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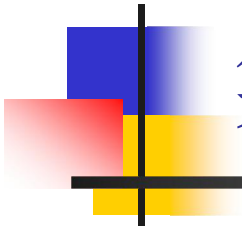

集成电路原理与设计

MOS器件

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长沟道MOS器件模型

- **3.1.1 MOS晶体管阈值电压分析**
- **3.1.2 MOS晶体管电流方程**
- **3.2.1 MOS晶体管的亚阈值电流**
- **3.2.2 MOS晶体管的瞬态特性**
- **3.2.3 MOS器件模型**

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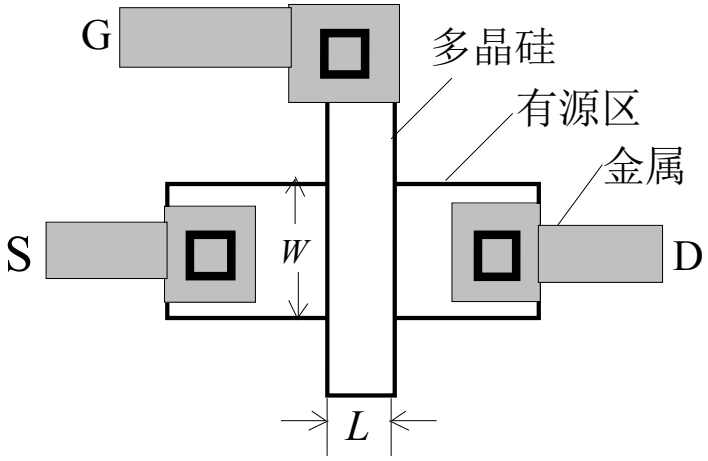
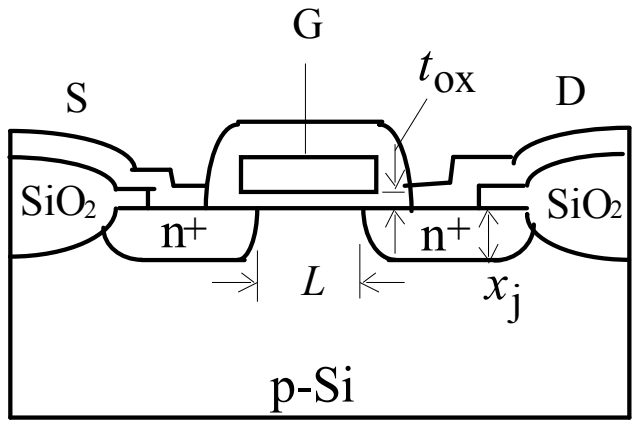
MOS晶体管的结构





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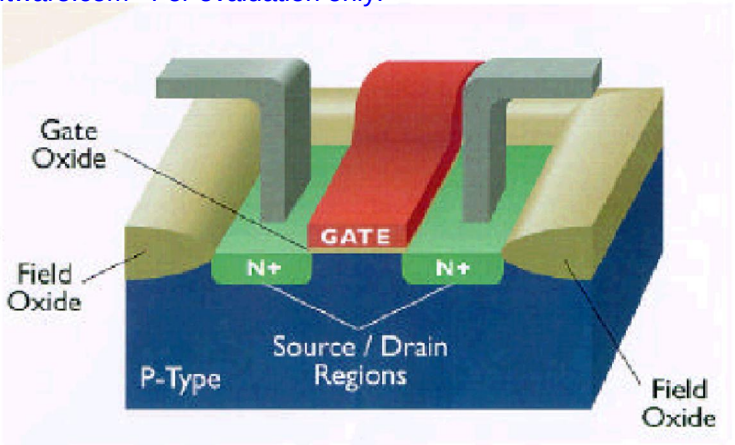
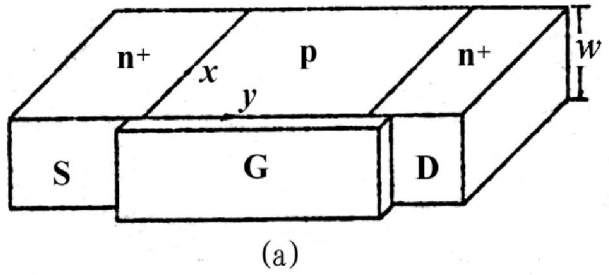
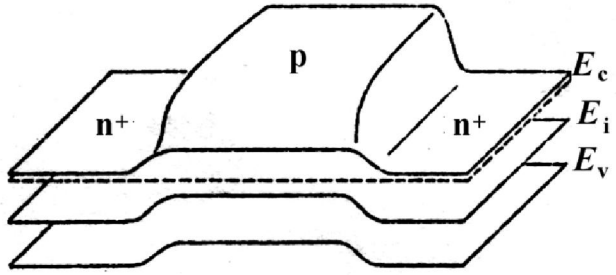
MOS晶体管工作原理





(a)



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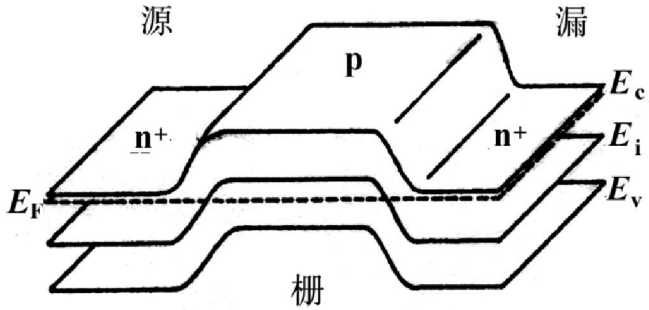

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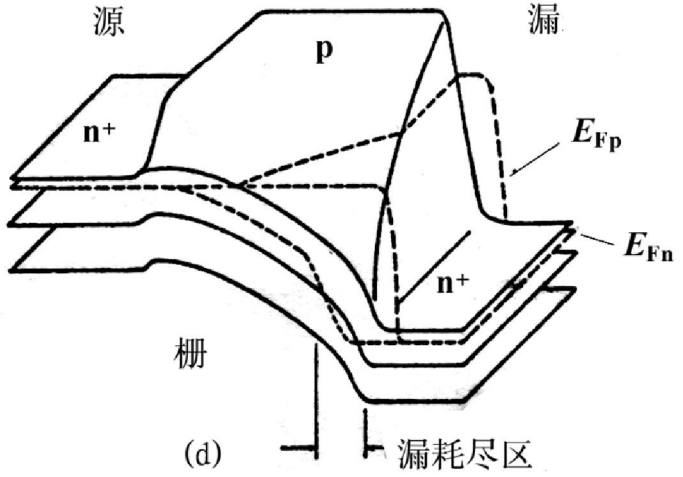

(d)

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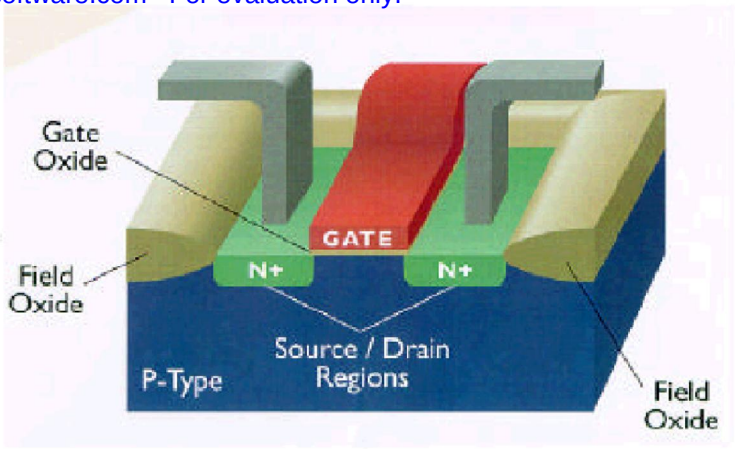
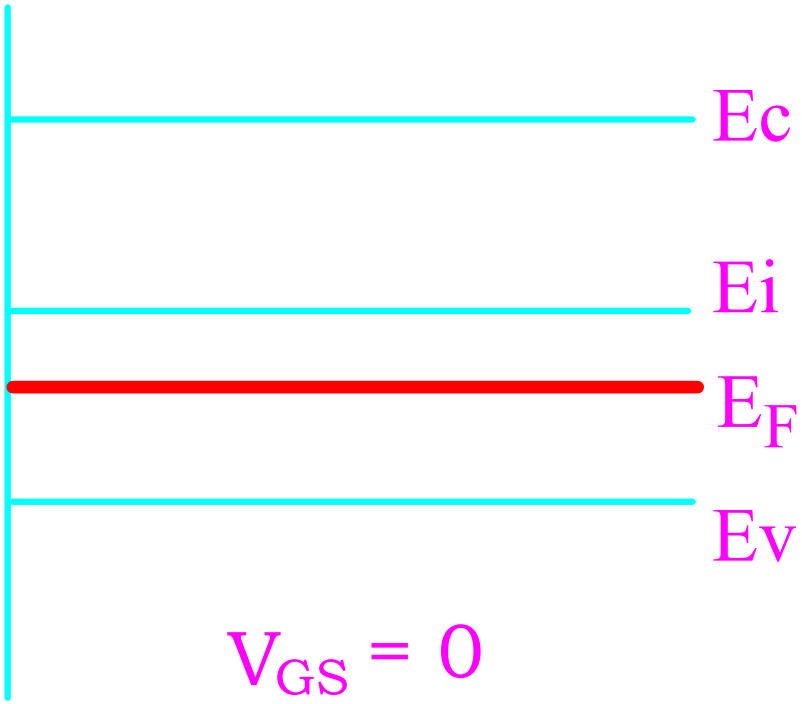
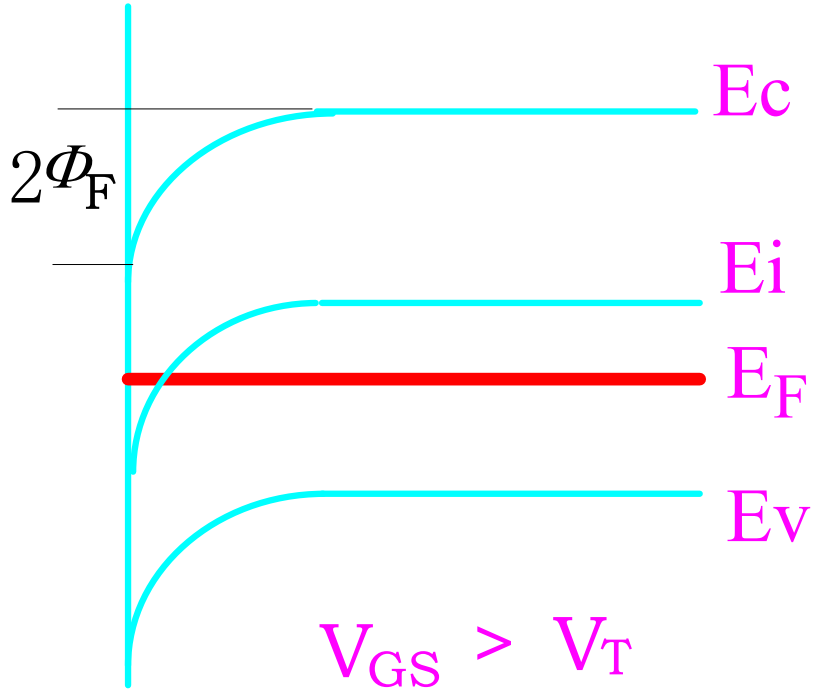
垂直方向能带图







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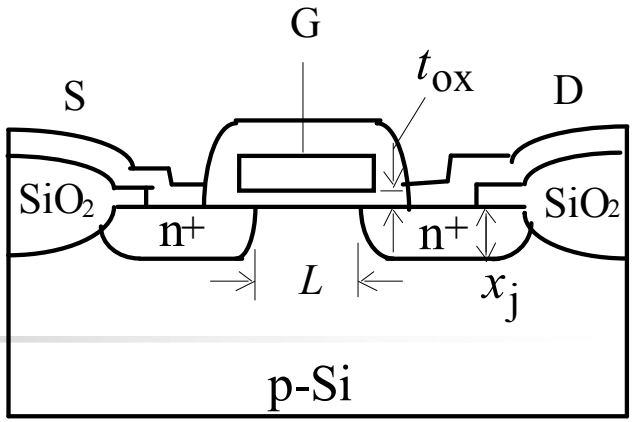
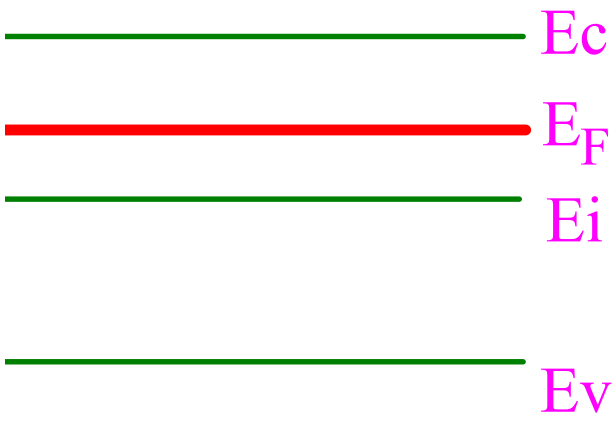
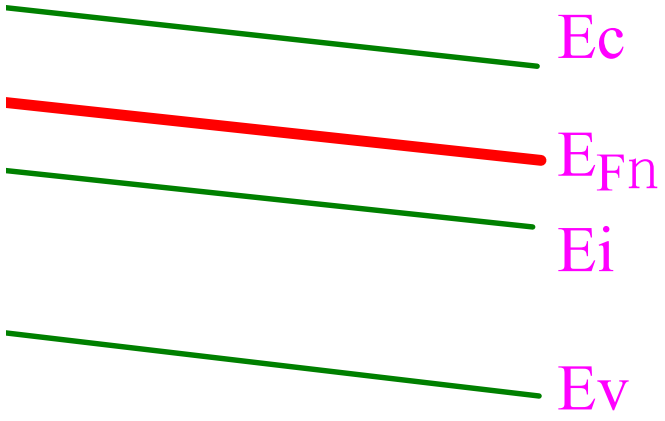
沿沟道方向能带图





$V_{DS} = 0$



$V_{DS} > 0$

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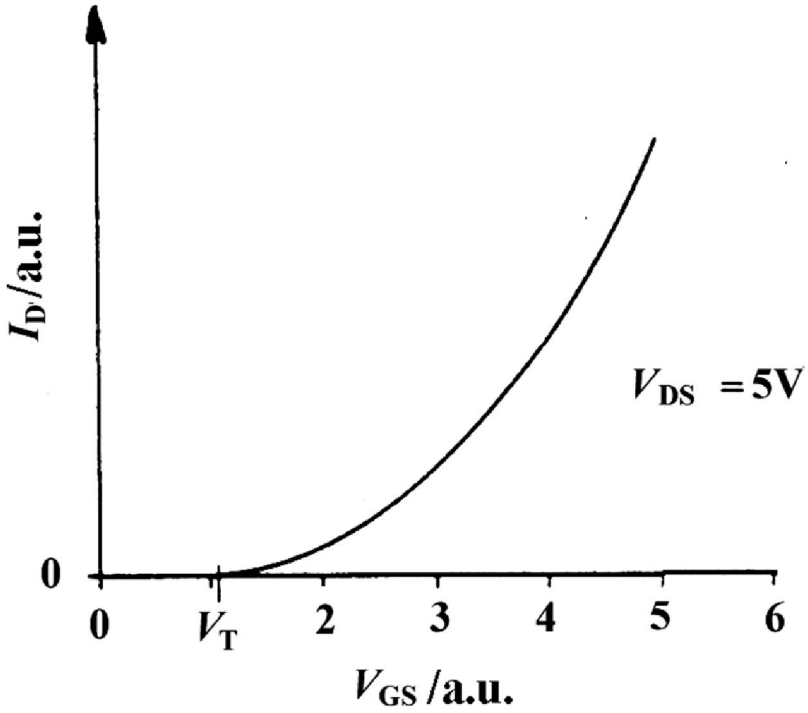
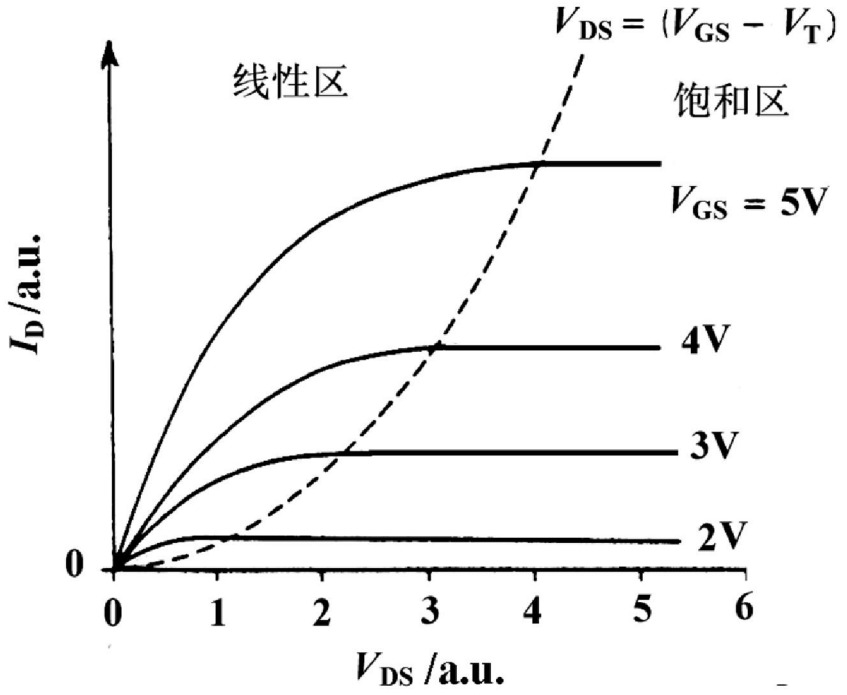
MOSFET的输入、输出特性曲线





