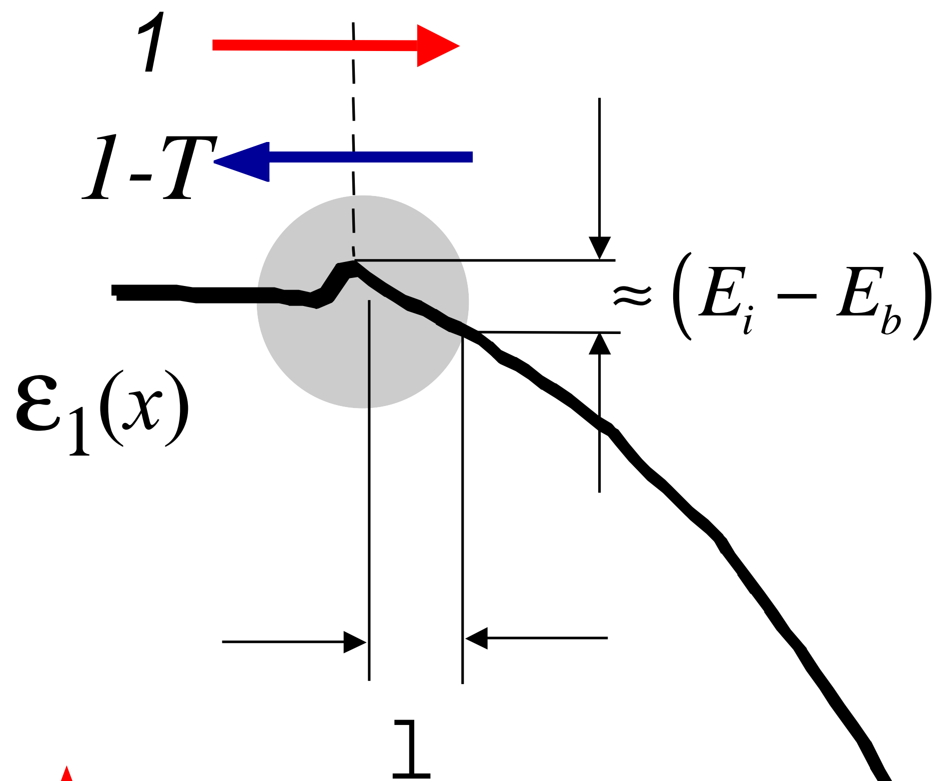


$P(x_1)$: probability of returning to the source after scattering first at x_1

$x_1 < \ell$ $P(x_1)$ large

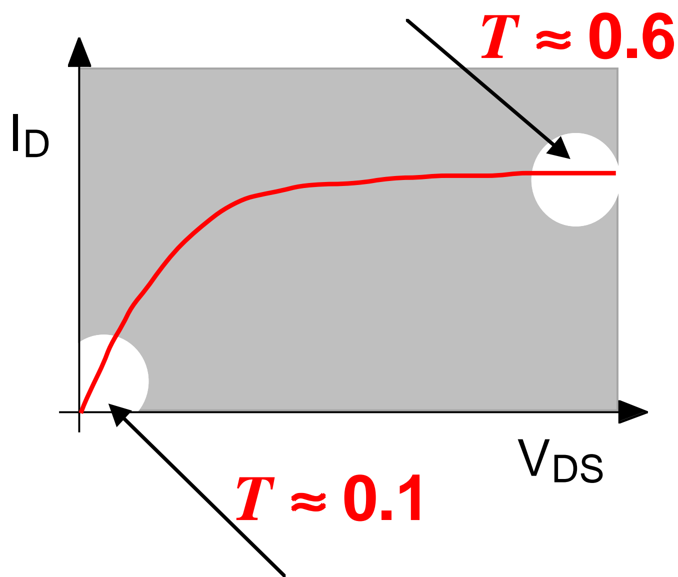
$x_1 > \ell$ $P(x_1)$ small

$$qV(\ell) \approx (E_i - E_b)$$

$$T \approx \frac{\lambda_o}{\ell + \lambda_o}$$

mobility is important for nanoscale FETs

$$I_D = W\,C_{ox}\upsilon_T\left(\frac{T}{2-T}\right)\left(V_{GS}-V_T\right)$$



$$I_D = W\,C_{ox}\left(\frac{\upsilon_T/2}{k_BT/q}\right)T\left(V_{GS}-V_T\right)V_{DS}$$

