微电子器件物理
MOS电容

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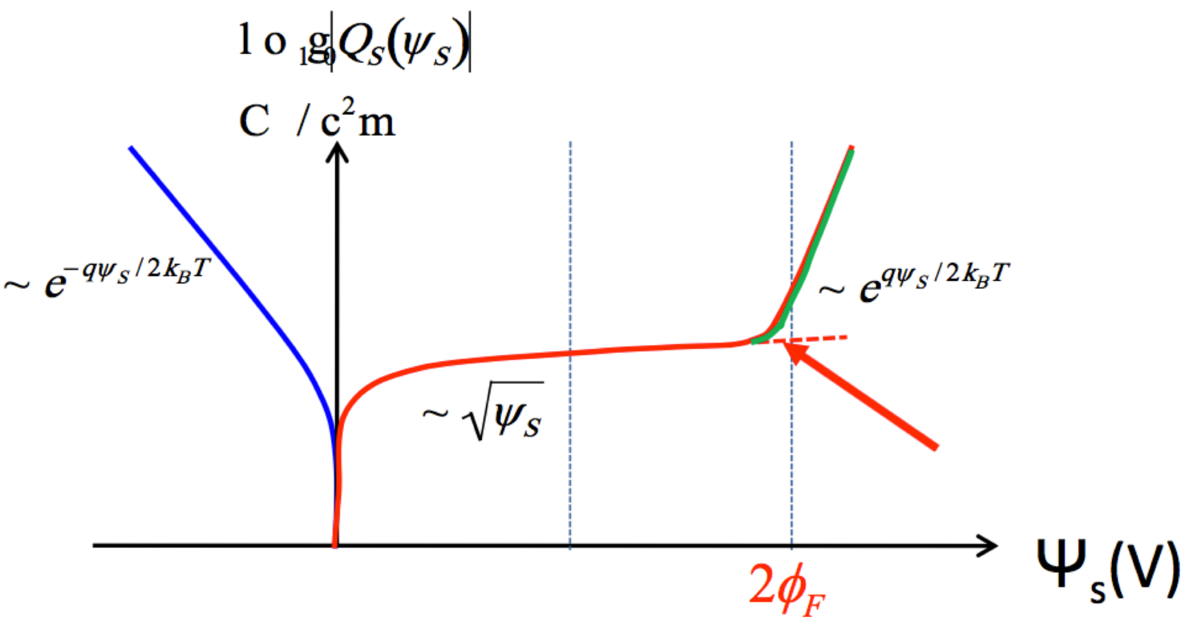
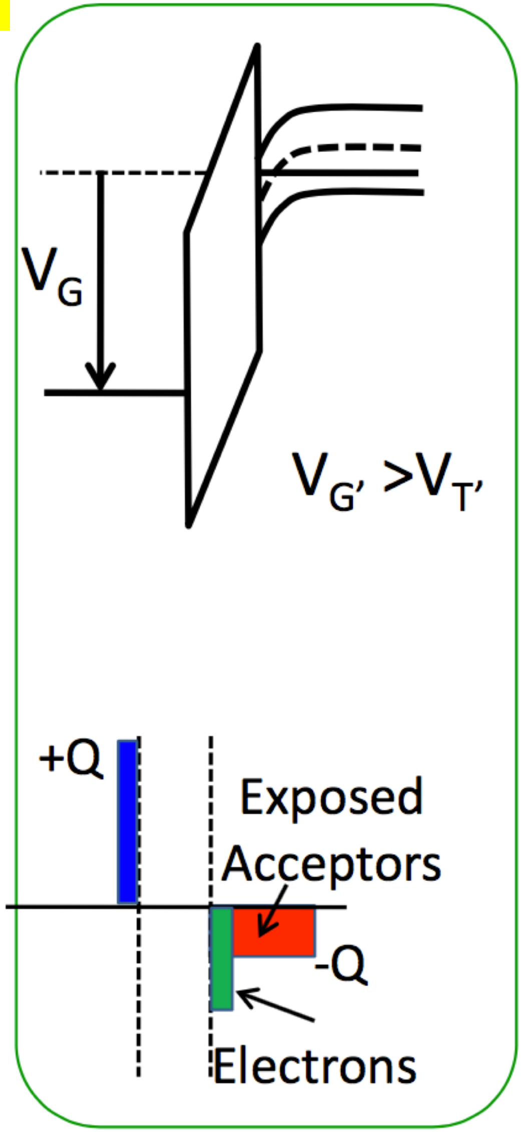
MOS电容：反型层形成

$$V_G = \frac{qN_A x_0}{\kappa_{ox}\varepsilon_0}\sqrt{\frac{2\kappa_{ox}\varepsilon_0}{qN_A}}\sqrt{\psi_s} + \psi_s$$

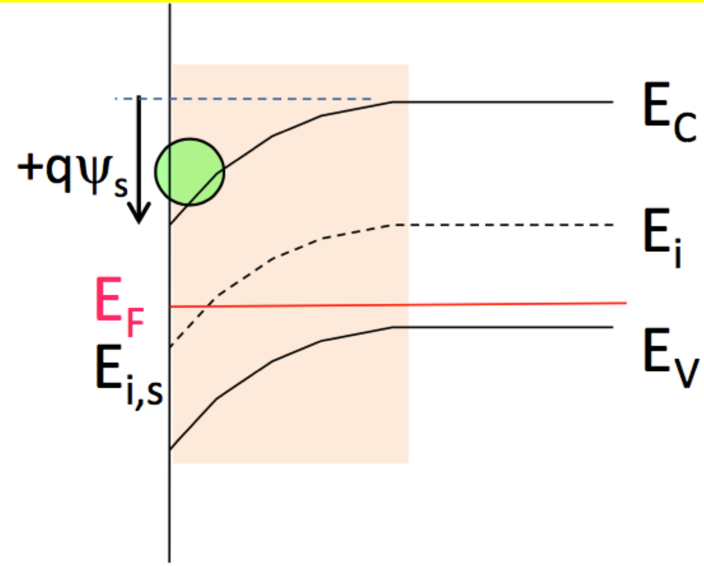
$$V_{th} = \frac{qN_A x_0}{\kappa_{ox}\varepsilon_0}\sqrt{\frac{2\kappa_{ox}\varepsilon_0}{qN_A}}\sqrt{2\phi_F} + 2\phi_F$$





MOS电容：反型层形成

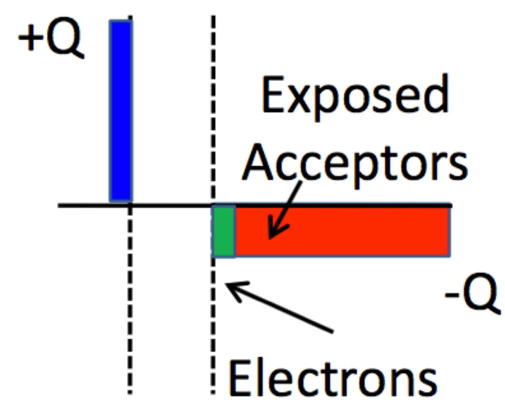
$$V_{th}=\frac{qN_A x_0}{\kappa_{ox}\varepsilon_0}\sqrt{\frac{2\kappa_{ox}\varepsilon_0}{qN_A}}\sqrt{2\phi_F}+2\phi_F$$



