Semiconductor Task Report

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January 10, 2016

1 From exercise session

1.1 Simulate a pn-junction

It was made the study of the effect of varying the temperature, donor/acceptor concentration and the material of the semiconductor (Si/Ge) in a 3x3μm n-bulk doped with p+ and n+ (pn-junction) in equilibrium. The results are compared with the theory.

In the interface of two dissimilar materials there will be a so called built in potential. In this case, the built in potential depends on the donor and acceptor dopant concentration (N_a, N_d), the intrinsic carrier concentration (n_i) of the used material and the temperature (T). The potential is given by the following equation:

$$\phi = \frac{kT}{q} ln \left(\frac{N_a \times N_d}{n_i^2} \right) \tag{1}$$

The depletion region in a pn-junction is a place free of charge carriers. It is possible to calculate the width of this space charge region with:

$$w = \left(\frac{2\epsilon_s \phi}{q} \left(\frac{1}{N_a} + \frac{1}{N_d} \right) \right)^{\frac{1}{2}} \tag{2}$$

The first analysis consists of changing the temperature and check how this affect the other variables. To make this simulation, the values of the donor/acceptor concentration were kept in 1e16 and it was measured 3 different temperatures using silicon as material. In table 1, one can see the results for varying the temperature, where it is possible to note that increasing the temperature results in a decrease of the junction potential. In the simulation, the width of the space charge region was the same for all the tested temperatures. The theoretical values was calculated and, for the potential, they are consistent with the simulation. However, the values for the width are far lower than the simulated. For the calculations was considered the silicon intrinsic carrier concentration as $n_i = 9.696e + 9cm^{-3}$ at 300K and permissivity as $\epsilon_s = 11.7 \times 8.85 \times 10^{-14} F/cm$.

Table 1: Changing the temperature in the simulation of the pn-junction

Temperature (K)	250	300	350
Junction potential (V)	0.81	0.71	0.61
Theory Junction Potential(V)	0.82	0.718	0.61
Electric Field (V/cm)	3.34e4-4.8e-9	3.12e4-2.27e-8	2.86e4-8.94e-8
Electron density	1.6e16-5.7e-1	1.6e16 -1.2e4	1.6e16 - 1.6e7
Width of space charge region (μm)	1.7	1.7	1.7
Theory Width(μm)	0.46	0.43	0.4

In the next table is presented the results when changing the acceptor concentration and keeping the donor concentration as 1×10^{16}. The results obtained from the theory are quite different from the simulation. For the junction potential, the gap between the values is not too high and it its still following the pattern of increasing the potential while increasing the donor concentration.

Table 2: Changing the acceptor concentration in the simulation of the pn-junction

Concentration	1e15	1e17	1e19
Junction potential (V)	0.6	0.82	1.0
Theory Junction Potential(V)	0.65	0.78	0.9
Electric Field (V/cm)	3.97e3-2.8	1.04e4-4.33e-14	5.79e5-2.04e-10
Electron density	1.6e15-1.17e5	1e17-1.32e3	1e19 - 1.2e2
Width of space charge region (μm)	3	0.6	0.34
Theory Width(μm)	0.97	0.33	0.36

In the step, the donor concentration is changed and the acceptor concentration is kept as 1×10^{16}.

Nice results!

Table 3: Changing the donor concentration in the simulation of the pn-junction

Concentration	1e14	1e15	1e17
Junction potential (V)	0.46	0.59	0.82
Theory Junction Potential(V)	0.48	0.53	0.85
Electric Field (V/cm)	6.24e4-1.43e-9	4.61e4-5.4e-10	1.31e4-1.59e-9
Electron density	1e16-1.2e2	1e16-1.32e3	1e16 - 1.17e5
Width of space charge region (μm)	2.06	1.2	1.09
Theory Width(μm)	2.5	0.83	0.09 (?)

In the case of the donor concentration of 1×10^{17} the graphic continues after the edges, so probably the width is larger than 2.06. Again, the values of the widths are quite different from the simulation, specially for a donor concentration of 1×10^{17}. It is unknown the reason

The region extend outside the geometry hence equilibrium condition is not valid.

of the disparity and it possibly is because of some confusion or misuse of the expression for calculate the width. The last case is to study the effects using Germanium instead of Silicon. The simulation is done keeping the temperature as 300K and the concentration of the dopants as 1×10^{14}.

Table 4: Effect of changing the material

Concentration = 1e14	Temperature = 300K
Junction potential (V)	0.31
Electric Field (V/cm)	1.61e4-3.06e-7
Electron density	1e16-5.11e10
Width of space charge region (μm)	1.5

It was made the simulation of a different pn-junction in order to obtain the IV-curve for reverse and forward bias. The simulation consisted of a 100 micron thick sensors with highly doped 3 micron thick implants on a low doped bulk with a concentration of 1×10^{15} on the n-type and a bulk with a concentration of 1×10^{13}. The simulation was made for 3 different temperatures using Silicon and for 2 temperatures using Germanium.

