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EXTRACTION OF $R_{DS(ON)}$ OF n-CHANNEL POWER MOSFET BY NUMERICAL SIMULATION MODEL

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In this paper we present an original method for n-channel power MOSFET resistance extraction in the operation mode ($R_{DS(ON)}$). The $I_{DS} = f(V_{DS})$ electrical characteristics measurements for the transistor and the Body-Drain junction are realized for the experimental determination and the extraction (by numerical analysis) of $R_{DS(ON)}$, respectively. Values of this resistance are extracted for different positive bias applied between the gate and the source ($+V_{GS}$). Physicals parameters obtained from the numerical analysis are inspected, and results shows that the numerically analysed junction characteristic is in very good correlation with the electrical measurement

Keywords: Power MOSFET; $R_{DS(ON)}$; Numerical simulation; Physicals parameters

1. INTRODUCTION

VDMOSFET operation (MOSFET with Vertical Diffusion) are mainly controlled by the gate voltage consists in modulating the channel conductivity resulting from the inversion layer created on the SiO_2_Si interface [1–4].

For the n-channel power MOSFETs devices, When a positive bias is applied to the gate with respect to the source ($+V_{GS}$), an electric field appears, created across the gate oxide region and into the Si surface region immediately below the gate region (Fig. 1). If the gate bias is sufficiently large and positive (for the n-channel operation), the

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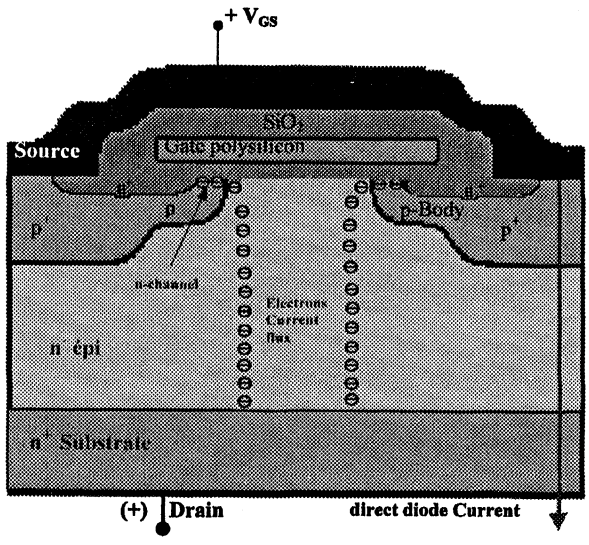

FIGURE 1 Cross-section for n-channel Power MOSFET structure.

majority carriers (holes in the p-body) are depleted in this surface region, and the minority carriers (electrons) are attracted to this region (for $V_{GS} \geq V_{th}$) [5–8]. Thus, when a potential is applied between the drain and the source contacts (n^+-doped regions in Fig. 1), the inversion layer provides a low resistance current channel easing the electrons flow from the source to the drain. The device is then said to be turned on, and the control gate bias potential at which the channel begins to conduct appreciable current, is called the threshold voltage (V_{th}) of the device [9–12].

Reducing the gate voltage to below V_{th} will cause the MOSFET to turn OFF. Then if the drain-source bias change to a negative values ($-V_{DS}$), the body-drain junction become forward biased (The source is positively biased with respect to the drain) and a direct current flows through the source cell across the forward p-n junction (see Fig. 1) results in minority carriers injection into the substrate. At low gate voltage, a transistor reverse current can flow along the small inversion layer and the resulting current is, generally, the sum of the direct diode current and of the reverse transistor current [13]. As the channel switches OFF, for a null gate voltage, the resulting current consists in the diode current only.

