$p = N_V e^{\frac{E_V-E_F}{KT}} = n_i e^{\frac{E_i-E_F}{KT}} = \frac{N_A-N_D}{2}+\sqrt{\left(\frac{N_A-N_D}{2}\right)^2+n_i^2}$ fm $p+N_D-n-N_A=0$ $\quad E_i = \frac{E_c+E_v}{2}+\frac{KT}{2}\bullet\ln\frac{N_v}{N_c} = \frac{E_c+E_v}{2}+\frac{3}{4}kT\bullet\ln\frac{m_p^*}{m_n^*}$

$n = N_c e^{\frac{E_F-E_c}{KT}} = n_i e^{\frac{E_F-E_i}{KT}} = \frac{N_D-N_A}{2}+\sqrt{\left(\frac{N_D-N_A}{2}\right)^2+n_i^2}$ $\quad \rho = \frac{1}{q(n\mu_n+p\mu_p)}, \frac{D}{\mu}=\frac{KT}{q}$ $\quad I = I_o\left(e^{\frac{qV_A}{KT}}-1\right), I_o \equiv qA\left(\frac{D_p n_i^2}{L_p N_D}+\frac{D_n n_i^2}{L_n N_A}\right)$ $\quad f(E)=\frac{1}{1+e^{\frac{E-E_F}{KT}}}$

$J_p = q\mu_p pE - qD_p\bullet\nabla p = -q\mu_p p\left(\frac{d\Psi_i}{dx}+\frac{KT}{qp}\frac{dp}{dx}\right) = -q\mu_p p\frac{d\phi_p}{dx} = \mu_p p\nabla E_{FP}$, $\quad \phi_p = \Psi_i + \frac{KT}{q}\ln\frac{p}{n_i}$, $\quad q(\phi_p-\Psi_i)=KT\ln\frac{p}{n_i}, p = n_i e^{\frac{E_i-E_{Fp}}{KT}}$

$J_n = q\mu_n nE + qD_n\bullet\nabla n = -q\mu_n n\left(\frac{d\Psi_i}{dx}-\frac{KT}{qn}\frac{dn}{dx}\right) = -q\mu_n n\frac{d\phi_n}{dx}=\mu_n n\nabla E_{FN}$, $\quad \phi_n = \Psi_i - \frac{KT}{q}\ln\frac{n}{n_i}$, $\quad -q(\phi_n-\Psi_i)=KT\ln\frac{n}{n_i}, n = n_i e^{\frac{E_{Fn}-E_i}{KT}}$

Continuity Equ: RG Statistics (low level inj) $np=n_i^2$ is only valid for within a single si, not for pn j

$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla J_n + \left.\frac{\partial n}{\partial t}\right|_{thermalRG} + \left.\frac{\partial n}{\partial t}\right|_{otherRG}$ $\quad \left.\frac{\partial n}{\partial t}\right|_{thermalRG} = -\frac{\Delta n}{\tau_n}, \tau_n = \frac{1}{C_n N_T}$ $\quad V_{BR} \propto \frac{N_A+N_D}{N_AN_D} \propto \frac{1}{N_B}$ for assym dope jn. N_B the low doped side

$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla J_p + \left.\frac{\partial p}{\partial t}\right|_{thermalRG} + \left.\frac{\partial p}{\partial t}\right|_{otherRG}$ $\quad \left.\frac{\partial p}{\partial t}\right|_{thermalRG} = -\frac{\Delta p}{\tau_p}, \tau_p = \frac{1}{C_p N_T}$ $\quad$ Poisson $\frac{dE}{dx} = -\frac{d^2\phi}{dx^2} = \frac{\rho(x)}{\varepsilon}, E = \int -qN_A dx = -qN_A x_p \to N_A x_p = N_D x_n$