$$I_{DS} = W\,C_{ox}\left(V_{GS}-V_T\right)\tilde{\upsilon}_T\left(\frac{T}{2-T}\right)\times$$

$$\left\{\frac{1-\dfrac{F_{1/2}(\eta_F-U_{DS})}{F_{1/2}(\eta_F)}}{1+\left(\dfrac{T}{2-T}\right)\dfrac{\ln(1+e^{\eta_F-U_{DS}})}{\ln(1+e^{\eta_F})}}\right\}$$

$$T=\frac{\lambda_o}{1+\lambda_o}$$

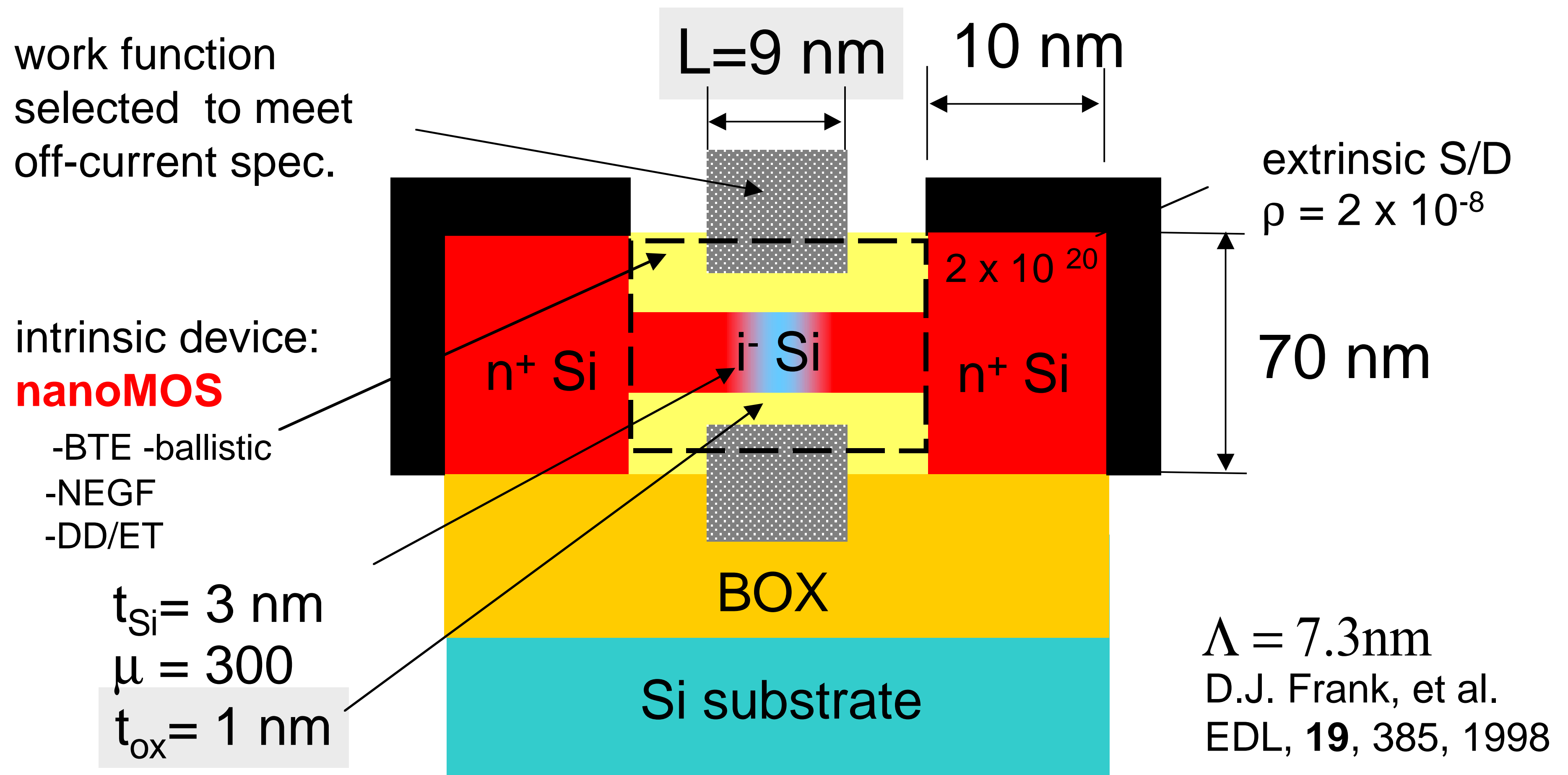
- scattering theory provides a clear picture of MOSFETs at the scaling limit:

  -source velocity is limited by thermal injection

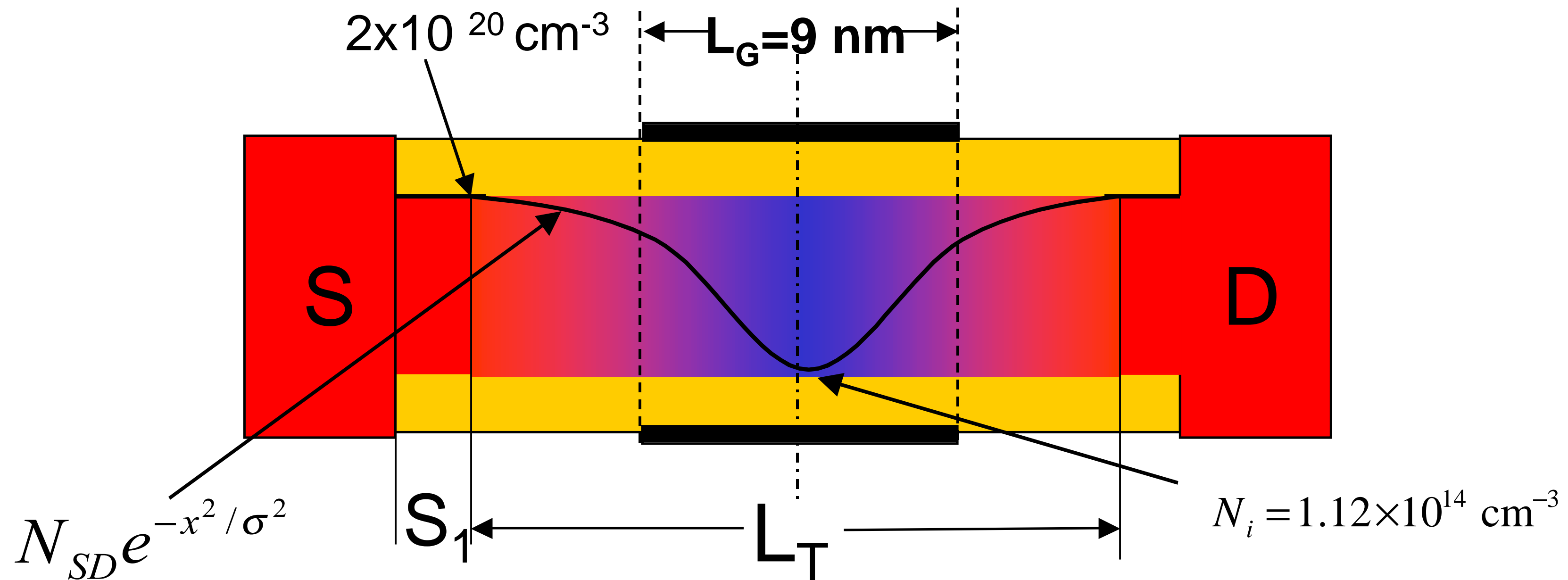
  -velocity saturation occurs at the source