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MOS晶体管阈值电压分析

阈值电压的定义：

使源端半导体表面达到强反型的栅压，是区分MOS器件导通和截止的分界点。

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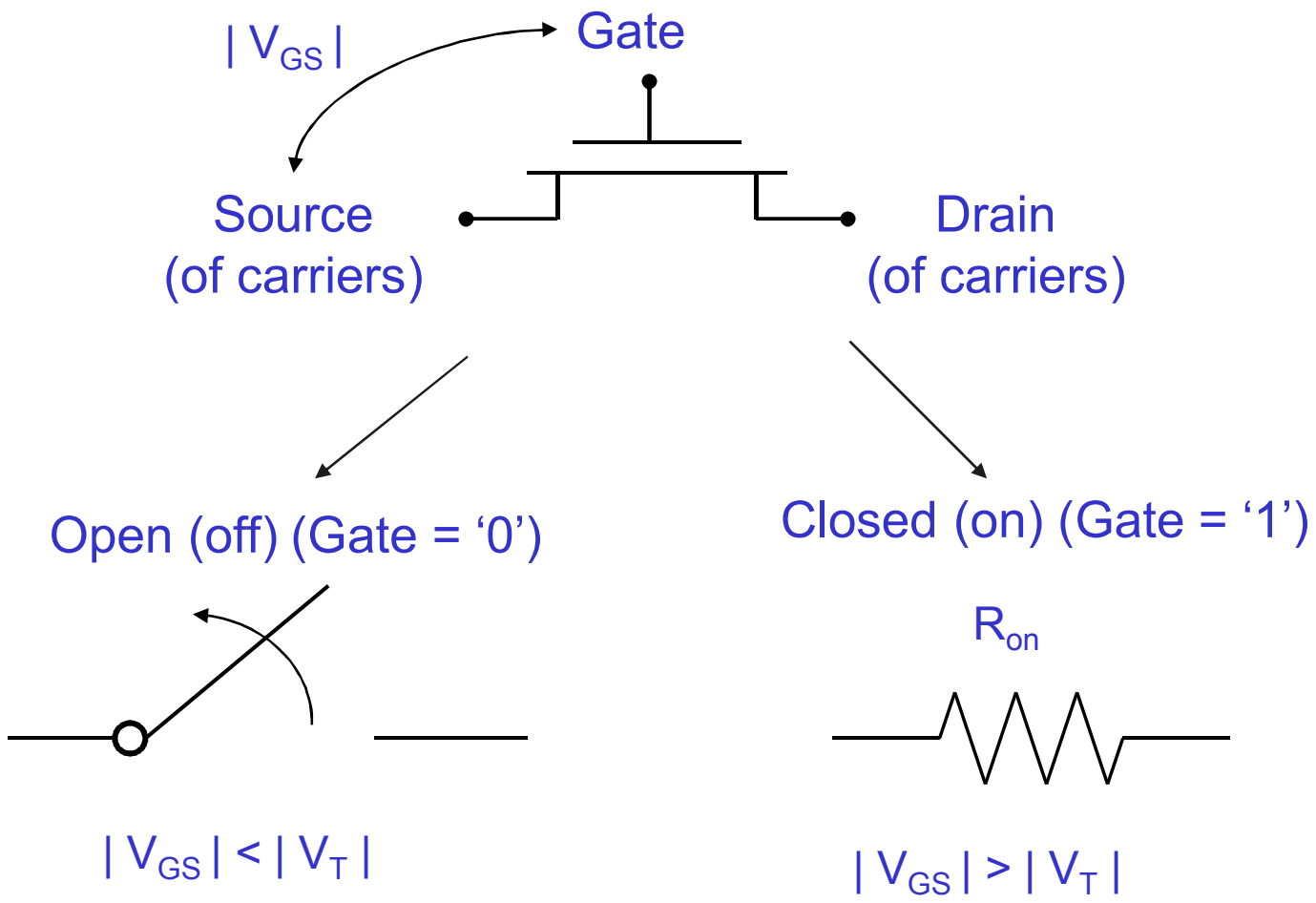
Switch Model of NMOS Transistor



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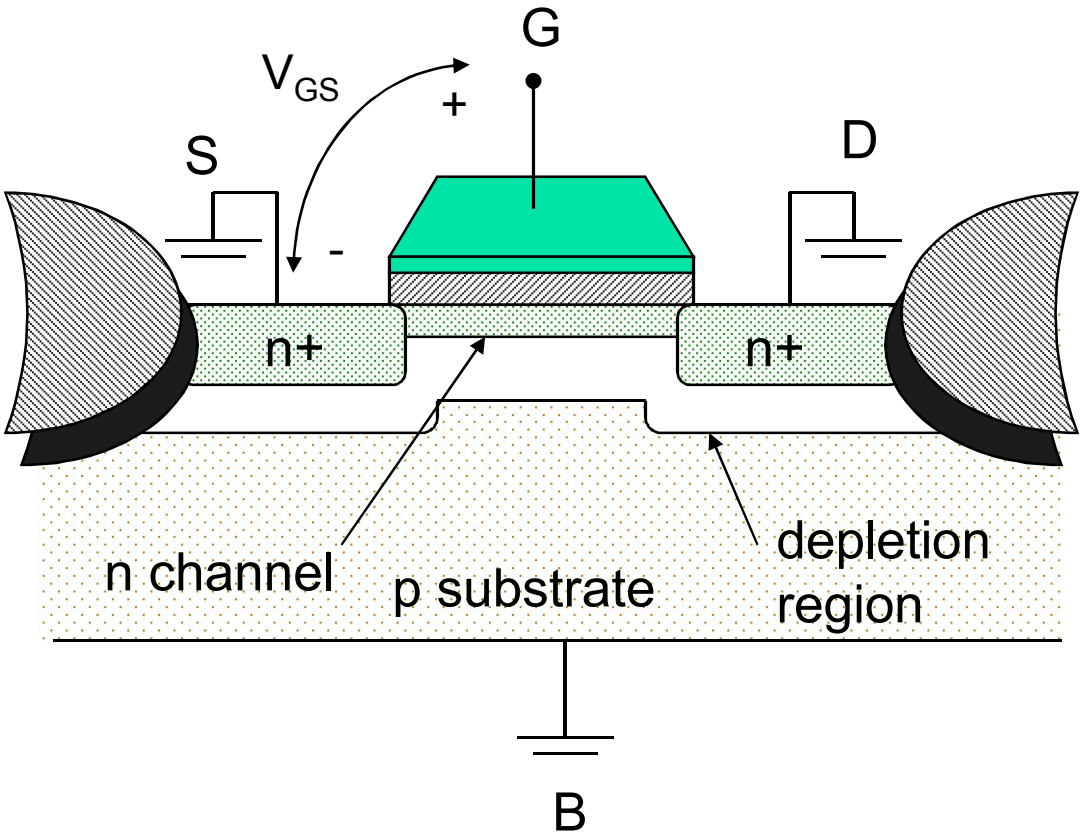
阈值电压

半导体表面达到强反型的栅压-- V_T



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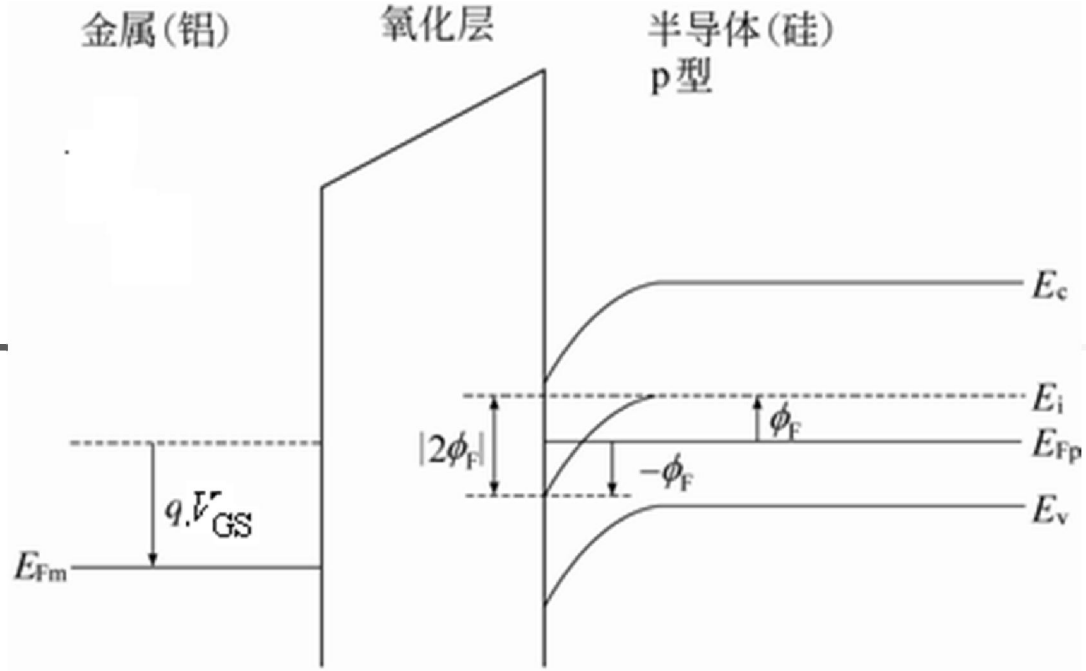

1、阈值电压公式(假设NMOS源端和衬底接地)

$$V_T = V_{FB} + V_{ox} + \varphi_s$$

V_{FB}对应半导体平带电压

V_{ox}对应栅氧化层上的压降

φ_s 对应半导体表面耗尽层上的压降

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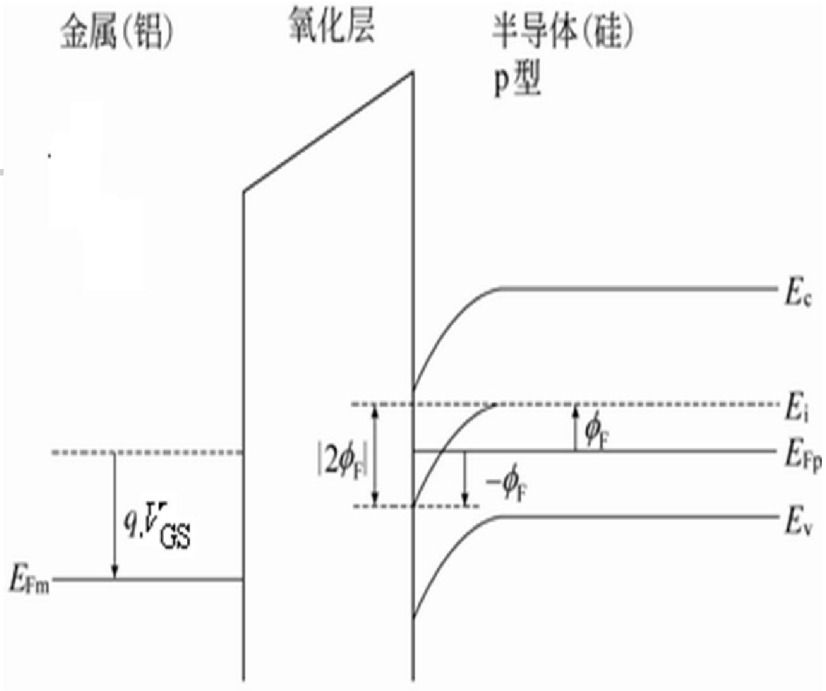
阈值电压：耗尽层压降—表面势

$$V_T = V_{FB} + V_{ox} + \varphi_s$$

$$V_T = V_{FB} + 2\varphi_F - \frac{Q_{Bm}}{C_{ox}}$$



φ_F 是衬底费米势

$$\varphi_F = (kT/q)\ln(N_A/n_i) \quad \text{(NMOS)}$$

$$\varphi_F = -(kT/q)\ln(N_D/n_i) \quad \text{(PMOS)}$$

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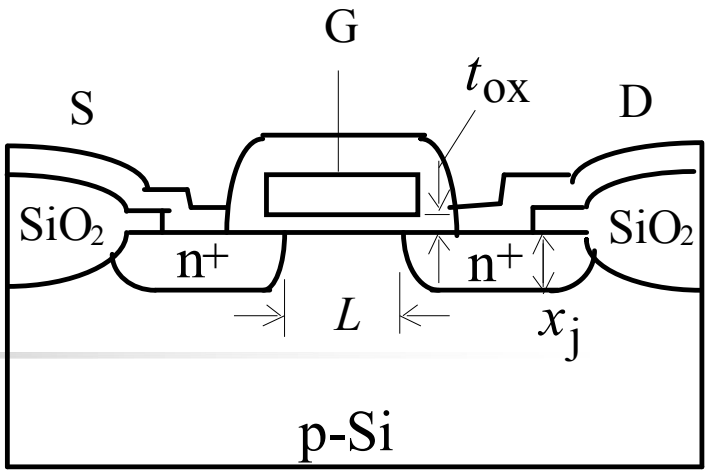
阈值电压：氧化层压降

$$V_T = V_{FB} + V_{ox} + \varphi_s$$



$$V_T = V_{FB} + 2\phi_F - \frac{Q_{Bm}}{C_{ox}}$$

Q_{BM}/C_{ox}对应栅氧化层上的压降（NMOS）

$$Q_{BM} = -[2\epsilon_0\epsilon_{Si}qN_A(2\ \phi_F)]^{1/2}$$

$$C_{ox} = \epsilon_0\epsilon_{ox}/t_{ox}$$

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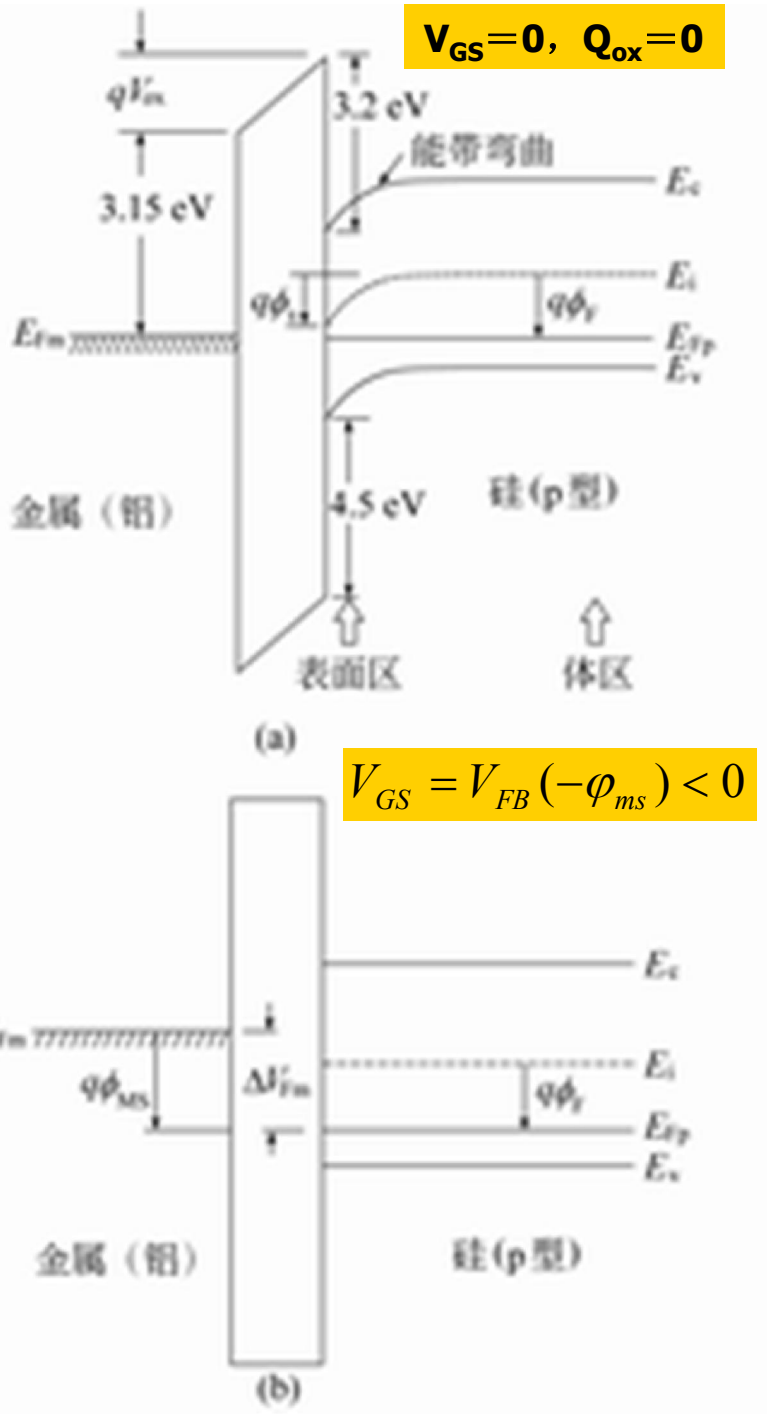
V_{FB}：半导体平带电压

$$V_T = V_{FB} + 2\phi_F - \frac{Q_{Bm}}{C_{ox}}$$

$$V_{FB} = \varphi_{MS} - \frac{Q_{ox}}{C_{ox}}$$

- 栅氧化层中的可动电荷和固定电荷以及界面态电荷
- 栅材料和硅衬底之间的功函数差
- 外加栅压抵消这部分能带弯曲，使得能带恢复平直，称为平带电压



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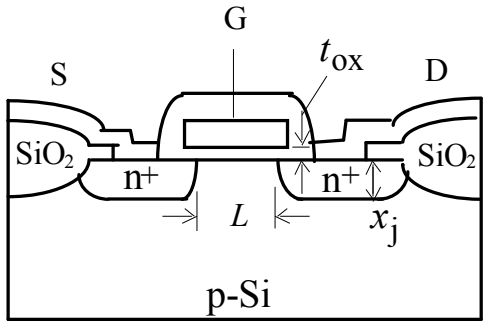
体效应对阈值电压的影响



