微电子器件物理
PN结的电容

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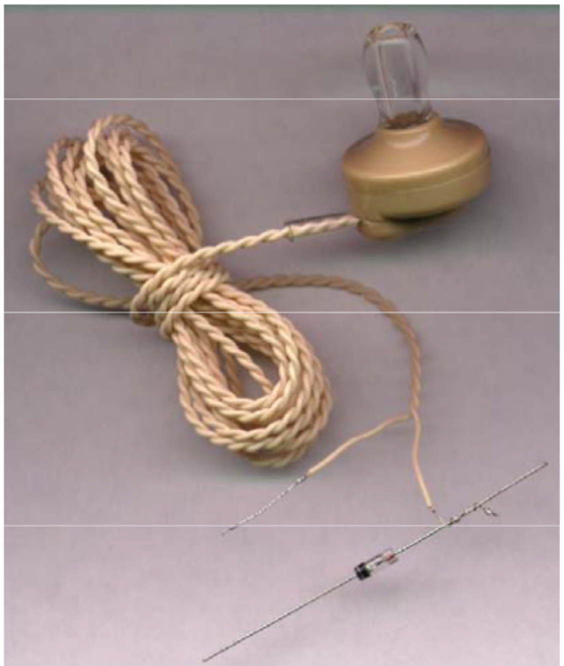
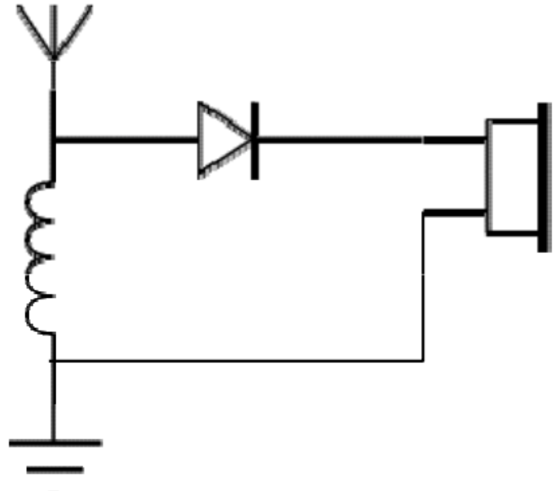
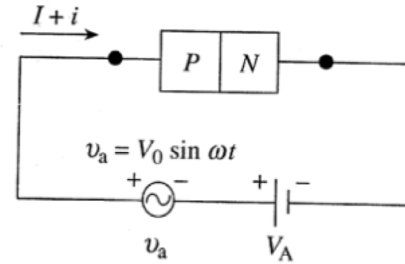
2020/09/22

