Micro-Fabrication of Terahertz Metamaterial Absorbers

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We present a polarisation insensitive resonant metamaterial absorber in the THz region. The device consists of a metal/dielectric spacer/metal structure allowing us to maximize absorption by varying the dielectric material and thickness hence the effective electrical permittivity and magnetic permeability. An experimental absorption of 77% and 65% at 2.12 THz (in the operating frequency range of THz QCLs) is observed for a spacer of polyimide or silicon dioxide respectively.

Since the first theoretical [1] and experimental demonstration [2] of the unique properties of metamaterials (MM) research into the topic has grown rapidly. MMs can provide a highly controllable electromagnetic response in different frequency bands enabling investigations in to new possibilities such as perfect lenses and invisibility cloaks. A further aspect, however, of MMs that is currently provoking wide interest is the topic of so called MM perfect absorbers. By manipulating the effective electrical permittivity, ε, and magnetic permeability, μ, absorption close to unity is possible.

The schematic of a single unit cell of our MM absorber is shown in Fig. 1(a) and the layer cross-section is shown in Fig. 1(b). Two metallic elements: one ground plane and a cross shaped resonator are separated by a dielectric layer of thickness, *t*. The cross-shaped resonator is an example of an electric ring resonator (ERR) and couples strongly to uniform electric fields, but negligibly to magnetic ones. By pairing the ERR with a metallic ground plane the magnetic component of the incident THz wave couples to both the centre section of the ERR and the ground plane thus generating anti-parallel currents resulting in a resonant response.

In fabricating the MM absorber, first a 20/300 nm Ti/Au metallic ground plane was evaporated onto a silicon substrate. The dielectric layer was then deposited on to this metallic film either by spin coating a liquid polyimide (HD Microsystems PI2545) or by a plasma enhanced vapour deposition of SiO_2. The polyimide thickness was modified by varying the spin speed/duration and by using multiple coatings. The MM cross-shaped absorber was defined in a bi-layer of PMMA e-beam resist using a Vistec VB6 e-beam tool and a second 20/300 nm film of Ti/Au evaporated and lifted off. SEM images of a MM pixel and a section of the array are shown in Figs. 1(c).

Samples were characterized under vacuum in a Bruker IFS 66v/S Fourier Transform Infrared Spectrometer in transmission mode at normal incidence and in reflection mode at 30° incidence. As shown in Fig 1(d) the absorption spectra are insensitive to the incident polarisation angle. The experimentally obtained transmission and absorption spectra as well as the simulated data for a MM absorber with a 3.1 μm thick polyimide dielectric spacer are shown in Fig. 2(a). The experimental transmission is zero across the entire frequency range while the peak absorption was measured to be 77% at 2.12 THz. This result is in excellent agreement with the simulated absorption maximum of 81%. Fig. 2(b) shows the experimental data for MM absorbers with polyimide thicknesses ranging from 1-7.5 μm and for an absorber where the dielectric is 3 μm of SiO_2. The effective permittivity and permeability were extracted from the simulated data via inversion of the S parameters [3]. As can be observed, the real parts of the optical constants are equal when they are close to zero – a condition required for zero reflection. In addition, when the real part of the permittivity is positive the real part of the permeability is negative, and vice versa – a condition required for zero transmission.

References:

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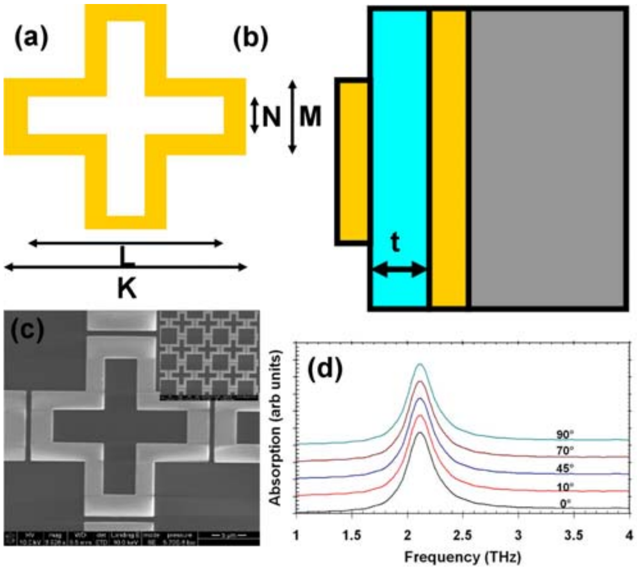

Fig. 1. (a) Schematic of the ERR of the MM absorber and (b) cross-section of complete MM absorber. (c) SEM image of the unit cell and (inset) section of the array. (d) Absorption spectra for different incident polarisation angles showing polarisation insensitivity of the MM structure. Each successive plot from 0-90° is offset by one major unit of the ordinate axis. All MM structures presented here had a repeat-period of 27 μm and dimensions K = 26 μm, L = 20 μm, M = 10 μm and N = 5 μm

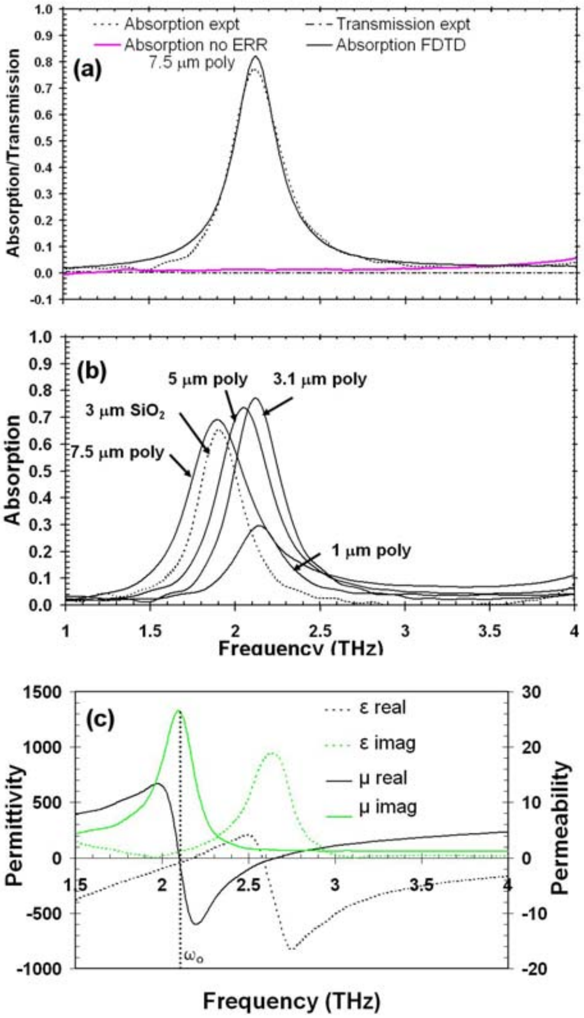

Fig. 2. (a) Experimental and simulated data of a MM absorber with a polyimide thickness of 3.1 μm. The transmission is zero across the entire frequency range. (b) Experimental absorption spectra for MMs with differing dielectric spacer thickness and type. (c) Extracted optical parameters from simulated 3.1 μm thick polyimide MM absorber