(9A-4)

A Charge Conservative Capacitance Model for Short Channel MOSFET's

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1.Introduction

Recently a lot of attention has been paid to modeling the intrinsic capacitance of MOS transistors[1],[2]. It is necessary to define terminal charges as the state variables in the circuit simulation for charge conservation. We present a charge-based capacitance model for short channel transistors. This model includes various second-order effects such as velocity saturation,mobility degradation and channel-length modulation.

2.Results and Discussion

We derive the charge expression in the strong inversion region as the function of each terminal voltage. Inter-nodal capacitances are given by the derivative of the charges.

In the linear region, gate,bulk, and channel charges per unit area are given below :

$$qg(y)= Cox[Vgs-Vfb-2\varphi_F-Vy] \tag{1}$$

$$qb(y)=-Cox[Vth-Vfb-2\varphi_F-(1-a)Vy] \tag{2}$$

$$qc(y)=-Cox[Vgs-Vth-a\cdot Vy] \tag{3}$$

"a" is the body-effect coefficient which is defined by :

$$a=1+ge.K_1/(2\sqrt{Vx})+K_2 \tag{4}$$

$$ge=1-fe/(C_1+C_2\cdot Vx) \tag{5}$$

$$fe=1-Exp[-(C_1+C_2\cdot Vx)Vds/(6Vx)] \tag{6}$$

$$Vx=2\varphi_F-Vbs \tag{7}$$

where Vfb : flat band voltage
φ_F : quasi-Fermi potential
Vy : surface potential along the channel at y
K_1,K_2 : back-gate constants
C_1=1.744 , C_2=0.8364

In the conventional model such as BSIM[2], "fe" is equal to 1. But this treatment neglects Vds dependence of body factor and causes a serious error in the capacitance characteristics which are related to the bulk charge when small Vds is applied[3]. Each terminal charge is obtained by integrating(1)-(3) over the entire channel region. Second order effects have already been incorporated in the DC model. In the integration these effects are introduced in the charge expression through the (dy/dVy) term[4]. This transverse field(Ey) is given by :

$$Ey=dVy/dy=[(Vgs-Vth-a.Vy)We\cdot Us\cdot Cox/Ids-Vm/Us]-1 \tag{8}$$

where Us : effective mobility degraded by vertical field
Vm : saturation velocity

To calculate the source and the drain charges, we adopt the following charge partioning scheme[5]

$$Qs=We\int qc(y)(1-y/Le)dy \tag{9}$$

$$Qd=We\int qc(y)\cdot y/Le\cdot dy \tag{10}$$

where Le,We : effective channel length and width

We have to define the saturation voltage(Vdsat) to derive the charge expression in the saturation region. In view of the convergence problem, the derivative of each charge has to be continuous through the different operation regions. So we derive the Vdsat from :

$$dQi/dVds=0 \quad (i=g,b,d,s) \tag{12}$$

And the solution of these four equations is :

$$Vdsat=(Vgs-Vth)/(a\cdot Ks) \tag{13}$$

$$Ks=[1+\sqrt{1+2Us(Vgs-Vth)/(a\cdot Le\cdot Vm)}]/2 \tag{14}$$

For short channel devices, Vdsat is reduced because of the velocity saturation effect, which is indicated by the Ks term of the above equation. This term is set to 1 in the conventional model. Equation (13) is exactly the same form as in the DC model. So the accuracy of the DC parameters is closely reflected in the charge model. Figure 1 and Figure 2 show some examples of the comparison of the voltage dependences of this new charge-based capacitance model with the conventional model[2]. In Fig.1 Cbs is equal to Cbd at Vds=0 which is not achieved in the conventional model. Figure 2 shows gate-capacitance versus Vgs characteristics of long and short channel devices.Cgd gradually increases in the saturation region due to velocity saturation and channel-length modulation[6].

3.Conclusion

We derive the charge-based capacitance model which accounts for various second-order effects. These effects are notable in the short channel devices.