$V = -\int Edx = \frac{1}{2}qN_A x_p^2 \to V_{bi} = \frac{q(N_A x_p^2+N_D x_n^2)}{2\varepsilon}$ get $X_n = \sqrt{\frac{2\varepsilon_o\varepsilon_{si}}{q}\left(\frac{N_A}{N_D(N_A+N_D)}\right)V_{bi}}, W=\sqrt{\frac{2\varepsilon_o\varepsilon_{si}}{q}\left(\frac{N_A+N_D}{N_AN_D}\right)V_{bi}} \Rightarrow \begin{matrix}V_{bi}-V_R\\V_{bi}+V_R\end{matrix}$ $\quad \begin{matrix}J = J_n(x)+J_p(x)\\ = J_n(-x_p)+J_p(x_n)\end{matrix}$

$qV_{bi} = (E_i-E_{Fp})+(E_{Fn}-E_i)\to V_{bi}=\frac{KT}{q}\ln\frac{N_DN_A}{n_i^2}, np = n_pp_p = n_np_n = n_i^2 e^{\frac{qV_A}{KT}}, \begin{matrix}V_A=V_F\\V_A=-V_R\end{matrix}$, $\quad \log Id\_Vg \to$ **carrier recomb in dep reg due to trap, hi lev inj, lo lev inj assump fail, Rs.**

Acc	Vg<Vfb	Φs<0	$V_g = V_{FB}+V_{ox}+\phi_s, V_{ox} = -\frac{Q_s}{C_{ox}}$	$Q_s = -C_{ox}(V_g-V_{FB}), \phi_s$ small.	$\frac{\varepsilon_{SiO2}}{EOT} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{\varepsilon_{di}}{d}$
FB	Vg=Vfb	=0	$V_g = V_{FB}$ $\quad Q_s = 0$	$\Downarrow E = \int\frac{-qN_A}{\varepsilon}dx = -\frac{qN_A}{\varepsilon}X_{dm}, V = \int -Edx = \frac{1}{2}\frac{qN_A}{\varepsilon}X_{dm}^2 = \phi_s \to W = \sqrt{\frac{2\varepsilon_{si}\phi_s}{qN_A}}$	
Depletion	Vg>Vfb	0<Φs<2Φb	$V_g = V_{FB}+\frac{\sqrt{2qN_A\varepsilon_{si}\phi_s}}{C_{ox}}+\phi_s$	$Q_s = Q_D = -qN_AW = -\sqrt{2qN_A\varepsilon_{si}\phi_s}$	$C_{si} = -\frac{\partial Q_s}{\partial\phi_s} = \sqrt{\frac{qN_A\varepsilon_{si}}{2\phi_s}}$
Thresh	Vg=Vth	=2Φb	$V_g = V_{FB}+\frac{\sqrt{2qN_A\varepsilon_{si}2\phi_b}}{C_{ox}}+2\phi_b = V_{th}$	$Q_s = Q_n+Q_D = Q_D = -\sqrt{2qN_A\varepsilon_{si}2\phi_b}, Qn\approx 0$	$W_m = \sqrt{\frac{2\varepsilon_{si}(2\phi_b)}{qN_A}}$
Inv	Vg>Vth	>2Φb	$V_g = V_{th}-\frac{Q_n}{C_{ox}}$	$Q_n = -C_{ox}(V_g-V_{th})$ $Q_s = Q_n+Q_D = -C_{ox}(V_g-V_{th})+Q_D$	

General Analysis: consider maj/min carrier,get low f CV. Depl approx→gd for hi f CV& deep depl, Not accu for C_{FB}. Not gd approx when W small. Abrupt tx fm 1 reg to another

$Q_{si} = \pm\sqrt{\frac{2q\varepsilon_{si}}{\beta}}\left[P_{po}\left(e^{-\beta\phi}+\beta\phi-1\right)+n_{po}\left(e^{\beta\phi}-\beta\phi-1\right)\right]^{\frac{1}{2}}, \beta = \frac{q}{KT} \to C_{si} \equiv \frac{\partial Q_{si}}{\partial\phi_s} = \ldots, C_{si,FB} = \frac{\varepsilon_{si}}{L_D}, L_D = \sqrt{\frac{\varepsilon_{si}}{qN_A\beta}}, C_{si,th(LF)} = \frac{2\varepsilon_{si}}{W_M}, C_{si,th(HF)} = \frac{\varepsilon_{si}}{W_M}$

