MODELING STATIC AND DYNAMIC BEHAVIOR OF POWER DEVICES

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ABSTRACT

Comments on models of physical parameters involved in numerical power device simulation are given. Problems associated with carrier-carrier scattering, recombination and heavy doping are stressed. A transient quasi-three-dimensional simulation of a thyristor illustrates the state of the art in numerical power device modeling.

INTRODUCTION

Due to the progress in sophistication of power devices the development of numerical analysis tools capable of reliably simulating device behavior under typical conditions for power devices (high voltage/ high current) has become necessary. In the last decade activities in that field have been carried out only in a very few research groups worldwide. However, due to the increasing need by device engineers and the advances made in modeling techniques it can be expected that numerical modeling of power devices will become an accepted methodology in the near future.

COMMENTS ON PHYSICAL MODELS

Proper models for the physical phenomena in semiconductor devices are obviously the first essential requirement of any modeling activity. The basic equations and models for their parameters for the purpose of numerical device modeling have been extensively reviewed in the literature for VLSI devices. One recent review has been published by e.g. Engl et.al. (5). Therefore, I shall concentrate only on phenomena which are of primary relevance for power devices.

Mobility Modeling

Additionally to lattice, ionized impurity, surface scattering and drift velocity saturation the influence of carrier-carrier scattering plays a dominating role particularly in the on-state of power devices. Fig.1 and Fig.2 show the electron and hole mobility versus free carrier concentration, respectively. The four graphs denote the model of Dorkel et.al. (4) (fully drawn line), the model of Adler (2) (dashed line), an earlier model of Adler (1) (dot-dashed line) and the model of Engl and Dirks (6) (dotted) line. A background doping concentration of $10^{14}cm^{-3}$ has been assumed for the calculation. The corresponding formulae and their associated coefficients can be found in the references. The models show a fairly pronounced scatter, although all authors have claimed perfect agreement between measured and simulated results. This subject is therefore to be recommended for further investigations in order to reach a solid basis for device modeling.

Recombination Modeling

Of major importance for power devices is Auger recombination. In all modeling programs I am aware of the Auger recombination rate is modeled by:

$$R_{AU} = (C_n \cdot n + C_p \cdot p) \cdot (n \cdot p - n_{ie}^2)$$

This rate is usually added in the simplest manner to the classical Shockley-Read-Hall expression for thermal recombination to give the total effective recombination rate. The above given formula has been derived by assuming direct band to band Auger transitions. Recent investigations e.g. (11), however, have clearly demonstrated that trap assisted Auger recombination is the dominant Auger effect. From that point of view it is clear that the values for the Auger coefficients C_n, C_p presented in the literature vary significantly (cf. (13)). A more elaborate treatment of Auger recombination, particularly the interaction with SRH recombination, has been developed in (7). These results are strongly to be recommended for implementation in power device modeling

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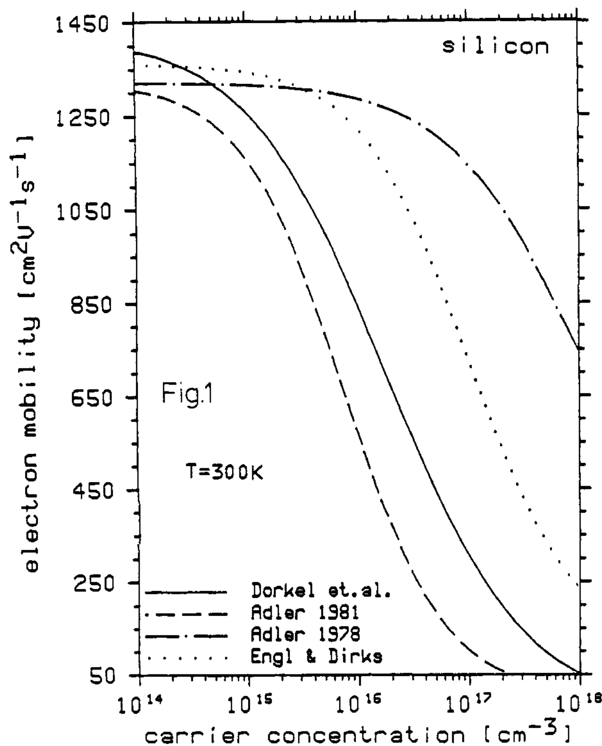
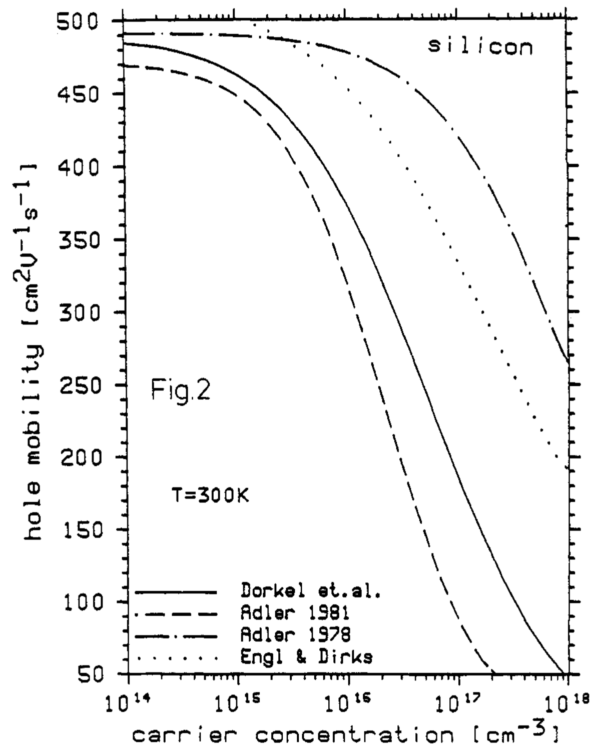




