

微电子器件物理

MOS电容

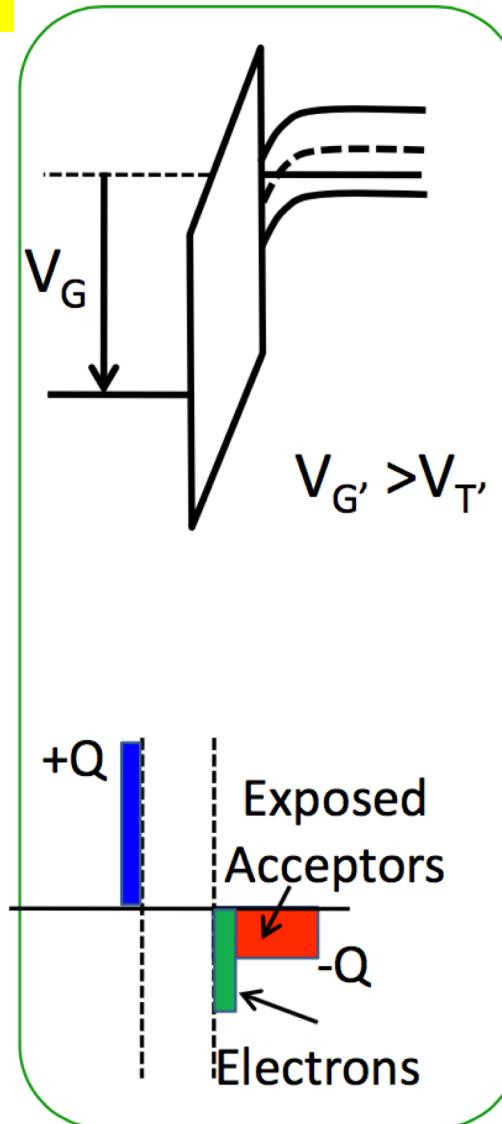
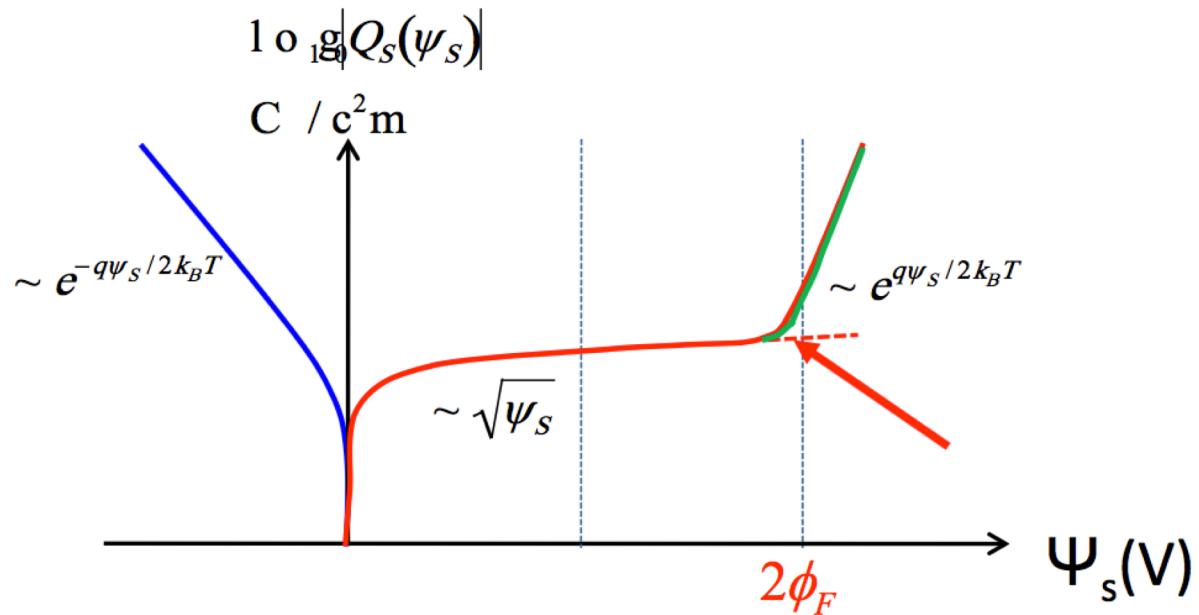
曾琅

2020/10/13

MOS电容：反型层形成

$$V_G = \frac{qN_A x_0}{\kappa_{ox} \epsilon_0} \sqrt{\frac{2\kappa_{ox} \epsilon_0}{qN_A}} \sqrt{\psi_s} + \psi_s$$

$$V_{th} = \frac{qN_A x_0}{\kappa_{ox} \epsilon_0} \sqrt{\frac{2\kappa_{ox} \epsilon_0}{qN_A}} \sqrt{2\phi_F} + 2\phi_F$$



MOS电容：反型层形成

$$V_{th} = \frac{qN_A x_0}{\kappa_{ox} \epsilon_0} \sqrt{\frac{2\kappa_{ox} \epsilon_0}{qN_A}} \sqrt{2\phi_F} + 2\phi_F$$

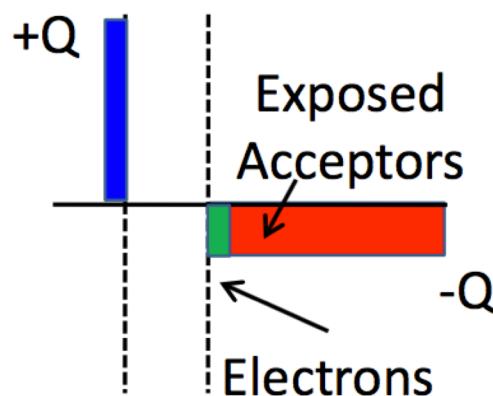
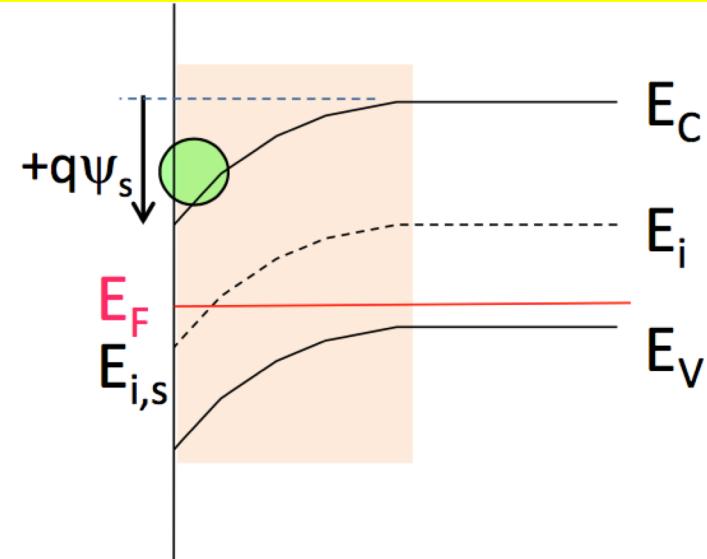
$$n_{Is} = n_i e^{(E_F - E_{is})\beta}$$