PN结的交流特性

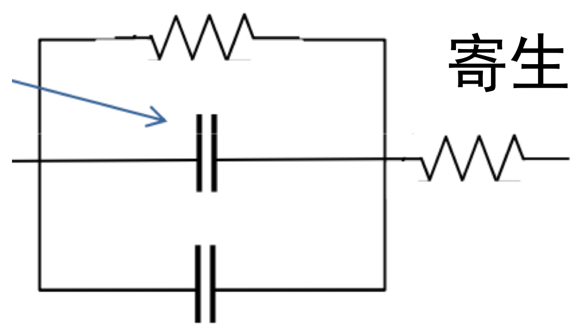






电导

结电容



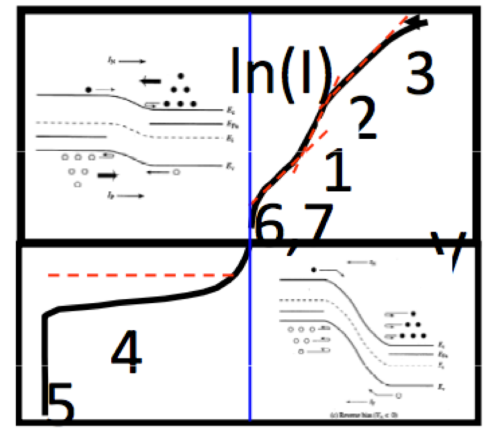
寄生串联电阻

扩散电容

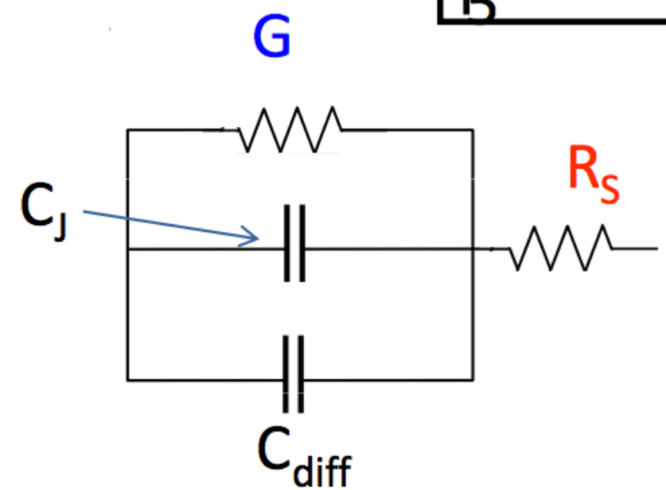
正向导通电导

$$I = I_o\left(e^{q(V_A - R_S I)\beta/m} - 1\right)$$

非理想因子



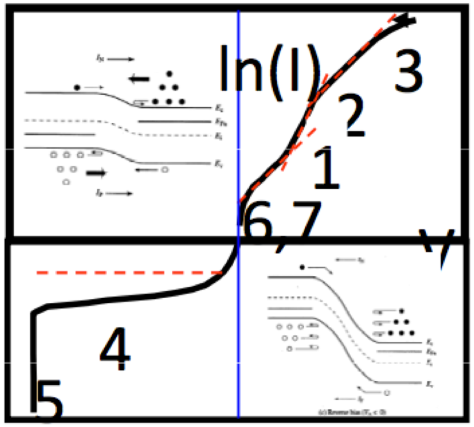
$$\ln\frac{I+I_o}{I_0} = q(V_A - R_S I)\frac{\beta}{m}$$



$$\frac{m}{q\beta(I+I_o)} = \frac{dV_A}{dI} - R_S$$

$$\frac{1}{g_{FB}} = R_S + \frac{m}{q\beta(I+I_0)}$$

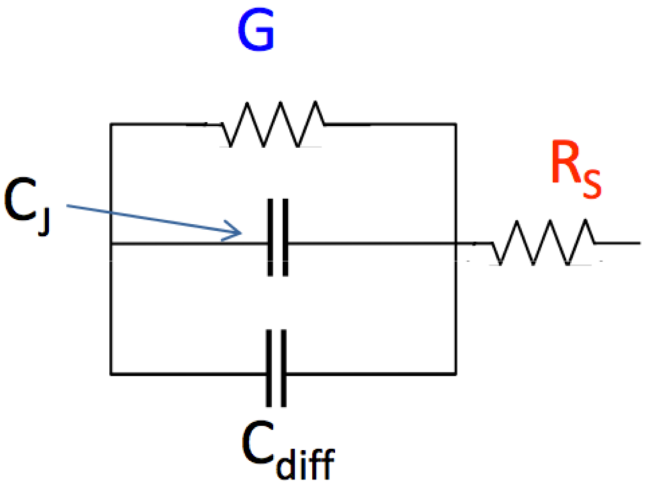
反向导通电导



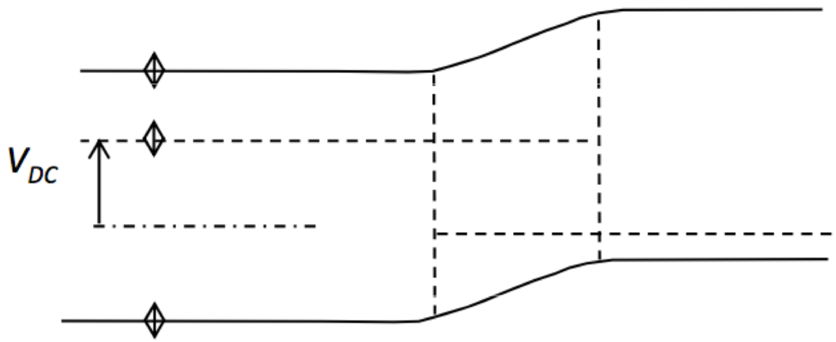
$$I = I_o\left(e^{q(V_A - R_S I)\beta/m} - 1\right) - \frac{qn_i}{2\tau}B_0\sqrt{V_{bi} - V_A}$$

