POTENTIAL AND DRAIN CURRENT SIMULATION OF A SYMMETRIC DOUBLE GATED MOLYBDENUM DISULFIDE (MOS2) TRANSISTOR

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ABSTRACT

As the scaling of silicon MOSFET reaches its physical limit, research efforts have been made in exploring alternative devices. In this paper, we have examined the enhanced drain current, electrostatic potential, mobility, and electric field for a symmetric structure of Double gated Molybdenum Disulfide (MoS_2) transistor. The performance of the device has been simulated using Technology Computer-Aided Design (TCAD) simulation tool. The above mentioned comparison model of drain current built by use of symmetric Double gated MoS_2 transistor has shown superior performances when compared with that of Silicon transistor. There is an enhancement of 0.1 μA in its drain current and the mobility is 50 higher than the silicon based transistor, under the condition that this device has the same geometry. It was performed by incorporating the quantum mechanical effects in molybdenum disulfide (MoS_2) based transistor. Due to its high performance in low power operating voltages, MoS_2 transistor will be suitable for low power applications.

KEYWORDS

2D material, MoS_2, Drain Current, FET, TCAD Simulation tool.

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1. INTRODUCTION

In the recent decade, silicon-based transistor has reached its scaling limit. Hence, researchers have been discovering solutions for finding alternative channel materials for future semiconductor devices; such has the transition metal dichalcogenides (TMDs) material of MoS_2, which is chosen due to their high ON- OFF ratio and mobility. Unlike graphene, MoS_2 material has large bandgap of 1.23 eV, so it can be easily turned off. Compared to Silicon dioxide, high k dielectric materials are mostly preferred because of its reduced threshold voltage and improve current ON/OFF ratio (Ajayan *et al.*, 2017; Pravin *et al.*, 2016a; Ryu *et al.*, 2016; Boucart & Ionescu, 2007).

We present the simulated result of drain current, electrostatic potential, mobility, and electric field for symmetric double gated MoS_2 transistor using Technology Computer-Aided Design (TCAD) simulation tool. Here we have been used the drift diffusion model is the carrier transport model in Sentaurus Device ("Sentaurus™ Device User Guide. Version K-2015.06", 2015). Based on the literature survey (Pravin *et al.*, 2016b; Pravin *et al.*, 2018; Semiconductor Industry Association, 2015; Tiwari *et al.*, 2017), our numerical model has been simulated. Finally, we have to extract the physical parameters of drain current, electrostatic potential, mobility, and electric field for MoS_2 based transistor by TCAD simulation tool. We have to compare the obtained results of MoS_2 material and silicon material, where our proposed model has shown the higher performance.

In this paper, we address a symmetric Double gated MoS_2 transistor, it produces the higher drain current compared to Single gate MoS_2 transistor.

2. MATERIALS AND METHODS

The physical structure of symmetric Double gated MoS_2 based transistor is presented in Figure 1, which has been modeled with channel length (Lch) of 20 nm, 10 nm thickness of the gate oxide (tox), and channel thickness (tch) of 10 nm (Jiang *et al.*, 2015). These values are shown in Table 1.

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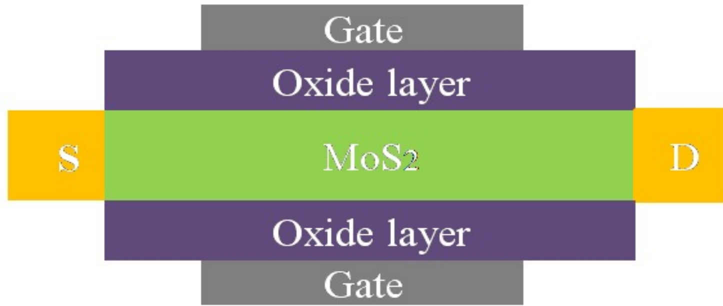

Figure 1. Device geometry of symmetric Double gated MoS_2 transistor.
Source: own elaboration.

Table 1. Values of the physical structure of the double-gate MoS_2-based symmetric transistor.