- 假设衬底和源端等电位
- 如果衬底和源端之间有电压，阈值电压会发生变化，也称为衬偏效应

衬底偏压V_{BS}的影响

$$V_T = V_{FB} + 2\varphi_F + \gamma\sqrt{2\varphi_F - V_{BS}}$$

$$\gamma = \frac{\sqrt{2\varepsilon_0\varepsilon_{Si}qN_A}}{C_{ox}}$$

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衬底偏压V_{BS}对阈值影响

- **NMOS**器件一般加负的衬底偏压，即$V_{BS}<0$，保证源和衬底之间**pn**结反偏隔离
- 这样耗尽层展宽，阈值电压公式中耗尽层电荷增加，阈值电压增加

$$Q'_{Bm} = -\sqrt{2\varepsilon_0\varepsilon_{si}qN_A(2\phi_F - V_{BS})}$$

$$V_T = V_{FB} + 2\phi_F - \frac{Q'_{Bm}}{C_{ox}}$$

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体效应对阈值电压的影响

- 引入体效应因子

$$V_T = V_{FB} + 2\varphi_F + \gamma\sqrt{2\varphi_F - V_{BS}}$$

- 带衬偏电压的阈值电压公式

$$\gamma = \frac{\sqrt{2\varepsilon_0\varepsilon_{Si}qN_A}}{C_{ox}}$$

- 体效应引起的阈值电压变化

$$\Delta V_T = V_T - V_{T0} = \gamma(\sqrt{2\varphi_F - V_{BS}} - \sqrt{2\varphi_F})$$

$$V_{T0} = V_{FB} + 2\varphi_F + \gamma\sqrt{2\varphi_F}$$

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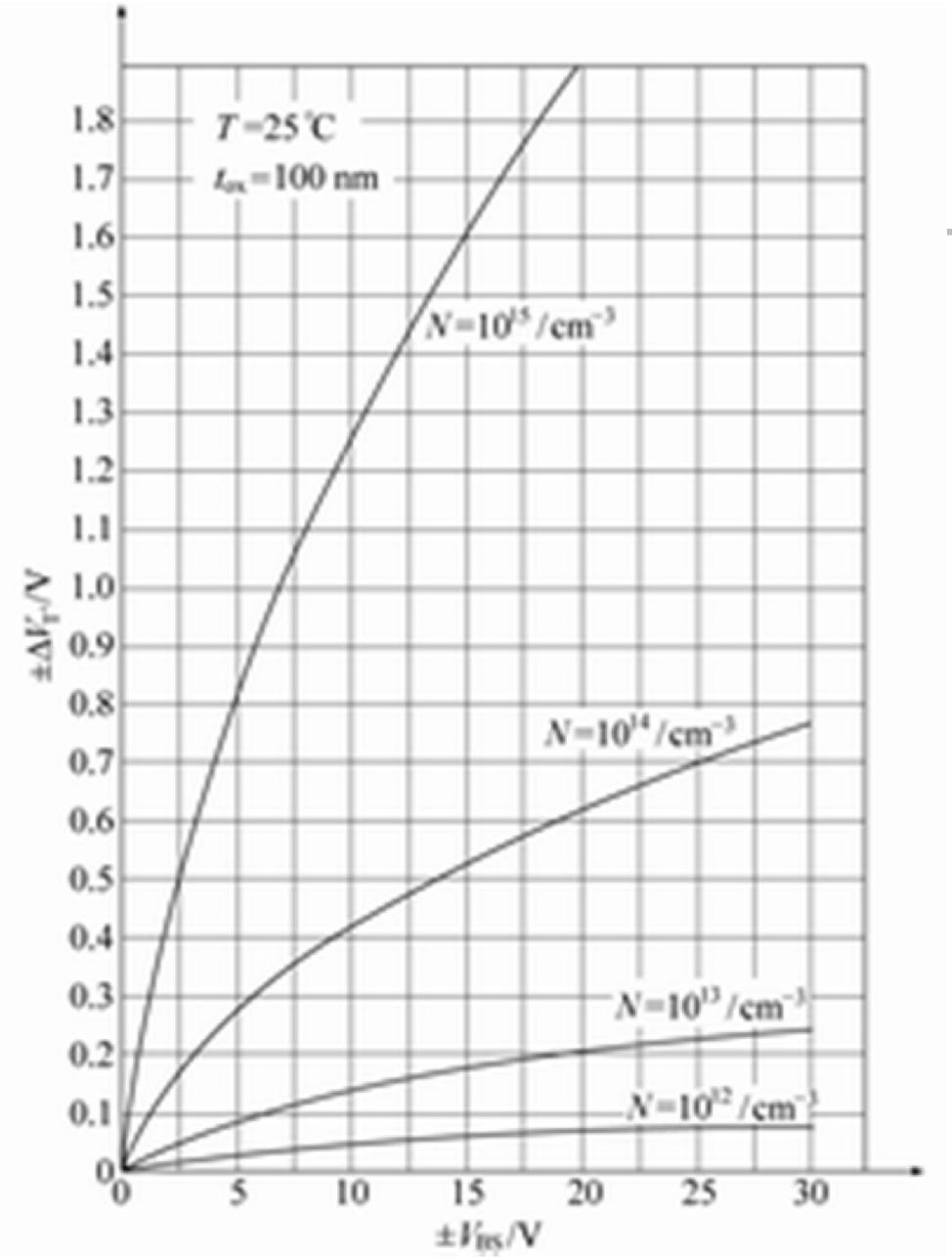
$$V_T = V_{FB} + 2\varphi_F + \gamma\sqrt{2\varphi_F - V_{BS}}$$

$$\Delta V_T = V_T - V_{T0} = \gamma(\sqrt{2\varphi_F - V_{BS}} - \sqrt{2\varphi_F})$$

$$\gamma = \frac{\sqrt{2\varepsilon_0\varepsilon_{Si}qN_A}}{C_{ox}}$$



- 不同衬底掺杂浓度下，衬底偏压引起阈值电压的变化

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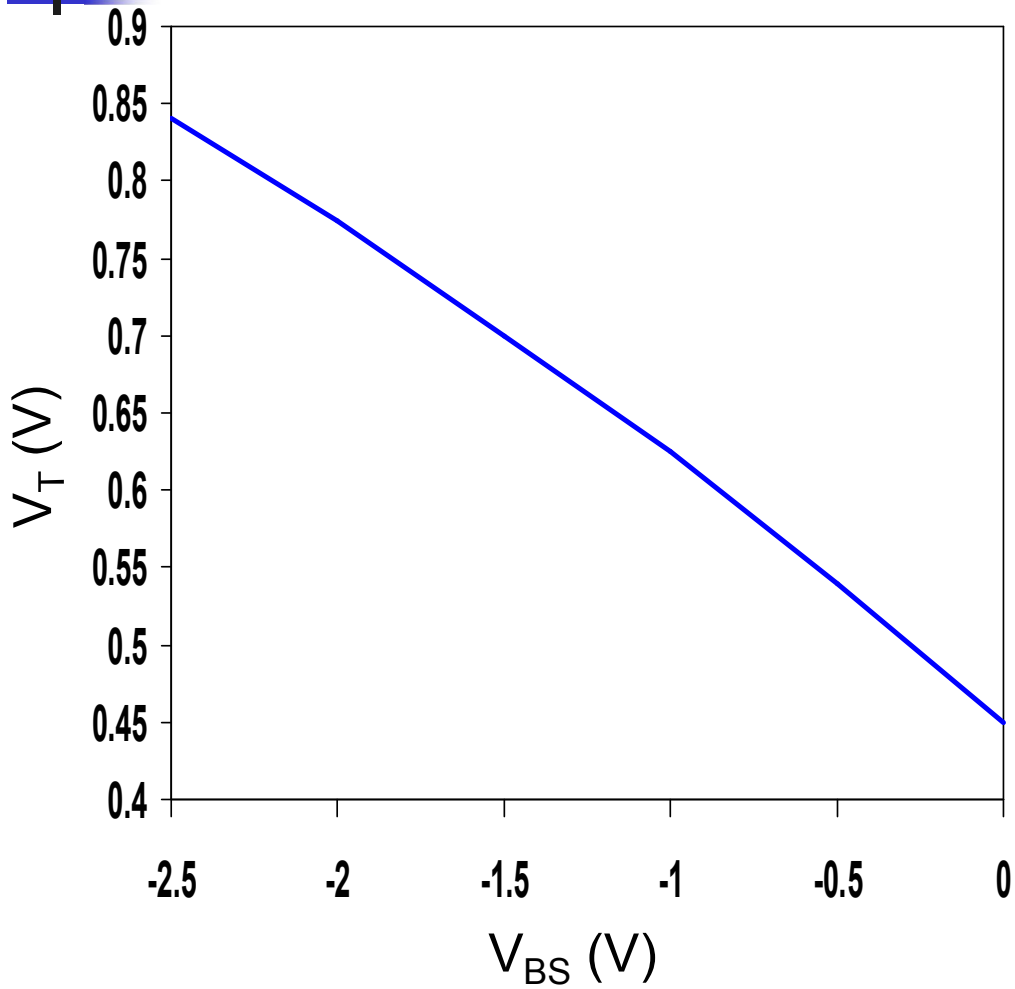
The Body Effect



- **A negative bias V_{bs} =2.5V，causes V_T to increase from 0.45V to 0.85V**

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体效应的应用

- 电路中不是所有器件的源和衬底均能够短接，这个时候体效应引起阈值电压的变化，影响电路性能

- 动态阈值控制电路中，利用衬底偏压调节阈值，满足高速和低功耗不同应用的需要

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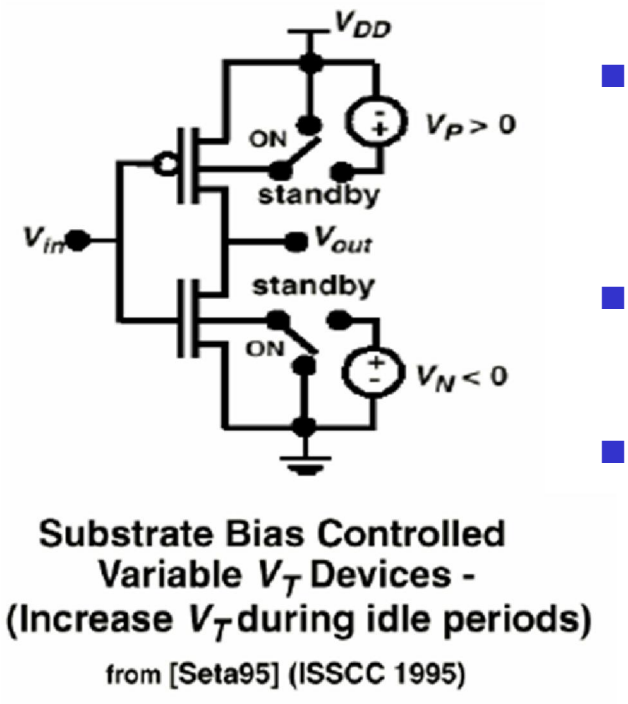
VTCMOS：可变阈值的方法

- 利用MOS器件的体效应，通过调整衬底偏压动态改变器件的阈值电压



Substrate Bias Controlled Variable V_T Devices - (Increase V_T during idle periods)

from [Seta95] (ISSCC 1995)

- 正向偏置FBB（Forward Body Bias），对NMOS器件来说，源端接地，则提高衬底电位，降低阈值
- 反向偏置RBB（Reverse Body Bias），提高阈值，降低静态泄漏
- 零偏置ZBB（Zero Body Bias），正常使用，不加衬底偏置

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长沟道MOS器件模型

- 3.1.1 MOS晶体管阈值电压分析
- 3.1.2 MOS晶体管电流方程
- 3.2.1 MOS晶体管的亚阈值电流
- 3.2.2 MOS晶体管的瞬态特性
- 3.2.3 MOS器件模型

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3.1.2 MOS晶体管的电流电压特性

- 漏电压对MOS特性的影响
- 简单电流方程
- 亚阈值区电流方程

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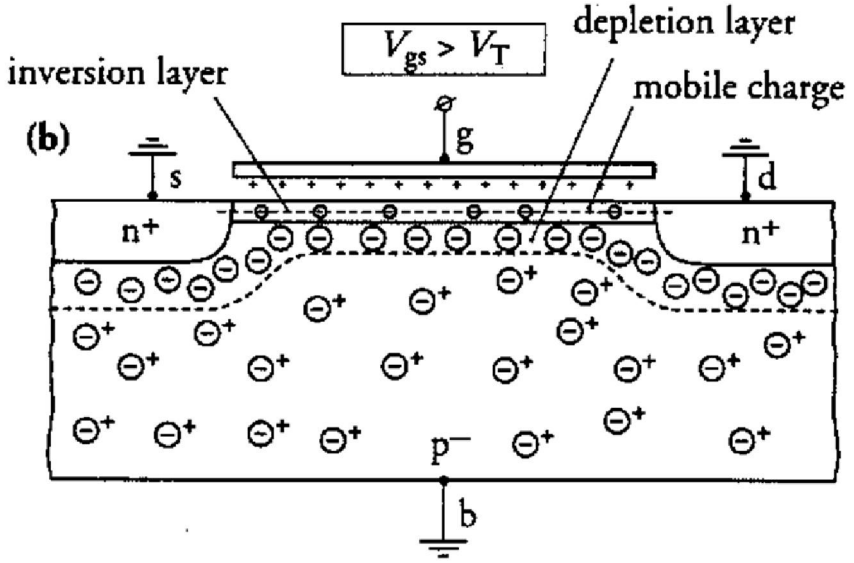
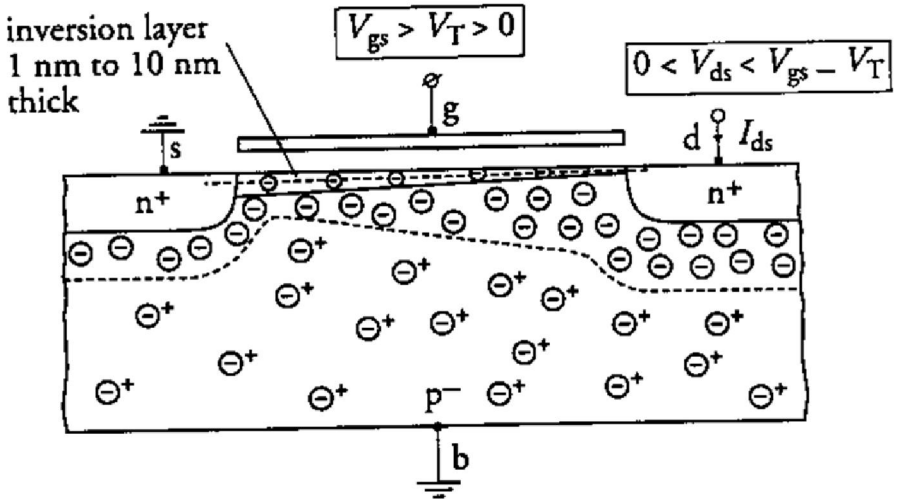
1、漏电压对MOS特性的影响

- 栅电压高于阈值电压，沟道区形成导电沟道
- 加上漏电压**Vds**，形成横向电场，**NMOS**沟道电子定向运动
- 线性区





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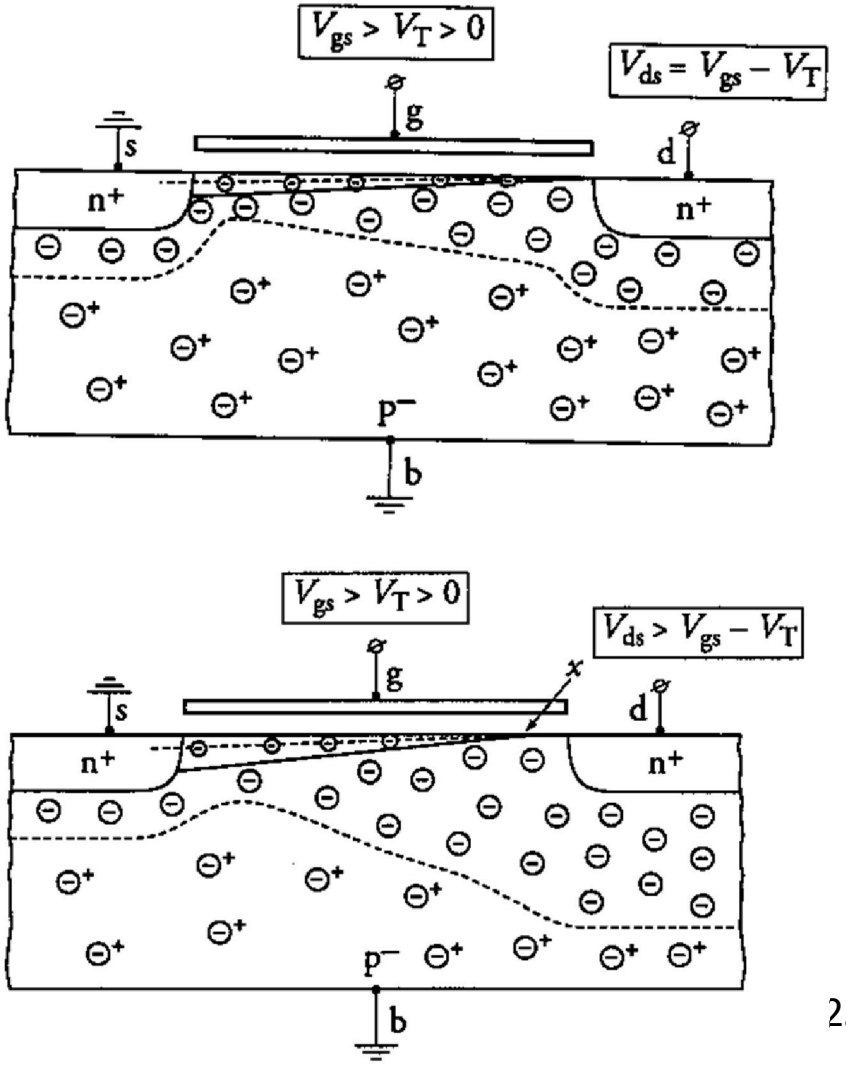
漏电压对MOS特性的影响