$$n_{1s}=n_i e^{(E_F-E_{is})\beta}$$

$$=n_i e^{(E_F-E_{i(bulk)})\beta}\times e^{(E_{i(bulk)}-E_{is})\beta}$$

$$=n_i e^{-\phi_F\beta}e^{(E_{i(bulk)}-E_{is})\beta}$$



$$n_{1s}=n_i e^{-\phi_F\beta}e^{2\phi_F\beta}$$

$$=n_i e^{\phi_F\beta}=N_A$$

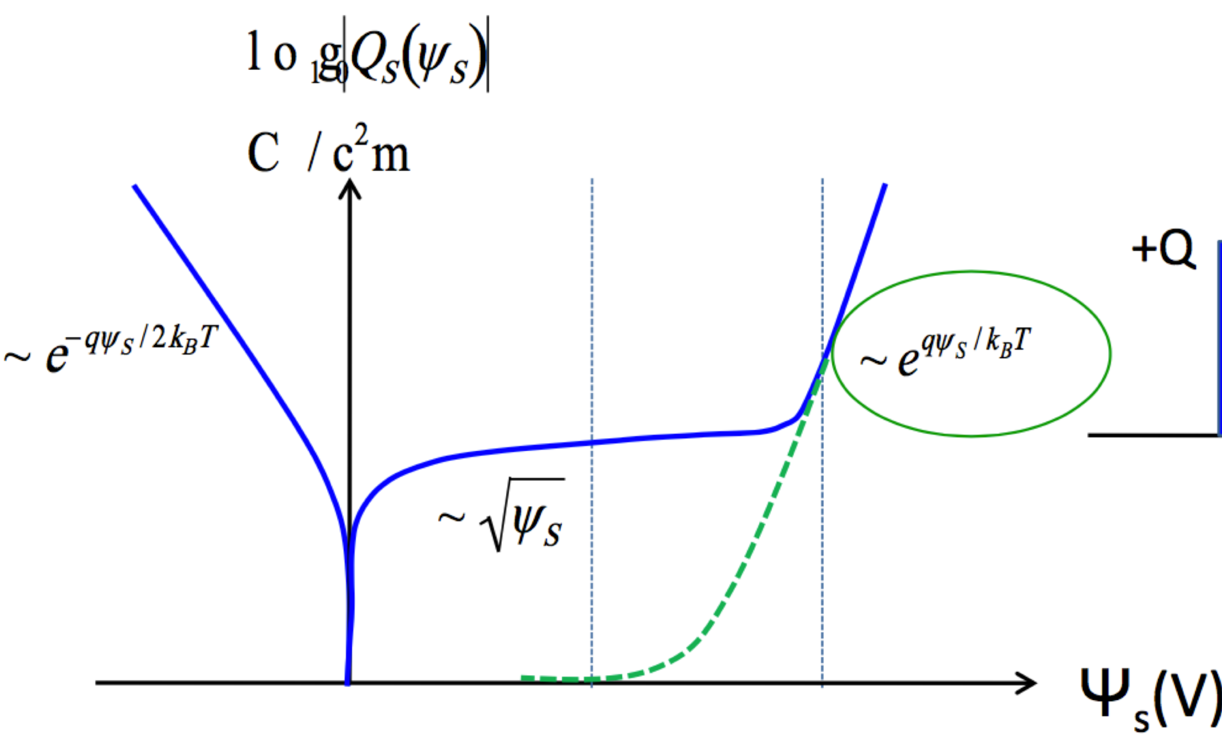
电子浓度等于受主浓度

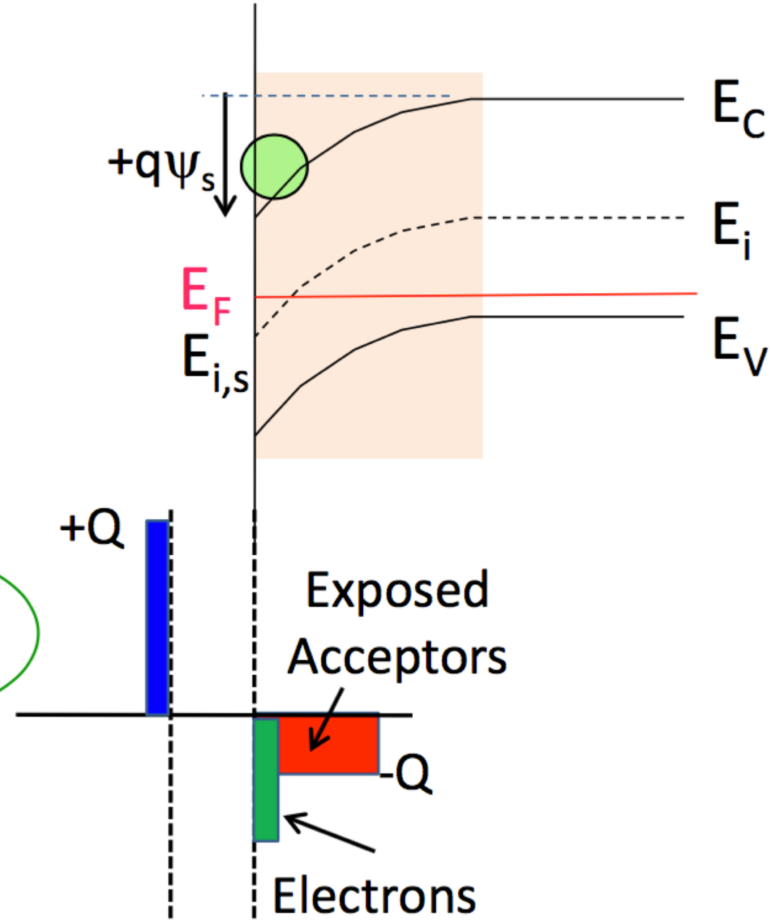
低于阈值时的电荷

$$n_{1s} = n_i e^{-\phi_F \beta} e^{\left(E_{i(bulk)} - E_{is}\right)\beta}$$

$$\equiv B e^{q\psi_s \beta}$$

$$V_G = \frac{qN_A x_0}{\kappa_{ox}\varepsilon_0}\sqrt{\frac{2\kappa_{ox}\varepsilon_0}{qN_A}}\sqrt{\psi_s} + \psi_s$$





低于阈值时的电荷

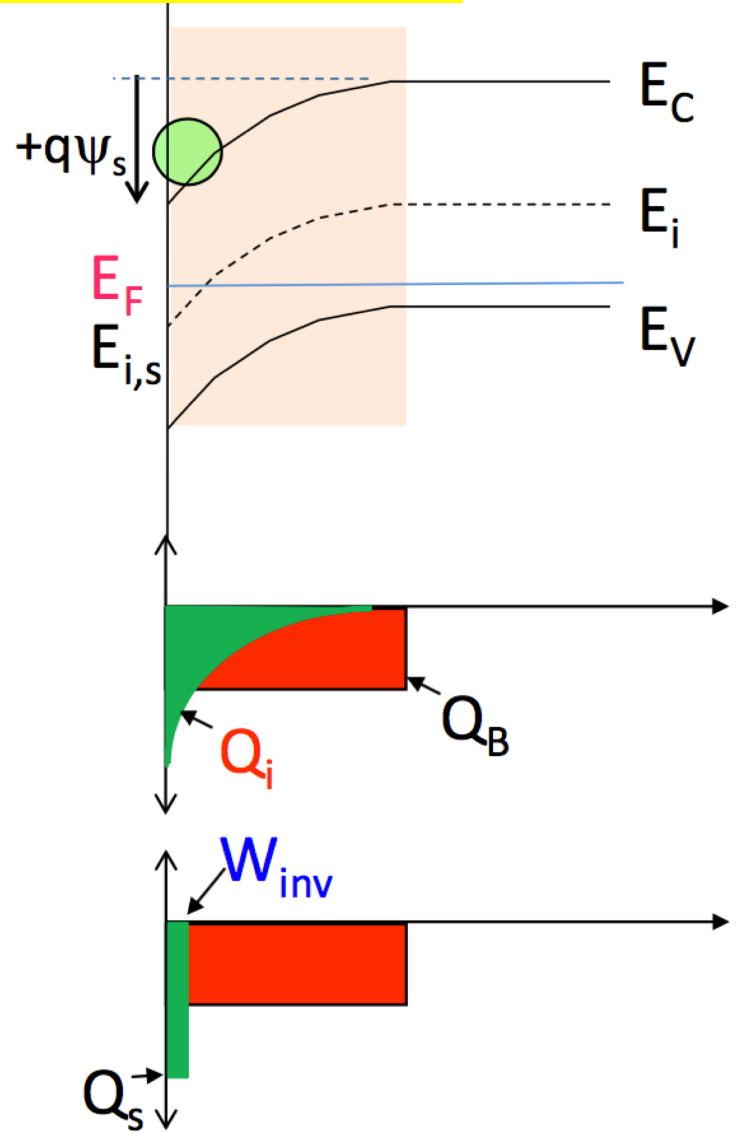
$$\frac{Q_i}{q} = \int_0^\infty n(x)\,dx = \int_0^\infty \frac{n_i^2}{N_B} e^{q\psi(x)\beta}\,dx$$

$$= \frac{n_i^2}{N_B}\int_0^\infty e^{q\psi(x)\beta}\frac{1}{\frac{d\psi}{dx}}d\psi$$

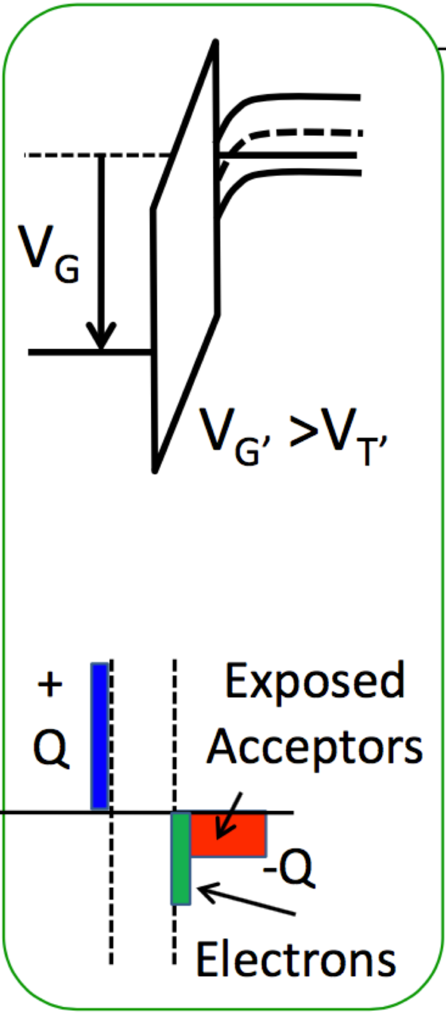
$$= \frac{n_i^2}{N_B}\int_0^\infty e^{q\psi(x)\beta}\frac{1}{\mathcal{E}(x)}d\psi$$

$$\approx \frac{1}{\langle \mathcal{E}(x)\rangle}\frac{n_i^2}{N_B}\int_0^\infty e^{q\psi(x)\beta}d\psi$$

$$= \frac{\left(\frac{k_B T}{q}\right)}{\langle \mathcal{E}(x)\rangle}\times\frac{n_i^2}{N_B}e^{q\psi_s\beta} \equiv W_{inv}\times n_s$$