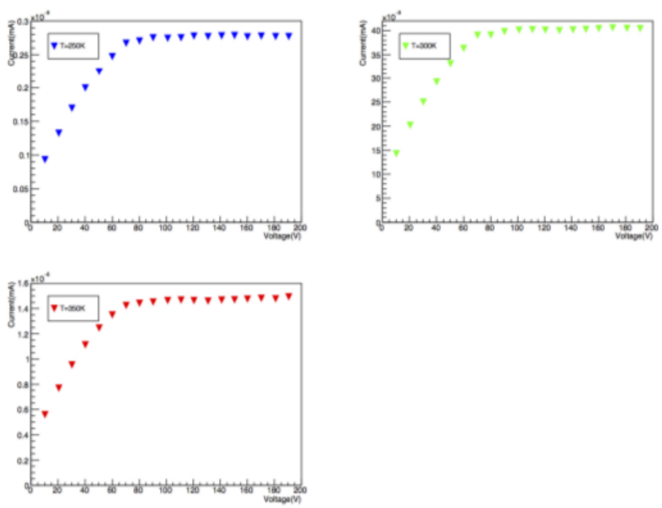

Figure 1: IV-Curves for Silicon for T= 250K, 300K and 350K in Reverse Bias

Using this, it is possible to obtain the depletion voltage for both cases. For the Silicon, the depletion voltage it occurs around V = 60V and , for Germanium, it occurs for V = 19V at 300K and 25V at 350K.

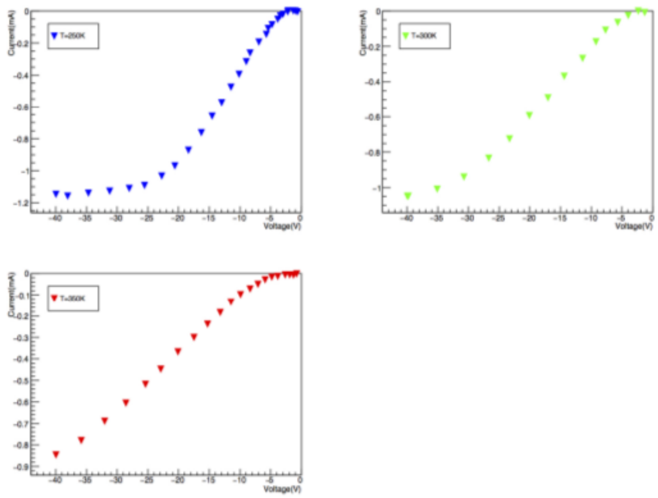

Figure 2: IV-Curves for Silicon for T= 250K, 300K and 350K in Forward Bias

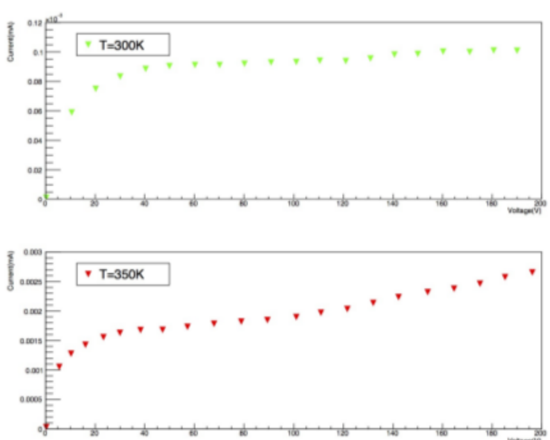

Figure 3: IV-Curves for Germanium for T= 300K and 350K in Reverse Bias

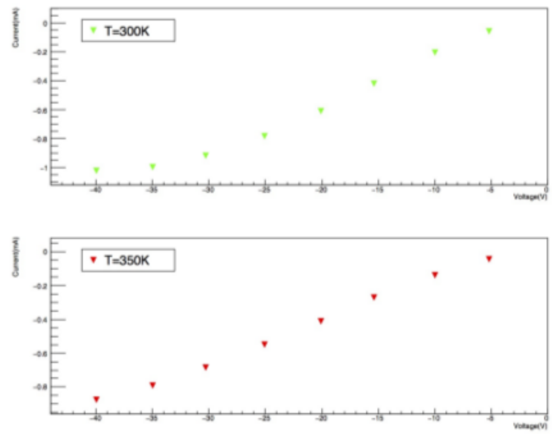

Figure 4: IV-Curves for Germanium for T= 300K and 350K in Forward Bias

2 Schottky contact

In this part is done a study of a Metal Semiconductor, which is a type of junction that uses a metal in contact with a semiconductor material. In this case, the subject is the Schottky contact. It was done the same analysis of the pn-junction for the Schottky contact. Due to Schottky contact disposal, the electron density is concentrated in the region close to the contact. For that, when increasing the acceptor concentration also increases the Electric Field. The temperature does not affect strongly the device. To finish the analysis, it is constructed an IV-curve for the Schottky contact and then estimated the depletion voltage.

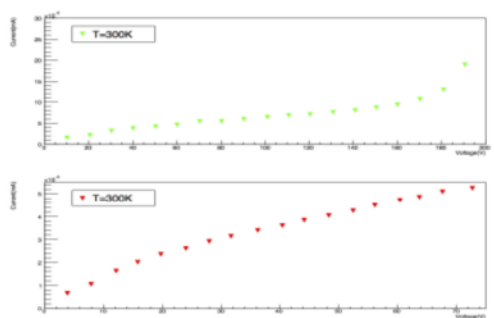

Figure 5: IV-Curve for Shottky contact at T=300K for Reverse Bias

The upper graphic is the simulation until V = 200V and the lower graphic is showing the simulation until the depletion voltage of the pn-junction. The depletion voltage found to the Schottky contact is V = 15V.

The Schottky device do not deplete the same way as a pn-junction.
The region grows slowly into the device.