CONDUCTIVITY AND DIELECTRIC RESPONSE OF CARBON-BASED COMPOSITES IN A BROAD FREQUENCY RANGE

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1 Introduction

Composites formed by a dielectric ceramic or polymer matrix and a conductive filler are very interesting materials since their physical properties, such as optical, electrical and magnetic properties as well as tribological, corrosion-resistance and wear properties can be tailored, which makes them attractive for many new electronic, optical, magnetic and structural applications. In particular, the introduction of carbon based nanoparticles, such as CNTs or CNFs, in polymeric or ceramic matrices has led to the development of materials for a wide variety of new applications [1], and devices based on tunable electrical conductivity [2], piezoresistivity [3], magnetoresistivity [4] or electromagnetic shielding [5]. CNTs are subject to much stronger Van der Waals forces than CNFs, so it becomes necessary to disperse or functionalize CNTs, increasing production costs. Unlike conventional composites, the electrical percolation threshold in these systems is more complex. To determine percolation and dielectric dispersion studies have focused as a rule in the frequency range up to 10^6 Hz, where standard capacitance and impedance measurements can be carried out.

2 Experimental

Two systems of dielectric-conductor composites (multiwalled carbon nanotubes with poly(ethylene terephthalate) – PET-MWCNT (0–3 vol%) and alumina-carbon nanofibers – Al_2O_3-CNF (0–9 vol%) were studied using standard low-frequency dielectric measurements, microwave open-end coaxial technique, time-domain THz transmission, Fourier-transform infrared spectroscopies and DC resistivity. The effective AC conductivity and permittivity spectra were determined in the extremely broad frequency range (10^{-4} – 10^{14} Hz) and in a broad temperature range (5 – 380 K), focused on the percolation threshold and its vicinity.

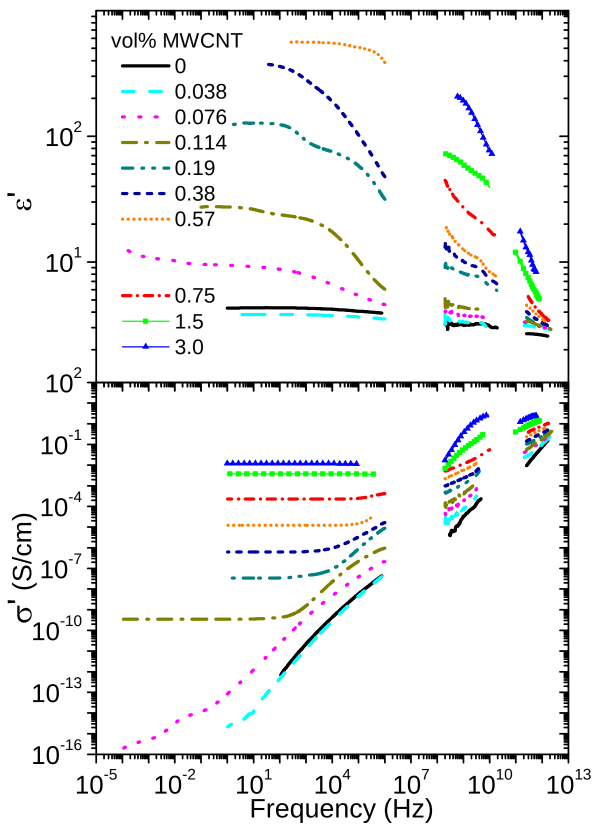

Fig.1. Dielectric permittivity and AC conductivity spectra of PET-MWCNT composites at room temperature in a broad frequency range.

3 Results and Discussion

A very low electrical percolation threshold of PET-MWCNT (0.07 vol% MWCNT) was revealed from the low-frequency conductivity plateau (Fig. 1) as well as from DC conductivity, whose values show up the same critical power dependence on the MWCNT concentration with the exponent of 4.3. Temperature dependence has shown semiconductor behavior with small concentration-independent but temperature dependent activation energy of ~3 meV. The behavior is compatible with the fluctuation-induced tunneling conductivity through a thin (~1 nm) polymer contact layer between the adjacent MWCNTs within the percolated clusters. At higher frequencies, deviations from the simple universal conductivity behavior are observed, which indicate some distribution of energy barriers for the electron hopping mechanism. Behavior of the frequency dependent AC conductivity and permittivity (Fig. 1) around the percolation threshold will be discussed and compared with the predictions of the effective-medium models and critical power-laws.

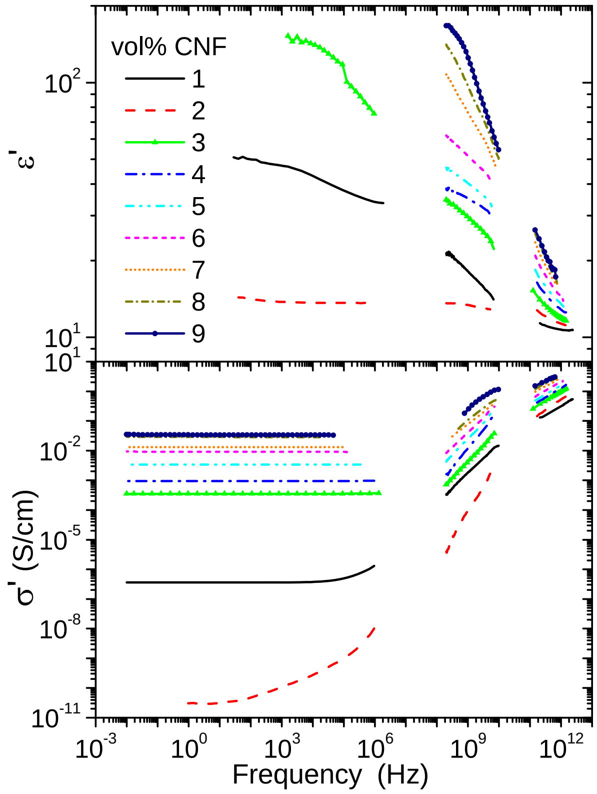

Fig.2. Dielectric permittivity and AC conductivity spectra of Al_2O_3-CNF composites at room temperature in a broad frequency range.

In opposition to polymer composites, in the Al_2O_3-CNF system the percolation is dependent on the grain size and composite microstructure. Changes of several orders of magnitude in the low frequency conductivity have been detected for concentrations of ~1–3 vol% CNF. Remarkably, the DC conductivity is higher in the sample with 1 vol% CNF than in the sample with 2 vol% CNF (Fig. 2). To explain these results, a modified percolation model was proposed based on the core-shell structure idea, taking into account the effect of the minority phase concentration (CNF in the shells) on the DC conductivity of the composite (considering percolation in the shells).

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