Accum Φs<0	$P_{po}e^{-\frac{\beta\phi_s}{2}}$ dominant. $Q_{si}\propto e^{-\frac{\beta\phi_s}{2}}$	Qs<0	$C_T=C_{ox}$, C_{ox} alone.	Find N_A, $\frac{1}{C_{min}} = \frac{1}{C_{ox}}+\frac{1}{C_{s,min}} = \frac{1}{C_{ox}}+\frac{W_m}{\varepsilon_{si}} \Rightarrow W_m \Rightarrow N_A$
FB, Φs=0	Qsi=0		$\frac{C_T}{C_{ox}} = \frac{1}{1+C_{ox}\sqrt{\frac{2\phi_s}{qN_A\varepsilon_{si}}}}$	Find V_{FB}, $\Rightarrow L_D \Rightarrow C_{s,FB} = \frac{\varepsilon_{si}}{L_D} \Rightarrow \frac{1}{C_{FB}} = \frac{1}{C_{ox}}+\frac{1}{C_{s,FB}} \Rightarrow V_{FB}$
Depletion 0<Φs<2Φb	$P_{po}>n_{po}$, $\beta\phi_s >> e^{-\beta\phi_s}$, $Q_{si}\propto\sqrt{2q\varepsilon_{si}N_A\phi_s}$ C_{ox} in series with C_d	Qs>0		Meas Qit→donor like, <midgap, fill neutral, empty pos. Acce like, >midgap, fill neg, empty neutral. || **Stretchout in CV** due to Qit→ When Φs<0,Vg swept into neg. Pos Q fm empty donorlike i/f state
Inversion Φs>2Φb	$n_{po}e^{\beta\phi}$ dominant. $Q_{si}\propto e^{\frac{\beta\phi_s}{2}}$	Qs>0	$\frac{C_T}{C_{ox}} = \frac{1}{1+C_{ox}\sqrt{\frac{2(2\phi_b)}{qN_A\varepsilon_{si}}}}$	abv EF, neg CV sh, $\Delta V = \frac{-q}{C_i}\int_{\phi_s}^{0}D_{it}(\phi)d\phi, for\ \phi_s<0$

HF&LF CV →assume Cit can't resp fast (but actually not)→get Cit. Interface trap density, $D_{it} = \frac{1}{q}\frac{dN_{it}}{dE} = \frac{1}{q}\frac{dQ_{it}}{(-\phi_s)} = \frac{1}{q}C_{it}, C_{it} = -\frac{dQ_{it}}{d\phi_s}$,need to find Φs as a fn of Vg.

V_{FB} shift due to oxide charges. $\Delta V_{FB} = x_1\xi_{ox} = -\frac{x_1}{\varepsilon_{ox}}Q_{ox}, \{x_1 = 0..t_{ox}\} = -\frac{1}{C_{ox}t_{ox}}\int_0^{x1}x\rho(x)dx$,ΔV_{FB} max when x1=t_{ox}. $V_{th} = \ldots-\frac{Q_f}{C_{ox}}\{fix\_c\}+\Delta V_{FB}\{oxide\_c\}$

Meas Qf →Ideal CV (no Qf) & Meas CV (have Qf) → $Q_f = qN_f = \Delta V_{FB}C_{ox}$,from VFB vs EOT plot $V_{FB} = \phi_{MS}-\frac{Q_F t_{ox}}{\varepsilon_{ox}}$

Meas Qm→E>1MV/cm,300°C,15min,cool get left curve VG+→then VG-. $Q_m = qN_m = (V_{FB-}-V_{FB+})C_{ox} = \Delta V_{FB}C_{ox}$

