AN APPLICATION OF THE RAMO SHOCKLEY THEOREM FOR CALCULATION OF THE TERMINAL CURRENTS OF A MOSFET BY THE PARTICLE SIMULATION

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The Ramo Shockley theorem[1,2] was originally devised to compute the instantaneous currents induced in neighboring conductors by a given specified electron motion in vacuum tubes. Recently, the theorem has been extended so that the theorem can be applied for computing the terminal currents in semiconductor device with fixed space charges when the electrode potentials are constant or time-varying[3,4].

As MOSFETs are miniaturized, the need for the particle simulation such as Monte Carlo method is increasing to understand operations of the devices. However, a comprehensive algorithm for the calculations of the various electrode currents such as steady-state, transient and noise currents for source and drain of a MOSFET has not been introduced for particle simulation so far.

In this paper, we are going to present an algorithm which gives the steady-state, transient and noise currents altogether for any semiconductor device using Ramo-Shockley theorem coupled with particle simulation. We apply this algorithm for computing the various terminal currents of a MOSFET with channel length of 0.25μm. For the particle simulation, we have employed a new method called the Brownian particle simulation which has been developed recently by the authors[5]. It has been shown [5] that this new method can be easily coupled with the conventional Monte Carlo method so that both the computational efficiency and accuracy can be achieved simultaneously by allocating Brownian particles in the N$^+$ region and the conventional MC particles in the channel region of a MOSFET. In this paper, we use throughout the device the Brownian particle method where the electric field is updated by the solution of Poisson's equation at a time step of 0.5 femto seconds.

The extension of the Ramo-Shockley theorem [3,4] says that the induced current at the jth electrode $i_j(t)$ due to the motion of the charged particles can be given as

$$i_j(t) = -\sum_{i}^{N} q_i \, \underline{\nabla} f_j(\underline{r}_i) \cdot \underline{v}_i(t).$$

where, $\underline{v}_i$, $\underline{r}_i$ and q_i are the velocity, position and charge of the ith particle, N is the total number of the charged particles in the device, and $f_j(\underline{r}_i)$ is the electric potential at $\underline{r}_i$ when the jth electrode is kept at unit potential while all other electrodes are grounded and all the charge is removed from the device.

Fig.1 shows the cross section of the simulated device. Fig.2 (a) and (b) are the profiles of f in the drain section when the unit potential is applied to the source and drain, respectively. Fig. 3 (a) and (b) show the average electron density and potential profiles, respectively, obtained from the particle simulation when the V_G=2V and V_D=2V. Fig. 4 shows the induced electrode currents at the source, drain, gate after steady state is reached. In the figure, the D.C. terminal current obtained by the particle counting method are also shown as solid line.

In conclusion, we have shown applicability of the Ramo-Shockley theorem to the calculation of terminal currents of a MOSFET using the particle simulation.

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[2] W. Shockley, J. Appl. Phys. 9, 635(1938)
[3] H.S. Kim, H.S. Min, T.W. Tang and Y.J. Park, submitted for publication to Solid-State Electronics.
[4] P. De Visschere, Solid-State Electronics, 33, 455(1990)
[5] G.Y. Jin, Y.J. Park and H.S. Min, to be published on IEEE Trans. CAD/ICAS, Aug., 1991.

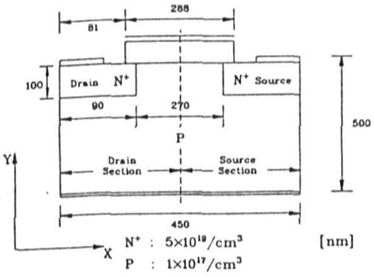

Fig. 1. Device Structure.

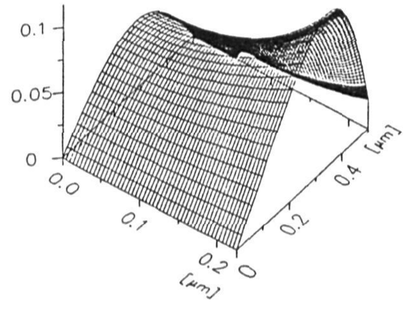

Fig. 2. (a) Profile of f with the source electrode kept at unit potential.

