Chapter 9 Stress Effect Model

The mechanical stress effect induced by process causes the performance of MOSFET to be function of the active area size (OD: oxide definition) and the location of the device in the active area. The necessity of new models to describe the layout dependence of MOS parameters due to stress effect becomes very urgent in advance CMOS technologies. Influence of stress on mobility has been well known since the 0.13um technology. The stress influence on saturation velocity is also experimentally demonstrated. Stress-induced enhancement or suppression of dopant diffusion during the processing is reported. Since the doping profile may be changed due to different STI sizes and stress, the threshold voltage shift and changes of other second-order effects, such as DIBL and body effect, were shown in process integration.

Experimental analysis shows that there exist at least two different mechanisms within the influence of stress effect on device characteristics. The first one is mobility related which is induced by the band structure modification. The second one is Vth related as a result of doping profile variation. Both of them follow the same 1/LOD trend but reveal different L and W scaling. A BSIM4 compatible phenomenological stress model based on these findings has been developed by modifying some parameters. Note that the following equations have no impact on the iteration time because there are no voltage-controlled components in them.

9.1 Mobility Related Equations

Mobility changes induced by stress effect is modeled by adjusting U_0 and V_{sat} according to different W, L and OD shapes. The relative change of mobility is defined as follows:

$$\rho_{\mu_{eff}} = \frac{\Delta\mu_{eff}}{\mu_{eff0}} = \frac{\mu_{eff} - \mu_{eff0}}{\mu_{eff0}} \tag{9.1}$$

So we have

$$\frac{\mu_{eff}}{\mu_{eff0}} = 1 + \rho_{\mu_{eff}} \tag{9.2}$$

Figure (9.1) shows the typical layout of a MOSFET on active layout surrounded by STI isolation. SA, SB are the distances between isolation edge to Poly from one and the other side, respectively [27]. 2D simulation shows that stress distribution can be expressed by a simple function of SA and SB. Figure (9.2) shows the schematic stress distribution in the OD region [29].

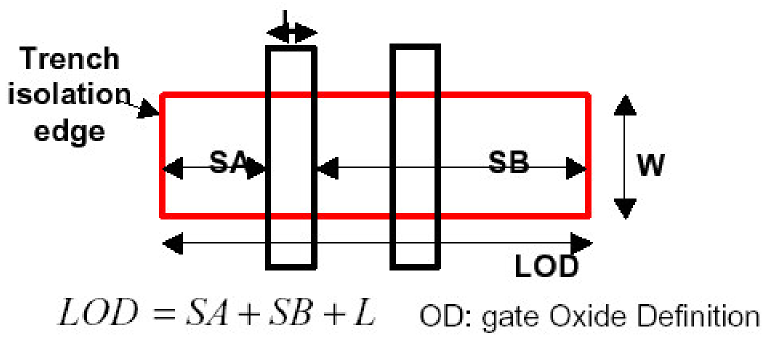

Fig. 9.1 shows the typical layout of a MOSFET [27]

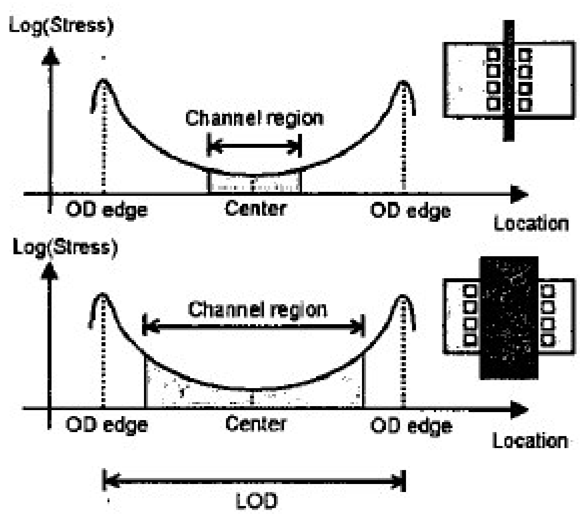

Fig. 9.2 Schematic stress distribution in the OD region [29]

Assuming that mobility relative change is proportional to stress distribution. It can be described as function of SA, SB(LOD effect), L, W, and T dependence.

$$\rho_{\mu_{eff}} = \frac{KU0}{Kstress\_u0} \cdot \left(Inv\_sa + Inv\_sb \right) \tag{9.3}$$

where $Inv\_sa = \dfrac{1}{SA + 0.5 \cdot L_{drawn}}$, $Inv\_sb = \dfrac{1}{SB + 0.5 \cdot L_{drawn}}$,

$$Kstress\_u0 = \left(\begin{array}{l} 1 + \dfrac{LKU0}{(L_{drawn} + XL)^{LLODKU0}} + \dfrac{WKU0}{(W_{drawn} + XW + WLOD)^{WLODKU0}} \\ + \dfrac{PKU0}{(L_{drawn} + XL)^{LLODKU0} \cdot (W_{drawn} + XW + WLOD)^{WLODKU0}} \cdot \left(1 + TKU0 \cdot \left(\dfrac{Temperature}{TNOM} - 1 \right) \right) \end{array} \right)$$

