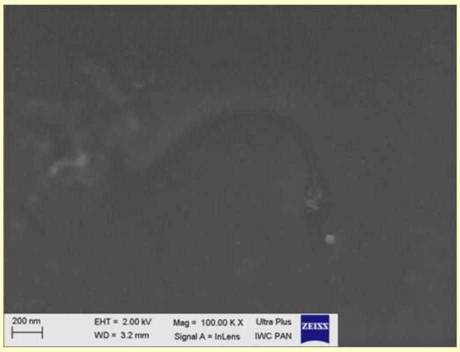
Impedance analysis of PEDOT:PSS/CNT composites below percolation threshold

I. Karbovnyk[1*], H. Klym[2], D. Chalyy[3], D. Lukashevych[2], I. Zhydenko[3]

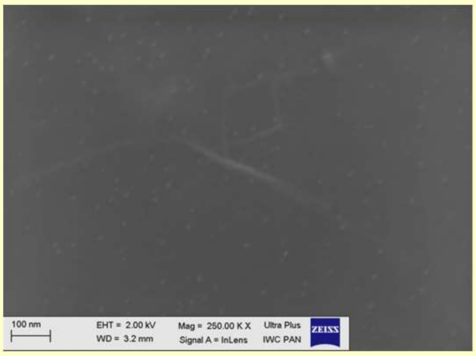
[1]Ivan Franko National University of Lviv, Lviv, Ukraine
[2]Lviv Polytechnic National University, Ukraine, Lviv, Ukraine
[3]Lviv State University of Life Safety, Lviv, Ukraine
*e-mail: ivan.karbovnyk@lnu.edu.ua

Nanocomposite layers of PEDOT:PSS polymer which incorporate randomly dispersed carbon nanotubes were thoroughly examined by means of high-resolution scanning electron microscopy and subjected to electrical studies at different frequencies in a wide range of temperatures. Comparison between the performance of pure PEDOT:PSS layers, layers reinforced with single-walled nanotubes and those reinforced with multi-walled nanotubes is made.

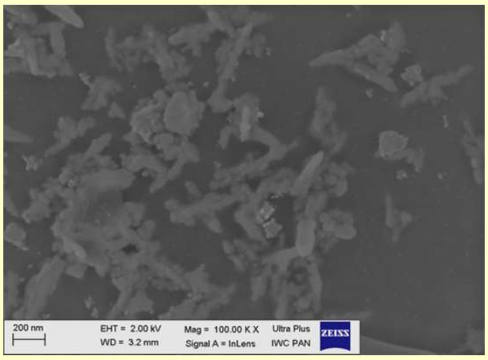
SEM image



SEM image of an individual single-walled nanotube inside PEDOT:PSS / 12 wt. % SWCNTs composite



SEM image of a conductive path formed by several individual single-walled nanotubes inside PEDOT:PSS / 12 wt. % SWCNTs composite

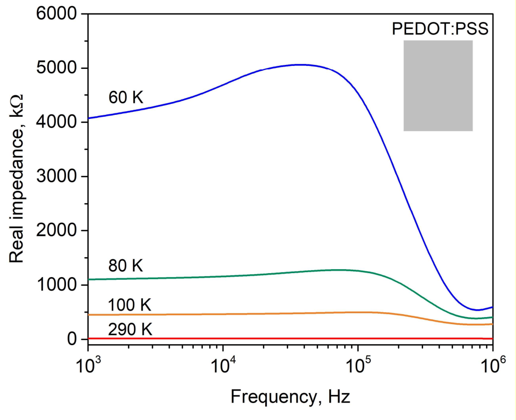


SEM image of bundles of MWCNTs inside (PEDOT:PSS / 12 wt. % MWCNTs composite)

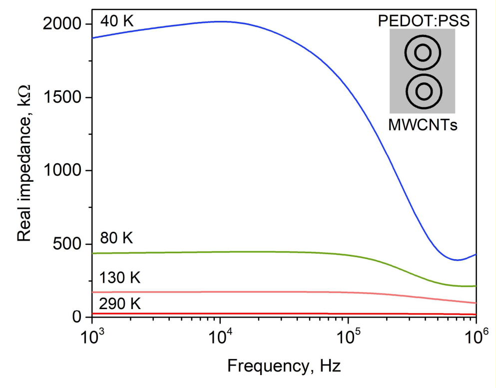
High-resolution imaging of the prepared samples was done using ZEISS Ultra Plus scanning electron microscope equipped with two secondary electrons detecting systems. SEM studies also indicated that aggregation of nanotubes is more likely to occur in MWCNTs composites.

