GRAPHENE-BASED RADIATION DETECTION SENSOR MODELING

JAVAD SAMADI

UNIVERSITI TEKNOLOGI MALAYSIA

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JAVAD SAMADI

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
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Dedicated, in thankful appreciation for support, and encouragement to my beloved parents and my cousin Mustafa.

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Javad Samadi

ABSTRACT

Graphene as a single layer graphite with one atom thickness and two dimensional structures is satisfying prospective nanoelectronics demands and also opens new portals in electronics. To meet specifications of future cutting edge applications, lead us selecting graphene with the purpose of model an eligible transistor regarding gamma-ray (Ionizing Radiation) detection. With utilizing graphene as a top-gate of a FET, weve concluded a detecting device with exceptional sensitivity which doubles the range of sensitivity. In this paper gradient of graphene conductivity during the gamma-ray exposure (Ionizing Radiation) is reported.The capability of swift localizing sources of gamma radiation would aid urgent situation responders to disable, detach or securely take out devices with radioactive sources. In this work, Local electric field's ultra-sensitivity feature of the Single-Layer Graphene exploited by put graphene in adjacency of the ionized gamma-ray absorber which consequently flow a current across the surface of the graphene. Subsequently, weve calculated the factor in order to define a detecting feature as an accessory characteristic of the sensor.

ABSTRAK

Graphene adalah satu lapisan grafit setebal satu atom dan ia mempunyai struktur dua dimensi dimana ia mendapat permintaan yang tinggi dalam bidang nanoelektrik dan juga membuka portal baru dalam bidang elektronik. Untuk memenuhi ciri-ciri penggunaan pinggir pemotongan bagi masa hadapan, kami telah memilih graphene sebagai model transistor yang bersesuaian dengan pengesanan sinaran gama (sinaran penionan). Dengan menggunakan graphene sebagia pintu atas FET, kami menyimpulkan bahawa peranti ini mempunyai daya pengesanan yang luar biasa dimana lingkungan pengesanannya digandakan. Dalam kajian ini, garis kecerenun bagi kekonduksian graphene sewaktu pemancaran sinar gama telah direkodkan.Keupayaan penempatan sumber radiasi gama yang pantas akan membantu situasi genting penggerak balas untuk mematikan, menanggalkan atau mengeluarkan peranti dengan selamat daripada sumber radioaktif. Dalam kajian ini, ciri-ciri ultra-sensitivity medan elektrik tempatan bagi Graphene Tunggal-Lapisan akan dieksploitasi dengan memasukkan grahpene secara bersebelahan dengan penyerap trion sinaran gama dan seterusnya membenarkan pengaliran elektrik pada seluruh permukaan graphene. Seterusnya, kami telah menghitung faktor dengan tujuan untuk mentakrifkan ciri mengesan sebagai ciri eksesori pengesan.

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LIST OF ABBREVIATIONS

SB – Schottky Barrier
SEM – Scanning Electron Microscope
VTC – Voltage Transfer Characteristic
SWNT – Single Wall Nanotube
SPINFET – Spin Field Effect Transistor
Q1D – Quasi-One-Dimensional
Q2D – Quasi-Two-Dimensional
PMOS – P Channel Metal-Oxide-Semiconductor Swing
NMOS – N Channel Metal-Oxide-Semiconductor
PTM – Predictive Technology Model
pFET – Ptype Field Effect Transistor
SPICE – Simulation Program Integrated Circuits Especially
O – Ohmic
ND – Nondegenerate
nFET – Ntype Field Effect Transistor
NEGF – Non-Equilibrium Green Function
MWNT – Multiwall Nanotube
MOSFET – Metal-Oxide-Semiconductor Field-Effect Transistor
MOS – Metal-Oxide-Semiconductor
ITRS – International Technology Roadmap for Semiconductor
IC – Integrated Circuit
HFET – Heterojunction Field Effect Transistor
GNR – Graphene Nanoribbon

DOS – Density of state

DIBL – Drain-Induced Barrier Lowering

DC – Direct Current

D – Degenerate

CVD – Chemical Vapour Deposition

CNFET – Carbon Nanotube Field-Effect Transistor

CMOS – Complementary Metal-Oxide-Semiconductor

CNT – Carbon Nanotube

AC – Alternative Current

ABM – Analog Behavioural Modeling

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LIST OF SYMBOLS

E_C – Conduction band
ε_c – Critical electric field
ε – Electric field
D_o – Metallic density of state
$D(E)$ – Density of state
d – Diameter
C_Q – Quantum capacitance
C_C – Oxide capacitance
C_L – Load capacitance
C_int – Intrinsic capacitance
C_{GS} – Gate to source capacitance
C_{GD} – Gate to drain capacitance
C_g – Gate capacitance
C_{ext} – Extrinsic capacitance
C_{DB} – Drain to bulk capacitance
C – Capacitance
A – Area cross section
a_{cc} – Nearest C-C bonding distance
a – Vector of lattice
σ – Conductivity
γ – Fitting parameter
Γ – Gamma function
$\Im$ – Fermi-Dirac function