$$\approx -I_0 - \frac{qn_i}{2\tau}B_0\sqrt{V_{bi} - V_A}$$

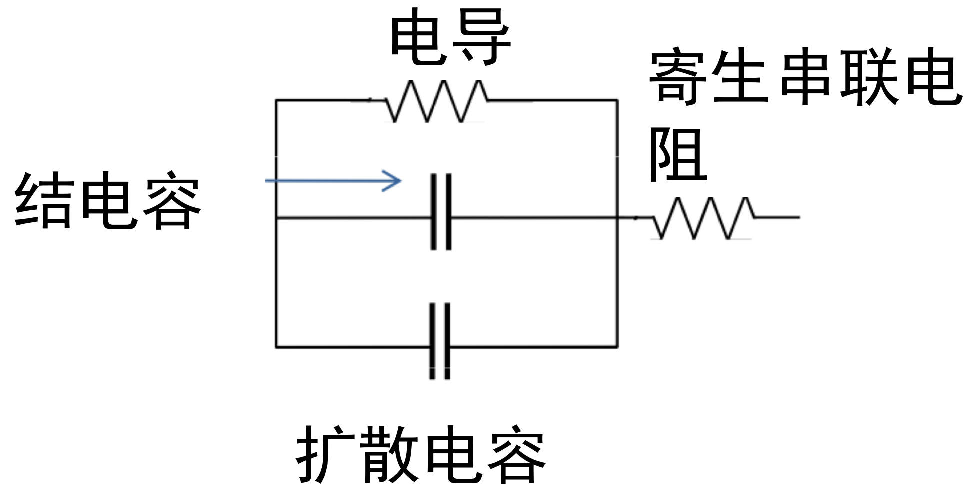
$$\frac{1}{g_{RB}} = \frac{qn_i B_0}{2\tau\sqrt{V_{bi} - V_A}}$$



