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Abstract

Poster presentation - We investigate carbon-based materials (graphite, graphite nanofibers and multi-walled carbon nanotubes) using terahertz time-domain spectroscopy (THz-TDS). The THz-TDS of carbon-based materials has been especially useful for understanding of many fundamental physical properties (e.g. the electronic structure and electron-phonon interactions, etc.) of all sp² carbons, given that carbon-based materials can be either semiconducting or metallic depending on their geometric structures. A significant difference was obtained in the spectra of graphite nanofibers as compared to the multi-walled carbon nanotubes and graphite.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Zhang, H., Horvat, J. & Lewis, R. A. (2016). Terahertz spectroscopic characterization for carbon-based materials. International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz (pp. 1-2). United States: IEEE.

Terahertz Spectroscopic Characterization for Carbon-based Materials

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Introduction

Terahertz time-domain spectroscopy (THz-TDS) has been used in materials characterization, particularly of lightweight molecules and semiconductors, to determine the carrier concentration and mobility. The Drude-Lorentz model may be linked by the frequency-dependent dielectric response to the material free-carrier dynamic properties, including the plasma angular frequency and the damping rate.

Carbon can be made into very long chains of interconnecting carbon-carbon bonds which are strong and stable. Graphite is an allotrope of carbon, classified as a semimetal, and is characterized by a highly anisotropic three-dimensional (3D) band structure. The research into thermal, electrical and optical properties of graphite has been triggered by graphene and others (e.g. graphite nanofibers, carbon nanotubes and amorphous carbon materials).

In this work, we concentrate on the seldom-used frequency range of 0.1-1.0 THz, which cannot be accessed by standard far-infrared spectrometers. THz spectra of graphite, graphite nanofibers and multi-walled carbon nanotubes are measured.

Methods

THz-TDS is a powerful technique to study materials properties such as complex dielectric response and conductivity in the far-infrared spectral region, with the advantages of high signal-to-noise ratio (SNR), non-contact optical probe, and measuring the amplitude and phase of electric field simultaneously, thus not requiring Kramers-Kronig (K-K) transformation.

Figure 1. Schematic of THz-TDS system

The goal of this characterization is to extract “optical” constants of materials: refractive index (n) and absorption coefficient (α), which can be related with the complex dielectric constant.

$$n(\nu) = 1 + \frac{c}{2\pi\nu d} \phi(\nu)$$

$$\alpha(\nu) = -\frac{2}{d} \ln \left\{ A(\nu) \frac{[n(\nu) + 1]^2}{4n(\nu)} \right\} \cong -\frac{1}{d} \ln T(\nu)$$

$$\alpha_{\max} d = 2 \ln \left[DR \frac{4n}{(n+1)^2} \right]$$

d : sample thickness, Φ and A : phase and amplitude in frequency, T : transmittance, and DR : the frequency-dependent dynamic range.

Fresnel equations describe transmission and reflection of THz wave at each interface. Fabry-Perot effect may occur at sample/air interfaces because of high refractive index contrasts.

Results

Fig. 2. Absorption Coefficient of Graphite, Nanofiber and Carbon Nanotube.

Fig. 3. (a) Transmission Intensity for Graphite and empty aperture, the latter representing the instrument response function. (b) Transmission Intensity of Graphite normalized to the empty aperture intensity.

Fig. 4. (a) Transmission Intensity for Carbon Nanotube and empty aperture, the latter representing the instrument response function. (b) Transmission Intensity of Carbon Nanotube normalized to the empty aperture intensity.

Fig. 5. (a) Transmission Intensity for Nanofiber and empty aperture, the latter representing the instrument response function. (b) Transmission Intensity of Nanofiber normalized to the empty aperture intensity.

Conclusion

Our results indicate that carbon-based materials have interesting transmission properties in this range, arising from the intermolecular bonds. The bands at these energies most likely occur through involvement of an extended π -electron system along the molecular backbone on which charge carriers are delocalized. Van der Waals forces also likely have effect at these energies.

Acknowledgements

This work is supported by the Australian Research Council (ARC) and University of Wollongong, Australia.

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