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

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

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

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



电子浓度等于受主浓度

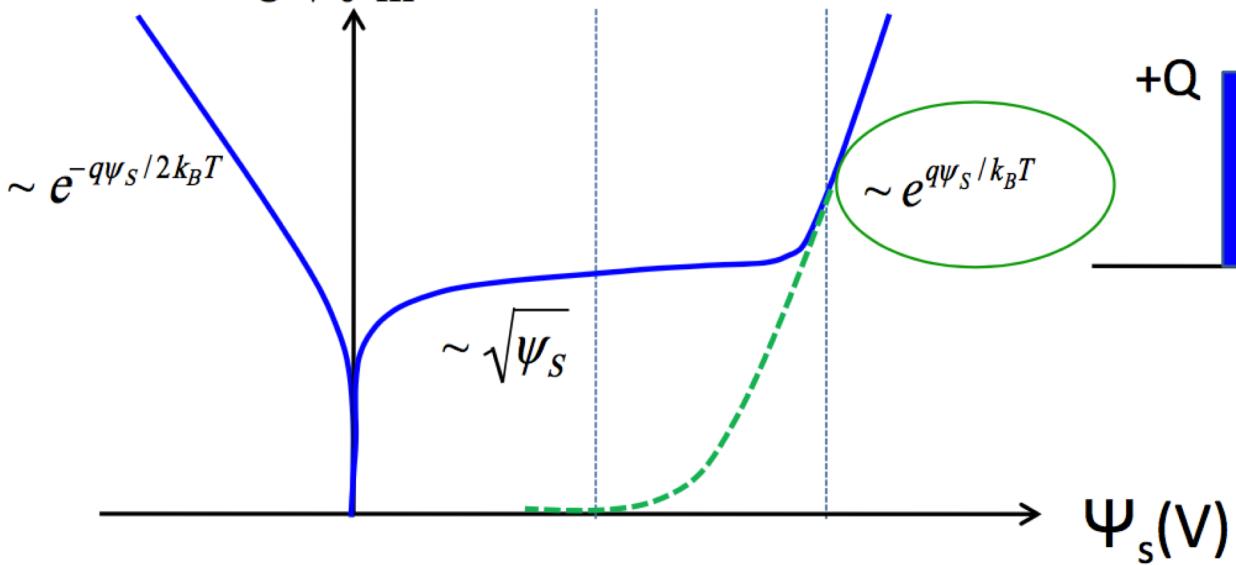
低于阈值时的电荷

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

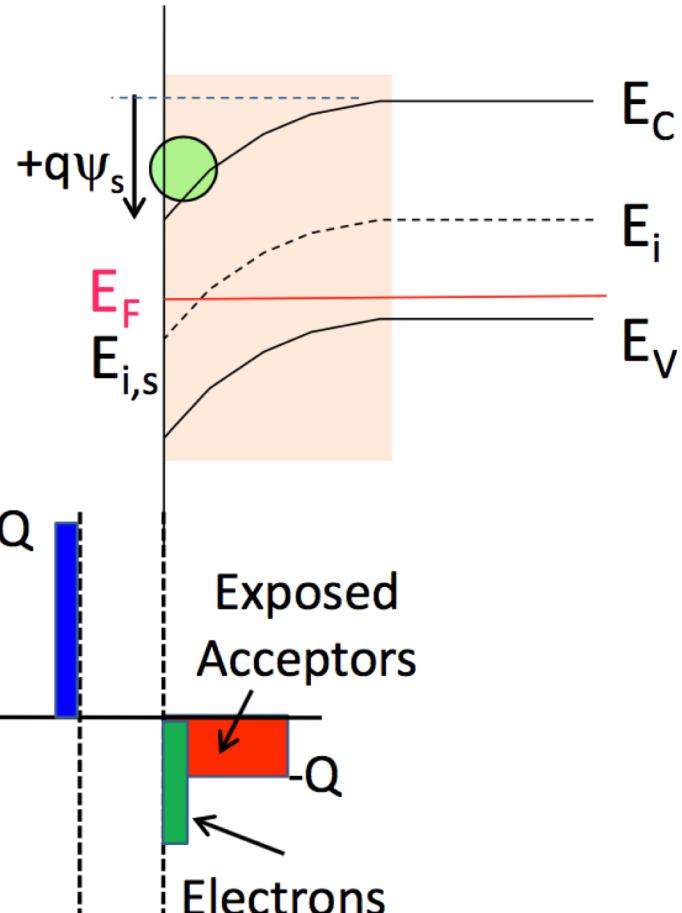
$$\equiv B e^{q\psi_s \beta}$$

$$10 \lg |Q_s(\psi_s)|$$

$$\text{C / } \text{c}^2 \text{m}$$

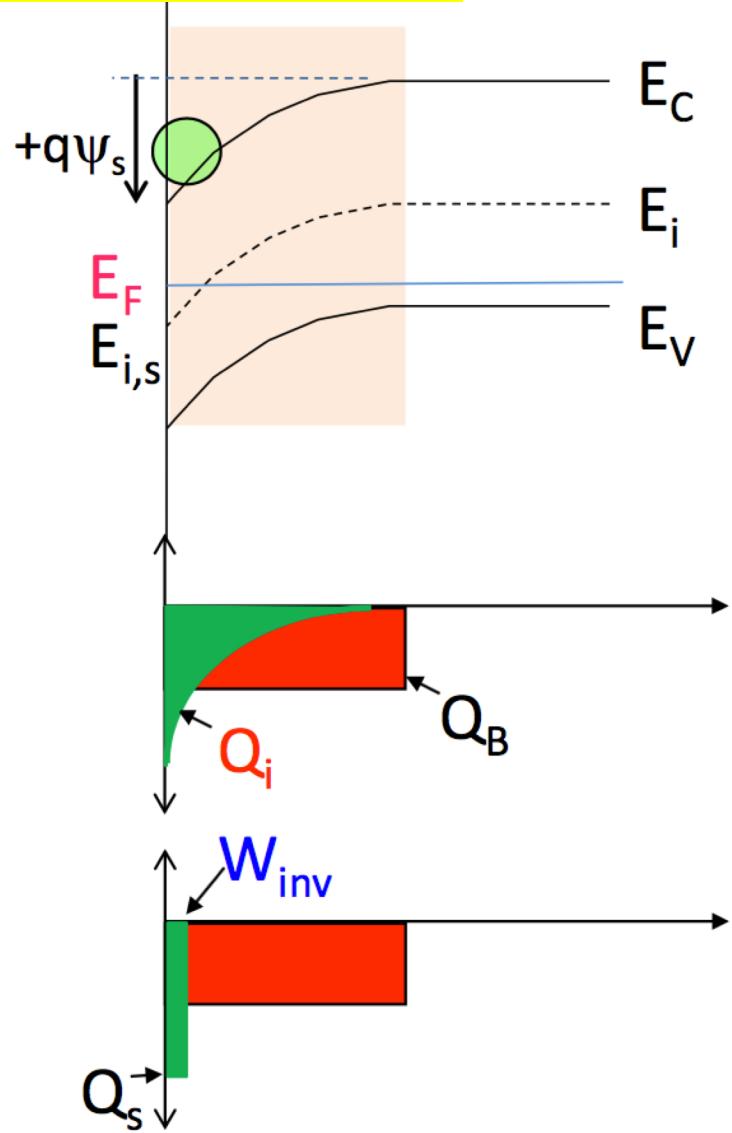


$$V_G = \frac{qN_A x_0}{\kappa_{ox} \epsilon_0} \sqrt{\frac{2\kappa_{ox} \epsilon_0}{qN_A}} \sqrt{\psi_s} + \psi_s$$

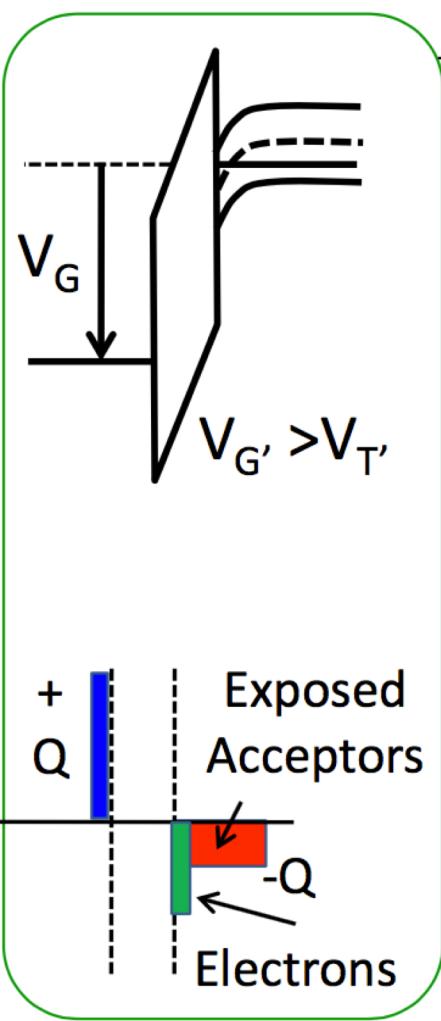


低于阈值时的电荷

$$\begin{aligned}
 \frac{Q_i}{q} &= \int_0^{\infty} n(x) dx = \int_0^{\infty} \frac{n_i^2}{N_B} e^{q\psi(x)\beta} dx \\
 &= \frac{n_i^2}{N_B} \int_0^{\infty} e^{q\psi(x)\beta} \frac{1}{d\psi} d\psi \\
 &= \frac{n_i^2}{N_B} \int_0^{\infty} e^{q\psi(x)\beta} \frac{1}{\mathcal{E}(x)} d\psi \\
 &\approx \frac{1}{\langle \mathcal{E}(x) \rangle} \frac{n_i^2}{N_B} \int_0^{\infty} e^{q\psi(x)\beta} d\psi \\
 &= \left(\frac{k_B T}{q} \right) \times \frac{n_i^2}{N_B} e^{q\psi_s \beta} \equiv W_{inv} \times n_s
 \end{aligned}$$



