# Grid size independent model of inversion layer carrier mobility

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## I. INTRODUCTION

The universality of effective carrier mobility $\mu_{eff}$ in MOSFET's inversion layer has been reported [1], [2]. In order to realize the accurate device simulation of MOSFET's, a mobility model considering the universality is indispensable. Two kinds of methods have been proposed. The method proposed by Watt[3] prepares only one grid in the inversion layer. On the other hand, a local field model (LFM) in which the inversion layer carrier mobility $\mu_{inv}$ depend on the local electric field has been proposed by Shin *et al.* [4].

Lee [5] performed a detailed examination on the simulation accuracy of these models. It was found that the Watt's method was difficult to decide the position of the second grid point. On the other hand, LFM had strong grid size dependency. Very fine grids were required for accurate simulation of the drain current $I_D$ using LFM [4], [6]. This causes serious problems of making computer resources huge, and/or making an automatic grid generation difficult.

The LFM proposed by Shin *et al.* was derived from the requirement that the calculated conductance of a whole inversion layer $g_d$ gave the measured value. However, the resulting $g_d$ or $I_D$ varies with the grid size strongly. The authors intend to solve this inconsistency to examine this grid size dependency, and propose a new grid size independent LFM.

## II. PROBLEMS

Fig. 1 shows the simulated $g_d$ using the LFM by Shin *et al.* (dotted lines). It strongly depended on the grid size. Fig. 1 also shows the simulated $g_d$ using the present model (solid lines), which indicates no grid size dependency. Fig. 2 shows the $\mu_{inv}$ distribution in the inversion layer using the LFM by Shin *et al.* In this model, $\mu_{inv}$ is a function of the local field. Thus, $\mu_{inv}$ abruptly changes in the inversion layer, because the local field changes abruptly. The mobility for each control volume (CV) is calculated at a grid point. In simulation, therefore, $\mu_{inv}$ becomes stairs-like. The difference of the mobility values between these stairs and the original distribution results in the grid size dependency of LFM.

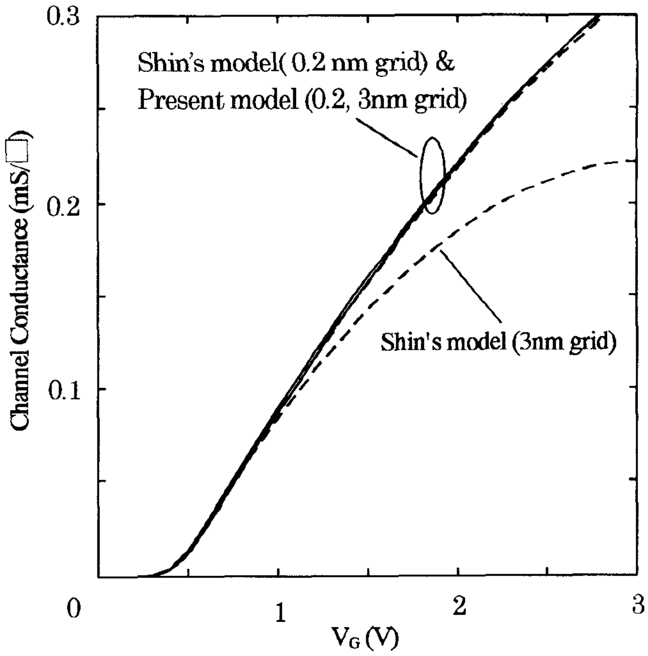


Fig.1. Channel conductance simulated with the fine(0.2 nm) and coarse(3nm) grids. The solid lines represent the results using the present model. The dotted lines represent the results using the model by Shin *et al.* The 1D-simulations were carried out in the depth direction. The substrate was $1x10^{17}cm^{-3}$ p-type, Tox=10nm and the gate was $N^+$ polySi.

## III. NOVEL METHOD FOR $\mu_{inv}$ CALCULATION

The cause of the inaccuracy of the LFM is the use of the $\mu_{inv}$ *at a grid point* as the mobility *in CV.* Thus, the authors propose a novel model which gives $\mu_{eff,\ cv}$, the effective mobility in each CV.

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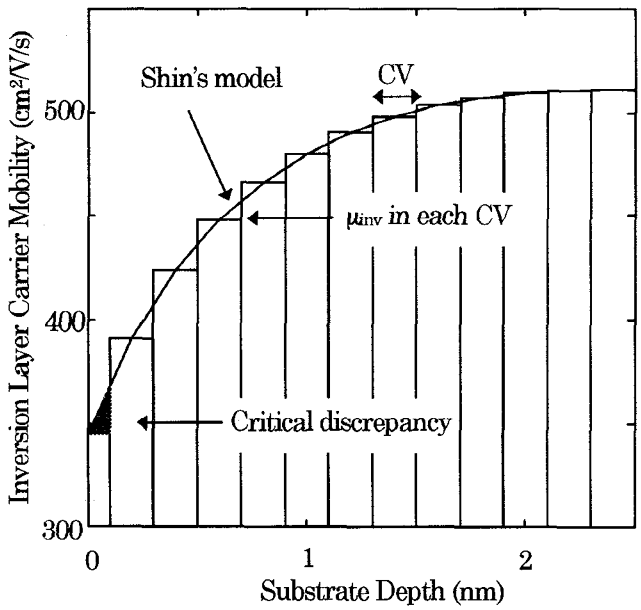


Fig. 2. Mobility distribution in the inversion layer. The solid line represents the mobility calculated using the model by Shin *et al.* The columns represent the mobility for each CV, which was defined by the mobility at the grid. $V_G$ was 2V.

