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High Speed Electronics 2019 – Exercise 2 Solutions

1. a) Charge centroid capacitance accounts for the band bending. Hence the total gate capacitance is

$$\frac{1}{C_g} = \frac{1}{C_{ox}} + \frac{1}{C_q} + \frac{1}{C_c}$$

$$\frac{1}{C_g} = \frac{1}{0.049} + \frac{1}{0.017} + \frac{1}{0.06}$$

C_g = 0.01 F/m^2

b) The quantum well is confined with thickness t_w = 6nm. Assuming infinite quantum well, the energy states of the quantized bands is given by

$$E_n = \frac{h^2\pi^2 n^2}{2m^* t_w}$$

E_1 = 0.45 eV
E_2 = 1.82 eV

2. Ignoring C_c ,

$$\frac{1}{C_g} = \frac{1}{C_{ox}} + \frac{1}{C_q}$$

$$\frac{1}{C_g} = \frac{t_{ox}}{\mathcal{E}_{ox}\mathcal{E}_0} + \frac{\pi h^2}{q^2 m^*}$$

$$C_g = \frac{\mathcal{E}_{ox}\mathcal{E}_0 q^2 m^*}{t_{ox} q^2 m^* + \pi h^2 \mathcal{E}_{ox}\mathcal{E}_0}$$

Divide by q^2m^*

$$C_g = \frac{\mathcal{E}_{ox}\mathcal{E}_0}{t_{ox} + \Delta t}$$

$$\Delta t = \frac{\pi h^2 \mathcal{E}_{ox}\mathcal{E}_0}{q^2 m^*}$$

From (1), Δt = 11 nm

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3. a)

$$V_{ds,sat} = \frac{C'_{ox}}{C'_{ox} + \frac{C_q}{2}}(V_{GS} - V_T)$$

$$C'_{ox} = C_{ox}||C_c = 0.027\ F/m^2$$

= 0.23 V

b)

$$I_{ds,sat} = \frac{qW2\sqrt{2m^*}}{3\pi^2 h^2}\left(\frac{qC'_{ox}}{C'_{ox} + \frac{C_q}{2}}\right)^{\frac{3}{2}}(V_{GS} - V_T)^{\frac{3}{2}}$$

= 1.45 mA/µm

4. a)

$$I_{ds,sat} = \frac{qW2\sqrt{2m^*}}{3\pi^2 h^2}\left(\frac{qC'_{ox}}{C'_{ox} + \frac{q^2 m^*}{2\pi h^2}}\right)^{\frac{3}{2}}(V_{GS} - V_T)^{\frac{3}{2}}$$

- For large m^*, $(m^*)^{3/2}$ is much larger than $(m^*)^{1/2}$ and hence larger denominator causes $I_{ds,sat} \longrightarrow 0$
- For small m^*, $(m^*)^{1/2}$ becomes very small and capacitance term becomes constant as m^* is small and hence $I_{ds,sat} \longrightarrow 0$

b) Summarizing everything independent of m^* to be a constant K,

$$I_{ds,sat} = K\left(\frac{\sqrt{m^*}}{\left(C'_{ox} + \frac{q^2 m^*}{2\pi h^2}\right)^{\frac{3}{2}}}\right)$$

$$\frac{\partial I_{ds,sat}}{\partial m^*} = K\left(\frac{1}{2\sqrt{m^*}\left(C'_{ox} + \frac{q^2 m^*}{2\pi h^2}\right)^{\frac{3}{2}}} - \frac{3\sqrt{m^*}}{2\left(C'_{ox} + \frac{q^2 m^*}{2\pi h^2}\right)^{\frac{5}{2}}}\left(\frac{q^2}{2\pi h^2}\right)\right)$$

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c) Taking out the common factors from both the terms in the above equation,

$$0 = \frac{1}{2} - \frac{3}{2}\frac{q^2 m^*}{2\pi h^2\left(C'_{ox} + \frac{q^2 m^*}{2\pi h^2}\right)}$$

$$m^*_{opt} = \frac{\pi h^2 C'_{ox}}{q^2}$$

d) Using the above equation, the optimum m^* for the FET in (1) can be calculated as

$m^* = 0.04\ m_0$

5. Since the doping level is high, one can assume a vertical contact.

Contact length L_c = 100nm

Contact width W_c = 500nm

Well thickness t_w = 6nm

Length between contacts L_{gap} = 50nm

a)

$$L_T = \sqrt{\frac{\rho_\sigma}{R_{SH}}} = \sqrt{\frac{\rho_\sigma}{\left(\frac{\rho_n}{t_w}\right)}} = \sqrt{\frac{\rho_\sigma}{\left(\frac{1/qn\mu}{t_w}\right)}}$$

L_T = 62 nm (R_{SH} = 260 Ω)

b)

$$R_C = R_{SH}\frac{L_T}{W_c} = 32.24\ \Omega$$

c)

$$R_{access} = \frac{L_{gap}}{W_c}R_{SH} = 26\ \Omega$$

d) V_{GS} gets reduced to $V_{GS} - R_S I_D$

Source resistance $R_s = R_c + R_{access}$ = 58.24 Ω

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Assuming width of the device W = 500nm

Voltage drop across the source resistance $R_S I_D$ = 58.24*1.45*10^{-3}*500*10^{-3} = 42 mV

Hence applied $V_{GS} - V_T$ is reduced from 0.3V to $V_{GS} - V_T - R_S I_D$ which is 0.258V

Thus the saturation current is reduced from 1.45mA/µm to 1.16mA/µm.