1 Drift - Diffusion simulation using MATLAB

A drift diffusion solver using Scharfetter - Gummel iteration has been studied and implemented using MATALB. The validity of the model has been checked using a long PN junction diode. This report explains the simulation procedure and simulation results of long PN junctions using MATLAB. I have used constant mobility and SRH recombination for this simulations. Three long devices have been simulated and its results are include in this report. For the first two devices, the simulation result has been compared with analytical result. Third device's simulation result has been compared with the simulation result obtained for the same device in Sentaurus TCAD. Finally the simulations are completed for a short diode also.

2 Diode1- The class room diode.

The material parameters used for this diode not matching with actual material parameter. This is to get a initial feel of how this model works for a normal class room diode. The parameters used for this diode is listed below.

Device parameter	n-Side	p-Side
$length(\mu m)$	200	200
$doping(/cm^3)$	10^{18}	10^{18}

Material parameter	electrons	holes
$\tau(\mu s)$	0.01	0.01
$mobility(cm^2/Vs)$	1500	1500

The analytical calculations can be done as follows.

$$L_n = \sqrt{V_t.\mu_n.\tau_n} = \sqrt{.026X1500X0.01X10^{-6}} = 6.244X10^{-4}cm \simeq 6.24\mu m \tag{1}$$
$$L_p = \sqrt{V_t.\mu_p.\tau_p} = \sqrt{.026X1500X0.01X10^{-6}} = 6.244X10^{-4}cm \simeq 6.24\mu m \tag{2}$$

$$\Delta p_n = p_n(exp(qV/KT) - 1) = 225(e^{0.625/0.26} - 1) \simeq 6.19X10^{12} \tag{3}$$
$$\Delta n_p = n_p(exp(qV/KT) - 1) = 225(e^{0.625/0.26} - 1) \simeq 6.19X10^{12} \tag{4}$$

minority carrier at $10.L_n$, $10.L_n$ can be calculated as

$$\delta_p \simeq \Delta p_n.exp(-x/L_p) = \Delta p_n e^{-10} \simeq 2.8X10^8 \tag{5}$$
$$\delta_n \simeq \Delta n_p.exp(-x/L_n) = \Delta n_p e^{-10} \simeq 2.8X10^8 \tag{6}$$

The simulation results are shown in Fig.1,Fig.2,Fig.3. The carrier densities from the simulation results are included as data tips in corresponding figure.

3 Diode2- The diode with real material parameters.

The parameters used for diode2 is listed below.

Device parameter	n-Side	p-Side
$length(\mu m)$	200	200
$doping(/cm^3)$	10^{17}	10^{16}

Material parameter	electrons	holes
$\tau(\mu s)$	0.01	0.01
$mobility(cm^2/Vs)$	1417	470

The analytical calculations can be done as follows.

$$L_n = \sqrt{V_t.\mu_n.\tau_n} = \sqrt{.026X1417X0.01X10^{-6}} = 6.06X10^{-4}cm \simeq 6.06\mu m \tag{7}$$
$$L_p = \sqrt{V_t.\mu_p.\tau_p} = \sqrt{.026X470X0.01X10^{-6}} = 3.49X10^{-4}cm \simeq 3.49\mu m \tag{8}$$

$$\Delta p_n = p_n(exp(qV/KT) - 1) = 2250(e^{0.625/0.26} - 1) \simeq 6.19X10^{13} \tag{9}$$
$$\Delta n_p = n_p(exp(qV/KT) - 1) = 22500(e^{0.625/0.26} - 1) \simeq 6.19X10^{14} \tag{10}$$

minority carrier at $10.L_n$, $10.L_n$ can be calculated as

$$\delta_n \simeq \Delta n_p.exp(-x/L_n) = \Delta n_p e^{-10} \simeq 2.8X10^{10} \tag{11}$$
$$\delta_p \simeq \Delta p_n.exp(-x/L_p) = \Delta p_n e^{-10} \simeq 2.8X10^{9} \tag{12}$$

The simulation results are shown in Fig.4,Fig.5,Fig.6. The carrier densities from the simulation results are included as data tips in corresponding figure.

