Háskóli Íslands
Verkfræðideild
Rafmagns- og tölvuverkfræðiskor

Vor 2004

08.32.23 Smárásir

Formúlublað

1 Fastar

$$q = 1.602 \times 10^{-19} \quad \text{C}$$

$$N_{\text{Av}} = 6.022 \times 10^{23} \quad \text{sameindir/mól}$$

$$k = 1.38 \times 10^{-23}\text{J/K} = 8.62 \times 10^{-5} \quad \text{eV/K}$$

$$\epsilon_0 = 8.854 \times 10^{-14} \quad \text{F/cm}$$

$$\epsilon_{\text{ox}}/\epsilon_0 = 3.9$$

$$\epsilon_{\text{Si}}/\epsilon_0 = 11.9$$

$$\epsilon_{\text{Ge}}/\epsilon_0 = 16$$

$$\epsilon_{\text{GaAs}}/\epsilon_0 = 13.1$$

Fyrir kísil við stofuhita:

$$n_{\text{i}} = 9.65 \times 10^{9} \quad \text{cm}^{-3}$$

Fyrir GaAs við stofuhita:

$$n_{\text{i}} = 2.25 \times 10^{9} \quad \text{cm}^{-3}$$

2 Ræktun

$$k_0 = \frac{C_{\text{s}}}{C_{\text{l}}}$$

$$C_{\text{s}} = k_0 C_0 \left[1 - \frac{M}{M_0}\right]^{k_0 - 1}$$

3 Hálfleiðarar

$$E_{\text{H}} = -\frac{m_{\text{e}} q^4}{8\epsilon_0^2 h^2 n^2} = -\frac{13.6}{n^2}$$

$$E_{\text{g}} = 1.17 - \frac{(4.73 \times 10^{-4})T^2}{(T + 636)} \qquad \text{kísill}$$

$$E_{\text{g}} = 1.52 - \frac{(5.4 \times 10^{-4})T^2}{(T + 204)} \qquad \text{GaAs}$$

$$m^* = \frac{\hbar^2}{d^2E/dk^2}$$

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_{\text{F}}}{kT}\right)}$$

$$n = \int_{\infty}^{E_{\text{c}}} f(E)N(E)dE$$

$$N(E) = 4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} E^{1/2}$$

$$f(E) \approx \exp\left(-\frac{E - E_{\text{F}}}{kT}\right) \text{ ef } E - E_{\text{F}} > 3kT$$

$$f(E) \approx 1 - \exp\left(-\frac{E_{\text{F}} - E}{kT}\right) \text{ ef } E - E_{\text{F}} < 3kT$$

$$n \approx N_{\text{c}} \exp\left(-\frac{E_{\text{c}} - E_{\text{F}}}{kT}\right)$$

$$N_{\text{c}} = 2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2}$$

$$p \approx N_{\text{v}} \exp\left(-\frac{E_{\text{F}} - E_{\text{v}}}{kT}\right)$$

$$N_{\text{v}} = 2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2}$$

$$np = N_\mathrm{c} N_\mathrm{v} \exp\left(-\frac{E_\mathrm{g}}{kT}\right) = n_\mathrm{i}^2$$

$$n = n_\mathrm{i} \exp\left(\frac{E_\mathrm{F} - E_\mathrm{i}}{kT}\right)$$

$$p = n_\mathrm{i} \exp\left(\frac{E_\mathrm{i} - E_\mathrm{F}}{kT}\right)$$

$$E_\mathrm{c} - E_\mathrm{F} = kT \ln\left(\frac{N_\mathrm{c}}{N_\mathrm{D}}\right)$$

$$E_\mathrm{F} - E_\mathrm{v} = kT \ln\left(\frac{N_\mathrm{v}}{N_\mathrm{A}}\right)$$

