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Physics

MICROWAVE ABSORPTION IN METASURFACES INDUCED BY EDDY CURRENTS

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Efficient absorption of a metasurface composed of perpendicularly oriented graphite "meta-strips" is experimentally demonstrated, with the length of meta-strips being around half of the incident wavelength. The absorptance of the metasurface under a normally incident electromagnetic field polarized along meta-strips exceeds 90% in the spectrum of 8–12 GHz. The proposed metasurface is featured by wide incidence angle tolerance.

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Introduction. Microwave absorbers are of great interest due to many important practical applications. Various types of electromagnetic absorbers have been suggested, including the Salisbury screen [1], the Jaumann absorber [2], the Dalenbach layer [3], cross mesh absorbers [4], etc. Recently, absorbers covering entire range of the electromagnetic spectrum from the visible to microwaves attracted huge interest due to many potential applications, such as microwave compatibility of devices [5], sensors [6], bolometers [7], solar energy harvesting [8], and thermal emitters. In addition, many military and space applications such as the creation of "invisible" aircraft, the concealment of ground military radar systems, and the development of anechoic chambers, require efficient microwave stealth surfaces and highly absorbing structures operating in the 2–18 GHz frequency range. In this sense, the processing of new materials that absorb radar signals has recently become an issue of great importance requiring a great deal of research. On the other hand, the rapid development of wireless communication technology has led to the widespread use of electronic devices in various fields. This has contributed to an increase in electromagnetic pollution. One can overcome this issue by utilizing microwave absorbing materials, capable to effectively absorb electromagnetic waves and reduce the negative effects of electromagnetic noise.

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Electromagnetic wave absorbers must have a number of specific characteristics, for instance, independence of the absorption coefficient from the incidence angle and polarization [9], frequency bandwidth of the efficient absorption [10], etc. A number of methods have been proposed to design efficient absorbers in the terahertz [11], microwave [12], infrared [13] and optical [14] spectra.

The creation of broadband absorbers based on metasurfaces in the microwave has aroused great interest in recent years [15, 16]. As a result of their action, the absorbed electromagnetic energy is converted into thermal or other types of energy. As a result of the interaction of electromagnetic waves with the absorber, reflection and transmission of electromagnetic waves is practically absent. An efficient absorber must have light weight, small thickness, easy method of production and wide incidence and polarization angle tolerance.

The first metamaterial-based microwave absorber, proposed by Landy and co-authors in 2008, opened up common strategies to design absorbers with the small thickness [17]. Since then, many researchers have focused on the design and development of metamaterials, and particularly their two-dimensional counterparts also calledmetasurfaces, ranging from the microwave to the optical [18]. However, because of their resonant nature, absorbers utilizing the metamaterial concept are usually narrowband.

Sample and Experiment. The achieved efficient absorption with the proposed metasurface is conditioned by relatively high absorption cross-sections of individual meta-atom elements, on the one hand, and a favorable phase shift of the reflected electromagnetic field from the metasurface on the other. The system consists of graphite strips periodically distributed on a dielectric layer. Graphite layer was created by continuous hatching of the rough surface of a piece of an otherwise transparent dielectric. Due to the applied pressure while hatching, a continuous graphite layer was created on the dielectric surface with the estimated thickness being around 50 μm. Then rectangular strip-like pieces were cut from the graphite-coated dielectric. As the final step, an array of narrow rectangular cavities was defined on the surface of the dielectric substrate by applying a laser patterning technique and the fabricated strips were carefully placed inside the cavities. Such a technique ensures the uniform nature of the meta-atoms. The system of periodically placed graphite tapes on the dielectric surface provides maximum absorption of the metasurface and minimum reflection from it Fig. 1.

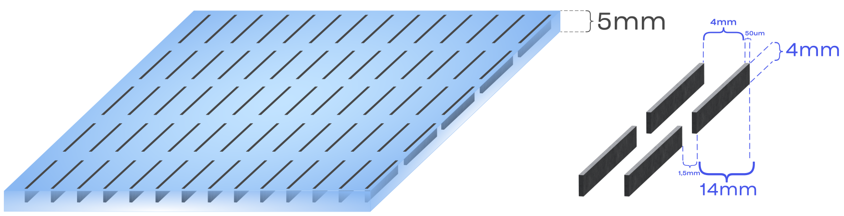

Fig. 1. The schematic of the metasurface array and the unit-cell dimensions.