4 Diode3- The diode which is simulated in Sentaurus

The parameters used for diode3 is listed below. The simulation of this diode also completed in Sentaurus TCAD. Here both simulation results are compared

Device parameter	n-Side	p-Side
$length(\mu m)$	140	140
$doping(/cm^3)$	10^{17}	10^{16}

Material parameter	electrons	holes
$\tau(\mu s)$	0.05	0.0027
$mobility(cm^2/Vs)$	1417	470

$$L_n = \sqrt{V_t.\mu_n.\tau_n} = \sqrt{.026X1417X0.05X10^{-6}} = 1.3572X10^{-3}cm \simeq 13.5\mu m \tag{13}$$
$$L_p = \sqrt{V_t.\mu_p.\tau_p} = \sqrt{.026X470X0.002727X10^{-6}} = 1.82557X10^{-4}cm \simeq 1.82\mu m \tag{14}$$

The matlab simulation results are shown in Fig.7,Fig.8,Fig.9. The results are compared with Sentaurus simulations given in Fig.10, Fig.11, Fig 12.

5 Diode4- The short diode

The validity of the model is evaluated for short device also. The device dimensions and doping profiles are as follows

Device parameter	n-Side	p-Side
$length(\mu m)$	20	20
$doping(/cm^3)$	10^{17}	10^{16}

Material parameter	electrons	holes
$\tau(\mu s)$	0.05	0.0027
$mobility(cm^2/Vs)$	1417	470

$$L_n = \sqrt{V_t.\mu_n.\tau_n} = \sqrt{.026X1417X0.05X10^{-6}} = 1.3572X10^{-3}cm \simeq 13.5\mu m \tag{15}$$

$$L_p = \sqrt{V_t.\mu_p.\tau_p} = \sqrt{.026X470X0.002727X10^{-6}} = 1.82557X10^{-4}cm \simeq 1.82\mu m \tag{16}$$

The matlab simulation results are shown in Fig.13,Fig.14,Fig.15.

6 Results and discussions

The energy band diagrams, carrier density and IV characteristics of all the diodes are given in the following pages. The device is mentioned as the figure name. Note that in Sentaurus, node currents are expressed in $A/\mu m$.. The following points has to be noted.

- The dependence of simulation results on voltage step and criteria for finding the optimum step size also has to be studied and implemented.
- The model works only for Recombination terms with carrier density term in the denominator(eg. SRH). Direct recombination (which has no density term in the denominator) fails to converge. This dependence on recombination mechanism has been reported in literature, forums etc. This has to be completely understand and to be implemented.

