Two dimensional analysis of the avalanche effect in MOS Transistors

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During the last years much work has been invested in the two-dimensional modelling of the MOS-transistor. In this work we describe an extension of a previously published model /1/,/2/, /3/, to allow for two dimensional avalanche modelling.

Ignoring the avalanche effect besides the Poisson equation only one continuity equation need be solved. In this situation some authors estimate avalanche current by calculating the ionization integral of just one carrier type neglecting hole current and the resulting changes of electric field and current flow by the avalanche effect. As this procedure is insufficient to provide reliable results the model proposed in the following is based on the solution of both carrier equations consistently with the Poisson equation. Avalanche is modelled as given below:

$$\mathrm{div}\,\vec{J}_n = -(G_a + G_{th} - R_{th})\,q$$

$$\mathrm{div}\,\vec{J}_p = (G_a + G_{th} - R_{th})\,q$$

with

$$G_a = |\vec{J}_n|\,\alpha_n \exp\left(\frac{-\beta_n\,|\vec{J}_n|}{\vec{E}\cdot\vec{J}_n}\right) + |\vec{J}_p|\,\alpha_p \exp\left(\frac{-\beta_p\,|\vec{J}_p|}{\vec{E}\cdot\vec{J}_p}\right)$$

$$G_{th} - R_{th} = \frac{n_i^2 - p\,n}{(p+p_1)\tau_p + (n+n_1)\tau_n} + G_s - R_s$$

G_a is the production rate of electron-hole pairs due to avalanche generation. It is asumed that only the field component parallel to the current density vector can cause ionization. The ionization parameters $\alpha_n, \beta_n, \alpha_p, \beta_p$ have been published by various authors /4/, /5/, /6/. $G_s - R_s$ is the usual surface generation-recombination term. The first term in $G_{th} - R_{th}$ is the Shockley-Read-Hall term describing the thermal generation-recombination process. If avalanche effect is excluded $G_{th} - R_{th}$ can also be omitted because the generation-recombination current is negligible compared to the current of the inversion layer. Analysing the avalanche effect $G_{th} - R_{th}$ must not be omitted because in the essential parts of the device the hole density increases by several decades due to avalanche ionization and therefore recombination will dominate over thermal generation.

Usually a considerable amount of ionization occurs in MOSFET's operating in saturation region in a small part near the drain electrode. There the electrons are pushed to drain by the electric field and holes are pushed first towards surface and from there towards source. In some distance from drain the electric field component perpendicular to the surface changes sign and therefore a certain part of the holes will flow towards bulk (Fig.1). As a simple experiment shows, the increase of bulk current due to avalanche is several decades smaller than the increase of source current. The dominance of the avalanche current to the source contact is due to several overlapping processes:

1. Recombination of electron-hole pairs in the source region due to the very large product $n \cdot p$ especially at the surface (Fig. 1).
2. Due to the positive space charge of holes the electron density will increase to satisfy Poisson's equation giving rise to an additional electron flow.
3. The flow of holes into bulk will cause a potential drop in the lightly doped substrate and will therefore simulate a more positive bulk voltage causing a higher source-drain current.

The main problem in this model results from solving a system of 3 partial differential equations. As described in /1/ this can be done by a Gummel cycle calculating each equation repeatedly by the finite difference method in two dimensions. If the drain voltage is not too close to breakdown voltage, computation time can be economized by solving more often Poisson's equation and the continuity equation for minorities (electrons in an n-channel device) than the continuity equation for majorities. Computation time will increase rapidly when drain voltage increases towards breakdown voltage.

In our contribution detailed avalanche drain and bulk current calculations will be compared with experimental results.

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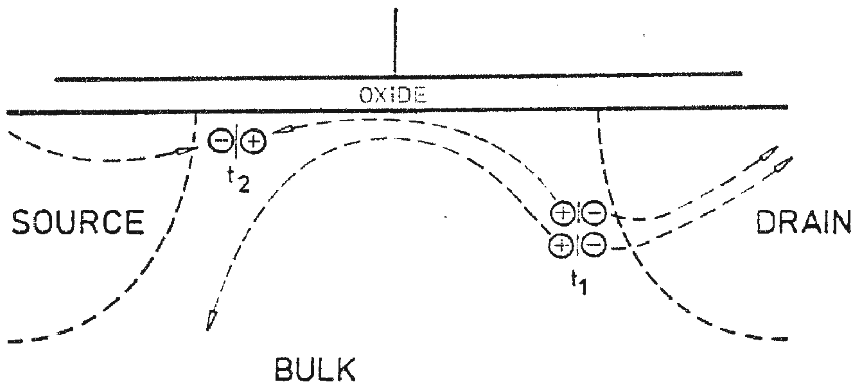

Fig. 1

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