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Full Length Article

Design and analysis of high sensitivity photosensor using Cylindrical Surrounding Gate MOSFET for low power applications

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ABSTRACT

In this paper, a high sensitivity photosensor is proposed that utilizes the Zinc Oxide (metallic ZnO) which act as a transparent optical window over channel. High sensitivity is achieved by using Cylindrical Surrounding Gate Metal Oxide Semiconductor Field Effect Transistor (CSG MOSFET). On being exposed to light there is substantial increase in conductance and thereby change in the subthreshold current under exposure is utilized as a sensitivity parameter. Most of the Conventional FET based photosensors that are available utilizes threshold voltage as the parameter for sensitivity comparison but in this proposed sensor, under illumination change in the conductance resulting in variation of the subthreshold current is considered to be the sensitivity parameter. Performance comparison with Double Gate Metal Oxide Semiconductor Field Effect Transistor (DG MOSFET) in terms of sensitivity, threshold voltage and I_{on}/I_{off} ratio is also done and observed results shows that CSG MOSFET is an ideal candidate for being used as a high sensitivity photosensor because in CSG MOSFET due to effective control of gate over channel low dark current, high sensitivity, low threshold voltage and high I_{on}/I_{off} ratio can be achieved. Further impact of channel radius on responsivity (R_e), quantum efficiency (Q_e) and I_{on}/I_{off} ratio is also studied for the proposed device.

1. Introduction

Nowadays the demand of low power and highly sensitive photosensors is growing at an astonishing rate for being used in many application such as in flame detectors, chemical composition analysis, missile plume prediction, medical diagnosis and treatment, surveillance cameras etc. [1–6], and also in optical interconnects for inter chip data communication [7] and in optical storage media [8]. Compatibility of Field Effect Transistors (FETs) for integrated circuit have helped in the successful development of these devices for their use as photosensors. Silicon (Si) based photodetectors are generally being utilized as a part of a large number of these applications because of the fact that they occupy less volume, have high signal to noise ratio, abundantly available and being congenial with microelectronics they are extensively used in the areas of defence and civil applications [9].

Sensitivity is one of the most important parameter which judges the effectiveness of the photosensor. Today most of the research work is totally centered on in using highly photosensitive channel material [10], transparent gate material [11] and back illumination method [12,13] to enhance the photoresponse, but in this paper device engineering is utilized to achieve the targets, as in order to achieve a very low dark current device engineering plays a crucial role. In order to further increase the sensitivity for the desired region of spectrum ZnO as a gate material is utilized which act as an optical filter. ZnO being a transparent gate material for UV–visible spectrum [14] has the benefit of providing less reflection for the desired region of spectrum so that a large portion of light occurrence on the gate material reaches to the semiconductor.

Photodiodes other than MOSFET based i.e. Avalanche photodiodes; PIN photodiode, p-n junction photodiodes etc. have their own limitations. Low Q_e of p-n junction photodiode [15], high noise in avalanche photodiodes [16] and speed limitation due to transit time of the generated photocarriers in PIN photodiode [17] restrict their use as a high sensitivity photosensors and hence MOSFET based photosensor can be effectively used to overcome all these limitations. MOSFET based photosensors dissipate very low power because of very high input impedance, they also introduce less noise due to participation of majority charge carriers and can also withstand high temperature.

As compared to DG MOSFET, CSG MOSFET have several advantages including better electrostatic coupling between gate and the channel as gate electrode completely surrounds the channel and hence off state leakage current gradually decreases, higher I_{on}/I_{off}

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ratio for fixed drain voltage and reduced short channel effects (SCEs) [18].

In this paper CSG MOSFET with ZnO as a gate and silicon dioxide (SiO_2) as gate dielectric is used for designing high sensitivity low power photosensor. The combined advantageous effect of device engineering and channel material engineering is utilized to achieve our goal of designing a photosensor that can effectively use in UV–visible spectrum applications. In this paper performance comparison with DG MOSFET in terms of dark current, threshold voltage and I_{on}/I_{off} ratio is also done and results shows that CSG MOSFET is superior in performance as a highly sensitive photosensor. Impact of channel radius on responsivity (R), quantum efficiency (Q_e) and I_{on}/I_{off} ratio is also studied for the proposed device.

2. Device structure and simulation setup

Fig. 1(a) depicts the 2D-cross section view of CSG MOSFET and Fig. 1(b) 3D-Simulated structure of DG MOSFET under incident radiation Fig. 1(c) depicts the 3D-simulated structure of CSG MOSFET under incident radiation. R is the radius of channel, L is the channel length, L_S is the source length, L_D is the drain length, z is the channel direction, and t_{ox} is the oxide thickness.