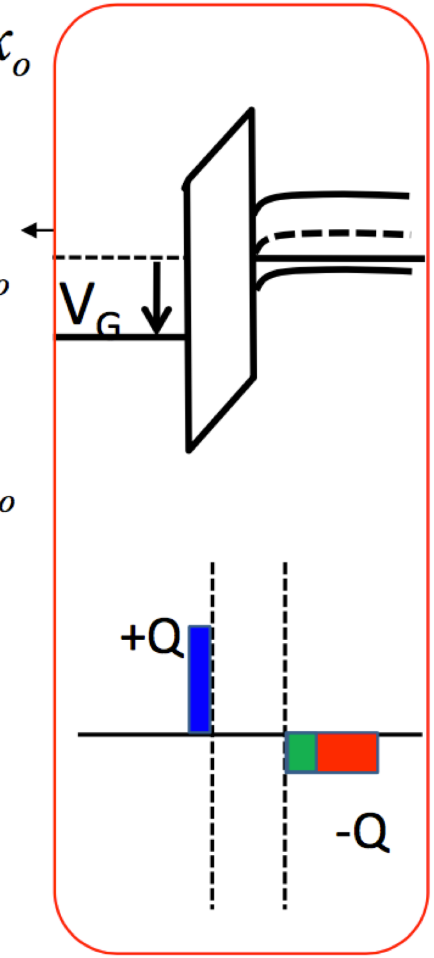
高于阈值时的电荷



$$V_G = \psi_s + \mathcal{E}_{ox} x_o = \psi_s - \left[\frac{Q_i(\psi_s)+Q_F}{\kappa_{ox}\varepsilon_0}\right] x_o$$

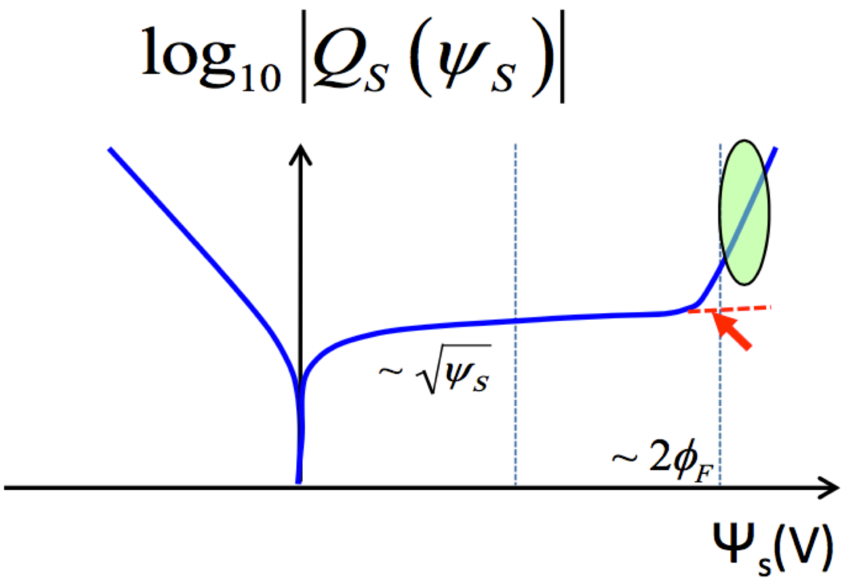
$$V_{th} = 2\phi_F + \mathcal{E}_{ox} x_o = 2\phi_F - \left(\frac{Q_i(2\phi_F)+Q_F}{\kappa_{ox}\varepsilon_0}\right) x_o$$

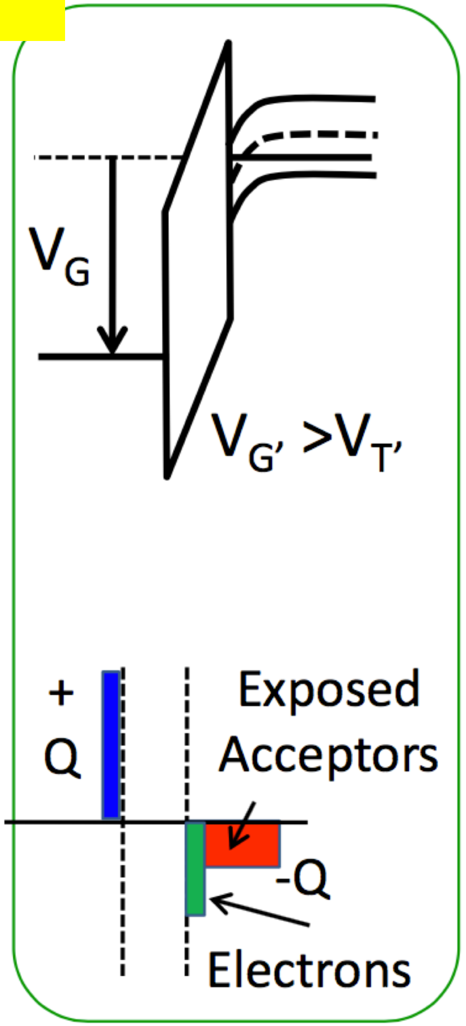
$$V_G - V_{th} = (\psi_s - 2\phi_F) + \frac{Q_i(\psi_s) - Q_i(2\phi_F)}{\kappa_{ox}\varepsilon_0} x_o$$



$$\boxed{Q_i = C_{ox}(V_G - V_{th})}$$

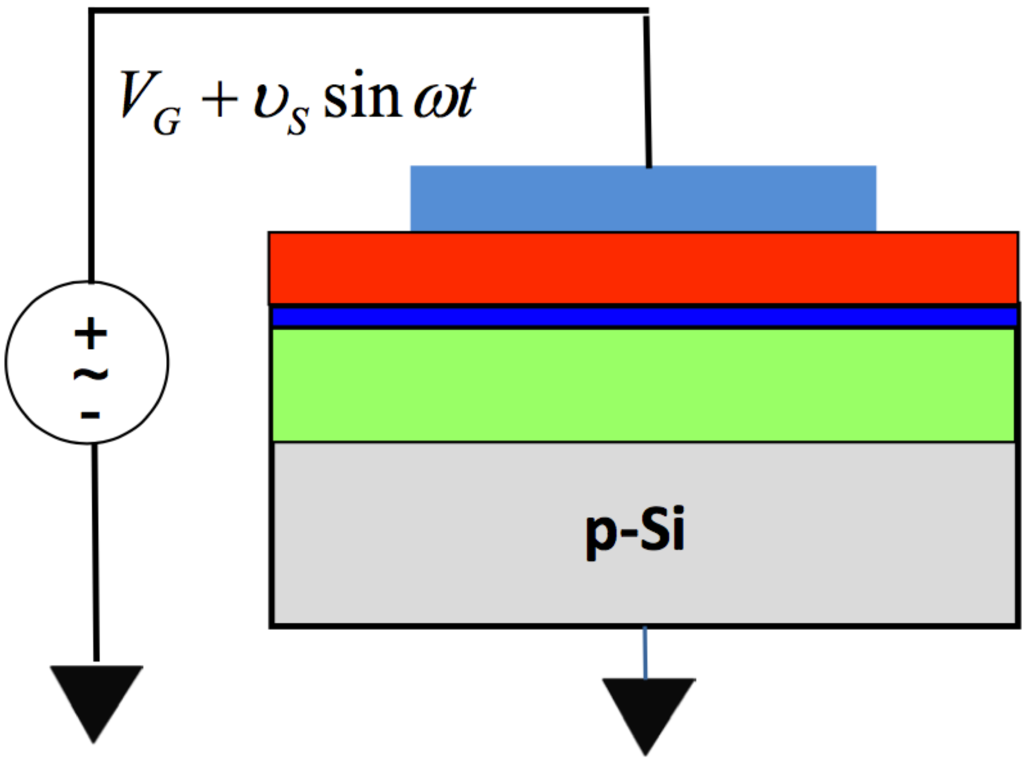
高于阈值时的电荷





- 很小的表面势变化引起很大的反型层电荷变化
- 反型层变化引起氧化层电压的变化

MOS的小信号电容



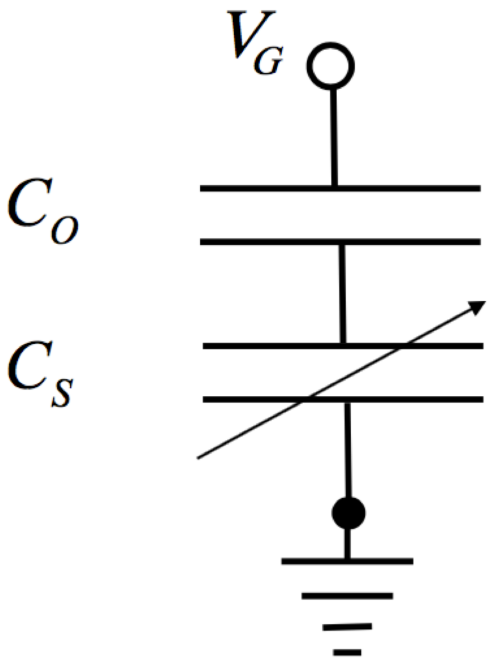
$$C_G \equiv \frac{dQ_G}{dV_G} = \frac{d(-Q_S)}{dV_G}$$

