ISSN: 2454-4248
167 – 170

ATLAS simulation of Photodetector based on Graphene/SiO2 Interface

Komal Verma
PG Student: VLSI Department
Of
YMCA University of Science and Technology
Faridabad, India
komal53021@gmail.com

Heena Verma
PG Student: VLSI Department
Of
YMCA University of Science and Technology
Faridabad, India
heenaverma46@gmail.com

***Abstract*—**Photo detector is considered to be one of the essential elements of optical receiver that converts optical signal (light) into electrical signal (current/voltage) using photoelectric effect. The ideal photo detector should posses good sensitivity (Responsivity) at the desired wavelength, response time, bandwidth, low noise and insensitive to temperature variations. Many researchers proposed distinctive strategies to accomplish these qualities one of which is utilization of 2D materials at interfacial gating or as channel waveguide. Graphene due to its extraordinary optical properties along with electronic, mechanics and thermodynamics properties is considered to be one of the most promising 2D material for optoelectronic application. This paper investigates interface engineering of graphene with Silicon Oxide (G-SiO2) on silicon substrate using Silvaco-Virtual Fabrication Tool.

Keywords-*Graphene; Photodetector;2D material.*

*****

I. Introduction

The transformation of hooked light energy into some other custom of energy, such as electrical or thermal energy is carried out by photo detector. There are numerous applications like Video imaging, optical communications, biomedical imaging, security, night-vision, gas sensing. Photo detector widely used in optical communication because of its high operating speed that enhance the data rate .A variety of material are used for photo detector to expand the wavelength range of operation and performance in term of speed, noise and sensitivity. Graphene is an enabling material for photonics and optoelectronics. [4]

As Graphene is gapless which allows charge carrier generation by light absorption over a very wide energy spectrum which includes ultraviolet, visible, Short Wave Infrared (SWIR), Near-Infrared (NIR), Mid-Infrared (MIR) and TeraHertz (THz) spectral system. In addition, graphene shows ultrafast carrier dynamics, wavelength-independent absorption, tunable optical properties via electrostatic doping ,low dissipation rates and high mobility.[1,2] Because of high mobility of carrier(~200,000 cm2 V-1s-1) at room temperature) , fast conversion of photons into electric currents or voltages take place and for normal incidence illumination, it has broadband absorption of πα=~2.3% per layer. Also, Graphene can co-work with some traditional semiconductors like Silicon and silicon oxide and form Schottky junction. A significant effort has been devoted to developing photo detectors, on the number basis of distinct characteristics of Graphene a variety of optoelectronics devices have been demonstrated such as photo detectors.

II. Physical Mechanisms Enabling Photodetection

A. Photoelectric effect

The working principle of photo detector is photoelectric effect, first defined by Heinrich Hertz in 1887. He proposed that when light shines on a material surface and electrons emit from material's surface. When photons irradiating onto a piece of substance acquires a certain minimum cutoff frequency in order to knock out electrons from its surface and the energy required for this phenomenon is called work function (ϕ).The cutoff frequency is therefore a measure of the work function of the metal.

For a specific colour of light (i.e. a certain frequency or wavelength), the energy of the photons is given by $E = hf = hc/\lambda$.

As energy is conserved so if the photon has a higher energy than work function (ϕ) then excess energy goes into the kinetic energy E_k of the electron that was emitted from the substance. Most of the electrons below the surface required additional energy to eject the electron from the material which cannot contribute to the kinetic energy of the electron. This is explained by photoelectric equation,

$$hf = \phi + E_k \quad (1)$$

Kinetic energy defined by

$$\phi - hf = E_k \quad (2)$$

h= the Plank constant 6.63 x 10-34 J s
f = the frequency of the incident light in hertz (Hz)
ϕ = the work function in joules (J)
E_k= the maximum kinetic energy of the emitted electrons in joules (J)

As working principle of photo detector explain effect of light on material, therefore different material shows different behavior when exposed to light. Ideal requirements of photo detector are excellent linearity of output current with incident light, quick response, wide spectral response, small change in output current with temperature.