The studied metasurface differs from other similar absorbers by two main features. First, the surfaces of the conductive "meta-strips" forming it are oriented not parallel but perpendicular to the metasurface. Secondly, the metallic "metatapes", in our case, have been replaced by graphite. Graphite is one of the exceptional materials whose real and imaginary parts of the dielectric permittivity in the microwave frequency range are close in values to each other. This makes it possible to control the reflection phase, which is of fundamental importance in the studied process. It is also noteworthy that the longitudinal dimensions of the tapes are of the order of the length of the incident wave. The schematic sketch of the experimental setup is shown in Fig. 2.

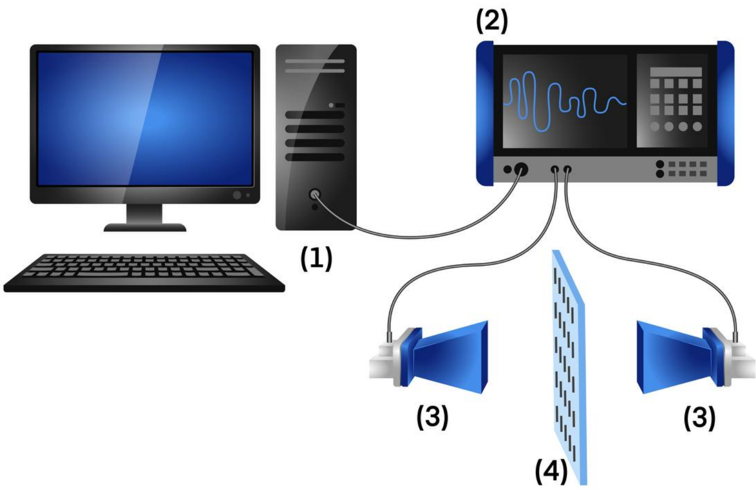

Fig. 2. The schematic sketch of the experiment: (1) computer; (2) vector network analizer (VNA); (3) horn antennas; (4) metasurface.

The experiments were carried out by analyzing reflection S_{11} and transmission S_{21} parameters of the metasurface derived by a R&S VNA ZNB20 vector network analyzer. The system consists of two horn antennas, facing one another at a distance of 50 *cm*, which are respectively connected to the first and second inputs, and samples are located in-between the antennas. Identical horn antennas connected to the inputs operate in the frequency range from 7.8 *GHz* to 12.4 *GHz*.

Results and Discussion. The results were recorded and processed by a computer connected to the VNA. We used signal reflected from a metallic mirror as a reference for the reflection S_{11} coefficient of the metasurface, whereas for the transmission S_{21} parameter was compared with that of the free space (Fig. 3). The incident electromagnetic wave is polarized along the longer sides of strips.

Experimental results show that in the case of normal incidence of a microwave on the metasurface, the absorbed power exceeds 90%. The absorbance decreases by approximately 10% when the incidence angle is 30°

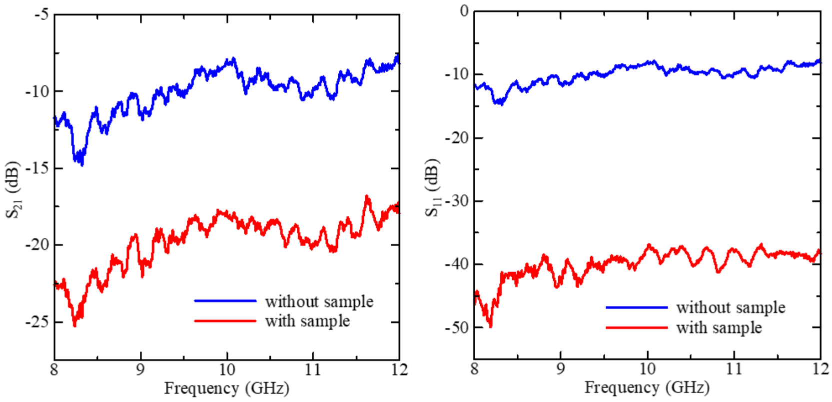

Fig. 3. Experimental results of the transmission S_{21} (left) and reflection S_{11} (right) parameters of the system without (blue lines) and with (red lines) the sample.