2. NUMERICAL ANALYSIS MODEL FOR JUNCTION CHARACTERISTIC

Current (I) and voltage (V) values of two hundred points of experimental I-V Junction current, are computer-driven *via* a data acquisition board and stored for modelling analysis. The description of the I-V characteristics of silicon p-n junctions have been thoroughly developed [14, 15]. The related implicit Eq. (1) introduces the classical parameters, series (R_s), shunt (R_{sh}) resistances, the ideality factor (A), the reverse diffusion current (I_{01}) and the reverse recombination current (I_{02}).

$$I = \frac{V - R_s I}{R_{sh}} + I_{01}\left[\exp\left(\frac{q}{KT}(V - R_s I)\right) - 1\right] + I_{02}\left[\exp\left(\frac{q}{AKT}(V - R_s I)\right) - 1\right] \quad (1)$$

The electronic diffusion-recombination phenomena in the quasi-neutral region of the junction (reverse current I_{01}) is separated from the surface and space-charge region recombination phenomena (reverse current I_{02}). This practice is recognized through its implementation in the Spice model of the diode. The equivalent electrical circuit for the junction is represented in Figure 2, two diodes D1 and D2 in parallel taking into account the diffusion and recombination mechanisms to which are added series (R_s) and shunt resistances (R_{sh}). A specially conceived software [16], PARADI, extracts the

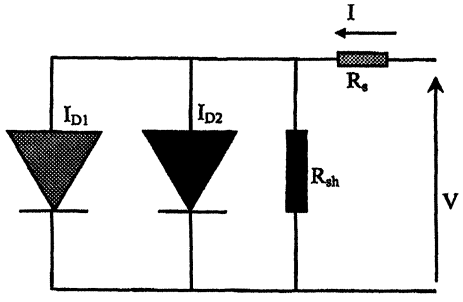

FIGURE 2 Equivalent electrical circuit for a junction studied by a model with two exponential.

values of I_{01}, I_{02}, A, R_s and R_{sh} from the experimental I-V diode measurements.

From the point of view of the diode direct current measurement, any tiny subthreshold channel current would appear as a current flowing through the shunt resistance (Eq. 1).

3. RESULTS AND DISCUSSION

The electrical characteristics $I_{DS} = f(V_{DS})$ for the transistor and the Body-Drain junction of the n-channel VDMOSFET (IRF 130, International Rectifier) were determined using the setup represented in Figure 3. The Body-Drain junction current (I-V) measured for different gate voltage (V_{GS}) values is represented in Figure 4. Experimental values of $R_{DS(ON)}$ for the different V_{GS} are obtained from the transistor current expression $I_{DS} = f(V_{DS})$ which have an expression in the linear region given by:

$$I_{DS} = \mu_{eff} C_{ox} \frac{W}{Z} (V_{GS} - V_{th}) V_{DS} \tag{2}$$

The conductance have an expression given by:

$$g_d = \frac{\partial I_{DS}}{\partial V_{DS}}\Big|_{VGS=cste} = \mu_{eff} C_{ox} \frac{W}{Z} (V_{GS} - V_{th}) \tag{3}$$

and the transistor resistance ($R_{DS(ON)}$) can be written by:

$$R = \frac{1}{g_d} = \frac{1}{\mu_{eff} C_{ox} \frac{W}{Z} (V_{GS} - V_{th})} \tag{4}$$

in this expression μ_{eff} indicates the carriers effective mobility, Cox the gate oxide capacity, W the channel width, Z the channel length and V_{th} the threshold voltage.

The parameter V_{th} in Eq. (5) must be determined to separate the junction direct current studied by numerical analysis from the transistor reverse current. V_{th} was obtained in the saturation region where the VDMOSFET current is given [17] by:

