7

6.13

Calculate the V_T of a Si p-channel MOS transistor for an n^+-polysilicon gate with silicon oxide thickness $= 50A, N_d = 1 \times 10^{18}\ cm^{-3}$ and a fixed charge of $2 \times 10^{10}\ q\ C/cm^2$. Is it an enhancement- or depletion-mode device? What B dose is required to change the V_T to $0\ V$? Assume a shallow B implant.

✓ Answer

$V_T = V_{FB} - \frac{Q_d}{C_i} + \phi_s$

$\phi_s = -\frac{2kT}{q} \ln\left(\frac{N_d}{n_i}\right) = -0.9541912625367326\ V$

$Q_d = -2(\epsilon_s q N_d \phi_F)^{1/2} = 5.646838224612736 \times 10^{-7}$

$C_i = \frac{\epsilon_i}{d} = 6.903 \times 10^{-7}$

$V_{FB} = \phi_{ms} - \frac{Q_i}{C_i} = 0.6382687030790191\ V$

$V_T = -1.1339492470736394\ V$

Enhancement

$\Delta N_B = -\frac{-\Delta V_T C_{ox}}{q} = 4.892282282843 \times 10^{12}$

6.21

An n-channel enhancement-mode MOSFET with $50\ nm$ thick HfO_2 high-k gate dielectric ($\epsilon_r = 25$) has a flat band voltage of $0.5\ V$, and substrate doping of $10^{18}\ cm^{-3}$. The intrinsic carrier concentration is $10^{11}\ cm^{-3}$, effective electron channel mobility is $250\ cm^2/Vs$, and $\epsilon_r = 15$. What is the drive current for a $50\ \mu m$ wide and $2\ \mu m$ long device at $V_G = 3V$ and $V_D = 0.05\ V$? What is the saturation current at this gate bias?