- 漏压不断增加，反偏pn结耗尽区不断扩展
- 漏压达到夹断电压，漏端沟道夹断
- 饱和区



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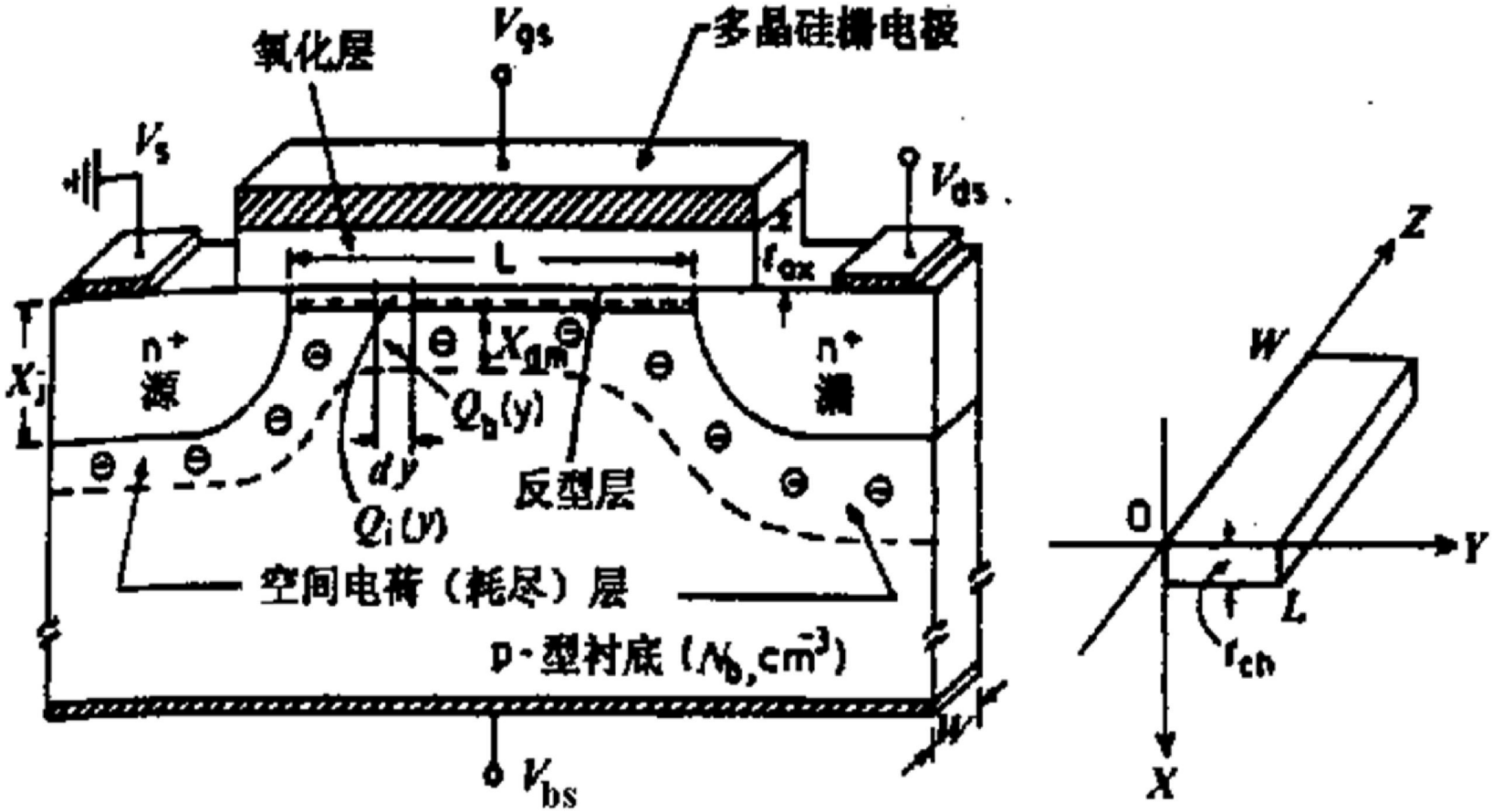
2 简单电流方程



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推导电流方程的一些近似处理

- 缓变沟道近似
- 强反型近似
- 只考虑漂移运动，忽略扩散电流
- 假定载流子的表面迁移率是常数
- 利用薄层电荷近似

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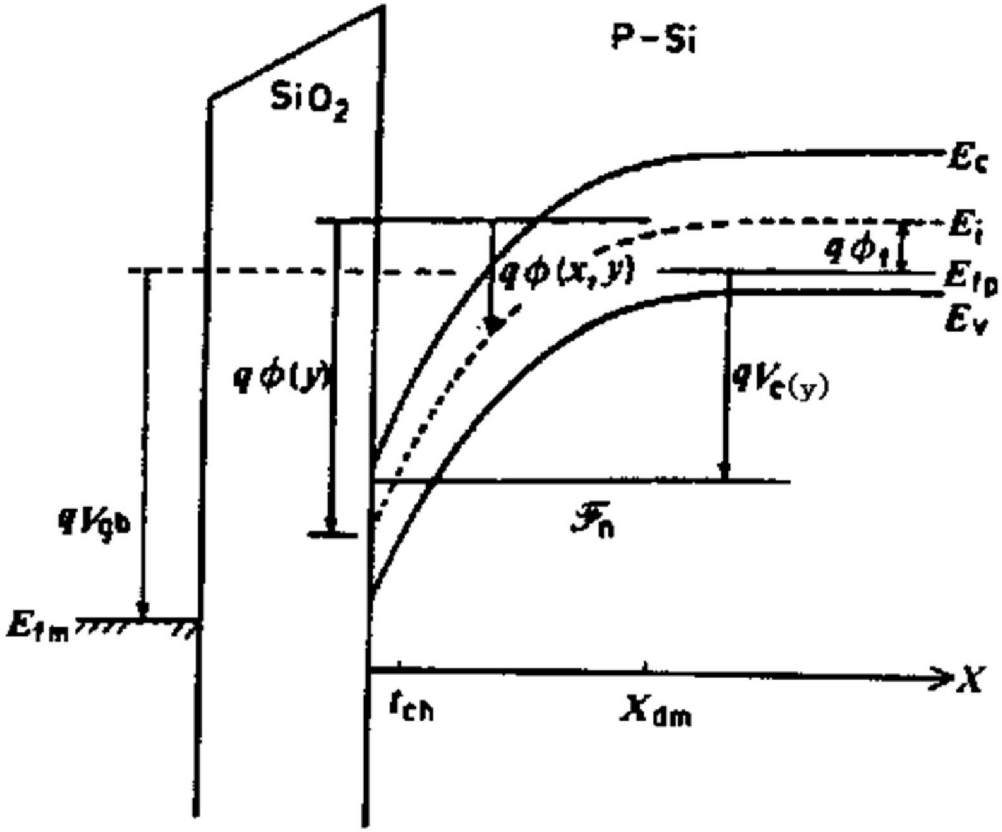
MOS晶体管沟道中y点的能带图



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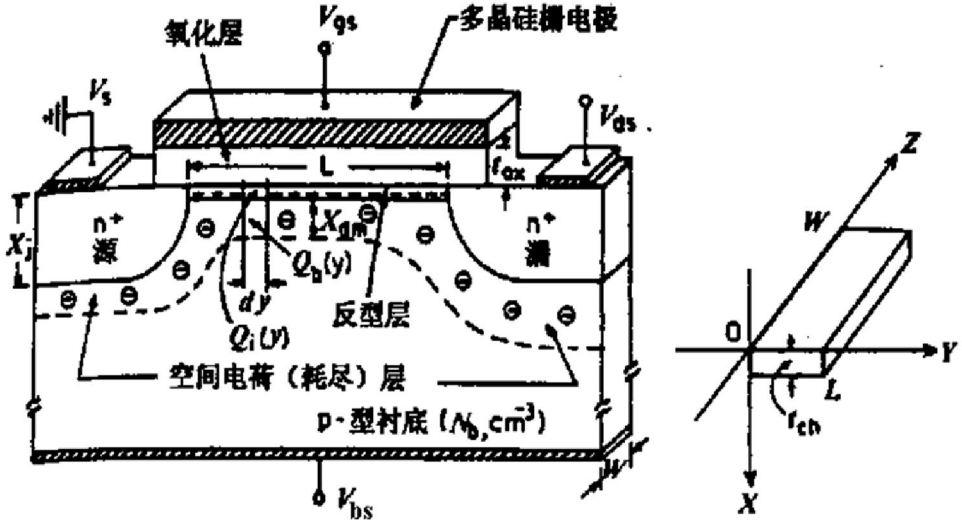
根据高斯定理：

源端和衬底接地



$$Q_s(y) = -\varepsilon_0 \varepsilon_{si} E_x = -C_{ox} V_{ox}(y)$$

$$V_{ox}(y) = V_{GS} - V_{FB} - 2\phi_F - V(y)$$

$$Q_c(y) = Q_s(y) - Q_B(y) \approx Q_s(y) - Q_{Bm}$$

$$= -C_{ox}\left[V_{GS} - V_{FB} - 2\phi_F - V(y) + \frac{Q_{Bm}}{C_{ox}}\right]$$

$$= -C_{ox}\left[V_{GS} - V_T - V(y)\right]$$

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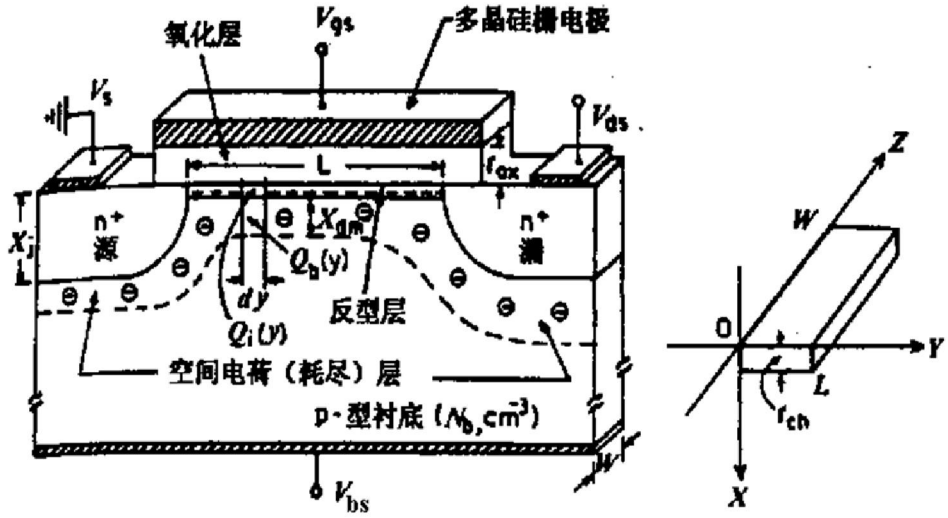
根据欧姆定律：



- 对电流公式进行积分，其中$V_c(y)$是漏电压沿沟道方向的电压降
- 漏压较小的时候，沟道连续（0—L），$V_c(y)$为（0—Vds）
- 得到线性区电流方程

$$I_D = W\mu_{eff}\left|Q_c(y)\right|\frac{dV(y)}{dy},$$

$$Q_c(y) = -C_{ox}(V_{GS} - V_T - V_c(y))$$

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在 V_{DS}较小时，从源到漏都存在导电沟道，根据电流连续，两边积分得到*线性区*电流：

*线性区*电流：$$I_D = \beta\left[\left(V_{GS} - V_T\right)V_{DS} - \frac{1}{2}V_{DS}^{\ 2}\right]$$

$$\approx \beta\left(V_{GS} - V_T\right)V_{DS}, \qquad V_{DS}\ \text{很小时。}$$

导电因子**β**　　$$\beta = \frac{W}{L}\mu_{eff}C_{ox}$$

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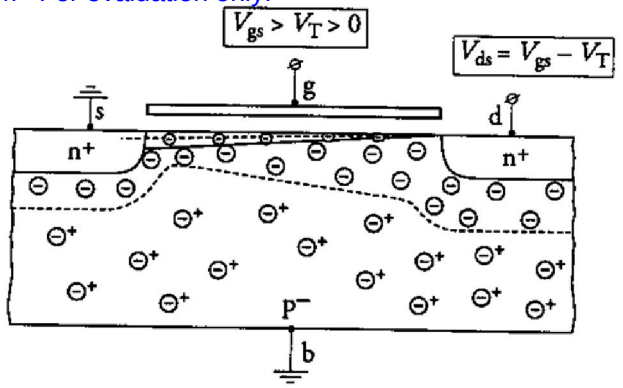
饱和区电流



- 当漏压增大到一定程度，漏端沟道夹断，器件进入饱和区

$$I_D = \beta\left[(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right]$$

$$\approx \beta(V_{GS} - V_T)V_{DS}, \quad V_{DS} \text{ 很小时。}$$

$$\beta = \frac{W}{L}\mu_{eff}C_{ox}$$

- 夹断点处的电压称为漏饱和电压$V_{Dsat} = V_{GS} - V_T$，代入线性区电流公式，得到饱和区电流

$$I_D = \frac{\beta}{2}(V_{GS} - V_T)^2$$

$$V_{Dsat} = V_{GS} - V_T$$

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电流方程：端电压形式

$$I_D = K\left[\left(V_G - V_T - V_S\right)^2 - \left(V_G - V_T - V_D\right)^2\right]$$

$$K = \frac{1}{2}\mu_{eff} C_{ox}\frac{W}{L} = \frac{1}{2}K'\frac{W}{L},\quad K' = \mu_{eff} C_{ox}$$

- 导电因子：**K**因子
- 本征导电因子：**K'**
- 端电压形式的电流方程体现了**MOS**器件的源漏对称的特点

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$$I_D = K\left[\left(V_G - V_T - V_S\right)^2 - \left(V_G - V_T - V_D\right)^2\right]$$

$$K = \frac{1}{2}\mu_{eff} C_{ox}\frac{W}{L} = \frac{1}{2}K'\frac{W}{L},\quad K' = \mu_{eff} C_{ox}$$

工作区	NMOS	PMOS
截止区	$(V_G\text{-}V_T\text{-}V_S) \le 0$	$(V_G\text{-}V_T\text{-}V_S \ge 0$
线性区	$(V_G\text{-}V_T\text{-}V_S) > 0$ $(V_G\text{-}V_T\text{-}V_D) > 0$	$(V_G\text{-}V_T\text{-}V_S) < 0$ $(V_G\text{-}V_T\text{-}V_D) < 0$
饱和区	$(V_G\text{-}V_T\text{-}V_S) > 0$ $(V_G\text{-}V_T\text{-}V_D) \le 0$	$(V_G\text{-}V_T\text{-}V_S) < 0$ $(V_G\text{-}V_T\text{-}V_D) \ge 0$

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长沟道MOS器件模型

- **3.1.1 MOS晶体管阈值电压分析**
- **3.1.2 MOS晶体管电流方程**
- **3.2.1 MOS晶体管的亚阈值电流**
- **3.2.2 MOS晶体管的瞬态特性**
- **3.2.3 MOS器件模型**

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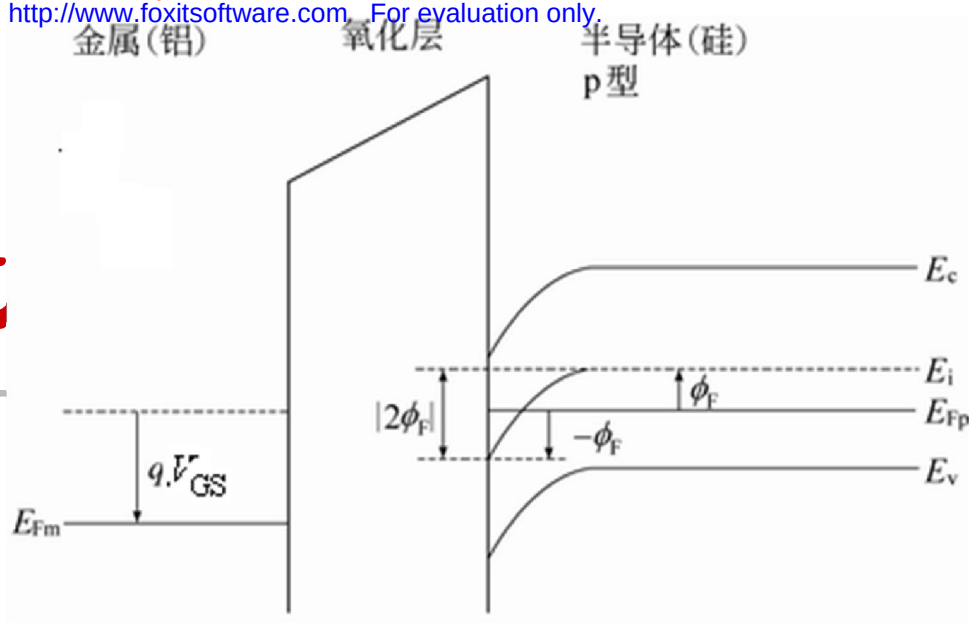
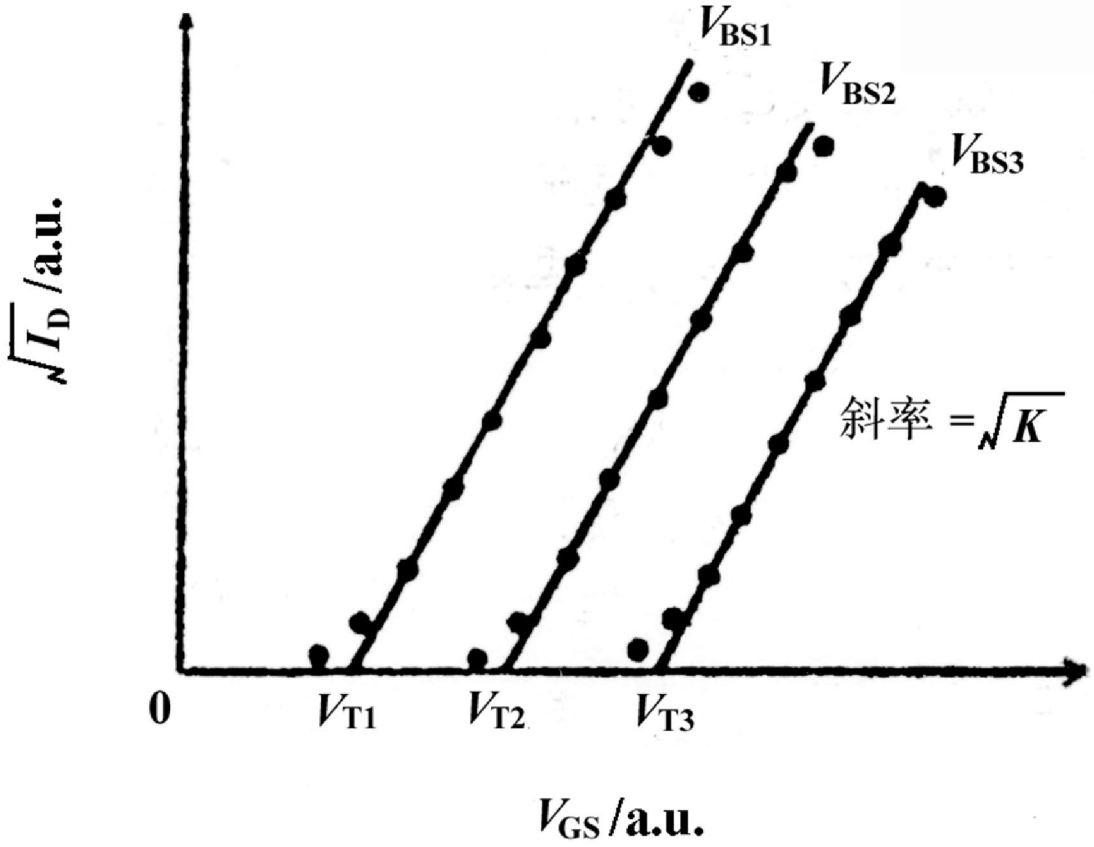
亚阈值区电流





