Chapter 14: Well Proximity Effect Model

Retrograde well profiles have several key advantages for highly scaled bulk complementary metal oxide semiconductor(CMOS) technology. With the advent of high-energy implanters and reduced thermal cycle processing, it has become possible to provide a relatively heavily doped deep nwell and pwell without affecting the critical device-related doping at the surface. The deep well implants provide a low resistance path and suppress parasitic bipolar gain for latchup protection, and can also improve soft error rate and noise isolation. A deep buried layer is also key to forming triple-well structures for isolated-well NMOSFETs. However, deep buried layers can affect devices located near the mask edge. Some of the ions scattered out of the edge of the photoresist are implanted in the silicon surface near the mask edge, altering the threshold voltage of those devices[17]. It is observed a threshold voltage shifts of up to 100 mV in a deep boron retrograde pwell, a deep phosphorus retrograde nwell, and also a triple-well implementation with a deep phosphorus isolation layer below the pwell over a lateral distance on the order of a micrometer[17]. This effect is called well proximity effect.

BSIM4 considers the influence of well proximity effect on threshold voltage, mobility, and body effect. This well proximity effect model is developed by Compact Model Council[18].

14.1 Well Proximity Effect Model

Experimental analysis[17] shows that well proximity effect is strong function of distance of FET from mask edge, and electrical quantities influenced by it follow the same geometrical trend. A phenomenological model based on these findings has been developed by modifying some parameters in the BSIM model. Note that the following equations have no impact on the iteration time because there are no voltage-controlled components in them.

14.1.1 Equations for Threshold Voltage, Body Effect, and Mobility

Due to the well proximity effect, their new equations can be described as:

(14.1.1)

$$\boldsymbol{Vth}0 = \boldsymbol{Vth}0_{org} + \mathrm{KVTH0WE} \cdot (\mathrm{SCA} + \mathrm{WEB} \cdot \mathrm{SCB} + \mathrm{WEC} \cdot \mathrm{SCC})$$

$$\boldsymbol{K}2 = \boldsymbol{K}2_{org} + \mathrm{K2WE} \cdot (\mathrm{SCA} + \mathrm{WEB} \cdot \mathrm{SCB} + \mathrm{WEC} \cdot \mathrm{SCC})$$

$$\boldsymbol{\mu}_{eff} = \boldsymbol{\mu}_{eff,org} \cdot (1 + \mathrm{KU0WE} \cdot (\mathrm{SCA} + \mathrm{WEB} \cdot \mathrm{SCB} + \mathrm{WEC} \cdot \mathrm{SCC}))$$

where SCA, SCB, SCC are instance parameters that represent the integral of the first/second/third distribution function for scattered well dopant.

14.2 Extraction of Instance Parameters (for post-layout simulation)

14.2.1 SCA, SCB, SCC calculation

Figure(14.1) shows the typical layout of a MOSFET with an irregular shape well surrounded by other retrograde implanted wells. The measurement for SCi and Wi and Li could be done by the projection of channel region (overlap of OD and PO).