So that

$$\mu_{eff} = \frac{1 + \rho_{\mu_{eff}}(SA, SB)}{1 + \rho_{\mu_{eff}}(SA_{ref}, SB_{ref})} \mu_{eff0} \tag{9.4}$$

$$v_{sattemp} = \frac{1 + KVSAT \cdot \rho_{\mu_{eff}}(SA, SB)}{1 + KVSAT \cdot \rho_{\mu_{eff}}(SA_{ref}, SB_{ref})} v_{sattemp0} \tag{9.5}$$

where μ_{eff0}, $v_{sattemp0}$ are low field mobility and low field saturation velocity at SA_{ref}, SB_{ref}.

SA_{ref}, SB_{ref} are reference distances between OD edge to poly from one and the other side.

9.2 Vth-related Equations

Vth0, K2 and ETA0 are modified to cover the doping profile change in the devices with different LOD. They use the same 1/LOD formulas as shown in section(13.1.1), but different equations for W and L scaling:

$$VTH0 = VTH0_{original} + \frac{KVTH0}{Kstress\_vth0}\left(Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref}\right) \quad (9.6)$$

$$K2 = K2_{original} + \frac{STK2}{Kstress\_vth0^{LODK2}} \cdot \left(Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref}\right) \quad (9.7)$$

$$ETA0 = ETA0_{original} + \frac{STETA0}{Kstress\_vth0^{LODETA0}} \cdot \left(Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref}\right) \quad (9.8)$$

where $Inv\_sa_{ref} = \frac{1}{SA_{ref} + 0.5 \cdot L_{drawn}}$, $\quad Inv\_sb_{ref} = \frac{1}{SB_{ref} + 0.5 \cdot L_{drawn}}$

$$Kstress\_vth0 = \left(\begin{array}{l} 1 + \frac{LKVTH0}{(L_{drawn} + XL)^{LLODKVTH}} + \frac{WKVTH0}{(W_{drawn} + XW + WLOD)^{WLODKVTH}} \\ + \frac{PKU0}{(L_{drawn} + XL)^{LLODKVTH} \cdot (W_{drawn} + XW + WLOD)^{WLODKVTH}} \end{array} \right)$$

9.3 Multiple Finger Device

For multiple finger devices, as shown the layout in Fig. 9.3, the total LOD effect is the average of LOD effect to every finger. That is:

$$Inv\_sa = \frac{1}{NF} \sum_{i=0}^{NF-1} \frac{1}{SA + 0.5 \cdot L_{drawn} + i \cdot (SD + L_{drawn})}$$

$$Inv\_sb = \frac{1}{NF} \sum_{i=0}^{NF-1} \frac{1}{SB + 0.5 \cdot L_{drawn} + i \cdot (SD + L_{drawn})}$$

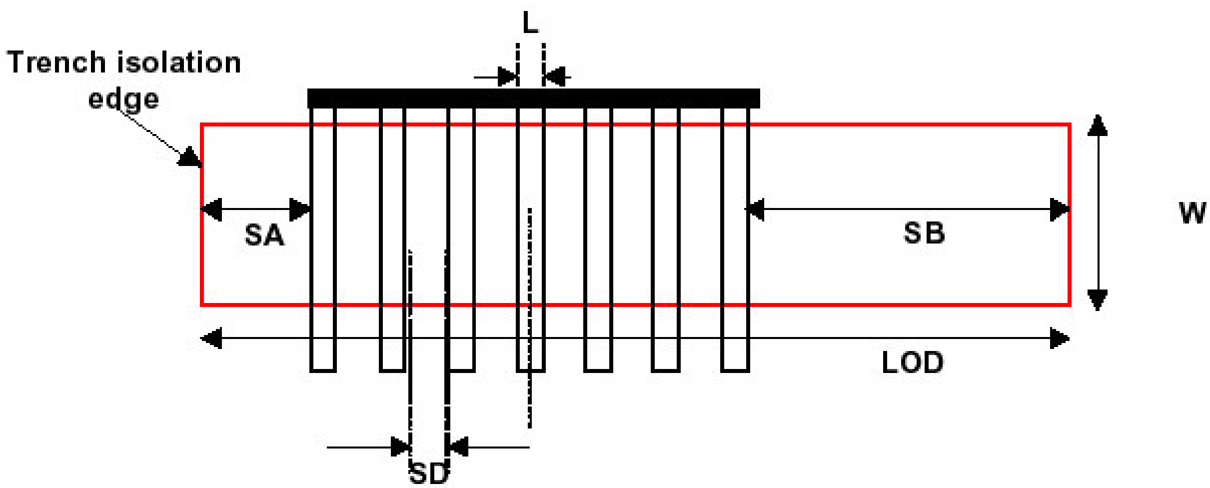

Fig. 9.3 Layout of multiple-finger MOSFET [27]