$$np = n_\mathrm{i}^2$$

Við stofuhita fyrir kísil

$$N_\mathrm{c} = 2.8 \times 10^{19} \ \ \mathrm{cm}^{-3}$$

$$N_\mathrm{v} = 1.04 \times 10^{19} \ \ \mathrm{cm}^{-3}$$

Við stofuhita fyrir GaAs

$$N_\mathrm{c} = 4.7 \times 10^{17} \ \ \mathrm{cm}^{-3}$$

$$N_\mathrm{v} = 7 \times 10^{18} \ \ \mathrm{cm}^{-3}$$

n-leiðandi hálfleiðari

$$n_\mathrm{n} = \frac{1}{2}\left[N_\mathrm{D} - N_\mathrm{A} + \sqrt{(N_\mathrm{D} - N_\mathrm{A})^2 + 4n_\mathrm{i}^2}\right]$$

og

$$p_\mathrm{n} = \frac{n_\mathrm{i}^2}{n_\mathrm{n}}$$

p-leiðandi hálfleiðari

$$p_\mathrm{p} = \frac{1}{2}\left[N_\mathrm{A} - N_\mathrm{D} + \sqrt{(N_\mathrm{A} - N_\mathrm{D})^2 + 4n_\mathrm{i}^2}\right]$$

og

$$n_\mathrm{p} = \frac{n_\mathrm{i}^2}{p_\mathrm{p}}$$

$$N_\mathrm{C} = 2\left(\frac{m_e^* kT}{2\pi\hbar^2}\right)^{3/2}$$

$$N_\mathrm{V} = 2\left(\frac{m_h^* kT}{2\pi\hbar^2}\right)^{3/2}$$

$$J = \sigma\mathcal{E}$$

$$\sigma = \frac{nq^2\tau}{m_\mathrm{n}^*} \quad [\Omega\mathrm{cm}]^{-1}$$

$$\sigma = qn\mu_\mathrm{n}$$

$$\mu_\mathrm{n} = \frac{q\tau}{m_\mathrm{n}^*}$$

$$J = q(n\mu_\mathrm{n} + p\mu_\mathrm{p})\mathcal{E} = \sigma\mathcal{E}$$

$$R = \frac{\rho L}{Wd} = \frac{L}{Wd}\frac{1}{\sigma}$$

4 MOSFET

MOS kjörtvistur

$$q\phi_\mathrm{ms} = q(\phi_\mathrm{m} - \phi_\mathrm{s})$$

$$q\phi_\mathrm{ms} = q\phi_\mathrm{m} - \left[q\chi + \frac{E_\mathrm{g}}{2} + q\phi_\mathrm{b}\right]$$

$$Q_\mathrm{sc} = -qN_\mathrm{A}x_\mathrm{dmax} \approx -\sqrt{2q\epsilon_\mathrm{s}N_\mathrm{A}(2\psi_\mathrm{b})}$$

$$\psi_\mathrm{s}(\text{umhverfing}) \approx 2\psi_\mathrm{b} = \frac{2kT}{q}\ln\left(\frac{N_\mathrm{A}}{n_\mathrm{i}}\right)$$

$$x_{\mathrm{dmax}} = \left(\frac{2\epsilon_{\mathrm{s}}\psi_{\mathrm{s}}(\mathrm{umhv.})}{qN_{\mathrm{A}}}\right)^{1/2} \approx \left(\frac{2\epsilon_{\mathrm{s}}(2\psi_{\mathrm{b}})}{qN_{\mathrm{A}}}\right)^{1/2}$$

$$C_{\mathrm{ox}} = \frac{\epsilon_{\mathrm{ox}}}{d}$$

$$C_{\mathrm{d}} = \frac{\epsilon_{\mathrm{s}}}{x_{\mathrm{d}}}$$

$$C = \frac{C_{\mathrm{ox}}C_{\mathrm{d}}}{C_{\mathrm{ox}} + C_{\mathrm{d}}}$$

$$I_{\mathrm{D}} \approx \frac{W}{L}\mu_{\mathrm{n}}C_{\mathrm{ox}}(V_{\mathrm{G}} - V_{\mathrm{T}})V_{\mathrm{D}}$$

ef $V_{\mathrm{D}} \ll (V_{\mathrm{G}} - V_{\mathrm{T}})$

$$V_{\mathrm{T}} \approx \frac{\sqrt{2\epsilon_{\mathrm{s}}qN_{\mathrm{A}}(2\psi_{\mathrm{b}})}}{C_{\mathrm{ox}}} + 2\psi_{\mathrm{b}}$$

$$V_{\mathrm{Dsat}} \approx V_{\mathrm{G}} - 2\psi_{\mathrm{b}} + K^2\left[1 - \left(1 + \frac{2V_{\mathrm{G}}}{K^2}\right)^{1/2}\right]$$

