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The Limit of Applicability of the Drift-Diffusion Model

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Numerical simulation of semiconductor devices is now widely used in device development for advanced integrated circuits. The long accepted standard numerical simulation technique is modeling by self-consistently solving Poisson's equation and the current-continuity equation including mobility and impact ionizaion models as a function of the local electric field. (1,2) However, as device dimensions are reduced into the submicrometer range, the applicability of these drift-diffusion equations comes into question. (3,4) A significant error occurs because the field changes very rapidly in space so that the carrier energy at some point may deviate greatly from that corresponding to the local electric field. Therefore, using the Monte Carlo calculation, we investigate the limit of applicability of the traditional model from the viewpoint of impact ionization.

The electric field as a function of the position is calculated with a two dimensional drift-diffusion model. The Monte Carlo calculation is one dimensional for simplicity. We extracted the one dimentional electric field distribution under the channel in the direction from source to drain. Figure 1 and 2 show the electric field distribution of MOSFETs with channel lengths 1um and 0.5um respectively. These figures show that the shorter the channel, the abrupter the rise of electric field. We made three other field distributions which consist of constnat field-gradient. One is similar to the distribution of the calculation result of 0.5um MOSFETs. The others are the distributions which field-gradinet is one-two and one-five deviation of the former distribution. The electric field distributions are shown in Fig.3. In Fig.4~Fig.8 we show the impact ionization coefficients calculated by the Monte Carlo method under various electric field distributions and the coefficients which can be obtained by the formula as a function of the local electric field used in the dirft-diffusion model are also shown for comparison. In Fig.4 ~ Fig.8 we find out that the deviation between the Monte Carlo result and the calculation from local electric field becomes significant where the field-gradient is about 1.0x10^{10}V/cm^2 and that field gradient corresponds to 0.5um MOSFETs.

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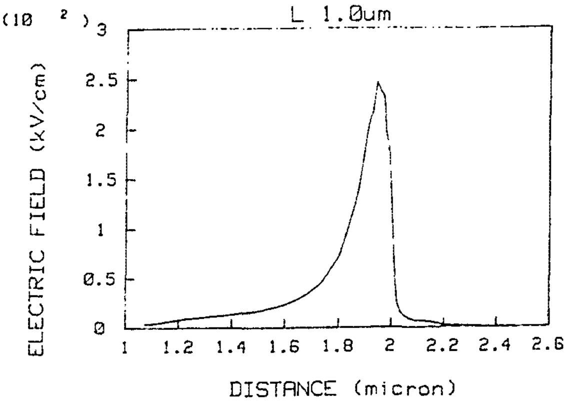

Figure 1 Electric field distribution under the channel in the direction from source to drain for 1.0um channel MOSFET.

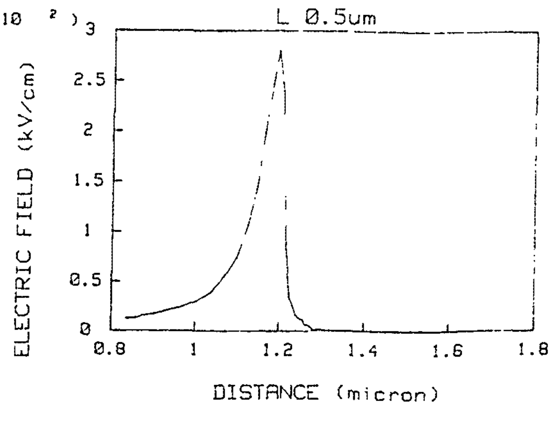

Figure 2 Electric field distribution under the channel in the direction from source to drain for 0.5um channel MOSFET.

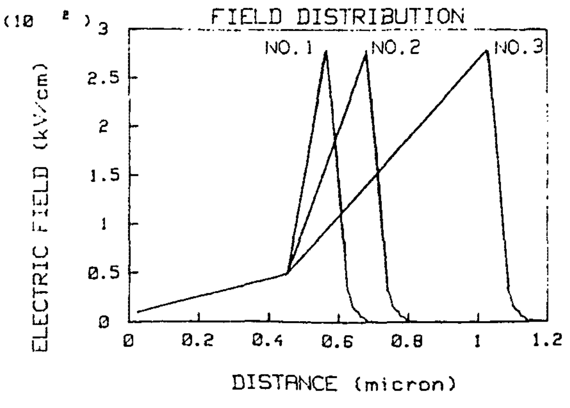

Figure 3 Electric field distributions with various field-gradients.

