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Influence of Technological Parameters on Properties of MOSFETs

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Abstract

The field-effect transistors are always among the omnipresent electronic components in our daily life, they play a very important part in new technology. They reside in the middle of the revolution which carried a great part of technological development of very high level.

In the frame of our work, we are interested in the study of the field effect transistor metal oxide semiconductor called MOSFET. After analytical studying the component static characteristics, according to different operation regimes, a numerical simulation was worked out. The influence of technological dimensions (L, Z, a, and N_d) was studied.

The obtained results allow us to determine optimal parameters of the devices from the view point of their applications and specific use.

Keywords: MOSFET, physical parameters, geometrical parameters, technological, semiconductor.

INTRODUCTION

Several research laboratories showed the interest of using the field effect transistor metal oxide semiconductor (MOSFET) for the realization of analog and logic integrated circuits. A fairly good technological realization can only be achieved with a deep knowledge of the component physics and all the intrinsic and extrinsic phenomena that can limit its performances. In this paper, we propose an analytical model (simulation) of current-voltage characteristics of a MOSFET, then we have elaborated a software that enable us to solve the system of differential equations and plot a series of different curves.

CURRENT-VOLTAGE CHARACTERISTICS

To calculate the drain current expression as a function of the drain voltage for different values of the gate voltage, we use the following hypothesis [1, 2]:

- The insulator (SiO_2) is ideal: absence of charge traps in insulator and at the interface of the semiconductor. There is no difference in work between metal and the semiconductor;
- The mobility of the carriers is constant in the inversion layer;
- The doping of the channel is uniform in all the substrate;
- The leakage current is negligible.

Approximation of the gradual charge: The transverse field E_x in the channel is more important than the longitudinal field E_y. Thus the variation of the drain current I_D with the drain-source voltage V_D and the gate-source voltage V_G is given by the following general relation [3]:

$$I_D = \frac{Z\mu C_{ox}}{L}\left(\left(V_G - \frac{V_D}{2} - 2\phi_{Fi}\right)V_D - \frac{2}{3}\frac{\left(2eN_a\varepsilon_S\right)^{1/2}}{C_{ox}}\left(\left(V_D + 2\phi_{Fi}\right)^{3/2} - \left(2\phi_{Fi}\right)^{3/2}\right)\right) \quad (1)$$

However, this equation is rewritten differently, according to the operation regime of the transistor which depends primarily on the value of the drain voltage V_D. These regimes are:

A. Linear regime

The drain voltage in this regime obeys to the following condition: $V_D \le V_G - V_T$

Thus, the equation of drain current is rewritten [4, 5, 6]:

$$I_D = \frac{Z\mu C_{ox}}{L}\left(V_G - V_T\right)V_D \quad (2)$$

With V_T is the threshold voltage and C_{ox} is the insulator capacitance, both are given by:

$$V_T = 2\phi_{Fi} + \left(4eN_a\varepsilon_s\phi_{Fi}\right)^{1/2} / C_{ox} \quad (3)$$

$$C_{ox} = \frac{\varepsilon_{ox}}{d} \quad (4)$$

B. Saturation Regime

The drain voltage is conditioned by: $V_D > V_G - V_T$

The drain current becomes [4, 5, 6]:

$$I_{Dsat} = \frac{Z\mu C_{ox}}{2L}\left(V_G - V_T\right)^2 = \frac{Z\mu C_{ox}}{2L}V_{Dsat}^2 \quad (5)$$

