Carrier Temperature Model Including Energy Flux

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1. INTRDUCTION

The trend towards half micron devices or smaller, requires the re-examination of the applicability of the conventional drift-diffusion model. We previously proposed a model based on the assumption that the carrier energy distribution remains close to its equilibrium state. However, if the electic field and its gradient in the device become excessively large, non-equilibrium carrier transport conditions will occur. Therefore, non-equilibrium transport phenomena should be included in the simulation model for deep sub-micron devices.

In this work, a carrier temperature model including energy flux is introduced and this model is applied to the device simulator.

2. MODEL

We used the fourth moment equation of the Boltzmann transport equations (BTE) to determine the carrier temperature.

$$\nabla\cdot\vec{s} = \vec{J}\cdot\vec{E} - nB \quad (1)$$

$$\vec{s} = -\alpha\left[\mu_n \xi \vec{E} + \nabla(kT_e \mu_n \xi/q)\right] , \quad (2)$$

where s is the energy flux, B is the energy dissipation factor, ξ is average energy of electron and α is constant. Now using the energy relaxation time τ B is given by

$$B = (\xi - \xi_0)/\tau \quad . \quad (3)$$

The average energy ξ is given by

$$\xi = (3/2)kT_e \quad . \quad (4)$$

The electron temperature T_e is defined by equation (1) and (2).

3. RESULTS

The model was applied to an abrupt p-n junction to investigate the influence of the assumption the $\nabla\cdot\vec{s}=0$. Impurity concentration of the n and p region were $10^{20}/cm^3$ and $10^{17}/cm^3$, respectively. The junction depth of n region was 0.1um. A reverse bias of 2V was applied.

The electron temperature distibution is shown in Fig.1. The parameter was the relaxation time. In the case of the assumption that $\nabla\cdot\vec{s}=0$, the electron temperature was very sensitive to τ_e . On the other hand, the electron temperature did not change sensitively to τ_e and it was lower than in previous cases.

The maximum electron temperature was reached at a depth of 0.2um even if the junction depth was 0.1um. The mechanism is explained as follows. There are a large number of electrons in the region from 0.1 $\sim$ 0.2 um so that the gradient of Fermi-Potential is relatively small in this region and electron temperature is not increased.

The effect of α on the electron temperature is shown as Fig.2. The electron temperature was considerably influenced by α .

We applied the proposed model to an n-channel MOSFET having 0.5um gate length and compared with the conventional drift-diffusion model. We used $\tau_e = \tau_h = 0.1$pS and assumed α =1. It is clear that the drain current increases compared with the conventional model as shown in Fig.3. This result is explained by the channel depth by which the carrier spread to the substarte , as is obvious from Fig.4-1 and Fig.4-2. The maximum electron temperature was greater than 2400K near the drain edge as shown in Fig.5.

4. CONCLUSION

We have proposed a carrier temperature model including enegry flux for the drift-diffusion type device simulator and we obtained results which were useful for the analysis of deep sub-micron devices.

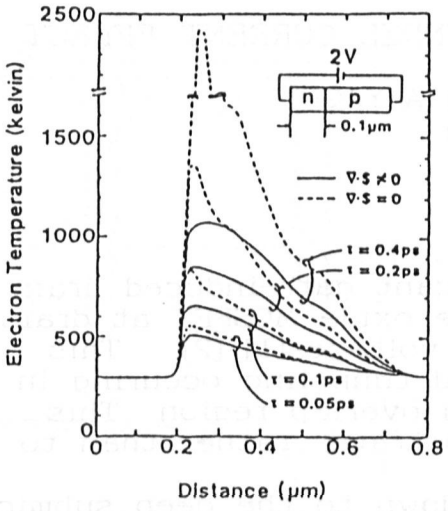

Fig.1 Electron temperature distribution in the abrupt junction caluculated the case of assumption of ∇·s=0 and present model. Parameter is enegry relaxation time.