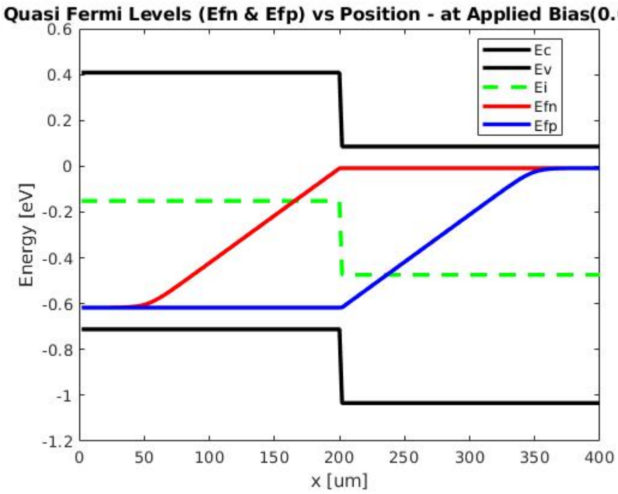

Figure 1: diode1:Band diagram

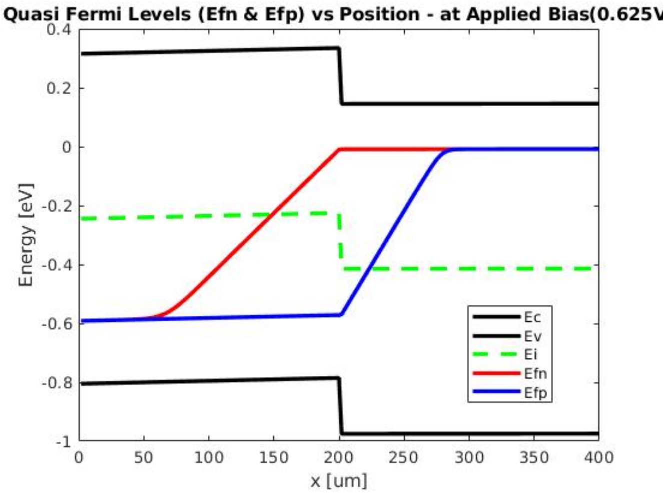

Figure 4: diode2:Band diagram

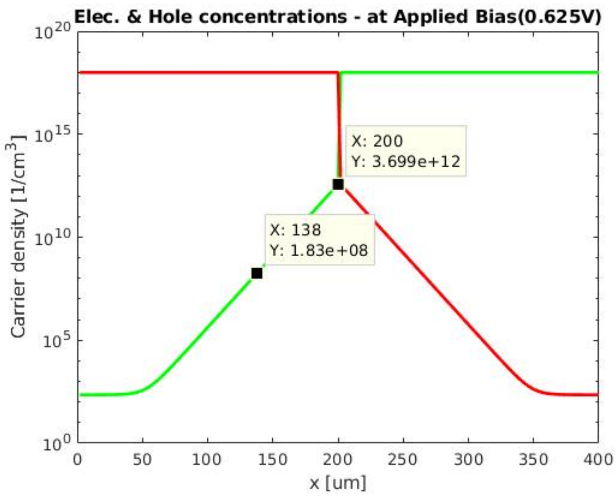

Figure 2: diode1:Carrier density

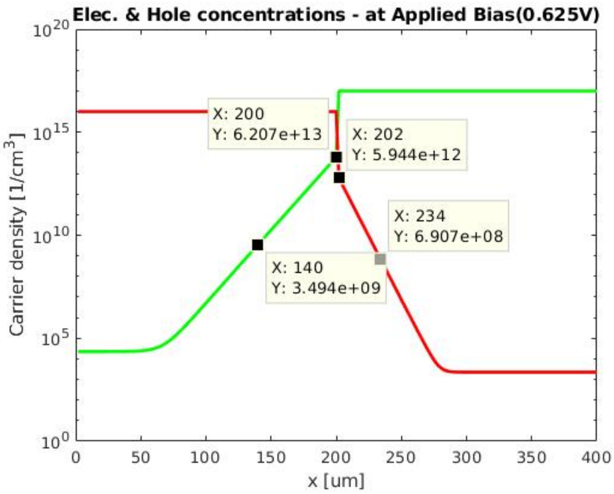

Figure 5: diode2:Carrier density

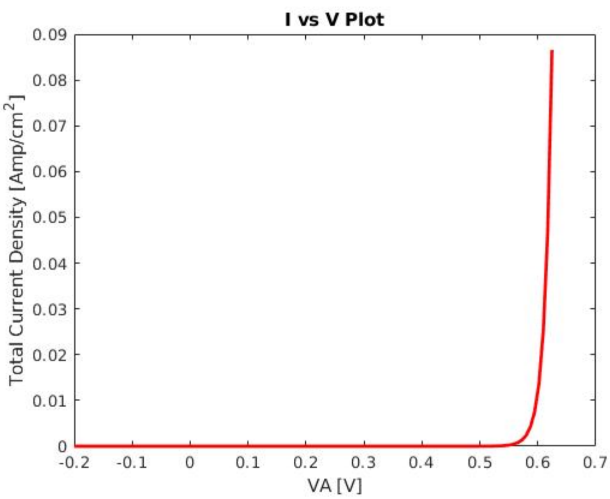

Figure 3: diode1:IV characteristics

