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METAMATERIAL WITH HIGH OPTICAL ABSORPTION

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Artificial absorbing materials with unique electromagnetic properties are considered. They are called metamaterials and are determined by their subwavelength building blocks. Manipulation of those blocks allows defining of the electric and magnetic responses to incident radiation. Because fabrication of three-dimensional metamaterials is complex and challenging, especially for optical frequencies of incident radiation this paper proposes a simple, easy to construct metamaterial absorber of electromagnetic radiation at optical frequencies.

Key words: metamaterial absorber, optical absorption, nanoresonator

Metamaterials are one of the most exciting areas of applied physics nowadays. Because of their peculiar properties, such as negative refraction index [1], fantastic possibilities become now a reality, e. g. electromagnetic cloak [2]. Metamaterial is a wide name for an engineered material, artificially structured periodic material, crafted to have certain properties. Its electromagnetic properties are determined by their subwavelength building blocks. Metamaterials possess an ability of independent tailored electric and magnetic responses to incident radiation [3, 4].

Aim of this paper is to propose a simple, easy to construct and cheap metamaterial absorber of electromagnetic radiation at optical frequencies. Such absorbers have wide applications in modern day science, e.g. spectroscopy, solar cell enhancement, thermal imaging, emissivity control, etc [5–14]. Metamaterials composed of nanoscale resonators with adjustable electromagnetic response can become good optical wavelength absorbers [16]. Their advantage is the possibility to construct broadband optical absorbers with advanced functionalities.

The extent of electromagnetic losses in the constituent material depends on its capability to convert electromagnetic energy into heat. We can consider the entire metamaterial to be characterized by a complex electric permittivity $\varepsilon(\omega) = \varepsilon_1 + i\varepsilon_2$ and magnetic permeability $\mu(\omega) = \mu_1 + i\mu_2$, as an effective medium [17] and use nanoscale resonators to add large imaginary parts into the effective permittivity/permeability dispersion of the homogenous medium [18]. Loss components of the optical constants (ε_2 and μ_2) have the potential for the creation of materials with high absorption properties. This imaginary parts result in high absorption over certain band around resonance of the passing wave. By manipulating resonances in ε and μ independently, it is possible to absorb both the incident electric and magnetic field.

Metamaterial, which can be a good absorber in optical wavelength region, has to consist of building blocks way smaller than optical wavelength. Much effort has been devoted to metamaterials design and fabrication for obtaining desired optical properties. However, the fabrication of three-dimensional metamaterials is challenging, because current metamaterials fabrication techniques rely highly on top-down lithographic approaches [19]. There have been attempts to engineer a metamaterial with broad bandwidth by integrating many nanoscale resonators into a unit cell by stacking them on top of each other [15]. Fabricating multiple aligned nanoscale features is complex and time-consuming, and the proposed structures are only strongly absorbing for a single polarization.

Bossard et al. [16] have proposed an interesting design for optical metamaterial absorber with wide bandwidth. Their idea is to create metamaterial absorbers based on electromagnetic band gap surfaces. This approach led them to the metamaterial absorber unit cell shown on Figure 1 (figure from [16]). It integrates three well-designed electromagnetic elements in a single metal screen layer that meets predesigned fabricati-

