Dielectrophoresis of Impedance Spectroscopy on Single-Walled Carbon Nanotubes using N,N-Dimenthylformamide

Ahmad Sabry Mohamad, Kai F. Hoettges, and Michael Phycraft Hughes

Abstract**—**This study investigates nanowires using Dielectrophoresis (DEP) in non-aqueous suspension of SWNTs nanoparticles dispersed in N,N-DIMENTHYLFORMAMIDE (DMF). The self-assembly of nanowires in DEP impedance spectroscopy can be determined. In this work, dielectrophoretic measurements of inorganic have been used to estimate the permittivity and conductivity characteristic of the nanowires. As in aqueous such as salt solution has been dominating the transport of SWNT, which are the wire growth threshold depend on applied voltage. While DEP assembly of nanowires depend on applied frequency, the applications of dielectrophoretic collection are measured using impedance spectroscopy.

Keywords**—** Dielectrophoresis, impedance spectroscopy, nanowires, N,N-DIMENTHYLFORMAMIDE, SWNT.

I. Introduction

An ionic liquid is a salt in the liquid state. They are also composed entirely of ions and have wide range of solvent properties. Their unique properties include non-volatility, high polarity because of their ionic nature and ability to dissolve in polar or non-polar materials (ability to transfer the electric effect). Ionic liquids are considered alternative solvent as a 'green' credentials and versatile. DEP can be employed for particle manipulation in non-aqueous solvent of DMF. Their dielectric suspension offers the opportunity to exert much stronger DEP force on the nanoparticles through the application of AC voltages. Thus, in this work, the combinations of DEP and impedance spectroscopy are presented to provide a rapid and accurate measurement of dielectrophoretic collection of nanomaterials.

II. Preparation of Materials

The DEP manipulation of nanoparticle was carried out on polynomial electrode of gold (Au) microelectrodes, defined on glass substrates. The microelectrodes gap is 8 µm. SWNTs (50-70% carbon basis, Diameter: 10 nm, Length: 1 µm), were obtained from Sigma-Aldrich Company Limited UK. The N,N-Dimenthylformamide (HCON(CH3)2) has been used as a medium of conductivity for all the nanoparticles. This ionic solvent was purchased from the same company. The nanoparticles was suspended in 25 ml of HCON(CH3)2 containing 0.01 W% (SWNT: 0.0106g) then sonicated for 30 minutes. The sample was mixed briefly using rotamixer for 30 seconds (Tucker UK limited).

III. Experimental Setup

NumetriQ Impedance Analyser PSM1735 interfaced with Impedance analysis N4L via RS232 connected to personal computer (PC) using serial cable to CommVIEW version 1.15 (Newtons4th Limited UK) has been used to analyse the data of resistance of the interelectrode gap at 1 second intervals. The electrode configuration was based on that as described by Dimaki et. al., [1]. The analyser PSM1735 measurement was done by applying 10 VP-P, at five per decade between 100 Hz and 6.3 MHz. The data analysis process began prior to the SWNTs concentration being placed on the electrodes and continued for typically 3 minutes. The time constant of the change of resistance as a function of time was then acquired. The whole experiment was repeated three times to verify the consistency of the results.

IV. Experimental Results

Figure 1 shows a representative selection of impedance versus time data. Two type of form clearly indicate that initial resistance dropped after 30 seconds and then followed by an exponential decrease to a stable value at 200 s. The highest values of SWNT impedance were measured from 100 Hz at 14 ×10-7 Ω to 630 kHz at 0.2 ×10-7 Ω.

The reciprocal collection time constant as a function of frequency with the predicted value using model of DEP collection is plotted with three population. The velocity of SWNTs particles passing through a volume is directly proportional to the value of the real part of the Clausius-Mossotti factor.

The time constant is inversely proportional to the force of DEP collection population of impedance. Figure 2 shows that, three population of impedance forms conduction of SWNT.

