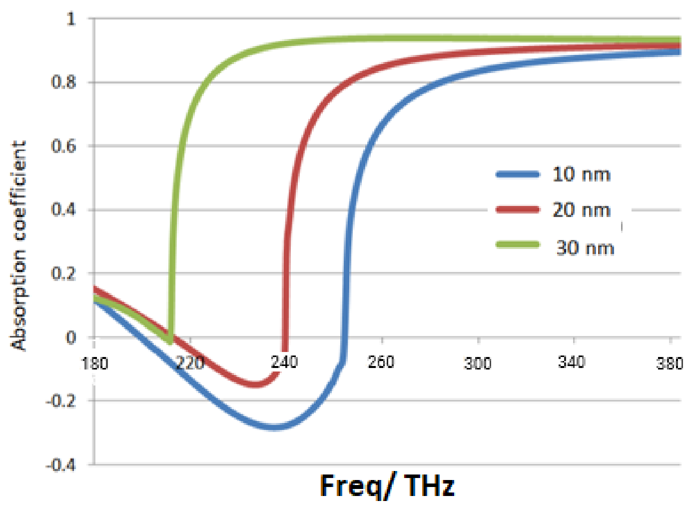

Figure 2. Absorption spectrum of three cluster configurations

In order to understand more about electromagnetism absorption mechanism, we consider the electric field and magnetic field distribution around these particles at 260 THz, 245 THz and 220 THz respectively. The results are shown in Figure 3. It is clear that the larger the distance is, the weaker the electric field and magnetic field is. The field focuses on outside the particle, among these particles. From that, we concluded that the absorption coefficient definitely depends on how gold-nanoparticle arrange in the cluster. In this case, the absorption rate depends on the distance between the particles. We can apply this characteristic for the optical sensor such as the detection of different nanogold configuration by the absorption spectrum analyse. The absorption performance of these clusters can also be used for the energy havester in the IR range.

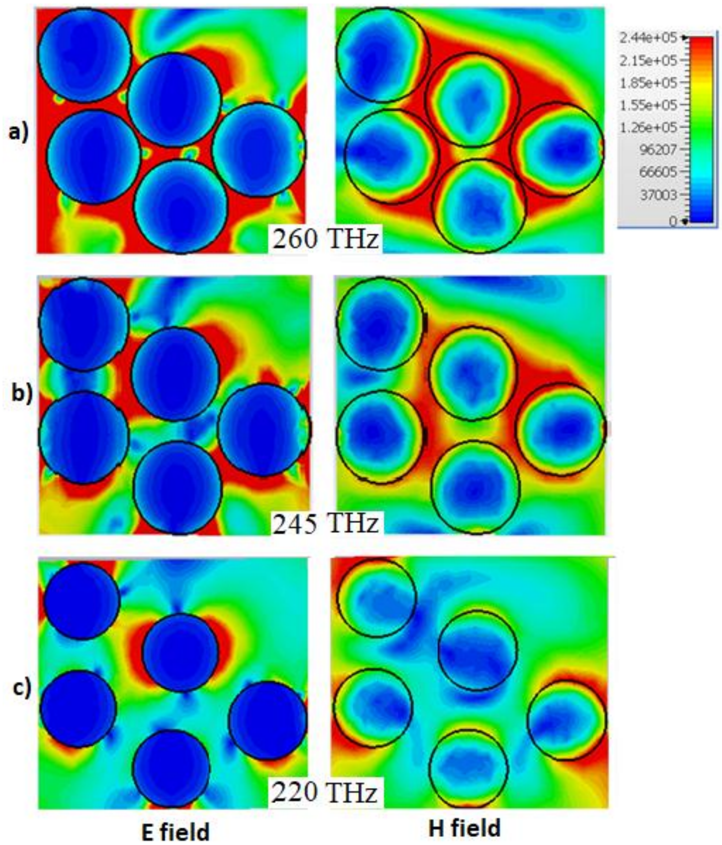

Figure 3. Electric field and magnetic field distribution of three cluster type

2.3. Distance of the defect

Three configurations of this cluster are chosen to investigate, in each cluster, 4-gold nanoparticles are fixed and another is placed at a different distance far from the others of 10 nm, 20 nm, 30 nm, respectively (Figure 4). The radius of each particle remains 100 nm.

