Exercise 2

2-1 The circuit shown in Fig.2.1 illustrates a single-channel MOS resistor with a W/L of 2μm/2μm. Using Table.2.1 model parameters calculate the small-signal on resistance of the MOS transistor at various values for VS and fill in the table below. (Note that the transistor was in linear region, VB=0, I_{DS}=0)

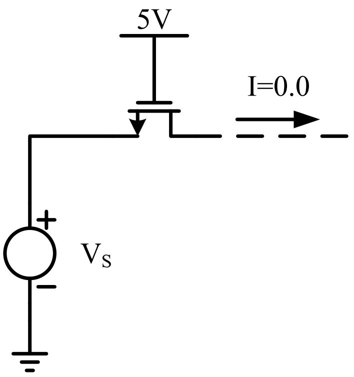

Fig.2. 1

Vs(V)	R(Ω)
0.0	
1.0	
2.0	
3.0	
4.0	
5.0	

Answer

The equation for threshold voltage is represented with absolute values so that it can be applied to n-channel or p-channel transistors without confusion.

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}]$$

$$r_{on} = \frac{1}{\partial I_D/\partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)}$$

For n-channel device

$V_{T0} = 0.7 \ \ \gamma = 0.45 \ \ 2|\Phi_F| = 0.9 \ \ K = 134$

(1) When $V_S = 0, V_{GS} = 5$and $V_{SB} = 0$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 0.7$$

$$r_{on} = \frac{1}{\partial I_D/\partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 1.736K\Omega$$

(2) When $V_S = 1, V_{GS} = 4$and $V_{SB} = 1$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 0.893$$

$$r_{on} = \frac{1}{\partial I_D/\partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 2.402K\Omega$$

(3) When $V_S = 2, V_{GS} = 3$and $V_{SB} = 2$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 1.039$$

$$r_{on} = \frac{1}{\partial I_D/\partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 3.806K\Omega$$

(4) When $V_S = 3, V_{GS} = 2$ and $V_{SB} = 3$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 1.162$$

$$r_{on} = \frac{1}{\partial I_D/\partial V_{DS}} = \frac{L}{KW(|V_{GS}| - |V_T| - |V_{DS}|)} = 8.905K\Omega$$

(5) When $V_S = 4, V_{GS} = 1$ and $V_{SB} = 4$

$$|V_T| = |V_{T0}| + \gamma[\sqrt{2|\Phi_F| + |V_{SB}|} - \sqrt{2|\Phi_F|}] = 1.269$$

$V_{GS} < V_T$ The device is cutoff, so r_{on} = infinity

(6) When $V_S = 5, V_{GS} = 0$ and $V_{SB} = 5$

The device is cutoff, so r_{on} = infinity

Vs(V)	R(Ω)
0.0	1.736K
1.0	2.402K
2.0	3.806K
3.0	8.905K
4.0	infinity
5.0	infinity

2-2 An NMOS with W=50μm and L=0.5μm operates in the saturated region and its layout is folded shown as Fig2.2. Calculate the all capacitances by using the parameters in Table2.2 and C_{ox}=3.8×10^{-3} F/m, V_R=0.6V. Assume that the minimum size (lateral) of S/D region is 1.5μm

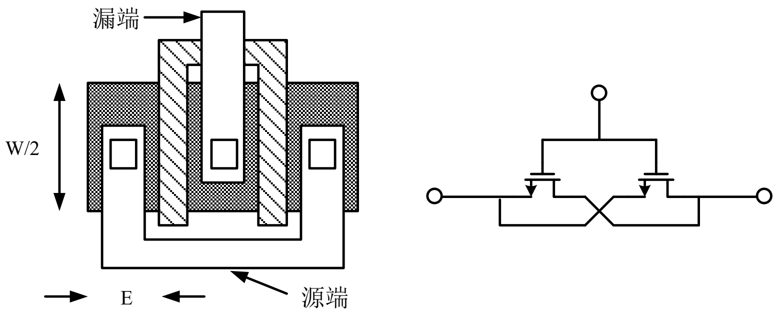

Fig.2. 2

Answer:

$$C_{j0} = 0.56 \times \frac{10^{-3}F}{m^2}, C_{jsw0} = 0.35 \times \frac{10^{-11}F}{m}, m_j = 0.45, m_{jsw} = 0.2$$

$$C_{ov} = 0.4 \times \frac{10^{-9}F}{m}, W = 50\mu m, L = 0.5\mu m, L_D = 0.08\mu m, E = 1.5\mu m$$

$$V_R = 0.6V, 2\Phi_F = 0.9V, C_{ox} = 3.8 \times 10^{-3}F/m^2, P_{SUB} = 9 \times 10^8 m^{-3}$$