Electrical Studies

Electrical studies were performed using E7-20 RLC measuring instrument. This instrument is designed to measure the parameters of samples represented by a parallel or serial two-element equivalent circuit. Harmonic voltage (1 V) in the frequency range from 1000 Hz up to 1 MHz was used as an excitation signal. The instrument ensures the 3% accuracy of impedance absolute value measurements. For the purpose of measurement at different temperatures we exploited custom-designed cryostat. DE-202A closed cycle cryocooler from Advanced Research Systems was used as additional equipment. Temperature regulation capabilities were provided by Cryocon 32 controller from Cryogenic Control Systems Inc. Measurements in cooling and heating regimes were carried out, though in the present report mainly data, obtained in cooling regime are analyzed.



Real part of the pure PEDOT:PSS layer impedance as a function of frequency at different temperatures.

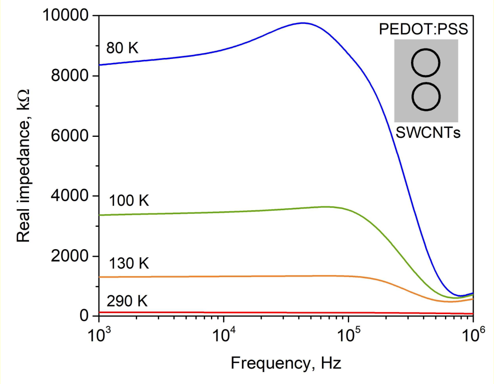


Real part of the PEDOT:PSS – MWCNTs composite layer impedance as a function of frequency at different temperatures.

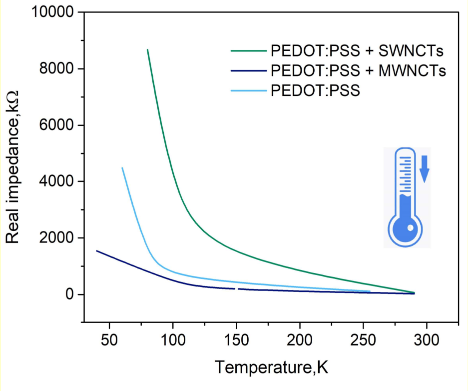
To see the difference in the electrical performance of obtained samples, impedance tests were carried out. Based on the readings from E7-20 instrument, which initially measures absolute value of the impedance of the sample and phase angle between applied voltage and current through the sample, we have recalculated real and imaginary parts of the impedance. First, measurements were made at room temperature and then samples were cooled in helium cryostat down to temperatures as low as 40 K. Real part of the lateral impedance Re(Z) as a function of frequency in the range 1 kHz – 1 MHz is shown in Fig. 4, Fig. 5 and Fig. 6 for the polymer samples without any nanofiller as well as for those with 12 wt.% loadings SWCNTs and MWCNTs, respectively. Results obtained for various temperatures are presented.

Most notable temperature effect on the real part of the impedance of fabricated polymer/CNTs composite layers is that Re (Z) increases drastically starting from certain temperature, which is different for samples with different composition. For pure polymer this occurs already at 80…90 K and below 60 K Re (Z) is almost out of the measurable range. For layers reinforced with SWCNTs, increase of impedance is more gradual and even more so for MWCNTs-reinforced composites. In the latter case, reliable measurements can be performed even at temperatures as low as 40K.

In samples with incorporated CNTs the conditions for residual water storage are potentially different due to structural changes introduced by specific nanofiller, so that time needed for complete water removal is different and the process is eventually finished at different temperature. This assumption is further supported by the fact that samples with MWCNTs show slower growth of real impedance with decreasing temperature and generally have higher conductivity at lowest measured temperatures. To support this discussion, plots of real impedance vs. temperature in cooling regime are presented for different composite layers.



Real part of the PEDOT:PSS – SWCNTs composite layer impedance as a function of frequency at different temperatures.



Real impedance of obtained layers vs temperature at 100 kHz frequency (cooling regime). Solid curves are the result of measured temperature points interpolation.