þar sem

$$K \equiv \frac{\epsilon_{\mathrm{Si}}qN_{\mathrm{A}}}{C_{\mathrm{ox}}}$$

$$I_{\mathrm{Dsat}} \approx \frac{W\mu_{\mathrm{n}}C_{\mathrm{ox}}}{2L}(V_{\mathrm{G}} - V_{\mathrm{T}})^2$$

Frávik frá kjörhegðan

$$V_{\mathrm{FB}} = \phi_{\mathrm{ms}} - \frac{Q_{\mathrm{it}}}{C_{\mathrm{ox}}}$$

$$V_{\mathrm{T}} = \phi_{\mathrm{ms}} - \frac{Q_{\mathrm{it}}}{C_{\mathrm{ox}}} - \frac{Q_{\mathrm{sc}}}{C_{\mathrm{ox}}} + 2\psi_{\mathrm{b}}$$

$$\psi_{\mathrm{b}} = (E_{\mathrm{i}} - E_{\mathrm{F}})/q$$

$$\Delta V_{\mathrm{T}} = \frac{\sqrt{2q\epsilon_{\mathrm{s}}N_{\mathrm{A}}}}{C_{\mathrm{o}}}\left[(2\psi_{\mathrm{b}} + V_{\mathrm{BS}})^{1/2} - (2\psi_{\mathrm{b}})^{1/2}\right]$$

$$x_{\mathrm{S}} = \left(\frac{2\epsilon_{\mathrm{s}}}{qN_{\mathrm{A}}}(V_{\mathrm{bi}} + V_{\mathrm{BS}})\right)^{1/2}$$

$$x_{\mathrm{D}} = \left(\frac{2\epsilon_{\mathrm{s}}}{qN_{\mathrm{A}}}(V_{\mathrm{D}} + V_{\mathrm{bi}} + V_{\mathrm{BS}})\right)^{1/2}$$

5 Viðnám

$$R = \frac{\rho L}{A}$$

$$\sigma = \frac{1}{\rho} = (q\mu_{\mathrm{n}}n + q\mu_{\mathrm{p}}p)$$

$$R = \frac{1}{G} = \frac{L}{W}\frac{1}{g}$$

6 Hreyfifræði gass

$$pV = RT = N_{\mathrm{Av}}kT$$

$$f_{\mathrm{v}} = \frac{4}{\sqrt{\pi}}\left(\frac{m}{2kT}\right)^{3/2} v^2 \exp\left(-\frac{mv^2}{2kT}\right)$$

$$\phi = \frac{p}{(2\pi mkT)^{1/2}} = 3.51 \times 10^{22}\left(\frac{p}{\sqrt{MT}}\right)$$

7 Lagvöxtur

$$C_{\mathrm{s}} = \frac{C_{\mathrm{g}}}{1 + (k_{\mathrm{s}}/h_{\mathrm{g}})}$$

$$v = \frac{k_{\mathrm{s}}h_{\mathrm{g}}}{k_{\mathrm{s}} + h_{\mathrm{g}}}\left(\frac{C_{\mathrm{t}}}{C_{\mathrm{a}}}\right)y$$

$$\delta(x) \approx \sqrt{\frac{\mu x}{\rho_{\mathrm{d}}v}}$$

$$\bar{\delta}(x) = \frac{1}{L}\int_0^L \delta(x)dx = \frac{2}{3}\sqrt{\frac{\mu L}{\rho_{\mathrm{d}}v}}$$

$$h_{\mathrm{g}} = \frac{D_{\mathrm{g}}}{\delta} = \frac{3}{2}D_{\mathrm{g}}\sqrt{\frac{v\rho_{\mathrm{d}}}{\mu L}}$$

