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Graphene based effectual photodetector for photonic integrated circuit

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ABSTRACT

Graphene based p-i-n photodetector circuit is thoroughly addressed in the present research at signal of 650 nm, where intrinsic layer is wrapped with graphene material and it plays vital role to realise effectual detector. To accomplish the same, various parameters of intrinsic layer such as reflectance, transmittance, absorbance, and photocurrent and quantum efficiency are lucidly included to compute the overall transmitted efficiency of the proposed photodetector. Reflectance as well as transmittance is examined by employing plane wave expansion (PWE) method whereas numerical equations are used to find other aforementioned parameters of the intrinsic graphene layer. Simulation results affirm that there is negligible reflectance of 0.0000002 and transmittance of 0.05 from the graphene layer whereas 94% of light get absorbed in the intrinsic layer, pertaining to the proposed structure, and as a result of which intrinsic graphene layer generates massive photocurrent with respect to apposite potential difference in the photodetector circuit. Moreover, photocurrent and quantum efficiency of the said photodetector is analysed with the variation of potential across the photodetector. Finally, it is divulged that photocurrent increases from 3.01 mA to 3.10 mA and quantum efficiency increases from 38.33% to 39.44% with the variation of applied voltage from 0.34 V to 0.43 V respectively. The above piece of work asserts that graphene material is a suitable candidate for photodetector as well as photonic integrated circuits.

1. Introduction

The potential of nanophotonic devices has gathered plethora of research interest in recent years for onchip optical communications. Integration of large number of photonics devices on silicon based waveguide, leads to an efficient optical interconnectors for light wave circuits [1–6]. Photodetector, regarded as the principal building blocks of photonics integrated circuit, used at the receiving end of the optical link which convert light signal back into electrical signal by absorption of photons in the intrinsic layer. Therefore, strong absorption and effective collection of photo-generated carriers are anticipated for efficient photodetection which can find novel applications in optical signal processing and optical computations. To realise strong absorption, different semiconductor materials have been widely used for design of photodetector. Also researchers feel that semiconductor based nanomaterials could be a suitable runner for better absorbance property. To envisage the same, researchers believe that graphene could be a right choice for solving above said problem. Graphene, formed by sp2 hybridized orbital bonded carbon crystal, is an exceptionally promising material in the advancement of novel optoelectronic devices. Owing to its outstanding electrical and optical properties, graphene has been considered as excellent optoelectronic material to realise high performance optoelectronic devices including

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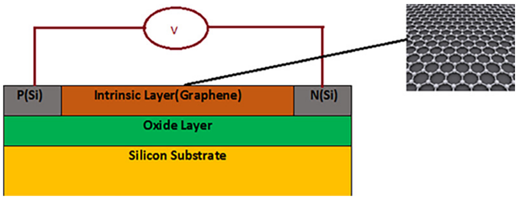

Fig. 1. SOI integrated photodetector structure.

optical modulator, plasmonic devices, remote sensing, imaging, saturable absorber, photovoltaic module, photodetector, polarizer etc [7–14]. Above all, graphene can efficiently be integrated with present silicon-on-insulator (SOI) waveguide structure by using CMOS technology [15,16], permitting manufacture of cheap graphene based devices. Recent theoretical and experimental analysis on graphene based photdetector [17] reflects relatively low quantum efficiency and responsivity. In reference [18,19], authors demonstrated zero-bias operation in uni-travelling-carrier photodiodes (UTC-PD) considering higher built-in E-field for a high bandwidth operation but concluded with less quantum efficiency. Here, we report a simple silicon-graphene-silicon photodetector operating at 650 nm having absorbance of 94% and maximum quantum efficiency of 39.44%. In this research external reverse bias potential is applied for more absorption of photo carriers, thereby resulting fast and efficient photodetection.

2. Structure analysis

In the current work, we have reported an efficient photodetector, which is suitably embedded with silicon photonic waveguide and the configuration of the proposed structure is illustrated in Fig. 1. The tunable optoelectronic properties of graphene are judiciously utilized in designing of the intrinsic layer of p-i-n photodetector whereas p and n regions are designed by using silicon. Because of two dimensional structures, graphene can be efficiently integrated with planar photonic devices which significantly enhance the overall performance of SOI waveguide. As far as fabrication feasibility is concerned, one layer of graphene is developed by chemical vapour deposition (CVD) process on copper foil and transferred onto the intrinsic region of the suggested photodetector structure. Also here, the thickness of p and n regions are selected to be 1 nm each whereas thickness of graphene based intrinsic region is taken to be 0.53 nm. The above mentioned thicknesses are considered in nanometre scale to explore the benefits of nanotechnology in photonics integrated circuits. The aforementioned structure is manipulated with a signal of 650 nm and furthermore, a reverse potential is applied across the proposed photodetector to enhance the absorbance and thereby to increase the emitted photocurrent. Furthermore, reflectance and transmittance is computed by employing plane wave expansion method whereas absorbance, photocurrent and efficiency is realised by using numerical equations.

3. Mathematical treatment

Moving to intrinsic property of graphene, though different parameters (temperature, pressure, concentration, resistance, impedance, impurities etc) control the property of graphene, chemical potential plays vital role with respect to apposite reverse potential, which leads to the managing of efficiency of the device. Further optical properties of graphene i.e. optical absorption can be reformed by means of varying its chemical potential. For a particular wavelength, a small variation of chemical potential may give rise a significant changes in the conductivity. The external voltage applied across the photodetector can be obtained from the chemical potential [20] as stated below,

$$v_g = \frac{e * p}{c_g} + \frac{\mu(p)}{e} + \phi_0 \tag{1}$$

where v_g is the external voltage applied across p and n region of the proposed photodetector, ϕ_0 is the electrical potential permitted to doping, c_g is graphene capacitance per unit area and μ is the applied chemical potential and p indicates charge carrier densities. As absorbance of photocarriers in the intrinsic region of photodetector plays vital role in determining photocurrent, hence it must be treated as outmost importance. The absorbance attributable principally due to interband optical transition which depends on the structure parameters. The absorbance of graphene contingent upon the frequency dependent interband absorption, which is given as,

$$\alpha(w) = \frac{\left(q + \frac{\hbar w - E_{res}}{2\Gamma}\right)^2}{1 + \left(\frac{\hbar w - E_{res}}{2\Gamma}\right)^2} * \sigma_{inter}(\mathrm{w}) + \sigma_{intra}(w) m \tag{2}$$

where $\Gamma = 0.78$, $q = = -1$, $E_{res} = 5.02$ eV used from reference [21] and w is frequency of incident light signal.

$$\sigma_{inter}(w) = \frac{\Pi^2 e^2}{c\hbar}\left[\tanh\left(\frac{\hbar w + 2E_F}{4K_B T}\right) + \tanh\left(\frac{\hbar w - 2E_F}{4K_B T}\right)\right. \tag{3}$$

and