In order to extricate device characteristics under dark SILVACO ATLAS-3D simulator [19] is utilized to simulate CSG MOSFET. The parameters utilized in simulation process are as given in Table 1. It also incorporates advance LUMINOUS-3D optical device simulator to extricate device characteristics under incident radiation which uses Ray Trace method for calculating the photogeneration rate at defined mesh points. The optical parameters for the incident radiation such as radiation intensity, wavelength and location is set by using BEAM keyword incorporated in LUMINOUS-3D module. Various models used for the purpose of simulation of CSG MOSFET are: Field Dependent Mobility model (FDM) and Shockley Read Hall model (SRH). FDM model takes into consideration the dependence of carrier mobility with high electric field and SRH model accounts for the chances of recombination phenomenon at traps. The thickness of both ZnO as a transparent gate material and SiO_2 as a gate dielectric is kept small so that most of the light falling on the gate region reaches Silicon (Si) channel underneath. The path of light from air to the Si channel underneath is obstructed due to reflections at three interfaces namely air to gate (ZnO), gate to oxide (SiO_2) and oxide to semiconductor (Si). Reflection at theses interfaces helps in analyzing the behavior of device under incident radiation. The reflection coefficients for these three interfaces can be calculated using the formula [20]:

Table 1
Parameters utilized in simulation process.

Symbol	Definition	Value
L	Channel length	1.0 μm
t_{si}	Silicon film thickness	0.5 μm
R	Channel radius (t_{si} = 2R)	0.25 μm
L_S	Source length	0.5 μm
L_D	Drain length	0.5 μm
t_{ox}	Oxide thickness	10 nm
N_A	Channel doping	$1 \times 1016\ \text{cm}^{-3}$
N_D	Source/Drain doping	$1 \times 1020\ \text{cm}^{-3}$

$$R_c = \frac{(n_c - n_{c+1})^2 + k_{c+1}^2}{(n_c + n_{c+1})^2 + k_{c+1}^2} \tag{1}$$

where R_1, R_2 and R_3 are the reflection coefficients at the three interfaces i.e. air to gate (ZnO), gate to oxide (SiO_2) and oxide to semiconductor (Si) respectively. n_1, n_2, n_3 and n_4 are the real part of refractive index of air, gate, oxide and semiconductor respectively and k_c's are the corresponding imaginary part of the refractive indexes. SOPRA database [21] is referred to get the real and imaginary values of the refractive index in order to calculate the reflection coefficients and for the purpose of simulation of CSG MOSFET under incident radiation. Table 2 shows the real and imaginary refractive index values for ZnO, SiO_2 and Si for different wavelengths of incident radiation and the calculated reflection coefficients for above

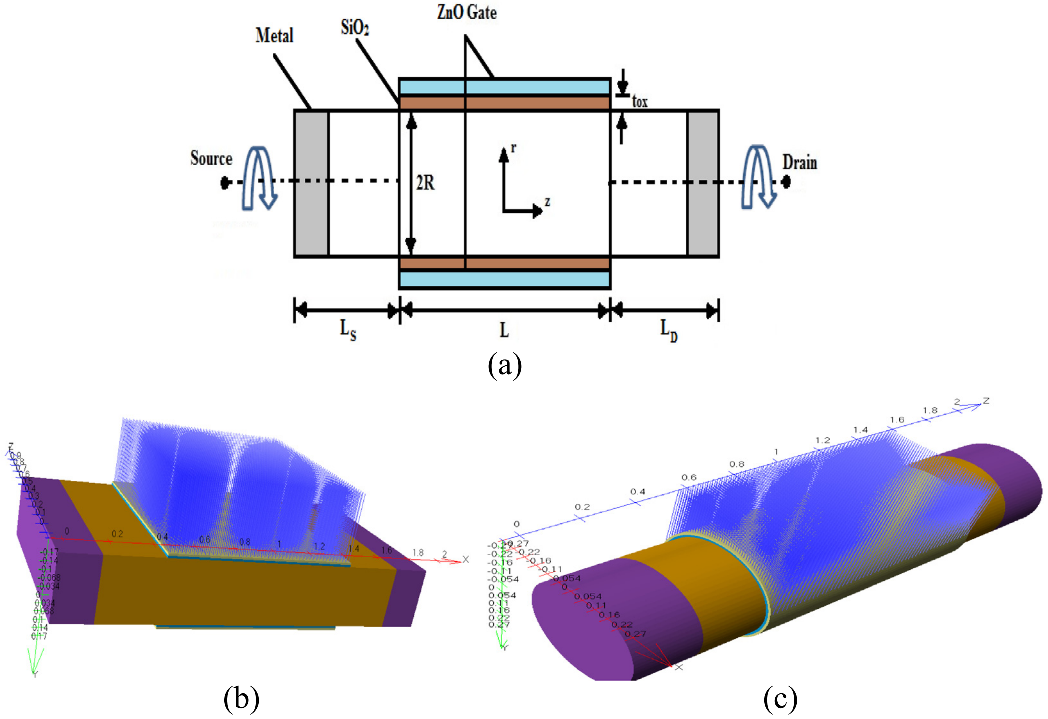

Fig. 1. (a) 2D-Cross Section of CSG MOSFET (b) 3D-Simulated structure of DG MOSFET under incident radiation (c) 3D-Simulated structure of CSG MOSFET under incident radiation.

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