	Tran	Long	Vert		
				Barrier height → dielectric side, neg Q for Ef<Φcnl,pos Q for Ef>Φcnl	nmos Φm~Ec, easy oxided
pfet	T	C	T	$\phi_b = S(\phi_{m,vac}-\phi_{cnl})+\phi_{cnl}-\chi_s \to \phi_{m,eff} = \phi_b+\chi_s = S\phi_{m,vac}+(1-S)\phi_{cnl} = \phi_{cnl}+S(\phi_{m,vac}-\phi_{cnl})$	pmos Φm~Ev, etching prob
nfet	T	T	C		xtal orient, diff repredicible Φm.

$q\phi \equiv E_{i,bulk}-E_{i,x}$,On-set of inv→ $n_s = \frac{n_i^2}{N_A}e^{\frac{E_i-E_F}{KT}} = \frac{n_i^2}{N_A}e^{\frac{q2\phi_B}{KT}} = N_A \to \frac{N_A}{n_i} = e^{\frac{q\phi_B}{KT}}$ $\quad$ *To* **reduce GIDL,** $\mathbf{T_{ox}}\uparrow E\downarrow, LDD, Trap\downarrow$ $\quad q\phi_s \equiv E_{i,bulk}-E_{i,surf}$, $\phi_b = \frac{KT}{q}\ln\frac{N_A}{n_i}, p\_type$

$n(x,y)=n(\Psi,V)=\frac{n_i^2}{N_A}e^{\frac{q(\Psi-V)}{KT}}, n(x)=\frac{n_i^2}{N_A}e^{\frac{q\Psi}{KT}}=n_i e^{\frac{q(\Psi-\Psi_B)}{KT}}$ *Vth* **adj, if dopant & subs same type** $\Delta V_{th}=\frac{qD_i}{C_{ox}}, D_i\to\frac{atom}{cm^2}$ $q\phi_b\equiv E_{i,bulk}-E_F,\ \phi_b=-\frac{KT}{q}\ln\frac{N_D}{n_i}, n\_type$

$J_n(x,y)=-q\mu_n n(x,y)\frac{dV(y)}{dy}\to I_{ds}(y)=qW\int_0^{xi}\mu_n n(x,y)\frac{dV(y)}{dy}dx=qW\mu_{eff}\frac{dV(y)}{dy}\int_0^{xi}n(x,y)dx=-W\mu_{eff}\frac{dV(y)}{dy}Q_i(y)\to I_{ds}=\mu_{eff}\frac{W}{L}\int_0^{V_{ds}}-Q_i(V)dV$

PaoSah $Q_i(V)=-q\int_{\Psi_s}^{\Psi_B}n(\Psi,V)\frac{dx}{d\Psi}d\Psi=-q\int_{\Psi_B}^{\Psi_s}\frac{n(\Psi,V)}{E(\Psi,V)}d\Psi$ **sqr law → bulk Q const, more inv Q, predict hi cur** **PaoSah → accu, auto - tx, numeric**
bulk Q model → bulk Q non - const, more.less inv Q Q sh → 0inv layer, large err in weak inv

Charge sheet $I_d(y)=\mu W(-Q_i)\frac{d\Psi_s}{dy}+W\mu\frac{KT}{q}\frac{dQ_i}{dy}, I_d=W\left[\int_0^{xi}q\mu_n n(x,y)\frac{d\Psi}{dy}dx-\frac{KT}{q}\mu_n\frac{\partial}{\partial y}\int_0^{xi}qn(x,y)dx\right]=\frac{W}{L}\mu_n\left[\int_{\Psi_{surf0}}^{\Psi_{surfL}}-Q_i d\Psi_s+\frac{KT}{q}\int_{Q_{i0}}^{Q_{iL}}dQ_i\right]$

Var dep charge, bulk charge, $V(y)\neq0$, $Q_d=-\sqrt{2qN_A\varepsilon_{si}\Psi_s(y)}, Q_s=-C_{ox}(V_g-V_{fb}-\Psi_s(y)), \Psi_s(y)=2\Psi_B+V(y)\to Q_i=Q_s-Q_d$

