SIMULATION OF SEMICONDUCTOR DEVICES AND PROCESSES Vol. 5
Edited by S. Selberherr, H. Stippel, E. Strasser - September 1993

Importance of Hole Generation on Modeling and Simulation of Schottky and MESFET Structures

D. Donoval, J. Racko, and C. M. Snowden[†]

Microelectronics Department, Slovak Technical University
Ilkovicova 3, SQ-81219 Bratislava, SLOVAKIA
[†]Microwave and Terahertz Technology Group, University of Leeds
Leeds, LS2 9JT, UNITED KINGDOM

Abstract

A new semiclassical model for the modelling and simulation of the electrical properties of rectifying metal-semiconductor structures has been developed. The contribution of hole current to the total current through the interface is significant for reverse biased Schottky structures and cannot be neglected in the model.

1. Introduction

The need for an accurate simulation of the electrical characteristics of MESFET, HEMT and other related structures which use the Schottky contact as a gate electrode to control the output characteristics requires a rigorous model. The simulated results are strongly dependent on the proper definition of discretization schemes and boundary conditions. Although there exists many different approaches for expressing the boundary conditions at the Schottky interface [1,2,3], the agreement between simulated and experimental results is still generally not satisfactory, especially in the reverse direction of applied voltages [4]. Most of the models express the concentrations of electrons and holes at the interface, but in many cases, for example the simulation of MESFET structures, the minority carriers are neglected [5]. The aim of this paper is to point out the importance of generation-recombination processes within the analysed structure. In some cases the hole current through the interface exceeds the electron current and the minority carriers cannot be neglected.

2. Description of the simulator

For the simulation of electrical characteristics of Schottky structures we have used the recently developed simulator DEVSIM [6]. It is based on a revised theory of current flow through the Schottky contact [7]. The final expression of current flow takes into account not only the thermionic-emission/drift-diffusion current but also the generation-recombination current within the space charge region and the injection of holes into the quasi-neutral epitaxial region. It can be rewritten in the following form

$$J = \frac{q v_{rn}^{s}}{\frac{v_{rn}^{s}}{v_{dn}} + 1}\left\{ n_0\left[\exp\left(\frac{V_a}{V_t}\right) - \frac{v_{rn}^{m}}{v_{rn}^{s}}\right] + n_{gr}\right\} - \frac{q v_{rp}^{s}}{\frac{v_{rp}^{s}}{v_{dp}} + 1}\left\{ p_0\left[\exp\left(-\frac{V_a}{V_t}\right) - \frac{v_{rp}^{m}}{v_{rp}^{s}}\right] + p_{gr}\right\} \tag{1}$$

where

$$n_{gr} = \frac{1}{V_t}\int_0^L \frac{\exp(-\psi(x)/V_t)}{\mu_n(x)} \cdot \left[\int_0^x U(x')\,dx'\right] dx \tag{2}$$

$$p_{gr} = \frac{1}{V_t}\int_0^L \frac{\exp(\psi(x)/V_t)}{\mu_p(x)} \cdot \left[\int_0^x U(x')\,dx'\right] dx \tag{3}$$

relate contribution of generated/recombinated carriers within the analysed structure to their actual concentrations. The equilibrium free carrier concentrations at the interface are

$$n_0 = N_c \exp\left(-\frac{\phi_b}{kT}\right), \qquad p_0 = N_v \exp\left(-\frac{\phi_b - E_g}{kT}\right) \tag{4}$$

where ϕ_b is the effective Schottky barrier height, v_{dn} and v_{dp} have the dimensionality of velocity [8], v_{rn}^{m} , v_{rn}^{s} , v_{rp}^{m} and v_{rp}^{s} are the recombination velocities through which the influence of electric field strength and current density at the interface is introduced [1,9]. All other symbols have their usual meaning.

When the generation-recombination rate is set to zero and the contribution of holes is neglected, the derived expression for current has the same form as derived by Crowell and Sze [8].