$\varepsilon_{si} = 11.7 \times 8.85 \times 10^{-12} F/m, q = 1.6 \times 10^{-19} C$

$$C_j = \frac{C_{j0}}{(1 + V_R/2\Phi_F)^{m_j}} = 0.445\ fF/\mu m^2\ C_{jsw} = \frac{C_{jsw0}}{(1 + V_R/2\Phi_F)^{m_{jsw}}} = 3.16 \times \frac{10^{-3} fF}{\mu m}$$

$$L_{eff} = L - 2L_D = 0.34\ \mu m \qquad C_d = W L_{eff} \sqrt{q \varepsilon_{si} P_{SUB}/4\Phi_F} = 1.55 \times 10^{-6} fF$$

$$C_{DB} = \frac{W}{2} E C_j + 2(\frac{W}{2} + E) C_{jsw} = 16.85 fF$$

$$C_{SB} = 2(\frac{W}{2} E C_j + 2(\frac{W}{2} + E) C_{jsw}) = 33.71 fF$$

$$C_{GD} = 2(\frac{W}{2} C_{ov}) = 20.0 fF$$

$$C_{GS} = \frac{2}{3} W L_{eff} C_{ox} + W C_{ov} = 63 fF$$

$$C_{GB} = \frac{W L_{eff} C_{OX} C_d}{(W L_{eff} C_{ox} + C_d)} = 1.55 \times 10^{-6} fF$$

2-3 There is an N-type current source, I_D is 0.5mA, and the drain-source voltage V_{DS} must more than 0.4V when it works as a current source. If the minimum output resistance is 20 KΩ, determine the length and width of the device by using the parameters in Table.2.2.

Answer:

$$\begin{cases} r_o = \dfrac{1}{\lambda I_D} = 20K\Omega \\ I_D = 0.5mA \end{cases} \quad \Rightarrow \quad \lambda=0.1$$

From the table2.2, L can be determined as L=0.5um.(

$$L_{eff} = L - 2L_D = 0.5\mu m - 2 \times 0.08\mu m = 0.34\mu m$$

Calculating W

$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L_{eff}} (V_{GS} - V_{TH})^2, \qquad V_{GS}\text{-}V_{TH}=V_{DSAT}=0.4V$$

$$\frac{W}{L_{eff}} = \frac{I_D}{\frac{1}{2}\mu_n C_{ox} (V_{GS} - V_{TH})^2} = \frac{0.5 \times 10^{-3}}{\frac{1}{2} \times 134 \times 10^{-6} \times 0.4^2} = 46.64$$

$\therefore\ W = 46.64 L_{eff} = 15.86 \mu m$

2-4 A "ring" MOS structure is shown in Fig.2.3. Explain how the device operations and estimate its equivalent aspect ratio. Calculate the drain junction capacitance of the structure. (use Cj and Cjsw)

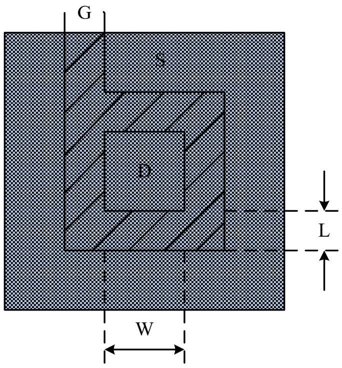

Fig.2. 3

Answer:

Width/length ratio is 4W/L

$$C_{DB} = W^2 C_j + 4WC_{jsw}$$

2-5 Find the small-signal model (g_m, g_{mb}, g_{ds}) for an n-channel transistor with the drain at 4 V, gate at 4 V, source at 2 V, and the bulk at 0 V. Assume the model parameters from Table.2.1, and W/L = 10 μm/1 μm.