$$V_G = \psi_S - \frac{Q_S}{C_O}$$

$$\frac{dV_G}{d(-Q_S)} = \frac{d\psi_S}{d(-Q_S)} + \frac{1}{C_O}$$

$$\frac{1}{C_G} = \frac{1}{C_S} + \frac{1}{C_O}$$

MOS的小信号电容



$$\frac{1}{C_G} = \frac{1}{C_S} + \frac{1}{C_O}$$

$$C_S \equiv \frac{d\left(-Q_S\right)}{d\psi_S}$$

$$Q_S\left(\psi_S\right)$$

我们已经推导过了

m的定义

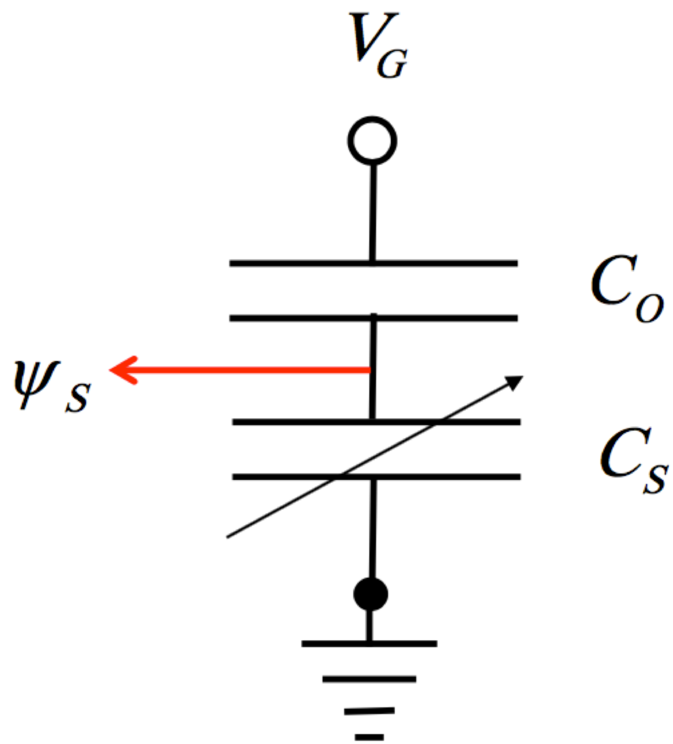
$$m = \left(1 + C_S / C_O\right)$$

体效应因子

$$m = \left(1 + \kappa_S x_O / \kappa_0 W_T\right)$$

通常

$$1.1 \le m \le 1.4$$



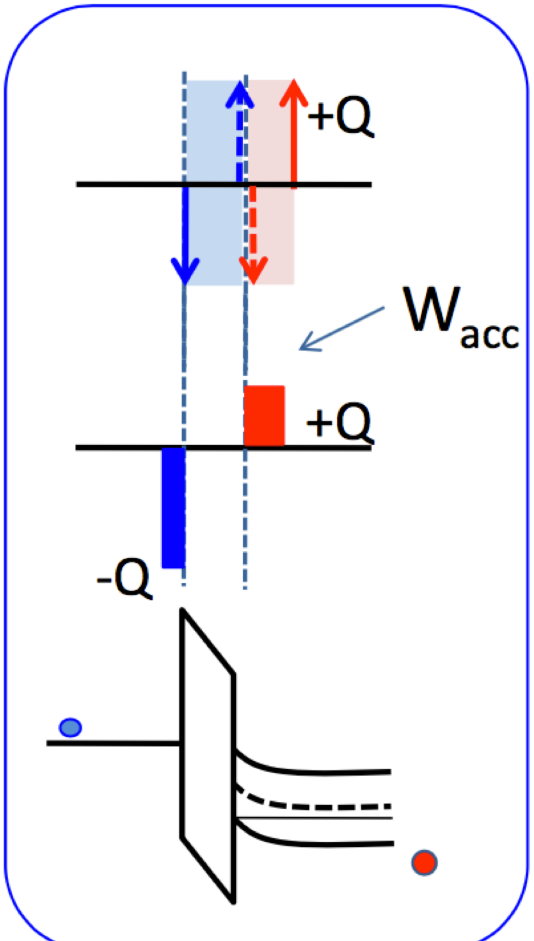
$$\psi_S = \frac{C_O}{C_O + C_S} V_G \equiv \frac{V_G}{m}$$