高于阈值时的电荷

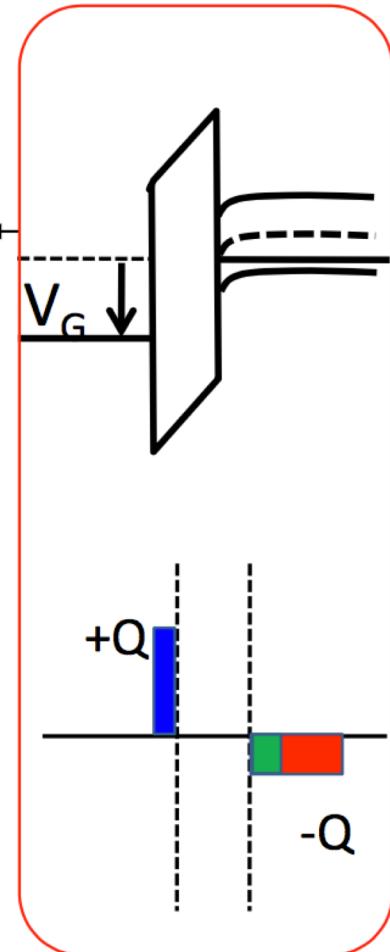


$$V_G = \psi_s + \mathcal{E}_{ox} x_o = \psi_s - \left[\frac{Q_i(\psi_s) + Q_F}{\kappa_{ox} \mathcal{E}_0} \right] x_o$$

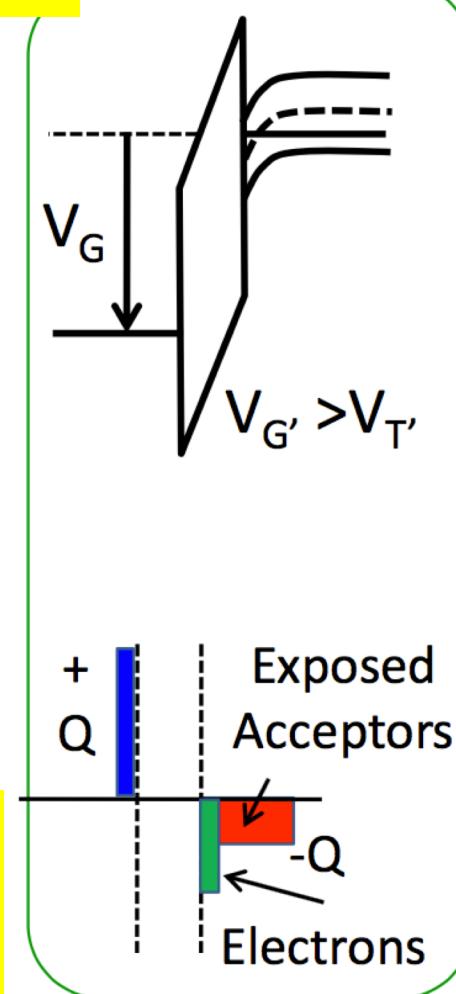
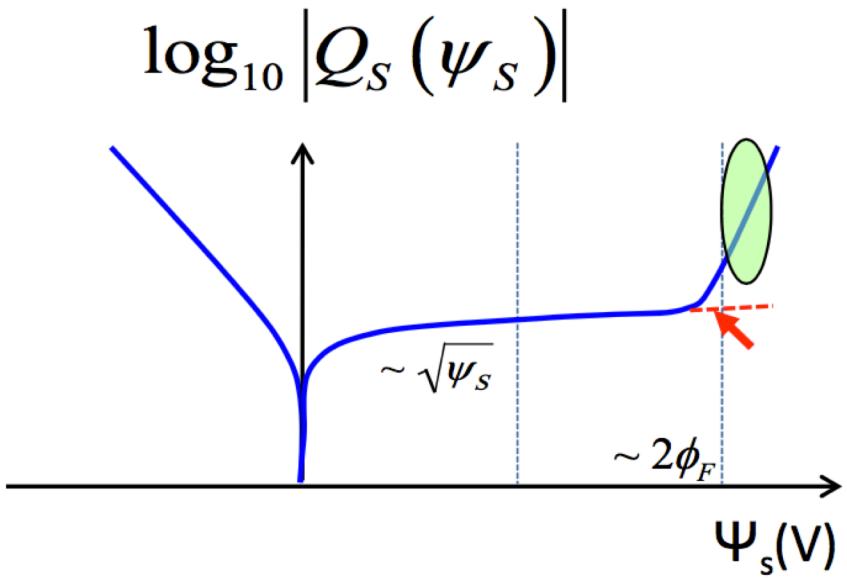
$$V_{th} = 2\phi_F + \mathcal{E}_{ox} x_o = 2\phi_F - \left(\frac{Q_i(2\phi_F) + Q_F}{\kappa_{ox} \mathcal{E}_0} \right) x_o$$

$$V_G - V_{th} = (\psi_s - 2\phi_F) + \frac{Q_i(\psi_s) - Q_i(2\phi_F)}{\kappa_{ox} \mathcal{E}_0} x_o$$

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

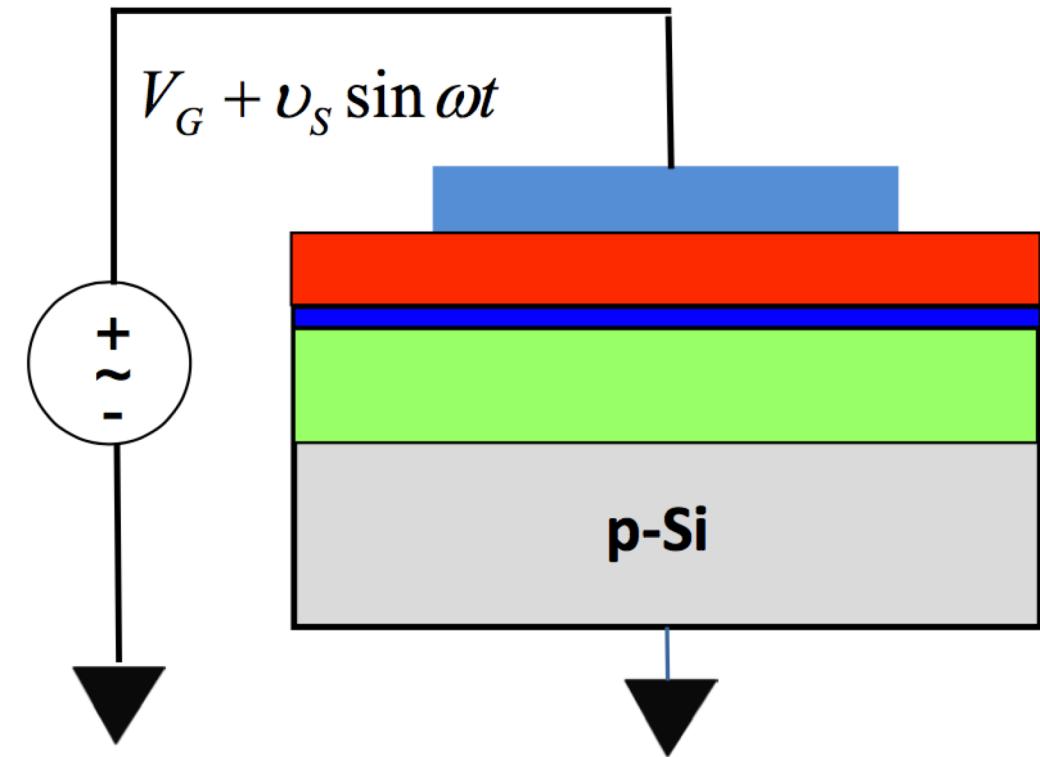


高于阈值时的电荷



- 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



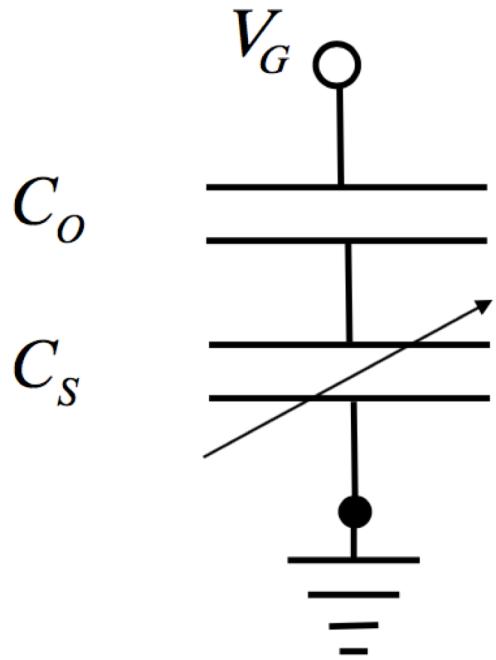
$$C_G \equiv \frac{dQ_G}{dV_G} = \frac{d(-Q_S)}{dV_G}$$

