Modeling and experimental demonstration of terahertz frequency tunable metamaterial absorber

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Abstract. The aim of this research is design of tunable narrowband THz metamaterial absorber, which achieves a resonant absorptivity of 100%. This structure is a promising candidate for selective reflective mirror for THz narrowband absorption.

1. Introduction

At a recent time scientists make huge efforts in research and creation of electromagnetic (EM) materials and new alternative methods of devices components design based on metamaterials [1]. Metamaterials (MM) are artificial composite structures, which EM properties originate from oscillating electrons in unit cell composed of conductive definite form of components, made of metal e.g. copper or gold. The effective electromagnetic properties of metamaterials at any frequency can be engineered to take on arbitrary values, including those not appearing in nature, such as negative permittivity, negative permeability, negative refractive index. It allows obtaining unusual physical effects such as negative refraction [2], backward wave, superlens, superprism effects, etc [3-5]. Sub wavelength metamaterial unit cell duplicates to forming material, which allows receiving resonance response of metamaterial electric and magnetic properties. Application metamaterials for THz frequency range is perspective, because THz radiation could be applied for different science researches and practical applications, such as security systems, detectors, microobjects imaging, different medicine applications, communication systems, etc [6-13].

Design, fabrication and characterization of metamaterial absorbers (MA) were shown in reports [14-18]. Our work is devoted to development of ideal (absorptivity up to unity) metamaterial absorber for terahertz frequency range.

2. Simulation

The structure based on ERR was chosen for creation of tunable absorber for terahertz frequency range, analogous to structures of reports provided earlier. For simulation the parameters of structure were chosen in such a way as to achieve the absorptivity of A=0.99 at resonant peaks in the frequency range from 0.25 to 1.75 THz. Unit cell of proposed absorber is illustrated in Fig. 1; it consists of 4 layers:

1) silicon substrate;
2) lower metallic copper film, to operate as reflective layer;
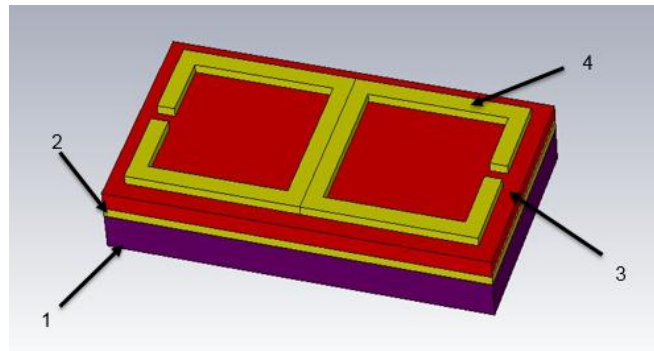3) dielectric layer of polymide;
4) copper double ERR.

Figure 1. Model of MA unit cell, perspective view.

Table 1. Parameters of the MA unit cell..

layer	Material	Layer thickness h, μm
1	Silicon	320
2	Copper	0.5
3	Photoresist SU-8	12
4	Copper	0.5

Design of the MA unit cell with double ERR is illustrated in Fig. 2. It consists of two ERR connected to each other by one side. They could be defining by a set of parameters:

- g – a ERR gap;
- w – a ERR lines width;
- a, b – a ERR length and width;
- x, y– a MA unit cell length and width;
- p – a distance between ERR edge and unit cell border.
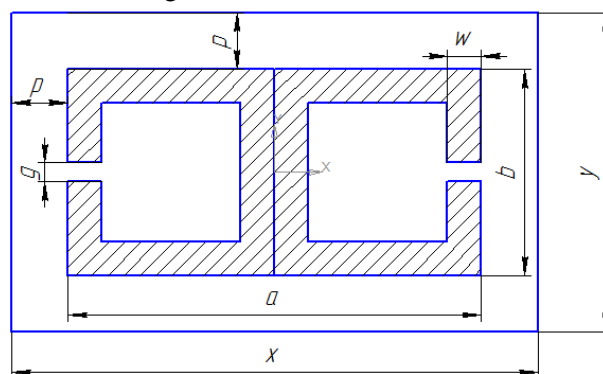

Figure 2 – Design of MA unit cell, top view.

The influence of polymide layer thickness on structure spectrum is shown in Figure 3. Maximal absorptivity is achieved at the thickness of 18 μm; the bigger difference between optimal and real layer thickness, the lower absorptivity. This is an implicit dependence between layer thickness and peak frequency.
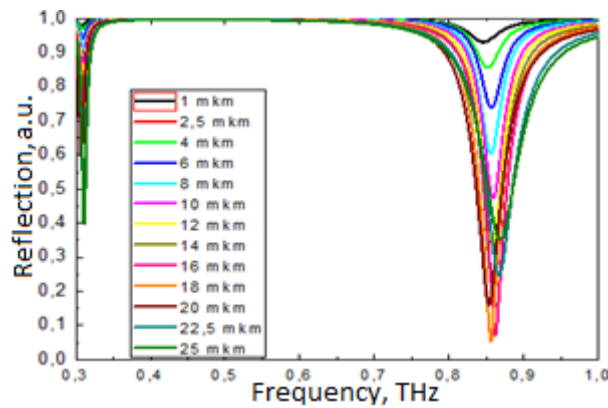
Figure 3. Influence of polymide layer thickness on structure spectrum (in case of TE-polarization).