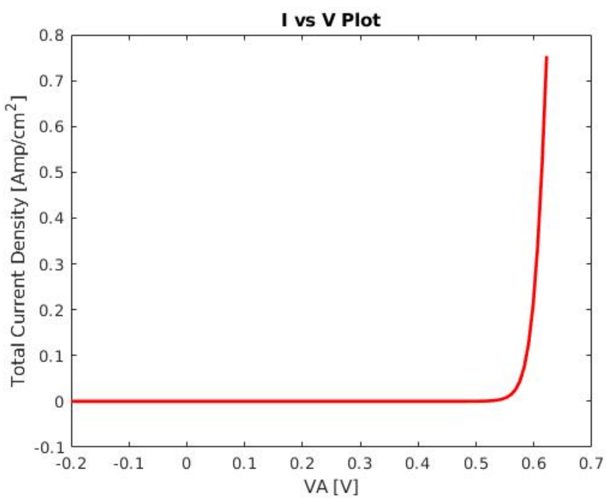

Figure 6: diode2:IV characteristics

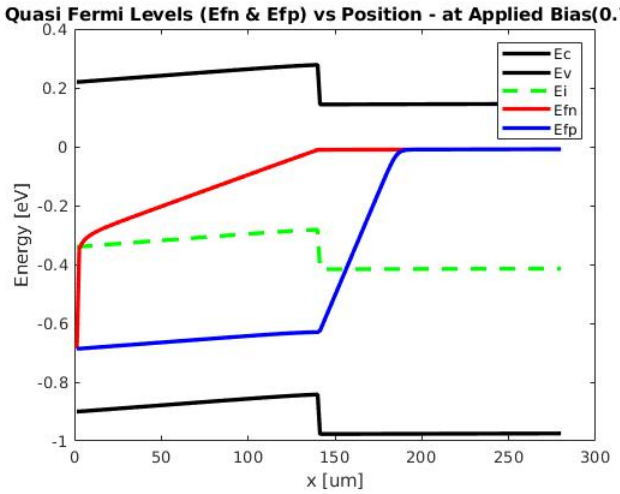

Figure 7: diode3:Band diagram

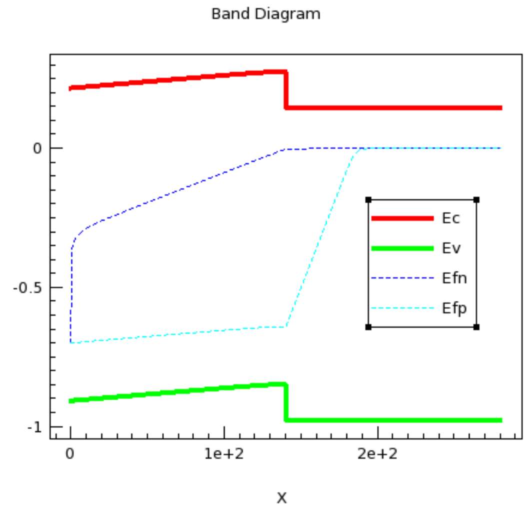

Figure 10: diode3:Band diagram

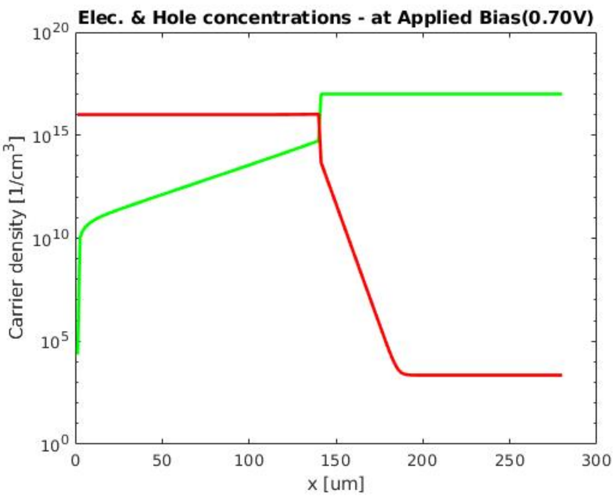

Figure 8: diode3:Carrier density

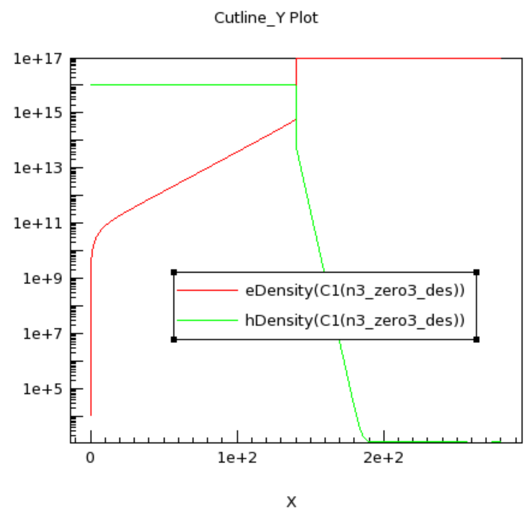

Figure 11: diode3:Carrier density