  -the scattering that matters occurs near the source

  -"mobility" is relevant to nanoscale MOSFETs



Taichi Su, J.P.Denton, G.W.Neudeck, *IEEE International SOI Conf, Oct. 2000, pp. 110-111*



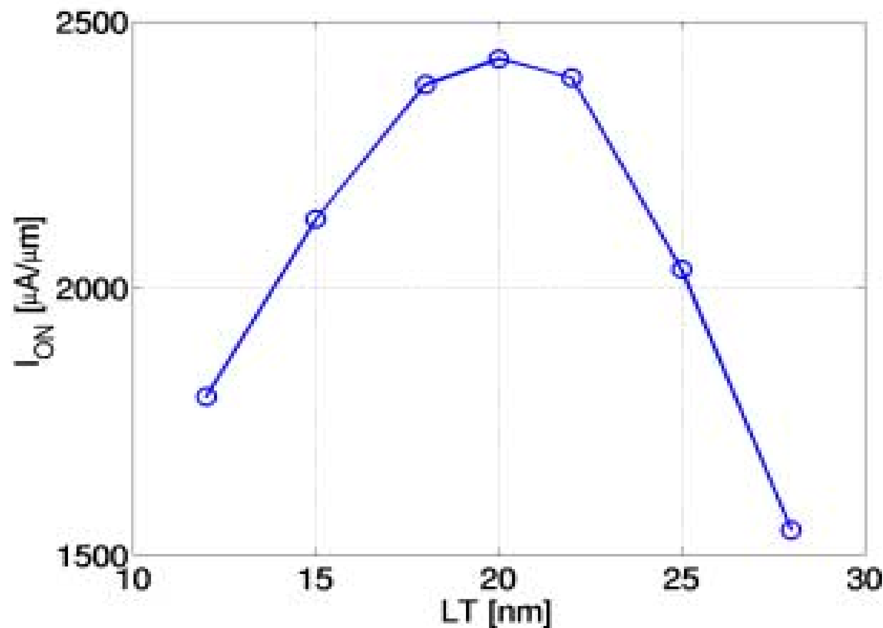
For a specified maximum doping, doping gradient, and I_{off}:

examine I_{on}, S, DIBL vs. L_T.

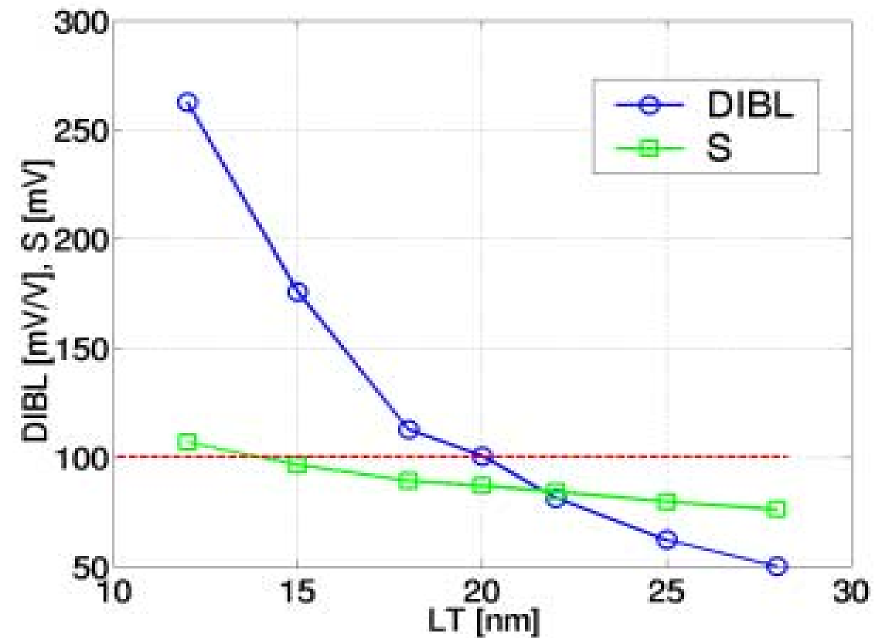
$$g \equiv \left| \frac{dx}{d\log_{10} N} \right|_{\text{at 1 dec point}} = 2\,\text{nm/dec}$$