$$V_G = \psi_s - \frac{Q_S}{C_o}$$

$$\frac{dV_G}{d(-Q_S)} = \frac{d\psi_s}{d(-Q_S)} + \frac{1}{C_o}$$

$$\frac{1}{C_G} = \frac{1}{C_s} + \frac{1}{C_o}$$

MOS的小信号电容



我们已经推导过了

$$\frac{1}{C_G} = \frac{1}{C_s} + \frac{1}{C_o}$$

$$C_s \equiv \frac{d(-Q_s)}{d\psi_s}$$

$$Q_s(\psi_s)$$

m的定义

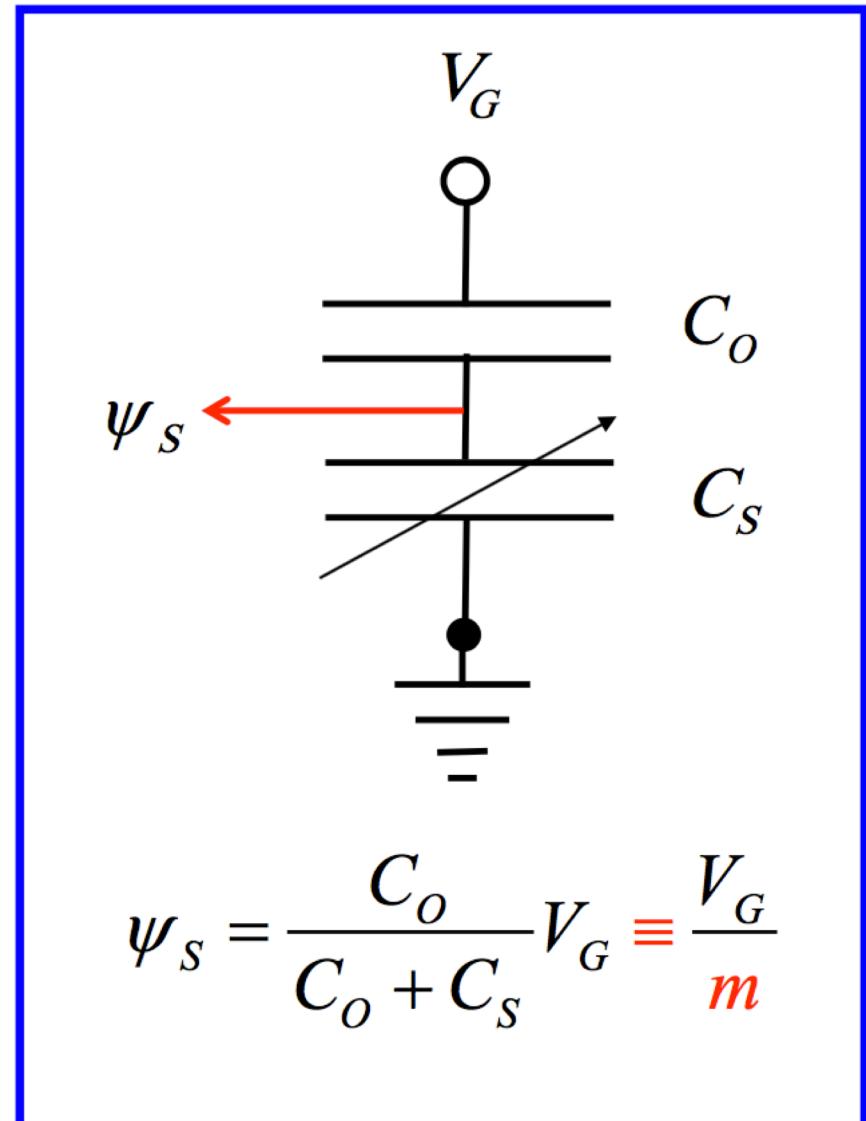
$$m = (1 + C_s / C_o)$$

体效应因子

$$m = (1 + \kappa_s x_o / \kappa_0 W_T)$$

通常

$$1.1 \leq m \leq 1.4$$

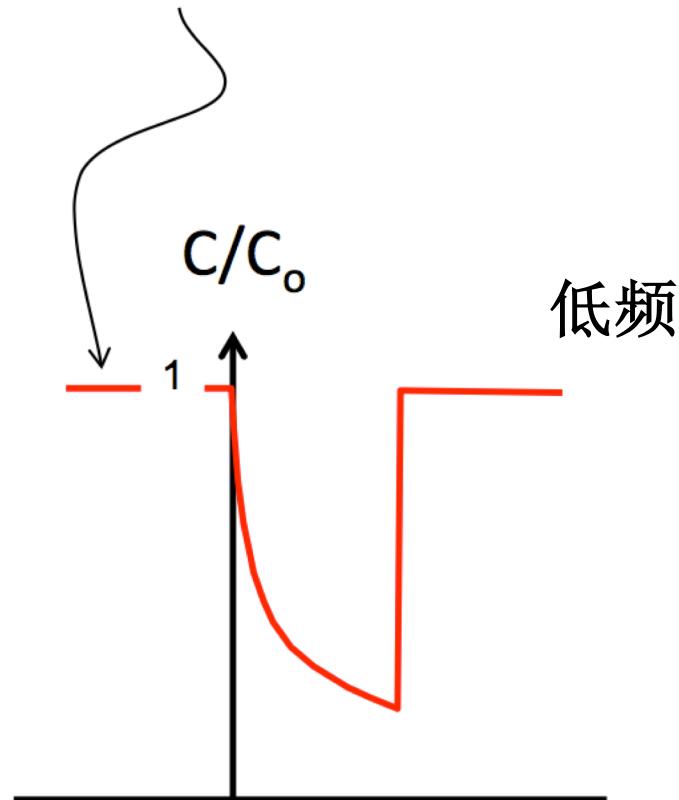
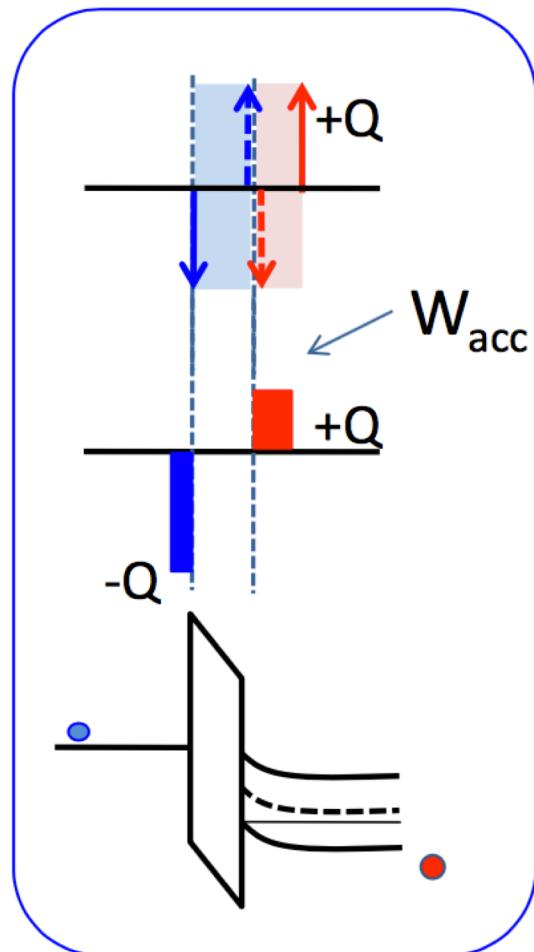


MOS的小信号电容：积累

$$C_{j,acc} \approx \frac{\kappa_{ox} \epsilon_0}{x_0} \equiv C_0$$

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

$$C_{s,acc} \equiv \frac{\kappa_s \epsilon_0}{W_{acc}}$$



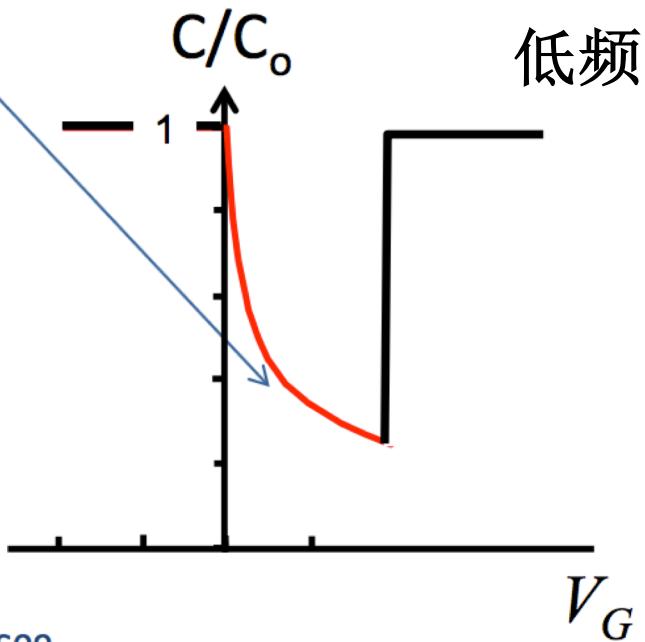
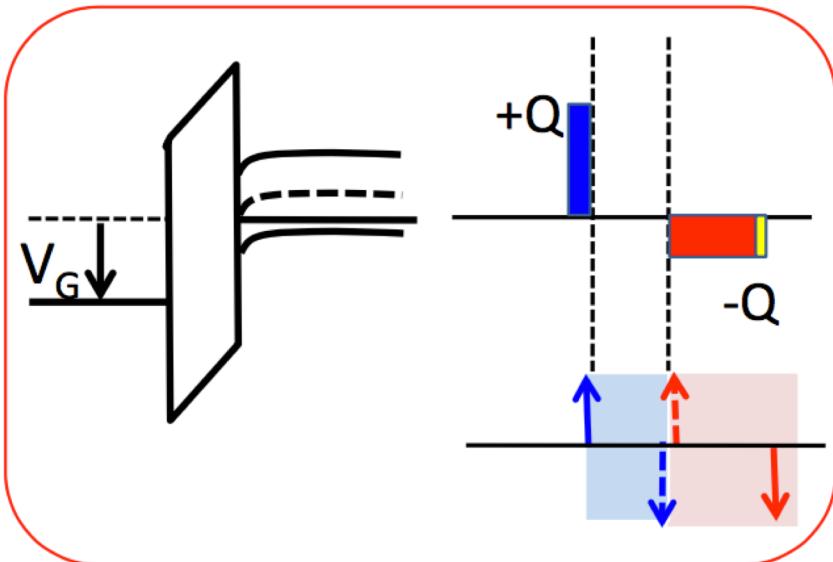
MOS的小信号电容：耗尽