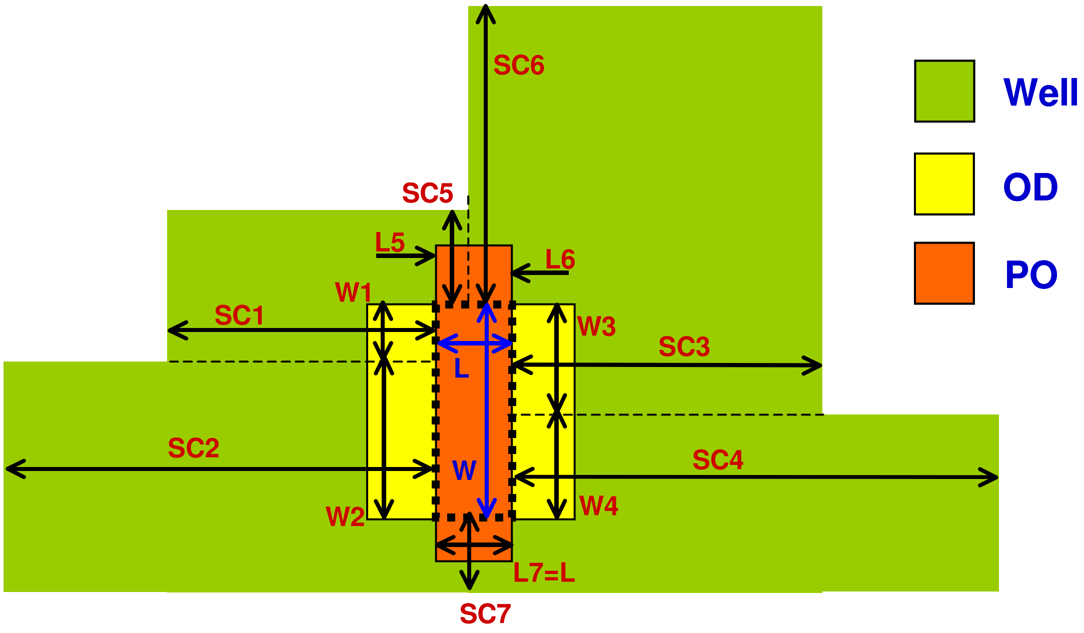

Fig. (14.1) the typical layout of a MOSFET

SCA, SCB, SCC can be calculated through:

(14.2.1)

$$\mathrm{SCA} = \left\{ \begin{array}{l} \dfrac{1}{W_{drawn} \cdot L_{drawn}} \\ \cdot \left[\sum_{i=1}^{n} \left(W_i \cdot \int_{SC_i}^{SC_i + L_{drawn}} f_A(u) du \right) + \sum_{i=n+1}^{n+m} \left(L_i \cdot \int_{SC_i}^{SC_i + W_{drawn}} f_A(u) du \right) + corners\_A \right] \end{array} \right\}$$

$$f_A(u) = \frac{SC_{ref}^{\,2}}{u^2}$$

(14.2.2)

$$\mathrm{SCB} = \left\{ \begin{array}{l} \dfrac{1}{W_{drawn} \cdot L_{drawn}} \\ \cdot \left[\sum_{i=1}^{n} \left(W_i \cdot \int_{SC_i}^{SC_i + L_{drawn}} f_B(u) du \right) + \sum_{i=n+1}^{n+m} \left(L_i \cdot \int_{SC_i}^{SC_i + W_{drawn}} f_B(u) du \right) + corners\_B \right] \end{array} \right\}$$

$$f_B(u) = \frac{u}{SC_{ref}} \exp(-10 \cdot \frac{u}{SC_{ref}})$$

(14.2.3)

$$\mathrm{SCC} = \left\{ \begin{array}{l} \dfrac{1}{W_{drawn} \cdot L_{drawn}} \\ \cdot \left[\sum_{i=1}^{n} \left(W_i \cdot \int_{SC_i}^{SC_i + L_{drawn}} f_C(u) du \right) + \sum_{i=n+1}^{n+m} \left(L_i \cdot \int_{SC_i}^{SC_i + W_{drawn}} f_C(u) du \right) + corners\_C \right] \end{array} \right\}$$

$$f_C(u) = \frac{u}{SC_{ref}} \exp(-20 \cdot \frac{u}{SC_{ref}})$$

(n is the number of segments in the projection of L direction. And m is the number of segments in the project of W direction.)

The impact of scattered dopants from well corners outside the projection regions can be calculated (see Fig. 14.2) as:

(14.2.4)

$$corners\_A = \sum_{i=n+m+1}^{n+m+4}\left(\frac{1}{2}\frac{L_{drawn}W_{drawn}}{L_{drawn}+W_{drawn}}\cdot\int_{SCX_i+SCY_i}^{SCX_i+SCY_i+L_{drawn}+W_{drawn}} f_A(u)du\right)$$

$$corners\_B = \sum_{i=n+m+1}^{n+m+4}\left(\frac{1}{2}\frac{L_{drawn}W_{drawn}}{L_{drawn}+W_{drawn}}\cdot\int_{SCX_i+SCY_i}^{SCX_i+SCY_i+L_{drawn}+W_{drawn}} f_B(u)du\right)$$

$$corners\_C = \sum_{i=n+m+1}^{n+m+4}\left(\frac{1}{2}\frac{L_{drawn}W_{drawn}}{L_{drawn}+W_{drawn}}\cdot\int_{SCX_i+SCY_i}^{SCX_i+SCY_i+L_{drawn}+W_{drawn}} f_C(u)du\right)$$

