Stress Effect Model in BSIM3v3 Model

Stress effect models are now implemented in major models such as BSIM4 or HiSIM. The need for evermore accurate models with a strong relation to technology is accute. Since BSIM3v3 is still a widely-used model and has not been totally replaced by its successor, an improvement was made to the model in ***SmartSpice*** to fulfill customers need for stress effect equations.

Background

The stress effect became important for simulation because of more and more shrinking processes. The smaller devices now require efficient isolation techniques. One of them is Shallow Trench Isolation (STI), mainly used with strain channel materials.

Shallow Trench Isolation is used to replace LOCOS, as shown on the schematic in Figure 1.

This particular process induces a mechanical stress on the device structure. Because of this behavior, device performance is related to the dimension of the active area, as well as the location of the device.

It has been shown that :

- Stress has an influence on mobility
- Saturation velocity is also modified
- Dopant diffusion during processing is modified, leading to different doping profiles. This implies a threshold voltage shift as well as changes in second-order effect such as Drain-Induced Barrier Lowering (DIBL) and body effect

Berkeley University considered that the effect of stress is due to two main mechanisms: mobility variation induced by changes in the band structure, and influence on threshold voltage because of different doping profiles as explained above.

Both of these mechanisms have the same dependence on $1/L_{OD}$ (invert of the Length of Oxide Definition), but show a different trend with regard to width and length of the device.

Implementation

When the effect is enabled, the following model elements are modified :

- Mobility
- Saturation velocity
- Threshold voltage
- Drain-Induced Barrier Lowering (DIBL)
- Body Effect

The approach used is to tune model parameters values to account for the Stress Effect : it is a phenomenological model.

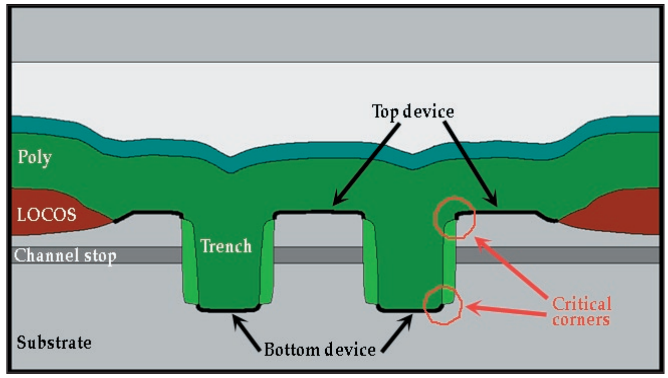


Figure 1. Process cross-section showing showing stress regions.

The Stress Effect was initially developed by Berkeley University in the BSIM4 model. It was improved with new equations along the official releases of the model. Silvaco implementation (both in BSIM3v3 and BSIM4) provides all of these implementations, using a dedicated selector: *STIMOD*.

In ***SmartSpice***, the user can select among four equations sets:

- *STIMOD = 0*: No stress effect
- *STIMOD = 1*: Berkeley model, -version
- *STIMOD = 2*: TSMC model for irregular devices
- *STIMOD =* 3: Berkeley model for multi-finger devices

Enabling the Stress Effect model does not imply a longer simulation time, since expressions do not depend on voltages. It is computed only once before running the simulation.

Berkeley β-version model (STIMOD=1)

Since the implementation was greatly changed between BSIM4v3.0-β and BSIM4v3.0, Silvaco chose to keep both implementations. The mobility *U0(T)*and *VSAT(T)* carrier velocity are computed using the following equations:

$$U0'(T) = \frac{U0(T)}{1+\rho} \quad \text{and} \quad VSAT'(T) = \frac{VSAT(T)}{1+K\cdot\rho}$$

where

$$\rho = SK0\cdot\left[\rho'\cdot\frac{\sinh\left(\frac{NF}{2\cdot SL}\cdot(SD+L)\right)}{NF\cdot\sinh\left(\frac{SD+L}{2\cdot SL}\right)} + \frac{SK2}{W}\cdot\exp\left(-\frac{W}{SW}\right)\right]$$

$$\rho' = \left(1+\frac{SK1}{LOD}\right)\cdot\left(\exp\left(-\frac{SA+D}{SL}\right)+\exp\left(-\frac{SB+D}{SL}\right)\right)\cdot\frac{\sinh\left(\frac{L_{eff}}{2\cdot SL}\right)}{\frac{L_{eff}}{2\cdot SL}}$$

$$D = 0.5\cdot(NF\cdot L+(NF-1)\cdot SD)$$

$$LOD = SA+SB+2\cdot D$$

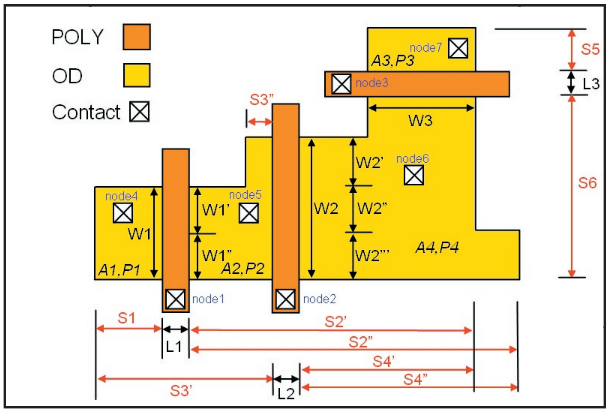


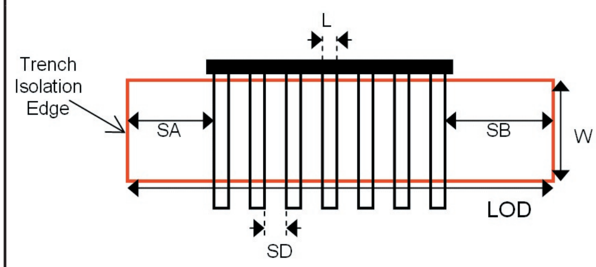
Figure 2. Layout dimensions for stress calculation STIMOD=2.