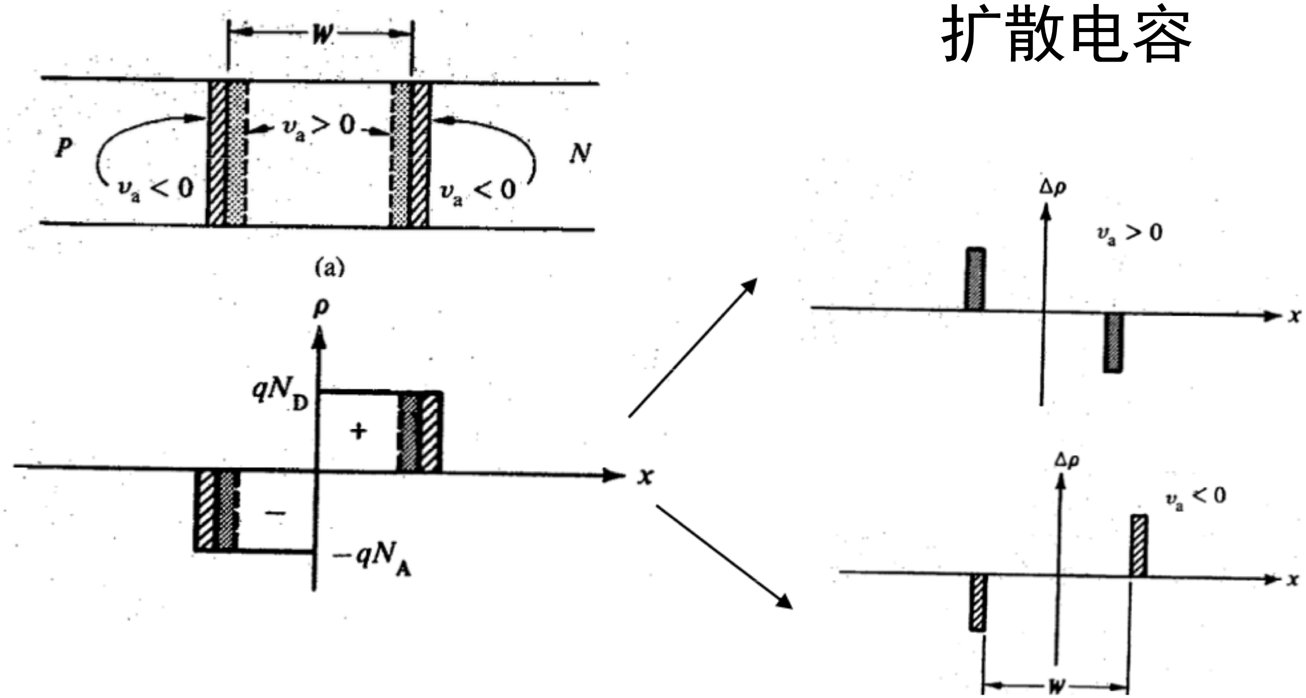
PN结电容



V_{DC}

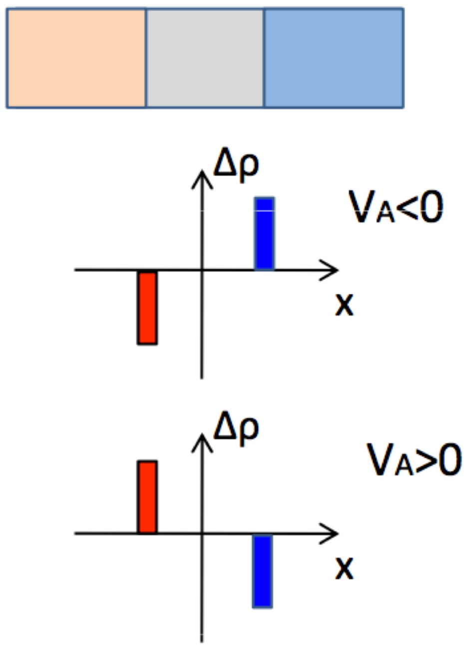


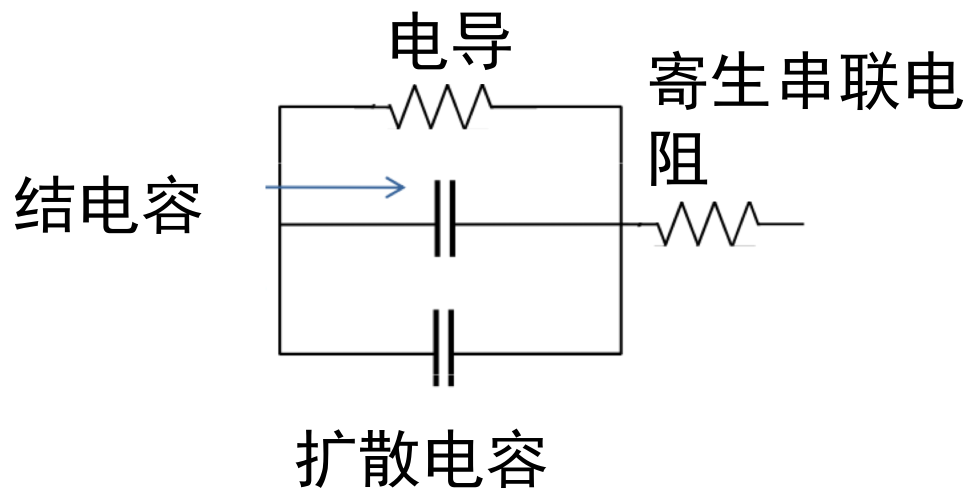
电导
寄生串联电阻
结电容
扩散电容

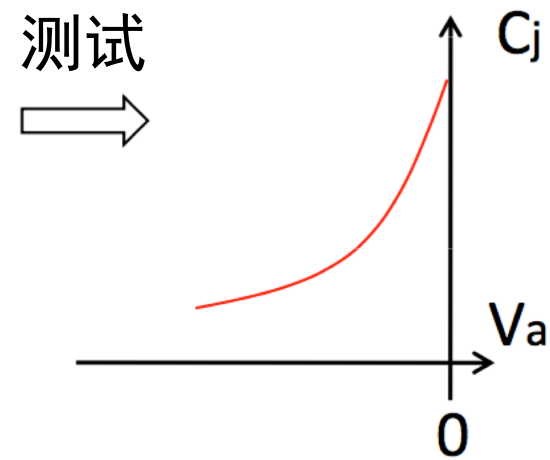


W
P
N
$v_a > 0$
$v_a < 0$
$v_a < 0$
(a)
ρ
qN_D
$-qN_A$
+
−
x
Δρ
$v_a > 0$
x
Δρ
$v_a < 0$
x
W