From simulation results in Figure 5, the absorption coefficient is changed when one cluster is moved far from the others. To specific, the lowest peak is moved slightly to the left - lower frequency. This means when we increase the distance between one particle with the others, the frequency is red-shifted and the absorption band increases.

Figure 4. Configurations with 5-gold-particle cluster

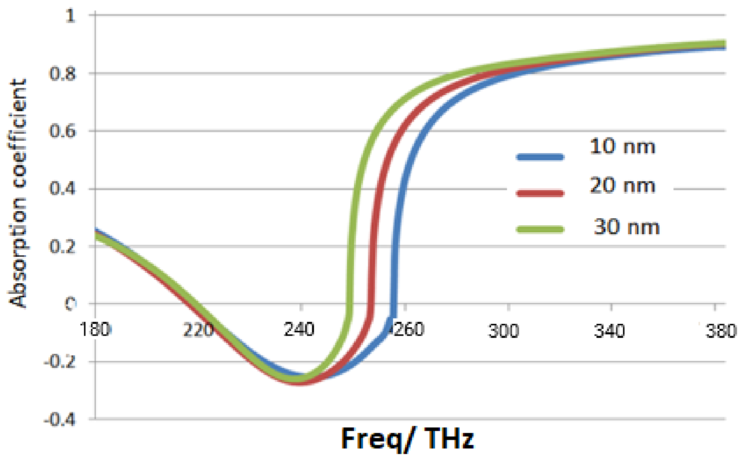

Figure 5. Absorption spectrum of 3 configurations with 5-gold-particle cluster

We observe the concentration of electric and magnetic fields in the cluster structure with the defect distant equal 20 nm at a resonant frequency to understand more about resonance characteristics, as a case study. We choose the frequency of 350 THz at which the absorption rate is high (~90%). The result is presented in Figure 6. We see that when the particle moves far away, the distribution of the magnetic field of structure focuses among 4 particles, and losing field with others. The electric field focus on the outside of the particle. Therefore, the structure can absorb energy more efficiently.

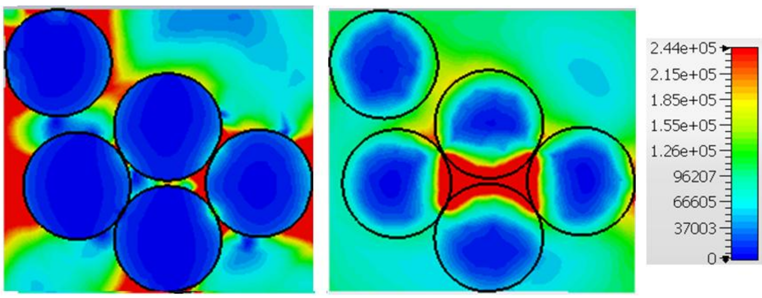

Figure 6. Observation of electric (left) and magnetic (right) field distribution at 350 THz, the cluster with distance 20 nm

2.4. Change in particle radius

This study considers the structure of closely packed nanoparticle with the different particle radius of 100 nm, 200 nm and 300 nm as shown in Figure 7. The absorption rate is shown in Figure 8.

