AinShams University
Faculty of Engineering

Quantum Transport Characteristics of Tuned Mesoscopic Devices

A thesis submitted in partial fulfillment of the award of M.Sc dergree in

Engineering Physics

By

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STATEMENT

This thesis is submitted as partial fulfillment of M.Sc. degree in Engineering Physics, Faculty of Engineering, Ain-Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or qualification at any other scientific entity.

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List of Publications

1. Ahmed M. Elseddawy, Walid A. Zein and Adel H. Phillips, Carbon Nanotube based Mass Nano-Biosensor, Journal of American science 8(10):566-573, (2012) .

2. Ahmed M. Elseddawy, Walid A. Zein and Adel H. Phillips, Carbon Nanotube-Based Nanoelectromechanical Resonator as Strain Sensor, Accepted for publication in Journal of Computational and Theoretical Nanoscience, April (2013).

3. Ahmed M. Elseddawy, Walid A. Zein and Adel H. Phillips, Carbon Nanotube-Based Nanoelectromechanical Resonator as Mass Biosensor. Submitted to International Journal of Nanoscience, March (2013) .

Abstract

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Two models of Carbon Nanotube based Nano-electromechanical systems are proposed in the present thesis. These models are used for (i) Mass detection of bio-molecules, and (ii) strain sensing.

First Model –Mass detection of bio- molecules.

Nano-electromechanical system based carbon nanotube is investigated as mass sensor of bio-molecules. The device in this case is modeled as carbon nanotube cantilever coupled to electronic tunneling process through such carbon nanotube. The conductance of this device is studied under the effects of both magnetic field and ac-field of wide range of frequencies. The resonant frequency shift and quality factor of the vibrating carbon nanotube cantilever are expressed in terms of the conductance of the device. Results for the conductance show periodic oscillations, which is due to photon assisted tunneling process. The resonant frequency shift and quality factor are solved numerically with dependence on the dimension of the carbon nanotube cantilever for different values of the mass of the bio-molecule. Results show that both these parameters depend strongly on the length and the difference in radii of carbon nanotube. The high value of the quality factor is impacted to applications of the present device to ultrafast bio-sensors and actuators.

Also, the variation of both the resonant frequency shift and the quality factor with the position of the attached mass are investigated.

Results show that both the resonant frequency shift and the quality factor are very sensitive to the attached mass of bio-molecule and its position. Also, the photon energy of the induced ac-field enhances the sensitivity of these parameters. The present research shows that SWCNT based resonator can be used for sensing the trace acetone concentration in human breath, which leads to convenient, accurate and painless breath diagnosis of diabetics.

Second Model-Strain Sensor.

Strain sensing via quantum nanodevice is investigated under the effect of an ac-field. This nanodevice is modeled as semiconducting carbon nanotube (CNT) quantum dot. This CNT quantum dot is connected to two metallic leads. A metallic gate is used to govern the electrostatics and the switching of the CNT channel. A back gate is used to control the contact of the interface of CNT quantum dot/metal. A formula for the current is derived using Landauer-Buttiker equation and also a gauge factor is derived. Results show that due to the effect of tensile strain, the quantum transport characteristics are changed. Also, our calculation of strain induced band gap energy variations in CNT can be technological relevance. The present research is very important for sensing strain in nanostructured materials.

Keywords; Carbon nanotube (CNT); Nanoelectromechanical (NEMS) resonator; ac-field; Biosensor, Mass sensor, Biomolecule ,Strain sensor.

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List of Symbols

$\Delta\upsilon$	The resonant frequency shift
Q	The quality factor
υ	The resonant frequency of the vibrating CNT,
C_g	The coupling gate capacitance with CNT,
V_g	The gate voltage
C_{CNT}	The CNT capacitance
Γ	The tunneling probability of the electrons through the device
G	The conductance of the CNT quantum device
k_{spring}	The effective spring constant of cantilever.
Y	The Young's modulus of CNT
i	The moment of inertia
L	The length of CNT
ρ	The density of CNT
A	The cross section area
$m_{bio-mol}$	The mass of the attached bio-molecule
$(-\frac{\partial f_{FD}}{\partial E})$	is the first derivative of Fermi-Dirac distribution function
k_B	Boltzmann's constant
T	The absolute temperature
E	The energy of the tunneled electrons
E_F	The Fermi-energy
$\hbar\omega$	The photon energy of the induced ac-field

J_n	The n^{th} order Bessel function corresponding to the n^{th} different side bands
V_{ac}	The amplitude of the induced ac-field
e	The electron charge
V_{sd}	The source-drain voltage
f_{FD}	The Fermi-Dirac distribution function
V_b	The barrier height at the interface between the leads and the CNT
B	The applied magnetic field
$\hbar$	The reduced Planck's constant
m^*	The effective mass of the charge carrier
a	The distance from the fixed end of the SWCNT cantilever at the moment when the bio-molecule is positioned (see Fig II. 1b).
F	The weight of the attached bio-molecule.

Strain Sensing

V_{ac}	The amplitude of the ac-field
ω	Frequency.
I	The electric current
$f_{FD(s)}$	Fermi-Dirac distribution function corresponding to source
$f_{FD(d)}$	Fermi-Dirac distribution function corresponding drain lead respectively
V_{sd}	The bias voltage
E	The energy of the tunneled electrons
e	The electronic charge
$\Gamma_{withPhoton}(E)$	The photon assisted tunneling probability
$\Gamma_{withoutPhotons}(E - n\hbar\omega)$	The tunneling probability without photons
C	The coupling capacitance between CNT quantum dot and the leads
a_{CNT}	The lattice constant of CNT
γ_o	The nearest neighbor hopping integral
ε_g	The strained band gap energy
d	The diameter of CNT