Table 2 presents 5 variants of MA with different geometric parameters.

Table 2. Geometric parameters of simulated MA

№ MA sample	a, μm	b, μm	g, μm	p, μm	w, μm
	Geometric parameters				
1	180	90	10	10	12
2	220	110	10	10	18
3	260	130	10	10	25
4	300	150	10	10	32
5	340	170	10	10	40

All variants of MA were optimized during the simulation. They demonstrate high absorption of THz radiation with absorptivity approximately 1 (Fig. 4). The enlargement of geometrical parameters redshifts peak frequency.
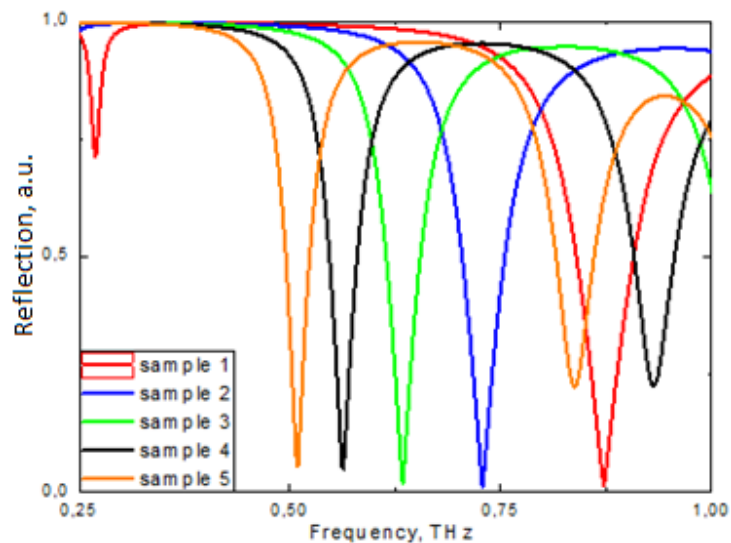

Figure 4. Spectra of 5 samples with geometric parameters from Table 2 (in case of TE-polarization).

3. Sample fabrication

Process of experimental samples manufacturing consists in the following:

1. substrate preparing: firstly thin chrome layer (20 nm) and after that copper layer (500 nm) was sputtered on silicon substrate, using ion-vacuum spattering method;
2. liquid polyimide solution SU-8 was sputtered using centrifuge;
3. photoresist layer was applied by centrifuge and image was formed by photolithography;
4. another copper layer was sputtered (0,5 mm) as electronic resonant rings;
5. photoresist deleting.

Process of MA sample fabrication schematically is sketched in Fig. 5. Microimage of fabricated sample presented in Fig. 6.
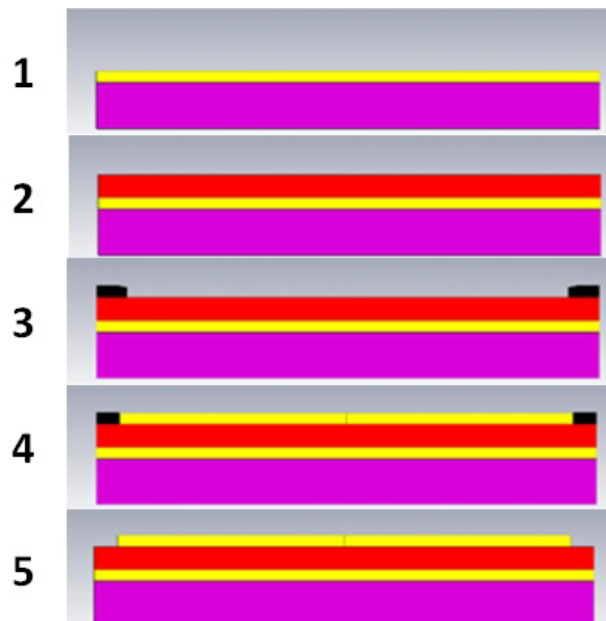

Figure 5. 5 steps of MA sample fabrication (violet - silicon, yellow - copper, red - polyimide, black - photoresist).

Figure 6. Microimage of fabricated MA sample with set of parameters: a=208μm, b=98μm, p=13μm, g=23μm, w=6μm.