$$I_{DS(sat)} \approx \mu_n C_{ox} W/L (V_{GS} - V_{th})^2 \tag{5}$$

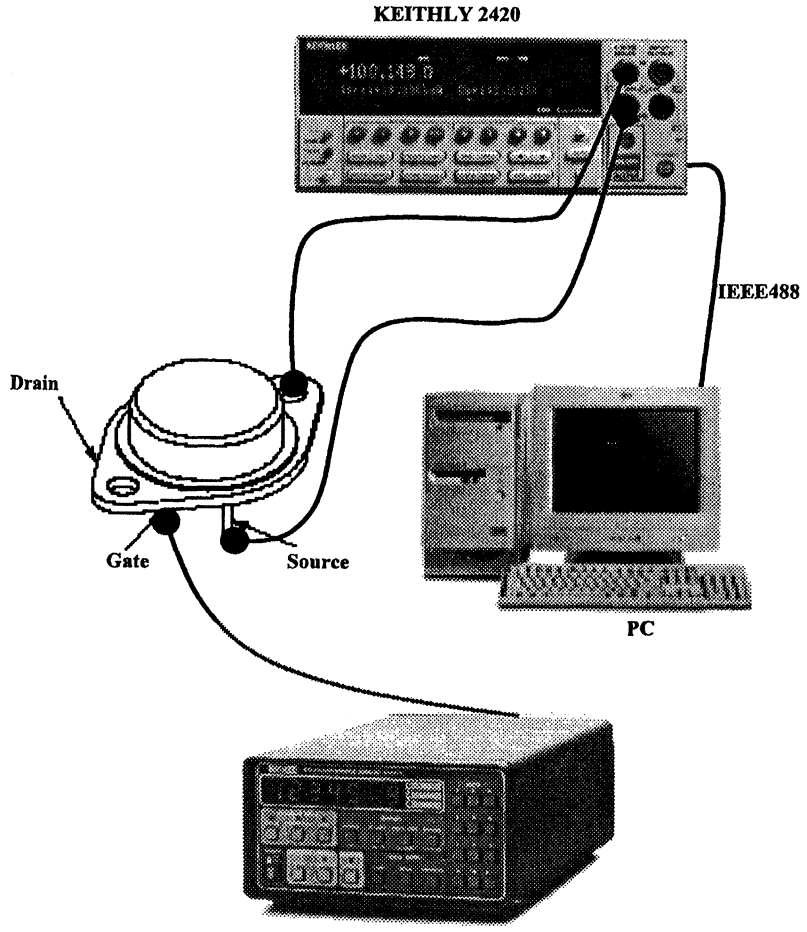

FIGURE 3 Experimental set-up for electrical characteristics measurements.

V_{th} can be deduced from the linearly extrapolated value at the V_{GS} axis, V_{th} have a values about 3 V for the studied devices (IRF 130).

By plotting the transistor current I_{DS} *versus* V_{DS}, the transistor conductance values (g_d), for different V_{GS}, can be experimentally deduced from the linearly extrapolated value at the V_{DS} axis (Fig. 5). Then $R_{DS(ON)}$ have the reverse value of g_d obtained from Figure 5.

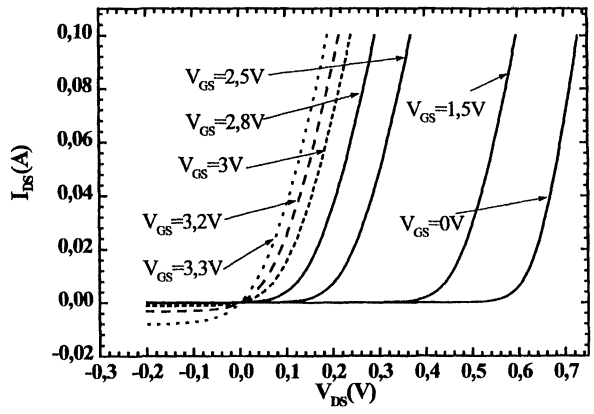

FIGURE 4 Body-Drain junction current (I-V) measured for different gate bias (V_{GS}).