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

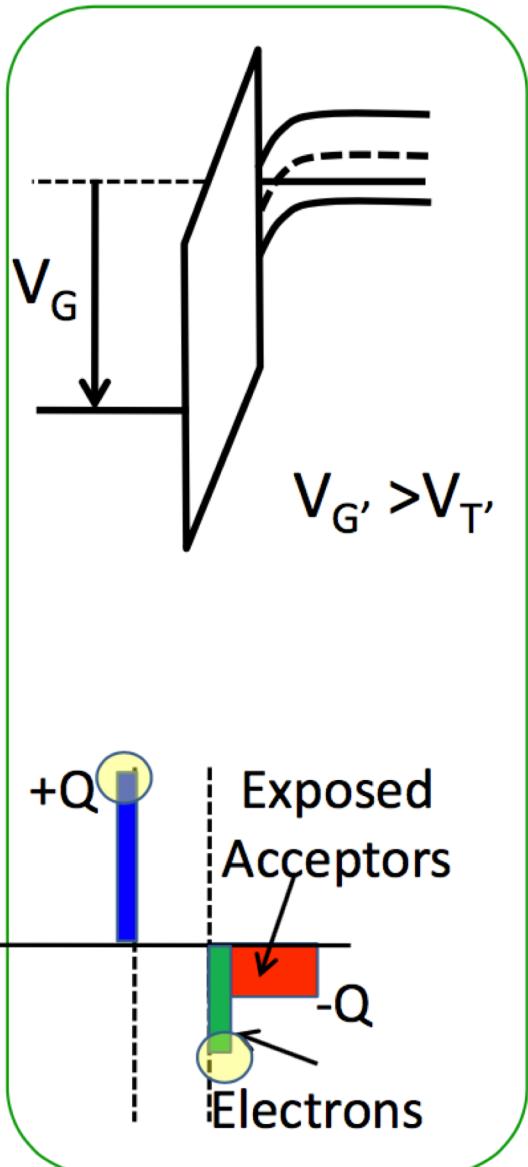
$$= \frac{C_0}{1 + \frac{\kappa_o \epsilon_0}{x_0} / \frac{\kappa_s \epsilon_0}{W}} = -\frac{C_o}{\sqrt{1 + \frac{V_G}{V_\delta}}}$$

$$V_G = \frac{qN_A W}{\kappa_o \epsilon_0} x_0 + \left(\frac{qN_A W^2}{2\kappa_s \epsilon_0} \right)$$

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



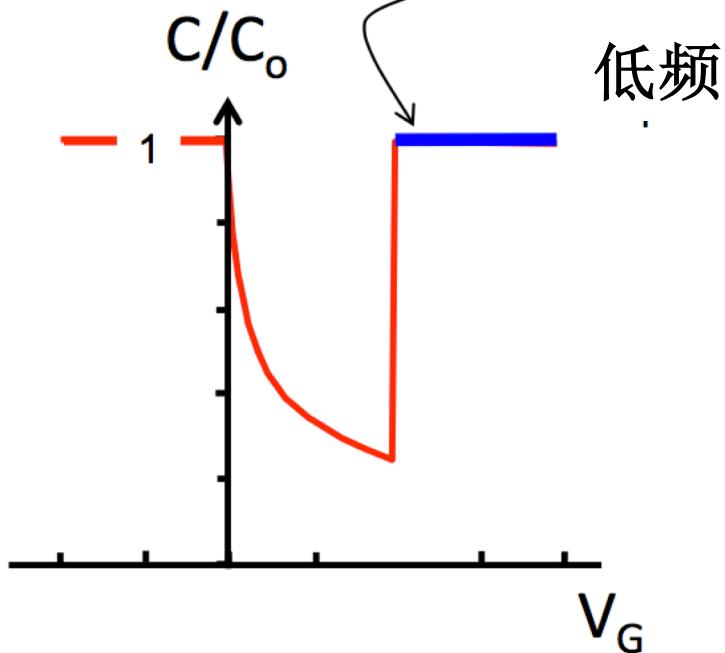
MOS的小信号电容：反型



$$C_{j,inv} \approx \frac{\kappa_s \epsilon_0}{x_0} \equiv C_0$$

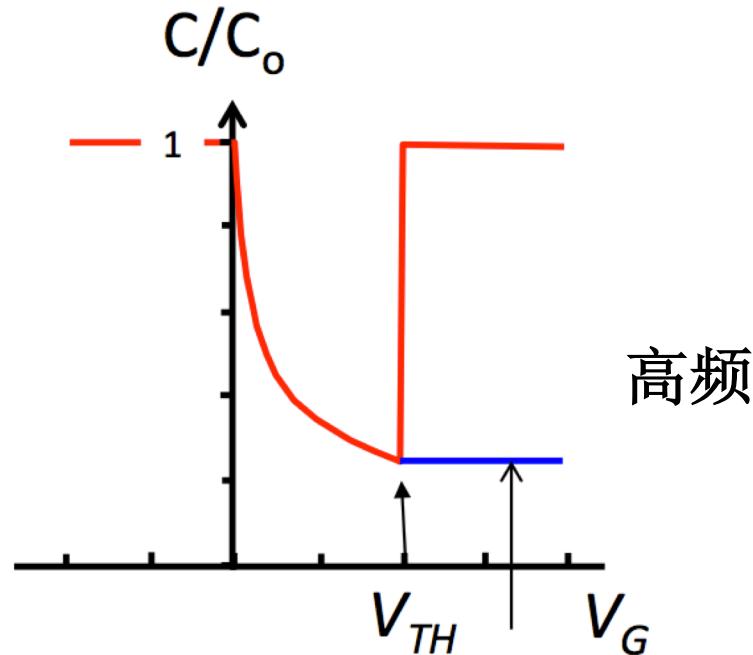
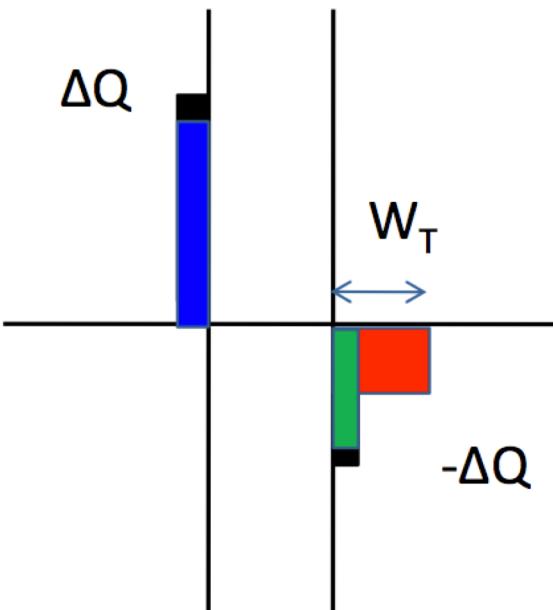
$$C_{j,inv} = \frac{C_o C_{inv}}{C_o + C_{inv}}$$