PN结电容：多数载流子







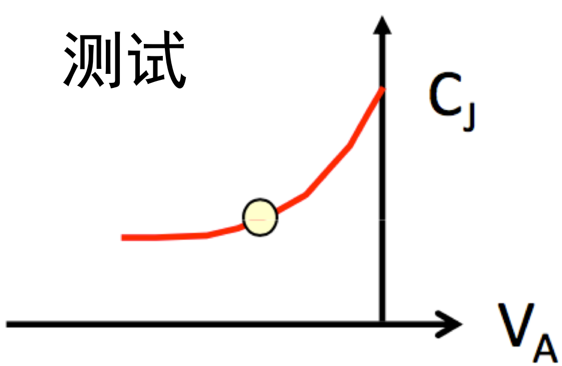
$$C_J = \frac{K_s\varepsilon_0 A}{W_n + W_p} = \frac{K_s\varepsilon_0 A}{\sqrt{\left(\frac{2K_s\varepsilon_0}{qN_D} + \frac{2K_s\varepsilon_0}{qN_A}\right)(V_{bi} - V_A)}}$$

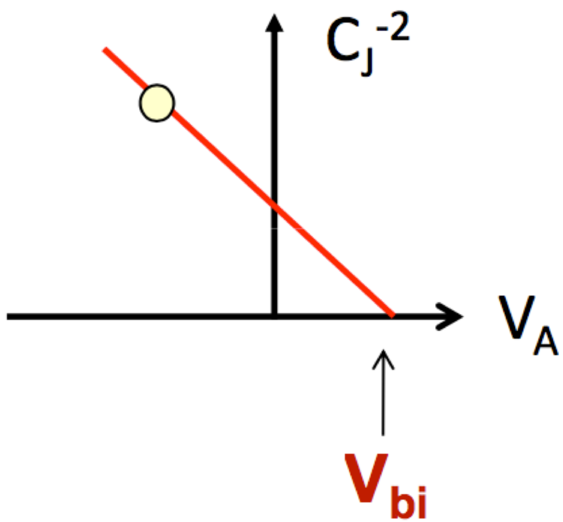
PN结电容：测量内建势

$$\frac{1}{C_J^{\,2}} \approx \frac{2}{qN_D(x)K_s\varepsilon_0 A^2}(V_{bi} - V_A)$$

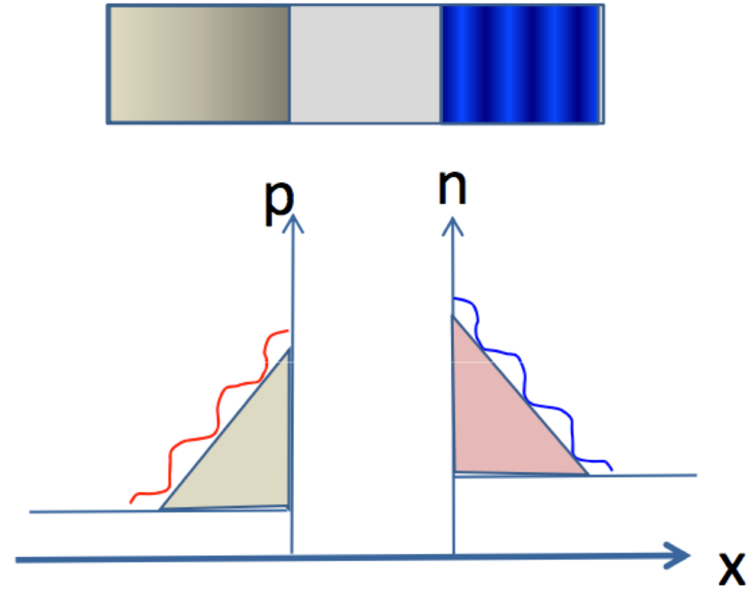
(Assume single sided p$^+$-n junction)