3. Experimental work

For simulation of electrical characteristics we have used the doping profile which can be seen in Fig. 1. Also the samples with $MoSi_2$-Si Schottky structures with nearly ideal I-V characteristics were prepared experimentally and ϕ_b = 0.64 eV was determined from forward I-V measurement. The distributions of free carriers at two different applied voltages in reverse direction are presented in Fig. 1a. The free holes generated within the space charge region are attracted towards the interface and the increase in their concentration with increase of generation rate is evident. Here the hole current in the vicinity of the interface may exceed the electron current (Fig. 1b). Fig. 2 shows the simulated reverse I-V characteristics for different lifetimes of free carriers. For low barrier height ϕ_{bo}=0.657 eV, which corresponds to the experimentally measured value of ϕ_b=0.64 eV for $MoSi_2$ - Si structure (Fig. 2a), the thermionic emission electron current is very high and the contribution of the generation current is masked, when the lifetimes of free carriers is less than 10^{-8} s.

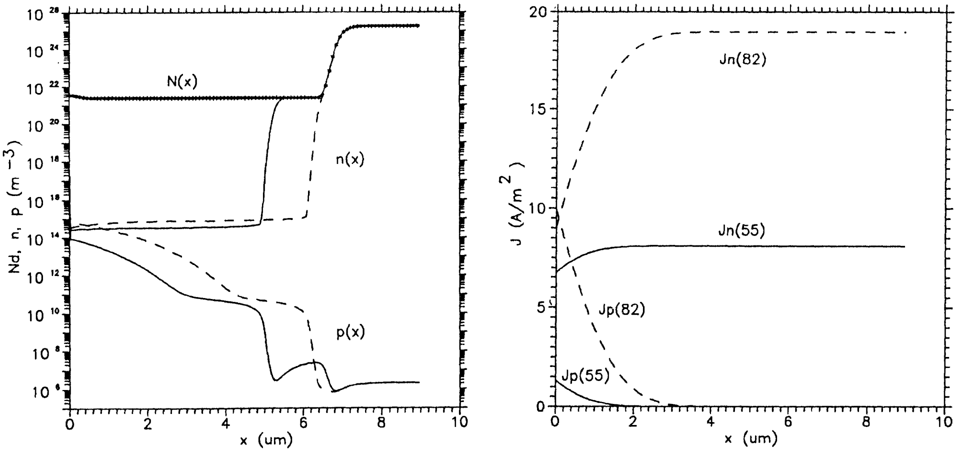

Fig. 1 a) Doping profile *** and concentrations of free carriers and b) current densities at V_r= 55 V (——) and V_r= 82V (——)

The electron current remains constant for all lifetimes and the increase of total current can be attributed to the increase of hole current. For high barrier height ϕ_{bo} = 0.85 eV the above mentioned effect dominates the I-V characteristics even for relatively long lifetimes of free carriers. From the previous analysis it is clear that the generated holes create the hole current which can exceed the electron current at certain reverse bias. Therefore their contribution cannot be neglected in the model. This effect has a particular significance for all structures with reverse biased Schottky contact on III-V compounds where the barrier height is high and lifetime of free carriers is short.