8 Oxun

$$x^2 + \frac{2D}{k}x = \frac{2DC_0}{C_1}(t+\tau)$$

$$\tau \equiv \left(d_0^2 + \frac{2Dd_0}{k}\right)\frac{C_1}{2DC_0}$$

$$x = \frac{D}{k}\left[\left(1 + \frac{2C_0k^2(t+\tau)}{DC_1}\right)^{1/2} - 1\right]$$

$$x^2 + Ax = B(t+\tau)$$

$$A \equiv \frac{2D}{k}$$

$$B \equiv \frac{2DC_0}{C_1}$$

$$\frac{B}{A} \equiv \frac{kC_0}{C_1}$$

9 Sveim

$$F = -D\frac{\partial C}{\partial x}$$

$$\frac{\partial C}{\partial t} = -\frac{\partial F}{\partial x} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right)$$

$$D = D_0 \exp\left(-\frac{E_\mathrm{a}}{kT}\right)$$

Fastur yfirborðsþéttleiki

$$C(x,t) = C_\mathrm{s}\mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$Q(t) = \int_0^\infty C(x,t)dx$$

$$Q(t) = \frac{2}{\sqrt{\pi}}C_\mathrm{s}\sqrt{Dt} \approx 1.13C_\mathrm{s}\sqrt{Dt}$$

Föst heildaríbót

$$\int_0^\infty C(x,t)dx = S$$

$$C(\infty,t) = 0$$

$$C(x,t) = \frac{S}{\sqrt{\pi Dt}}\exp\left(-\frac{x^2}{4Dt}\right)$$

$$C_\mathrm{s}(t) = \frac{S}{\sqrt{\pi Dt}}$$

10 Jónaígræðsla

$$\left(\frac{dE}{dx}\right)_\mathrm{tot} = S_\mathrm{n}(E) + S_\mathrm{e}(E)$$

$$\int_0^R dx = R = -\int_E^0 \frac{dE}{(dE/dx)_\mathrm{tot}}$$

$$S_\mathrm{e} = k_\mathrm{e}\sqrt{E}$$

$$N(x) = N_\mathrm{p}\exp\left[-\frac{(x-R_\mathrm{p})^2}{2(\Delta R_\mathrm{p})^2}\right]$$

$$Q = \int_0^\infty N(x)dx$$

$$Q = \sqrt{2\pi}N_\mathrm{p}\Delta R_\mathrm{p}$$

$$N(x) = \frac{N_\mathrm{p}}{\left[1 + \frac{4Dt}{2(\Delta R_\mathrm{p})^2}\right]^{1/2}}\exp\left[-\frac{(x-R_\mathrm{p})^2}{2(\Delta R_\mathrm{p})^2 + 4Dt}\right]$$

11 Málmar

$$\mathrm{MTF} \sim \frac{1}{J^2} \exp\left(\frac{E_\mathrm{a}}{kT}\right)$$

12 Lithography

$$\mathrm{CD} = W_\mathrm{min} \approx \sqrt{\lambda g}$$

$$R = \frac{0.61\lambda}{n \sin\theta}$$

$$R = \frac{0.61\lambda}{\mathrm{NA}} = k_1 \frac{\lambda}{\mathrm{NA}}$$

$$\mathrm{NA} \equiv n \sin\theta$$

$$\mathrm{DOF} = \pm\frac{R/2}{\tan\theta} \approx \pm\frac{R/2}{\sin\theta} = \pm k_2 \frac{\lambda}{(\mathrm{NA})^2}$$

$$\mathrm{MTF} = \frac{I_\mathrm{MAX} - I_\mathrm{MIN}}{I_\mathrm{MAX} + I_\mathrm{MIN}}$$

$$\mathrm{CMTF}_\mathrm{viðnám} = \frac{E_\mathrm{T} - E_1}{E_\mathrm{T} + E_1} = \frac{10^{1/\gamma} - 1}{10^{1/\gamma} + 1}$$

$$\gamma = \frac{1}{\log\left[\frac{E_\mathrm{T}}{E_1}\right]}$$

13 Framleiðni

Líkan Poisson

$$Y = \frac{1}{\mathrm{e}^{AD}}$$

Líkan Murphy

$$Y = \left[\frac{1 - \mathrm{e}^{-AD}}{AD}\right]^2$$

Líkan Seeds

$$Y = \frac{1}{\mathrm{e}^{\sqrt{AD}}}$$