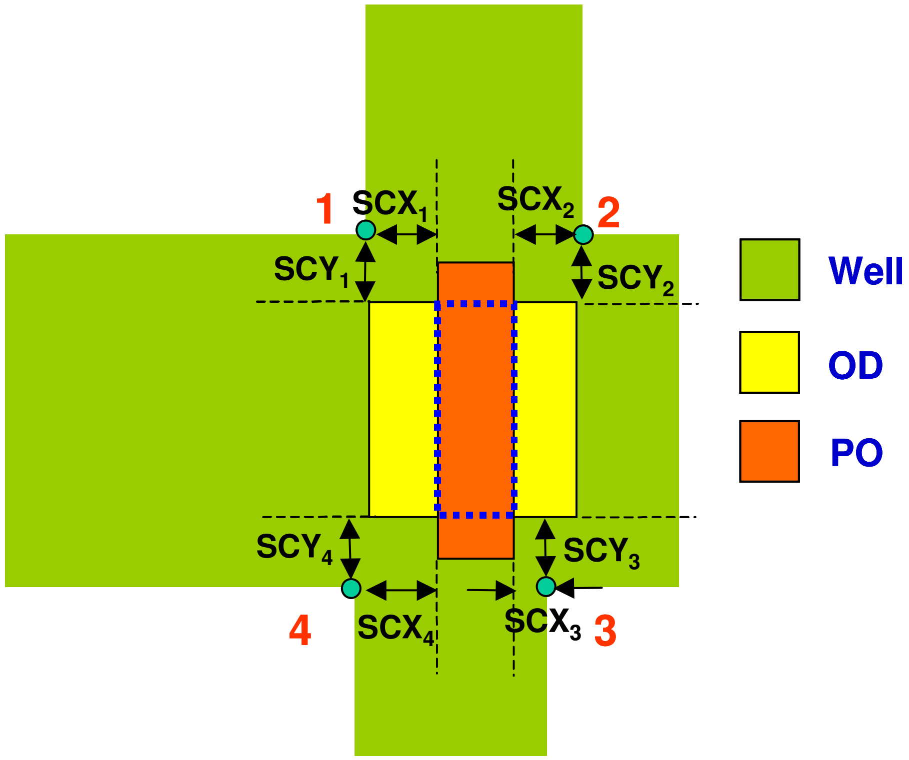

Fig. (14.2) layout for corner terms calculation

14.2.2 SC Definition (for Pre-layout Simulation)

SC is defined as “The distance to a single well edge used in calculations of SCA, SCB and SCC when layout information is not available”. If SCA, SCB and SCC are not given due to lack of detailed layout information, their estimation can be made by simulators based on the assumption that for most of layouts(Fig.14.3), the devices are close to only one well edge:

(14.2.5)

$$\mathrm{SCA} = \frac{\boldsymbol{SC}_{ref}^{\;2}}{\boldsymbol{W}_{drawn}} \cdot \left(\frac{1}{\boldsymbol{SC}} - \frac{1}{\boldsymbol{SC} + \boldsymbol{W}_{drawn}} \right)$$

$$\mathrm{SCB} = \frac{1}{\boldsymbol{W}_{drawn} \cdot \boldsymbol{SC}_{ref}} \left(\begin{array}{l} \frac{\boldsymbol{SC}_{ref}}{10} \cdot \boldsymbol{SC} \cdot \exp\left(-10 \cdot \frac{\boldsymbol{SC}}{\boldsymbol{SC}_{ref}} \right) + \frac{\boldsymbol{SC}_{ref}^{\;2}}{100} \exp\left(-10 \cdot \frac{\boldsymbol{SC}}{\boldsymbol{SC}_{ref}} \right) \\ - \frac{\boldsymbol{SC}_{ref}}{10} \cdot \left(\boldsymbol{SC} + \boldsymbol{W}_{drawn} \right) \cdot \exp\left(-10 \cdot \frac{\boldsymbol{SC} + \boldsymbol{W}_{drawn}}{\boldsymbol{SC}_{ref}} \right) \\ - \frac{\boldsymbol{SC}_{ref}^{\;2}}{100} \exp\left(-10 \cdot \frac{\boldsymbol{SC} + \boldsymbol{W}_{drawn}}{\boldsymbol{SC}_{ref}} \right) \end{array} \right)$$