假设为P$^+$N结



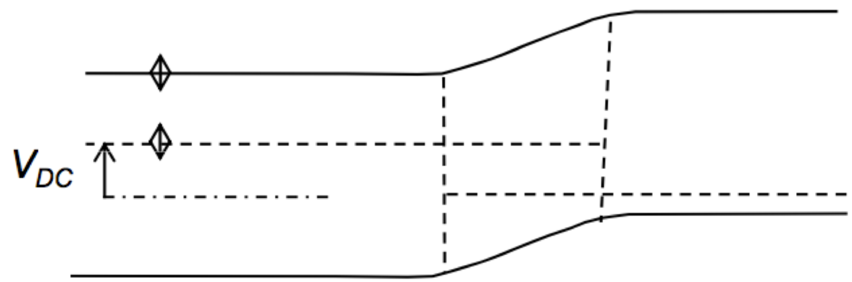


PN扩散电容：少数载流子



$$\mathbf{J}_N = q\cancel{n}\mu_N \mathcal{E} + qD_N \frac{dn}{dx}$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{dJ_n}{dx} - r_N + g_N$$



$$\frac{\partial\left(n_0 + \Delta n_{dc} + \Delta n_{ac} e^{j\omega t}\right)}{\partial t} = D_N \frac{d^2\left(n_0 + \Delta n_{dc} + \Delta n_{ac} e^{j\omega t}\right)}{dx^2} - \frac{\Delta n_{dc} + \Delta n_{ac} e^{j\omega t}}{\tau_n}$$

PN扩散电容：少数载流子

$$\frac{\partial\left(n_0+\Delta n_{dc}+\Delta n_{ac}e^{j\omega t}\right)}{\partial t}=D_N\frac{d^2\left(n_0+\Delta n_{dc}+\Delta n_{ac}e^{j\omega t}\right)}{dx^2}-\frac{\Delta n_{dc}+\Delta n_{ac}e^{j\omega t}}{\tau_n}$$

$$j\omega\Delta n_{ac}e^{j\omega t}=D_N\frac{d^2\Delta n_{dc}}{dx^2}+e^{j\omega t}\frac{d^2\Delta n_{ac}}{dx^2}-\frac{\Delta n_{dc}}{\tau_n}-e^{j\omega t}\frac{\Delta n_{ac}}{\tau_n}$$

$$\text{DC}:\quad 0=D_N\frac{d^2\Delta n_{dc}}{dx^2}-\frac{\Delta n_{dc}}{\tau_n}\Rightarrow\Delta n_{dc}=Ae^{-\frac{x}{L_n}}+Be^{+\frac{x}{L_n}}$$

$$\text{AC}:\quad 0=D_N\frac{d^2\Delta n_{ac}}{dx^2}-\left(j\omega\tau_n+1\right)\frac{\Delta n_{ac}}{\tau_n}\Rightarrow\Delta n_{ac}=Ce^{-\frac{x}{L_n*}}+De^{+\frac{x}{L_n*}}\rightarrow Ce^{-\frac{x}{L_n*}}$$

$$L_n^*=\sqrt{D_n\tau_n/\left(1+j\omega\tau_n\right)}\qquad\tau_n^*=\tau_n/\left(1+j\omega\tau_n\right)$$

PN扩散电容：边界条件

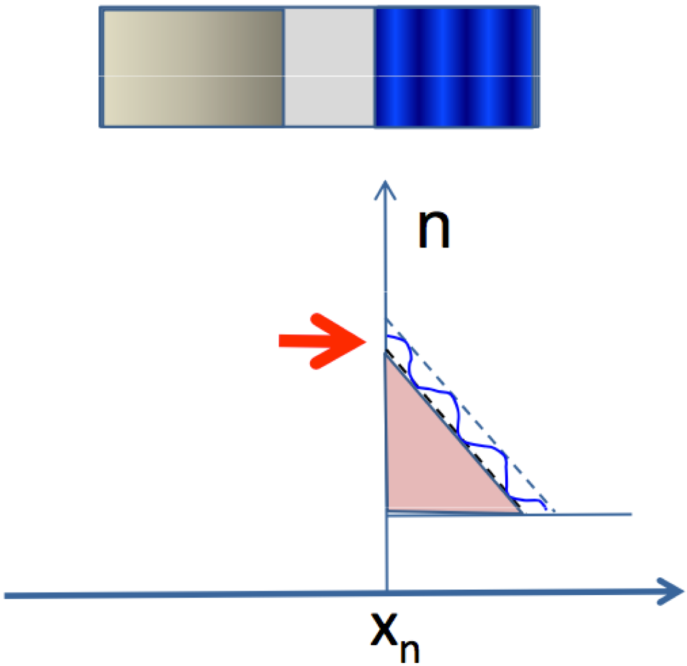
$$\Delta n_{dc}(x=0)=\frac{n_i^2}{N_A}\left(e^{\frac{qV_{dc}}{kT}}-1\right)$$