4. Experiment

In the present work compact TPS (terahertz pulsed spectroscopy) setup was used (analogous setup was used [19]). The setup operates in reflection mode and allows measuring the THz spectra between 0.25 and 1.75 THz. Fig. 7 represents the experimental setup design and illustrates the process of TPS waveform detection.
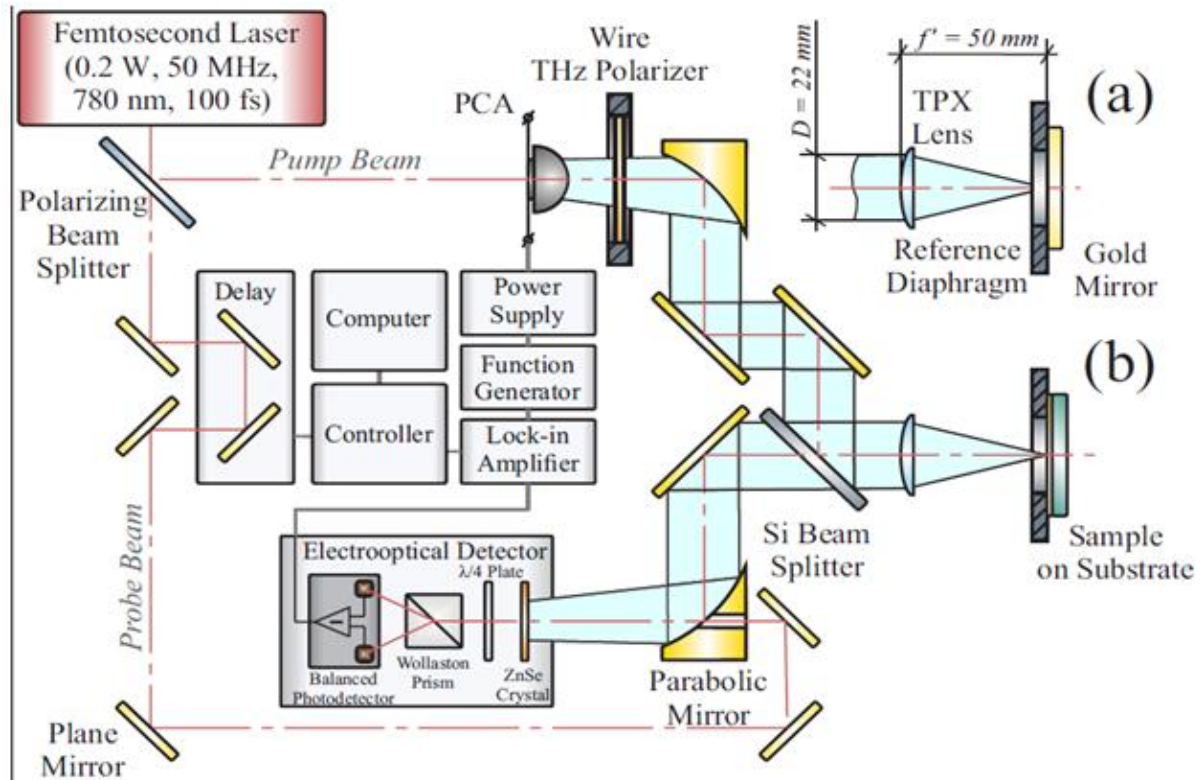

Figure 7. Design of reflective THz spectrometer.

The spectrum of the fabricated MA sample (with set of parameters: a=208μm, b=98μm, p=13μm, g=23μm, w=6μm) was investigated using reflective time-domain THz spectrometer [19] (Fig. 8).
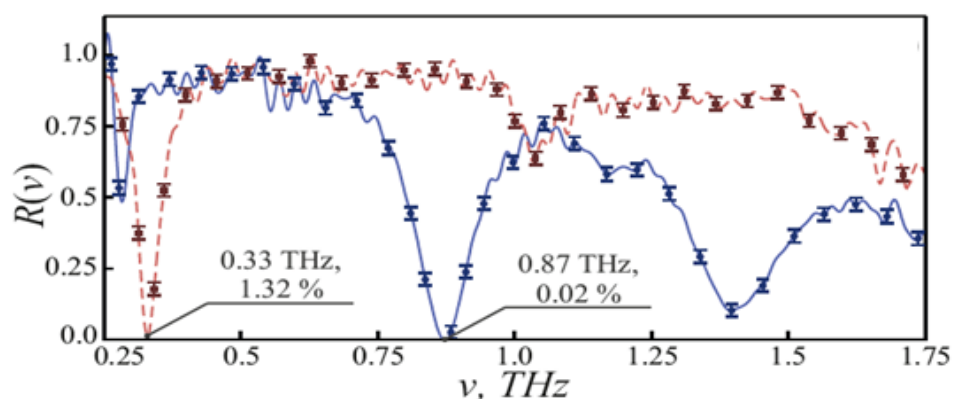

Figure 8. Spectrum of fabricated MA sample for TE-polarization (blue curve) and TM-polarization (red curve).

So absorption 99,98% was demonstrated at the frequency 0.87 THz for TE-polarization (blue curve) and 99,67% at the frequency 0,33 THz for TM polarization (red curve).

5. Conclusions

The results of geometrical parameters and polyimide layer thickness influence on absorption spectrum of MA based on ERR were shown by numerical method FDTD:

- theoretical research of polyimide layer thickness influence on absorption spectrum shows that maximal MA absorptivity is up to 100% at layer thickness of 18 μm;
- enlargement of MA geometrical parameters redshifts the absorption resonant frequency, it's caused by the increasing of ERR inductance.

Experimental results show absorption of 99,98% at the frequency of 0,87 THz for TE-polarization and 98,68% at the frequency of 0,33 THz for TM-polarization.

Acknowledgements

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