It is obvious that the structural features of the metasurface significantly contribute to absorption. In particular, it is of fundamental importance that in the structures the surfaces of the tapes are perpendicular to the metasurface. In our case, when a wave perpendicularly incident to the metasurface is polarized along the tape, the magnetic field of the wave penetrates the graphite tape. As a result, eddy currents are formed, which lead to increased Joule losses. In this case, the power of Joule losses can be estimated according to the formula [19]:

$$P = \frac{1}{16}\lambda h \frac{l^3 a^3}{l^2 + a^2}\omega^2 B^2, \tag{1}$$

here λ is the conductivity; l is the length; a is the width; h is the thickness of the metatape; ω is the frequency of the applied field; B is the magnetic induction. After simple transformations from (1) one obtains:

$$P = \frac{V}{8d^2} \cdot \frac{l^2 a^2}{l^2 + a^2} \cdot \frac{\omega}{c} S, \tag{2}$$

here V is the volume of the metatape; d is the thickness of the skin layer; c is the speed of light; S is the wave energy flux density. With $d = 50\ \mu m$ and the indicated parameters, for the absorption cross section we obtain: $\sigma = \frac{P}{S} \approx 5 \cdot 10^{-4} m^2$.

This value is approximately ten times greater than the cross-section area of the unit cell on the metasurface, and as the experiment shows, is optimal for absorption.

Conclusion. Thus, under a normal incident microwave electromagnetic field, the absorption of a metasurface composed of rectangular graphite strips oriented perpendicular to the surface normal of the substrate exceeds 90% in a broad frequency range of 8–12 GHz. This number decreases by approximately 10% when the incidence angle is 30°.

It is obvious that the structural features of the metasurface significantly contribute to the absorption power. In particular, it is important that in the considering structures, the surfaces of the graphite tapes are perpendicular to the metasurface. In our case, when a wave perpendicularly incident to the metasurface is polarized along the tape, the magnetic field of the wave penetrates through the tape. As a result, eddy flows are formed, which lead to Joule losses. Research has shown that when tape lengths are close to half of the length of the incident wave, more favorable conditions are created for effective absorption.

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REFERENCES

1. Emerson W.H. Electromagnetic Wave Absorbers and Anechoic Chambers through the Years. *IEEE Trans. Antenn. Propag.* **21** (1973), 484–490.
https://doi.org/10.1109/TAP.1973.1140517
2. Namai A., Sakurai S., et al. Synthesis of An Electromagnetic Wave Absorber for High-speed Wireless Communication. *J. Am. Chem. Soc.* **131** (2009), 1170–1173.
https://doi.org/10.1021/ja807943v
3. Munk B.A. *Frequency Selective Surfaces*. John Wiley and Sons (2000).
4. Tsai M.W., Chuang T.H., et al. High Performance Midinfrared Narrowband Plasmonic Thermal Emitter. *Appl. Phys. Lett.* **89** (2006), 173116.
https://doi.org/10.1063/1.2364860
5. Cheng C.W., Abbas M.N., et al. Wideangle Polarization Independent Infrared Broadband Absorbers Based on Metallic Multisized Disk Arrays. *Opt. Express* **20** (2012), 10376–10381.
https://doi.org/10.1364/OE.20.010376
6. La Spada L., Vegni L. Metamaterial-based Wideband Electromagnetic Wave Absorber. *Opt. Express* **24** (2016), 5763–5772.
https://doi.org/10.1364/OE.24.005763
7. Wen Q.Y., Zhang H.W., et al. Dual Band Terahertz Metamaterial Absorber: Design, Fabrication, and Characterization. *Appl. Phys. Lett.* **95** (2009), 241111.
https://doi.org/10.1063/1.3276072
8. Ding F., Cui Y.X., et al. Ultra-broadband Microwave Metamaterial Absorber. *Appl. Phys. Lett.* **100** (2012), 103506.
https://doi.org/10.1063/1.3692178
9. Popov E., Maystre D., et al. Total Absorption of Unpolarized Light by Crossed Gratings. *Opt. Express* **16** (2008), 6146–6155.
https://doi.org/0.1364/OE.16.006146