B. Photovoltaic effect

Photovoltaic (PV) effect closely related to photoelectric effect used excited electron within the material .The photocurrent generation is based on the separation of photo generated electron–hole (e–h) pairs by built-in electric fields at junctions between positively (p-type) and negatively (n-type) doped regions of Graphene or between differently doped regions. By applying a source–drain bias voltage (V_{bias}) same effect can be achieved that produced an external electric field. But this is generally not acceptable in case of Graphene, as it is a semimetal and therefore it generates a large dark current. The

 ISSN: 2454-4248
167 – 170

built-in field can be introduced either by local chemical doping, electrostatically by the use of (split) gates, or by taking advantage of the work-function difference between Graphene and a contacting metal. In the case of split gates, the doping can be adapted to be p or n, that depends on the applied gate voltages, whereas in the case of Graphene–metal junctions the doping in the contacted area is fixed. The doping is typically p-type for metals with a work function higher than that of intrinsic Graphene (4.45 eV), whereas the Graphene channel can be p or n. The photocurrent direction depends only on the direction of the electric field, not on the overall doping level. Thus, it alters sign when going from p–n to n–p, or from p–p+ to p+–p, where p+ means stronger p-type doping compared with p

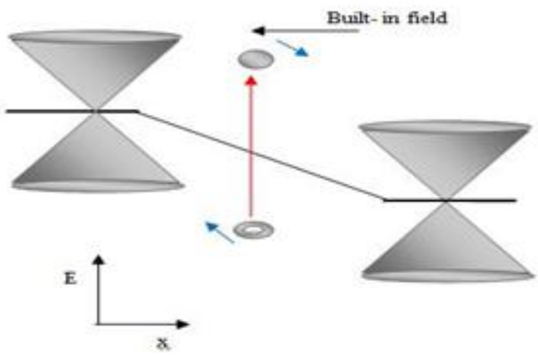

Fig1:Electron–hole (solid and open circle) separation by an internal electric field.[13]

C. Photo thermo-electric effect(PTE)

The photo-thermoelectric photocurrent is generated by thermoelectric effect, where a temperature gradient ∇T is directly converted into a voltage V_{TE}. In this effect Vte generated by the diffusion of charge carriers from the hot to the cold region. This process is directed by the Seebeck coefficient that is defined as $S = V_{TE}/\nabla T$. In graphene, the Seebeck coefficient is typically much larger than that of, for instance, gold [6].Because of the photo excitation, temperature difference is created. Absorbed photons in graphene lead to ultra[7,8] and efficient heating[9-12]. Diffusion occurs between photo excited hot region and region without photo excitation. Shown in Figure 2.

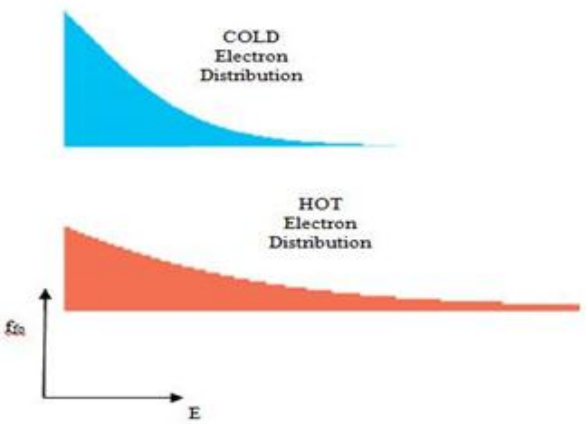

Fig2: Photo-induced electron heating in graphene leads to a broader Fermi–Dirac distribution (red), in comparison with the distribution without photo excitation (blue).[5]

The photo generated hot electrons can produce a photo Voltage, (VPTE) by the Photo-Thermo-Electric (PTE) effect (Seebeck effect) (Figure 3): VPTE = (S1 – S2)ΔTe, where S1,2 (in V K–1) is the thermoelectric power also called Seebeck coefficient in the two Graphene regions with different dopings and ΔTe=(Tel,hot-Tel,0) is the electron temperature difference between the regions.[12,13] Most of the time, V_{PTE} can be calculated by $V_{PTE} = \int S \cdot \nabla T_e \, dx$. The thermoelectric power S (also called thermo power) is related to the electrical conductivity σ by the Mott formula:

$$S = -\frac{\pi^2 k_B{}^2 T_e}{3q} \frac{1}{\sigma}\frac{\partial\sigma}{\partial\varepsilon} \qquad (3)$$

where q is the electron charge, and the derivative of the electrical conductivity σ with respect to energy ε must be evaluated at the Fermi energy, that is, at $\varepsilon = \varepsilon F = \hbar v_F k_F$, with ħ the reduced Planck constant, v_F the Fermi velocity (which in Graphene is ~106 m s^{-1}) and k_F the Fermi wavevector. This equation is valid only for kBT << εF.[12]