ψ – Wavefunction

V_T – Threshold voltage

V_t – Thermal voltage

V_{GS} – Gate to source voltage

V_{DS} – Drain to source voltage

V_{DD} – Supply voltage

W – Width

V_{ch} – Channel voltage

V_c – Critical voltage

v_{th} – Thermal velocity

v_{sat} – Saturation velocity

v_{inj} – Injection velocity

v_i – Intrinsic velocity

v_f – Fermi velocity

v_d – Drift velocity

v – Carrier velocity

U – Potential energy

μ_∞ – Intrinsic mobility

μ_{eff} – Effective mobility

μ_B – Ballistic mobility

μ_B – Mobility

T – Temperature

W – Gate oxide thickness

n – Carrier concentration

m^* – Effective mass

L_{ind} – Inductance

L – Length

ℓ_{eff} – Effective mean free path

ℓ_B – Ballistic mean free path

ℓ – Mean free path

k_B – Boltzmann Constant

k – Wavevector

I_{sat} – Saturation current

I_{DS} – Drain to source current

h – Plank’s constant

G – Conductance

F – Carrier force

E_v – Valence band

E_g – Bandgap energy

E_F – Fermi energy

E – energy

ε_o – Vacuum permittivity

t – C-C bonding energy

W – Quantum resistance

R_o – Ohmic resistance

$R_{channel}$ – Channel resistance

R_c – Contact resistance

R – resistance

r – Signal resistance

Q – Total number of charge

r – Signal resistance

q – Number of charge

p – Momentum

ρ – Resistivity

N_c – Effective density of state

η – Normalized Fermi energy

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LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Why detecting gamma ray

1.1.1 Chernobyl accident

First month of spring in 1986 one of the most enormous manmade catastrophic disasters took place in late Soviet Union, Chernobyl nuclear accident [3]. An event which still influencing the environment and the vast area with several miles square with difference stages of danger level is yet abandoned however the aftermaths are still devastating, crops withered, farms and lands became barren unproductive wastelands.

The radioactive energy released at Chernobyl was two times bigger than created by the bombs dropped on Hiroshima and Nagasaki during World War Second [4].

1.1.2 Fukushima Daiichi Nuclear Power Station

Most recent analogous event reported from combination of natural essence (Tsunami) followed by synthetic malfunction originating in Japan Island, another nuclear incident, malfunction in cooling tower results in reactors meltdown [5].

1.1.3 Operating NPPs around the globe

The first NPP (Nuclear Power Plant) established in USA in 1951. The most powerful NPP is operating in France [6].Despite several endeavors for the purpose of reducing these kinds of vulnerabilities by shutting down NPPs or converting nuclear power plants to gas and wind farms and The Decommissioning of Nuclear Reactors and Related Environmental Consequences, is a current issue in ”UNEP Global Environmental Alert Service (GEAS)”, there is already 441 active nuke plants around the world.

Table 1.1: Basic facts about Nuclear Power Plants in the World [7]

Number of operating NPPs in 2010	441
2.5	402.57
First NPP	USA, 1951
Most powerful NPP	Chooz, France, 1500 MW
Share of nuclear energy in world energy production	15%
Nuclear energy produced in 2009	2.598 TWh
Number of years of operation to January 2009	13,911
1.3	50.334
Number of countries with operating NPPs	30
Number of NPPs under construction (January 2010)	60
Number of NPPs that started operation in year 2010	5
Number of shut down NPPs	125
Number of decommissioned NPPs	17

1.1.4 MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging)

In other hand, NASA (National Aeronautics and Space Administration), with the help of LLNL (Lawrence Livermore National Laboratory) and U.S. Homeland Security, in order to investigate the structure of Mercurys core and its exospheres composition, launched a spacecraft with special electronic devices, including GRS (Gamma-Ray Spectrometer) [4,5,8,9]. MESSENGER spacecraft orbiting the planet Mercury. (Image courtesy of the National Aeronautics and Space Administration.) A gamma-ray spectrometer aboard the spacecraft will help scientists determine the abundance of elements in Mercurys crust.