Parameters	Values
Channel Length	20 nm
Gate Oxide	10 nm
Channel thickness	10 nm
Drain/Source Doping	1e18
Channel Doping	$1e^{21}$
MoS_2 band gap	1.23 eV

Source: own elaboration.

The Drift diffusion model and Shockley Read Hall Recombination model have been used in the simulation for determine the drain current of proposed device ("Sentaurus™ Device User Guide. Version K-2015.06", 2015).

DRIFT-DIFFUSION MODEL:

In Sentaurus Device, the default carrier transport model of drift-diffusion model is used. The electron current density and hole current density are given below,

$$\vec{J_n} = \mu_n(n\nabla E_C - 1.5nkT\nabla lnm_n) + D_n(\nabla_n - n\nabla ln\gamma_n)$$

$$\vec{J_p} = \mu_p\left(p\nabla E_v - 1.5pkT\nabla lnm_p\right) + D_p(\nabla_p - n\nabla ln\gamma_p)$$

https://doi.org/10.17993/3ctecno.2021.specialissue8.385-395

Due to spatial variations of the electron affinity, the electrostatic potential and the band gap. These terms are taken into the report the contribution. The remaining terms of effective masses of m_n and m_p are taken into the report the contribution due to the spatial variation and the gradient of concentration.

By using Einstein relation, the diffusivities D_n and D_p are derived through the mobilities.

$$D_n = kT\mu_n and D_p = kT\mu_p$$

SCHOCKLEY-READ-HALL RECOMBINATION:

In Sentaurus Device, Schockley-Read-Hall (SRH) recombination model is achieved:

$$R_{net}^{SRH} = \frac{np - n_{i,eff}^2}{\tau_p(n + n_1) + \tau_n(p + p_1)}$$

$$n_1 = n_{i,eff} \exp\left(\frac{E_{trap}}{KT}\right)$$

$$p_1 = n_{i,eff} \exp\left(\frac{-E_{trap}}{KT}\right)$$

The difference between the detect level and intrinsic level is termed as E_{trap}.

SRH DOPING DEPENDENCE:

In Sentaurus Device, the doping dependence of the SRH lifetimes is modeled with the help of Scharfetter relation:

$$\tau_{dop}(N_{A,0} + N_{D,0}) = \tau_{dop} + \frac{\tau_{max} - \tau_{min}}{1 + \left(\frac{N_{A,0+}N_{D,0}}{N_{ref}}\right)^{\gamma}}$$

When the argument Doping Dependence is particularized for the SRH Recombination, where the Scharfetter relation is used.

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3. RESULTS

Based on the equations obtained for Drift-Diffusion model and Schockley-Read-Hall Recombination was carried out in the MoS_2 structure for finding the drain current, electrostatic potential, mobility, and electric field.

The final results show that the proposed MoS_2 device structure displayed improved performances in terms of both drain current as well as mobility than the silicon transistor.

3.1. SIMULATION RESULT OF DRAIN CURRENT

The MoS_2 channel material based transistor device is simulated with drift diffusion model in Sentaurus Device. Figure 2 depicts the analyzation of the drain current of the transistor device. The obtained result produces higher drain current at 1 V of gate voltage for short channel length device. This result illustrates that the MoS_2 material produces higher drain current compared to silicon material. When we are applied high gate voltages it reaches the high drain current.

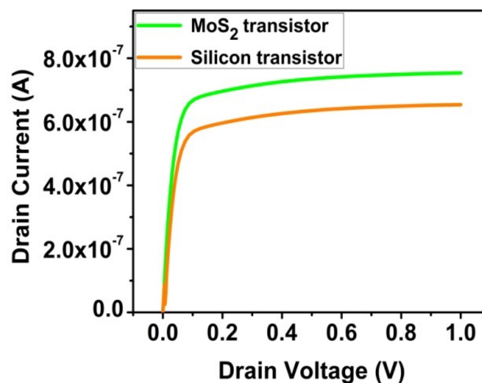

Figure 2. Comparison of drain current for MoS_2 material and Silicon material.
Source: own elaboration.