亚阈值区

$$\phi_F < \phi_s \leq 2\phi_F$$

MOS表面弱反型

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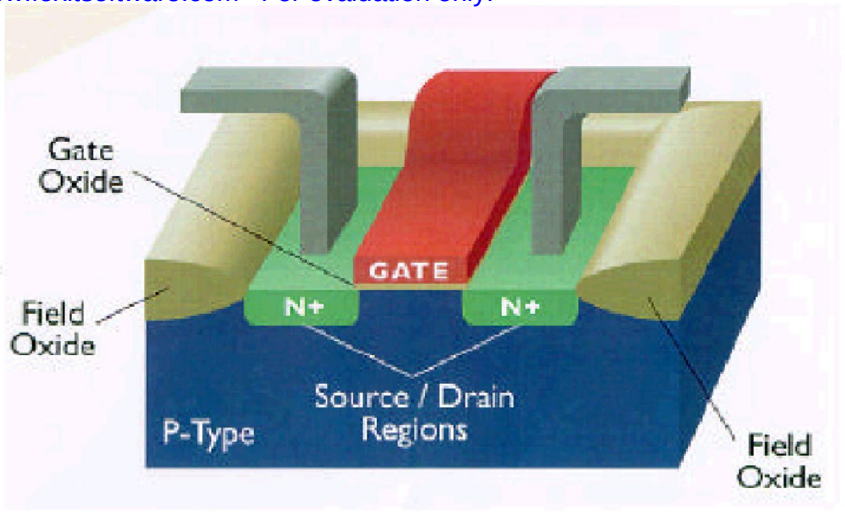
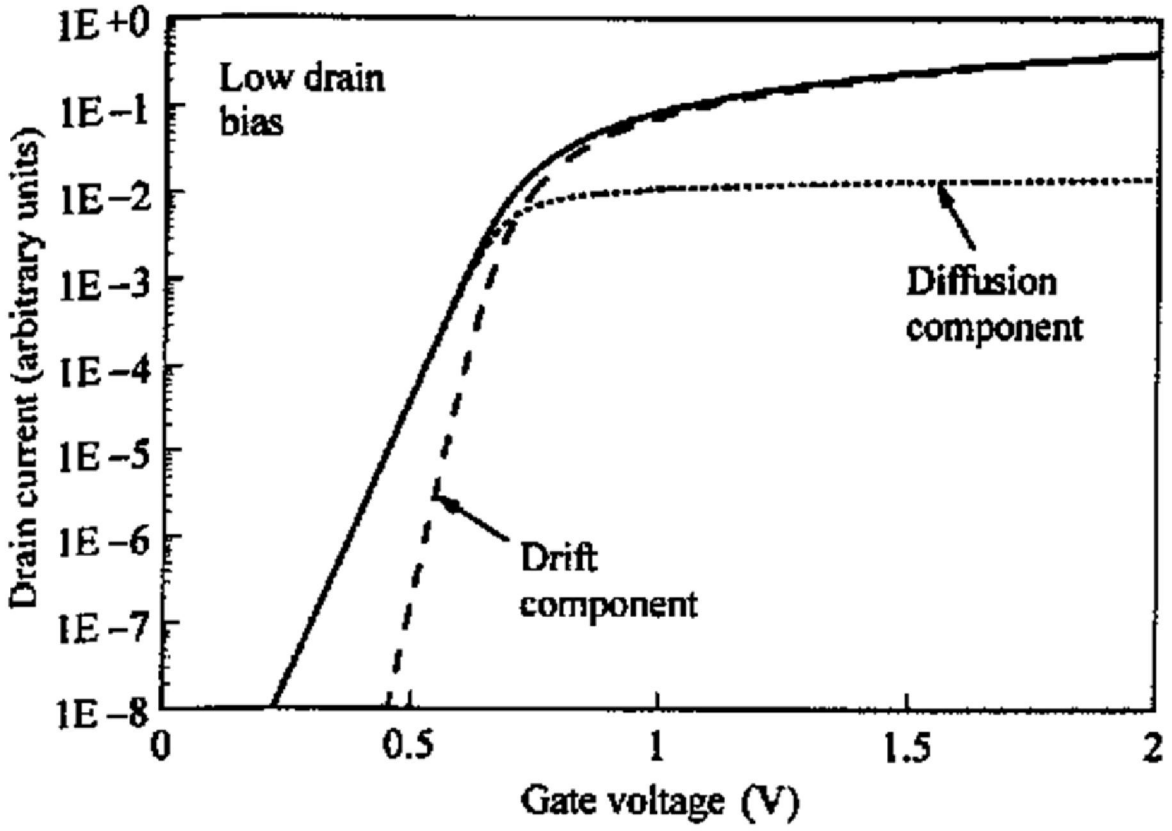
亚阈值电流特性



- 亚阈值区电流以载流子的扩散运动为主
- 弱反型的**MOS**表面相当于一个双极晶体管



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亚阈电流

$$I_D = -qAD_n \frac{dn}{dy} = qAD_n \left[\frac{n(0) - n(L)}{L} \right]$$

其中 $$D_n = \frac{kT}{q} \mu_n = V_t \mu_n$$

反型层厚度：
表面势减小
一个V_t距离

$$A = W \cdot x_i, \quad x_i = \frac{V_t}{E_s}, \quad E_s = \sqrt{\frac{2qN_A \phi_s}{\varepsilon_0 \varepsilon_{si}}}$$

$$n(0) = n_{p0} \exp\left(\frac{q\phi_s}{kT} \right)$$

$$n(L) = n_{p0} \exp\left[\frac{q(\phi_s - V_{DS})}{kT} \right]$$

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亚阈电流

$$E_s = \sqrt{\frac{2qN_A\phi_s}{\varepsilon_0\varepsilon_{si}}}$$

$$I_D = \frac{W}{L}\mu_n\left(\frac{kT}{q}\right)^2\frac{q}{E_s}n_{p0}\exp\left(\phi_s/V_t\right)\left[1-\exp\left(-V_{DS}/V_t\right)\right]$$

$$n_{p0} = n_i^2/N_A, \qquad C_D = \sqrt{\frac{\varepsilon_0\varepsilon_{si}qN_A}{2\phi_s}}$$

$$I_D = \frac{W}{L}\mu_n V_t^2 C_D\left(\frac{n_i}{N_A}\right)^2\exp\left(\phi_s/V_t\right)\left[1-\exp\left(-V_{DS}/V_t\right)\right]$$

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找出表面势与栅压的关系

$$V_{GS} = V_{FB} + \phi_s - \frac{Q_B}{C_{ox}}$$

$$Q_B = -[2\epsilon_0\epsilon_{Si} q N_A(\varphi_s)]^{1/2}$$

$$\phi_s = V_{GS} - V_{FB} + \frac{\gamma^2}{2}\left[1 - \sqrt{1 + \frac{4}{\gamma^2}(V_{GS} - V_{FB})}\right]$$

$$I_D = \frac{W}{L}\mu_n V_t^{\,2} C_D \left(\frac{n_i}{N_A}\right)^2 \exp\left(\phi_s / V_t\right)\left[1 - \exp\left(-V_{DS}/V_t\right)\right]$$

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表面势和栅压的线性关系

$$V_{GS} = V_{FB} + \phi_s - \frac{Q_B}{C_{ox}}$$

- 对$Q_B(\varphi_s)$做泰勒展开：

$$Q_B(\varphi_s) = Q_B(\varphi_{s0}) + (\varphi_s - \varphi_{s0})\frac{\partial Q_B}{\partial \varphi_s}$$

$$= Q_B(\varphi_{s0}) + (\varphi_s - \varphi_{s0})C_D$$

$$V_{GS} = V_{FB} + \phi_{s0} + \frac{Q_B(\phi_{s0})}{C_{ox}} + (\phi_s - \phi_{s0})\left(1 + \frac{C_D}{C_{ox}}\right)$$

$$V_{GS} = V_T + (\phi_s - 2\phi_F)\left(1 + \frac{C_D}{C_{ox}}\right),$$

$$\phi_s = 2\phi_F + \frac{V_{GS} - V_T}{n}, \qquad n = 1 + \frac{C_D}{C_{ox}}$$

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亚阈值电流

$$V_{GS} = V_T + (\phi_s - 2\phi_F)\left(1 + \frac{C_D}{C_{ox}}\right),$$

$$\phi_s = 2\phi_F + \frac{V_{GS} - V_T}{n}, \qquad n = 1 + \frac{C_D}{C_{ox}}$$

$$I_D = \frac{W}{L}\mu_n V_t^2 C_D \left(\frac{n_i}{N_A}\right)^2 \exp\left(\phi_s / V_t\right)\left[1 - \exp\left(-V_{DS}/V_t\right)\right]$$

$$I_D = I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)\left[1 - \exp\left(-V_{DS}/V_t\right)\right] \approx I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)$$

- 亚阈电流随着栅压指数变化
- 当漏压大于**$3V_t$**的时候，亚阈电流基本与漏压无关
- 亚阈电流同温度强烈相关

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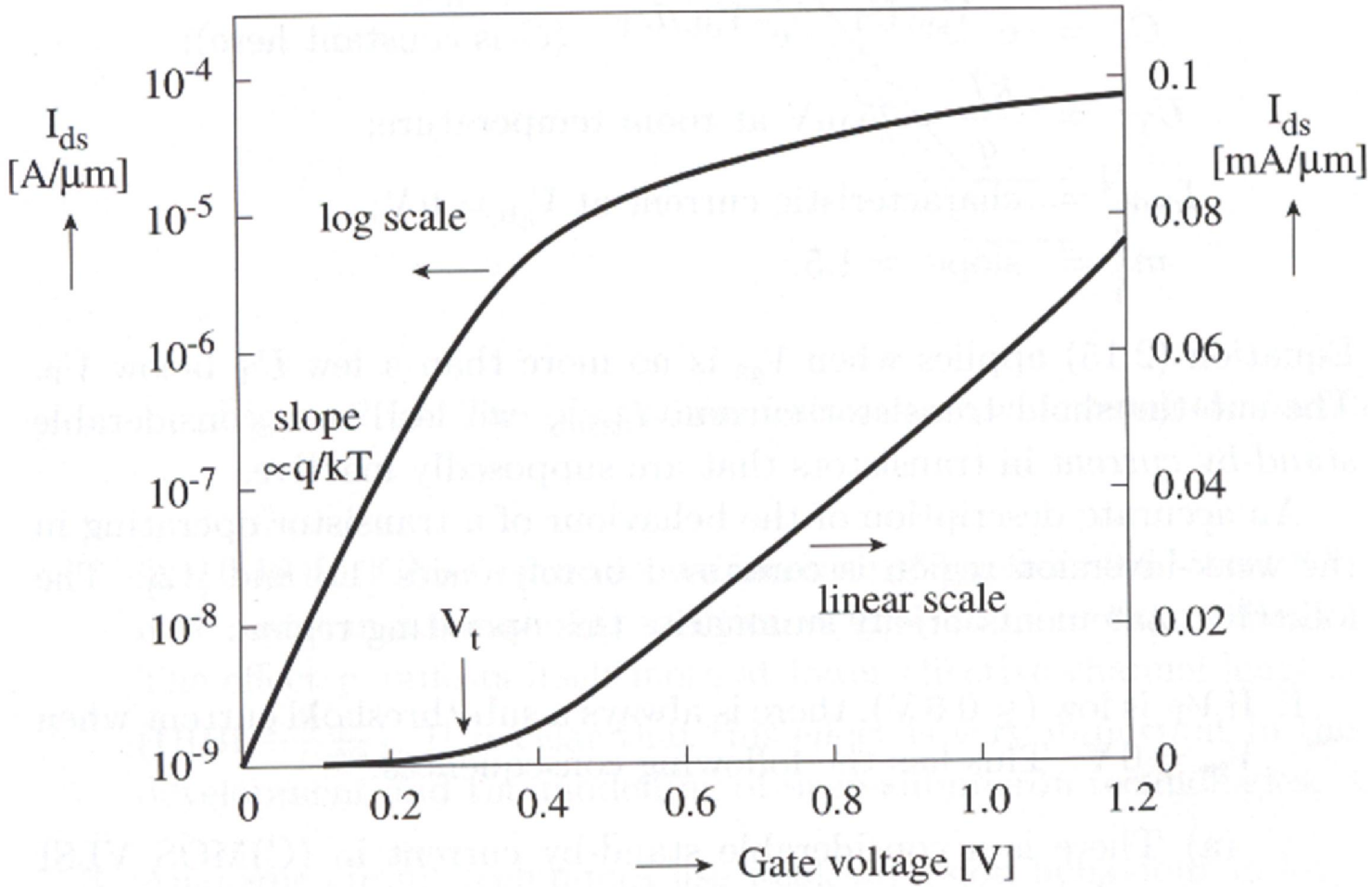
$$I_D = I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)\left[1 - \exp\left(-V_{DS}/V_t\right)\right] \approx I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)$$

亚阈值电流



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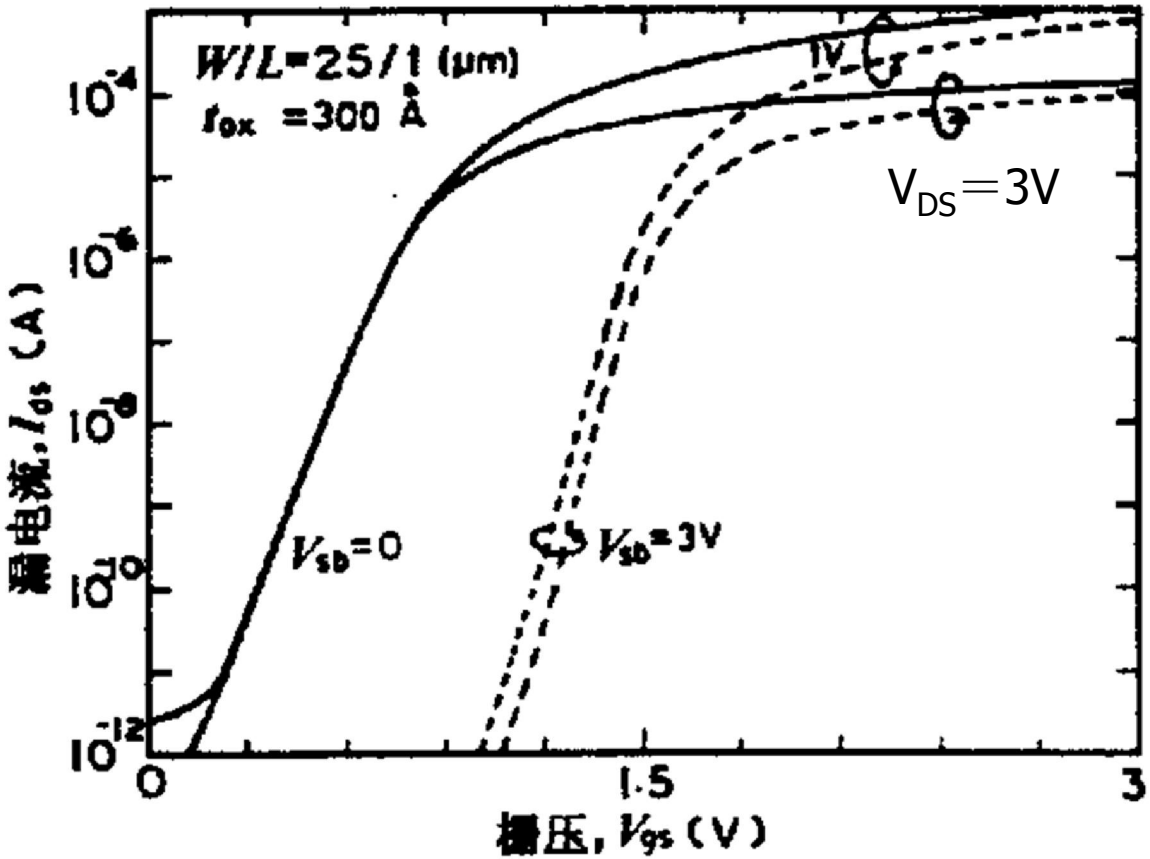
$$I_D = I_0 \exp\left(\frac{V_{GS}-V_T}{nV_t}\right)\left[1-\exp\left(-V_{DS}/V_t\right)\right] \approx I_0 \exp\left(\frac{V_{GS}-V_T}{nV_t}\right)$$