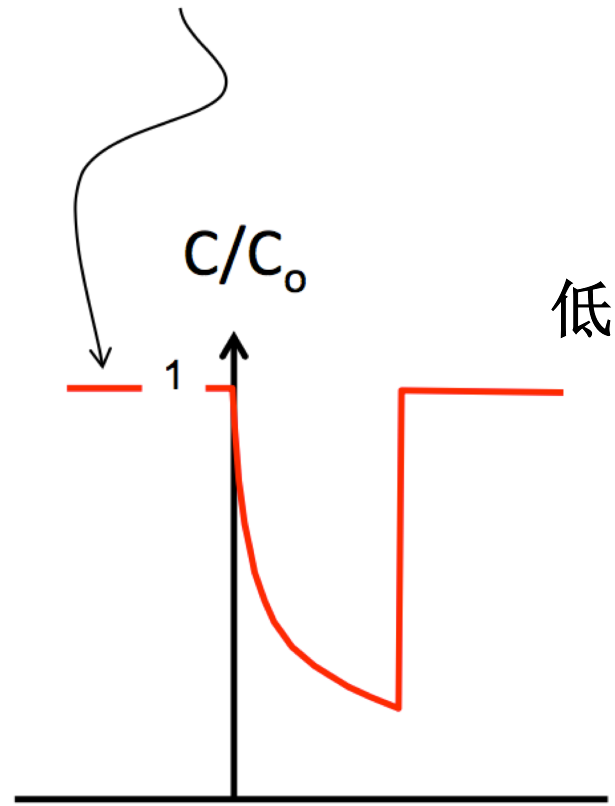
MOS的小信号电容：积累

$$C_{j,acc} \approx \frac{\kappa_{ox}\varepsilon_0}{x_0} \equiv C_0$$

$$C_{j,acc} = \frac{C_o C_{s,acc}}{C_o + C_{s,acc}}$$

$$C_{s,acc} \equiv \frac{\kappa_s \varepsilon_0}{W_{acc}}$$

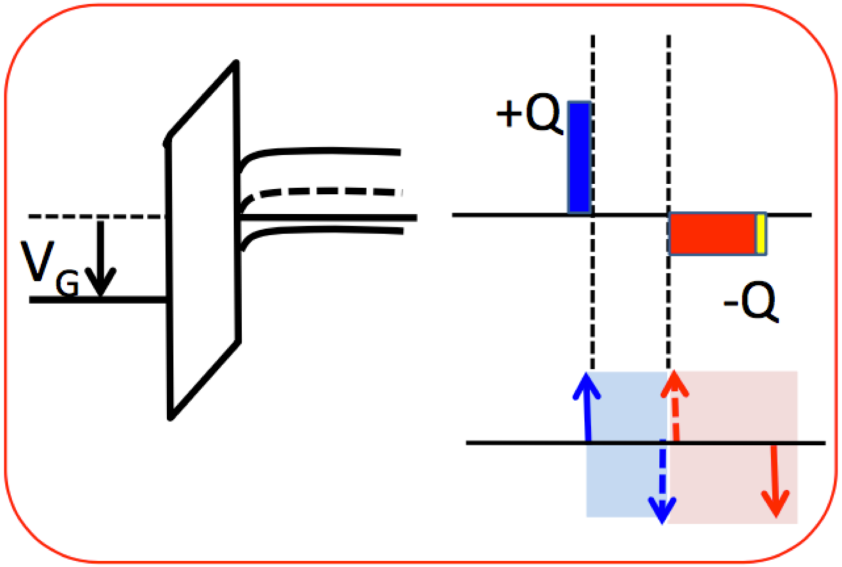




MOS的小信号电容：耗尽

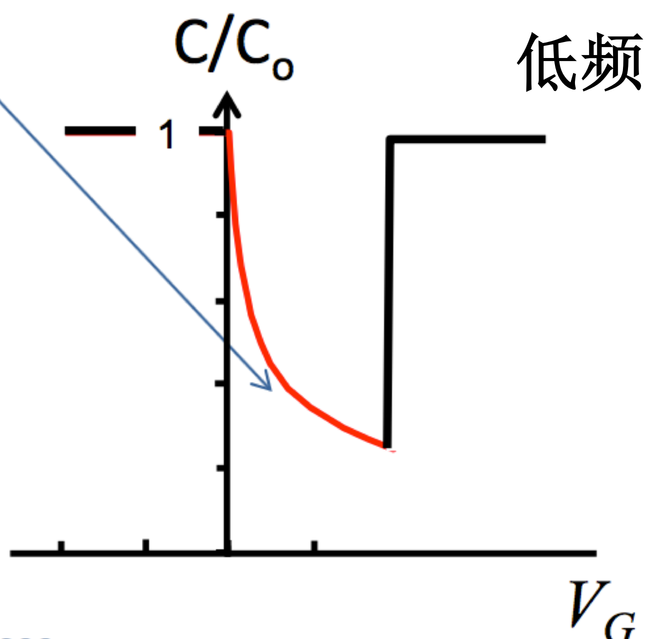
$$C_{j,dep} = \frac{C_0 C_s}{C_0 + C_s} = \frac{C_0}{1 + C_0 / C_s}$$

$$= \frac{C_0}{1 + \frac{\kappa_o \varepsilon_0}{x_0} \Big/ \frac{\kappa_s \varepsilon_0}{W}} = \frac{C_o}{\sqrt{1 + \frac{V_G}{V_\delta}}}$$

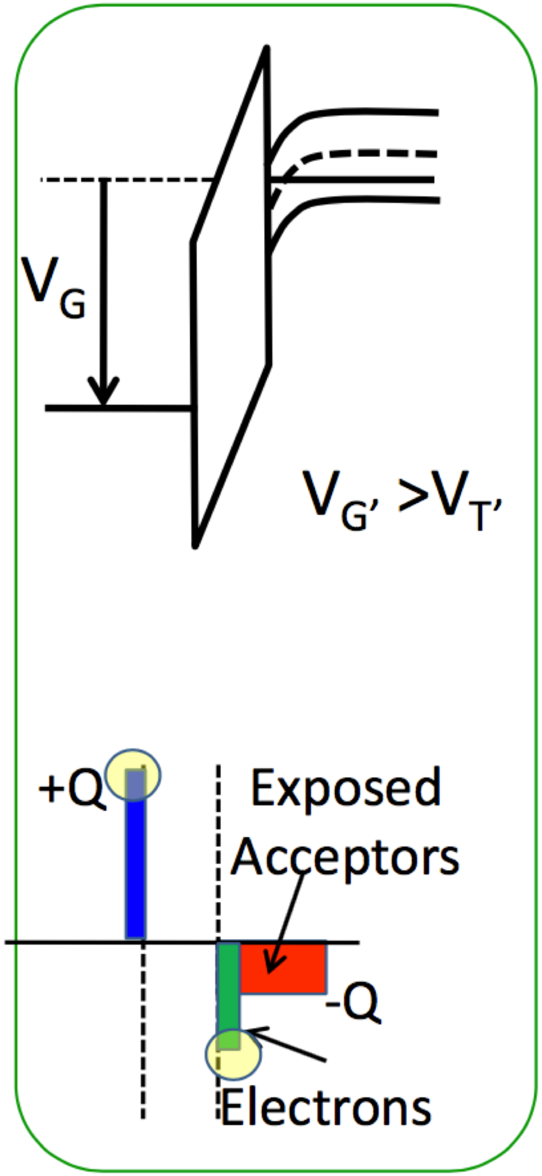


$$V_G = \frac{qN_A W}{\kappa_o \varepsilon_0} x_0 + \left(\frac{qN_A W^2}{2\kappa_s \varepsilon_0} \right)$$

$$\frac{\kappa_o}{\kappa_s} \frac{W}{x_0} = \sqrt{1 + \frac{V_G}{V_\delta}} - 1$$

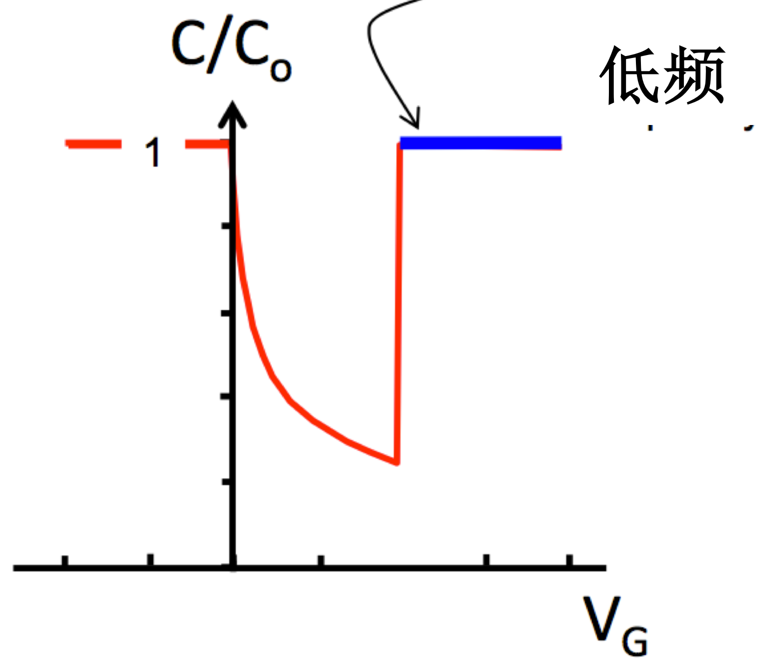


MOS的小信号电容：反型



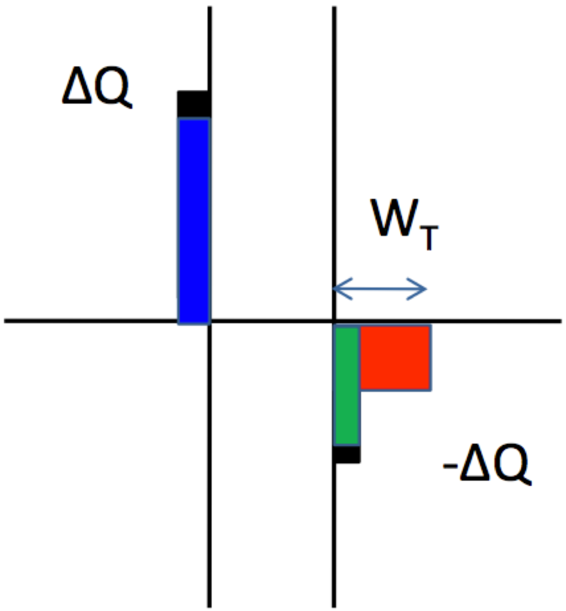
$$C_{j,inv} \approx \frac{\kappa_s \varepsilon_0}{x_0} \equiv C_0$$

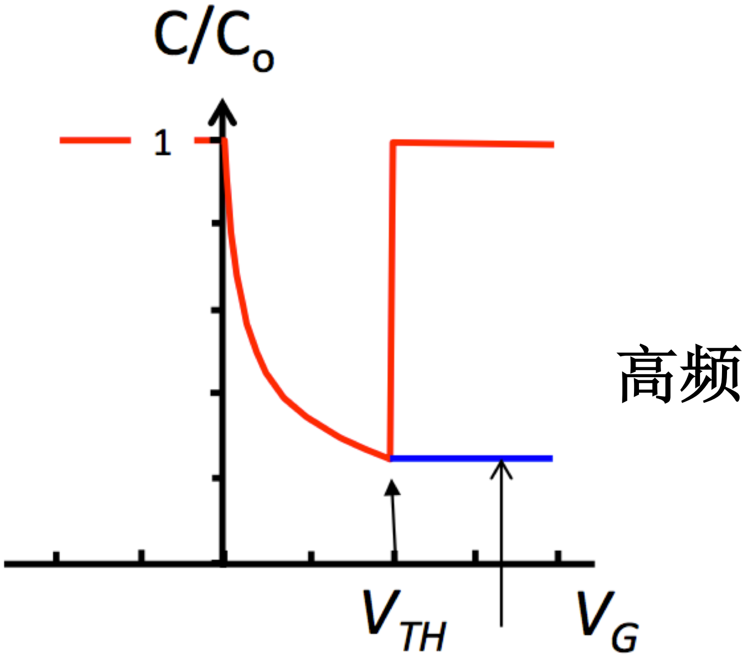
$$C_{j,inv} = \frac{C_o C_{inv}}{C_o + C_{inv}} \qquad C_{inv} \equiv \frac{\kappa_s \varepsilon_0}{W_{inv}}$$