Where V_{Dsat} is the saturation voltage given by:

$$V_{Dsat} = V_G - 2\phi_{Fi} = V_G - V_T \quad (6)$$

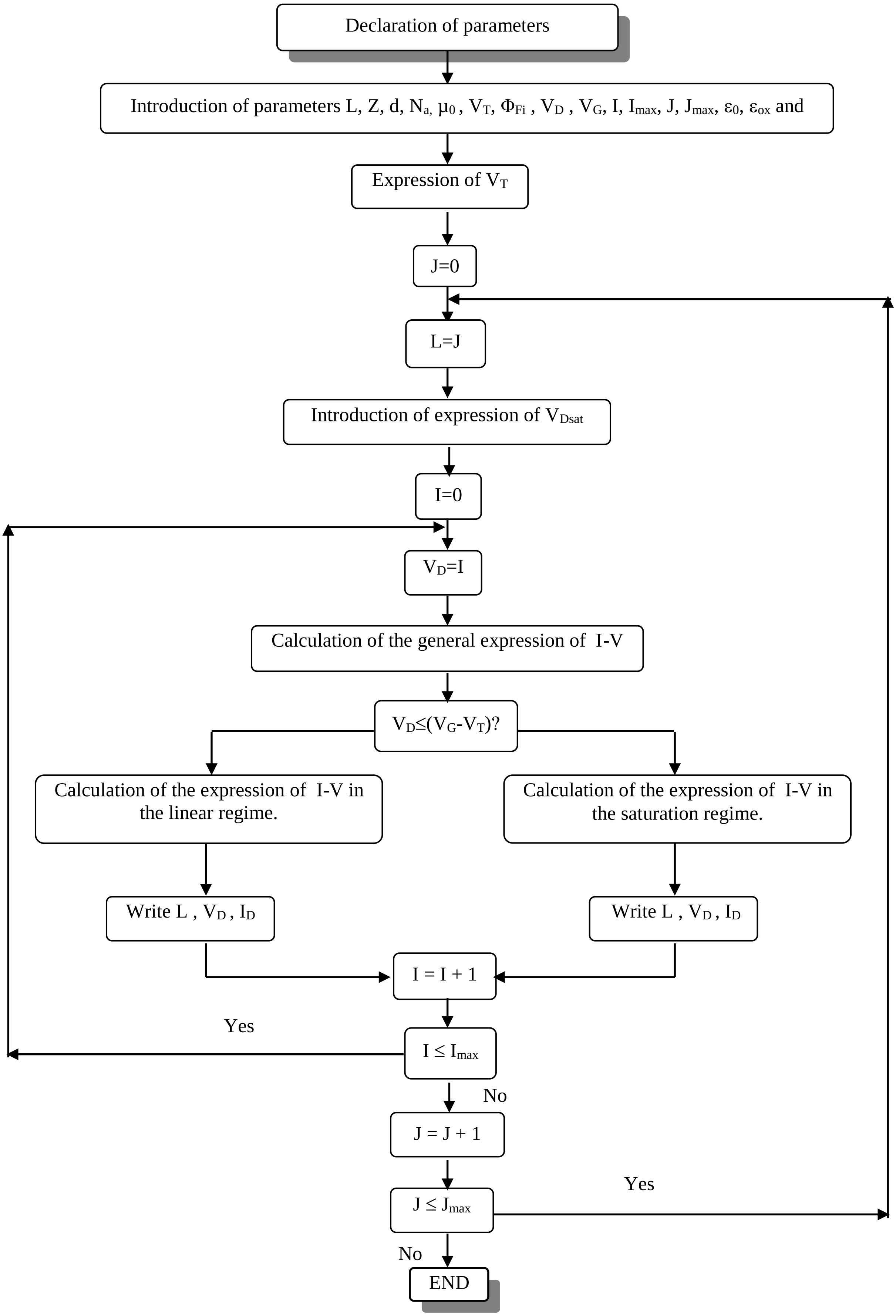

Figure 1. Flowchart of calculation of the drain current taking into account the effect of the physical and geometrical parameters.

RESULTS AND DISCUSSION

In order to validate the I-V characteristics of the MOSFET set up in the previous work, simulation software based on different formulas and equations is used as well as the obtained results and their discussions.

The simulation software is realized with FORTRAN 32, version 01, from the expressions obtained in the previous paragraphs. It allows the resolution of equation systems and the edition of the results in specific files [7].

With this software we are able to determine:

- The current-voltage characteristics in different operation regimes;
- The effect of geometrical and technological parameters (L, d, Z, and N_a) on the current-voltage characteristics.