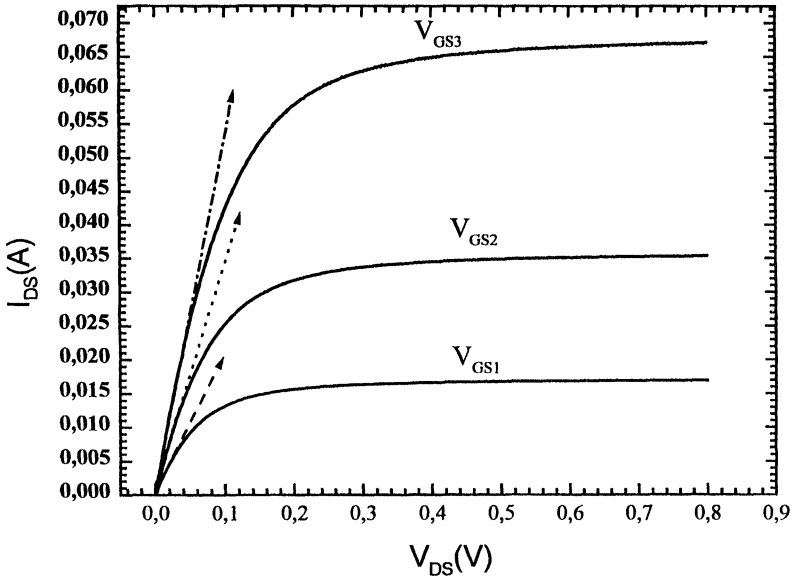

FIGURE 5 Transistor electrical $I_{DS} = f(V_{DS})$ used for $R_{DS(ON)}$ determination.

$R_{DS(ON)}$ experimentally obtained from above and R_{sh} (shunt resistance) numerically extracted from the junction characteristic (I-V) are represented in Figure 6. Gate voltage values is selected close

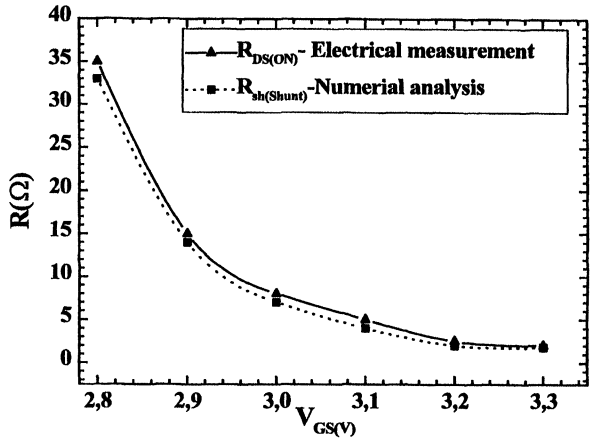

FIGURE 6 Comparison between the transistor resistance experimentally measured $R_{DS(ON)}$ and the shunt resistance $R_{(sh)}$ numerical extracted.

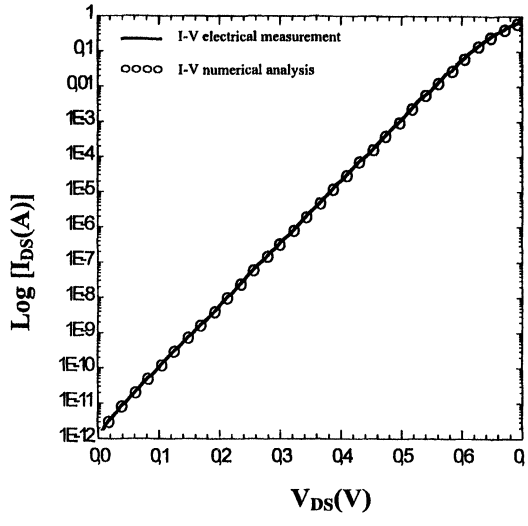

FIGURE 7 Comparison between the junction electrical characteristic and it is description by the model with two exponential.

to the threshold voltage (V_{th}) to study the surface potential influence on the channel conductivity. For a gate voltage values towards 0 V the transistor resistance ($R_{DS(ON)}$) values towards infinite and when gate

voltage become comparable to V_{th} the $R_{DS(ON)}$ toward 0 Ω. This result (Fig. 6) shows the good correlation between the electrical measurement and numerical analysis. Therefore it possible to identify the R_{sh} parameter, used in the two exponential model, with the transistor resistance.

Figure 7 gives a comparison between the experimental characteristic (junction current I-V) and its description using the extracted parameters from Eq. (7). The good agreement between these two curves shows the validity of the model.

4. CONCLUSION

A numerical analysis model for the junction Body-Drain characteristic allows to extract the MOSFET structure resistance in the operation mode ($R_{DS(ON)}$). Shunt resistance (R_{sh}) in the model with two exponential is identified as the transistor resistance ($R_{DS(ON)}$) and extracted values are in good agreement the experimentally values measured.

This method can be very useful to study the degradation properties of MOSFETs structure after irradiation or electrical stress, specially when this degradation are related to the surface potential.

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