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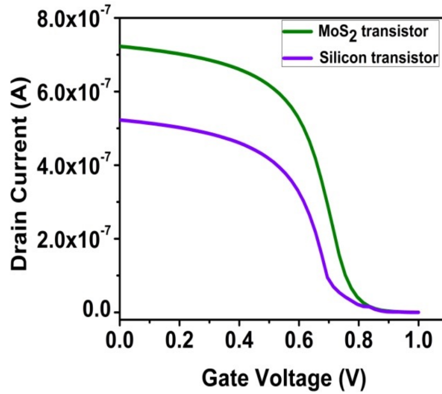

Figure 3. Comparison of drain current for MoS_2 material and Silicon material.
Source: own elaboration.

Figure 3 shows the output characteristics of drain current for MoS_2 material and silicon material. This result depicts the drain current with the function of gate voltage at 1 V of drain voltage.

3.2. SIMULATION RESULT OF ELECTRIC FIELD

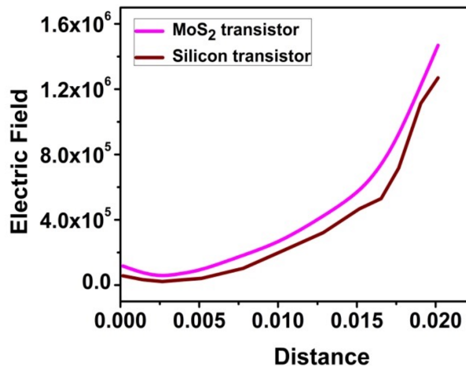

Figure 4. Analyzation of electric field for MoS_2 material and Silicon material.
Source: own elaboration.

Figure 4 shows the electric field for MoS_2 material and silicon material. This result depicts the electric field for MoS_2 produces a higher value tan the silicon transistor.

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3.3. SIMULATION RESULT OF MOBILITY

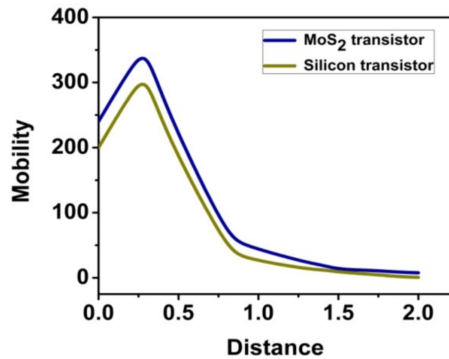

Figure 5. Mobility for MoS_2 material and Silicon material.
Source: own elaboration.

3.4. SIMULATION RESULT OF POTENTIAL

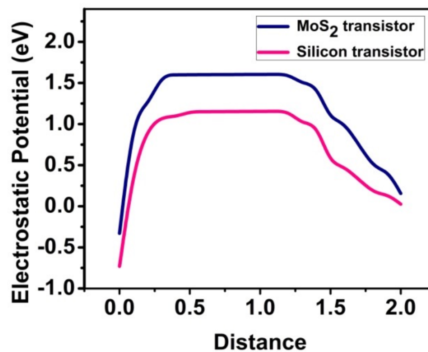

Figure 6. Comparison of electrostatic potential for MoS_2 material and Silicon material.
Source: own elaboration.

The above figure shows the mobility, and electrostatic potential for a symmetric structure of double gated MoS_2 transistor. The heavy doping of body makes difficult the potential calculation. To overcome this constraint, using Poisson equation in existence of important body doping. The electrostatic potential is achieved by solving Poisson equation.

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4. CONCLUSIONS

This paper introduced a MoS_2 based transistor with high k dielectric material, which has merits in terms of device performance of the reduced threshold voltage. A performance evaluation was done for the MoS_2 based transistor for finding out the drain current, electrostatic potential, mobility, and electric field. The performance of the device has been simulated using Technology Computer-Aided Design (TCAD) simulation tool. The above mentioned comparison model of drain current built by use of symmetric Double gated MoS_2 transistor has shown superior performances when compared with that of Silicon transistor. There is an enhancement of 0.1 μA in its drain current and the mobility is 50 higher than the silicon based transistor, under the condition that this device has the same geometry. It was performed by incorporating the quantum mechanical effects in molybdenum disulfide (MoS_2) based transistor. We have successfully investigated the MoS_2 material based transistor and its characteristics.

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