LOW VOLTAGE POWER TRANSISTOR MODEL FOR SPICE-LIKE ELECTRO-THERMAL CIRCUIT SIMULATION

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1. Introduction

Today's circuit simulators are standard tools in the development and optimization of electronic systems. However, until now the simulations have been limited to electronic functions because in the simulation models available today the temperature dependences can be taken into account at best by changing the static global temperature. In the power-electronic systems in particular, temperature is one of the critical parameters due to the non-negligible self heating effects and the fact that many properties of power semiconductors are very strongly temperature-dependent [1]. In this paper we present new SPICE-like simulation model for a low voltage power MOSFET containing a dynamic link between electrical and thermal component descriptions.

2. MOSFET circuit model description

The standard equivalent circuit diagram of the power MOSFET structure for SPICE-like circuit simulation is shown in Fig. 1. In order to be able to simulate the inherent heating dynamically, introduction of thermal equivalent circuit and its interactive coupling with electrical equivalent network is inevitable for a proper thermal description of the analyzed low voltage power MOSFET [2].

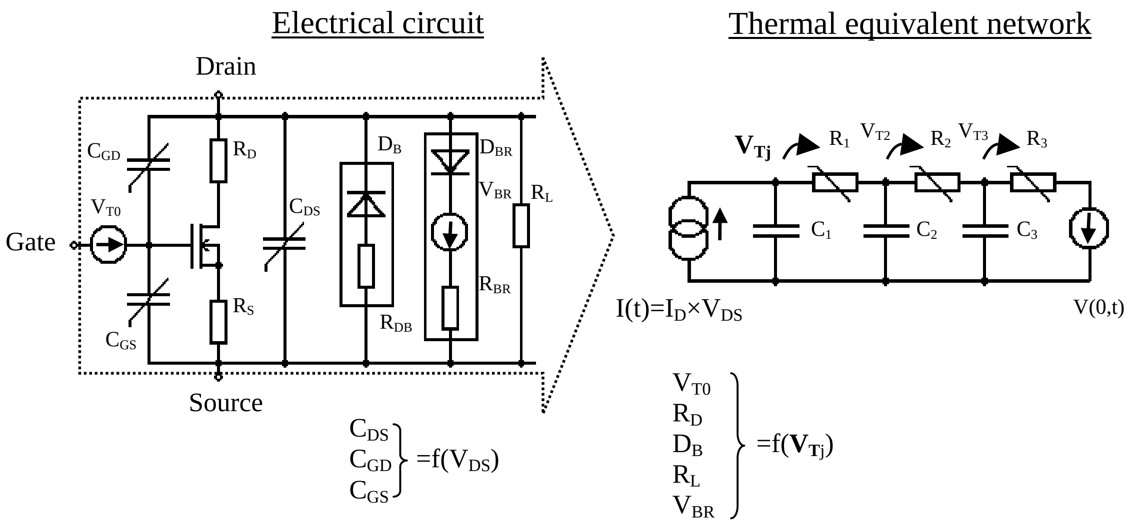

Fig.1: *Equivalent circuit diagram of the power MOSFET structure with self heating effect for SPICE-like circuit simulation.*

Power dissipation in the transistor is determined at all times and a current proportional to the dissipated power is fed into the thermal equivalent network. The V_{Tj} node voltage represents the junction temperature inside the structure. All non-linear temperature dependent parameters of the main MOSFET transistor parameters like threshold voltage V_{T0}, drain resistivity R_D, body diode D_B, leakage current through leakage resistance R_L and breakdown voltage V_{BR} are driven by the V_{Tj} node voltage using of the voltage controlled voltage source and voltage controlled current source [3].