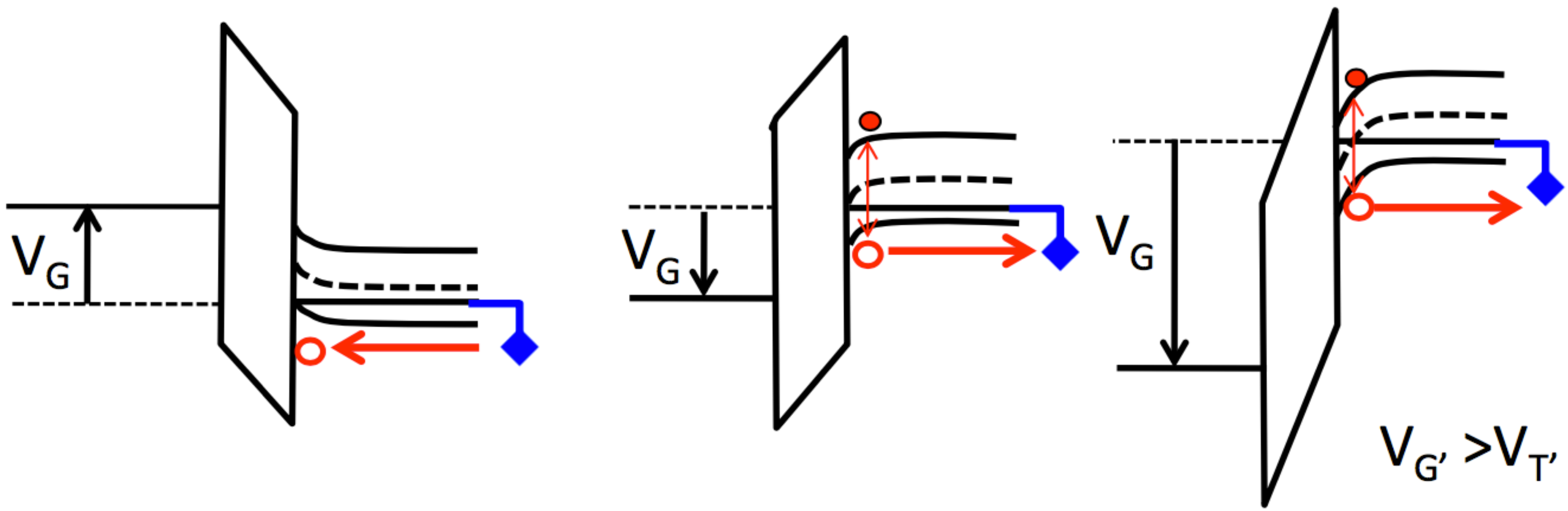
MOS的小信号电容：高频率

$$C_{j,inv} \approx \frac{\kappa_s \varepsilon_0}{x_0} \equiv C_0$$





响应时间



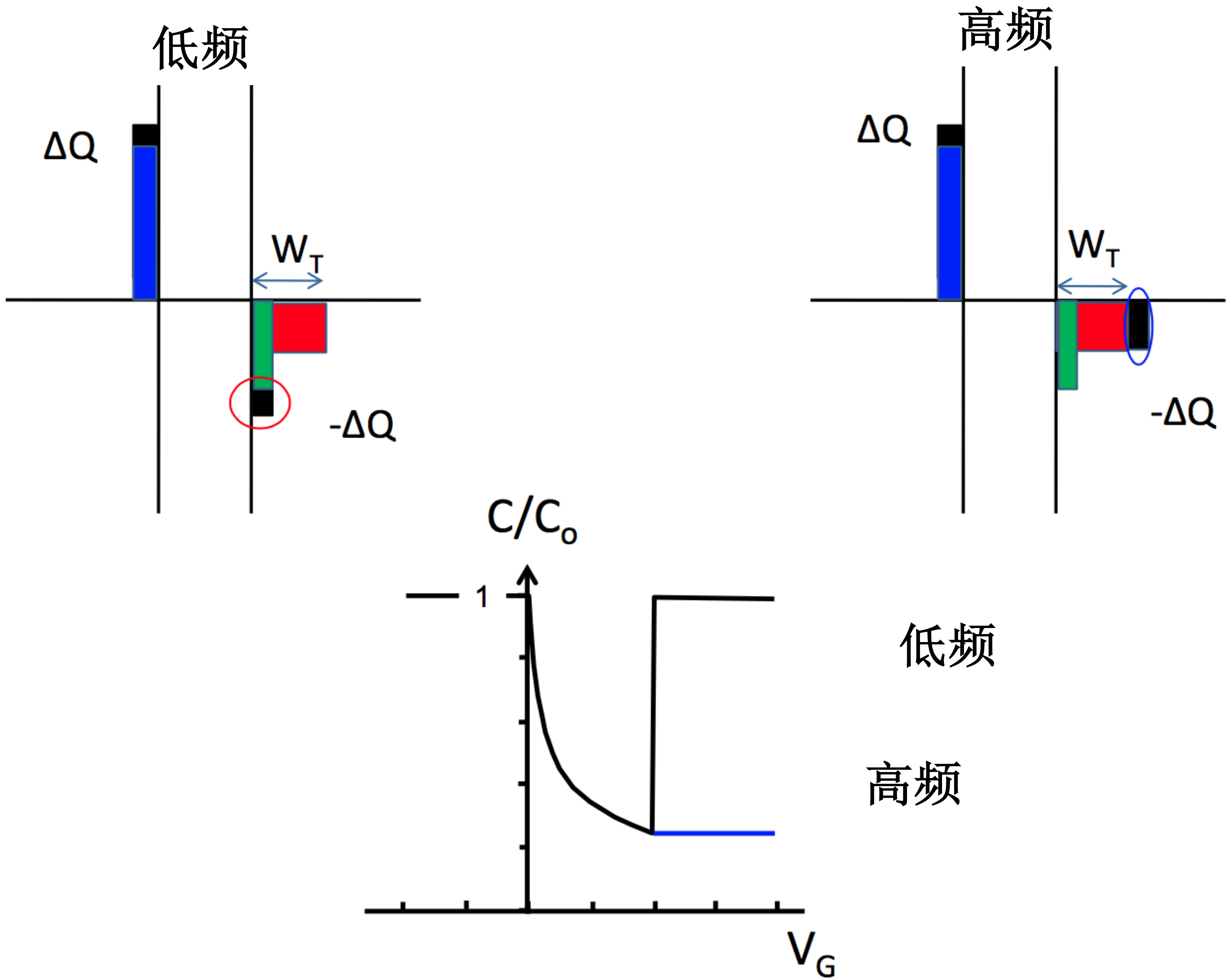
多数载流子

少数载流子（SRH）

$$\tau = \frac{\sigma}{\kappa_s \varepsilon_0}$$

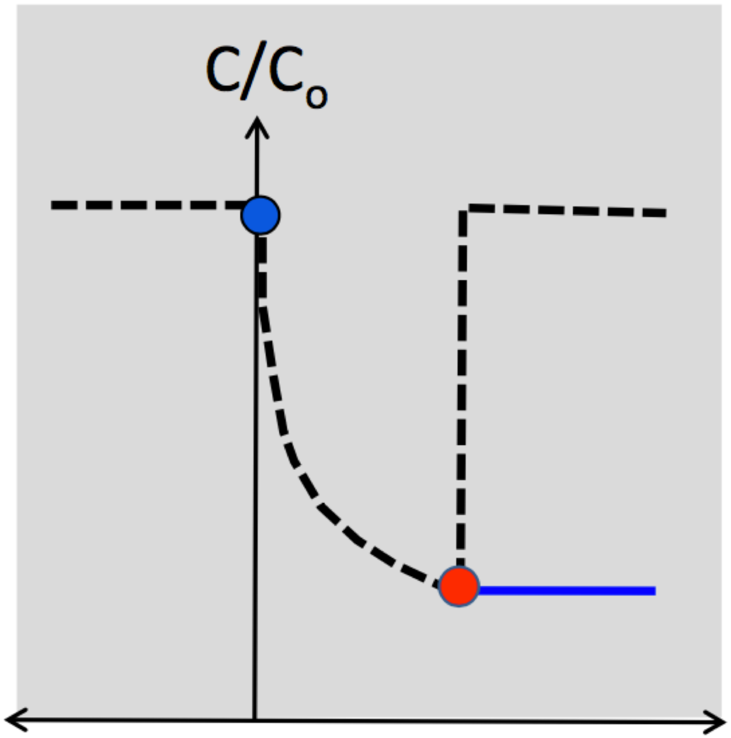
$$R = \frac{np - n_i^2}{\tau_n(p + p_1) + \tau_p(n + n_1)} \rightarrow \frac{-n_i}{\tau_n + \tau_p}$$

