Ain-Shams University

Faculty of Engineering

Spin Polarized Electronic Transport in Quantum Nanodevices

A thesis submitted in partial fulfillment for the award of the

Ph.D Degree in Engineering Physics

By

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STATEMENT

This thesis is submitted as partial fulfillment of Ph.D 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 S. Abdelrazek, Mohamed M. El-banna, and Adel H. Phillips, Quantum Spin Transport Characteristics in Graphene Field Effect Transistor. Open Science Journal of Modern Physics, **2(5)**, 55 (2015).

[2] Ahmed S. Abdelrazek, Mohamed M. El-banna, and Adel H. Phillips, Coherent Manipulation of Spin Thermoelectric Dynamics in Graphene Nanodevice. American Journal of Modern Physics and Application, **2(4)**, 67 (2015).

[3] Ahmed S. Abdelrazek, Mohamed M. El-banna, and Adel H. Phillips, Piezoelectric Effect on Spin Transport Characteristics of Ferromagnet/Semiconductor Junction, Open Science Journal of Modern Physics, **2(5)**, 72 (2015).

[4] Ahmed S. Abdelrazek, Mohamed M. El-banna, and Adel H. Phillips, Spin Dependent Peltier Effect in Ferromagnetic Graphene/Superconducting Graphene Junction, International Journal of Nanoscience and Nanoengineering, **2(6)**, 36 (2015).

[5] Ahmed S. Abdelrazek, Mohamed M. El-banna and Adel H. Phillips,. Photo-Spin Coherent Manipulation of Piezotronic Nanodevice, Micro & Nano Letters, 16 Sept.-2016,pp.1-5, doi: 10.1049/mnl.2016.0264.

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LIST OF SYMBOLS
AND
ABBREVIATIONS

- GMR: the giant magneto-resistance.
- E_g: The energy gap .
- $\hbar$: The reduced Planck's constant.
- $\hat{H}$: The Hamiltonian.
- V_g : The gate voltage.
- B: The applied magnetic field.
- V_{ac} : The amplitude of the AC-field.
- $\omega^{'}$: the frequencies of the AC-field.
- V_{sd} : The bias voltage.
- m*: The effective mass .
- ϕ_{SB} : The Schottky barrier height including the piezoelectric effect.
- σ : The Pauli matrices of spin.
- ψ: The components of the eigenfunction.
- μ_B : The Bohr magneton.
- h_o: The exchange field energy of ferromagnetic leads.
- $\theta\omega$: The angle between two rectilinear part of the nanowire.
- α: The strength of the spin-orbit coupling.
- ξ: The precession angle of spin in the curved region of nanowire.
- ω_{SOC} : The frequency associated with spin-orbit coupling.
- J_n: The n^{th} order of Bessel functions of first kind.
- E_F' :The Fermi level in the presence of piezopotential.

- ρ_{piezo} :The density of polarization charges.
- w_{piezo} :The width of polarization charges
- GF :The gauge factor
- η :The strain
- Y_b:The Young's modulus of the bulk material.
- E_s : The surface energy.
- ν_r :The Poisson's ratio
- k_B: The Boltzmann's constant.
- T: The absolute temperature.
- G: The conductance.
- g: The Lande g-factor.
- SP: The spin polarization.
- f_T : The cutoff frequency.
- C: The gate capacitance with the nanowire.
- v_F: The Fermi velocity.
- Δ: The superconducting order parameter.
- T_c : The critical temperature of superconductor graphene.
- $k_{\pm}$:The wave vector of quasiparticles in the ferromagnetic graphene.
- $k\pm$: The corresponding wave vector of quasiparticles in the superconducting graphene.
- E_{FI}:The Fermi-energy in the ferromagnetic graphene.
- θ: The Klein angle in ferromagnetic graphene (region I).
- S: The thermopower (Seebeck coefficient).
- K_e : The electronic thermal conductance.
- ZT: The thermoelectric figure of merit.
- Π: The Peltier coefficient.

- IT: Information technology.
- MBE: Molecular Beam Epitaxy.
- FM/SC: Ferromagnetic/Semiconductor.
- DMS: Diluted magnetic semiconductor.
- TM: Transition-metals.
- MTJ: Magnetic tunnel junction.
- Qubit: Quantum bit.
- LED: Light emitting diodes.
- PV: Photovoltaics.
- STM: Scanning tunneling microscopy.
- AFM: Atomic force microscopy.
- MTA: Micro-thermal analysis.
- SNOM: Scanning near-field optical microscopy.
- PZT: Lead zirconate titanate.
- MEMS: Micro-electromechanical system.
- Q1D: Quasi-one-dimensional.
- CMOS: Complementary metal oxide semiconductor.
- NW: Nanowire.
- FET: Field effect transistors.
- SWCNTFET: Single walled carbon nanotube field effect transistor.
- NEMS: Nanoelectromechanical system.
- QHE: Quantum Hall effect.
- NS: Normal metal/Superconducting metal.

THESIS SUMMERY

The Spintronics is the electronics that depend on the quantum concept of spin of electrons rather than their charge. The nanoelectronics which are based on spin require efficient ways to generate, manipulate and detect spin polarized currents and spin currents.

The present thesis is designed for investigating the quantum spin transport properties of two different types of nanostructures dominating nowadays nanoelectronics devices physics research.

First Model of Nanodevice:

Concerning this model we investigate the spin dynamics of nanoscale junction formed of diluted ferromagnetic semiconductor as two leads and a curved semiconducting nanowire. This nanowire is ZnO nanostructure, since it exhibits piezoelectric property. We shall study the spin transport characteristics of such junction by deducing the spin current for both different orientations of spin alignments by applying the effective mass approximation and the Floquet theory. The effect of strain, generated due bending the nanowire, on the spin current is investigated. Rashba spin-orbit interaction, the influence of the frequency of the induced ac-field and magnetic field are taken into consideration. Numerical calculations show that the spin current, for both orientations of spin alignment, varies with the induced strain strongly. This variation in the spin current with strain might be due to piezoelectric effect. Also, the strain gauge factor is calculated and it is noticed that this gauge factor varies with strain and attains a maximum value ≈ 973.4 at strain equals 0.1% and ≈ 961.9 at strain equals -0.1%. These large gauges factor may find applications in different fields of nanotechnology and bionanotechnology. It is noticed from calculations that the value of the frequency associated to spin-orbit coupling is affected by strain. The results appear that the spin transport