Terahertz metamaterials based on resonance in TiO_2 microspheres

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Abstract

Metamaterials composed of high-permittivity TiO_2 microspheres with diameters of 30–100 μm show a magnetic resonance in the THz range. The resonances observed in terahertz spectra were broadened by nonuniform sizes of microspheres and match those predicted by numerical simulations.

1. Introduction

We study electromagnetic metamaterials consisting of an array of TiO_2 microspheres. Particles with sizes ranging from 30 μm to 100 μm and high relative permittivity ($\varepsilon \approx 90$) exhibit magnetic Mie resonances in the range of 0.3 to 1 THz [1]. The array of microspheres therefore acts as a medium with effective permittivity and permeability substantially different from those of constituent media.

The submillimeter wavelength of the electromagnetic radiation allows reasonable resolution for imaging, still the metamaterials for this spectral range may be easily produced. Moreover, resonances in this spectral band could be conveniently measured using terahertz time-domain spectroscopy.

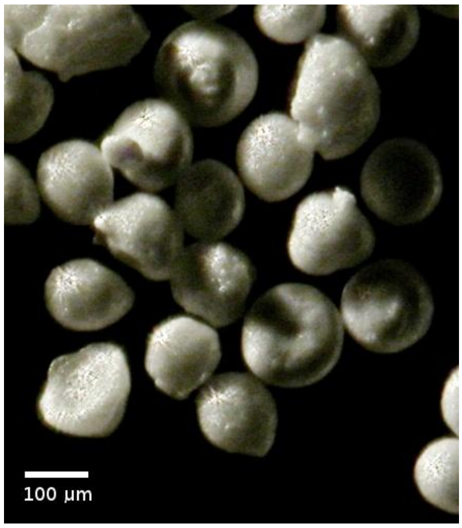

Fig. 1: *An optical microphotograph of the '100' sample*

2. Samples preparation and characterisation

Powder of TiO_2 was mixed with ethanol to obtain a liquid suspension, which was then sprayed through flame. This resulted in forming nearly spherical clusters.

These microspheres were then annealed in a tube furnace at 1500 K for 2 hours, in order to solidify them and to minimize their porosity. The microspheres were finally sieved and sorted according to their diameters (Fig. 1).

We characterized the samples using an optical microscope. Microscopic observations with crossed polarizers allowed us to conclude that the constituent material is polycrystalline with grain sizes of roughly 1 to 5 μm.

The size and ellipticity statistics of the microspheres were obtained by numerically processing series of digital microphotographs (see Fig. 2). Although the samples were sieved, we observed a broader distribution of sizes. We present two of the samples, named ”40–50” and ”100” according to the nominal particle size.

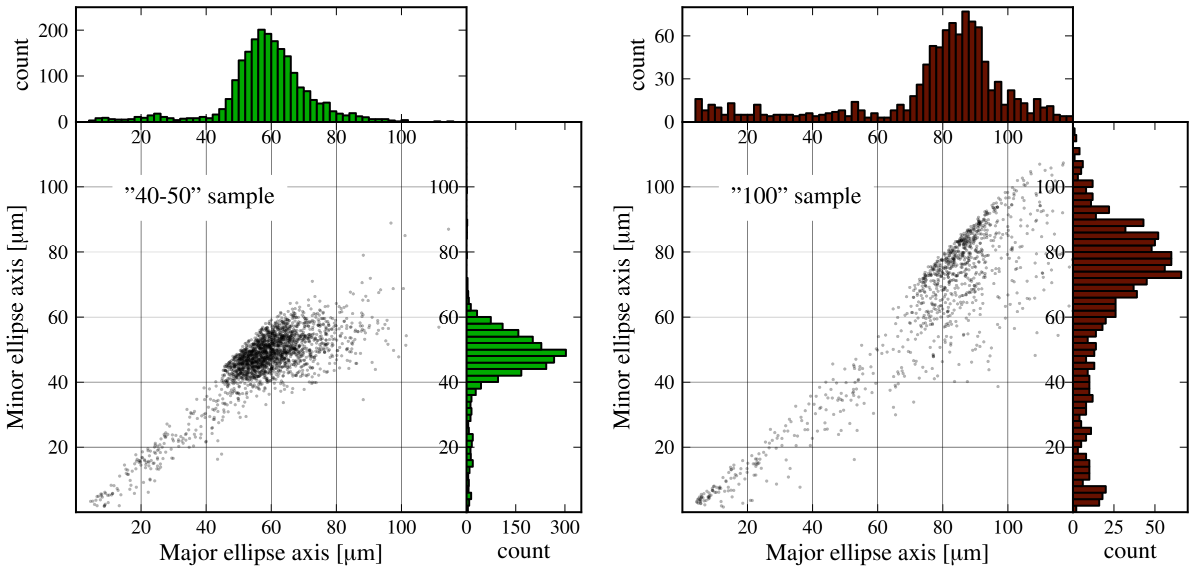

Fig. 2: *Major and minor axes statistics for two different samples, assuming elliptical particle shapes*

3. Experiment and results

We investigated the properties of several samples consisting of a single layer of randomly distributed TiO_2 microspheres with filling fraction of ≈15% using both numerical simulations and experimental THz transmission and reflection measurements.