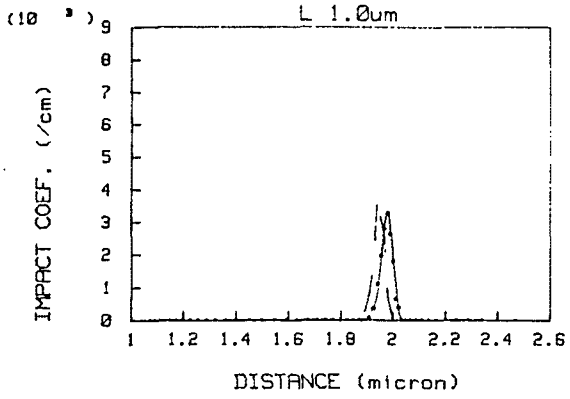

Figure 4 Impact ionization coefficients calculated by Monte Carlo (solid line) and by the formula as a function of the electric field (dashed line) for 1.0um MOSFET.

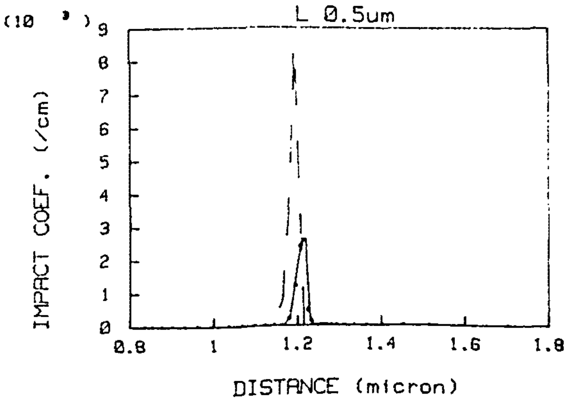

Figure 5 Impact ionization coefficients calculated by Monte Carlo (solid line) and by the formula as a function of the electric field (dashed line) for 0.5um MOSFET.

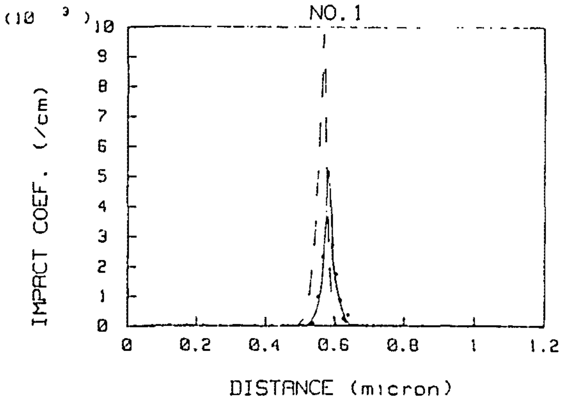

Figure 6 Impact ionization coefficients calculated by Monte Carlo (solid line) and by the formula as a function of the electric field (dashed line) for NO.1 field distribution.

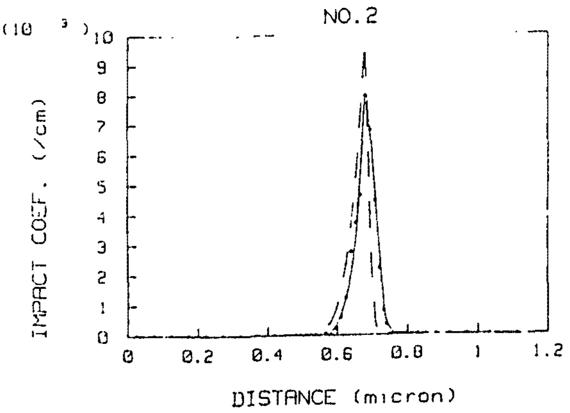

Figure 7 Impact ionization coefficients calculated by Monte Carlo (solid line) and by the formula as a function of the electric field (dashed line) for NO.2 field distribution.

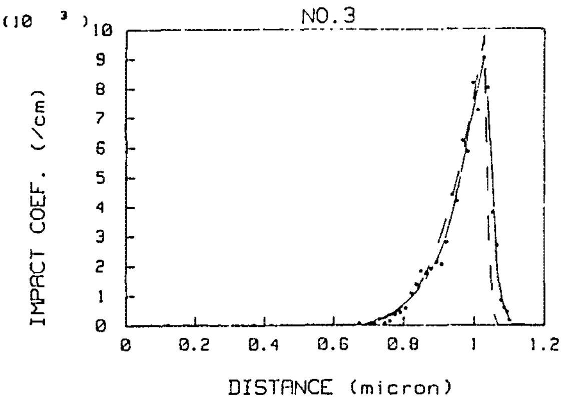

Figure 8 Impact ionization coefficients calculated by Monte Carlo (solid line) and by the formula as a function of the electric field (dashed line) for NO.3 field distribution.