✓ Answer

$\mu_n = 0.025\ m^2/Vs$

$V_{FB} = 0.5\ V$

$Z = 5 \times 10^{-5}\ m$

$L = 2 \times 10^{-6}\ m$

$t_{ox} = 5 \times 10^{-8}\ m$

$C_i = 4.425 \times 10^{-3}$

$\phi_F = 0.417\ V$

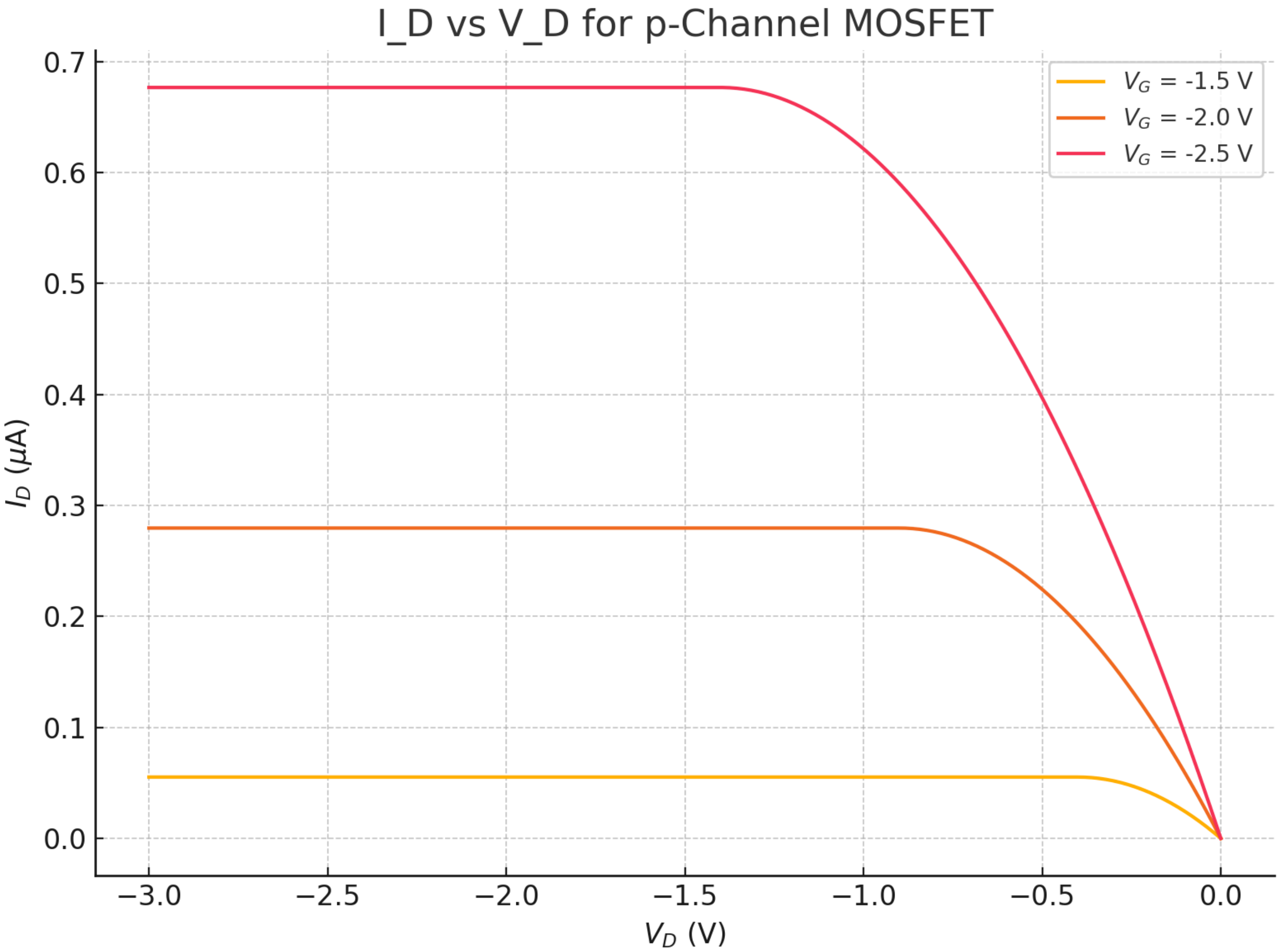
$V_T = 5.6\ V$

$V_G < V_T$ so the device stays off

6.32

Plot I_D vs. V_D with several values of V_G for a thin-oxide p-channel transistor with a $10\ \mu m$ oxide and $V_T = -1.1\ V$. Assume that I_D(sat.) remains constant beyond pinch-off. Assume that $\bar{\mu_p} = 200\ cm^2/Vs$, and $Z = 10\ L$.

```
import numpy as np
import matplotlib.pyplot as plt

# Constants
epsilon_0 = 8.85e-12
epsilon_r = 3.9
t_ox = 10e-6
C_ox = epsilon_0 * epsilon_r / t_ox

mu_p = 0.02
Z_by_L = 10
V_T = -1.1

# Gate voltages to plot
V_G_values = [-1.5, -2.0, -2.5]
V_D = np.linspace(0, -3, 300)

def compute_ID(V_G):
    V_SG = -V_G
    I_D = []
    for V_D_val in V_D:
        V_SD = -V_D_val
        if V_SD < (V_SG - abs(V_T)):
            ID_val = mu_p * C_ox * Z_by_L * ((V_SG - abs(V_T)) * V_SD - 0.5 * V_SD ** 2)
        else:
            ID_val = 0.5 * mu_p * C_ox * Z_by_L * (V_SG - abs(V_T)) ** 2
        I_D.append(ID_val)
    return np.array(I_D)

# Plotting
plt.figure(figsize=(8, 6))
for V_G in V_G_values:
    I_D = compute_ID(V_G)
    plt.plot(V_D, I_D * 1e6, label=f'$V_G$ = {V_G} V')

plt.title('I_D vs V_D for p-Channel MOSFET')
plt.xlabel('$V_D$ (V)')
plt.ylabel('$I_D$ ($\mu$A)')
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```



7.5

An npn BJT has emitter, base, and collector doping levels of $10^{19}\ cm^{-3}$, $5 \times 10^{18}\ cm^{-3}$, and $10^{17}\ cm^{-3}$, respectively. It is biased in the normal active mode, with an emitter-base voltage of $1V$. If the neutral base width is $100\ nm$, the emitter is $200\ nm$ wide, and we have *negligible* base recombination, calculate the emitter current, emitter injection efficiency, and base transport factor. You can assume electron and hole mobility of 500 and $100\ cm^2/Vs$, respectively, in the emitter, and 800 and $250\ cm^2/Vs$ in the base. The device gets heated up to $400\ K$ during operation such that $n_i = 10^{12}\ cm^{-3}$, and $\epsilon_r = 15$. Qualitatively sketch the device structure, the carrier concentrations, and the band diagram under bias below it. Assume the carrier lifetimes are $0.1\ \mu s$ everywhere.