Near Infra-red Photosensor using Optically Gated D-MOS Vertical TFET

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***Abstract*-This article reports a highly sensitive and low power photosensor using dual MOSCAP Vertical TFET for near infrared light detection in the wavelength range 0.7µm to 1µm. The optical voltage (V_{OP}) developed because of the photogeneration occurring within the gate region enhances the gate control over the channel and produces higher drain current. The sensitivity is calculated by measuring the alteration of drain current with wavelength. Peak sensitivity of the order of 10^5 is obtained at V_{GS}=0.5V and provides a maximum responsivity of 1.6×10^3 A/W at V_{GS}=1.5V for λ= 0.7µm. This modified TFET based hybrid photosensor can be a new generation of highly sensitive photosensor.**

I. Introduction

In recent times, the application of field effect transistors (FETs) as photosensor is gaining lot of interest due to its compatibility for integrated circuits, potential of downsizing the dimensions and ability to provide higher sensitivity [1]. The state-of-art FET based photosensors are successfully used in target tracking, diagnosis and treatment of diseases, optical interconnects for inter chip data communication etc. Because of its thermal limit of subthreshold swing (SS), MOSFET suffers from speed limitations. The tunnel FET (TFET) turns up to be a viable device for being use as low power device as band-to-band tunneling (BTBT) is its current transmission mechanism [2]. Unlike MOSFETs, TFETs can possess SS lower than 60mV/dec limit. The major research challenge in realizing low power TFET circuits lies in improving its ON state current and suppressing the ambipolar behaviour. Strong efforts have been made to boost the performance of TFETs through structural and material modifications [3]. The advantages of Vertical TFET (VTFET) over the conventional TFET in terms of ehanced I_{ON}/I_{OFF} ratio, steeper subthreshold swing (SS) have been demonstrated in the literature. This work proposes a type of VTFET having dual MOS capacitor (MOSCAP) geometry to operate as a highly sensitive photosensor by utilizing optical-gating technique. Section II discusses the sensor design and the working principle. Simulation strategy is discussed in section III. The spectral sensitivity analysis based on the alteration of drain current because of the change in wavelength of incoming light is investigated in Section IV. Section V concludes the work.

II. Sensor Design and Working Principle

The conventional TFET is modified using two MOS capacitors (MOSCAP) where channel/drain regions are vertically elevated and forms an inverted-T shape. It is named as dual MOSCAP vertical TFET (D-MOS VTFET) [4]. The epi layer which is intrinsic in nature (1×10^{15} cm^{-3}) resides in the region between the gate-stack and source. The combination of these three forms the MOSCAP region. The elevated channel separates source (p-type: 1×10^{20} cm^{-3}) and drain (n-type:1×10^{18} cm^{-3}) regions. This TFET has two source regions having an intrinsic Si layer of length L_{Gap}=20nm in between them. A 2nm SiGe δ-layer enhances the BTBT mechanism because of its lower forbidden

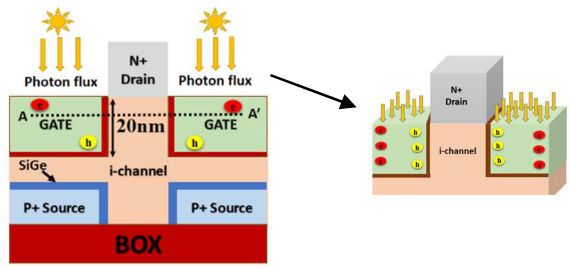

Fig. 1 Schematic illustration of optically gated Dual MOSCAP VTFET for photosensing application.