$$\left(\Delta n_{dc}+\Delta n_{ac}e^{j\omega t}\right)=\frac{n_i^2}{N_A+\Delta p_{ac}e^{j\omega t}}\left(e^{q\frac{V_{dc}+V_{ac}e^{j\omega t}}{kT}}-1\right)$$

$$\left(\Delta n_{dc}+\Delta n_{ac}e^{j\omega t}\right)\approx\frac{n_i^2}{N_A}\left(e^{\frac{qV_{dc}}{kT}}e^{\frac{qV_{ac}e^{j\omega t}}{kT}}-1\right)$$

$$\approx\frac{n_i^2}{N_A}\left\{e^{\frac{qV_{dc}}{kT}}\left(1+\frac{qV_{ac}e^{j\omega t}}{kT}\right)-1\right\}$$

$$\Delta n_{ac}(x=0)=\frac{qV_{ac}}{kT}\frac{n_i^2}{N_A}e^{\frac{qV_{dc}}{kT}}=C$$



PN扩散电容：AC电容与电导

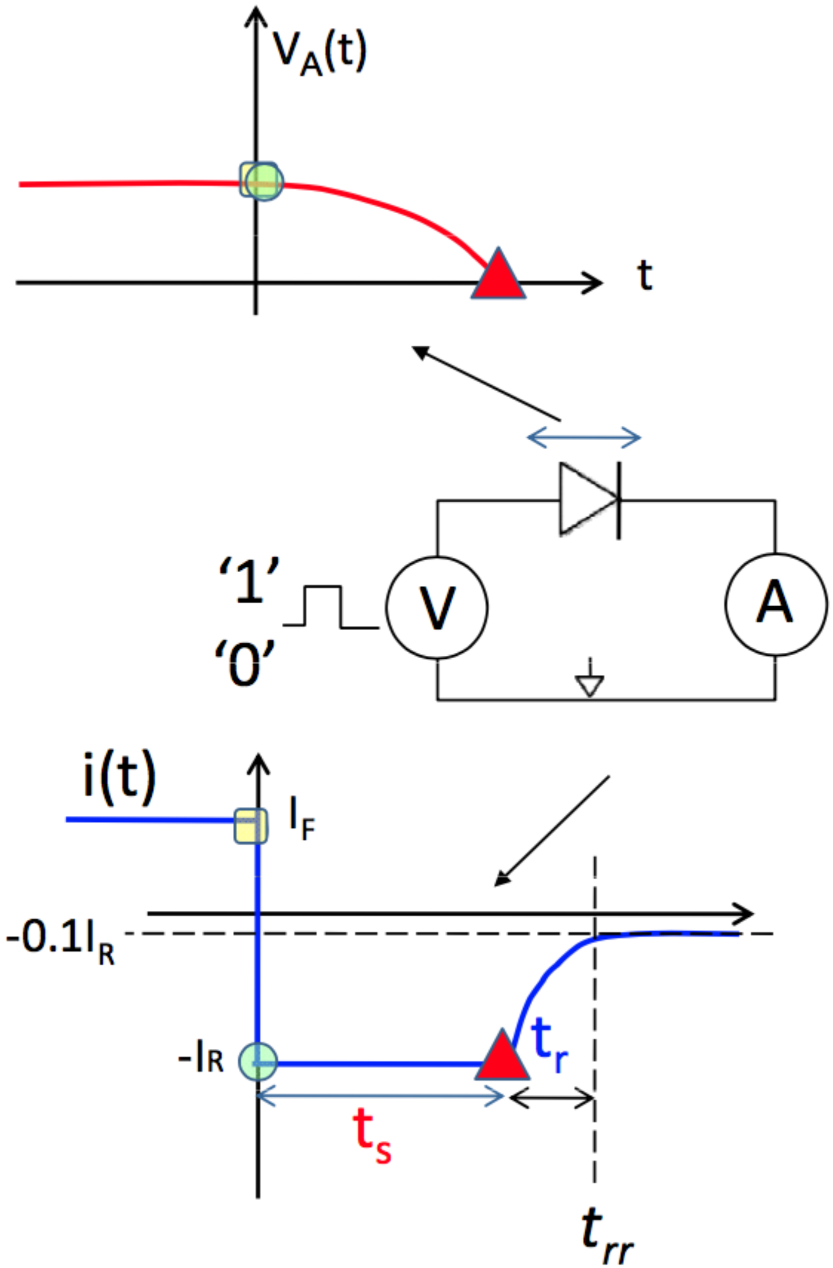
$$\Delta n_{ac}(x=0)=\frac{qV_{ac}}{kT}\frac{n_i^2}{N_A}e^{\frac{qV_{dc}}{kT}}=C$$