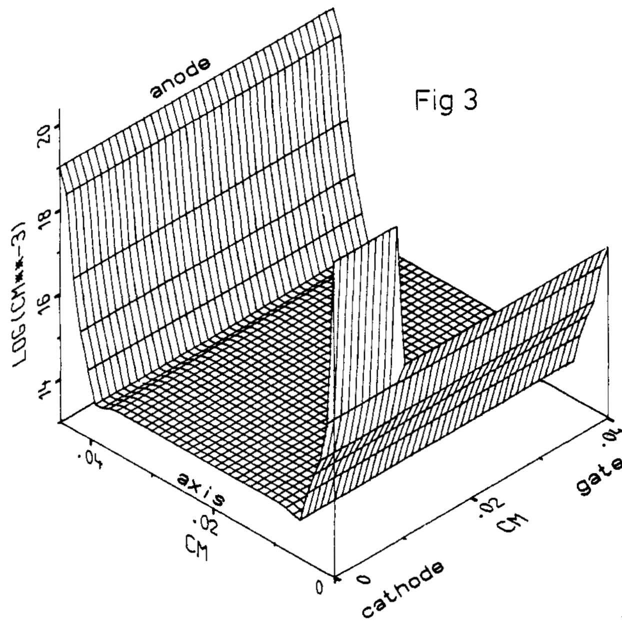
programs. A few remarks should also be given on the so established SRH recombination model. This model is only valid for a small perturbation from thermal equilibrium, as it was the intention of the authors. Furthermore, it has been assumed that the concentration of traps is considerably larger than the concentration of free carriers. In many operating conditions of power devices this is not the case, so that the SRH model will overestimate the thermal recombination. An extension to the SRH model which accounts properly for the saturation of recombination has been given in (7). Furthermore, a total lack exists in recombination models for transient simulations. The only constructive reference I can give is (3). These have not been missed very much so far, since multi-dimensional transient simulations are just now becoming possible due to the underlying mathematical complexity.

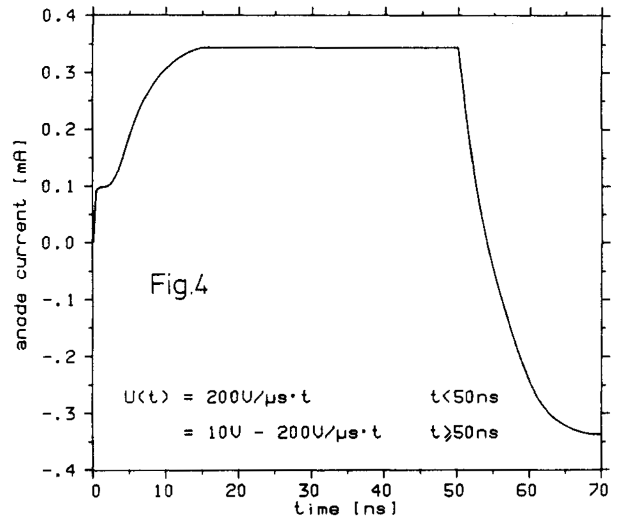
Heavy Doping Effects

Heavy doping effects can be roughly split into those which influence the band structure of the semiconductor (10) and into those which decrease the minority carrier lifetime (7). Both categories, however, are theoretically seen so complex that semi-empirical approaches have to be taken for the purpose of device modeling. The effects on the band structure are in most applications sufficiently described with just a doping dependent intrinsic concentration. The models by e.g. (8), (9), (12) will give reasonable results for that purpose. Published values of measured carrier lifetimes show such a scatter (cf. (13)) that none of the existing empirical expressions can be given preference. This subject should be a topic for thorough investigations in the near future.