Answer:

$$V_T = V_{T0} + \gamma\left[\sqrt{2|\Phi_F| + v_{SB}} - \sqrt{2|\Phi_F|}\right]$$

$$V_T = 0.7 + 0.45[\sqrt{0.9 + 2.0} - \sqrt{0.9}] = 1.04\,V$$

$$I_D = \frac{K'W}{L}(v_{GS} - v_T)^2(1 + \lambda v_{DS})$$

$$I_D = 134 \times 10^{-6} \times 10 \times (2 - 1.04)^2(1 + 0.1 \times 2) = 1482 \times 10^{-6}\ \text{A}$$

$$g_m = \sqrt{4\frac{KW}{L}I_D}$$

$$g_m = \sqrt{4 \times 134 \times 10^{-6} \times 10 \times 1482 \times 10^{-6}} = 2.818 \times 10^{-3}\ \text{S}$$

$$g_{mb} = g_m \frac{\gamma}{2(2|\Phi_F| + V_{SB})^{\frac{1}{2}}}$$

$$g_{mb} = 2.818 \times 10^{-3} \frac{0.45}{2(0.9 + 2.0)^{\frac{1}{2}}} = 372.3 \times 10^{-6}\ \text{S}$$

$$g_{ds} = \frac{\lambda I_D}{1 + \lambda V_{DS}}$$

$$g_{ds} = 1482 \times 10^{-6} \times 0.1 \div 1.2 = 123.5 \times 10^{-6}\ \text{S}$$

Table.2. 1

Typical Parameter Value				
Parameter Symbol	Parameter Description	n-Channel	p-Channel	Units
V_{T0}	Threshold voltage(V_{BS}=0)	0.7	-0.8	V
K	Transconductance parameter(in saturation)	134	50	$\mu A/V^2$
γ	Bulk threshold parameter	0.45	0.4	$V^{1/2}$
λ	Channel length modulation parameter	0.1	0.2	V^{-1}
$2\lvert\phi_F\rvert$	Surface potential at strong inversion	0.9	0.8	V

$*K' = \frac{1}{2}\mu C_{ox}$

Table.2.2

NMOS Model			
LEVEL=1	VTO=0.7	GAMMA=0.45	PHI=0.9
PSUB=9e+14	LD=0.08e-6	UO=350	LAMBDA=0.1
TOX=9e-9	PB=0.9	CJ=0.56e-3	CJSW=0.35e-11
MJ=0.45	MJSW=0.2	CGDO=0.4e-9	JS=1.0e-8
PMOS Model			
LEVEL=1	VTO=-0.8	GAMMA=0.4	PHI=0.8
PSUB=5e+14	LD=0.09e-6	UO=100	LAMBDA=0.2
TOX=9e-9	PB=0.9	CJ=0.94e-3	CJSW=0.32e-11
MJ=0.5	MJSW=0.3	CGDO=0.3e-9	JS=0.5e-8

上表给出的是 0.5μm 工艺 level 1 MOS SPICE 模型参数的典型值，其中的参数定义如下：

VTO:	VSB=0 时的阈值电压	（单位：V）
GAMMA:	体效应系数	（单位：$V^{1/2}$）
PHI:	$2\Phi_F$	（单位：V）
TOX:	栅氧厚度	（单位：m）
NSUB:	衬底掺杂浓度	（单位：cm^{-3}）
LD:	源/漏侧扩散长度	（单位：m）

UO:	沟道迁移率	（单位：cm2/(v/s)）
LAMBDA:	沟道长度调制系数	（单位：V^{-1}）
CJ:	单位面积的源/漏结电容	（单位：F/m^2）
CJSW:	单位长度的源/漏侧壁结电容	（单位：F/m）
PB:	源/漏结内建电势	（单位：V）
MJ:	CJ 公式中的幂指数	（无单位）
MJSW:	CJSW 等式中的幂指数	（无单位）
CGDO:	单位宽度的栅/漏交叠电容	（单位：F/m）
CGSO:	单位宽度的栅/源交叠电容	（单位：F/m）
JS:	源/漏结单位面积的漏电流	（单位：A/m^2）