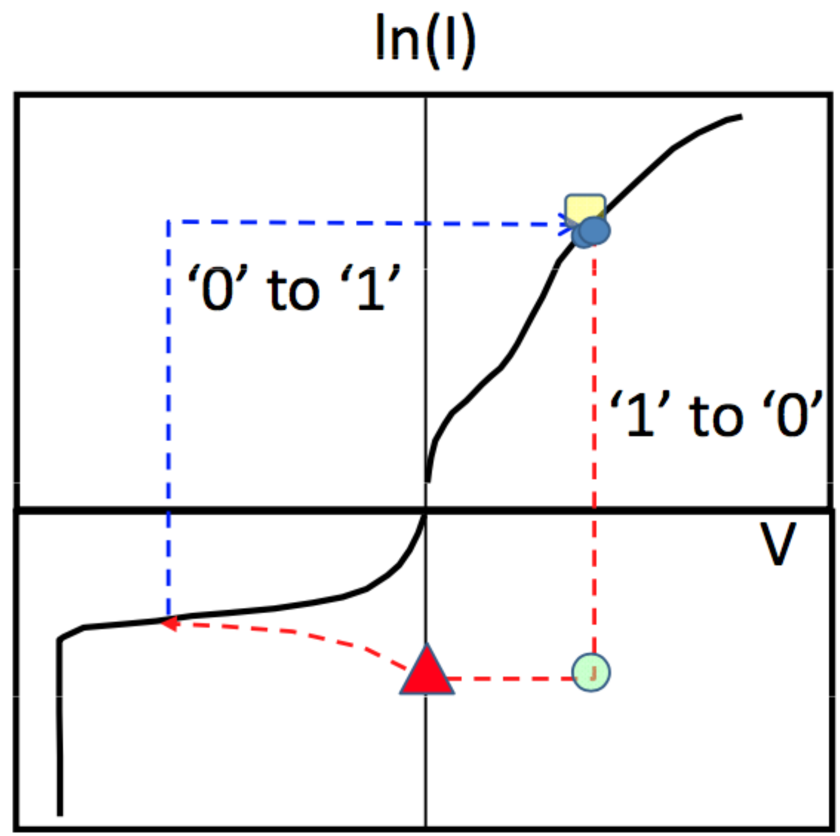
$$\Delta n_{ac}(x)=Ce^{-\frac{x}{L_n{}^*}}+De^{+\frac{x}{L_n{}^*}}\rightarrow Ce^{-\frac{x}{L_n{}^*}}$$

$$J_{ac}=-qD_n\left.\frac{d\Delta n_{ac}}{dx}\right|_{x=0}=\frac{qD_n}{L_n^*}\frac{qV_{ac}}{kT}\frac{n_i^2}{N_A}e^{\frac{qV_{dc}}{kT}}$$

$$Y_{ac}=\frac{J_{ac}}{V_{ac}}=\frac{q^2D_n}{L_n^*kT}\frac{n_i^2}{N_A}e^{\frac{qV_{dc}}{kT}}\equiv G_0\sqrt{1+j\omega\tau_n}$$

数字电路中PN结的应用





Thanks!

Q&A