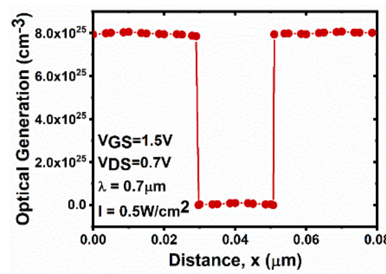

Fig. 2 Optical generation at gate region.

energy bandgap. The gate-stack is comprised of uniform horizontal and vertical oxide with SiO2 as oxide material. The mechanism of photoconductivity is adopted by employing optical gates made up of n-type silicon where photon absorption can take place. The 2D schematic illustration of optically gated D-MOS VTFET for photosensing application is shown in Fig. 1. The thickness of this optical gate is taken as 20nm with the intention that all the incident photons are absorbed entirely in this region. Optical generation occurs when the incident light falls normally into these gate regions. The optical generation occurring inside the device at the illumination state with light intensity I=0.5W/cm^2 and wavelength λ= 0.7µm is plotted in Fig. 2. Due to the incident light, the photogeneration takes place inside the gate region where electrons with more energy bandgap than that of Si moves from valence band to the conduction band giving rise to excess electron-hole pair (EHP). The quasi-equilibrium carrier concentrations in the gate region are given by [2],

$$\left.\begin{aligned} n &= n_0 + \Delta n(\lambda) \\ p &= p_0 + \Delta p(\lambda) \end{aligned}\right\} \qquad ((1))$$

where n_0 , p_0 are the electron and hole concentration respectively at the equilibrium state with no incident light and $\Delta n(\lambda), \Delta p(\lambda)$ are excess electron and hole concentration after photogeneration. The applied gate bias (V_{GS}) controls the movement of these carriers. Positive V_{GS} attracts the photo generated electrons whereas the holes are accumulated near the gate-oxide interface. Consequently, equilibrium state of the gate region is disturbed and thus uncoupling of electron (E_{fn}) and hole quasi fermi level (E_{fp}) happens. Due to this, a net photo voltage (V_{OP}) is developed across it and increases the channel conductance of the sensor [2]

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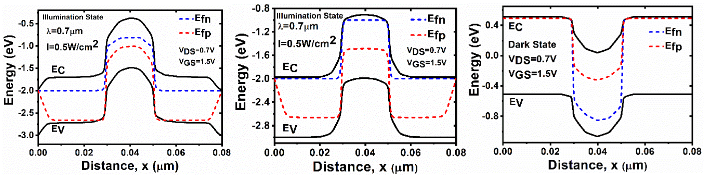


(a) (b) (c)

Fig. 3 Schematic illustration of enrgya band diagram uncoupling of quasi fermi levels at the illumination state (I=0.5W/cm^2 and λ= 0.7μm) along the line AA′ (a)near gate-oxide interface (b) top surface of optical gate (c) under take state.

$$V_{OP} = V_T \ln\left[1 + \left(\frac{\Delta n}{n_i}\right)^2 + \frac{\Delta n}{N_g}\left(1 + \left(\frac{N_g}{n_i}\right)^2\right)\right] \qquad (2)$$

Where N_g is the doping concentration of gate which is n-type. Fig. 3 (a) and (b) show the uncoupling of quasi fermi levels at the illumination state (I=0.5W/cm^2 and λ= 0.7μm) along the line AA′ near gate-oxide interface and top surface of optical gate respectively. Electron density is higher at top surface of the gate while at the bottom surface of gate, the hole concentration is more. This arrangement attracts more electrons in the channel region giving higher ON state current (I_{ON}). Fig. 3(c) shows the energy band diagram under dark state. The equilibrium state is maintained in this state. The energy band diagram showing the transfer of electron from source to channel is shown in Fig. 4(a).

III. SIMULATION STRATEGY

All the simulations related to the characterization of TFET architectures under consideration are carried out using Sentaurus TCAD tool. Non local BTBT model is employed for current transport mechanism to look after the tunneling in vertical TFET. Fermi-Dirac statistics and Band gap narrowing model is activated to take care of the mechanisms happening due to the high doping concentrations of the source and drain. Electron-hole pair recombination happening inside the device is done by SRH recombination model. Besides, the Doping Dependent Mobility Model are also added to drive the effect of doping concentration on mobility of carriers. Complex refractive index model with illumination using monochromatic light is adopted to produce optical generation in the gate region. The performance of this photosensor is investigated under low illumination intensity (I_0=0.5 W/cm^2) having wavelength near the infrared region (0.7 μm–1 μm).