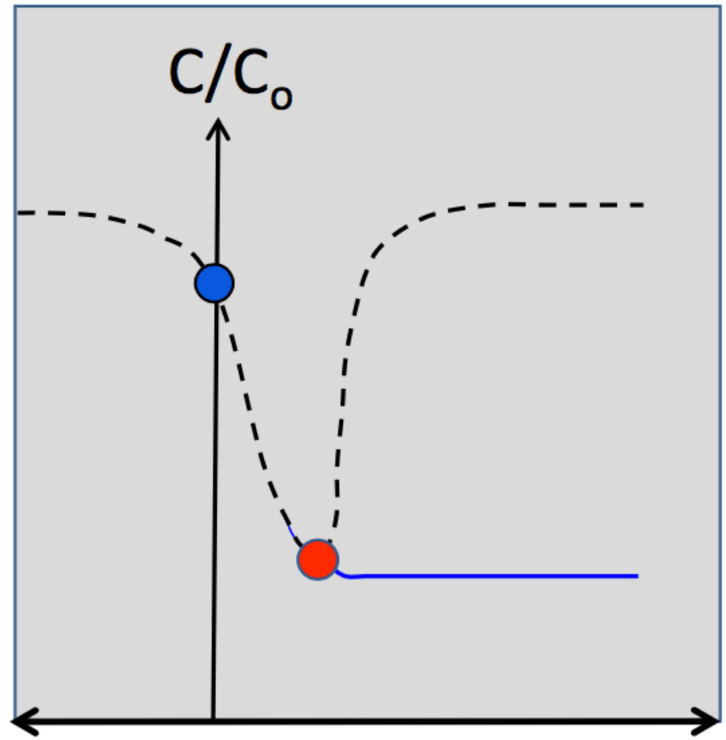
MOS的小信号电容：高频响应



理想CV特性与实际测量结果

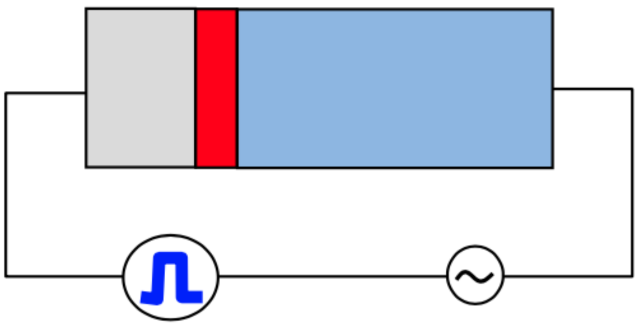
平带电压





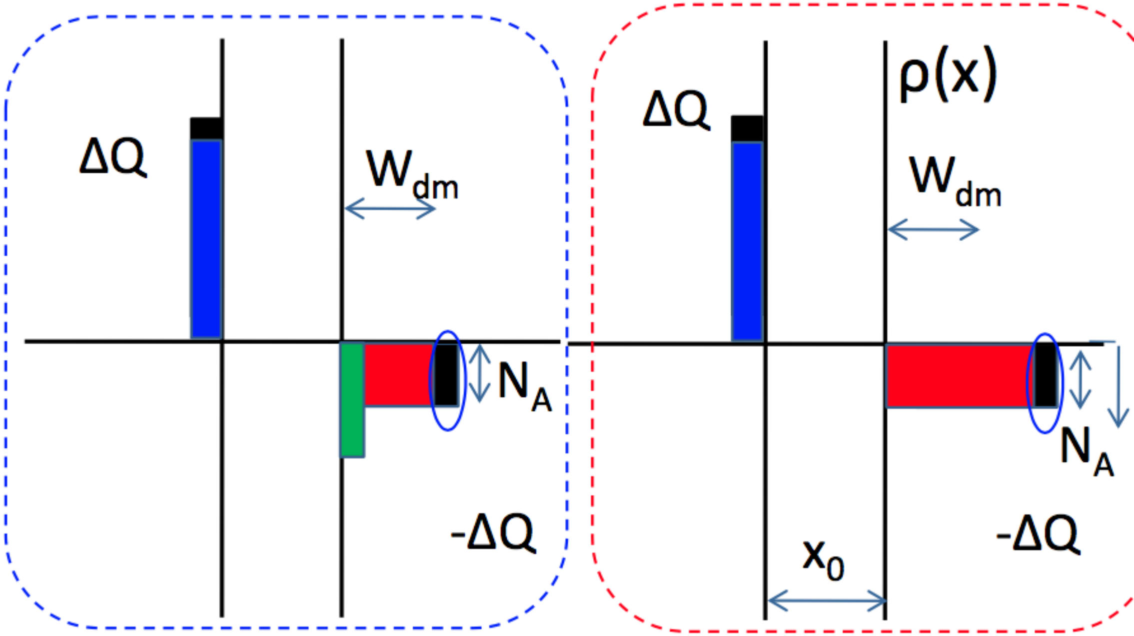
阈值电压

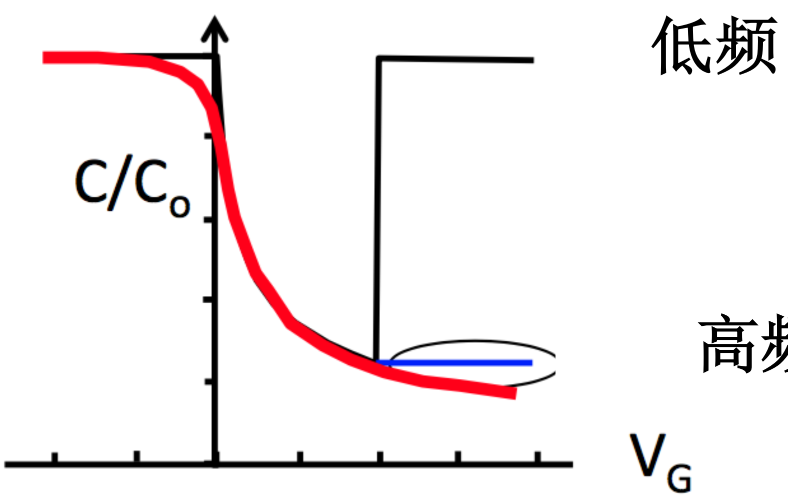
大信号MOS电容：深耗尽



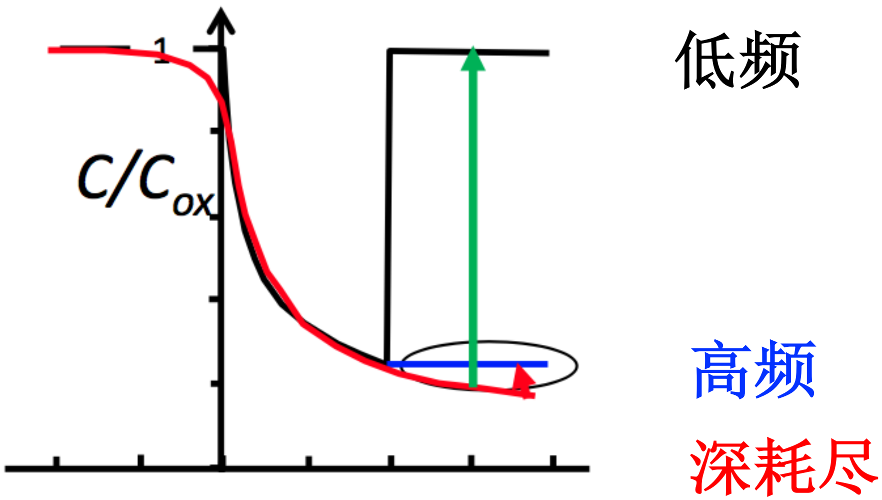
$$C_{j,dep} = \frac{C_0 C_s}{C_0 + C_s} = \frac{C_0}{1 + \frac{\kappa_{ox}}{\kappa_s}\frac{W}{x_0}}$$

