An Analytical Model for Band-to-Band Tunneling with Impact Ionization

M.Tanizawa, M.Ikeda, N.Kotani and Y.Akasaka

LSI R&D Laboratory, Mitsubishi Electric Corporation
4-1 Mizuhara, Itami, Hyogo, 664 Japan

1.Introduction

Drain leakage currents due to band-to-band tunneling (BTBT) have been studied intensively[1]-[5]. This phenomenon has to be taken into account for designing thin gate-oxide MOSFET's.

In this paper it is shown by experiment that impact ionization plays a significant role in modeling drain leakage in the deep subthreshold region. And a simple analytical BTBT model with impact ionization is presented here for the first time.

2.Model

The n-channel MOSFET's used in this study have conventional drain structure with the device parameters which are summarized in Table.1.

Fig.1 shows Vbs dependence of drain leakage currents. The previous 1-D models[1],[2] attribute drain leakage to BTBT which occurs in the depletion layer at the gate-to-drain overlap region. Only the field normal to the $Si-SiO_2$ interface is taken into account in these models. Therefore, the characteristics of drain leakage in Fig.1 cannot be explained by these models.

Fig.2 also shows drain leakage characteristics, in which two devices with channel lengths of 2.0 and 0.8μm are compared, keeping V_{db} constant at 4V. In the region where drain leakage dominates, there is no significant difference between these two curves. From this point we can assume that the functional form of drain leakage is expressed as

$$I_{ds} = f(V_{dg}, V_{db}) \qquad (1)$$

Next we model drain leakage in two steps. First, BTBT occurs due to the normal high field (E_n) which generates the mobile carriers. The amount of current caused by these carriers is termed I_{bt}. Second, the generated holes (for n-channel) are accelerated by the lateral high field (E_l) in the drain-substrate junction, and this causes impact ionization. Therefore, assuming that the impact ionization coefficient is given by $\alpha \approx \exp(-B_{b2}/E_l)$, drain leakage is given by integrating the product of α and I_{bt} across the junction. The result is

$$I_{ds} = A_l E_n \exp(-B_{bl}/E_n) \qquad (2)$$

$$A_l = A_{bl} W E_l \exp(-B_{b2}/E_l) \qquad (3)$$

$$E_l = \sqrt{2qN_b/\epsilon_{si}}\sqrt{V_{bi} + V_{db}} \qquad (4)$$

$$E_n = (V_{dg} + V_{fb} - \phi_s)/(3T_{ox}) \qquad (5)$$

$$\phi_s = K_0 - \sqrt{K_0^2 - V_{dg}^2} \qquad (6)$$

$$K_0 = V_{dg} + (qN_d T_{ox}^2 \epsilon_{si})/\epsilon_{ox}^2 \qquad (7)$$

where A_{bl}, B_{bl} and B_{b2} are constants and V_{bi} is built-in potential.

3.Results and Discussion

To confirm the accuracy of this model, it is necessary to extract three parameters (A_{bl}, B_{bl}, B_{b2}) from the experiment. First, we use the characteristics of $\log(I_{ds}/E_n)$ vs $1/E_n$ which is shown in Fig.3. Parallel straight lines corresponding to different V_{db}'s are observed. A_l and B_{bl} are extracted from the intersection and the slope of each line. Next we use the plot of $\log(A_l/E_l)$ vs $1/E_l$ with channel lengths of 0.8, 1.2 and 2.0μm, as shown in Fig.4. Again, a linear relationship is obtained, and A_{bl} and B_{b2} are extracted. The value of B_{b2} (≈3.3MV/cm) is close to that obtained from the substrate current experiment for p-channel MOSFET's (≈3.7MV/cm)[6]. These results suggest the physical accuracy of our model. The comparison between the calculated results and measured data is

shown in Fig.1. A good agreement is obtained.

4.Conclusion

A simple analytical model of drain leakage currents due to impact ionization induced by BTBT is presented. Results calculated by this model agree well with experimental results.

(References)

[1] T.Y.Chan et al.,in *IEDM Tech. Dig.*,p718(1987)

[2] C.Chang and J.Lien, in *IEDM Tech. Dig.*,p714(1987)

[3] R.Shirota et al.,in *IEDM Tech. Dig.*,p26(1988)

[4] K.Kurimoto et al.,in *IEDM Tech. Dig.*,p621(1989)

[5] M.Orlowski et al.,*IEEE Trans. Electron Device Lett.* ,vol.EDL-11,p593(1990)

[6] T.C.Ong et al.,*IEEE Trans. Electron Device Lett.*,vol.EDL-8,p413(1987)