Sqr law,1order $Q_b(y)=-\sqrt{2qN_A\varepsilon_{si}\Psi_s(y)}=-C_{ox}\gamma\sqrt{\Psi_s(y)}=-C_{ox}\gamma\sqrt{2\Psi_B}$ **v(y) = 0for bulk only**, $\gamma=\frac{\sqrt{2q\varepsilon_{si}\varepsilon_o N_A}}{C_{ox}}\to Q_i(y)=-C_{ox}(V_{gs}-V_{fb}-2\Psi_B-V(y))-Q_b(y)$

$=-C_{ox}[V_{gs}-V_{th}-V(y)], V_{th}=V_{fb}+2\Psi_B+\gamma\sqrt{2\Psi_B}, V_{fb}=\phi_{ms}-\frac{Q_f}{C_{ox}}\to I_{ds}=\mu_{eff}C_{ox}\frac{W}{L}\left[V_{gs}-V_{th}-\frac{V_{ds}}{2}\right]V_{ds}, \beta=k\frac{W}{L}=\mu_{eff}C_{ox}\frac{W}{L}, th\ \frac{dI_{ds}}{dV_{ds}}=0\to I_{dsat}=\frac{\beta}{2}(V_{gs}-V_{th})^2$

CLM $(L-l_d)I_{ds}=LI_{dsat}, I_{ds}\approx I_{dsat}\left(1+\frac{l_d}{L}\right)=I_{dsat}(1+\lambda V_{ds})$

subs bias $V_{th}=V_{fb}+2\Psi_B+\frac{\sqrt{2q\varepsilon_{si}\varepsilon_o N_A(2\Psi_B+V_{bs})}}{C_{ox}}=V_{fb}+2\Psi_B+\gamma\sqrt{2\Psi_B+V_{bs}}, \Delta V_{th}=\gamma\sqrt{2\Psi_B+V_{bs}}-\gamma\sqrt{2\Psi_B}, \frac{dV_{th}}{dV_{bs}}=\frac{\gamma}{2\sqrt{2\Psi_B+V_{bs}}}$

Sub-th cur $I_{ds}=\mu_{eff}\frac{W}{L}\frac{KT}{q}\int_{Q_i(y=0)}^{Q_i(y=L)}dQ_i=\frac{\mu_{eff}}{2}\frac{W}{L}\frac{C_{ox}\gamma}{\sqrt{\Psi_{s0}}}\left(\frac{KT}{q}\right)^2\left(\frac{n_i}{N_A}\right)^2 e^{\frac{q\Psi_{s0}}{KT}}\left(1-e^{\frac{-qV_{ds}}{KT}}\right)\propto\left(1-e^{\frac{-qV_{ds}}{KT}}\right), V_g=V_{fb}+\Psi_{s0}+\frac{\sqrt{2q\varepsilon_{si}\varepsilon_o N_A\Psi_{s0}}}{C_{ox}}$, *fm* **Vg get Ψ_{s0} get I_{ds}**

Sub-th swing $C_d\equiv\frac{\partial Q_b}{\partial\Psi_s}=\frac{\gamma C_{ox}}{2\sqrt{\Psi_s}}, \Psi_s-2\Psi_B=\frac{V_{gs}-V_{th}}{\eta}, \eta=1+\frac{C_d}{C_{ox}}+\frac{C_{it}}{C_{ox}}, I_{ds}=I_{pf}e^{\frac{q(V_{gs}-V_{th})}{\eta KT}}\left(1-e^{\frac{-qV_{ds}}{KT}}\right), I_{pf}=\beta\frac{C_d}{C_{ox}}\left(\frac{KT}{q}\right)^2, S_t=\left(\frac{d\log I_d}{dV_{gs}}\right)^{-1}=\frac{2.3KT}{q}\eta$