10. Munk B., Munk P., Pryor J. On Designing Jaumann and Circuit Analog Absorbers (CA Absorbers) or Oblique Angle of Incidence. *IEEE Trans. Antenn. Propag.* **55** (2007), 186–193.
https://doi.org/10.1109/TAP.2006.888395
11. Paul C.R. *Introduction to Electromagnetic Compatibility*. John Wiley and Sons (2006).
12. Grant J., Escorcia Carranza I., et al. A Monolithic Resonant Terahertz Sensor Element Comprising a Metamaterial Absorber and Micro-bolometer. *Laser Photonics Rev.* **7** (2013), 1043–1048.
https://doi.org/10.1002/lpor.201300087
13. Parsamyan H., Haroyan H., Nerkararyan Kh. Broadband Tunable Mid-infrared Absorber Based on Conductive Strip-like Meta-atom Elements. *Materials Today Communications* **31** (2022), 103692.
https://doi.org/10.1016/j.mtcomm.2022.103692
14. Bagmanci M., Karaaslan M., et al. Extremely-broad Band 6 Metamaterial Absorber for Solar Energy Harvesting Based on Star Shaped Resonator. *Opt. Quant. Electron.* **49** (2017), 257.
https://doi.org/10.1007/s11082-017-1091-7
15. Parsamyan H., Haroyan H., Nerkararyan Kh. Broadband Microwave Absorption Based on the Configuration Resonance of Wires. *Appl. Phys. A* **126** (2020), 773.
https://doi.org/10.1007/s00339-020-03964-x
16. Glybovski S., Tretyakov S., et al. Metasurfaces: From Microwaves to Visible. *Physics Reports* **634** (2016), 1–72.
https://doi.org/10.1016/j.physrep.2016.04.004
17. Landy N.I., Sajuyigbe S., et al. Perfect Metamaterial Absorber. *Phys. Rev. Lett.* **100** (2008), 207402.
https://doi.org/10.1103/PhysRevLett.100.207402
18. Shulin Sun, Qiong He, et al. Electromagnetic Metasurfaces: Physics and Applications. *Advances in Optics and Photonics* **11** (2019), 380–478.
https://doi.org/10.1364/AOP.11.000380
19. Siakavellas N.J. Two Simple Models for Analytical Calculation of Eddy Currents in Thin Conducting Plates. *IEEE Transactions on Magnetics* **33** (1997), 2245–2257.
https://www.academia.edu/5555437/Two_simple_models_for_analytical_calculation_of_eddy_currents_in_thin_conducting_plates

Դ. Ս. ՀԱՄԲԱՐՅԱՆ

ՄՐՐԿԱՅԻՆ ՀՈՍԱՆՔՆԵՐՈՎ ՊԱՅՄԱՆԱՎՈՐՎԱԾ ՄԻԿՐՈԱԼԻՔԱՅԻՆ ԿԼԱՆՈՒՄԸ ՄԵՏԱՄԱԿԵՐԵՎՈՒՅԹՆԵՐՈՒՄ

Փորձնականորեն հայտնաբերվել է ընկնող ալիքի երկարության կեսին հավասար և դրան ուղղահայաց դասավորված գրաֆիտե “մետաժապավեններից” բաղկացած մետամակերևույթի արդյունավետ կլանում: Մետամակերևույթի վրա նորմալ ընկնող և ժապավենի երկայնքով բևեռացված միկրոալիքային ճառագայթման գրանցված կլանումը գերազանցում է 90%-ը հաճախությունների 8–12 *GHz* փիրույթում և համեմատաբար քիչ է կախված անկման անկյունից:

Д. С. АМБАРЯН

МИКРОВОЛНОВОЕ ПОГЛОЩЕНИЕ В МЕТАПОВЕРХНОСТЯХ, ОБУСЛОВЛЕННОЕ ВИХРЕВЫМИ ТОКАМИ

Экспериментально обнаружено эффективное поглощение метаповерхности, состоящей из графитовых “металент", которые расположены перпендикулярно к падающей волне и длина которых близка к половине длины этой волны. Мощность поглощения микроволнового излучения, поляризированного вдоль ленты, при нормальном падении на метаповерхность превосходит 90% мощности излучения в диапазоне частот 8–12 *GHz* и сравнительно мало зависит от угла падения.