SPICE Problem Set#1

Semiconductor Fundamentals

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 for Si and kT=0.0259 eV.

Q1. An intrinsic silicon sample (with a length of 10 μm and uniform cross-sectional area of 1 μm^2) behaves like a resistor across which one connects a battery of 1V to measure the current flowing through the resistor. Implement a model of an intrinsic silicon resistor in Verilog-A and simulate I-V characteristics to plot the current (in logarithmic y-axis) with respect to 1000/T (linear x-axis) varying from 0.5 to 5 (i.e. T varies from 200 K to 2000 K). Assume both electron and hole mobilities are temperature-independent and their values at T=300 K can be used.

Following statements are related to the problems Q2 to Q6.

An n-type semiconductor bar (with a length of 10 μm and uniform cross-sectional area of 1 μm^2) behaves like a resistor across which one can connect a battery of 1V to measure the current flowing through the resistor. The doping concentration is N_D=10^{15}/cm^3. Implement a model of this resistor in Verilog-A and simulate I-V characteristics to plot curves in the following cases.

Q2. Plot the current as a function of temperature (T) varying from 300K to 600K. Assume complete ionization and both electron and hole mobilities are temperature-independent and their values at T=300 K can be used.

Q3. Actually impurity atoms are ionized following a rule which can be understood using the so called ionization coefficient defined as

$$\eta_D = \frac{\sqrt{\frac{8N_D}{N_C}\exp\left(\frac{E_C - E_D}{kT}\right) + 1} - 1}{\frac{4N_D}{N_C}\exp\left(\frac{E_C - E_D}{kT}\right)}$$

with E_C and E_D as the conduction band edge and donor energy level, respectively. Plot the current as a function of temperature (T) varying from 0K to 600K. Given that donor level is 0.045 eV below the conduction band edge. Both electron and hole mobilities are temperature-independent and their values at T=300 K can be used.

Q4. Actually both electron and hole mobilities are doping and temperature-dependent following the rules given as

$$\mu_n = 88\left(\frac{T}{300}\right)^{-0.57} + \frac{7.4\,x\,10^3\,T^{-2.33}}{1 + \frac{N}{1.26\,x\,10^{17}}\left(\frac{T}{300}\right)^{2.4}} \qquad \mu_p = 54.3\left(\frac{T}{300}\right)^{-0.57} + \frac{1.36\,x\,10^3\,T^{-2.23}}{1 + \frac{N}{2.35\,x\,10^{17}}\left(\frac{T}{300}\right)^{2.4}}$$

Here T is temperature in Kelvin and N is the total dopant density. Now repeat Q3 considering temperature and doping dependent electron and hole mobilities.

Q5. If you further dope the sample uniformly with Boron with a doping concentration varying from 10^{12} to $10^{18}/cm^3$, plot the current as a function of Boron doping concentration (N_A). Assume complete ionization and both electron and hole mobilities are temperature-independent and their values at T=300 K can be used.

Q6. Repeat Q5 considering ionization coefficient expression given in Q3 and temperature and doping dependent mobilities given in Q4.

Q7. Now assume that the doping concentration of a p-type sample (with a length of 10 μm and uniform cross-sectional area of 1 μm^2) is fixed at $N_A=10^{13}/cm^3$. The sample is under 1 V battery and uniformly illuminated, thereby generating an additional 10^{18} electron-hole pairs per cm^3 per second. Implement a model of this resistor in Verilog-A and simulate I-V characteristics. If the minority carrier lifetime in this sample is 1 μs, plot the voltage dependent (varying from 1 to 5 V) current flowing through this illuminated sample (under steady state) at 300 K and 400 K. Plot the excess current due to illumination. Also plot the voltage dependent current flowing through this sample under no illumination at 300 K and 400 K. You can assume complete ionization and both electron and hole mobilities are temperature-independent and their values at T=300 K can be used.