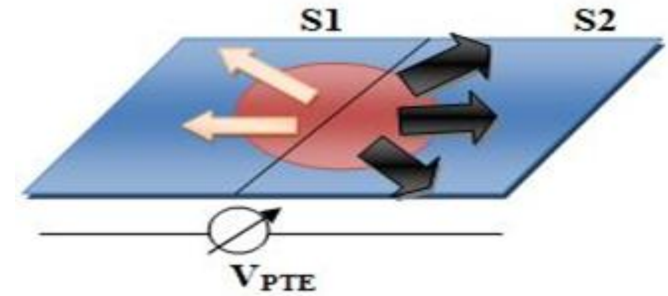

Fig 3: The carrier diffusion between photoexcited and non-photoexcited governed by the Seebeck coefficient S. If hot electrons are created at an interface of two regions with different Seebeck coefficients S1 and S2, a net photo-thermoelectric voltage VPTE is created due to net electron movement[14]

III. Terminology And Key Figures Of Merit In Photodetectors

When Light strike on a device, with a photon energy Eph and power Pin and have an incoming photon flux

$$\phi in = Pin/Eph, \qquad (4)$$

Absorbed photon $flux$

$$\phi abs = \phi inA\_abs \qquad (5)$$

A_abs the absorbed fraction.

The external quantum efficiency, EQE, is equal to the ratio of number of electron–hole (e–h) pairs per second collected to produce the photocurrent Iph, and the number of incident photons per second,:

$$EQE = (Iph/q)/\phi in \qquad (6)$$

where q is the electron charge.

The internal quantum efficiency (IQE) is calculated in a similar way but in this case the absorbed photon flux is considered: $IQE = (Iph/q)/\phi abs.$ (7)

The responsivity of a photo detector is calculated by the photocurrent Iph divided by the incident power: $Rph = Iph/Pin$ (8)

or if the photo induced voltage, Vph, is measured, then $Rv = Vph/Pin.$ (9)

The noise equivalent power (NEP) is the signal power where the signal-to-noise ratio is unity, usually expressed in units of W Hz–0.5. Another typical Figure of merit used to

characterize the performance of a detector is the specific detectivity D*, which is given by $D* = (A \cdot BW)0.5/NEP$. (10)
D* is measured in cm $Hz^{1/2}$ W^{-1}. Here, A is the area of the photosensitive region, and BW is the frequency bandwidth of the detector.
The external quantum efficiency for sensitized photoconductor is defined as $QE = \eta trans\, \eta abs$, (11)
where ηtrans is the charge transfer efficiency and ηabs is the light absorption efficiency.
A second important parameter is the lifetime τ_{tr}, how long charge residing in the particles, when light is incident change in carrier density Δn induced that scales linearly with τ_{tr}:
$\Delta n = \tau_{tr} \times QE \times \phi in.$ (12)
Photo detectors are often characterized by their photoconductive gain, $Gph = (Iph/q)/(\phi inQE)$ (13)

IV. PROPOSED STRUCTURE

The schematic diagram of proposed Photo detector is shown in Figure 4.The photo detector was fabricated with thickness of 300 nm of Silicon Oxide(SiO_2) followed by about 3.5µm thickness of n type Silicon substrate with $3x10^{15}$/cm3 doping concentration .The contacts have made by using a thickness of 200 nm of Gold (Au) as electrode. Because of optical transparency(only 2.3% of incident light absorbed) and high carrier mobility property a 0.3nm thick graphene layer that can absorb a wavelength of range 0.1 µm to 1.2 µm is used between the electrodes.