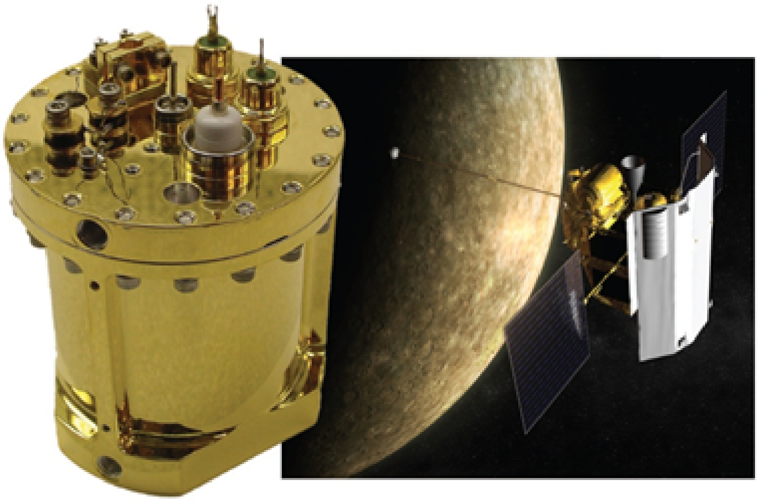

Figure 1.1: Image courtesy of the National Aeronautics and Space Administration

1.1.5 Nuclear terrorism

Nuclear terrorism and reported attempts made it serious to control the borders preventing this massive fatal ruinous threat. Between 1966 to 1977 ten terrorist incidents against nuclear installations endeavored in Europe [8].

Also 32 acts of suspected sabotage or intentional damage at domestic nuclear facilities reported from United States, between 1974 and 1986 [9]. Occurrences like mentioned samples, indicates the importance of taking serious all efforts relating to prevention of these uncontrollable and irreversible happening with long lasting succeeding consequences.

1.1.6 Sense the Gamma Ray

One of the primal actions which are extremely critical is sensing the leakage of nuclear material. In order to perform this operation we need to detect gamma ray, the more accurate, the better [10].

1.1.7 Issue of Accuracy in gamma Ray detection

In terms of gamma ray detecting accuracy and precision are the first priorities and have precedence with holding greatest importance which justifies executing any effort to achieve these factors [11].

1.2 Why graphene

Next generation of electronics is demanding speed, reliability, stability, flexibility and accuracy. Graphene (single layer graphite) with hexagonal structure as shown in Figure 1, has multiple times higher carrier mobility (compare to the Si) in excess of 200,000 cm2/V.s at electron density of 2x1011 cm-2 [3–5, 8, 9]. Graphene with 2D atomic structure fulfills these requirements and also inaugurates new gates in science specifically in electronics. Formerly, germanium used to be the first choice for researchers to be used in precise and fast gamma-ray detection.

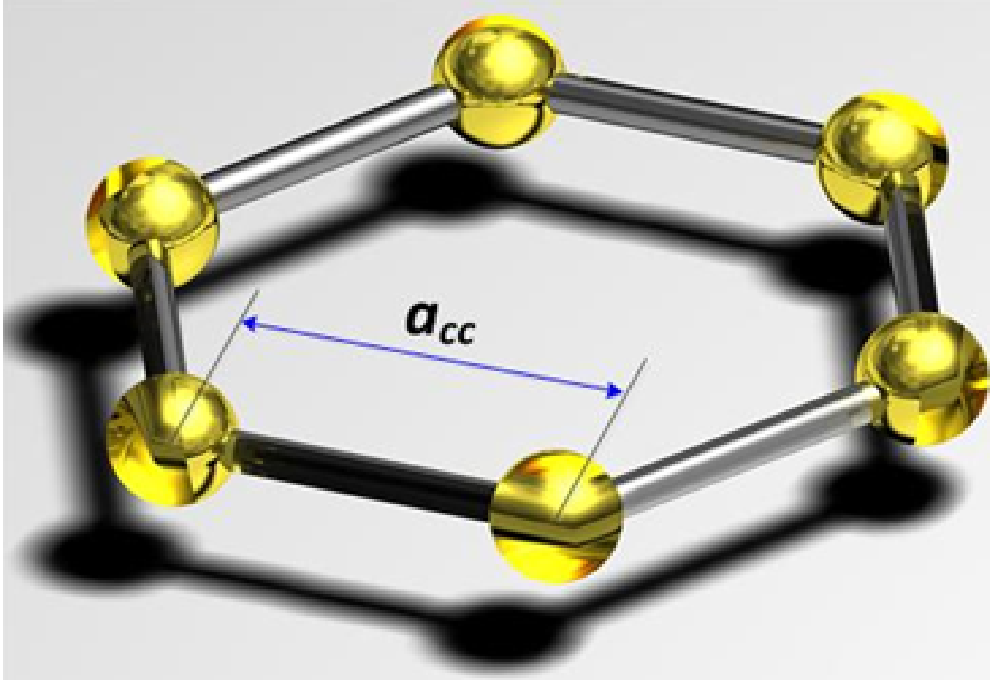

Figure 1.2: Brillouin zone, shows a hexagonal structure and C-C Bindings.