亚阈值区电流特性

- 长沟器件，不同漏压的亚阈电流近似相等
- 衬底偏压对亚阈电流有影响



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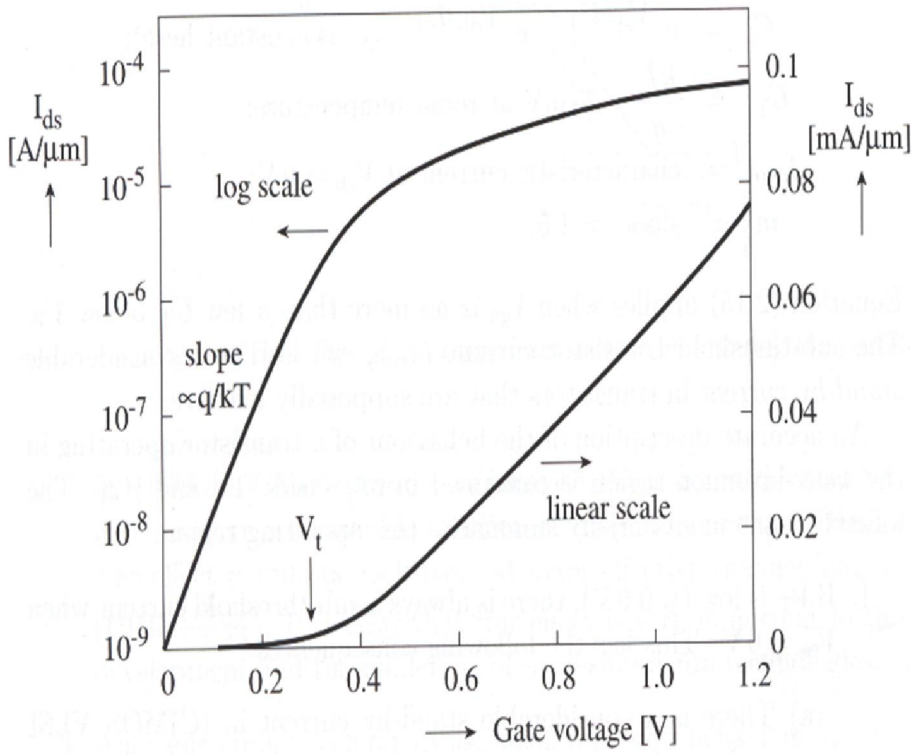
$$I_D = I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)$$

亞閾值斜率

$$S = \frac{dV_{GS}}{d(\lg I_D)} = (\ln 10)\frac{dV_{GS}}{d(\ln I_D)} = (\ln 10)nV_t$$

$$n = 1 + \frac{C_D}{C_{ox}}$$

$$\therefore S = V_t(\ln 10)\left(1 + \frac{C_D}{C_{ox}}\right)$$



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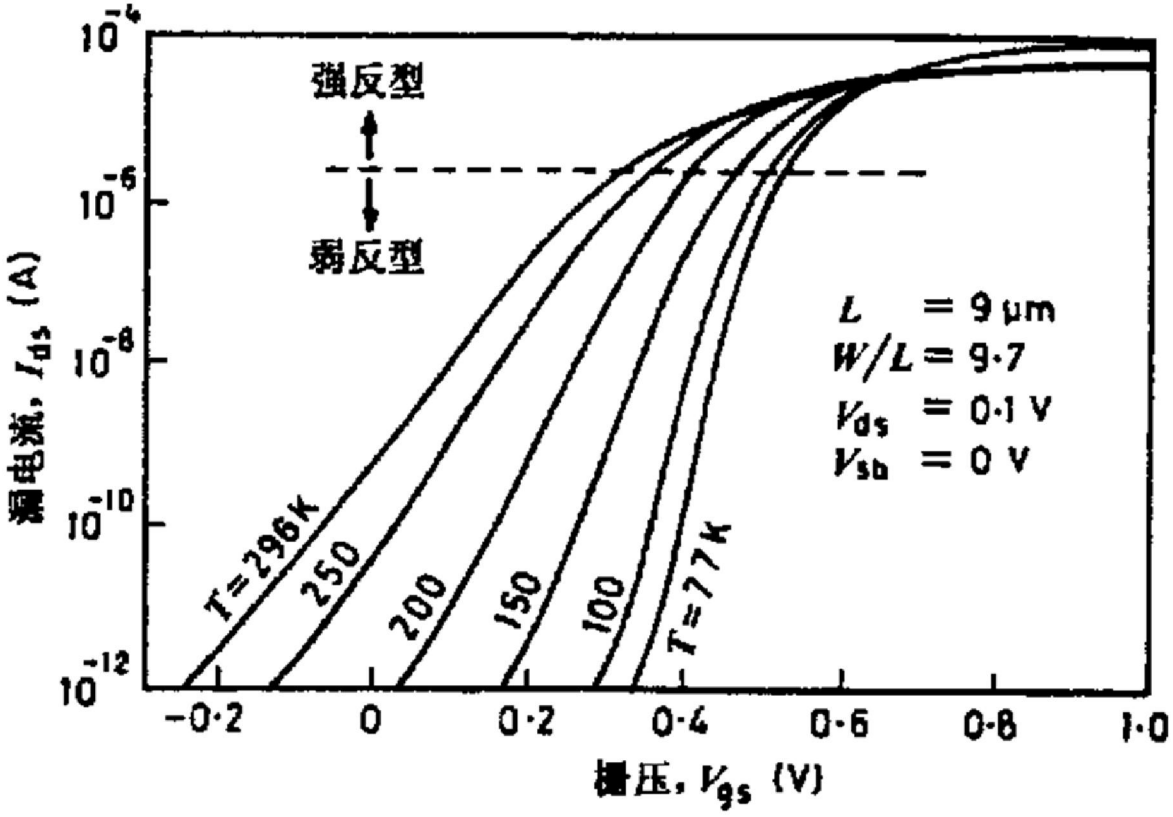
温度对亚阈值斜率的影响

$$n = 1 + \frac{C_D}{C_{ox}}$$

$$\therefore S = V_t(\ln 10)\left(1 + \frac{C_D}{C_{ox}}\right)$$



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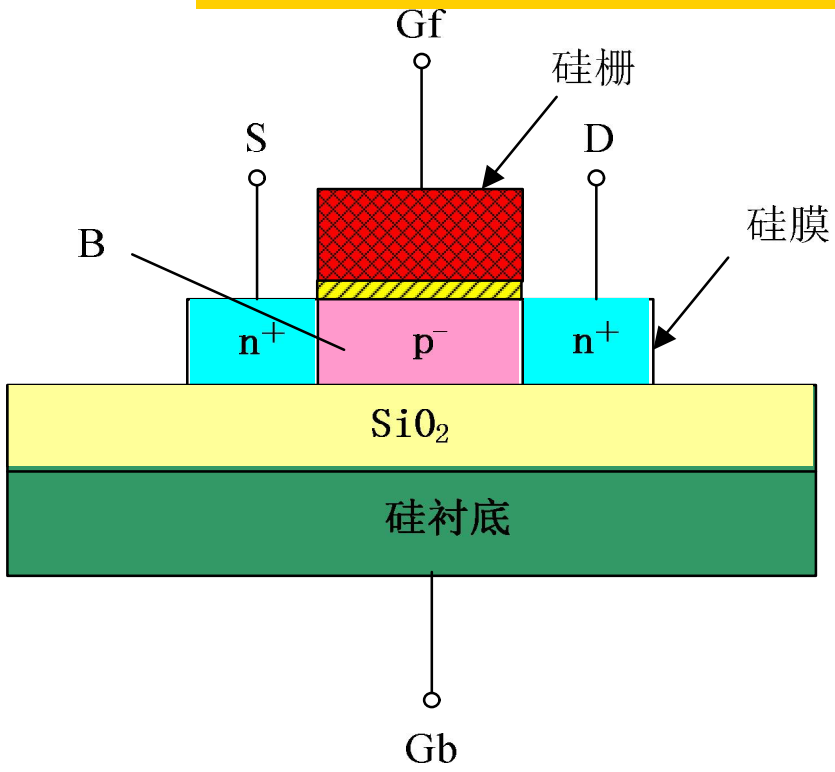
温度对亚阈值斜率的影响

$$n = 1 + \frac{C_D}{C_{ox}}$$

$$\therefore S = V_t(\ln 10)\left(1 + \frac{C_D}{C_{ox}}\right)$$

- 体硅的亚阈值斜率一般不小于90mv/dec
- 全耗尽SOI器件的亚阈值斜率可以接近理论极限值60mv/dec
- SOI器件基于更好的亚阈值特性



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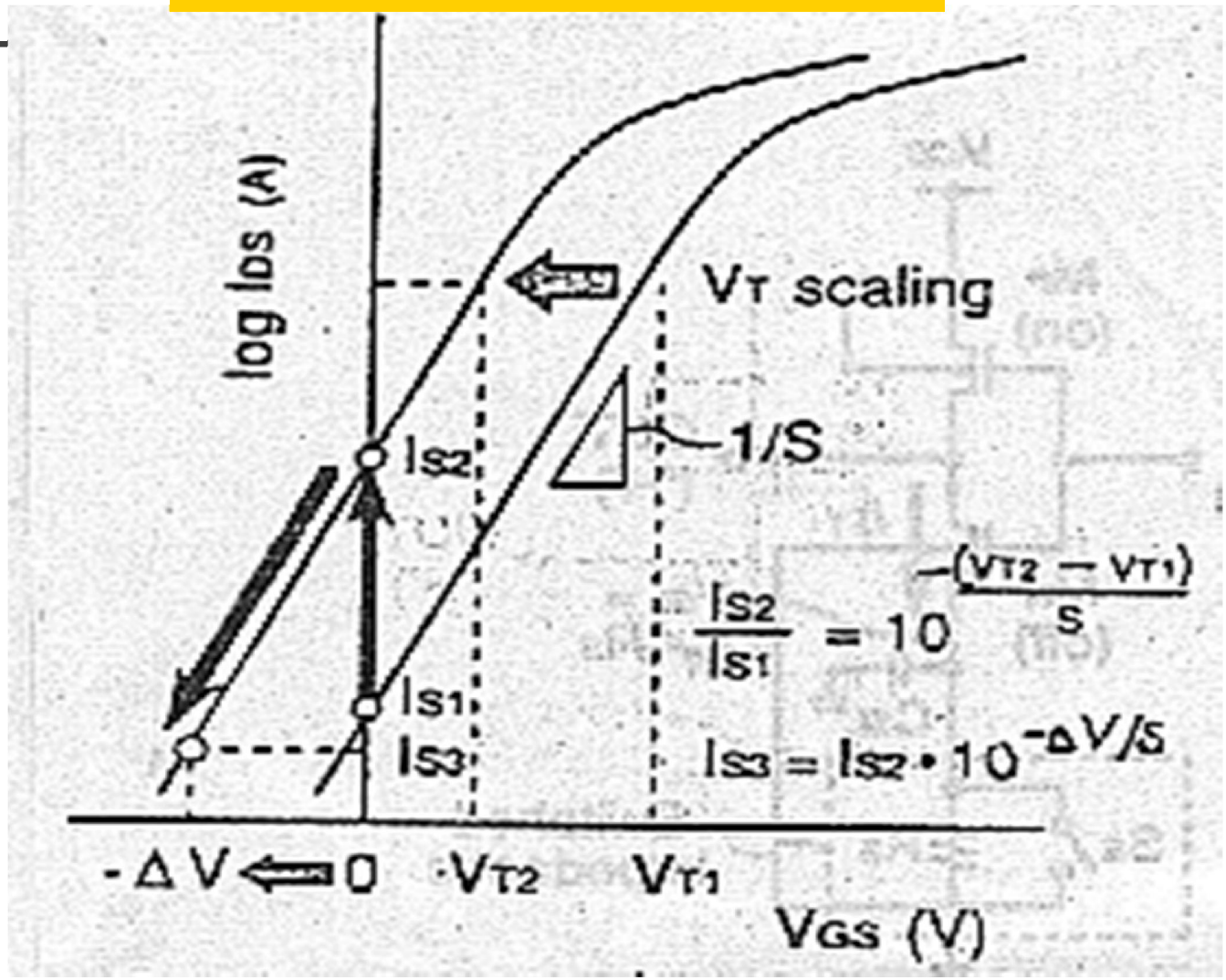
阈值电压对截止态电流的影响

$$I_D = I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)$$



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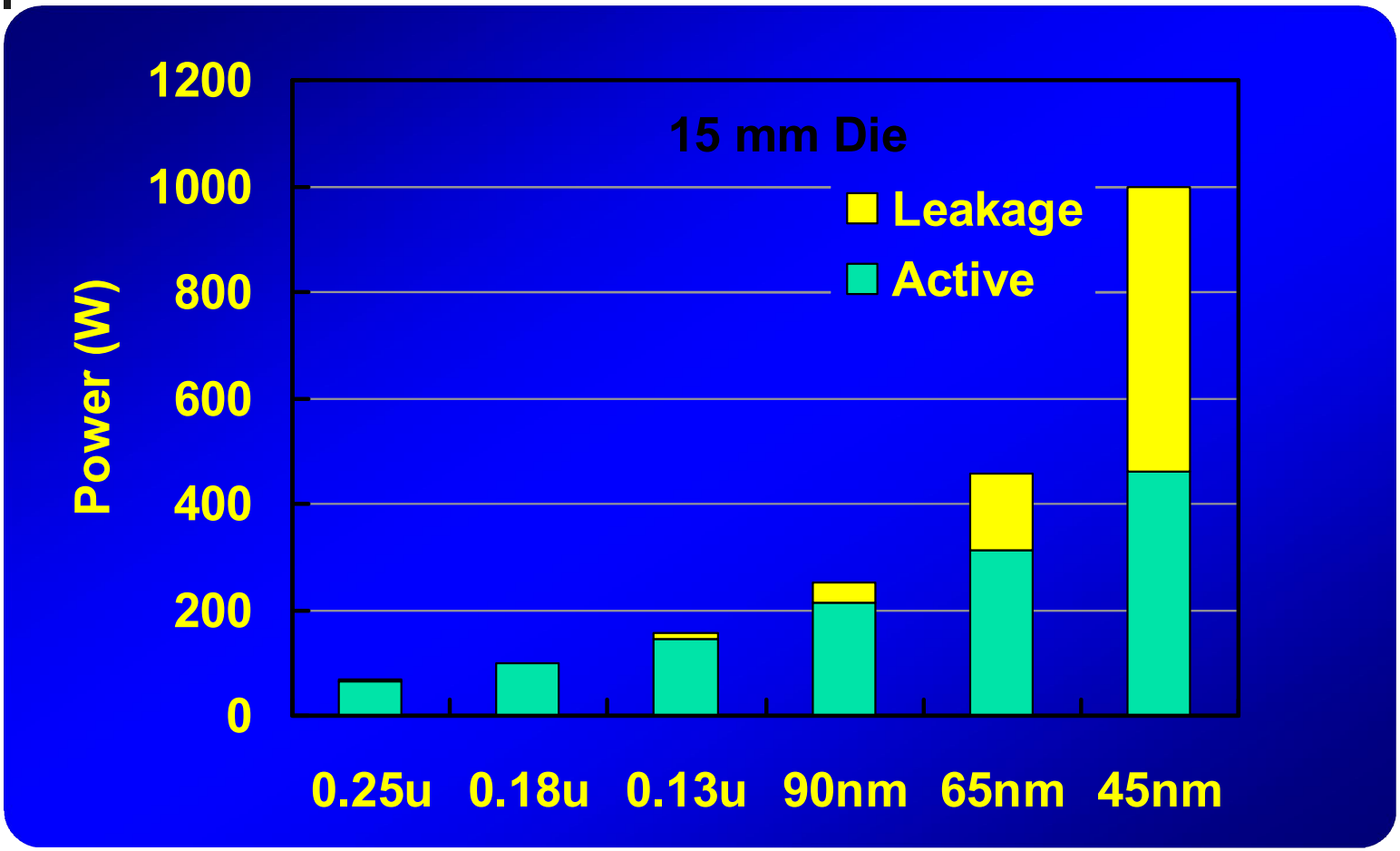
The Power Crisis

$$I_D = I_0 \exp\left(\frac{V_{GS} - V_T}{nV_t}\right)$$



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低功耗工艺

	CL018 G	CL018 LP	CL018 ULP	CL018 HS	CL015 HS	CL013 HS
V_{dd}	1.8 V	1.8 V	1.8 V	2 V	1.5 V	1.2 V
T_{ox} (effective)	42 Å	42 Å	42 Å	42 Å	29 Å	24 Å
L_{gate}	0.16 μm	0.16 μm	0.18 μm	0.13 μm	0.11 μm	0.08 μm
I_{DSat} (n/p) (μA/μm)	600/260	500/180	320/130	780/360	860/370	920/400
I_{off} (leakage) (ρA/μm)	20	1.60	0.15	300	1,800	13,000
V_{Tn}	0.42 V	0.63 V	0.73 V	0.40 V	0.29 V	0.25 V
FET Perf. (GHz)	30	22	14	43	52	80

From MPR, 2000

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长沟道MOS器件模型

- 3.1.1 MOS晶体管阈值电压分析
- 3.1.2 MOS晶体管电流方程
- 3.2.1 MOS晶体管的亚阈值电流
- 3.2.2 MOS晶体管的瞬态特性
- 3.2.3 MOS器件模型