$$C_{inv} \equiv \frac{\kappa_s \epsilon_0}{W_{inv}}$$

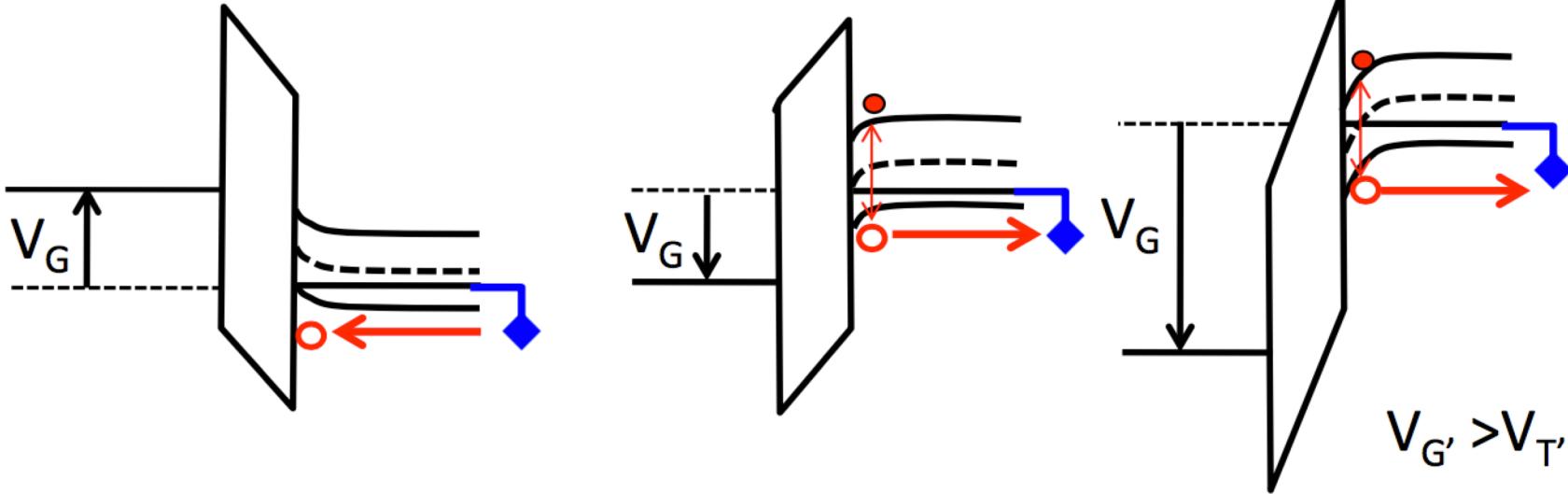


MOS的小信号电容：高频率

$$C_{j,inv} \approx \frac{K_s \epsilon_0}{x_0} \equiv C_0$$



响应时间



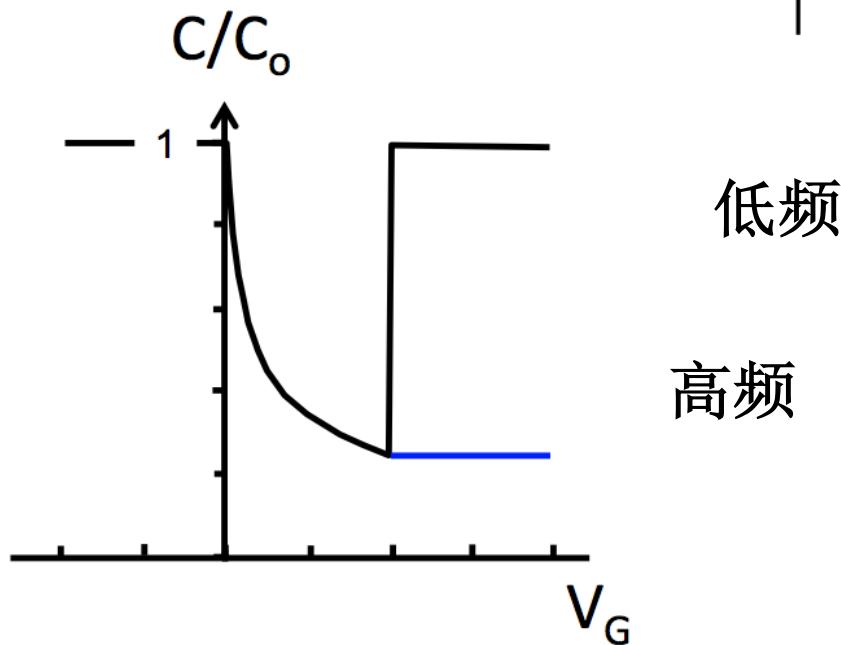
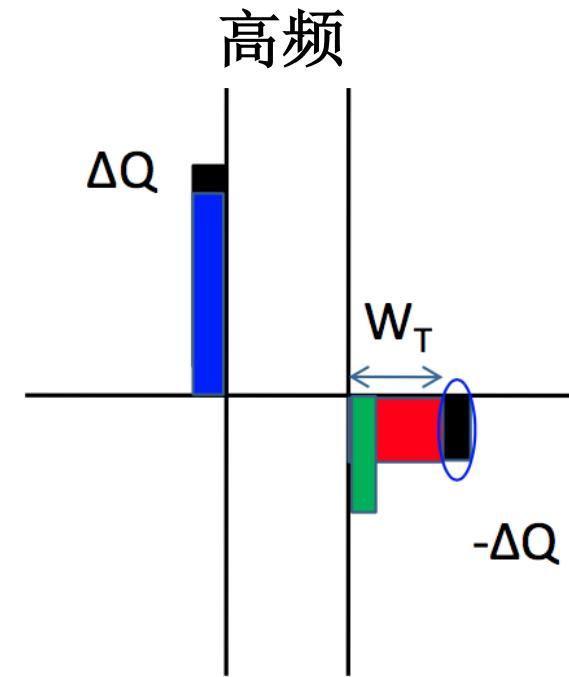
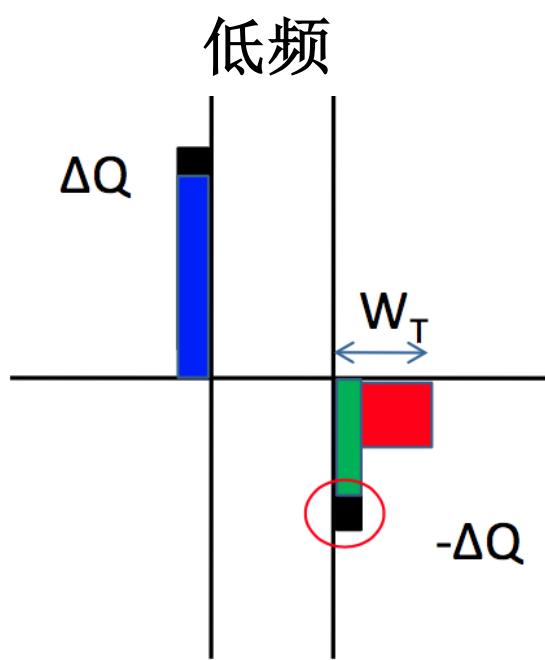
多数载流子

$$\tau = \frac{\sigma}{\kappa_s \epsilon_0}$$

少数载流子 (SRH)

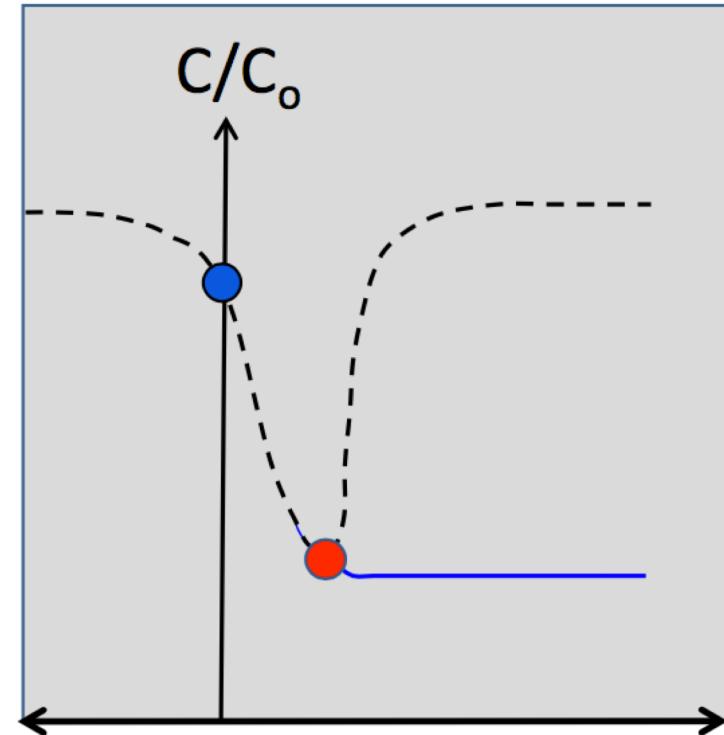
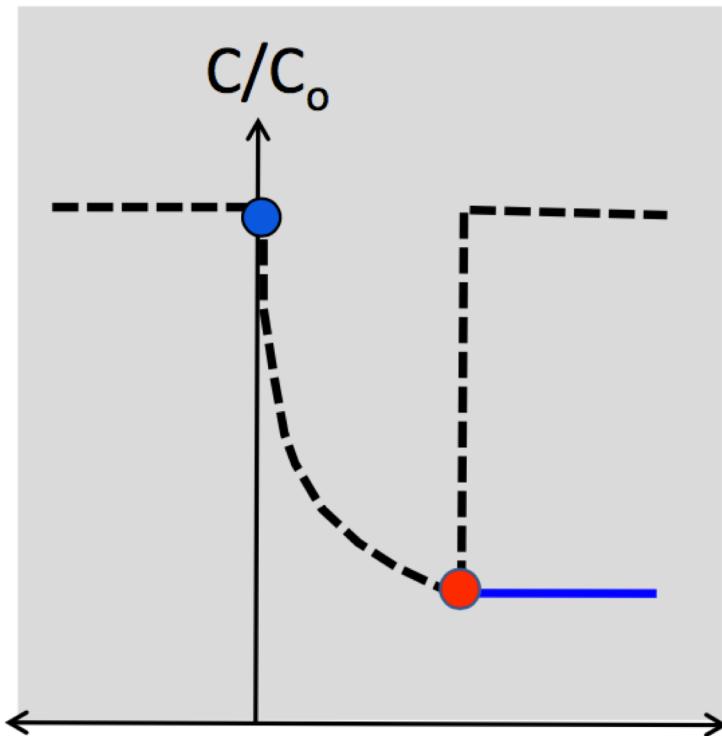
$$R = \frac{np - n_i^2}{\tau_n(p + p_1) + \tau_p(n + n_1)} \rightarrow \frac{-n_i}{\tau_n + \tau_p}$$