TSMC Model for Irregular Devices (STIMOD=2)

This model is suitable when there is only one finger. Parameters are used to describe square elements of the oxide layer geometry (Figure 2).

The equations used to compute the stress effect are the same as the ones when STIMOD=3, but with different intermediate geometry definitions:

$$\mathrm{Inv\_sa} = \sum_{i=1}^{10} \frac{\mathrm{SW}_i}{W} \cdot \frac{1}{\mathrm{SA}_i + 0.5 \cdot L} \text{ and } \mathrm{Inv\_sb} = \sum_{i=1}^{10} \frac{\mathrm{SW}_i}{W} \cdot \frac{1}{\mathrm{SB}_i + 0.5 \cdot L}$$



$$LOD = SA + SB + NF \cdot L + (NF - 1) \cdot SD$$

Figure 3. Berkley model diagram.

Berkeley Model for Multi-Finger Devices

This model is the one released by Berkeley in the final BSIM4v3.0 version. Parameters are used to compute the intermediate length LOD (Length of Oxide Definition).

Then equations shown in Figure 4 are used.

Conclusion

The Stress Effect model was first tested and improved in the BSIM4 model. Now that it is fully validated, it is also available in BSIM3v3 with the same selectable implementations. This will open new opportunities to customers that still use BSIM3v3 as standard.

$$U0'(T) = U0(T) \cdot \frac{1+\rho}{1+\rho_{\mathrm{ref}}}$$

$$VSAT'(T) = VSAT(T) \cdot \frac{1+\mathrm{KVSAT}\cdot\rho}{1+\mathrm{KVSAT}\cdot\rho_{\mathrm{ref}}}$$

$$VTH0'(T) = VTH0(T) + \frac{\mathrm{KVTH0}}{\mathrm{Kstress\_vth0}} \cdot (\mathrm{Inv\_sa} + \mathrm{Inv\_sb} - \mathrm{Inv\_sa\_ref} - \mathrm{Inv\_sb\_ref})$$

$$K2'(T) = K2(T) + \frac{\mathrm{STK2}}{\mathrm{Kstress\_vth0}^{LODK2}} \cdot (\mathrm{Inv\_sa} + \mathrm{Inv\_sb} - \mathrm{Inv\_sa\_ref} - \mathrm{Inv\_sb\_ref})$$

$$ETA0'(T) = ETA0(T) + \frac{\mathrm{STETA0}}{\mathrm{Kstress\_vth0}^{LODETA0}} \cdot (\mathrm{Inv\_sa} + \mathrm{Inv\_sb} - \mathrm{Inv\_sa\_ref} - \mathrm{Inv\_sb\_ref})$$

where

$$\rho = \frac{\mathrm{KU0}}{\mathrm{Kstress\_u0}} \cdot (\mathrm{Inv\_sa} + \mathrm{Inv\_sb})$$

$$\mathrm{Kstress\_u0} = \left(1 + \frac{\mathrm{LKU0}}{(L+XL)^{\mathbf{LLODKU0}}} + \frac{WKU0}{(W+XW+WLOD)^{\mathbf{WLODKU0}}} + \frac{PKU0}{(L+XL)^{\mathbf{LLODKU0}} \cdot (W+XW+WLOD)^{\mathbf{WLODKU0}}}\right) \cdot (1 + TKU0 \cdot (T_{ratio} - 1))$$

$$\mathrm{Inv\_sa} = \frac{1}{NF} \cdot \sum_{i=1}^{NF-1} \frac{1}{\mathrm{SA} + 0.5 \cdot L + i \cdot (SD + L)} \text{ and } \mathrm{Inv\_sb} = \frac{1}{NF} \cdot \sum_{i=1}^{NF-1} \frac{1}{\mathrm{SB} + 0.5 \cdot L + i \cdot (SD + L)}$$

$$\rho_{\mathrm{ref}} = \frac{\mathrm{KU0}}{\mathrm{Kstress\_u0}} \cdot (\mathrm{Inv\_sa\_ref} + \mathrm{Inv\_sb\_ref})$$

$$\mathrm{Inv\_sa\_ref} = \frac{1}{\mathrm{SAREF} + 0.5 \cdot L} \text{ and } \mathrm{Inv\_sb\_ref} = \frac{1}{\mathrm{SBREF} + 0.5 \cdot L}$$

$$\mathrm{Kstress\_vth0} = 1 + \frac{\mathrm{LKVTH0}}{(L+XL)^{\mathbf{LLODKVTH}}} + \frac{WKVTH0}{(W+XW+WLOD)^{\mathbf{WLODKVTH}}}$$

Figure 4. Parameter value modification due to stress effects.