Table.1 Device parameters of n-channel MOSFET's

	Terminology		
gate-oxide thickness	Tox	100	[Å]
channel width	W	10	[μm]
channel length	L	2, 1.2, 0.8	[μm]
substrate concentration	Nb	2.4×10^{17}	[cm^{-3}]
source/drain concentration	Nd	2.0×10^{20}	[cm^{-3}]

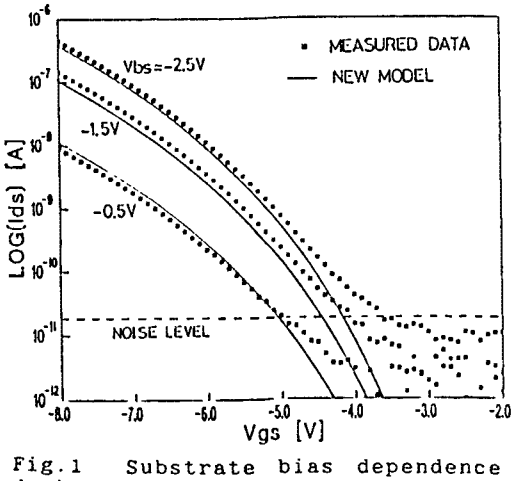

Fig.1 Substrate bias dependence of drain leakage currents of MOSFET with T_{ox}=100A, L=2.0μm and W=10μm. V_{ds}=0.2V.

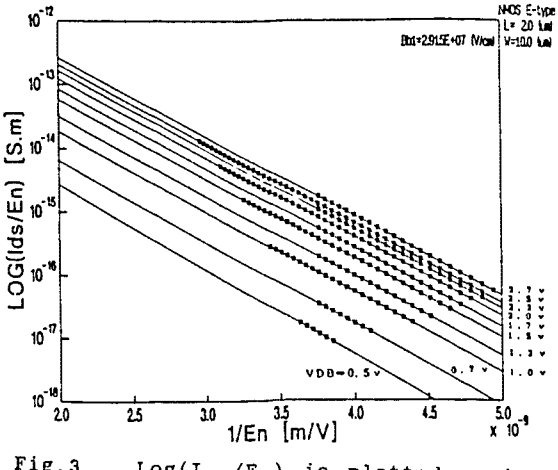

Fig.3 $Log(I_{ds}/E_n)$ is plotted against $1/E_n$ for MOSFET with channel length of 2μm. An experimental value of B_{b1}=29.15 MV/cm was obtained.

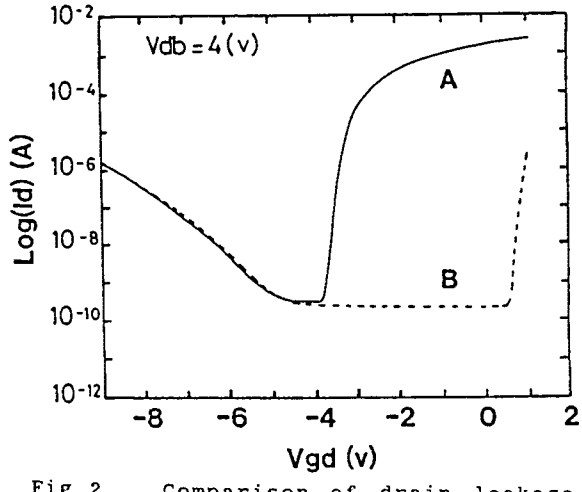

Fig.2 Comparison of drain leakage characteristics with channel lengths of 2.0μm (A) and 0.8μm (B). A: V_s=0V, V_d=4V, V_b=0V. Vg increases from -5 to 5V. B: V_s=0V, V_d=0.5V, V_b=-3.5V. Vg increases from -8.5 to 1.5V.

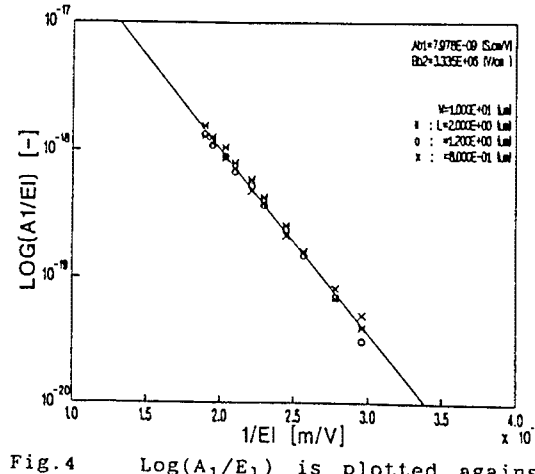

Fig.4 $Log(A_1/E_1)$ is plotted against $1/E_1$ for MOSFET's with channel lengths of 2μm (*), 1.2μm (o) and 0.8μm (x). Experimantal values of A_{b1}=7.978 S.nm/V and B_{b2}=3.335 MV/cm were obtained.