MOS的小信号电容：高频响应



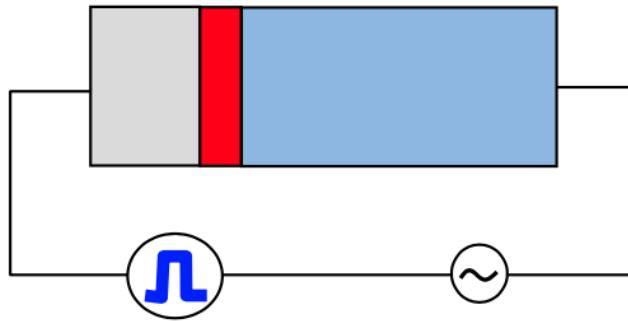
理想CV特性与实际测量结果

平带电压

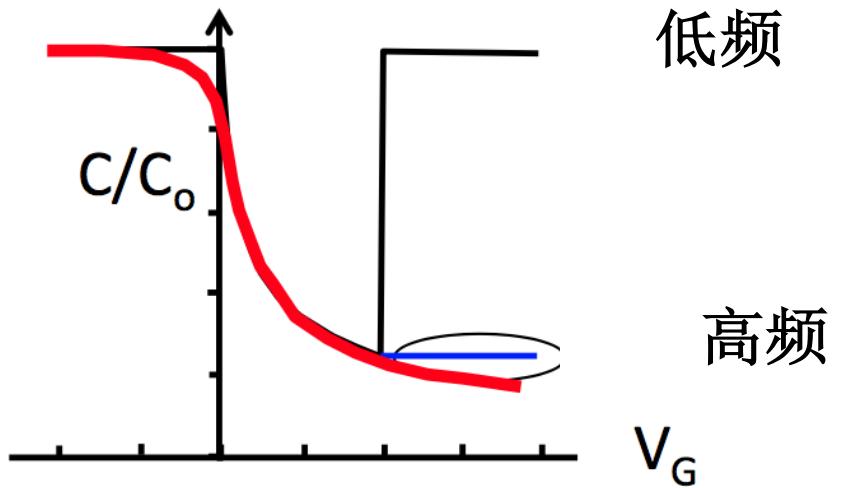
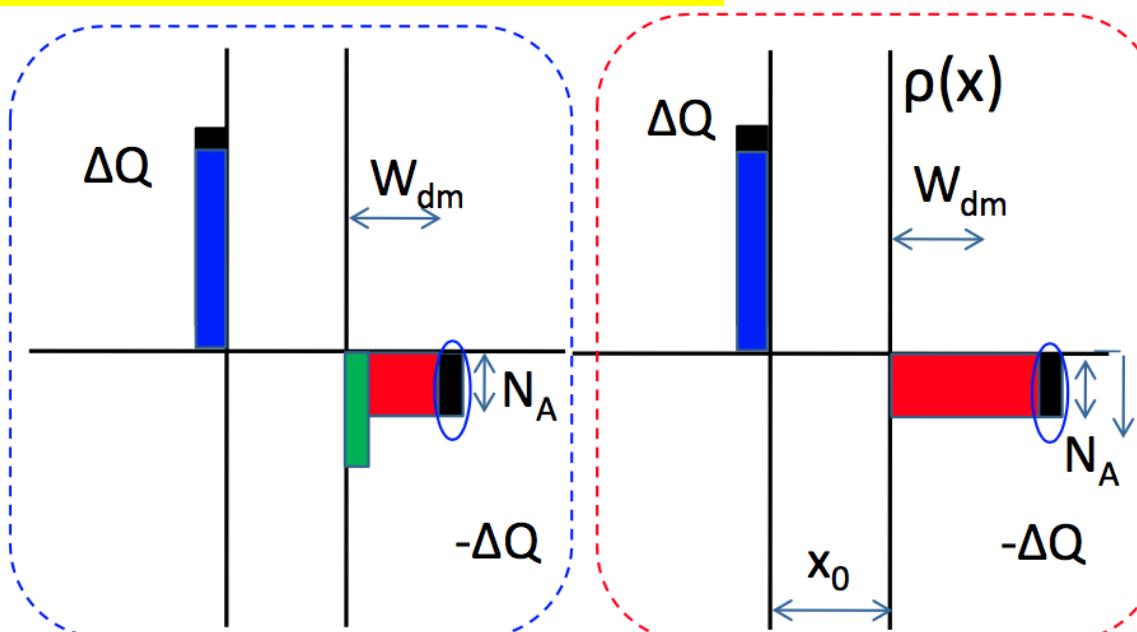


阈值电压

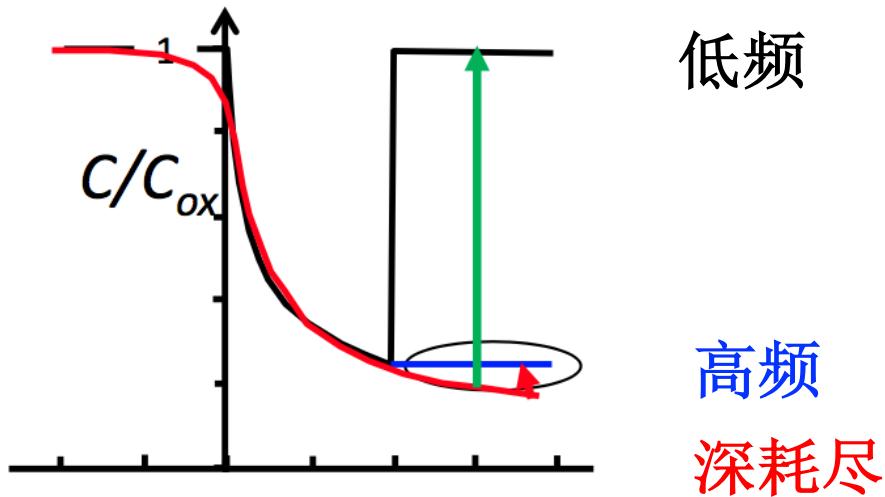
大信号MOS电容：深耗尽



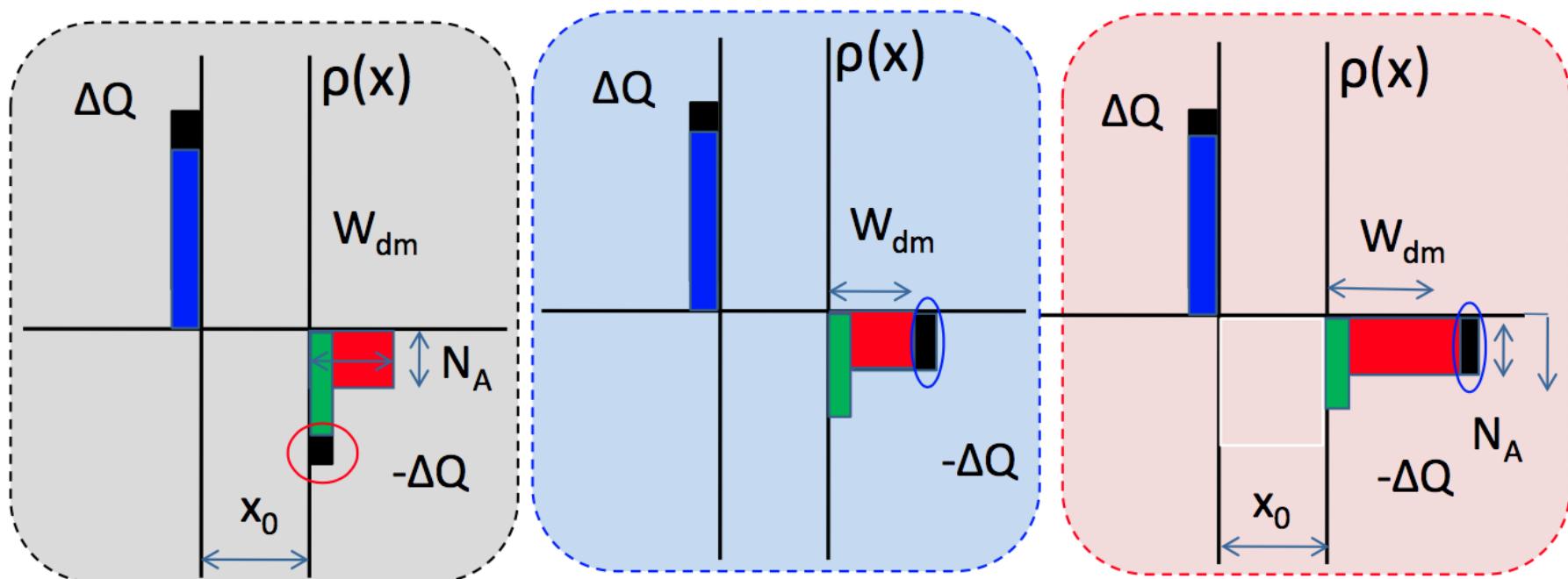
$$C_{j,dep} = \frac{C_0 C_s}{C_0 + C_s} = \frac{C_0}{1 + \frac{\kappa_{ox}}{\kappa_s} \frac{W}{x_0}}$$
$$= \frac{C_0}{\sqrt{1 + \frac{V_G}{V_\delta}}}$$