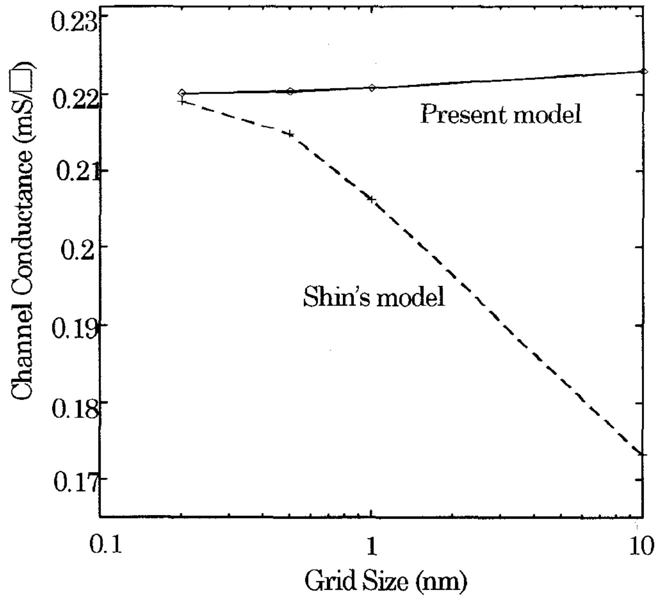


Fig. 3. Grid size dependency of the channel conductance. The solid line represents the result using the present model. The dotted line represents the result using the model by Shin *et al.* Incase of the present model, the channel conductance calculated by the 10 nm grid size was 1.3% larger than that of 0.2 nm grid size. $V_G$ was 2V.

The following equation defines $\mu_{eff,\,cv}$. That is, the effective mobility which the multiplication with carrier concentration gives the accurate conductance is given each CV.

$$\mu_{eff,cv} = \frac{\int_{cv} \mu_{inv}(z)n(z)dz}{\int_{cv} n(z)dz} \tag{1}$$

Here the intervals of these integrations are each CV, and n(z) is the carrier density. Note that these integrations can be performed analytically, if we assume the local field dependence of the $\mu_{inv}$. With some approximations, results are as follows.

$$\begin{aligned}&\mu_{eff,cv}(E_{\perp}^{'}, E_0)\\ &= \mu_{eff}(E_{eff}^{'}) + (E_{\perp}^{'} - E_0)\frac{d\mu_{eff}(E_{eff}^{'})}{dE_{\perp}^{'}}\end{aligned} \tag{2}$$

$$E_{\perp}^{'} = \frac{E_{\perp,t} + E_{\perp,b}}{2} \tag{3}$$

$$E_{eff}^{'} = \eta E_{\perp}^{'} + (1-\eta)E_0 \tag{4}$$

where $E_{\perp,t}$ and $E_{\perp,b}$ are the transverse field at the top and bottom boundary of each CV respectively, $\eta$=1/2 for electron and 1/3 for hole, $E_0$ is the transverse field at the edge of the inversion layer.

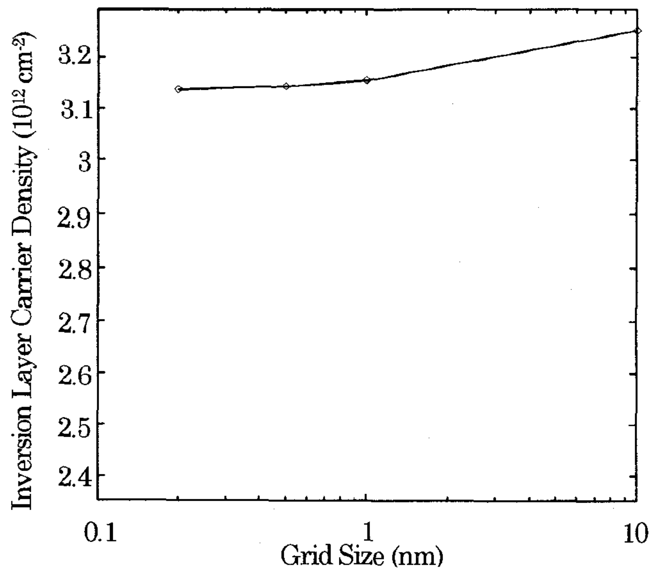


Fig. 4. Grid size dependency of $N_{inv}$. The $N_{inv}$ calculated by the 10 nm grid size was 3.7% larger than that of 0.2 nm grid size. $V_G$ was 2V.

## IV. Results and Discussions

Fig. 3 shows the grid size dependency of $g_d$. Even if the grids were coarse and there was only a single grid point in the inversion layer (*i.e.* 10 nm grid size), the proposed model could simulate $g_d$ correctly. This is because $\mu_{eff,\,cv}$ for the CV including the whole inversion layer goes to $\mu_{eff}$. Thus, the proposed model works as the Watt's model. On the other hand, it is obvious from the definition that the proposed model works as LFM if grids are fine.

Slight grid size dependency is seen in Fig. 3. This was not due to the mobility but the inversion layer carrier density $N_{inv}$ [7]. Fig. 4 shows the grid size dependency of $N_{inv}$. It turns out that the cause of the grid size dependency of $g_d$ in Fig. 3 was that of $N_{inv}$.

## V. Conclusion

The novel model of $\mu_{inv}$ was proposed, which gives the effective carrier mobility $\mu_{eff,\,cv}$ for each CV. It was shown that the proposed model could simulate $g_d$ of MOSFET's accurately for wide range of grid sizes.

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