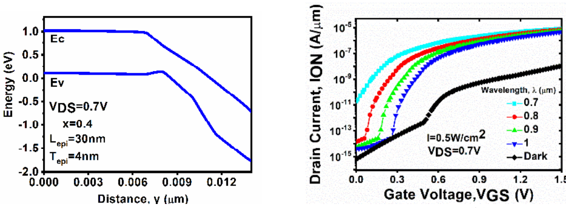
IV. RESULTS AND DISCUSSION

This section analyses the alteration of drain current as a result of the absorption of light having different wavelengths in the gate region. The performance of the proposed D-MOS VTFET based photosensor is studied considering the spectral sensitivity (S_n) which is calculated by measuring the ratio of drain current under illuminated state to the drain current with no incident light (dark state).

$$Spectral\ Sensitivity, S_n = \frac{I_{Photo} - I_{Dark}}{I_{Dark}} \qquad (3)$$

A. Spectral Response

Fig. 4(b) shows the transfer characteristics plots of the proposed photosensor at I_0=0.5 W/cm^2 and λ= 0.7μm to 1μm plotted against different applied gate bias. A significant upward shift in drain current with the decrease in wavelength of incoming light is observed. The drain current characteristics of all the four values of λ shows enhanced behavior as compare to the dark state



(a) (b)

Fig. 4 (a) Energy band diagram at ON state. (b) Transfer characteristics plots at different wavelength

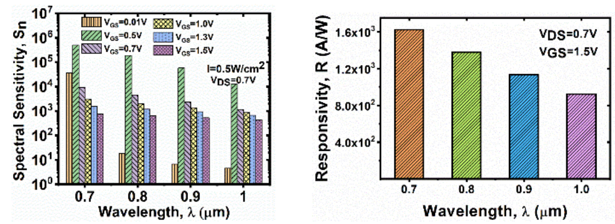


Fig. 5 (a) Spectral sensitivity for different wavelength. (b) corresponding Responsivity at V_{GS}=1.5V.

characteristics because of the existence of V_{OP}. The spectral sensitivity calculated using equation (3) is plotted in Fig. 5(a) for six different values of V_{GS}. The S_n gives higher value at the sub-threshold regime and it shows maximum result at V_{GS}=0.5V for all the considered wavelength range. The sensitivity is found to be increasing as wavelength of incoming light decreases. This is due to the increase in absorbance capacity of Si in this wavelength range. It reaches a peak value of the order of 10^5 which is quite high compare to the state-of-art photosensors. The responsivity (R) of the photosensor under the incident light intensity, I_0=0.5 W/cm^2 is shown in Fig. 5(b). It is calculated using equation (4).

$$R = \frac{I_{Photo}}{P_{Opt}} \qquad (4)$$

Where P_{opt} is the incident optical power. The responsivity is measured at V_{GS}=1.5V and its value is of the order of 10^3 in all the cases. The peak value of R is obtained for λ= 0.7μm and has a value R=1.6x10^3 A/W.

V. CONCLUSION

This article proposes an optically gated near infrared photosensor using D-MOS VTFET. The incoming photons are absorbed in the gate region and increases the channel conductance. The sensitivity of the sensor shows higher value in the sub-threshold regime and its value decreases when the device enters the super-threshold regime. The peak value is obtained at V_{GS}=0.5V which is of the order of 10^5 at λ= 0.7μm. The responsivity obtained in this case is R=1.6x10^3 A/W which is quite high as compare to the state-of-art sensors. Hence, the proposed optically gated photosensor using D-MOS VTFET is a viable candidate which can sense closely spaced spectral lines.

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