A Mobility Model for Deep Submicron MOSFET Device Simulation

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A mobility model in device simulation is an important parameter that greatly affects calculation results. The model proposed by Yamaguchi [1] has widely been used and later improved by Hiroki et al.[2]. These models are very easy to apply to device simulation, since the formulae used are simple and there is no need to distinguish the carrier flow in the inversion layer from that in the bulk region.

Recently very-short-channel MOSFETs with high substrate concentration and thin gate oxide have been developed according to the scaling law. When we use the mobility models mentioned above in a device simulator for these advanced MOSFETs, two problems arise. (1) The device simulator estimates an extremely low value for the mobility even in the inversion layer when impurity concentration is high, and (2) for a given impurity concentration, the simulator overestimates its value in proportional to $En^{-0.3}$ even at high normal field, where En denotes the value of the normal field. These characteristics are inconsistent with the experimental results previously reported [3]. Schwarz and Russek [4] have presented semi-empirical equations that include the screening effect caused by electrons in the inversion layer. However, it is necessary to find the inversion layer region in a device simulator since the equations cannot be applied to the pinchoff depletion region and source/drain high concentration region. Moreover the transverse-field dependence on the mobility is considered for the range up to $6X10^5$ V/cm, so it is not appropriate to use their model at high normal electric field as indicated by experimental results.

In this paper we propose a mobility model for deep submicron MOSFET device simulation. Our model is the first one that is not only applicable to the whole region of a MOSFET but also takes into account the screening effect in the inversion layer. The model also achieves an improved normal field dependence for thin gate oxide MOSFETs.

The impurity density dependence of our model is based on Scharfetter and Gummel's empirical expression [1] and includes the screening effect caused by free carriers by using a weight function. The function is based on the Brooks-Herring formula [5]. For the normal field dependence, we propose a formula that fits into the experimental data [3].

We performed long channel device simulations using our mobility model. We then calculated the effective mobility as a function of the effective normal field for various dopings. We give the calculation results of our model and Yamguchi's model in Fig.1 and Fig.2, respectively.

To compare our calculation results with the experimental results, MOSFETs with various channel doses and doping energies are fabricated. Typical channel profiles are given in Fig.3. Fig.4 depicts transconductance gm as a function of doping levels. The drain current of MOSFETs of channel length 0.4 μ m as a function of gate voltage is given in Fig.5.

From the results shown in these figures, it is clear that ours gives the results that fit into the experimental results while Yamaguchi's model does not. Therefore, we conclude that our mobility model is extremely good.

references
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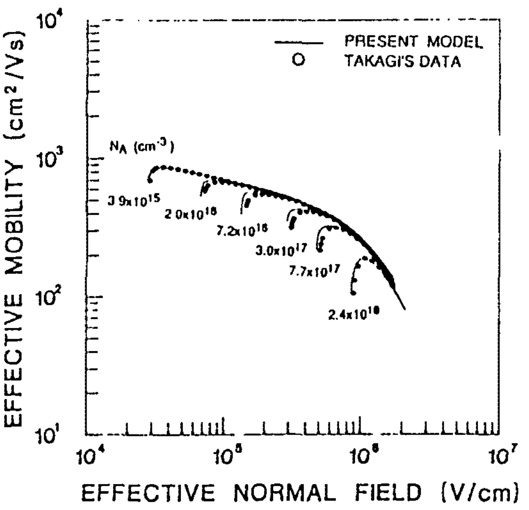

Fig. 1. Effective mobility versus effective normal field as a parameter of substrate concentration. The effective mobility is calculated by $\mu eff=L/(WqNinv)$ $Id/\ Vd$ with using the calculation results of the device simulator combined with the present mobility model. There is good agreement between calculations (solid line) result and experimental data (circle).

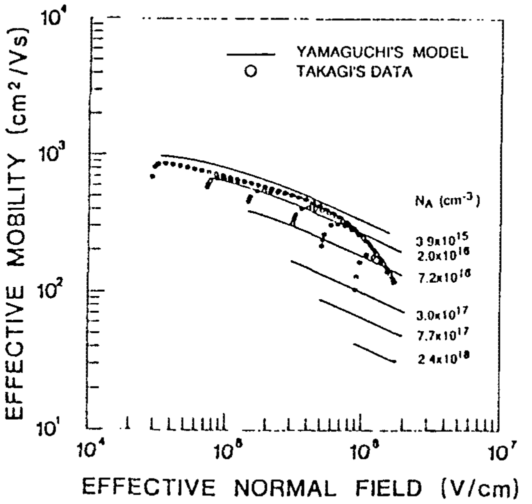

Fig. 2. Effective mobility versus effective normal field with using the Yamaguchi's mobility model. The effective mobility decreases with increasing the substrate concentration and the universal curve cannot be predicted.

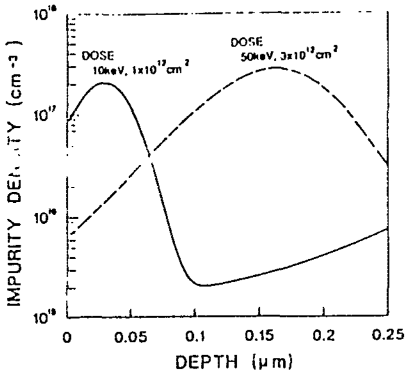

Fig. 3. Channel profiles of the devices for two types of doping energy. Solid line is 10keV, $1X10^{12}$ cm^{-2} and Dashed line is 50keV, $3X10^{12}$ cm^{-2}.

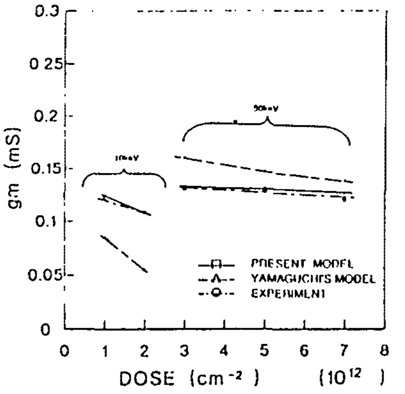

Fig. 4. Transconductance gm as a function of the channel dose. Experimental data, calculation results with using the present mobility model and results with using the Yamaguchi's model are given.

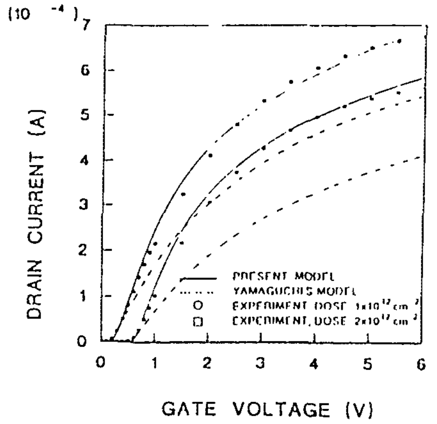

Fig. 5. Drain current versus gate voltage at a drain voltage of 0.1 V for 0.4μm channel length MOSFET.