$$\sigma = 2g\sqrt{\log_{10} e} = 2.64\text{nm}$$

Choose L_T to give the highest I_{ON} together with acceptable S and DIBL



I_{ON} vs. L_T, at I_{off} ~ 10uA/um

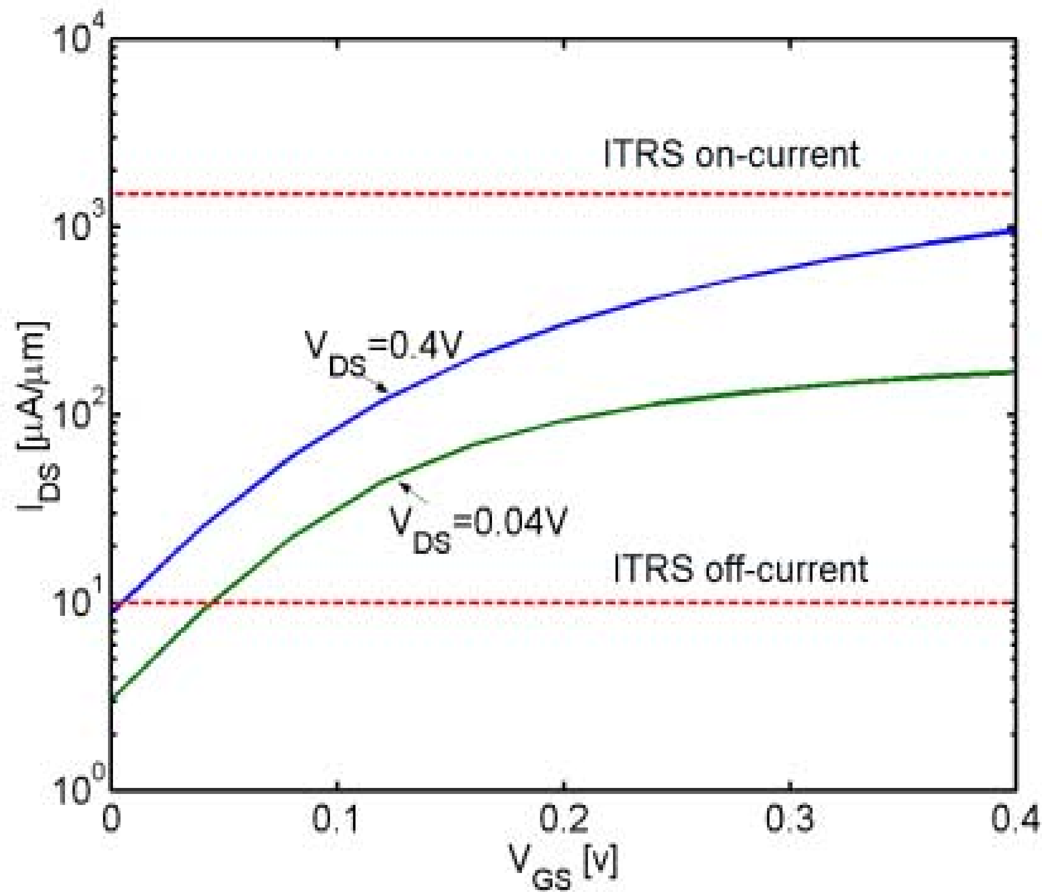


DIBL, S vs. L_T

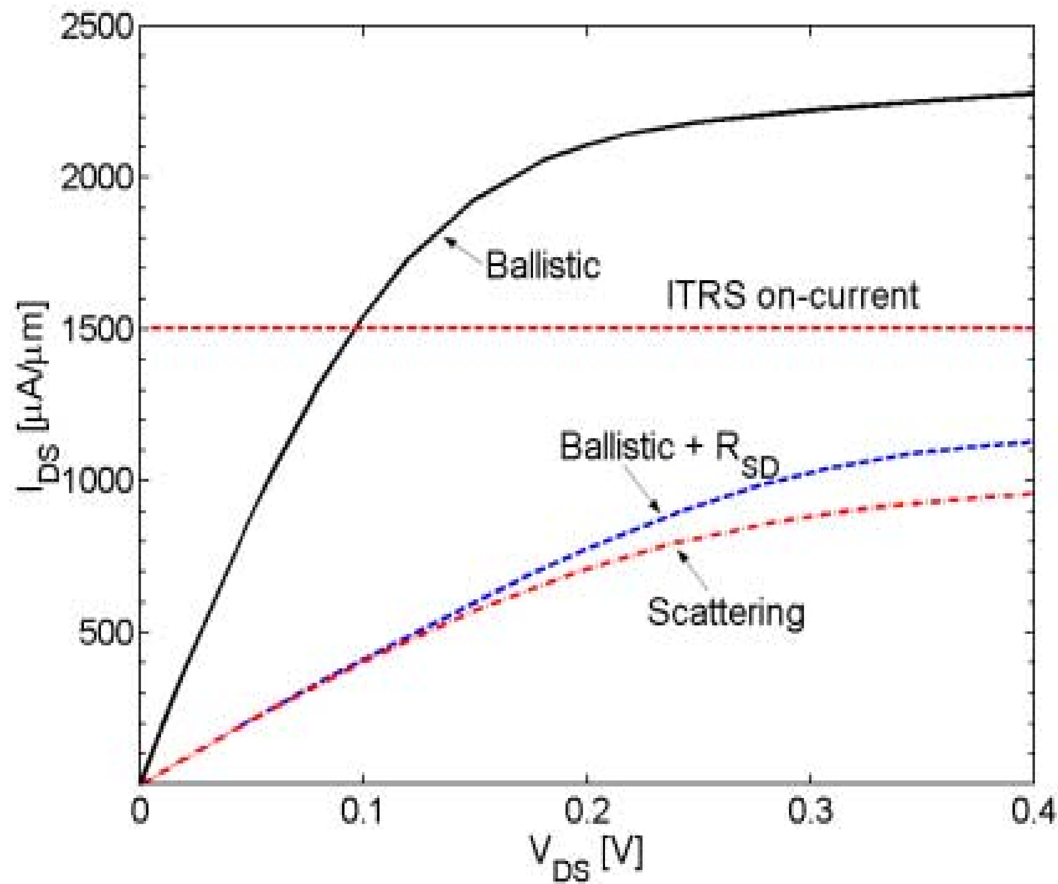
L_T=20nm is the optimized value! (Gate Work Function is 4.18eV.)

4. Design Issues for 10nm MOSFETs.....

a numerical study



	Value	ITRS
I_{on}(μA/μm)	**960**	1500
I_{off}(μA/μm)	9	10
DIBL(mV/V)	111	-----
S(mV/dec)	87	75
R_{SD} (Ω-μm)	**200**	80
V_{DD}/I_{on}	417	267
τ (ps)	0.16	0.15