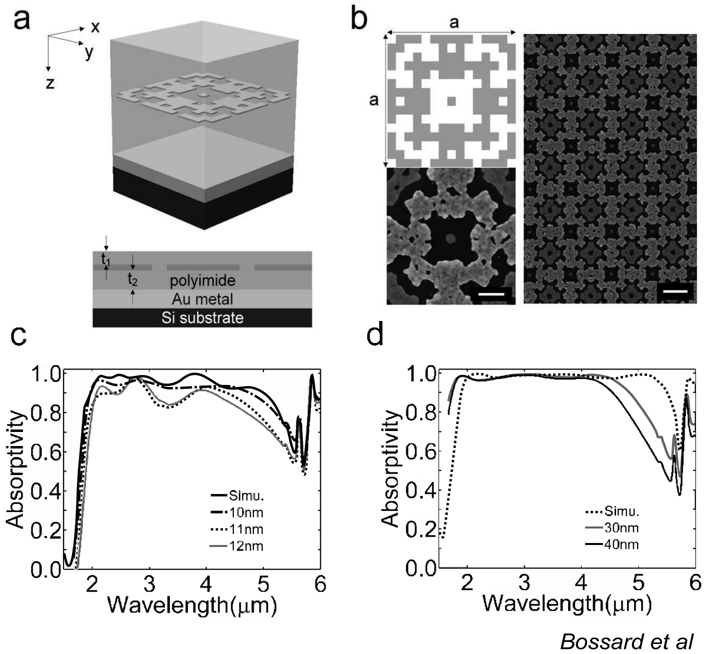

Fig. 1. (a) Diagram of the Au-based metamaterial absorber structure. (b) Top left: Top view of one unit cell of the design. Bottom left: Field Emission Scanning Electron Microscopy (FESEM) image of a unit cell of the fabricated structure. Scale bar is 200 nm. Right: Low-magnication FESEM image of the same structure. Scale bar is 600 nm. (c) Simulation and measurements for Au-based absorber under unpolarized illumination at normal incidence. The average Au thicknesses of the Au nanostructures determined by atomic force microscopy measurements are 10, 11, and 12 nm. (d) Simulation and measurements for Pd-based metamaterial absorbers with Pd nanostructure thicknesses of 30 and 40 nm under unpolarized illumination at normal incidence.

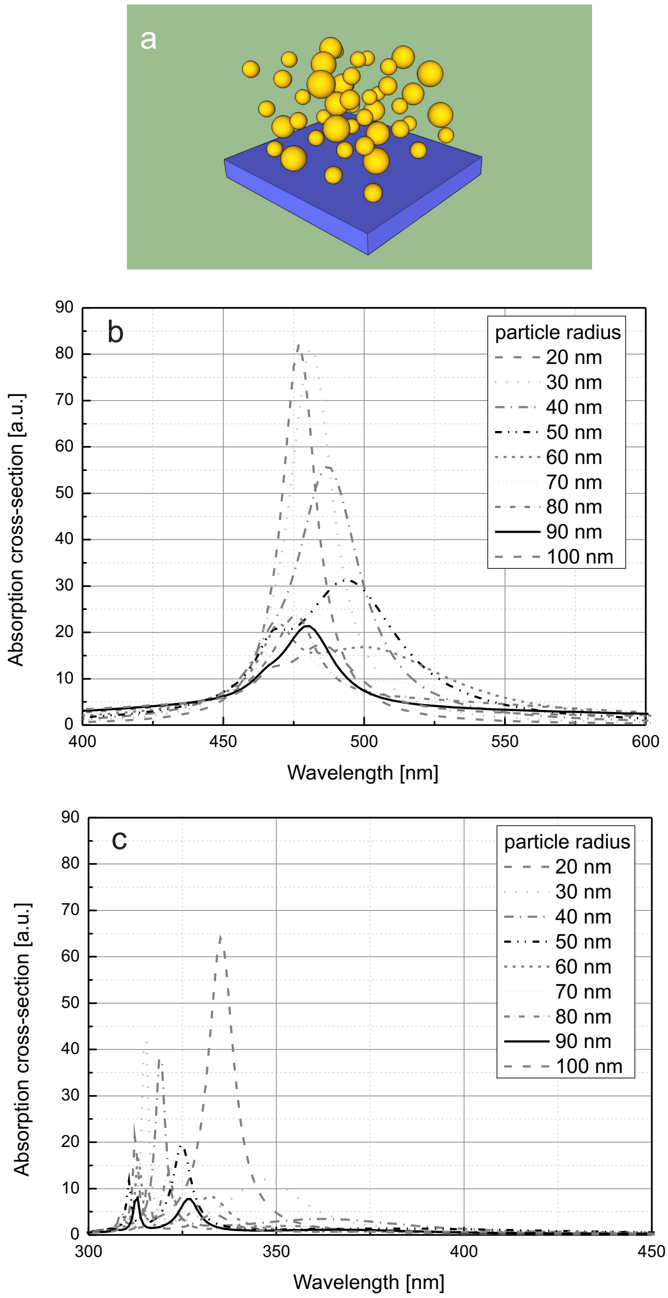

Fig. 2. (a) A schematic illustration of a model of metamaterial absorber consisting of Au spherical nanoparticles of different radii. (b, c) Simulated absorption cross-section of Au and Ag spherical nanoparticles correspondingly with radii from 20 to 100 nm. Graph shows multiple maxim a in absorption spectrum of gold or silver nanoparticles. Electric permittivity of gold and silver is taken from Johnson's and Christy's paper [20].

