LA-UR- 09-07901

Approved for public release; distribution is unlimited.

Title: Perfect terahertz absorber using fishnet based metafilm

Author(s): Abul K. Azad,
D. Yu Shchegolkov,
Hou-Tong Chen,
Antoinette J. Taylor,
E. I. Smirnova, and
John F. O'Hara

Intended for: Meeting/Conference submission for Conference on Lasers and Electro Optics. The Conference will be held on San Jose, CA, Date: May 16, 2010.

Los Alamos NATIONAL LABORATORY EST. 1943

11/23/09 - Sent to Susie for Toni's Signature

Perfect terahertz absorber using fishnet based metafilm

Abul K. Azad, D. Yu Shchegolkov, Hou-Tong Chen, Antoinette J. Taylor, E. I. Smirnova, and John F. O'Hara

[1]*MPA-CINT, Los Alamos National Laboratory, Los Alamos, NM-87545*
Email: aazad@lanl.gov

Abstract: We present a perfect terahertz (THz) absorber working for a broad-angle of incidence. The two fold symmetry of rectangular fishnet structure allows either complete absorption or mirror like reflection depending on the polarization of incident the THz beam.

OCIS codes: (999.9999) Terahertz;

Metamaterials enable the ability to control the electromagnetic wave in a unique fashion by designing the permittivity or permeability of composite materials with desired values. Although the initial idea of metamaterials was to obtain a negative index medium, however, the evolution of metamaterials (MMs) offers a variety of practically applicable devices for controlling electromagnetic wave such as tunable filters, modulators, phase shifters, compact antenna, absorbers [1-3], etc. Terahertz regime, a crucial domain of the electromagnetic wave, is suffering from the scarcity of the efficient devices and might take the advantage of metamaterials. Here, we demonstrate design, fabrication, and characterization of a terahertz absorber based on a simple fishnet metallic film separated from a ground mirror plane by a dielectric spacer. Such absorbers are in particular important for bolometric terahertz detectors, high sensitivity imaging, and terahertz anechoic chambers. Recently, split-ring-resonators (SRR) have been employed for metamaterial-based absorbers at microwave and THz frequencies. The experimental demonstration reveals that such absorbers have absorptivity close to unity at resonance frequencies. However, the downside of these designs is that they all employ resonators of rather complicated shape with many fine parts and so they are not easy to fabricate and are sensitive to distortions.

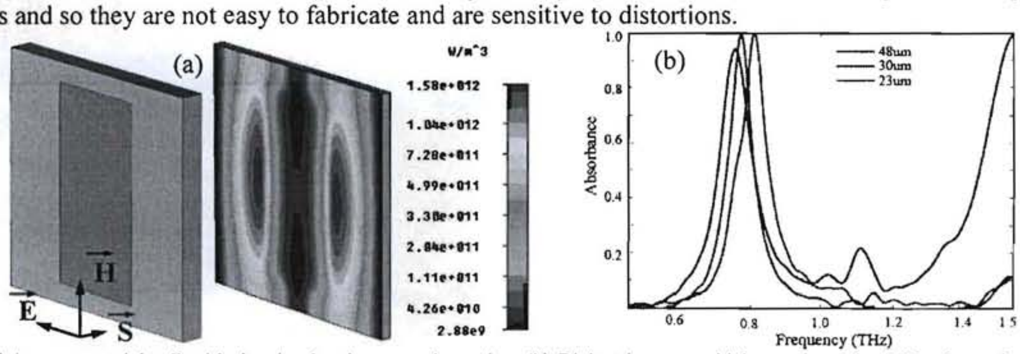

Fig. 1(a) Unit metamaterial cell with the simulated energy absorption. (b) Dielectric spacer thickness dependent THz absorption at 20° angle in TE orientation with THz electric field along the shorter axis of rectangular holes.

The samples used for this work are fabricated by using standard photolithograph in a bottom up fashion. First, the ground plane mirror is fabricated on a 1mm-thick silicon wafer by using e-beam deposition of 200-nm-thick gold (Au). On top of the Au film a thick layer of polyimide was spin coated and subsequently cured at 250°C for an hour. The cured-polyimide film has a refractive index of 1.85 with absorption of 20 cm^{-1}. The metallic fishnet structures are formed on polyimide layer using another 200-nm-thick Au layer. The size of the rectangular hole in the fishnet films is 150 μm × 75 μm with a periodicity of 180 μm. The principle of operation of this metamaterial is similar to a Fabry-Perot cavity except the semi-transparent mirror was replaced by a metallic fishnet layer. We have simulated terahertz reflection from such composite medium using Microwave Studio which shows that the electromagnetic energy is mostly dissipated in the polyimide film as depicted in Fig. 1(a).

We measured the absorbance of these metamaterials using a fiber-coupled photoconductive antenna based THz time domain spectrometer. The system is capable of measuring angle dependent reflection with a minimum angle of incidence 20° for both transverse electric (TE) and transverse magnetic (TM) incidence. During these measurements the polarization of the incident THz electric field was carefully align long the short axis of the rectangular hole. The ground plane mirror is optically thick enough to transmit any THz radiation which makes our absorption measurements simpler. The specular reflections from the metamaterials were compared with the reflections from a perfect mirror to calculate the absorbance. Fig. 1(b) compares the TE absorbance of such absorbers as a function of the thickness of the polyimide spacing layer for an incident angle of 20°. There is an optimum thickness of the polyimide layer for which the absorption reach to unity and in our case this thickness is 22 μm. The resonant frequency was blue-shifted when the polyimide thickness was reduced from 42 μm to 22 μm.