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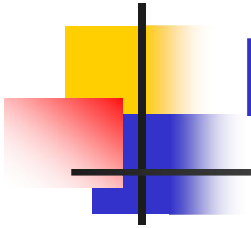

MOS晶体管的瞬态

- MOS晶体管的本征电容
- MOS晶体管的寄生电容

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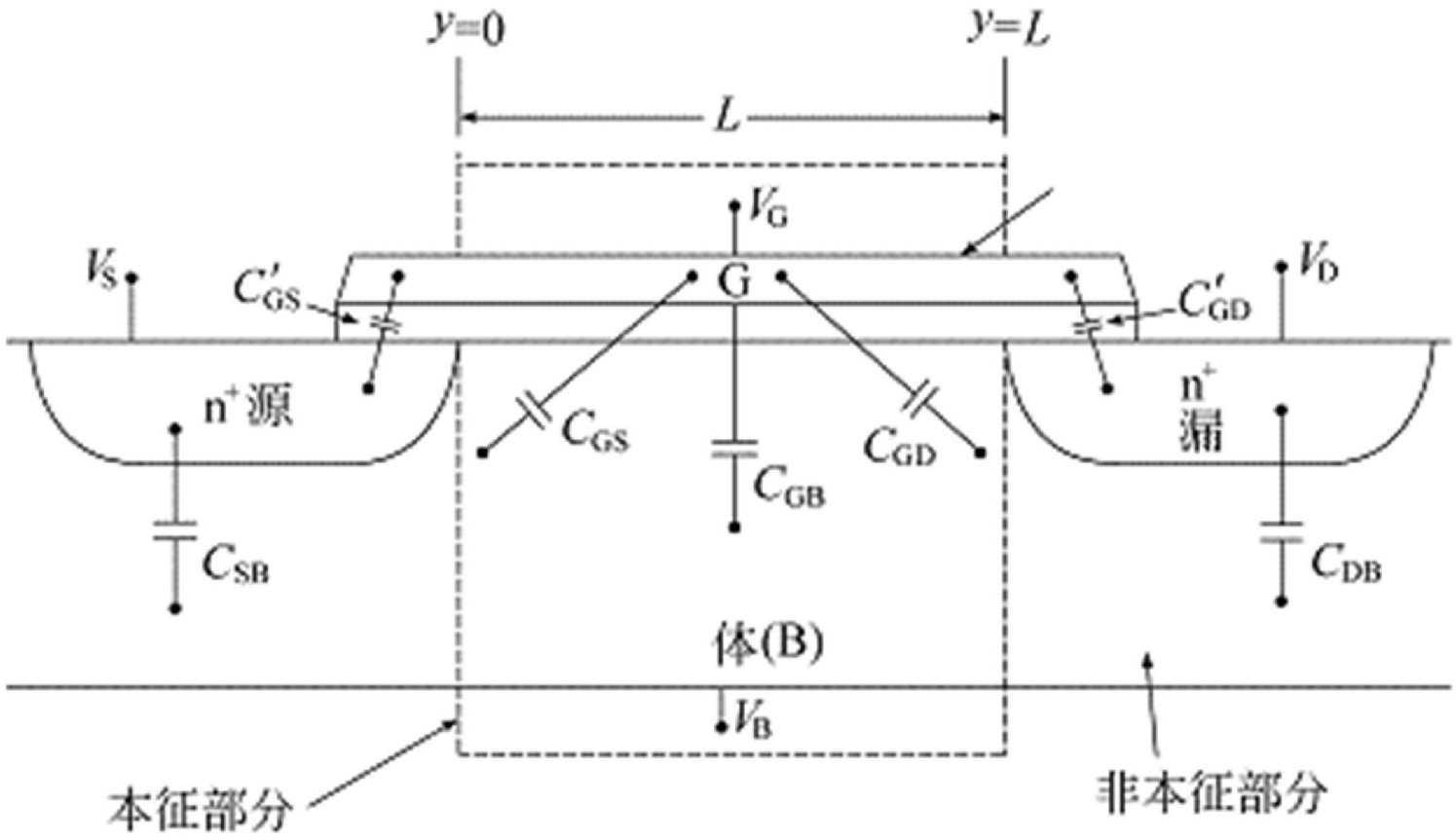
与MOS晶体管有关的电容



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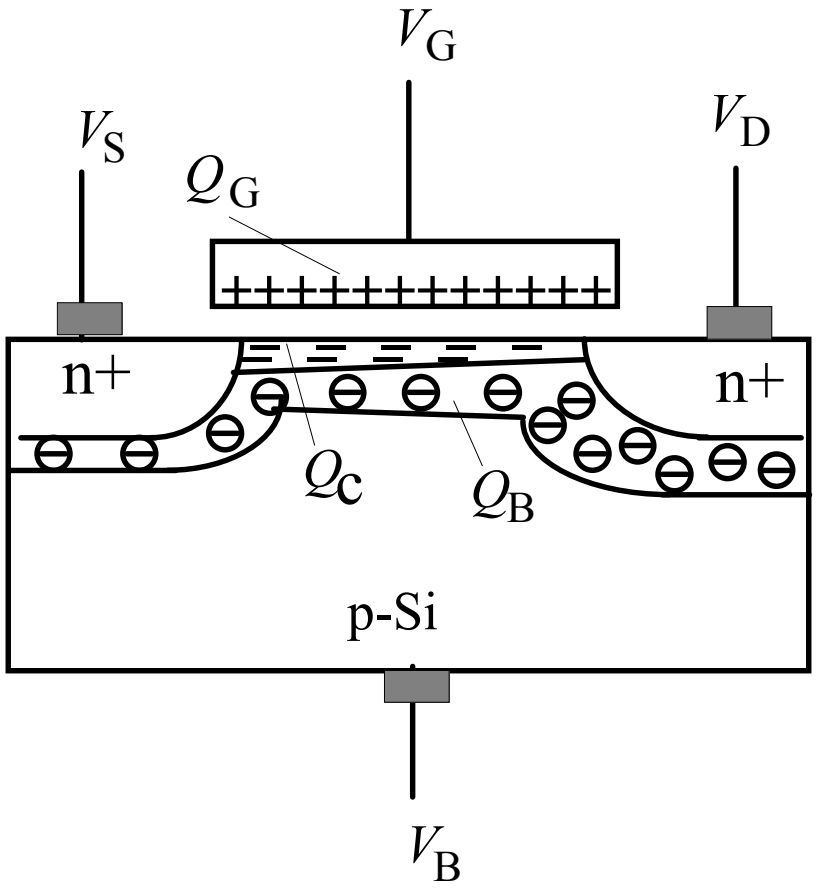
1 MOS晶体管的本征电容



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Meyer电容模型

3个集总电容：

$$C_{GS}=\frac{\partial Q_{GT}}{\partial V_{GS}},\quad C_{GD}=\frac{\partial Q_{GT}}{\partial V_{GD}},\quad C_{GB}=\frac{\partial Q_{GT}}{\partial V_{GB}}$$

$$Q_{GT}=-(Q_{CT}+Q_{BT})$$

强反型后 $\Delta Q_{GT}\approx-\Delta Q_{CT}$

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沟道区反型层电荷

$$C_{GS}=\frac{\partial Q_{GT}}{\partial V_{GS}},\quad C_{GD}=\frac{\partial Q_{GT}}{\partial V_{GD}},\quad C_{GB}=\frac{\partial Q_{GT}}{\partial V_{GB}}$$

$$Q_{CT}=-WC_{ox}\int_0^L\left[V_{GS}-V_T-V_c(y)\right]dy$$

$$=-\frac{2}{3}WLC_{ox}\frac{(V_{GS}-V_T)^3-(V_{GS}-V_T-V_{DS})^3}{\left[2(V_{GS}-V_T)-V_{DS}\right]V_{DS}}$$

$$Q_{CT}=-\frac{2}{3}WLC_{ox}\left[\frac{(V_{GS}-V_T)^3-(V_{GD}-V_T)^3}{(V_{GS}-V_T)^2-(V_{GD}-V_T)^2}\right]$$

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线性区本征电容

$$Q_{CT} = -\frac{2}{3}WLC_{ox}\left[\frac{(V_{GS}-V_T)^3-(V_{GD}-V_T)^3}{(V_{GS}-V_T)^2-(V_{GD}-V_T)^2}\right]$$

$$C_{GS} = -\frac{\partial Q_{CT}}{\partial V_{GS}} = \frac{2}{3}WLC_{ox}\left\{1-\frac{(V_{GS}-V_T-V_{DS})^2}{[2(V_{GS}-V_T)-V_{DS}]^2}\right\},$$

$$C_{GD} = -\frac{\partial Q_{CT}}{\partial V_{GD}} = \frac{2}{3}WLC_{ox}\left\{1-\frac{(V_{GS}-V_T)^2}{[2(V_{GS}-V_T)-V_{DS}]^2}\right\}$$

$$V_{DS}\to 0,\quad C_{GS}=C_{GD}=\frac{1}{2}WLC_{ox}$$

$$C_{GB} = -\frac{\partial Q_{BT}}{\partial V_{GB}} = 0$$

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饱和区本征电容

$$C_{GS}=-\frac{\partial Q_{CT}}{\partial V_{GS}}=\frac{2}{3}WLC_{ox}\left\{1-\frac{(V_{GS}-V_T-V_{DS})^2}{[2(V_{GS}-V_T)-V_{DS}]^2}\right\},$$

$$C_{GD}=-\frac{\partial Q_{CT}}{\partial V_{GD}}=\frac{2}{3}WLC_{ox}\left\{1-\frac{(V_{GS}-V_T)^2}{[2(V_{GS}-V_T)-V_{DS}]^2}\right\}$$

$$V_{DS}=V_{Dsat}=V_{GS}-V_T$$

$$C_{GS}=-\frac{\partial Q_{CT}}{\partial V_{GS}}=\frac{2}{3}WLC_{ox}$$

$$C_{GD}=-\frac{\partial Q_{CT}}{\partial V_{GD}}=0$$

$$C_{GB}=-\frac{\partial Q_{BT}}{\partial V_{GB}}=0$$

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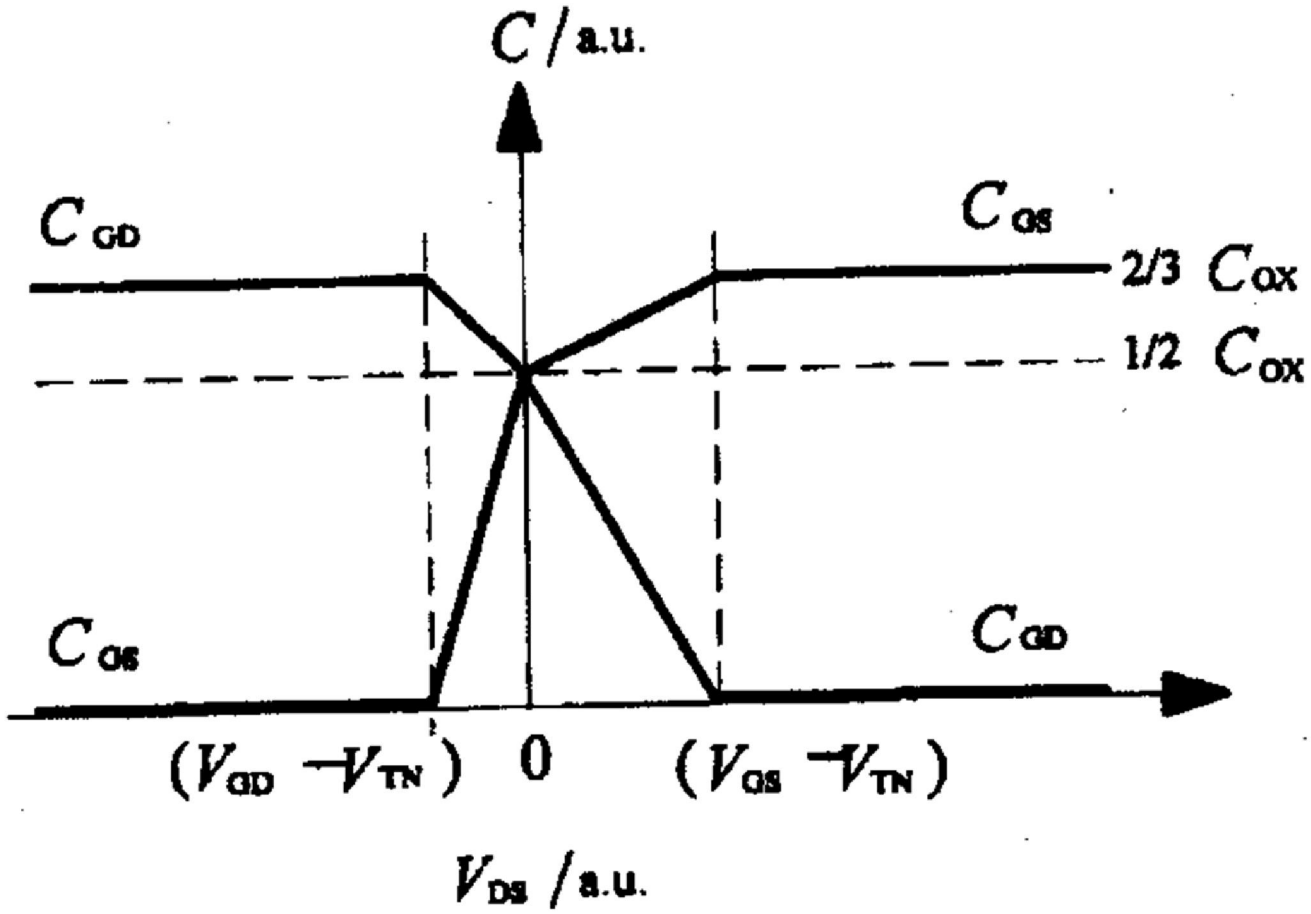
C_{GS}和C_{GD}电容随V_{DS}的变化



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截止区的本征电容

$$Q_{\mathrm{GT}} = -(Q_{\mathrm{CT}} + Q_{\mathrm{BT}}) = -Q_{\mathrm{BT}}$$

$$C_{GB} = -\frac{\partial Q_{BT}}{\partial V_{GB}} = \frac{WLC_{ox}}{\left[1 + 4(V_{GS} - V_{FB})/\gamma^2\right]^{1/2}}$$

$$C_{GS} = C_{GD} = 0$$

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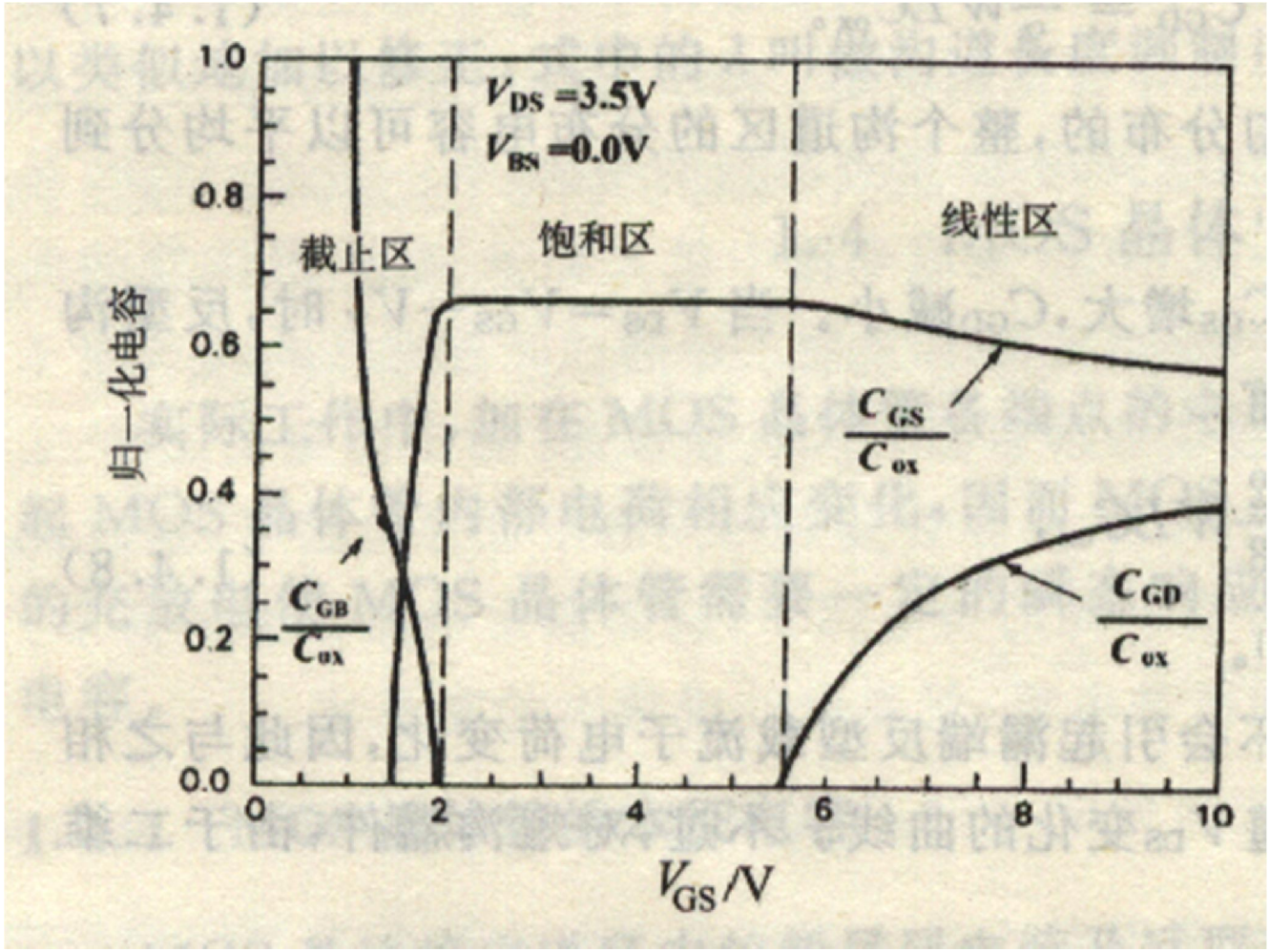
本征电容随V_{GS}的变化