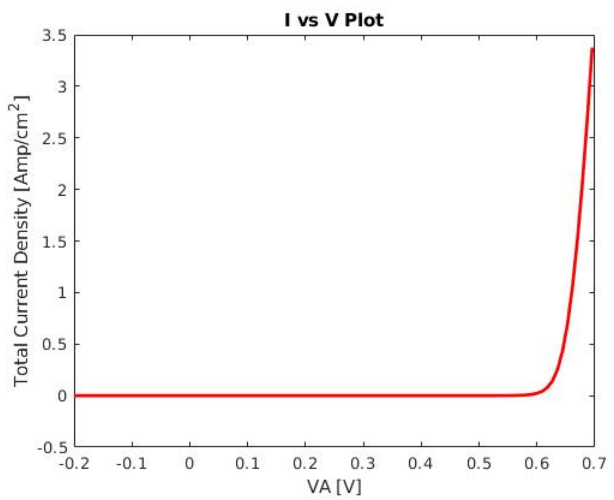

Figure 9: diode3:IV characteristics

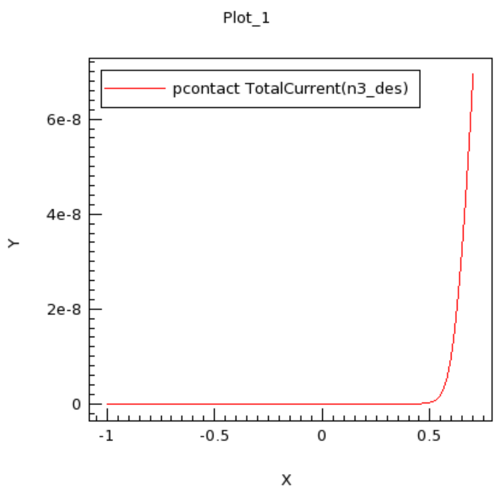

Figure 12: diode3:IV characteristics

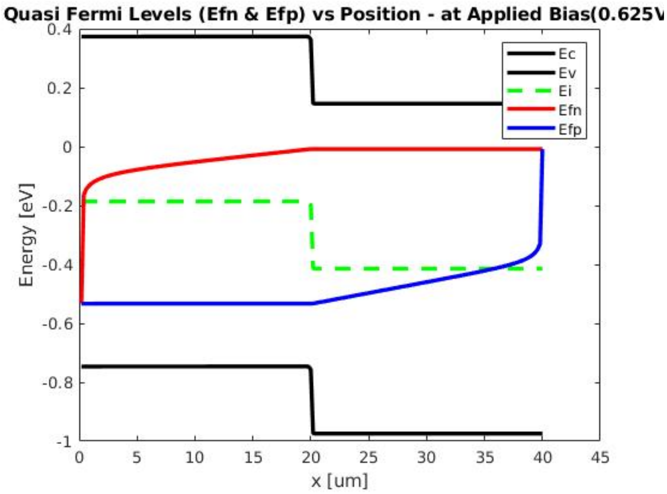

Figure 13: diode4:Band diagram

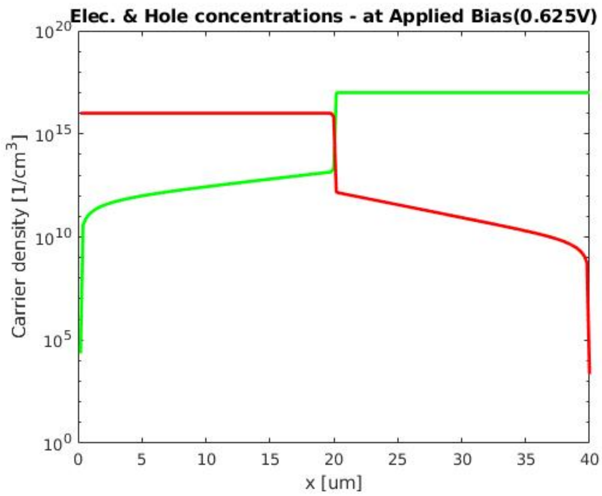

Figure 14: diode4:Carrier density

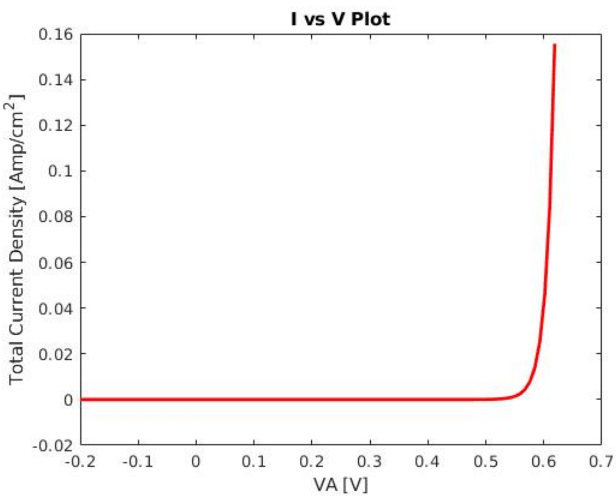

Figure 15: diode4:IV characteristics