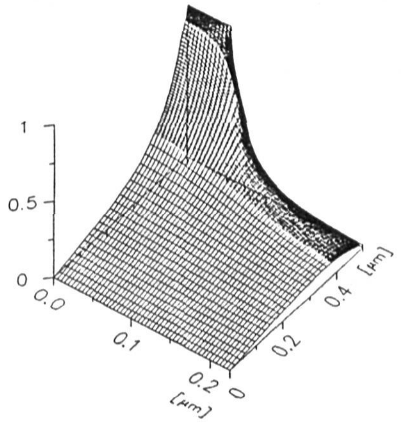

Fig. 2. (b) Profile of f with the drain electrode kept at unit potential.

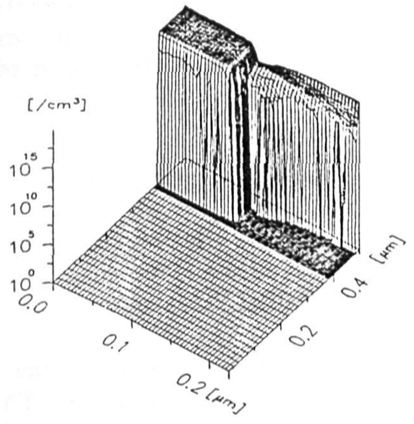

Fig. 3. (a-1) Average electron concentration profile in the drain section.

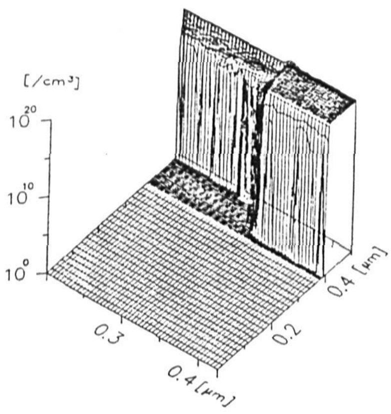

Fig. 3. (a-2) Average electron concentration profile in the source section.

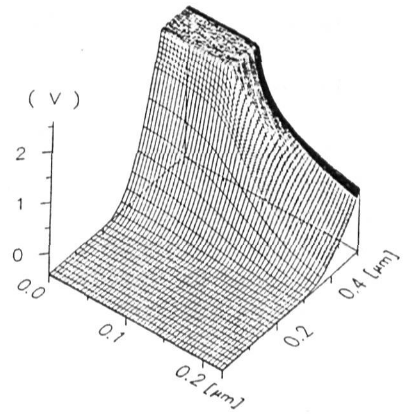

Fig. 3. (b-1) Potential profile in the drain section.

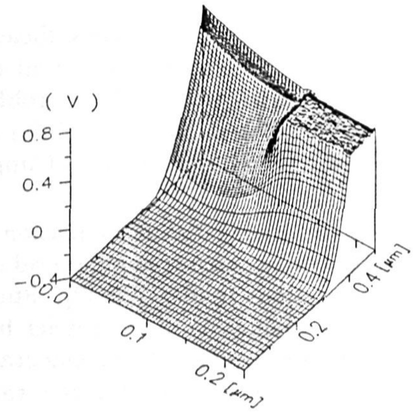

Fig. 3. (b-2) Potential profile in the source section.

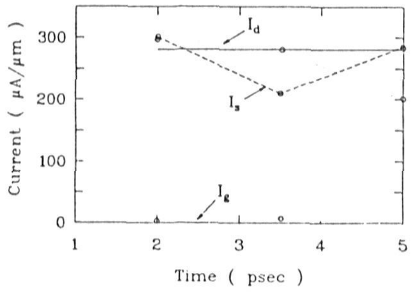

Fig. 4. Induced electrode currents at source, drain and gate.