$$\mathrm{SCC} = \frac{1}{\boldsymbol{W}_{drawn} \cdot \boldsymbol{SC}_{ref}} \left(\begin{array}{l} \frac{\boldsymbol{SC}_{ref}}{20} \cdot \boldsymbol{SC} \cdot \exp\left(-20 \cdot \frac{\boldsymbol{SC}}{\boldsymbol{SC}_{ref}} \right) + \frac{\boldsymbol{SC}_{ref}^{\;2}}{400} \exp\left(-20 \cdot \frac{\boldsymbol{SC}}{\boldsymbol{SC}_{ref}} \right) \\ - \frac{\boldsymbol{SC}_{ref}}{20} \cdot \left(\boldsymbol{SC} + \boldsymbol{W}_{drawn} \right) \cdot \exp\left(-20 \cdot \frac{\boldsymbol{SC} + \boldsymbol{W}_{drawn}}{\boldsymbol{SC}_{ref}} \right) \\ - \frac{\boldsymbol{SC}_{ref}^{\;2}}{400} \exp\left(-20 \cdot \frac{\boldsymbol{SC} + \boldsymbol{W}_{drawn}}{\boldsymbol{SC}_{ref}} \right) \end{array} \right)$$

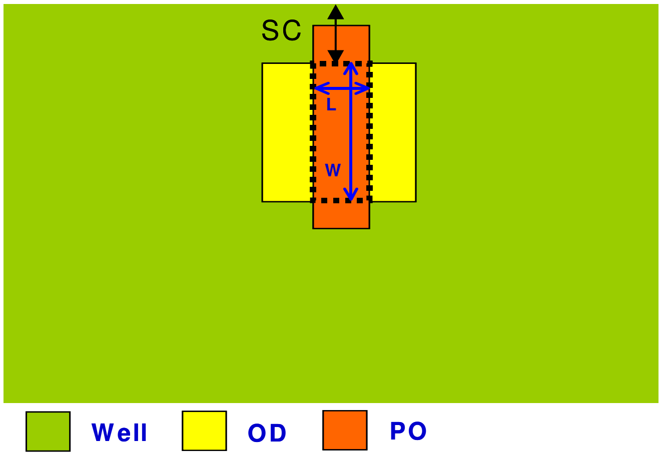

Fig. (14.3) layout for SCA, SCB, SCC estimation

For multi-finger case, still assuming there is only one well edge close to the multi-finger devices as shown in Fig. 14.4, the calculation of SCA, SCB and SCC can be (14.2.5).

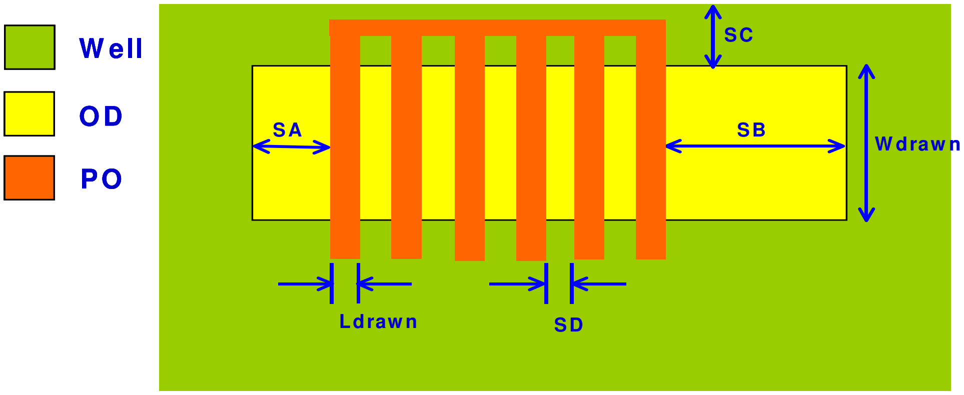

Fig. (14.4) layout for SCA, SCB, SCC estimation with multi-finger case