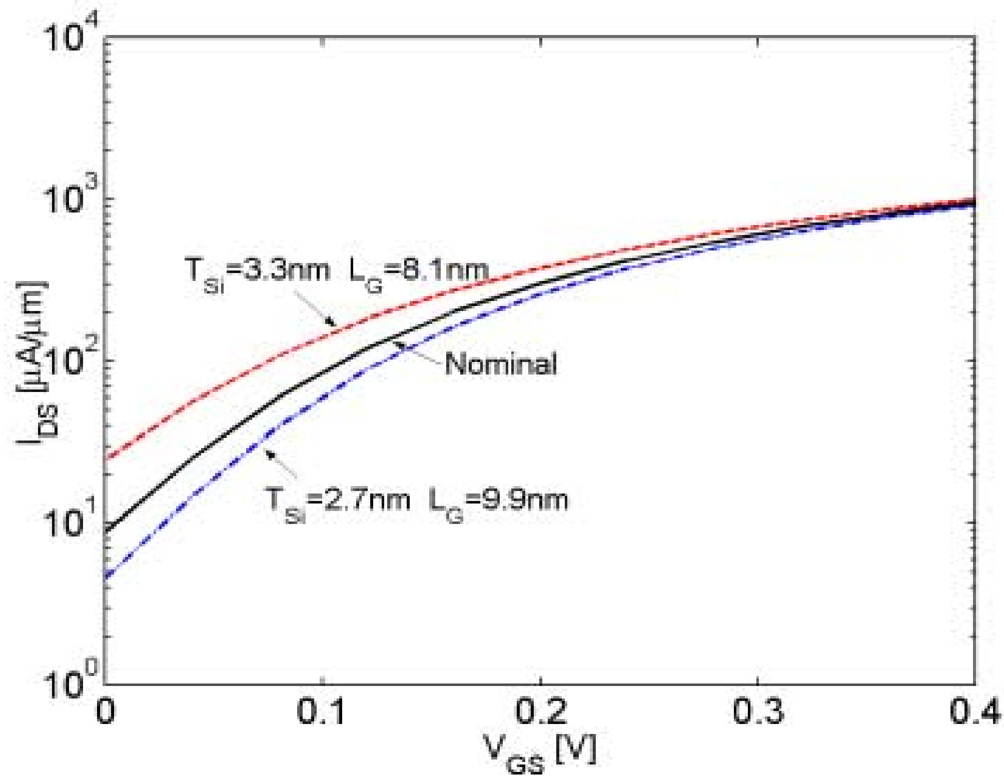


$$R_{SD} = 2\left(R_C + R_{ext}\right)$$

$$R_C \approx \frac{\rho_C}{A_C} = 25\,\Omega$$

$$R_{ext} \approx 25\,\Omega + 50\,\Omega$$

(tip)



$$T_{Si} = 3\text{ nm} \pm 0.3\text{ nm}$$

$$L_G = 9\text{ nm} \pm 0.9\text{ nm}$$

$$4.5 < I_{off} < 25\ \mu A/\mu m$$

$$920 < I_{on} < 1006\ \mu A/\mu m$$

$$40 < I_{on}/I_{off} < 205$$

$$I_D/W = Q_i(0)\langle \upsilon(0) \rangle$$

1) $Q_i(0)$:

fundamental limits:

source exhaustion: $Q_i/q \approx 6\times10^{13}\ \text{cm}^{-2} \quad (N_D\, t_{Si})$

insulator field $Q_i/q \approx 4\times10^{13}\ \text{cm}^{-2}$

practical limit:

$C_{eff}(V_{DD}-V_T)$ $Q_i/q \approx 0.8\times10^{13}\ \text{cm}^{-2}$

$C_{eff}(V_{DD}-V_T-I_DR_S)$ $Q_i/q \approx 0.5\times10^{13}\ \text{cm}^{-2}$

2) $<\upsilon(0)>$:

bandstructure, E_F limit: $\langle \upsilon(0) \rangle \approx 1.8\times10^{7}\ \text{cm/s}$

practical limit: (scattering) $\langle \upsilon(0) \rangle \approx 1.1\times10^{7}\ \text{cm/s}$

3) Result:

$$I_D(on) = q\left(0.5\times10^{13}\right)\left(1.2\times10^{7}\right) = 960\,\mu A/\mu m$$