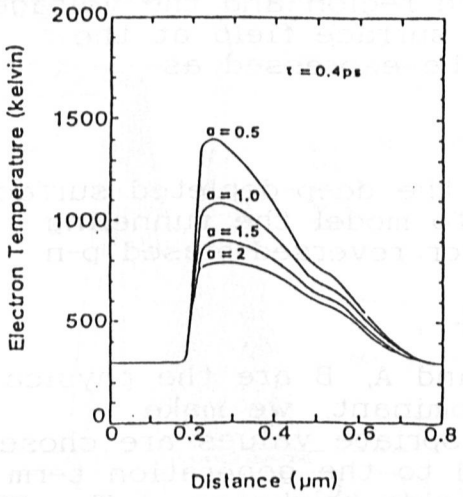

Fig.2 Electron temperature distribution in the abrupt junction. Parameter is constant α .

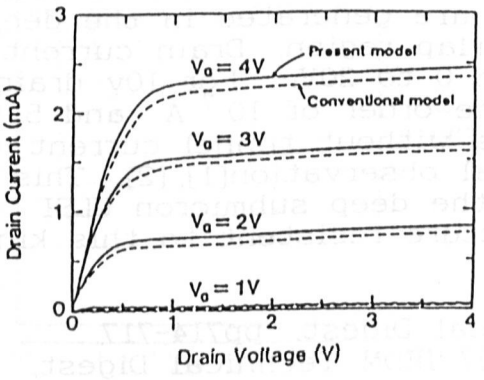

Fig.3 Drain current versus drain voltage of n-channel MOSFET having 0.5um gate length. Solid line and dashed line used present model and ∇·s=0, respectively.

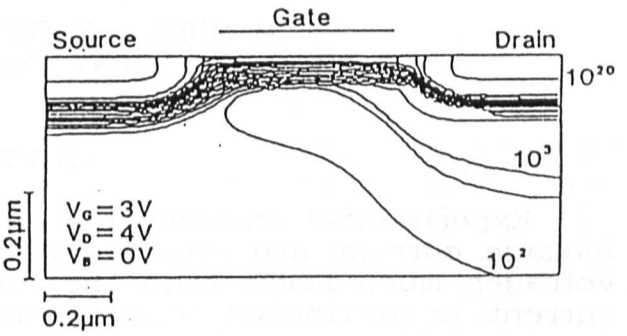

Fig.4-1 Electron density distribution in the MOSFET. (convensional model)

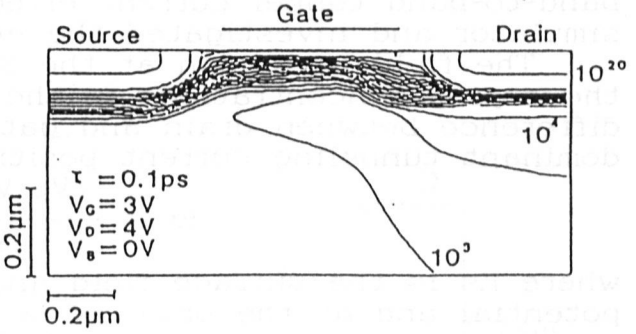

Fig.4-2 Electron density distribution in the MOSFET. (present model)

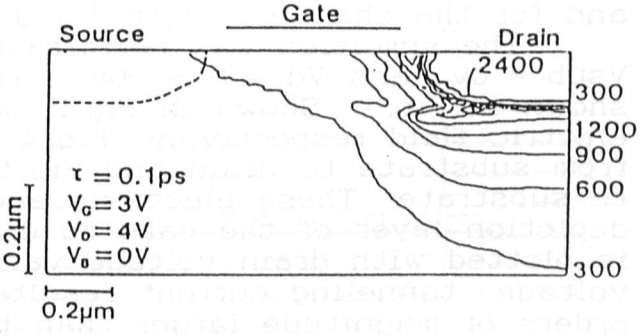

Fig 5 Electron temperature distribution in the MOSFET.