on constraints. They demonstrated a polarization-independent metallo-dielectric electromagnetic band gap based absorber with achieved an average absorptivity of 98% over the bandwidth from 1.77 to 4.81 μm and a wide $\pm 45°$ FOV.

But this design still requires complicated engineering. Another way to construct a light absorbing metamaterial is to mix different metal absorbing nanoparticles of different sizes. Spherical nanoparticles have and advantage of being relatively easy and cheap to produce. Such particles, being symmetrical, have their optical absorption independent on the direction of the incident electromagnetic radiation. If one requires an absorber of narrow bandwidth it is easy to choose the nanoparticles of defined size and material, to match the desired wavelengths of incident electromagnetic radiation. But if we need a material with broader bandwidth it is possible to implement nanoparticles of different sizes. Due to the inherent properties of metals, nanosized spheroids have eigen frequencies at which incident electromagnetic radiation induces resonances, causing high absorption. On the example of gold and silver spheroidal nanoparticles (see Figure 2) we can see how size of the absorbing nanoparticles relates to the wavelength of the incoming light. Such design is easy to implement, allows composition of metamaterial with tailored electromagnetic response. Figure 2a shows a simple model of metamaterial consisting of Au-nanospheres of different radii. Implementing nanoparticles of other metals, different sizes or shapes allows to modify the shape of the absorption spectra seen on the Figure 2b,c.

Broadband optical absorbers with advanced functionality become possible because of metamaterials. Metamaterials composed of nanoscale resonators with adjustable electromagnetic response create unique possibilities. Properties of the metamaterial optical absorber can be steered by choosing defined size and/or material of the nanoparticles used as building blocks. A relatively simple design has been proposed for metamaterial consisting of nanospheroids of different sizes and composition, which does not require complicated litographic methods. This communique is a first step of engineering a metamaterial, with designed absorbing properties. Real experimental setup, of measuring electromagnetic response of optical metamaterial is a topic of our future studies.

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МЕТАМАТЕРІАЛ З ВЕЛИКИМ ОПТИЧНИМ ПОГЛИНАННЯМ

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Розглядаються штучно сконструйовані метаматеріали з унікальними електромагнітними властивостями. Вони залежать від складових елементів цього матеріалу, які менші ніж довжина хвилі. Маніпулючи цими елементами, можна надати метаматеріалу відповідно задану електричну та магнетичну відповідь на падаюче випромінювання. Оскільки будова такого метаматеріалу є складною і вимогливою, особливо у випадку видимого діапазону хвиль, ця праця пропонує простий поглинаючий метаматеріал електромагнітного випромінювання видимого діапазону довжин хвиль.

Ключові слова: поглинаючий метаматеріал, оптичне поглинання, нанорезонатор.

МЕТАМАТЕРИАЛ С БОЛЬШИМ ОПТИЧЕСКИМ ПОГЛОЩЕНИЕМ

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Рассматриваются искусственно сконструированные метаматериалы с уникальными электромагнитными свойствами. Они зависят от составляющих элементов этого материала, которые меньше чем длина волны. Манипулируя этими элементами, можно предоставить метаматериала соответствии заданную электрическую и магнетическое ответ на падающее излучение. Поскольку строение такого метаматериала является сложной и требовательной, особенно в случае видимого диапазона волн, эта работа предлагает простой поглощающий метаматериал электромагнитного излучения видимого диапазона длин волн.

Ключевые слова: поглощающий метаматериал, оптическое поглощение, нанорезонатор.