A GLIMPSE ON RESULTS

Due to the lack of space it is only possible to present one example of a simulation result. This result is not intended to highlight a specific device effect but to didactically show some frame of the state of the art and the near future in numerical power device modeling. For that purpose a quasi-threedimensional (cylindrical symmetry) transient simulation of a thyristor will be discussed. Fig.3 shows the doping profile of the thyristor along the radius. The transient behavior of this device is simulated assuming an emitter shortcut to get information about the dU/dt performance. A ramp voltage with 200V/μs slope is applied between anode and cathode. Fig.4 shows the current over time characteristic obtained by simulation, and in Fig.5 snapshots of the electrical potential (first column), the electron density (second column) and the hole density (third column) are presented. As global result we can deduce that the device is not fired at the assumed dU/dt.





The initial phase of increasing current represents the loading of the depletion capacitances. The characteristic time constant of that phase is given by the resistance of the n-base times the depletion capacitances of the adjacent junctions. Beyond about 15ns we observe a constant loading current. Comparing the carrier density distributions at 17ns and 50ns, we can deduce that injection does not significantly increase. The formation of the space charge region is not inhibited, and therefore, the device will not be fired. Beyond 50ns the applied ramp voltage has been reversed. Again we can observe an RC constant for the reversal of the current. This time constant is shorter than the one observed in the initial phase because of the lower effective depletion capacitance.

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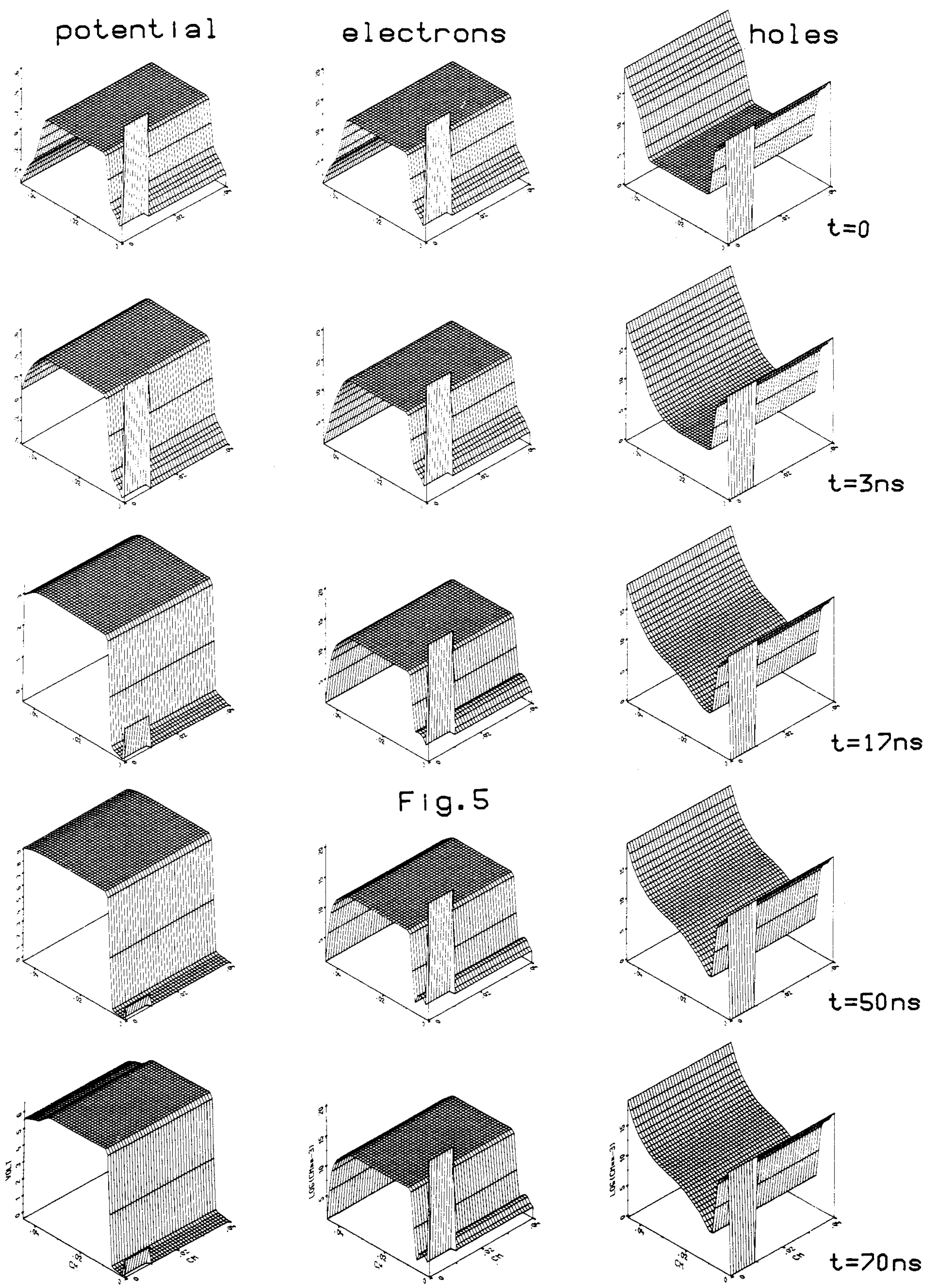

Fig.5

4.1