The flow chart of calculation is shown in Fig.1.

For the numerical calculation of the drain current versus bias voltage, one uses the data of transistors MOSFET1 (L=2.5μm); MOSFET2 (L=1.5μm) whose parameters are given in table I.

TABLE 1 : PARAMETERS OF MOSFETS 1 ET 2

MOSFET	L (μm)	D (A°)	Z (cm)	N_a (cm^{-3})	μ_0 ($cm^2.s^{-1}.v^{-1}$)	Φ_{Fi} (V)
MOSFET1	1.5	1500	3.53	10^{16}	277	0.35
MOSFET2	2.5	1000	2.81	10^{16}	360	0.35

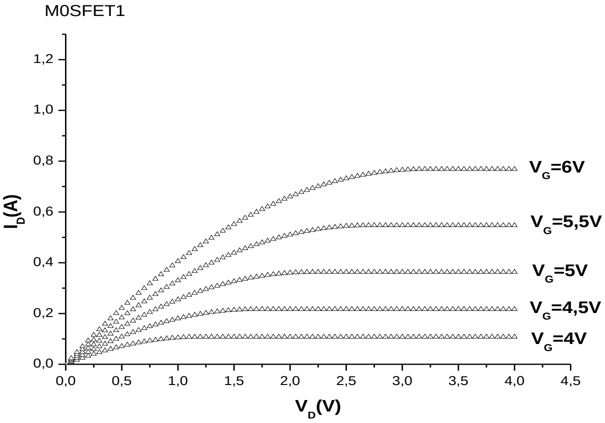

Figure 2. Variation of I_D versus V_D for various V_G values for MOSFET1 transistor.

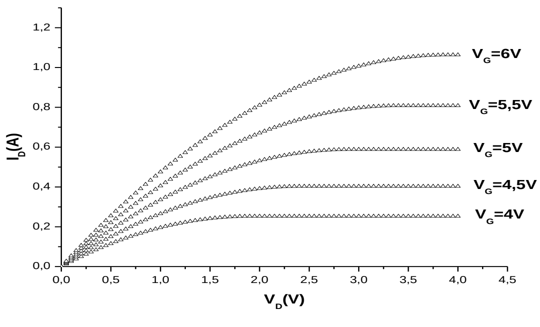

Figure 3. Variation of I_D versus V_D for various V_G values for MOSFET2 transistor.

The Fig. 2 and 3 represent the variation of the drain current I_D versus V_D for various values of V_G obtained respectively for the MOSFET1 (L=1.5 μm) and the MOSFET2 (L=2.5 μm), one notes that the drain current I_D increases with the voltage V_D, then it saturates in the case of the MOSFET2 for a value for which the Space Charge Region (S.C.R) covers all the channel, contrary to the MOSFET1 which is saturated before the channel pinch. This is due to the fact that the length of the channel is short, which leads quickly to appreciable electric field values and consequently, fast saturation of the carriers velocity in the channel.

This means that the saturation of the drain current, in this case, is related to the saturation of the carriers velocity. It should be also noted that I_D undergoes a reduction until its annulment for a nonzero value of V_G known as threshold voltage.

EFFECT OF PHYSICAL AND GEOMETRICAL PARAMETERS

In our numerical simulation [5], we have studied the influence of different physical and geometrical parameters **L** (length of the gate), **d** (thickness of the active layer), **Z** (width of the gate) and $\mathbf{N_a}$ (doping) on the electrical characteristics of the MOSFET transistors, parameters of which are gathered in Table II.

TABLE 2: PHYSICAL AND GEOMETRICAL PARAMETERS OF MOSFETS

Transistor	L (μm)	d (A°)	Z(cm)	N_a (cm^{-3})	μ_0 ($cm^2/s.v$)	Φ_{Fi}(V)
MOSFET3	1….4	1500	3.53	10^{16}	277	0.35
MOSFET4	1	600…1500	3.53	10^{16}	277	0.35
MOSFET5	1	600	2…6	10^{16}	277	0.35
MOSFET6	1	600	6	$10^{16}…310^{16}$	277	0.35

Theoretically, according to equation (1) increase in the drain current is decreased length **L** as they are inversely proportional.