A thermal system can be usually modeled with a discrete element electrical circuit, composed by resistances and capacitances, in which the temperatures and the thermal powers are retained as voltages and currents, respectively (Fig. 2). The electrical current generator source *I(t)* corresponds to the thermal power in the heat source *P(t)*. The resistances R_i and capacitances C_i represent the thermal resistances R_{thi} and thermal capacitances C_{thi} of the structure. Due to a close relationship with physical reality of the one-dimensional heat flow, the parameters for the *RC* equivalent circuit diagram can be derived directly from the Eq.(1) and Eq.(2). The physical variables are specified in their thermal equivalents by using of a geometry and thermal conductivity and thermal capacity of materials, where A is the surface, d_i is the thickness, κ and c are the thermal conductivity and heat capacity of the elements.

$$R_i \approx R_{th\,i} = \frac{d_i}{\kappa \cdot A} \tag{1}$$

$$C_i \approx C_{th\,i} = c \cdot d_i \cdot A \tag{2}$$

Due to a temperature dependence of the thermal conductivity [4] of used materials the thermal network with temperature depended resistors was designed. The resistors are driven by a voltage/temperature in relevant node according a function characterizing temperature dependent thermal conductivity of selected material.

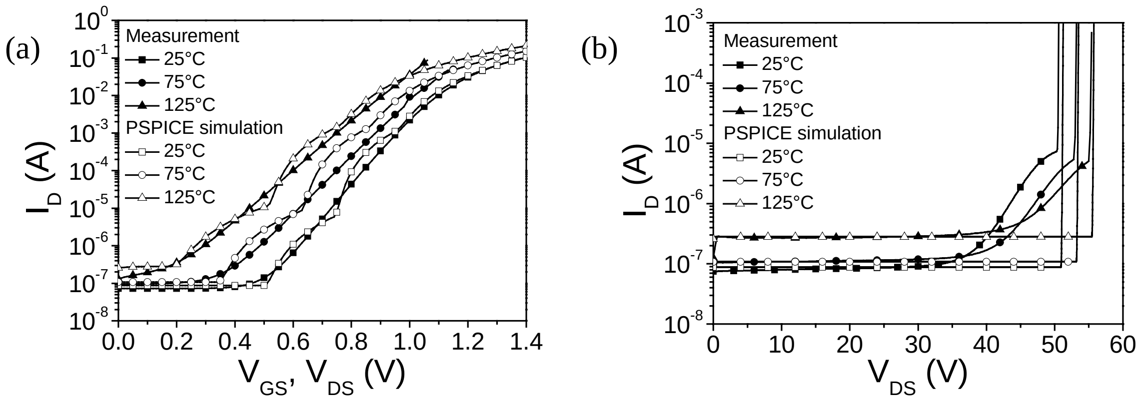

Fig.2: *(a) Transfer and (b) breakdown characteristics at different temperatures of analyzed MOSFET for measurement and SPICE model simulation.*

The electrical part of the SPICE-like model of analyzed low voltage power MOSFET consists of three MOS transistors in level 1 model connected in parallel. Three transistors are used for better fitting of transconductance in transfer characteristic. The temperature dependence of the threshold voltage and transconductance is driven by three voltage controlled voltage sources V_{T0}. The linear driving function is set according of the measured temperature depended transfer characteristics (Fig. 2a). The temperature dependence of the breakdown voltage V_{BR} is driven by linear function in voltage controlled voltage source as well. Fig. 2 shows transfer and breakdown characteristics at different temperatures of analyzed MOSFET transistor for measurement and SPICE model simulation.

All temperature depended resistor included in MOSFET model: drain resistance R_D, leakage resistance R_L, body diode resistance R_{DB} and thermal resistances R_{thi} are created by a voltage controlled current sources connected as voltage controlled resistors (Fig. 3a). The driving functions of the temperature dependences R_D, R_L and R_{DB} are set according with measured characteristics. The driving temperature function of the thermal resistances R_{thi} is polynomial function of the second row [5].

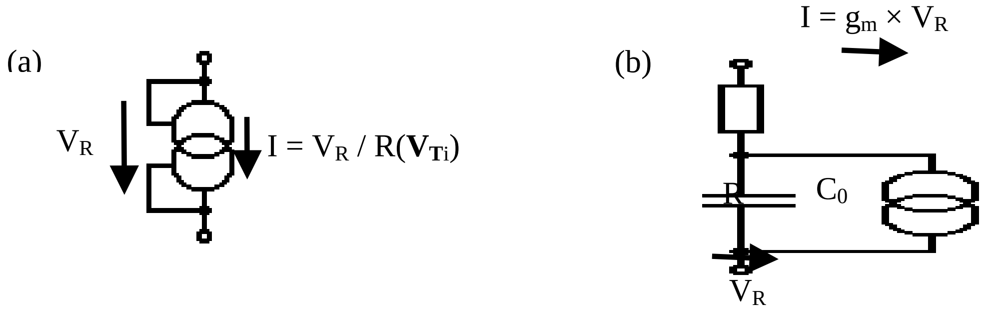

Fig.3: *(a) Connection of temperature/voltage controlled resistor using by voltage controlled current source, (b) basic circuit for the voltage controlled capacitive reactance.*