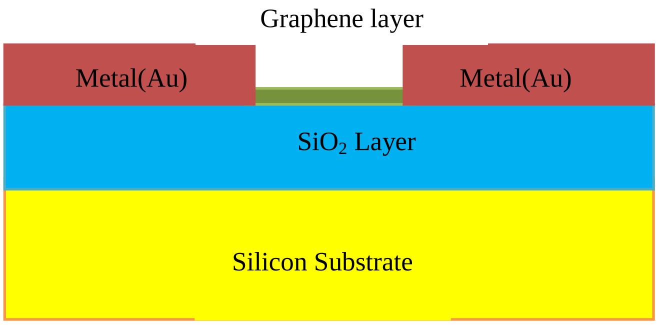

Fig.4 Schematic of Proposed Photodetector.

Figure 5 and 6 shows the simulated structure using ATLAS under dark condition and illumination of light of wave length range from 0.1 µm to 1.2 µm.

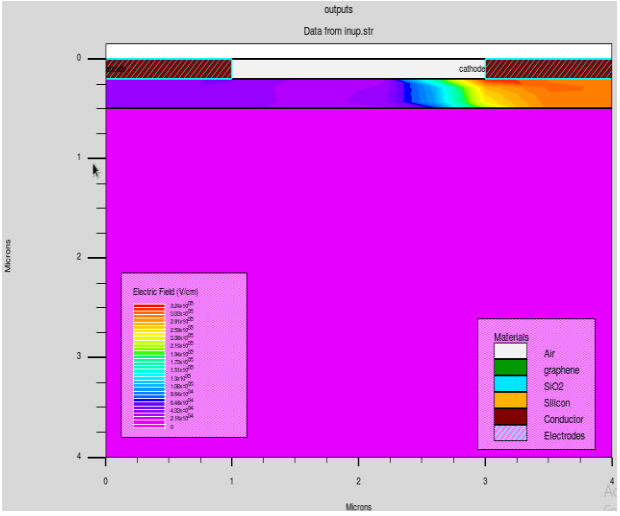

Fig.5 Proposed Structure under dark condition.

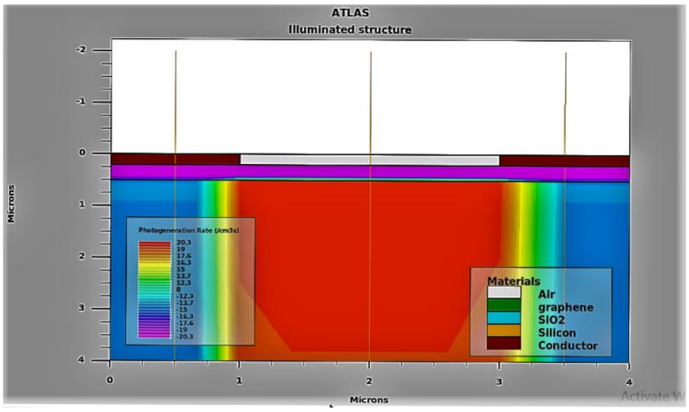

Fig.6 Structure of photo detector under illumination of light of wavelength range from 0.1 µm to 1.2 µm.

IV. RESULT AND DISCUSSION

For proposed photo detector, the dark current is measured as 7.56×10^{-13}A with the photo current has been found out $9.0341x10^{-13}$ A at 10V DC bias. The dark and photo current-voltage characteristics are a significant factor for a photo detector that are simulated and shown in Figure 7 with different bias voltages.

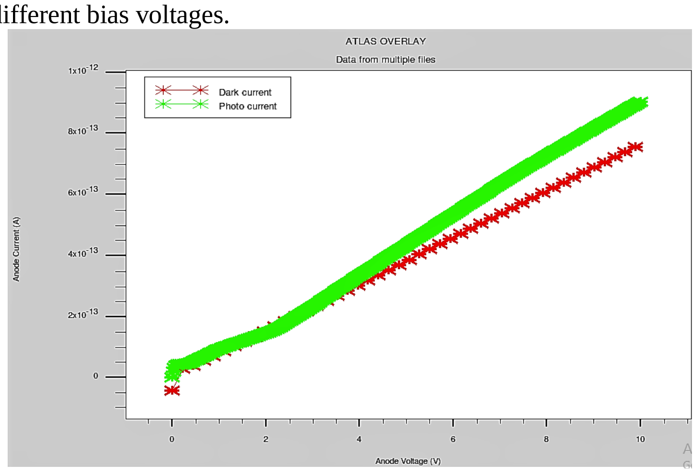

Fig. 7 Dark and Photo I-V Characteristics at different bias voltages.