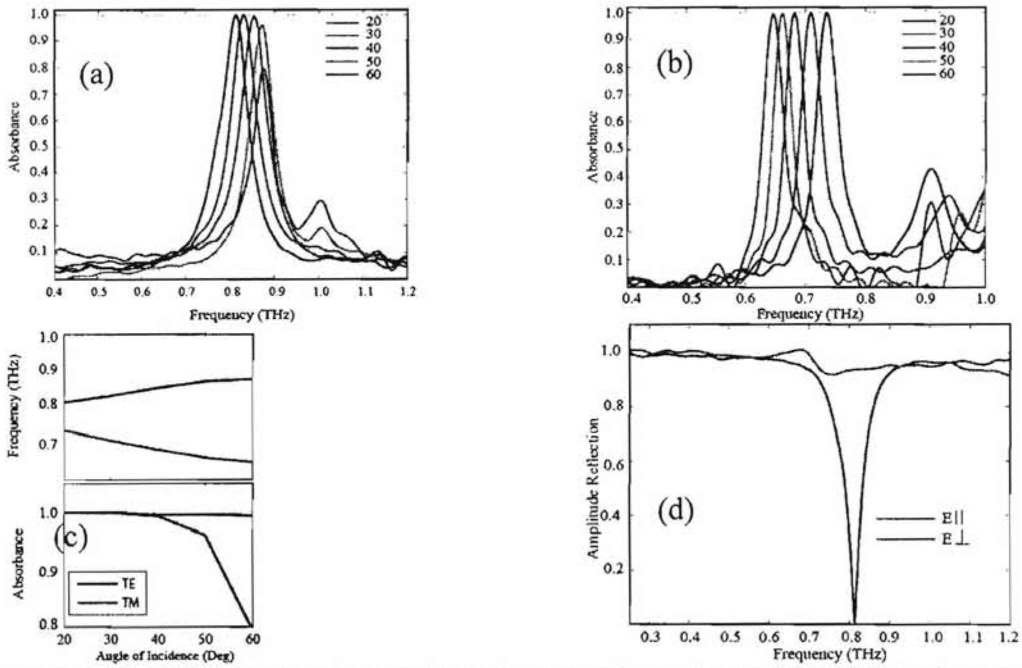

Fig. 1 Measured (a) TE and (b) TM absorption at various incident angles. (c) Angle dependent peak absorption frequency and absorbance at TE and TM incident. (d) Comparison of reflections for two orthogonal orientations of the THz electric fields.

To understand the angle dependent absorption, we restricted our measurements only on the MM sample made of 22μm-thick polyimide film. The sample was measured at various angle of incident for both TE and TM orientations. Fig. 2(a) and (b) shows the absorption for TE and TM incidence, respectively. At TE incidence the absorption remains over 99% for an incident angle up to 40° and after that we observed a gradual downslide. The absorption peak frequency shows a blue shift with increasing angle of incidence. The absorber works more efficiently for TM incidence at higher incident angle. Measured absorptions remain almost 100% for 60° angle of incident. We did not increase the angle of the incident more than 60° because of the finite size of the sample. Again, the absorption peak shows a red shift with increasing angle of incidence. The angle dependent absorption peak frequency and the absorbance are shown in Fig. 2(c). The angle dependent absorption frequency for TE and TM should converse to a single frequency for normal incident or for transverse electric and magnetic (TEM) incident. Our measured data predicts the absorption frequency for TEM incidence around 0.78 THz. Both TE and TM polarization shows a strong depends of the peak absorption frequency on the angle of incidence. This can benefit some applications such as mechanically frequency tunable absorbers. We have not noticed any significant change in the absorption line width.

We also measured THz reflections with the electric field polarization parallel ($E_{\|}$) and perpendicular ($E_{\perp}$) to the smaller axis of the rectangular hole at 20° angle in TE orientation. The reflections of two orthogonal polarizations are shown in Fig. 2(d). The absorber shows almost mirror like reflection for $E_{\perp}$ orientation with reflection amplitude as high as 95% which turns to a very little absorption. However, for similar configuration the $E_{\|}$ reflection amplitude is almost zero or shows a complete absorption. The two fold symmetry of our absorber design might be useful for designing polarizing mirrors for circularly polarized THz beam. Such metafilm absorbers may be utilized in THz bolometer-type detectors, nonreflecting surfaces, thermal imaging, and narrow band THz sources. Combined with thermo detectors these absorbers might find application for precise frequency-selective detection of THz radiation. It is also worth noting that the absorption peak frequency can be tuned dynamically by introducing special dielectrics as the spacer whose permittivity can be controlled by electrical or optical fields.

This work was performed in part, at the Center for Integrated Nanotechnology, Los Alamos National Laboratory.

Reference:

[1] H. -T. Chen, J. F. O'Hara, Abul K. Azad, A. J. Taylor, R. D. Averitt, *et al, Nature Photonics,* Volume 2, 295(2008).
[2] C. J. Lee, K. M. K. H. Leong, and T. Itoh, IEEE Trans. Ant. Prop., Vol 54, 2283(2006).
[3] N.I. Landy, S. Sajuyigbe, J.J. Mock et al, Phys. Rev. Lett., V. 100, p. 207402 (2008).