Off cur $I_{ds}(V_{gs}=0)\approx\mu_{eff}\frac{W}{L}\left(\frac{KT}{q}\right)^2 e^{\frac{-qV_{th}}{\eta KT}}$ T dep $V_{th}=\left(-\frac{E_g}{2q}-\Psi_B\right)+2\Psi_B+\frac{\sqrt{2q\varepsilon_{si}\varepsilon_o N_A(2\Psi_B)}}{C_{ox}}$ **n + poly → nmos** **p + poly → pmos** $\frac{dV_{th}}{dT}=\frac{d\phi_{ms}}{dT}+\frac{d\Psi_B}{dT}\left(2+\frac{\sqrt{\varepsilon_{si}qN_A}}{C_{ox}\sqrt{\Psi_B}}\right)$

Charg Sharing → $Q_b=qN_bX_{dm}$ → Xj↑,tox↑,Nb↓Xdm↑, Vds↑Xdd↑, ΔVth is larger. To red DIBL, L↑,Vds↓

$F_l=\frac{L+L'}{2L}=\frac{L+(L-2X_c)}{2L}, X_c=X_j\left(\sqrt{1+\frac{2X_{dm}}{X_j}}-1\right), Q_b'=qN_bX_{dm}\left(\frac{L+L'}{2L}\right)=qN_bX_{dm}\left[1-\frac{X_j}{L}\left(\sqrt{1+\frac{2X_{dm}}{X_j}}-1\right)\right]=qN_bX_{dm}F_l=\gamma C_{ox}F_l\sqrt{\phi_f+V_{sb}}$

$\Delta V_{th}=V_{th,lc}-V_{th,sc}=\frac{\Delta Q_b}{C_{ox}}=\frac{Q_b}{C_{ox}}(1-F_l), V_{th,sc}=V_{fb}+2\phi_f+\gamma F_l\sqrt{2\phi_f+V_{sb}}=V_{fb}+2\phi_f+\gamma\sqrt{2\phi_f+V_{sb}}-\frac{\Delta Q_b}{C_{ox}}$ DIBL $V_{th}(V_{ds})=V_{th0}-\sigma V_{ds}, \sigma=\frac{\varepsilon_o\varepsilon_{si}(\sigma_0+\sigma_1V_{sb})}{\pi C_{ox}L^m}$

Narrow Width eff $\Delta V_{th}=\frac{Q_T}{C_T}-\frac{Q_b}{C_{ox}}=\frac{Q_b+2Q_{tap}+2Q_{fox}}{C_{ox}+2n_1C_{tap}+2n_2C_{fox}}-\frac{Q_b}{C_{ox}}=0\ ideal$, Small geo eff $\Delta V_{th}=-\frac{\Delta Q_l}{C_{ox}}+\frac{\Delta Q_W}{C_{ox}}$ to red DIBL, g more ctrl of Φb. tox↓Nb↑Xj↓L↑

Ch Mob $\frac{1}{\mu_s}=\frac{1}{\mu_{ph}}+\frac{1}{\mu_c}+\frac{1}{\mu_{sr}}, \mu_{eff}=\frac{\int_0^{xi}\mu_n n(x)dx}{\int_0^{xi}n(x)dx}, \xi_{eff}\equiv\frac{\xi_{x1}+\xi_{x2}}{2}=\frac{1}{2}\left(\frac{Q_D+Q_N}{\varepsilon_o\varepsilon_{si}}+\frac{Q_D}{\varepsilon_o\varepsilon_{si}}\right)=\frac{1}{\varepsilon_o\varepsilon_{si}}\left(Q_D+\frac{Q_N}{2}\right)for\_e=\frac{1}{\varepsilon_o\varepsilon_{si}}\left(Q_D+\frac{Q_N}{3}\right)for\_h$