ISSN: 2454-4248
167 – 170

It has been noticed that as we vary the cathode voltage anode current vary. Figure 8 shows variation of anode current at different cathode bias.

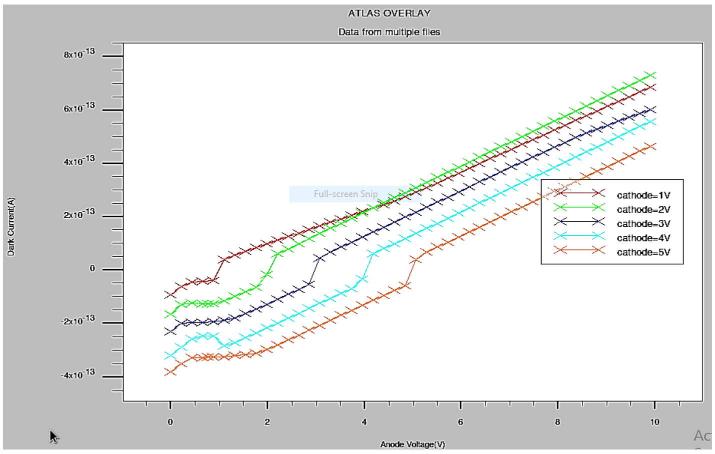

Fig. 8 Variation of anode current at different cathode bias

Figure 9 and 10 illustrates the Dark and photocurrent-voltage characteristics respectively for the projected photodetector at different spacing between the electrodes.

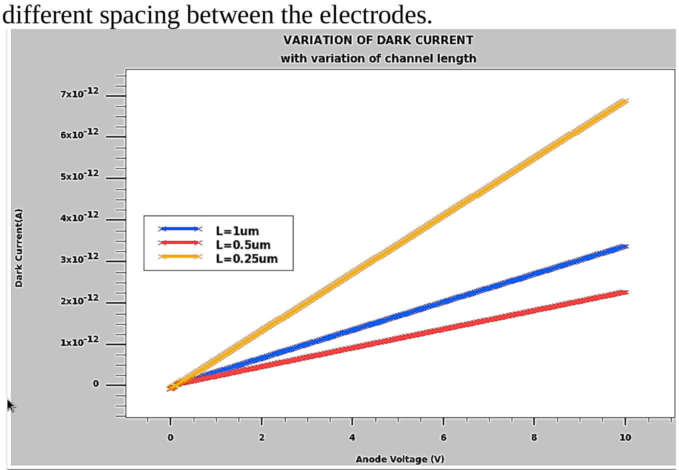

Fig. 9 Variation of Dark current at different spacing

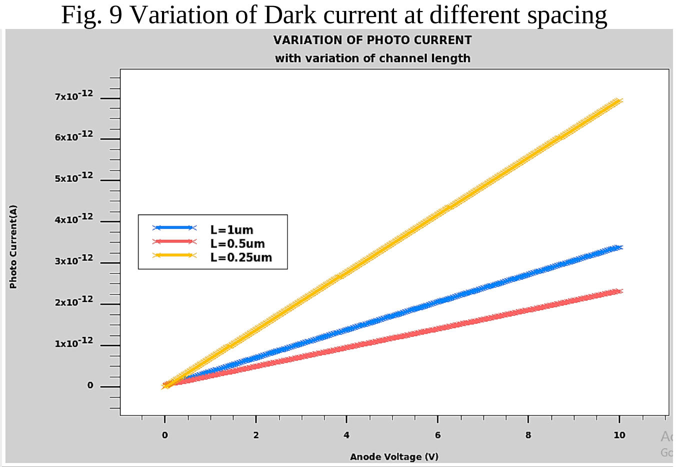

Fig. 10 Variation of Photo current at different spacing

Table 1 illustrate values of photo and dark current at different graphene length.

