Exploiting extreme coupling to realize a metamaterial perfect absorber

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Recent developments in the field of metamaterials suggest that perfect absorbers have high potential for a number of applications and are therefore one focus of interest [1][2]. To achieve perfect absorption, transmission is commonly eliminated by metal-coating of the substrate whereby reflection is significantly suppressed by exploiting specifically tailored plasmonic resonances that dissipate the energy with no or only marginal radiation losses. In perfect absorbers, these plasmonic resonances are usually achieved by coupling a metallic nanoparticle with the metallic substrate by bringing them in close proximity [3][4]. While such functionality might be rather easily achieved for a specific propagation direction and frequency, it is a challenge to retain perfect absorption for all angles of incidence at a desired frequency; and possibly multiples thereof. In the present contribution we show that the exploitation of the extreme coupling regime between closely spaced nanostructured gold metal plates and the planar gold substrate allows for an easy control at even multiple resonance frequencies, which are extremely sensitive to the thickness d_{Oxide} (see Fig. 1). The extreme coupling here suggests that the distance between the metal plates and the planar substrates is only in the order of one or a few nanometer, a size domain only accessible by atomic layer deposition.

The fabrication of the “metamaterial perfect absorber”-structures (MPA) starts on wafer-level. A 4” fused-silica wafer was prefabricated and sliced in 15 x 15 mm² -chips which contain six 2 x 2 mm² gold mirror plates (thickness 200 nm), see figure 2. Each chip was individually coated with an ultrathin SiO_2-film in the thickness range of 1 to 10 nm using atomic layer deposition. On top of this dielectrical layer a 2D-gold grating with a period of 250 nm and dot-size up to 230 nm was prepared using electron beam lithography, thermal evaporation of gold and lift-off-technique (figure 3). As lift-off mask a thin two-layer resist (150 nm ZEP520A on 100 nm ARP617.03) was used and the aligned two-layer-e-beam-exposure was performed using the shaped beam writer SB350 OS (50 keV, Vistec Electron Beam GmbH).

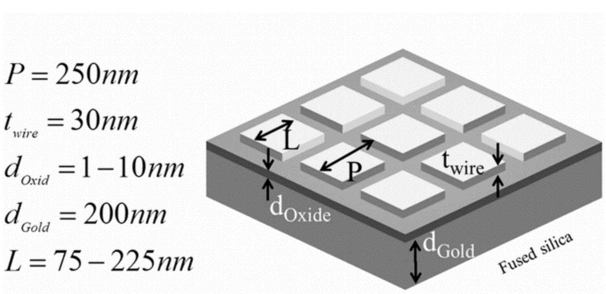


Fig. 1: Geometry of the metamaterial perfect absorber (MPA).

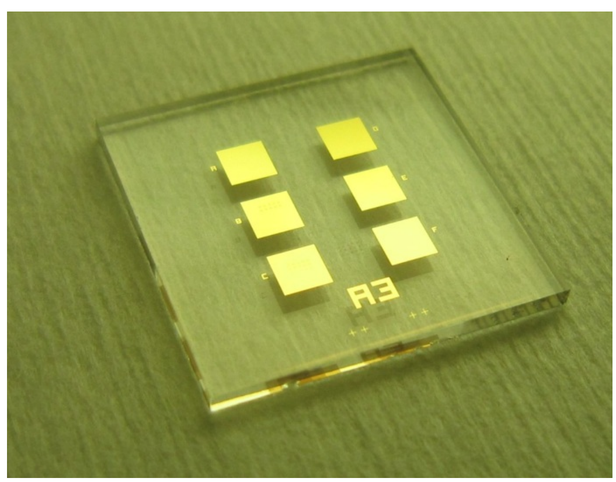
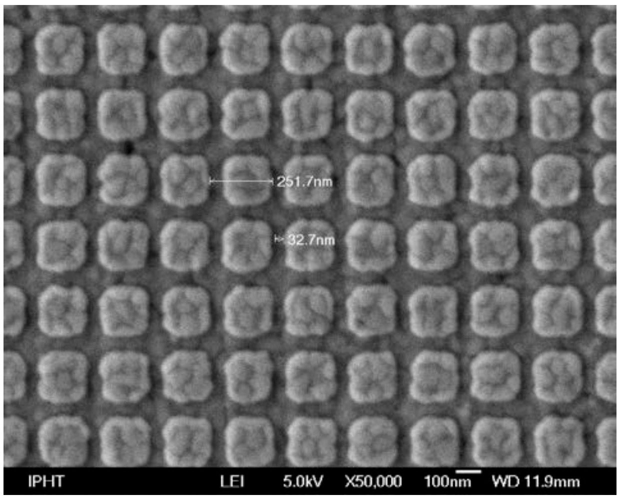


Fig 2: Fused-silica chip (15x15 mm²) containing five 2 x 2 mm² MPA-gratings and one gold reference plate for the optical characterization.

The optical response of the fabricated structures was determined with a FTIR Bruker Spectrometer (Vertex 80) connected to a microscope (Hyperion 2000) in reflectance mode. The reflection measurements were performed for TE and TM polarizations in the spectral range from 75 THz to 600 THz for angles of incidences of 0 and 70 degrees. The spectrum obtained for normal incidence on the sample shown in Fig. 3 is demonstrated in Fig. 4. The measured spectrum shows a very good correspondence with the simulated one. The minima at about 180 THz and 420 THz in the reflection spectrum correspond to the excitation of two modes in the structure. The excitation of these two modes proofs the presence of the isolating dielectric ALD layer.



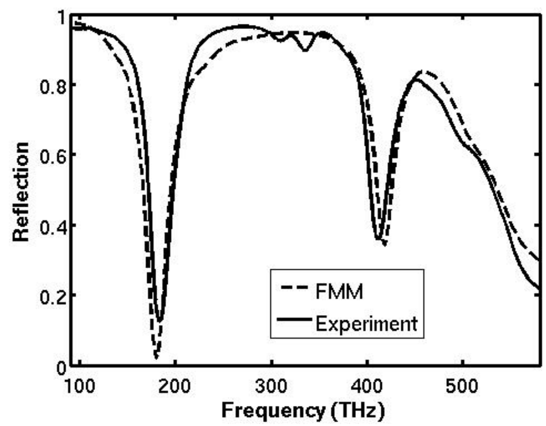


Fig 3: SEM-image of a MPA (lifted 2D-goldgrating with a pitch of 250 nm and a gap-width of 30 nm, thickness of gold: 30 nm).

Fig 4: Reflection at normal incidence as obtained by measurements and simulation. Note that the absorption is almost perfect at 180 THz (~ λ = 1.6 μm).

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References

[1] C. M. Watts, X. Liu, and W. J. Padilla, Metamaterial electromagnetic wave absorbers, Adv. Mater. 24, OP98--OP120, (2012).
[2] J. Hao, L. Zhou, and M. Qiu, Nearly total absorption of light and heat generation by plasmonic metamaterials, Phys. Rev. B 83, 165107 (2011).
[3] C. Menzel, R. Alaee, E. Pshenay-Severin, C. Helgert, A. Chipouline, C. Rockstuhl, T. Pertsch, and F. Lederer, “Genuine effectively biaxial left-handed metamaterials due to extreme coupling”, Opt. Lett. 37, 596 (2012).
[4] C. Wu, B. Neuner, G. Shvets, J. John, A. Milder, B. Zollars, and S. Savoy, ”Large-area wide-angle spectrally selective plasmonic absorber,” Phys. Rev. B 84, 075102 (2011).