$\mu_s=\frac{\mu_o}{1+\theta_1\xi_{eff}^{0.3}+\theta_2\xi_{eff}^m}, m=2\ for\_e=1\ for\_h, \mu_s=\frac{\mu_o}{1+\theta(V_{gs}-V_{th})}$ Velo Sat $v=\mu_{eff}\xi_y/\left[1+\left(\frac{\xi_y}{\xi_{sat}}\right)^n\right]^{\frac{1}{n}}$ $n=2e$, $n=1h$, $v=\frac{\mu_{eff}\xi_y}{1+(\xi_y/\xi_{sat})}$, *use piecewise* **but** $\xi_{sat}=2v_{sat}/\mu_{eff}$

Id in sh ch $I_{ds}(y)=-WQ_i(y)v=-WQ_i(y)\frac{\mu_{eff}\xi_y}{1+\frac{\xi_y}{\xi_{sat}}}, I_{ds}=\frac{-\mu_{eff}\frac{W}{L}\int_0^{V_{ds}}Q_i(y)dV}{1+\frac{1}{\xi_{sat}}\frac{V_{ds}}{L}}=\frac{std\ \mathbf{I_{triod}}}{1+\frac{1}{\xi_{sat}}\frac{V_{ds}}{L}}, \int_0^{V_{ds}}Q_i(y)dV=\int_0^{V_{ds}}-C_{ox}(V_{gs}-V_{th}-V)dV$ *no* **y var of Qb over est** $\mu_{eff,S}<\mu_{eff,D}$, *under* **est**

Rm T $\xi^{-1/3}$→acoustic phonon sc, ξ^{-2}→surf rough sc, Lo T ξ^{-2} clear→phonon sc negl, lo E, μc domi, hi E, surf rough sc domi. $\xi^{-1/3}$ not clear, lo T, phonon sc negl.

Idsat&Vdsat $I_{ds}(y)=-WQ_i(y)v, I_{d,sat}=v_{sat}WC_{ox}(V_{gs}-V_{th}-V_{d,sat}), V_{d,sat}=\frac{\xi_{sat}LV_g'}{\xi_{sat}L+V_g'}=V_g'-\frac{V_g'^2}{\xi_{sat}L+V_g'}, I_{d,sat}=v_{sat}WC_{ox}\frac{V_g'^2}{\xi_{sat}L+V_g'}$

$L\to\infty, I_{d,sat}=\frac{v_{sat}}{\xi_{sat}}\frac{W}{L}C_{ox}V_g'^2=long\_ch, L\to0, I_{d,sat}=v_{sat}WC_{ox}V_g'$,

$W_{dm}\propto\sqrt{\frac{V_{dd}}{N_{sub}}}$ const field N_A↑k const v N_A↑k^2. C∝A/d, inv c per dev, Q_i=CV, inv c dens per dev, Q_i=CV/A, I=WQ_iμξ, v=μξ, τ=(V/I)C

Vel sat $\xi_{max}=-\sqrt{\left(\frac{V_{ds}-V_{d,sat}}{l}\right)^2+\xi_{sat}^2}=-\frac{V_{ds}-V_{d,sat}}{l}$ **l → eff len vel sat reg** **if l very small**, $l=\sqrt{3t_{ox}x_j}\xrightarrow{2D}0.22x_j^{\frac{1}{2}}t_{ox}^{\frac{1}{3}}$ Subs I $I_{sub}\approx2I_{ds}e^{\frac{-B_i}{\xi_m}}=2I_{ds}e^{\frac{+lB_i}{V_{ds}-V_{d,sat}}}\to\frac{I_{sub}}{I_{ds}}\propto e^{\frac{+lB_i}{V_{ds}-V_{d,sat}}}$

I_{sub} vs V_{gs}, ini rise→I_{ds} inc with V_{gs}, V_{gs}↑$V_{d,sat}$↑V_{ds}-V_{dsat}↓ξ_m↓   CHE,lucky e,V_{gs}=V_{ds}→Ig curve. DrainAHC,V_{gs}~½V_{ds}.SubsHE.2genHE→Subs h cur→EHP→2e to oxide.