The body diode of the MOSFET transistor is modeled by voltage controlled current source which drives temperature depended saturation current I_S according the expressions:

$$I_{DB} = I_S \left(\exp\left(\frac{q(-V_{DS} + I_{DB} \cdot R_{DB})}{k \cdot V_{Tj}} \right) - 1 \right) \tag{3}$$

$$I_S = \exp(I_{S\_T0} + a_{DB} \cdot V_{Tj}) \tag{4}$$

where the a_{DB} is the a coefficient of temperature dependence. Fig. 4a shows *IV* characteristics of the body diode at different temperatures.

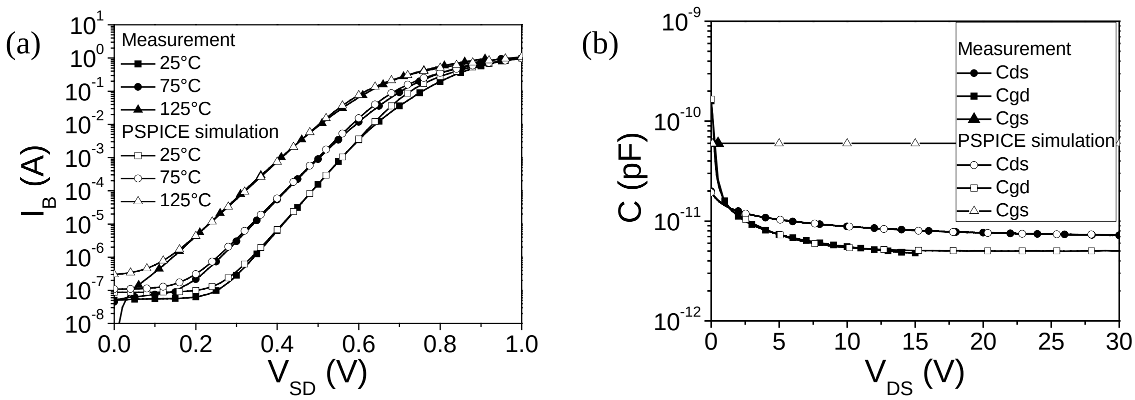

Fig.4: *(a) IV characteristics of the body diode at different temperatures and (b) CV characteristics of the analyzed MOSFET for measurement and SPICE model simulation.*

The SPICE level-1 MOSFET model does not account for the non-linear capacitive characteristics C_{GD}, C_{GS}, C_{DS} of a power MOSFET. All voltage depended capacitances are created by a subcircuits connected to MOSFET model. Fig. 3b shows the basic circuit which illustrates the operating principle of the proposed voltage-controlled capacitive reactance [6]. It consists of a resistor R in series with a fixed capacitor C_0 and a voltage-controlled current source which injects its current $g_m \times V_R$ into the fixed capacitor. The control voltage V of the current source is taken across the resistor R to ensure that the injected current has the same phase as the input current. The capacitance C of this circuit is given by:

$$C = C_0 / (1 + g_m \cdot R) \qquad (5)$$

The capacitance is controlled electronically (voltage controlled) by using a voltage controlled transconductance g_m according to the drain voltage function. Comparisons of measured and SPICE model capacitance are shown in Fig. 4b.

3. Conclusions

The SPICE-like simulation model of low voltage power MOSFET which contain a dynamic link between electrical and thermal component descriptions was presented. The static and dynamic measurements at different temperatures were used for calibration of main MOSFET model parameters and their temperature dependences. The very good agreement of simulation and measurement confirms the validity of the designed model.

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