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本征电容的简单分区模型

工作区	C_{GB}	C_{GS}	C_{GD}
截止区	WLCox	0	0
线性区	0	1/2 WLCox	1/2WLCox
饱和区	0	2/3 WLCox	0

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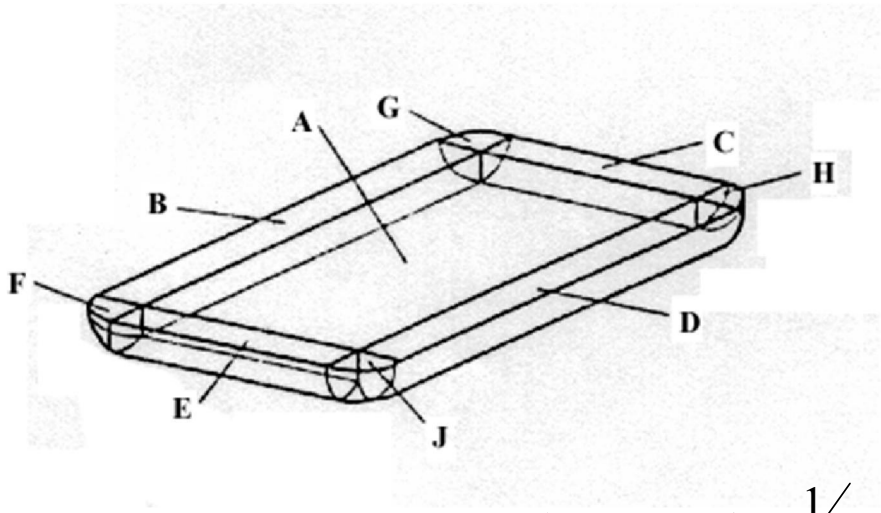
2 MOS晶体管的寄生电容

源、漏区pn结电容



$$C_{SB} = A_S C_{jA} + P_S C_{jP} + nC_{jc}$$

$$C_{DB} = A_D C_{jA} + P_D C_{jP} + nC_{jc}$$

$$C_{jA} = C_{j0}\left(1+\frac{V}{V_{bi}}\right)^{-1/2}$$

$$C_{jP} = C_{jp0}\left(1+\frac{V}{V_{bi}}\right)^{-1/3}$$

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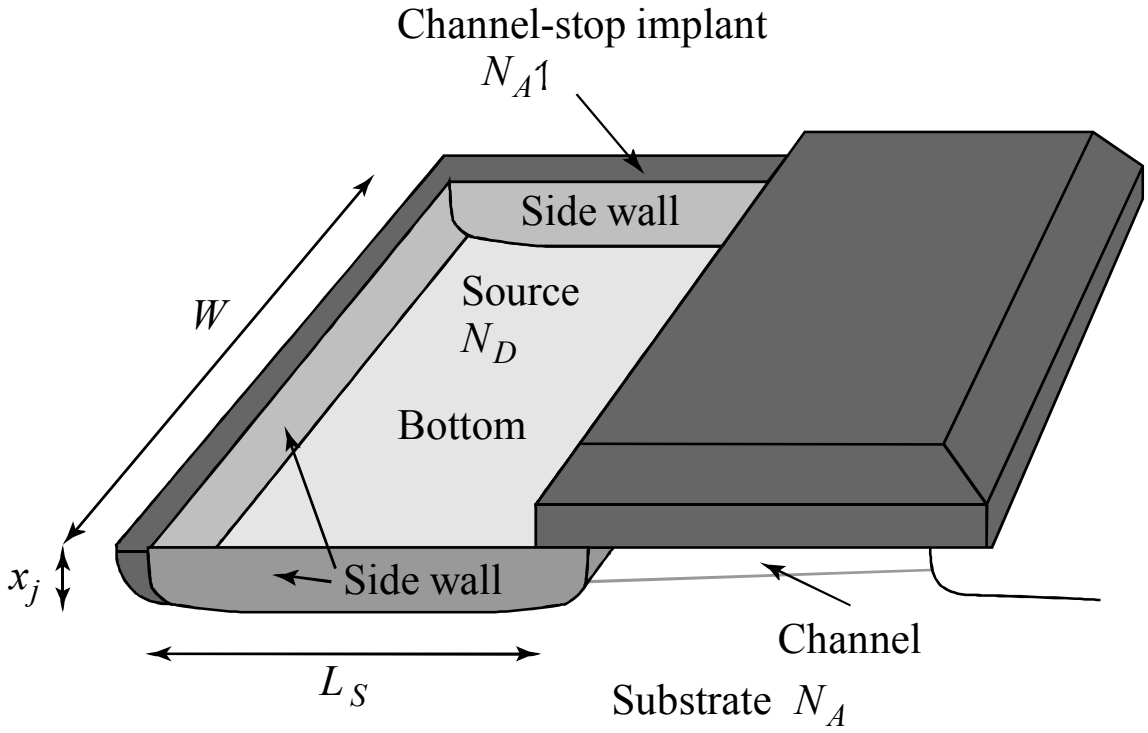
源、漏区pn结电容



$$C_{diff} = C_{bottom} + C_{sw} = C_j \times AREA + C_{jsw} \times PERIMETER$$
$$= C_j L_S W + C_{jsw}(2L_S + W)$$

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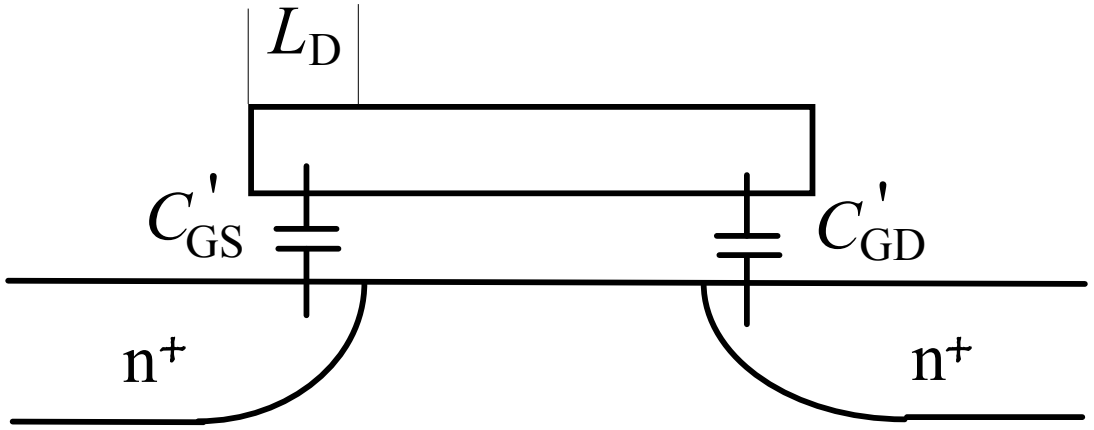
栅-源、栅-漏覆盖电容



$$C_{GS}' = C_{GD}' = WL_D C_{ox}$$

$$C_{GS}' = WC_{GS0}, \quad C_{GD}' = WC_{GD0}$$

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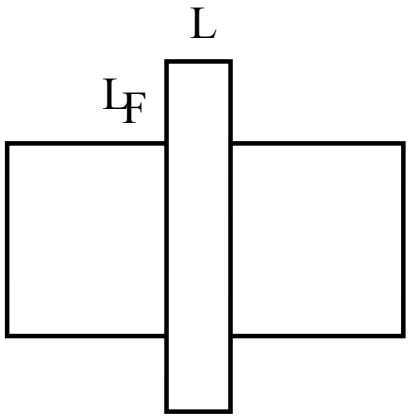
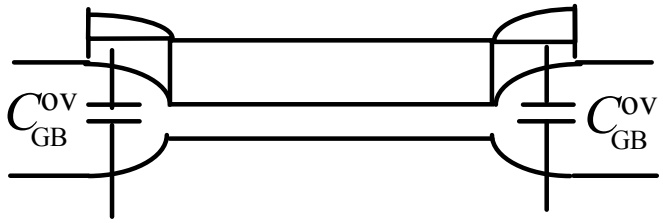
栅-衬底覆盖电容





$$C_{GB}' = L\,L_F C_{oxF} = LC_{GB0}$$

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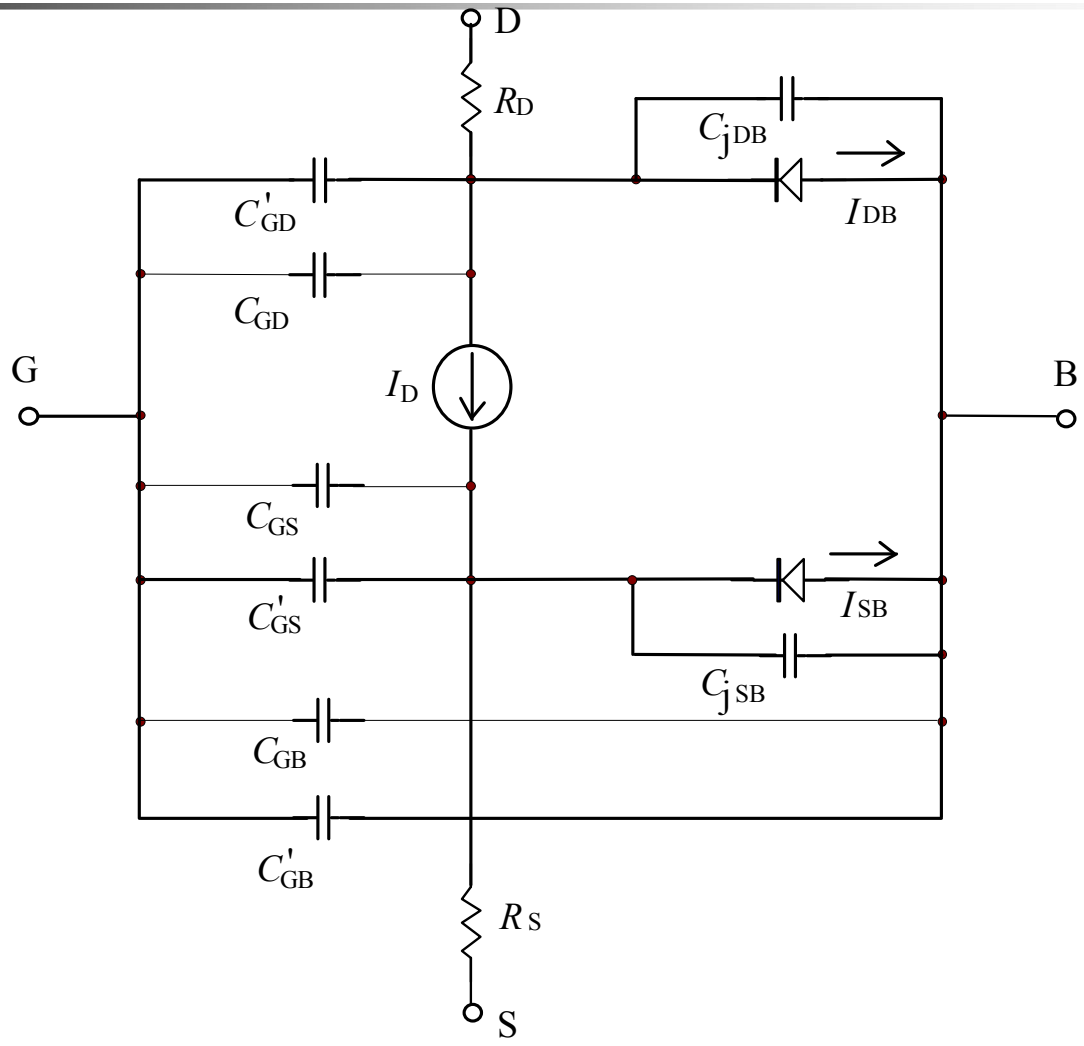
MOS晶体管的瞬态分析模型



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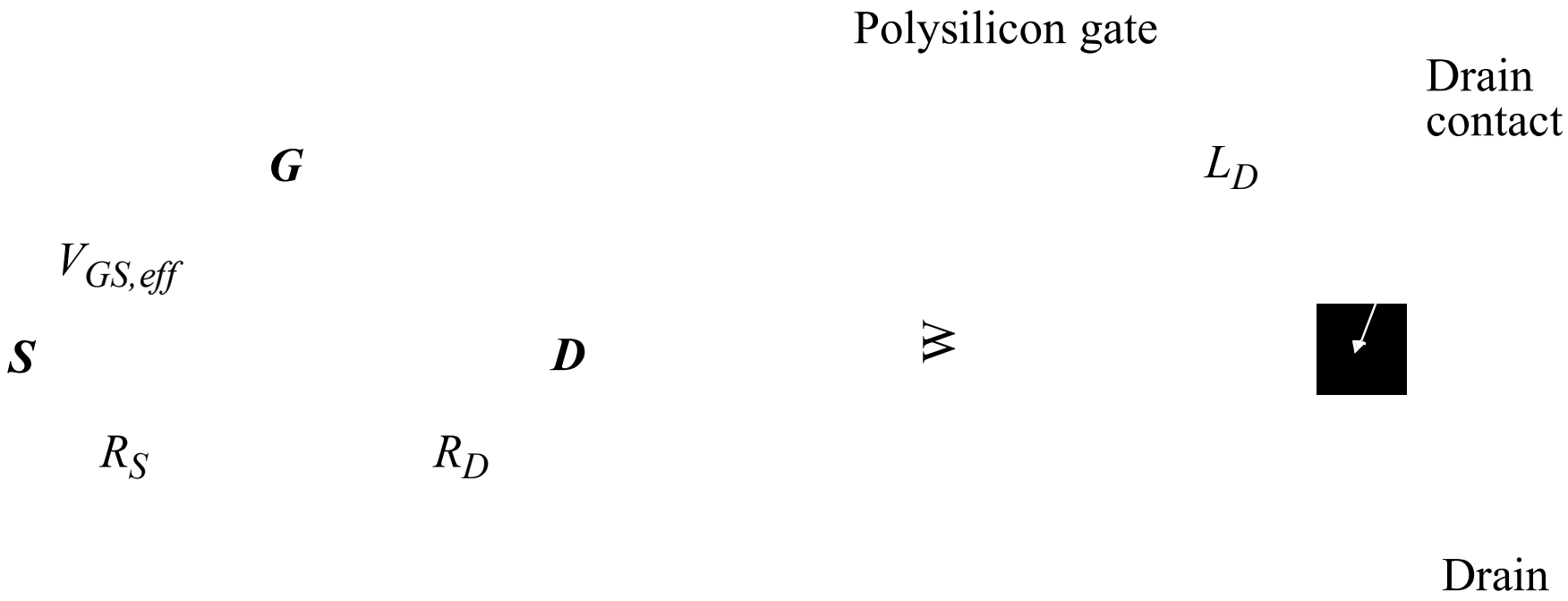
Parasitic Resistances



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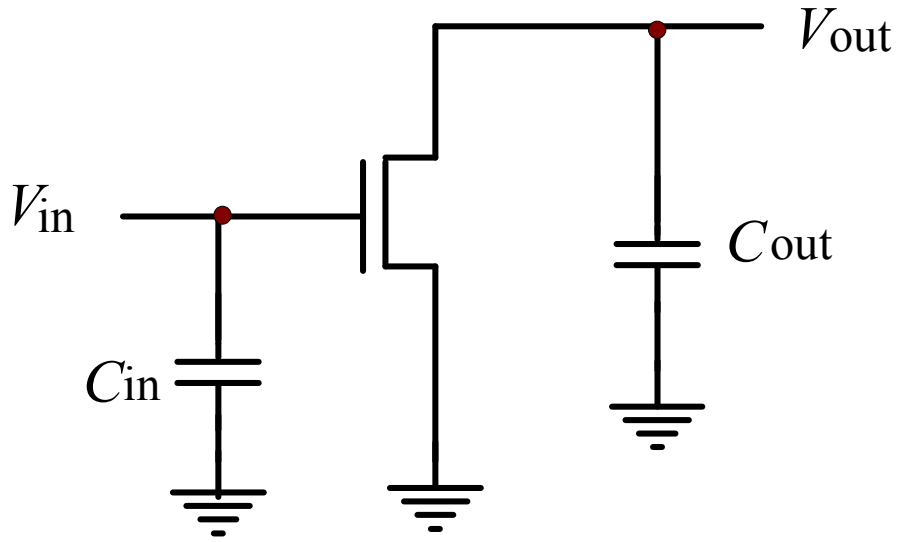
MOSFET电容的简化模型



$$C_{in} \approx WLC_{ox}$$

$$C_{out} \approx C_{DB}$$

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0.25 μm CMOS Capacitances

$$C_{jA} = C_{j0}\left(1+\frac{V}{V_{bi}}\right)^{-1/2}$$

$$C_{jP} = C_{jp0}\left(1+\frac{V}{V_{bi}}\right)^{-1/3}$$

	C_{ox} (fF/μm²)	C_O (fF/μm)	C_j (fF/μm²)	m_j	ϕ_b (V)	C_{jsw} (fF/μm)	m_{jsw}	ϕ_{bsw} (V)
NMOS	6	0.31	2	0.5	0.9	0.28	0.44	0.9
PMOS	6	0.27	1.9	0.48	0.9	0.22	0.32	0.9

- **W/L=0.36um/0.25um的NMOS（$L_{D,S}$=0.625u）**
- 根据设计规则，计算出栅和漏端的电容

$$C_G = WLC_{ox} = 0.54fF, \quad C'_{GD} = C'_{GS} = WC_O = 0.11fF, \quad \therefore C_{in} = 0.76fF$$

$$C_{bottom} = C_j WL_D = 0.45fF, \quad C_{sw} = C_{jsw}(W+2L_D) = 0.45fF, \quad \therefore C_{out} = 0.9fF$$

- 如果考虑反偏电压和适当的版图优化，二者基本相等，漏端电容甚至更小些