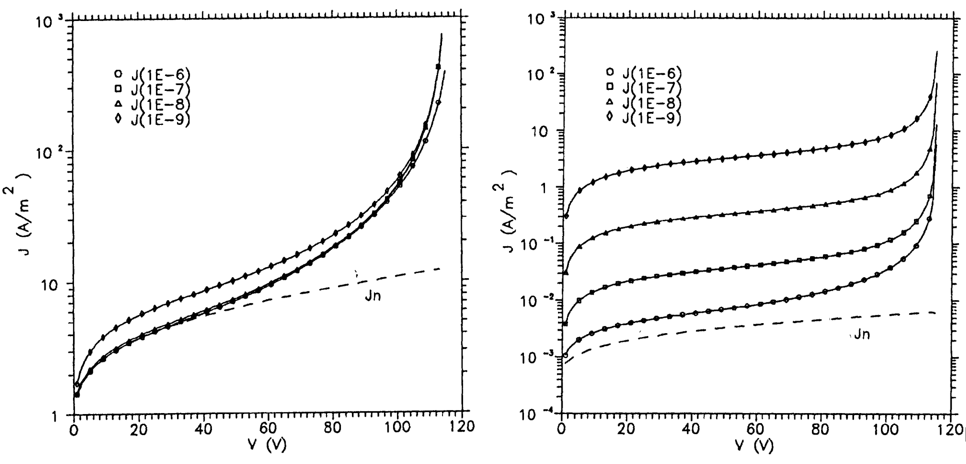

Fig. 2 Simulated reverse I-V characteristics for different lifetimes of free carriers for a) ϕ_b = 0.657 eV and b) ϕ_b = 0.85 eV

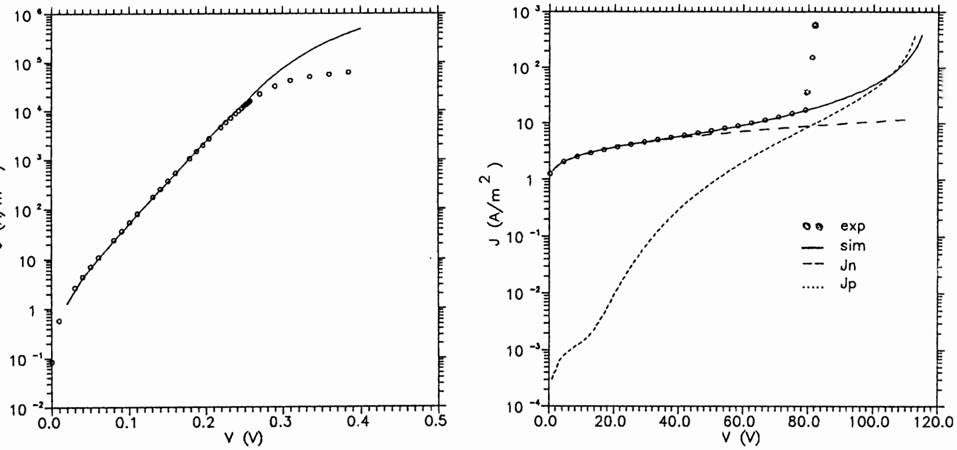

Fig.3 Simulated and experimental I-V characteristics of $MoSi_2$ - Si structure a) forward, b) reverse

We also compare the results of simulation with experimentally measured I-V characteristics (Fig.3). The very good correlation between simulated and experimental characteristics in the reverse direction is based on the introduction of hole current. The lower breakdown of experimental sample is determined by the breakdown of a guarded pn-junction at the contact periphery and appears earlier as the theoretical limit due to higher field in the cylindrical junction [10].

4. Conclusion

The influence of generation-recombination effects on the total current through the Schottky contact has been presented. The contribution of hole current to the total current can exceed the contribution of electron current at certain reverse applied voltage even for low barrier height and relatively long lifetimes of free carriers. Thus the contribution of minority carriers in the modelling of Schottky structures cannot be neglected. The very good agreement between the simulated and experimental I-V characteristics can be used as an evidence of validity of our approach.

References

[1] J.G. Adams and T. W. Tang, IEEE Electron Device Letters, EDL-7, 525, (1986)
[2] Semiconductor Device Modelling, Ed. C. M. Snowden, Springer Verlag, Berlin 1989
[3] J.O. Nylander, F. Masszi, S. Selberherr and S. Berg, Solid St. Electron, 32, 363, (1989)
[4] B.J. Baliga, Modern Power Devices, 428, Wiley, New York 1986
[5] C.M. Snowden, Intr. to Semicon. Device Modelling, World Scientific, Singapore 1986
[6] D. Donoval et al., Computational Material Science, 1, 51, (1992)
[7] J. Racko et al., Solid St. Electron., 35, 913, (1992)
[8] C.R. Crowell and S.M. Sze, Solid St. Electron., 9, 1035, (1966)
[9] R.B. Darling, Solid St. Electron., 31, 1031, (1988)
[10] S.M. Sze, Physics of Semiconductor Devices, Wiley, New York 1981