(References)
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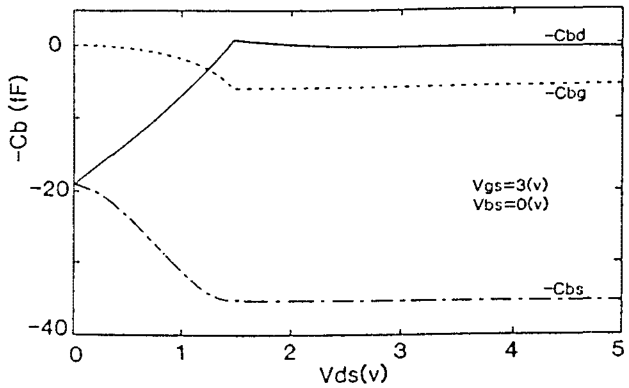
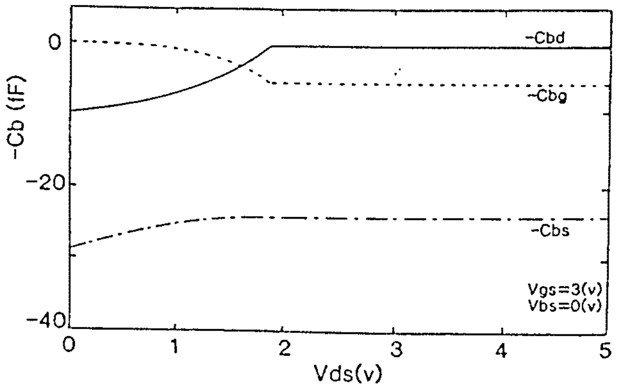


Fig.1(a) Cbg,Cbd,Cbs versus Vds.
Parameters are Weff=50um,Tox=250Å.
(Present model)



(b) Cbg,Cbd,Cbs versus Vds.
Parameters are Weff=50um,Tox=250Å.
(Conventional model)

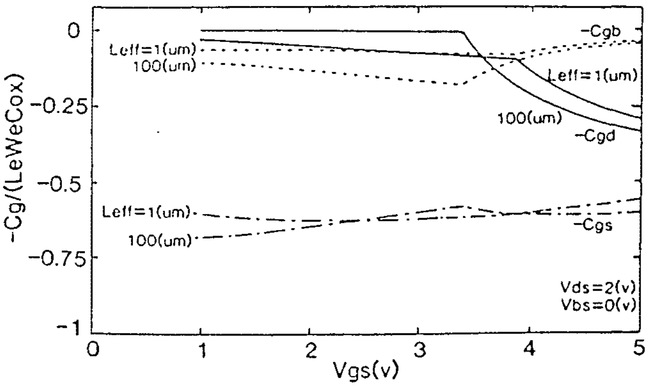
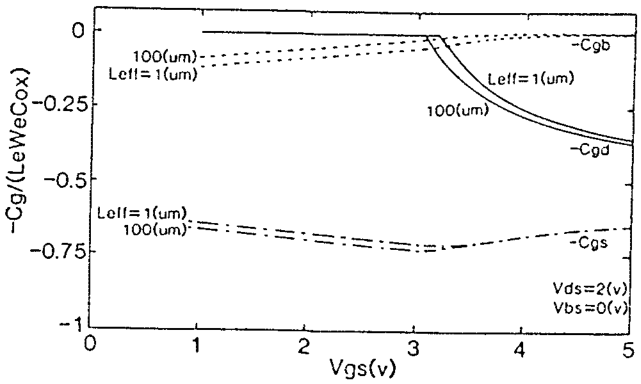


Fig.2(a) Normalized gate capacitances versus Vgs
for different channel lengths.
Parameters are Weff=50um,Tox=250Å.
(Present model)



(b) Normalized gate capacitances versus Vgs
for different channel lengths.
Parameters are Weff=50um,Tox=250Å.
(Conventional model)