$$= \frac{C_o}{\sqrt{1 + \frac{V_G}{V_\delta}}}$$

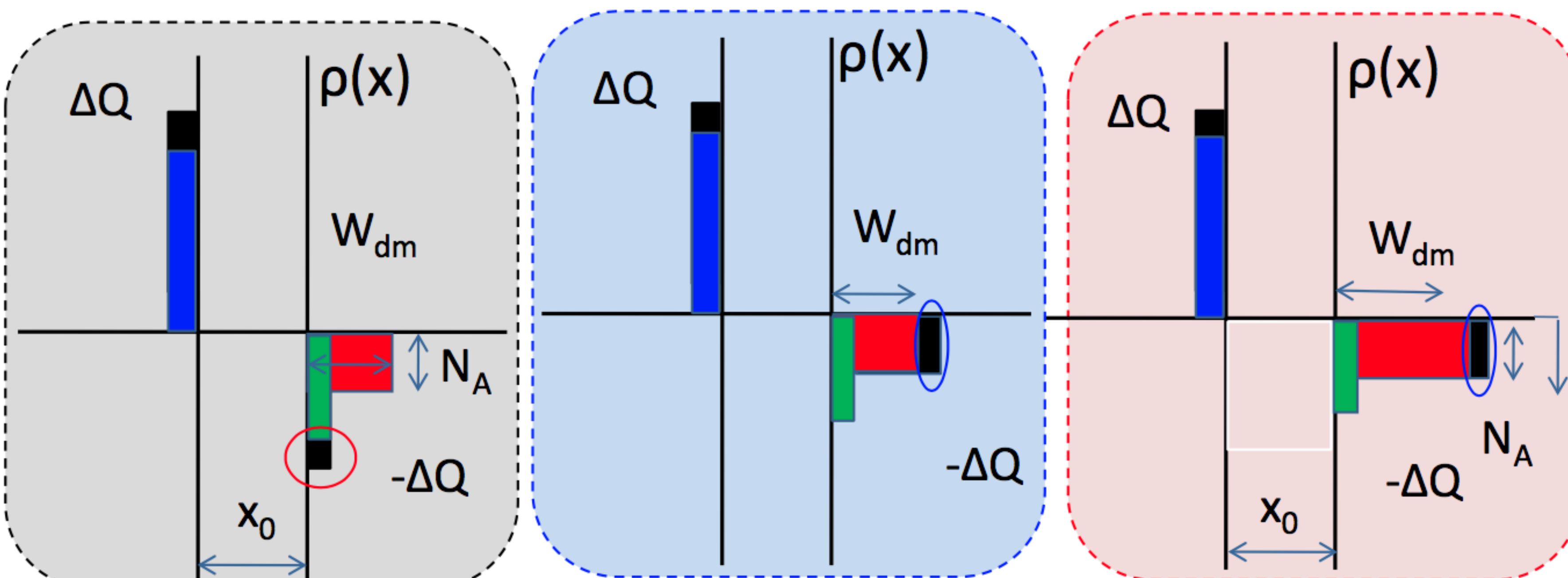




深耗尽情况

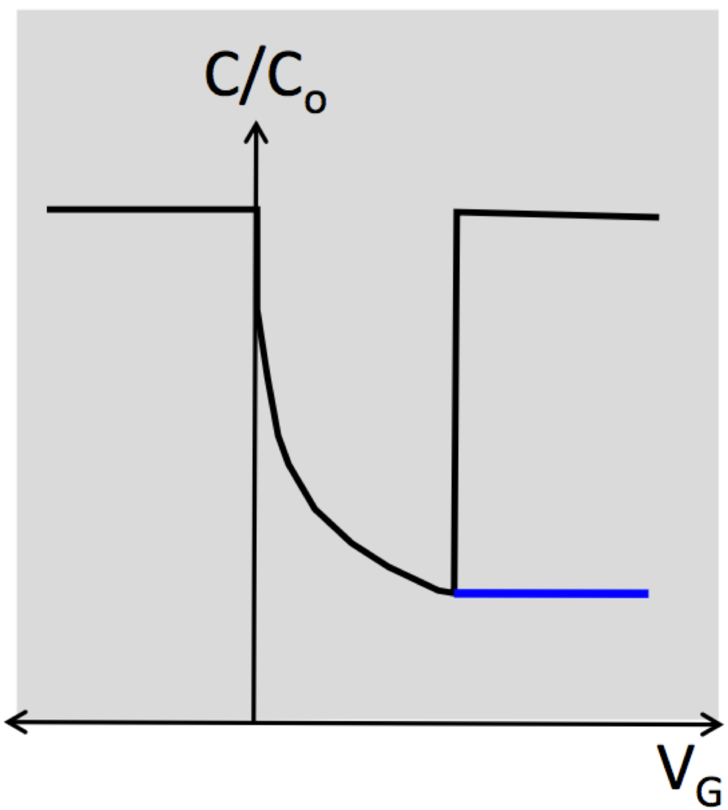


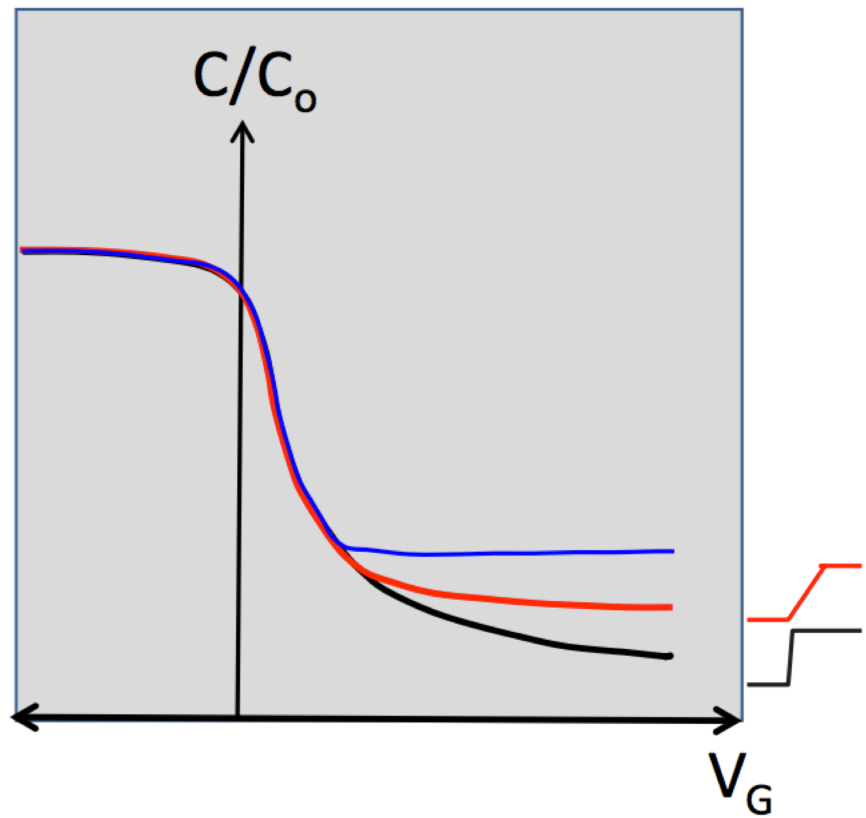
根据测量频率的不同，会出现低频曲线、或者高频曲线施加阶跃信号，则会出现深耗尽



理想CV特性与实际测量结果

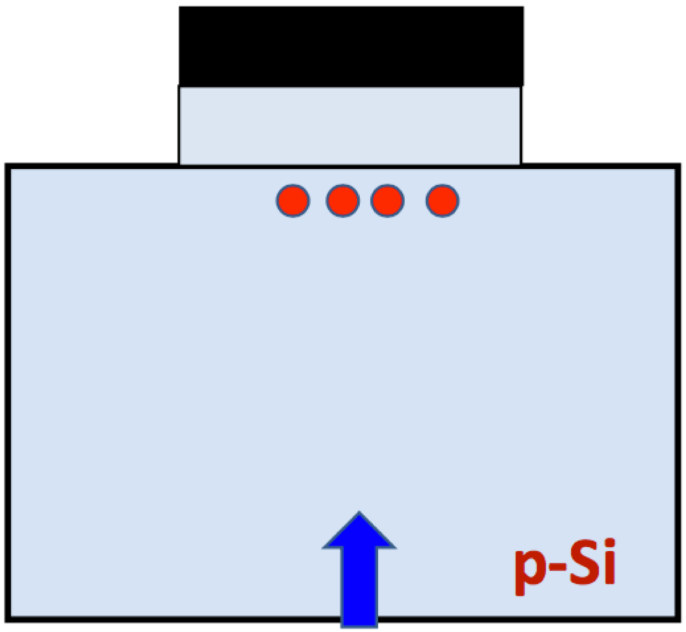
平带电压



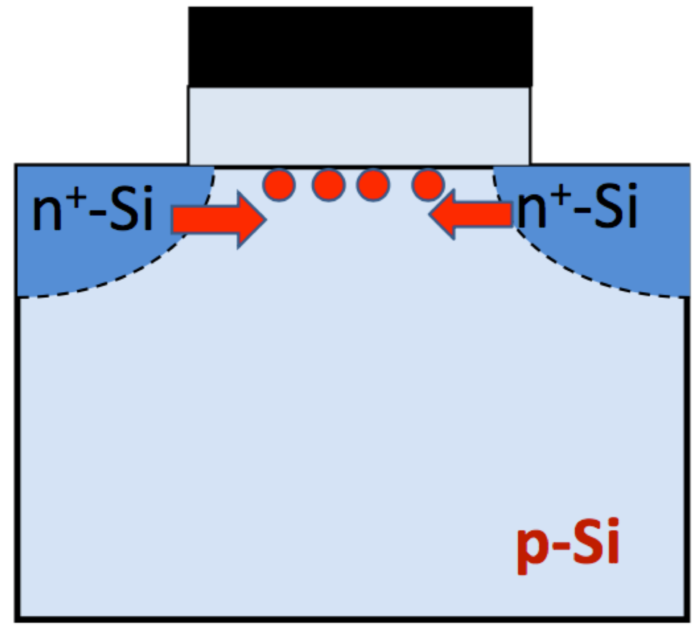


阈值电压

低频还是高频？



$$G = \frac{n_i}{2\tau}$$



通常表现出高频特性

通常表现出低频特性

如果是一束光照射在MOS电容上？

Thanks!
Q&A