Graphene length	Photo current(A)	Dark current(A)
1μm	1.732×10^{-12}	1.697×10^{-12}
0.5μm	2.304×10^{-12}	2.264×10^{-12}
0.25μm	6.904×10^{-12}	6.886×10^{-12}

Table 1

The photo absorption rate under illumination of light is shown in Figure 11

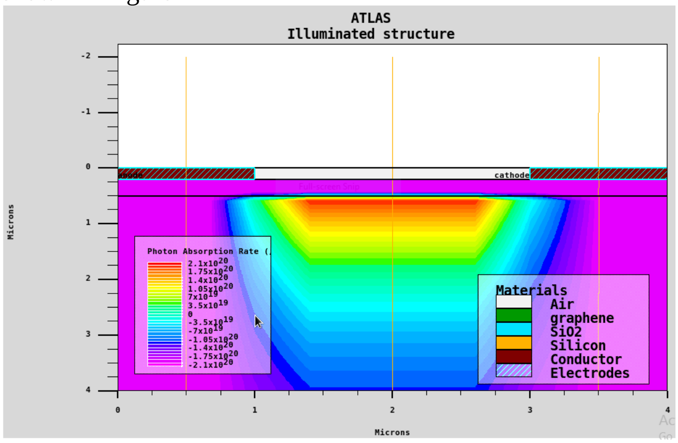

Fig. 11Photo absorption rate

REFERENCES

[1] Chen JH, Jang C, Ishigami M, Xiao S, Cullen WG, Williams ED, Fuhrer MS." Diffusive charge transport in Graphene on SiO 2". Solid State Communications. 2009 Jul 31;149(27):1080-6.

[2] Lohmann T, von Klitzing K, Smet JH. "Four-terminal magneto-transport in Graphene pn junctions created by spatially selective doping". Nano letters. 2009 Apr 10;9(5):1973-9

[3] Wang X, Tabakman SM, Dai H. "Atomic layer deposition of metal oxides on pristine and functionalized Graphene". Journal of the American Chemical Society. 2008 Jun 5;130(26):8152-3.

[4] Garces NY, Wheeler VD, Gaskill DK." Graphene functionalization and seeding for dielectric deposition and device integration". Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomena. 2012 May;30(3):030801.

[5] Koppens FH, Mueller T, Avouris P, Ferrari AC, Vitiello MS, Polini M. "Photodetectors based on graphene, other two-dimensional materials and hybrid systems". Nature nanotechnology. 2014 Oct 1;9(10):780-93.

[6] Tielrooij KJ, Massicotte M, Piatkowski L, Woessner A, Ma Q, Jarillo-Herrero P, van Hulst NF, Koppens FH. "Hot-carrier photocurrent effects at graphene–metal interfaces". Journal of Physics: Condensed Matter. 2015 Apr 2;27(16):164207.

[7] Wei P, Bao W, Pu Y, Lau CN, Shi J. "Anomalous thermoelectric transport of Dirac particles in graphene". Physical review letters. 2009 Apr 24;102(16):166808.

[8] Breusing M, Kuehn S, Winzer T, Malić E, Milde F, Severin N, Rabe JP, Ropers C, Knorr A, Elsaesser T. "Ultrafast nonequilibrium carrier dynamics in a single graphene laye"r. Physical Review B. 2011 Apr 19;83(15):153410.

[9] Breusing M, Ropers C, Elsaesser T." Ultrafast carrier dynamics in graphite". Physical review letters. 2009 Feb 27;102(8):086809.

[10] Winzer T, Knorr A, Malic E. Carrier multiplication in graphene. Nano letters. 2010 Nov 5;10(12):4839-43.

[11] Song JC, Tielrooij KJ, Koppens FH, Levitov LS. "Photoexcited carrier dynamics and impact-excitation cascade in graphene". Physical Review B. 2013 Apr 23;87(15):155429.

[12] Tielrooij KJ, Song JC, Jensen SA, Centeno A, Pesquera A, Elorza AZ, Bonn M, Levitov LS, Koppens FH. "Photoexcitation cascade and multiple hot-carrier generation in graphene". Nature Physics. 2013 Apr 1;9(4):248-52.