深耗尽情况

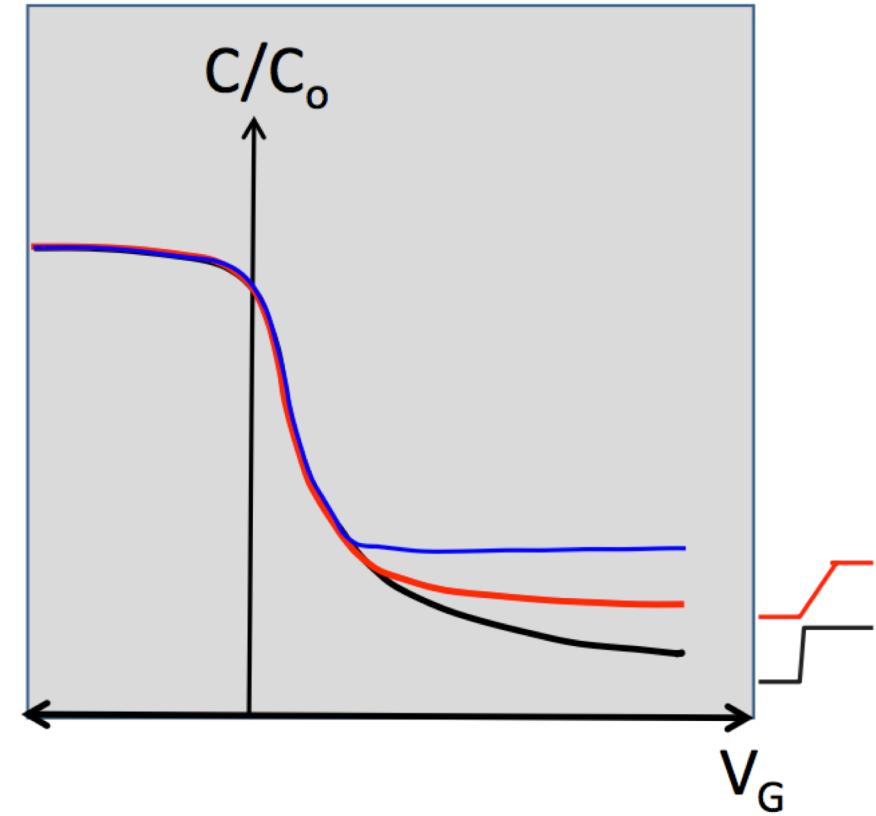
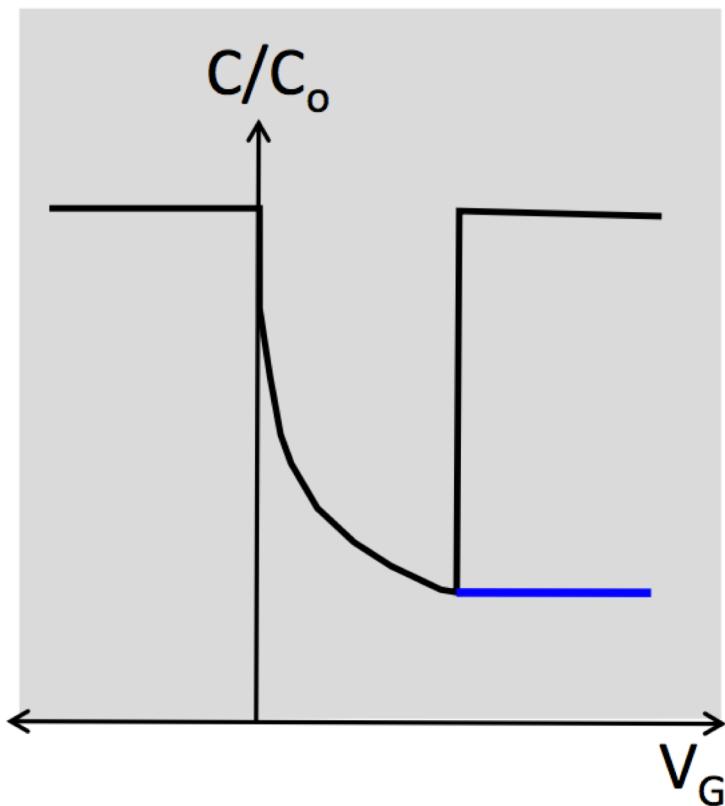


根据测量频率的不同，会出现低频曲线、或者高频曲线
施加阶跃信号，则会出现深耗尽



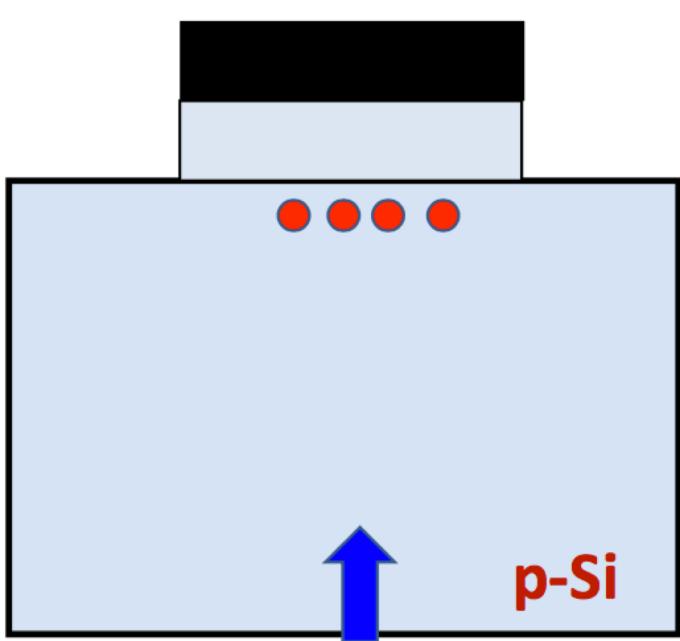
理想CV特性与实际测量结果

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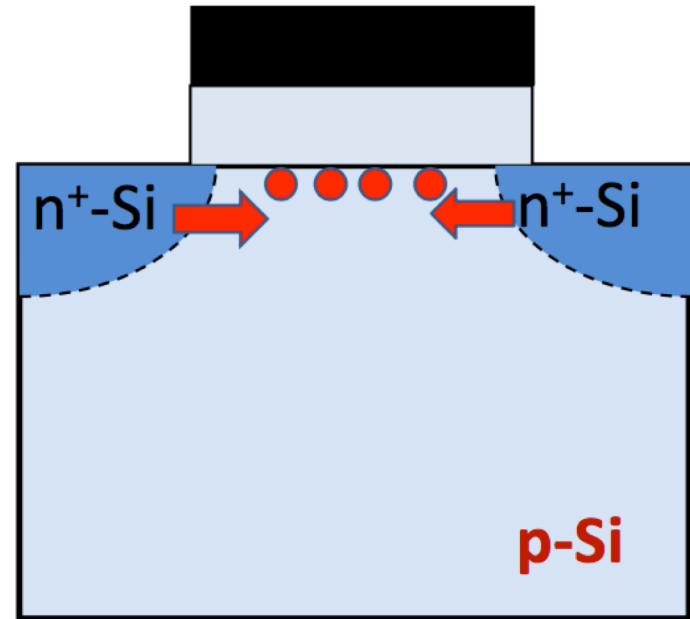
阈值电压

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？

CV

Thanks!
Q&A