In the experimental setup, a broadband terahertz pulse passed through one layer of microspheres. To obtain both transmission and reflection spectra, we surrounded the microspheres by thick sapphire slabs. This introduced additional echoes to the waveform, some of which were reflected at the sample-sapphire interface. These echoes were separated and served as additional inputs for the calculation of effective permittivity and permeability spectra. The detailed information on this method is provided in [2].

Numerical simulations confirm the possibility of reaching strong magnetic resonance in the terahertz range for a set of microspheres of the same size. This resonance is narrow and it becomes much less pronounced after being convolved according to the microsphere size distribution (Fig. 3).

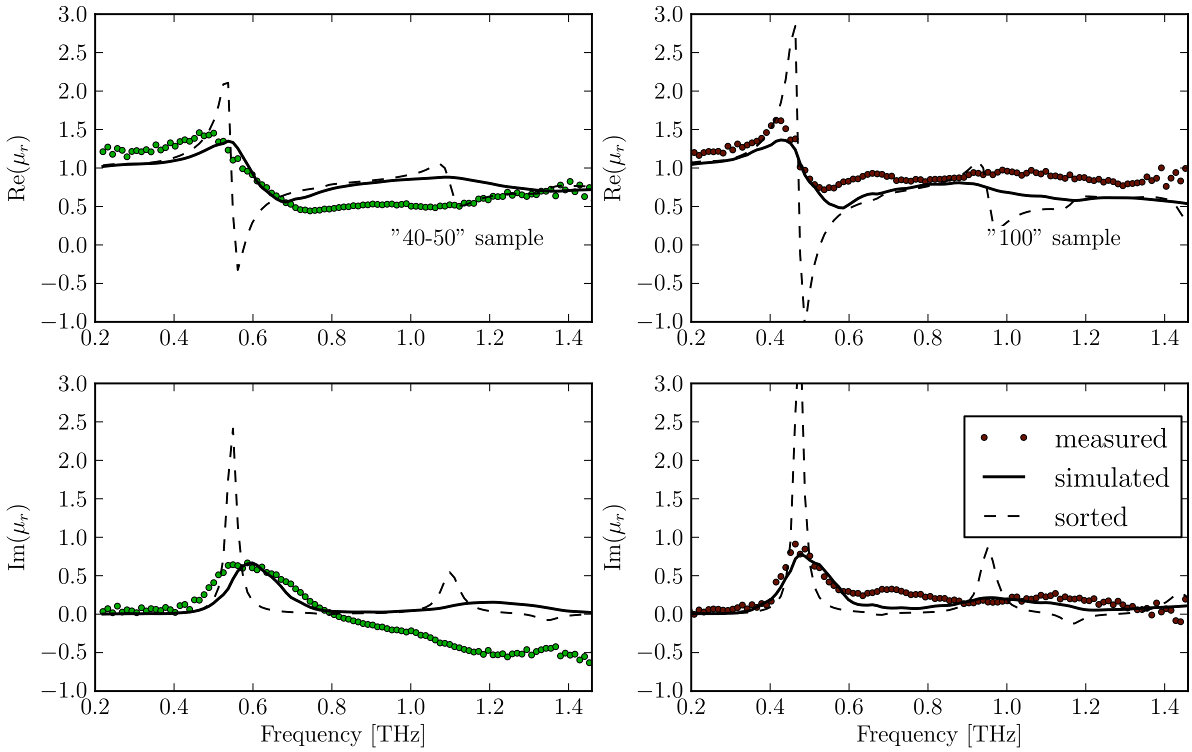

Fig. 3: *Comparison of measured and simulated spectra of complex relative permeability μ_r. Simulated spectra were broadened by the microspheres size distribution. Dashed line shows the simulated resonance for a perfectly sorted sample.*

4. Conclusion

The experiment proved that the magnetic response of the microspheres is determined by Mie resonance, in agreement with the numerical simulation. Negative permeability is predicted for monodisperse samples or samples with high filling fractions.

Our plan is to improve the sorting process, and to investigate the relation between the simulated single-sphere resonance and the overall response of the sample as well as possible improvements of the particle shape. Properly designed non-spherical shapes are expected to exhibit simultaneous electrical and magnetic resonance. This could be a way to fabricate cheap metamaterials in the THz range.

References

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[2] H. Němec *et al.*., *Resonant magnetic response of TiO2 microspheres at terahertz frequencies*, Applied Physics Letters, vol. 100, no. 6, p. 061117, 2012.