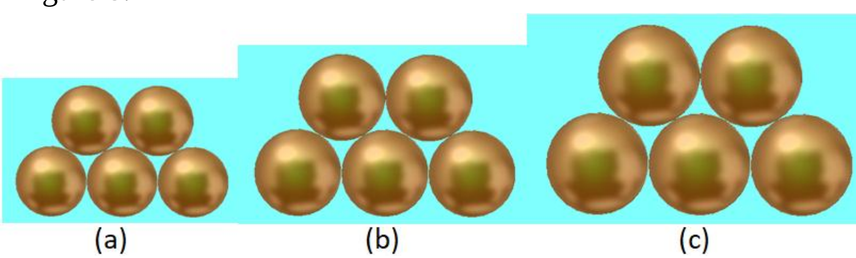

Figure 7. Gold nanoparticle with different radius (a) 100nm, (b) 200 nm, (c) 300 nm

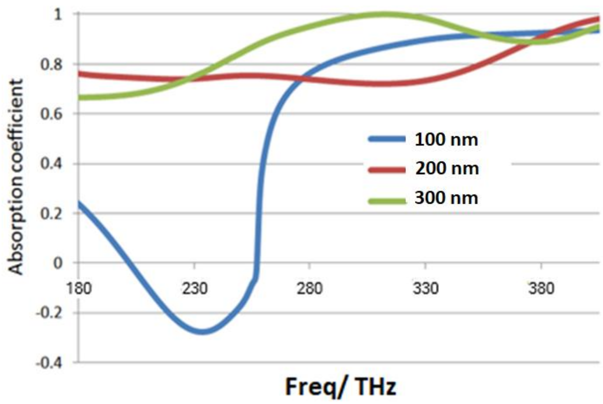

Figure 8. Absorption spectrum of 5-gold-particle cluster with different radius

As we can see that the clusters with the particle radius of 200 nm or 300 nm absorb well in all range of the infrared region 180 - 380 THz with the absorption rate is over 80%. With the cluster of the nanoparticle r = 100 nm, it possesses a high absorption range from the shore at f = 280 THz.

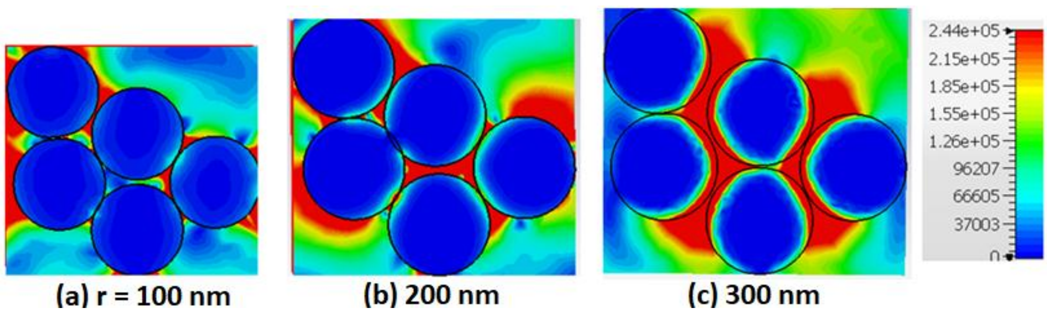

Figure 9. Observation of electric field distribution at 280 THz of three types of 5-particle cluster

Figure 9 represents the distribution of the electric field in each structure at 280 THz, the larger the radius of particles is, the stronger the electric field focus among the particles. At Figure 9a, most of the electric field concentrated outside the model, just a little bit among them. Compare to (b) and (c) it is obvious that the color of the electric field has changed, that means the strength of electric field increase. It can be concluded that the larger nanoclusters absorb more efficiency.

3. Conclusions

In this report, by changing the configuration of the nanoparticle cluster, we can alter the frequency range of the absorption spectrum. The distance between the nanoparticle increases makes the absorption spectrum extend to the redshift. That can explain by the electric field and magnetic field distribution among these particles. The nearer the particles is, the weaker electric field and magnetic field between them. The changing of the radius of the nanoparticle also affect on the absorption spectrum. The larger the particle is, the stronger intensity of the absorption occurs. We proved that by applying minor modifications in the position and shape of nanocluster, one can affect significantly on the electromagnetic responses, which is promising for nanosensor technology in the future.

Acknowledgements. This research was funded by the Vietnam National Foundation for Science and Technology Development (Grant No. 103.99-2017.26).

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