SPICE Problem Set#2
p-n Junction Diode

At 300 K assume

E_g=1.12 eV, N_C= 2.8x10^{19}/cm^3, N_V=10^{19}/cm^3, μ_n=1500 cm^2/V-s, μ_p= 500 cm^2/V-s, $\varepsilon_{r,Si}$=11.9, $\tau_n=\tau_p$=1 μs for Si,

E_g=0.66 eV, N_C= 1x10^{19}/cm^3, N_V=6x10^{18}/cm^3, μ_n=3900 cm^2/V-s, μ_p= 1900 cm^2/V-s, $\varepsilon_{r,Ge}$=16, $\tau_n=\tau_p$=1 μs for Ge,

E_g=1.42 eV, N_C= 4.7x10^{17}/cm^3, N_V=7x10^{18}/cm^3, μ_n=8500 cm^2/V-s, μ_p= 400 cm^2/V-s, $\varepsilon_{r,GaAs}$=13.1, $\tau_n=\tau_p$=0.1 μs for GaAs,

and kT=0.0259 eV, ε_0=8.85x10^{-14} F/cm.

Diode cross-sectional area A=1 μm^2, p-sided acceptor doping as N_A=10^{18} /cm^3 and n-sided donor doping as N_D=10^{16} /cm^3.

Q1. Separately implement Si, Ge and GaAs p-n junction diodes with a voltage dependent current source as $I=I_0(\exp(\frac{V}{\eta_1 V_T})-1)$ with η_1=1. Use I_0 as $I_0=qA(\frac{D_p p_{n0}}{L_p}+\frac{D_n n_{p0}}{L_n})$, $L_n=\sqrt{D_n \tau_n}$, $L_p=\sqrt{D_p \tau_p}$.

For all three diodes, plot current I as a function of voltage V varying from 0 to 0.75 V in a semilog axis (linear x-axis and logarithmic y-axis) for T= 300K. Estimate the values of the parameters I_0 from the plot and check if the values match well with the ones used in the simulation. Also plot the I-V characteristics of these diodes for T=200 K and T=400 K.

Q2. Simulate Full Wave Bridge rectifier circuits with (a) Ge, (b) Si and (c) GaAs p-n diodes and 1 kΩ load resistances. Apply (i) 10 V p-p, (ii) 100 V p-p input sine waves at 50 Hz. Observe the output waveforms in time domian when (i) T = 300 K, (ii) 400 K and (iii) 500 K. Under what kind of input voltages and temperatures, will you use Ge, Si or GaAs diodes in this rectification purpose?

Q3. Implement a Si p-n junction diode with voltage dependent current source as $I=I_0(\exp(\frac{V}{\eta_1 V_T})-1)+I_{0r}(\exp(\frac{V}{\eta_2 V_T})-1)$ with η_1=1 and η_2=2. Find I_0 following the expression in Q1 and use I_{0r} as $I_{0r}=\frac{qAn_i W}{2\tau}$ with W as the space charge width and $\tau=\tau_p=\tau_n$.

Plot current I as a function of voltage V varying from 0 to 0.75 V in a semilog axis at T=300 K. Estimate the values of the parameters I_0 and I_{0r} from the combined plot and check if these values match with the ones used in the simulation. Repeat this problem for Ge and GaAs p-n junction diodes and compare the I-V characteristics.

Q4. Add a series resistor R=10 mΩ in the diode implementation of **Q3** so that the current equation becomes implicit as $I=I_0(\exp(\frac{V-IR}{\eta_1 V_T})-1)+I_{0r}(\exp(\frac{V-IR}{\eta_2 V_T})-1)$. Use the parameter values obtained in **Q3**. Plot current I as a function of voltage V varying from 0 to 0.75 V in a semilog axis at T=300 K for a Si p-n diode. Vary the resistance values from 1 mΩ to 10 Ω and show the difference in the plots.

Q5. For a Si p-n diode, implement the charging current $\frac{dQ_j}{dt}$ in parallel with the current source given in **Q1** where Q_j is obtained as $Q_j = \int_0^V C_j\, dV = \int_0^V \left(\frac{C_{j0}}{\sqrt{1-\frac{V}{V_{bi}}}}\right) dV$. Run a fixed frequency AC simulation at f=2 MHz to find out the Y-parameter and plot the junction capacitance versus voltage varying from -2 V to 0.75 V. Also plot $1/C_j^2$ versus V to extract the parameters C_{j0} and V_{bi} and check if they match with the calculated values.

Q6. From the simulation of **Q5**, plot the conductance versus current for a Si p-n diode. If the current source expression in **Q5** is taken from **Q4** with R=1 Ω, plot the conductance versus current and compare with the previous plot. If one varies R from 1 mΩ to 10 Ω, how this conductance plot changes?

Q7. In the problem of **Q5** for a Si p-n diode, implement one additional parallel charging current component as $\frac{dQ_{diff}}{dt}$ where $Q_{diff} = I\tau$ with $\tau = \tau_p = \tau_n$. Now run a fixed frequency AC simulation at f=2 MHz to find out the Y-parameter and plot the junction capacitance versus voltage for voltage varying from -2 V to 0.75 V. Compare this plot with the one obtained from **Q5**. Plot the diffusion and junction capacitance components separately.