Fig. 4 obtained correspond well with theoretical predictions, we observe that the increase of the drain current corresponds to a reduction of the length **L** as they are inversely proportional.

Among other Fig. 5 and 7 shows that the drain current is believed to as there was a decrease in **d** and $\mathbf{N_a}$.

However Fig. 6 shows the variation of the drain current as a function of V_D for different settings **Z**. It is noted that the increase of this parameter increases the drain current.

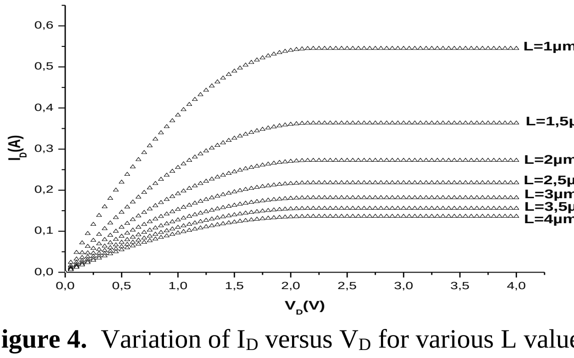

Figure 4. Variation of I_D versus V_D for various L values for MOSFET3 transistor.

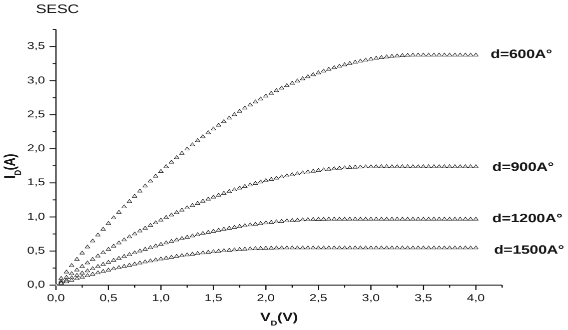

Figure 5. Variation of I_D versus V_D for various d values for MOSFET4 transistor.

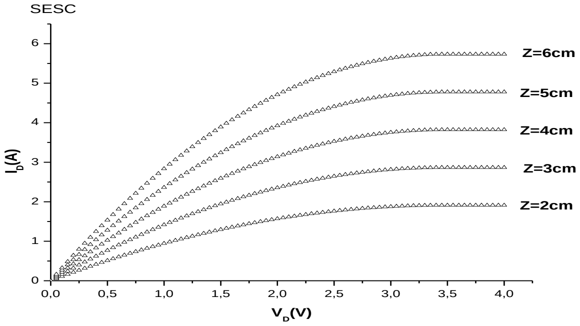

Figure 6. Variation of I_D versus V_D for various Z values for MOSFET5 transistor.

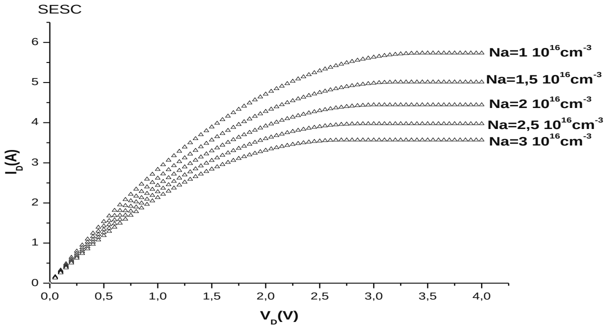

Figure 7. Variation of I_D versus V_D for various N_a values for MOSFET6 transistor.

GENERAL CONCLUSION

In this paper, we have proposed an analytical study of the current-voltage characteristics of the MOSFET using the simulation software. The influence of physical and geometrical parameters on these characteristics has been clearly established. The obtained results allow the focusing of the components geometry adapted to specific uses.

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