Ahmad Sabry Mohamad, Medical Engineering Technology Department, Universiti Kuala Lumpur, Selangor, 53100, Malaysia.

Kai F. Hoettges and Michael Phycraft Hughes are with Centre for Biomedical Engineering, Department of Mechanical Engineering Sciences, University of Surrey, Guildford, GU2 7XH, UK

Email: sabry@bmi.unikl.edu.my

http://dx.doi.org/10.15242/IIE.E1213608

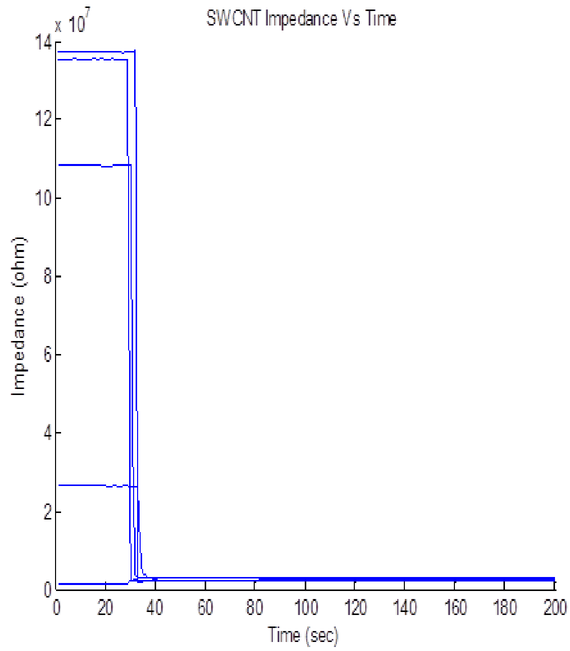

Fig. 1 Plot of SWNT with N,N-Dimenthylformamide of impedance as a function of time

The solid line represents the perfect fit to determine the net frequency dependent SWNTs collection. Three population of impedance appeared on semiconducting of SWNT metallic and carbon properties. Krupke et al. [2] demonstrated the separation of metallic/carbon and have proven that their behaviour of SWNT has to be two physical characters [3]. A spherical modeled to account for the transport of electrons in a medium with negligible electrical resistivity due to moving particles. In order to model rod-shaped nanoparticles, a thin ellipsoids approach has been used for modeling. DEP collection on third population (40 kHz - 630 kHz) was structured from the residues of Nickel and Yttrium catalysts, and indicates permittivity of 36.7ε0 at a low medium of conductivity of 1.96 mS/m after a spherical model has been used. Wang et al. [4] reported the effects of bimetallic catalyst (Nickel/Yttrium) affected by the concentration of SWNT. The metallic and semiconducting SWNT shows energy difference when they were mixed with catalyst. The relative population can be determined from the spectra of plot reciprocal collection time constant. The contributions of population indicate that 75.8 ±0.5% of metallic, 13.1 ±0.1% of semiconducting and 11.1 ±0.1% of bimetallic catalyst.

Moreover, the effect of an ohmic contact or Schottky barrier at the nanotubes-metal interface was presence when the SWNT bundle was assembled. This high electric field at the dielectric metallic of nanotube caused the ohmic contact to the nanotubes [5].

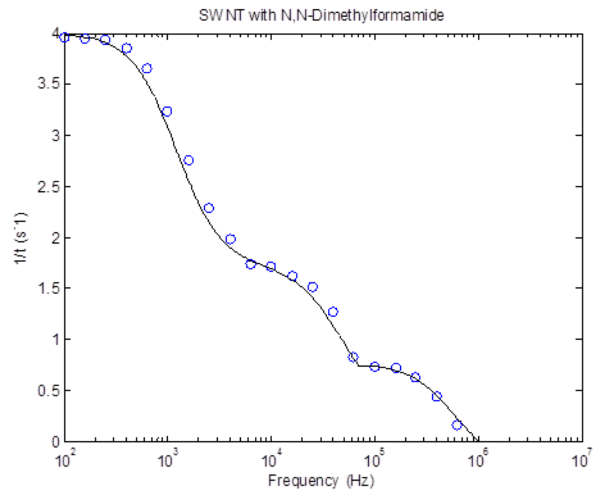

Fig. 2 Plot of SWNT with N,N-Dimenthylformamide on reciprocal collection time constant as a function of frequency with the predicted value using model of the dielectrophoretic collection

