Probing terahertz conductivity of individual conductive dipoles via near-field terahertz spectroscopy.

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Near-field terahertz spectroscopy can be used to probe the terahertz conductivity of individual resonant particles. We applied this technique to individual microsized carbon fibres and observed strong plasmonic resonances in the terahertz range. Analysing the resonance frequency of the samples and the degree of field enhancement induced by the incident terahertz pulse, we estimated their terahertz conductivity (1-5·10^4 S/m). This method can be useful for characterising semimetallic and semiconductor terahertz absorbers, microantennas and metamaterial elements.

I. INTRODUCTION

Terahertz (THz) response of semiconductors and semimetals resemble the behaviour of metals in the optical range. The emerging field of THz plasmonics does not merely replicate plasmonic effects well-known in optics. Due to versatile semoconductor doping techniques, it opens the possibility of creating tunable terahertz devices based on weakly-conductive resonant elements[1].

Characterising microsized paricles with pronounced ohmic losses in the THz range is a challenging task. Far-field spectroscopy would only detect resonators with high scattering efficiency, requiring high real conductivity values. The most common experimental technique is the indirect conductivity probing via THz spectroscopy of composites containing multiple samples [2]. Properties of individual particles are extracted via effecive media approximations. However, such methods are not applicable to composites with inhomogeneous, resonant or irregularily shaped inclusions [3].

In this work, we studied the THz behaviour of resonant weakly-conductive microsized particles through near-field time-domain THz spectroscopy based on subwavelength aperture probe[4]. We characterised carbon microfibres (CMFs) - thin milled carbon fibres with lengths varying from 10 μm to 150 μm. Analysing the degree of field enhancement produced in the near-field of the samples as well as their resonance frequencies and comparing them to those obtained via numerical simulations, we were able to estimate the conductivity of each individual CMF. Having confirmed that the THz conductivity of CMFs corresponds to the condition maximizing the dipole absorption to scattering ratio, we propose their use as THz absorbers with engineerable absorption profile.

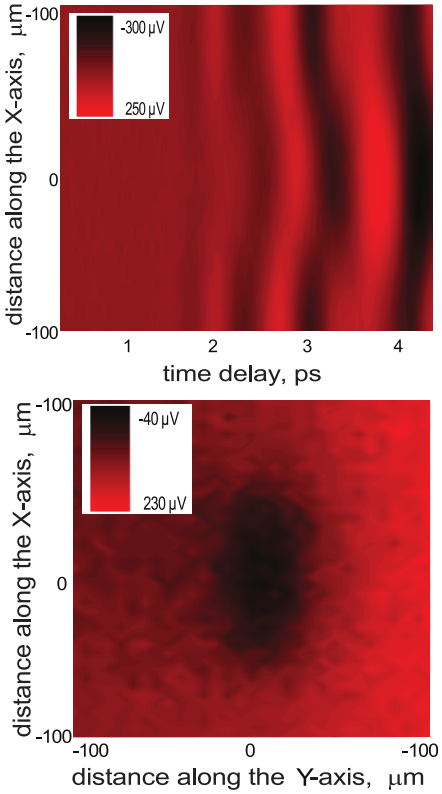


FIG. 1. (*above*) Space-time THz near-field map and (*below*) THz image (taken at ≈ 3ps delay time) of a 133μm-long CMF.

II. NEAR-FIELD THZ CONDUCTIVITY PROBING

We performed aperture-based near-field THz time-domain spectroscopy on individual CMFs and confirmed their resonant THz response (Fig. 1). Each sample was glued to a low density polyethylene (LDPE) film and placed in front of a 10 μm aperture probe. The CMFs were exposed to broadband THz pulse covering the frequency range of $0.5 - 2.5$ THz.

The THz conductivity of the samples was extracted from the enhancement of the near-field induced around them by the incident THz pulse, as well as the shift between their resonance frequencies and that of the corresponding perfectly conducting dipole. The CMF conductivity was experimentally estimated as $\approx 1 - 5 \cdot 10^4$ S/m. This value is very close to the condition maximizing the absorption to scattering ratio of resonant dipoles [5].

III. ENGINEERABLE THZ ABSORPTION IN CMF COMPOSITES

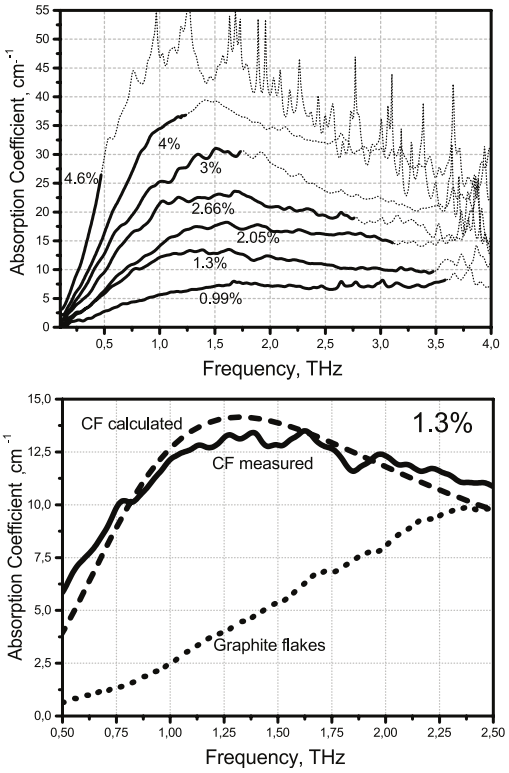


FIG. 2. (*above*) Experimentally obtained absorption coefficient of CMF/HDPE composites at different CMF concentrations (weight fractions shown in the plot). (*below*) Theoretically predicted and measured absorption coefficients of a 1.3% CMF/HDPE composite. Measured absorption coefficient of a 1.3% graphite flakes/HDPE composite is shown for comparison.

We studied composites consisting of high density polyethylene (HDPE) base with arbitrarily oriented and differently sized CMF inclusions. Using time-domain spectrometer Teraview TPS Spectra 3000, we measured the absorption coefficients of thin pellets ($1 - 2$mm) of such composites (Fig. 2). CMF composites demonstrate a clearly resonant behaviour: broad absorption peaks at around 1.5 THz indicate the presence of size effects distributed over lengths of CMFs in each sample. The absorption coefficient depends linearly on the concentration of CMF, and grows more rapidly in the vicinity of the resonance frequency.

Very high level of absorption at THz frequencies and a pronounced resonance behavior makes the spectroscopy of composites with higher concentration of CMFs extremely difficult. To obtain these spectra numerically, we combined the effective medium approximation and a simple dipole antenna model. We used the method-of-moments to model the scattering and absorption properties of CMFs considering them as lossy dipoles. This simple semi-analytical approach confirmed the spectral positions of measured resonances and allowed to predict absorption spectra of CMF composites with different lengths distributions (Fig. 2).

IV. CONCLUSION

We present an experimental technique for non-contact probing of THz conductivity of resonant, weakly conductive dipoles using near-field THz spectroscopy. We measured THz conductivity of CMFs and showed that it corresponds to efficiently absorbing resonant dipoles. Having the freedom of artificially creating any distribution of CMF lengths, we may pre-design the absorption profiles of the composites. In particular, almost flat absorption spectra are achievable in the THz frequency range. The simplicity of the model as well as low fabrication costs make CMFs worth further consideration for THz plasmonics and metamaterials applications.

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