1. A silicon diode is doped on the n-side with \( N_D = 1 \times 10^{19} \) cm\(^{-3}\) and on the p-side with \( N_A = 2 \times 10^{15} \) cm\(^{-3}\). What is the built-in voltage for the resulting p-n junction? At zero bias, what is the depletion region width? What is the depletion region width when reverse biased by -5 V?

\[
V_0 = \frac{kT}{q} \ln \left( \frac{N_A N_D}{n_i^2} \right) = 0.025 V \ln \left( \frac{2 \times 10^{15} \times 1 \times 10^{20}}{1.5 \times 10^{10}} \right) = 0.80 \text{ V (built-in voltage)}
\]

\[
W = \sqrt{\frac{2e_S V_0}{q} \left( \frac{1}{N_A} + \frac{1}{N_D} \right)} = \sqrt{\frac{2 \times 11.7 \times 8.8542 \times 10^{-14} \times 0.80}{1.602 \times 10^{-19}} \left( \frac{1}{2 \times 10^{16}} + \frac{1}{1 \times 10^{19}} \right)} = 7.2 \times 10^{-5} \text{ cm} = 720 \text{ nm}
\]

For a reverse bias of -5V, replace \( V_0 \) with \( V_0 + 5 = 5.80 \text{ V} \). This increases the depletion width to 1.9 \( \mu \text{m} \).

2. An NMOS transistor has a drain that makes a p-n junction with respect to the substrate with an area of 0.2 \( \mu \text{m} \times 0.2 \mu \text{m} \). Calculate the depletion region width and the junction capacitance for this junction when it is reversed biased by -1.5 V. Assume the drain region is very heavily doped (about \( 1 \times 10^{20} \) cm\(^{-3}\)) and the substrate doping is \( 2 \times 10^{16} \) cm\(^{-3}\).

\[
V_0 = \frac{kT}{q} \ln \left( \frac{N_A N_D}{n_i^2} \right) = 0.025 V \ln \left( \frac{2 \times 10^{16} \times 1 \times 10^{20}}{1.5 \times 10^{10}} \right) = 0.92 \text{ V (built-in voltage)}
\]

\[
W = \sqrt{\frac{2e_S (V_0 - V)}{q} \left( \frac{1}{N_A} + \frac{1}{N_D} \right)} = \sqrt{\frac{2 \times 11.7 \times 8.8542 \times 10^{-14} \times 0.92}{1.602 \times 10^{-19}} \left( \frac{1}{2 \times 10^{16}} + \frac{1}{1 \times 10^{19}} \right)} = 396 \text{ nm}
\]

\[
C_{p-n \text{ junction}} = A \sqrt{\frac{q \varepsilon_S}{2(V_0 - V) \left( \frac{N_D N_A}{N_D + N_A} \right)}} = \left( 2 \times 10^{-5} \right)^2 \sqrt{\frac{1.602 \times 10^{-19} \times 11.7 \times 8.8542 \times 10^{-14}}{2 \left( 1.5 + 0.92 \right)} \left( \frac{2 \times 10^{16} \times 1 \times 10^{20}}{2 \times 10^{16} + 1 \times 10^{26}} \right)}
\]

\[
C_{p-n \text{ junction}} = 1.05 \times 10^{-17} \text{ F}
\]

3. To measure the doping level of an n-type wafer, a p'-n junction is formed and its C-V curve is measured. The area of the junction is 100 \( \mu \text{m} \times 100 \mu \text{m} \). From the C-V data in the spreadsheet, estimate the wafer doping level. \textit{Hint}: Plot \( 1/C^2 \) vs. \( V \), then extract the slope by finding the best-fit line in the spreadsheet.
\[
\frac{1}{C^2} = -\frac{2}{A^2q\varepsilon_s N_D} (V - V_0), \text{ so the slope will be } \left( -\frac{2}{A^2q\varepsilon_s} \right) \left( \frac{1}{N_D} \right) = -1.2 \times 10^{39} \text{ V cm}^{-3}/\text{F}^2 \left( \frac{1}{N_D} \right)
\]

From the best-fit line, the measured slope is \(-6.152 \times 10^{22} \text{ V/F}^2\), giving \(N_D = 2.0 \times 10^{16} \text{ cm}^{-3}\).