V. Discussion

The population of nanoparticles for DEP exerted on a tube of polynomial are calculated from the MATLAB programme. Equation 1 [6] describes the dielectrophoresis forces to determine for a sphere to an inhomogeneneous electric field E, ∇ is the differential vector operator, εp* and εm* are the complex permittivity of the particles and medium, respectively, ε* = ε – j(σ/ω), where ε is the permittivity, σ is the angular frequency of the applied field, j=√-1, and Re is the real part respectively;

$$F_{Sphere} = 2\pi r^3 \varepsilon_m \,\mathrm{Re}\, [\frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + 2\varepsilon_m^*}]\, \nabla E^2 \tag{1}$$

For the prolate ellipsoid with major axis r1 and minor axis r2 the force is given by:

$$F_{Rod} = \frac{2\pi r_1 r_2^2 \varepsilon_m}{3} \,\mathrm{Re}\, [\frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_m^*}]\, \nabla E^2 \tag{2}$$

Which depends on relative magnitude of εp* and εm*, which are in turn related to ω, the DEP force acting on a particle can cause it to move either forwards or repels from high-field regions at electrode edges. The plot of reciprocal collection time shows that, each population contains dielectric dispersion which is visible to behave as semiconductor, metallic and bimetallic. This is consistent with behaviour that would be expected for a heterogeneous mix of nanomaterials properties. In order to obtain the properties of homogeneous nanoparticles in the absence of surface conduction effect, the calculation of Clausius-Mossotti factor for the frequencies using the MATLAB program.

Acknowledgements

The author thanks to Dr. F. Labeed for assistance with the experiments. This work was supported in part by the Malaysian Government under Grant Skim Tindikan MARA UniKL BMI.

REFERENCES

[1] Dimaki, M., & Bøggild, P. (2004). Dielectrophoresis of carbon nanotubes using microelectrodes: a numerical study. Nanotechnology, 15, 1095.
http://dx.doi.org/10.1088/0957-4484/15/8/039

[2] Krupke, R., Hennrich, F., Kappes, M. M., & Hilbert v. Löhneysen § (2004). Surface conductance induced dielectrophoresis of semiconducting single-walled carbon nanotubes. Nano Letters, 4(8), 1395-1399.
http://dx.doi.org/10.1021/nl0493794

[3] Krupke, R., Hennrich, F., Löhneysen, H., & Kappes, M. M. (2003). Separation of metallic from semiconducting single-walled carbon nanotubes. Science, 301(5631), 344.
http://dx.doi.org/10.1126/science.1086534

[4] Wang, Y., Zhang, Z., Liu, H., Xu, X., Pan, G., Guo, Z., . . . Lan, G. (2002). The effect of catalyst concentration on the synthesis of single-wall carbon nanotubes. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 58(10), 2089-2095.
http://dx.doi.org/10.1016/S1386-1425(01)00691-6

[5] Kim, B., Brintlinger, T., Cobas, E., Fuhrer, M., Zheng, H., Yu, Z., Eisenbeiser, K. (2004). High-performance carbon nanotube transistors on SrTiO/Si substrates. Applied physics letters, 84, 1946.
http://dx.doi.org/10.1063/1.1682691

[6] Mureau, N., Mendoza, E., Silva, S., Hoettges, K. F., & Hughes, M. P. (2006). In situ and real time determination of metallic and semiconducting single-walled carbon nanotubes in suspension via dielectrophoresis. Applied physics letters, 88, 243109.
http://dx.doi.org/10.1063/1.2207501