1.3 Graphene as the Top Gate of FET

Recent studies indicates high capability of carbon-based materials as a sensor platform. In terms of designing a gamma ray sensor, the main challenge is achieving high resolution in room temperature [6, 10, 11].

1.4 Zigzag structure

As an adequate substance for future trends in high-tech devices, the graphene with zigzag structure is chosen for modeling a FET to detect the gamma-ray, which is due to its higher electrical stability and constant metallic behaviour [7]) as shown in Figure 2.

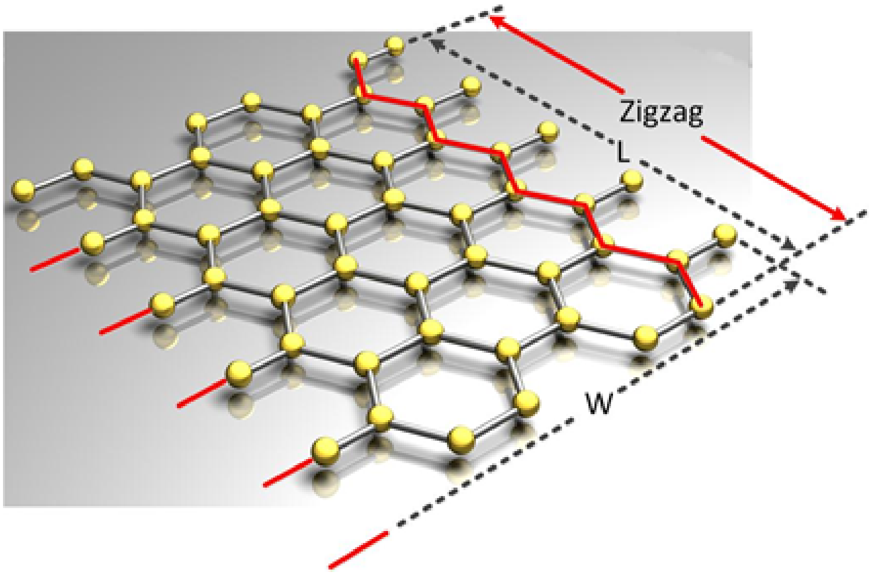

Figure 1.3: Zigzag structure of graphene used in the suggested model of the sensor exhibiting the W as width and L as Length of the sheet.

1.5 Sensitive to Local Electric Field

In order to achieve this goal, the ultra-sensitivity factor of the Single-Layer Graphene (SLG) is exploited with respect to local electric fields. An ionizated substance in neighborhood of graphene has resulted this desired electric field [12–14].

1.6 Gamma-ray Absorber

The perfect material which meets the requirements is a gamma-Ray absorber [15]. In this paper, Si is employed to role as an absorber, and the sensor is modeled as a FET, in which Vg plays as a controlling factor used in controlling the channel current because of the alteration in channel conductance.

1.7 Ionizing Radiation and Buffer (Oxide) layer

The local electric field induced by the gamma ray (Ionizing Radiation) in the absorber, which is in adjacency of the graphene, results in a current flow across the graphenes surface.

In this study, the proposed structure of sensor includes a semiconductor material (such as Si, Ge, and InSb) serving as a gamma-ray absorber. To avoid direct contact of SLG and absorber substrate, SiO2 as the oxide layer between them and Ag as the terminals substance are employed as illustrated in Figure 1.4,.

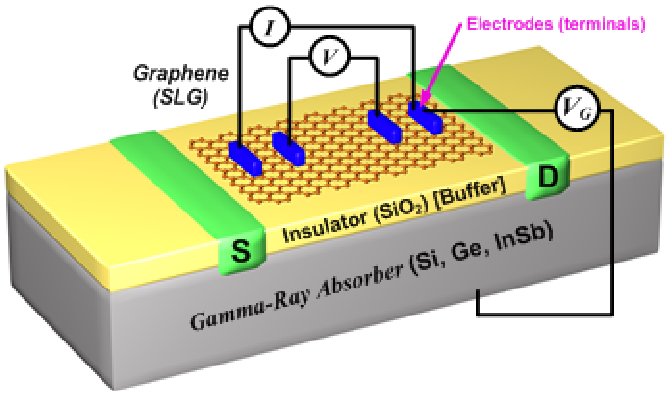

Figure 1.4: Schematic of the SLG FET, indicating gamma-ray absorber layer, buffer layer, graphene sheet and electrodes.

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