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Electrical properties of graphene / CNT hybrid films

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INTRODUCTION
Graphene plays an essential role beside the carbon nanotubes (CNTs) in the nanomaterial’s world in several energy applications due to their outstanding mechanical, thermal, optical and electrical properties which make it suitable for wide applications as field-effect transistors and batteries to solar cells and supercapacitors. Recently, hybrid nanostructures have received a great deal of attention in different studies which focused on graphene based material hybrid film. Sung Ho Kim reported the high performance TEs and FETs by using the single wall CNTs and graphene hybrid films. He found improvements in achievement in the sheet resistance that reached 300 $\Omega/\square$ with 96.4% transparency.

To date, all studies and papers focused in G/CNT hybrid film amazing electronic properties that make excellent willing materials which are utilized in different electrical devices. However, the influence of the hybrid film own nanostructure has never been exposed. In this study, the electronic properties of the electrode such as conductivity and specific capacitance were measured and investigated with different film’s contents, thickness or dimensions. This will provide important information about the electrode structure and how much influence can it has in its electronic properties which may cause damages to the devices if they are not taken into account.

EXPERIMENTAL/THEORETICAL STUDY
Graphene (G) and graphene oxide (GO)/carbon nanotubes (CNTs) hybrid films were fabricated as high performance electrode materials by a simple water solution casting method with different contents of single-wall CNT (SWCNT), multi wall CNT (MWCNT) and multi wall CNT with hydroxyl group (MWCNT-OH).

RESULTS AND DISCUSSION
The films with MWCNTs showed a layered, interconnected and well entangled structure at nano-scale (figure 1(a)). Such layer structures resulted in excellent surface finish and good mechanical properties. With increasing CNT contents, the capacitance of the G/MWCNT and GO/MWCNT films raised almost linearly and their resistance reduced. G/SWCNT and GO/SWCNT films did not form layered structures leading to a very low capacitance. The film length and thickness of the G/MWCNT and GO/MWCNT films have significant influences on the capacitance. As the length increased, the maximal capacitance and conductivity values decreased. However, both were found to be increased with increasing thickness. The maximal specific capacitance reached 130.68 F/g when the thickness of the G/MWCNT hybrid thin film was 96μm as shown in figure 1(b). It also showed a maximum conductivity of 44 S/cm in the 60wt% graphene/40wt% MWCNT film. On the other hand, nonlinear behaviour which could be quantum effect of capacitance during scanning with voltage was observed in the G/MWCNT and GO/MWCNT films.

CONCLUSION
The energy stored is, generally, directly proportional to the content of CNT, no matter SWCNT, MWCNTs or MWCNTs-OH been incorporated. Quantum effect was observed and analysed for films with high capacitance and this can cause a serious damage for the energy applications devices.

REFERENCES
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