**Broadband Dielectric Spectroscopy of Composites of Hybrid Multi-walled Carbon Nanotube-Cu Nanoparticle filled Polystyrene**

V. Bovtun1\*, J. Petzelt1, D. Nuzhnyy1, M. Kempa1, M. Savinov1, Z. Abd Razak2, C. Wan2, T. McNally2

1*Institute of Physics of the Czech Academy of Sciences, Na Slovance 2, 18221 Prague, Czech Republic, \*bovtun@fzu.cz*

2 *International Institute for Nanocomposites Manufacturing (IINM), WMG, University of Warwick, CV4 7AL Warwick, UK*

Composites of dielectric polymer matrices filled with 1D and 2D carbonaceous particles are effective materials for electromagnetic applications in electronics and telecommunications, military and civilian microwave techniques. Replacement of carbon nanoparticles by multi-walled carbon nanotubes (CNTs) with a high aspect ratio results in a decrease in the percolation threshold and allows for weight reduction and improved ductility of the composite material [1]. Furthermore, carbon nanofibres (CNFs) can alter the microstructure and morphology of the polymer and composite properties [2]. It is possible to further reduce the percolation threshold by creating an interconnected network of nanoparticles across the length scales dispersed in the polymer matrix. To better understand this phenomena, we studied composites of polystyrene (PS) filled with 1D CNTs and 0D Cu nanoparticles (CuNP).

Two series of the composites were prepared: a) PS-xCNT, x = 0.05 – 5 vol.% CNT; b) PS/Cu-xCNT where the loading of CuNP is 2 vol.% and x = 0.05 – 5 vol.% CNTs. The dielectric and *ac* conductivity spectra for both systems were recorded across the very broad frequency range, from 0.1 Hz up to 3 THz. The spectra showed significant frequency dependence in the whole frequency range investigated (Fig. 1) caused by several polarization or *ac* conductivity mechanisms and were modeled below the percolation threshold by a set of phenomenological Cole-Cole relaxations and one THz oscillator [3]. For a description of the low-frequency conductivity plateau observed in compositions above the electrical percolation threshold and corresponding to the *dc* conductivity in percolated CNT clusters, a Drude term was added. Above the plateau, the *ac* conductivity corresponding to the localized charge transport in the non-percolated clusters increased with frequency up to the THz range.

The electrical percolation threshold of PS-xCNT was calculated to be 0.12 vol.%. With 2 vol.% Cu addition, the percolation threshold decreased to 0.089 vol.%. The dispersion of CuNP and CNTs in PS matrix was observed with SEM. The CNTs were distributed homogeneously in the PS matrix, even at x = 5 vol.%. The addition of 2 vol.% of CuNPs facilitated the formation of an interconnected electrically conducting CNT-CuNP network.

Dielectric spectra were used for analysis of the shielding efficiency and microwave absorption of the composites in the high-frequency, microwave and THz ranges that allowed estimation of their potential for the electromagnetic applications.

1. D. Nuzhnyy, M. Savinov, V. Bovtun, M. Kempa, J. Petzelt, B. Mayoral, T. McNally. *Nanotechnology* **24**: 055707, 1-9, 2013.
2. L. Fernandez-Garcia, M. Suarez, J.L. Menendez, C. Pecharroman, D. Nuzhnyy, V. Bovtun, M. Savinov, M. Kempa, J. Petzelt. *Carbon* **57**, 380-387, 2013.
3. J. Petzelt, D. Nuzhnyy, V. Bovtun, M. Savinov, M. Kempa, I. Rychetsky. *Phys. Status Solidi A*, **210** (11), 2259*–*2271, 2013.



Fig. 1. Complex dielectric (ε’, ε”) and *ac* conductivity (σ) spectra of the Ps/Cu–xCNT composites. Symbols denote experimental points, lines correspond to the phenomenological fits.