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Electrical Properties and Scaling Behavior of MWCNT–Soda Lime Silica Glass

M.H. SHAABAN[1,3] and A.A. ALI[2]

1.—Chemistry Department, Faculty of Science, Tanta University, Tanta, Egypt. 2.—Glass Research Department, National Research Centre, Dokki, Cairo, Egypt. 3.—e-mail: mhani55@hotmail.com

Multiwall carbon nanotube (MWCNT)–soda lime silica glass composites were prepared by the direct mixing method. The dielectric properties of the composites were studied to explore the effect of MWCNT content on the conduction and relaxation mechanisms in such composites. A gradual increase in the direct-current (dc) conductivity σ_{dc} was observed up to 7 wt.% MWCNT, with a sharp increase in σ_{dc} for the 10 wt.% sample. Such behavior was related to the increase of internanotube connections. The correlation between σ_{dc} and the nanotube loading p followed the fluctuation-induced tunneling (FIT) model, which can be described by the equation, $\ln\sigma_{dc} \propto p^{-1/3}$. The alternating-current (ac) conductivity exhibited two distinct regimes: (i) a low-frequency plateau and (ii) a high-frequency dispersion regime. The switchover frequency between the two regimes indicated the conductivity relaxation. The onset frequency shifted to higher frequencies with increasing MWCNT content, which was related to connectivity improvement. Investigating the universality of the ac conductivity of these composites, it was found that the data obtained followed a Rolling scaling model. The obtained master curve revealed that the conductivity relaxation can be considered a temperature-independent process. The frequency dependence of the ac conductivity dielectric constant followed the intercluster polarization model.

Key words: Multiwall carbon nanotubes, soda lime silica glass, MWCNT–glass composites, electrical properties and scaling behavior

INTRODUCTION

Recently there has been great interest in the use of carbon nanotubes (CNTs) in the fabrication of composites. Such interest can be attributed to the outstanding properties that can be achieved when CNTs are used in the manufacture of such composites, which are widely used in many fields. This can be exemplified by the substantial improvements in the mechanical, optical, thermal, electrical, and electrochemical properties of composite materials achieved even at low doping levels.[1–3] Furthermore, CNTs have a great ability to be hosted within polymer matrices[2] or inorganic matrices, such as silicates or metals.[4,5]

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The behavior of CNTs was studied by Ebbesen et al.,[6] who reported that the electrical conductivity of individual nanotubes in the majority of cases increased with increasing temperature. The temperature dependence behavior of the electrical conductivity of nanotubes indicated a thermally activated process. The current band theory based on the Wigner–Seitz cell model predicted a gapless semiconductor for graphene. However, this model could not explain the observed thermal behavior.[7] A new band model by Fujita et al.[8] proposed that the normal charge carriers in graphene transport are electrons and holes. The electron (hole) wave packets extend over the carbon hexagon and carry the charges $-e$ or $+e$. Thermally activated electrons or