Design for easy surface machined and highly absorbing metamaterials for Infrared frequencies

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Abstract

Simple and novel design for metamaterial absorbers is proposed for mid infrared wavelengths. The design consists of periodic array of circular patches, textured on a continuous gold layer. These patches are separated from another continuous gold layer through a layer of dielectric. Our design shows almost 99% absorption for wavelength 6.11 µm and a resonant bandwidth of around 0.2 µm. Previous designs for such absorption profile demanded a tedious process of machining the top most layer. We propose a simple and direct texturing method to achieve significant absorption.

Keywords: surface machining, metamaterials, absorbers

1. Introduction

Metamaterials are the artificially designed structures having properties that are not ordinarily found in nature. One such example is negative index materials. A wide range of application of such materials can be found in terms of electromagnetic absorbers. Ranging from microwave to infrared, the progress in the field of metamaterial based electromagnetic (EM) absorbers has been remarkable in last two decades. The major advantage of using metamaterial for EM absorption is observed in terms of significantly reduced thickness and better control on the design. For example, our proposed design here is only 0.6-0.7 µm thick and yet it gives significant absorption as supported by our simulation results.

Though significant advancements have been witnessed for microwaves and other larger wavelengths, the field is evolving with much pace for IR and far visible range. Various theories also have been proposed to explain the behavior and so far, a universally accepted theory is of simultaneous excitation of electric and magnetic dipole which are generally excited in a tri layer system. However, we are yet to figure out the exact mechanism behind our design as the top layer texturing here is a bit different than the available literature. Metamaterials with near unity absorption are highly desirable for many applications including micro-bolometers, sensors, thermal imagers, and absorbers used in thermal photo-voltaic solar energy conversion.

So far, as reported in various literatures, it takes a predefined set of multi-step processes to manufacture metamaterial-based absorbers for infrared range. Standard photolithography and e-beam evaporation are few of such examples which help to machine the surface for our requirements. In our work, we propose a rather simple design to achieve a similar absorption profile. Also, the simulated design is such that it can easily be realized with the help of a high-power laser source such as excimer laser. The novelty of this work lies in the surface texturing to avoid complicated processes and attain an absorption profile in infrared region. This work can ease the design in term of machining as compared to an earlier work presented by Govind et al. [1] Our presented design is however representation of a rather as simple geometry as a circle but at the same time, it opens new possibilities with surface machining. Absorption coefficient up to unity has been demonstrated and it can be easily tuned for a range of wavelengths too.

2. Absorber Design

In this work, we present ultra-thin and highly absorbing metamaterial absorber. Our simple design consists of circular holes machined periodically on a continuous gold layer and can easily be textured by rapid laser machining process. This periodic array of holes is separated from a continuous gold layer with the help of a continuous dielectric layer. The holes as well as unit cell can be optimized as per our need which is very well supported by our simulated results. Here we went for a rather smaller unit cell and consequently a smaller hole majorly because of the simulation machine constraint available with us. However, if needed and desired, we can go for higher dimensions and hence absorption for higher wavelengths as well.

The optimization of our proposed design has been studied against the thickness of the dielectric separator and diameter of the hole. However, it is also to be mentioned that the resonant wavelength depends on the size of the unit cell as well. Another point to be considered here is that as soon as the hole diameter is put equal to the unit cell dimension, the absorption simply vanishes. The ground plane can be made extremely thin here and the limit to reduce this thickness is directly related with the skin depth of gold. For the purpose of dielectric separator, a thin layer of ZnSe (zinc selenide) has been used. Absorption can also be slightly tuned with the thickness of this dielectric separator. The representation of the unit cell design is given below:

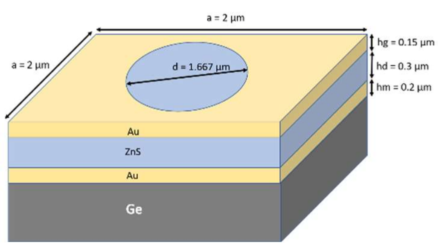

Fig 1: Design of the unit cell with dimensions and material choices

3. Simulation

The unit cell is simulated using COMSOL Multiphysics software. The software uses finite element method to perform electromagnetic calculation in which a continuous structure is divided in small and finite sized elements. Unknown functions are determined at these points. COMSOL solves Maxwell's equation to find out the solution in terms of either electric field E or magnetic field H. Parametric sweep has been used to study the optimization of the design against thickness of the dielectric separator and diameter of machined hole. To realize the periodicity in the model, Floquet periodicity has been implemented. Various parameters to define gold as well as the dielectric like dielectric permittivity for ZnSe, plasma frequency and damping frequency for gold has been taken from literature. [1]

The reason to choose circular aperture is due to its symmetry. Our knowledge from literature [1,2] suggests that designs involving a circular element gives polarization independent behavior. We have gone for a square unit cell. Our results are only valid for normal incidence. The absorption peak can be tuned well to the diameter of the aperture. Our future plan involves to study this new concept in FSS with different geometries like a square aperture and study it in the light of this work. Since this design is new in comparison to our typical FSS designs, a lot of possibilities are yet to be explored.

4. Results

We have attained a near unity absorption for our optimized design at wavelength λ=6.11 µm with bandwidth of around 0.2 µm. All the plots have been attached.

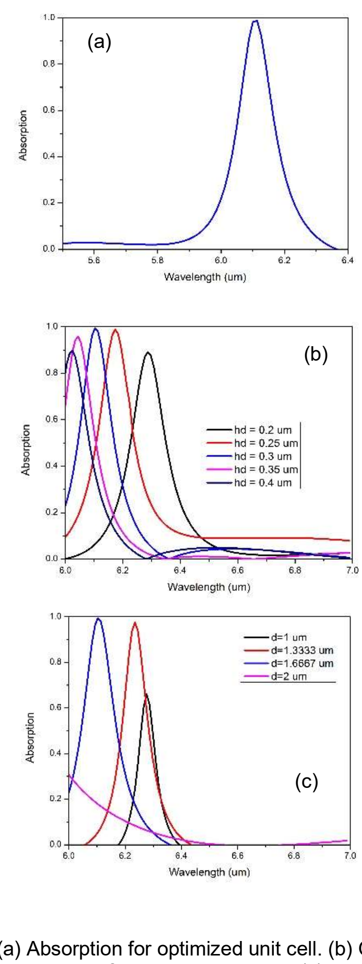

Fig 2: (a) Absorption for optimized unit cell. (b) Optimization against the thickness of dielectric separator. (c) optimization against diameter of the machined holes.

5. Conclusions

Design for ultrathin and easily tunable metamaterial absorbers have been reported. The unit cell has been simulated and optimized using COMSOL Multiphysics. The design can be realized in simple steps using a high-power laser by directly machining the surface of the tri-layer structure. The proposed design is novel in terms of drilled holes on a continuous gold layer and not a conventional isolated patch-based design. Future plan on this work would be to optimize even the drilled geometry and manufacture samples in our lab to test them further for various applications.

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