Study of a Semiconductor Sensor

Reseach training course in Detctor Technology in particle Physics

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Outline

The purpose of this exercise was to simulate different devices like a pn-diode and a schottky contact and investigate their properties. Furthermore a pn-diode has been measured in the laboratory and this diode was supposed to be simulated. The results of these exercises are summarized in this report. All the Simulations have been performed with the free software General-purpose Semiconductor Simulator gss [2].

Task 1: PN-diode

1.1 PN-junction

In table 1 the default values for the simulated pn diode can be found. These parameters have been changed and their influence on the junction potential, charged carrier concentration and electric field have been observed.

Temperature T	donor concentration Nd	acceptor concentration Na
300 K	10^{16} cm^{-1}	10^{16} cm^{-1}

Table 1: Default values for the simulated pn-diode.

We stared with Silicon and changed the temperature to T = 500 K first, where no big change has been noticed. When the temperature was changed to T = 100 K there has been, as expected, still no change in the charged carrier concentration, also no significant change in the potential but the electric field became much narrower and stronger.

Changing the donor concentration to a lower value Nd = 10^{14} cm^{-1} leads to an expected non symmetric potential which shows a steep behaviour in the donor and depletion region while the acceptor region stays flat. The electric field also stays quite high and flat on the donor side. When also the acceptor concentration is changed to Na = 10^{14} cm^{-1} the potential changes slowly form the donor side to the acceptor side without the steep fall in the depletion region. The electric field becomes very wide and looses it's strength by two orders of magnitude.

With the values Nd = 10^{16} and Na = 10^{18} the result for potential and electric field have a steeper slope on the acceptor side. The expected behaviour for the symmetric case with higher charge carrier concentration would be a stronger and narrower electric field with a very fast and steep potential difference between the n-type and p-type area.

While switching to Germanium with the default values no significant change has been observed. When the temperature has been changed to T = 500 K the change in the potential was also not noticeable but the electric field became much narrower and more fluctuations were visible. With lower temperature T = 100 K again no big changes can be reported.

The same changes for the charge carrier concentrations have been applied to Germanium as for Silicon. The results were comparable with each other. The electric field had a slightly steeper behaviour for different concentrations.

1.2 Applying a bias

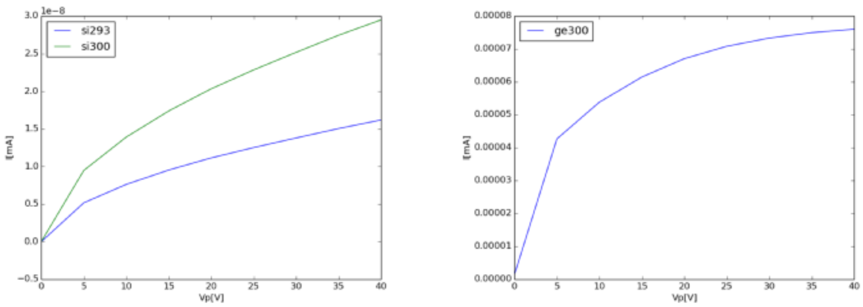
Using a 100 micron thick sensor with highly doped 3 micron thick implants on a low doped bulk an IV-curve was simulated. The used values can be found in table 2.

Material	T [K]	Nd [cm^{-1}]	Nd bulk [cm^{-1}]	Na [cm^{-1}]
Si	300	10^{17}	10^{13}	10^{17}
Si	200	10^{17}	10^{13}	10^{17}
Ge	300	10^{17}	10^{13}	10^{17}

Table 2: Default values for the simulated pn-diode.

The simulation was repeated for two temperatures for Silicon and for one temperature for Germanium. The IV-curves are displayed in figure 1. The Silicon sensors are still not fully depleted at 40 V, which means that a higher voltage should be applied. The Germanium sensor reaches the state of depletion at lower voltages, but according to the plot 1b also here higher voltages need to be applied. The according plots for the forward bias can be found in figure 2, where the current continuous rising.

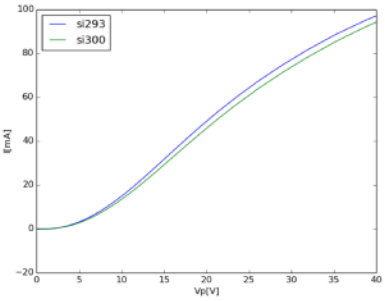
You could have run a sweep to a higher voltage....



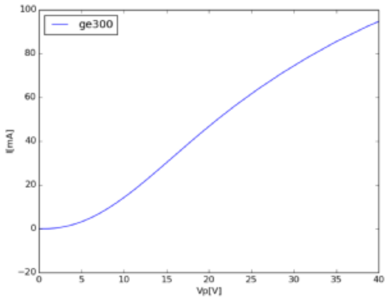
(a) IV-curves for Silicon for the temperatures 293 K and 300 K for reversed bias.

(b) IV-curve for with reversed bias applied for Germanium with a temperature of 300 K.

Figure 1: The plots show applied reversed bias to the simulated Silicon 1a and Germanium 1b for different temperatures.



(a) IV-curves for Silicon for the temperatures 293 K and 300 K for forward bias.



(b) IV-curve for with forward bias applied for Germanium with a temperature of 300 K.

nice plots!

Figure 2: The plots show applied forward bias to the simulated Silicon 1a and Germanium 1b for different temperatures.

1.3 Comparison to theory

For an asymmetric junction, where $Na >> Na$ the built in potential is given by

$$\Psi_0 = \frac{k_B T}{q} \cdot ln\left(\frac{NaNd}{n_i^2}\right), \tag{1}$$

where k_B is the Boltzman constant, T is the temperature, Na and Nd the acceptor and donor concentration respectively and n_i is the intrinsic charge carrier concentration of the material.

The depletion width W for $Na >> Na$ is derived as:

$$W \approx W_D = \sqrt{\frac{\epsilon_R \epsilon_0 (\Psi_0 + V_R)}{q N_D (1 + \frac{Nd}{Na})}} \approx \sqrt{\frac{\epsilon_R \epsilon_0 (\Psi_0 + V_R)}{q Nd}}, \tag{2}$$

where ϵ_R and ϵ_0 are the permittivities of the material and vacuum respectively, V_R is a voltage that can be applied and q represents the charge of an electron. It is challenging to read off the values from the figures in gss, therefore it is useful to use the maximum electric field E_{max} as variable to determine the width [1]:

$$W = \frac{2(\Psi_0 + V_R)}{E_{max}} \tag{3}$$

ni for other temperatures can be found in litterature

We have only theoretical values for n_i for a temperature of 300 K, therefore the comparison listed in table **??** 3 is made only for this temperature.

The values for the built in potential for Silicon agree with each other while the values for the widths and differ from each other. Also, for Germanium the potentials agree better with each other than the widths.

Na and Nd for the simulation?

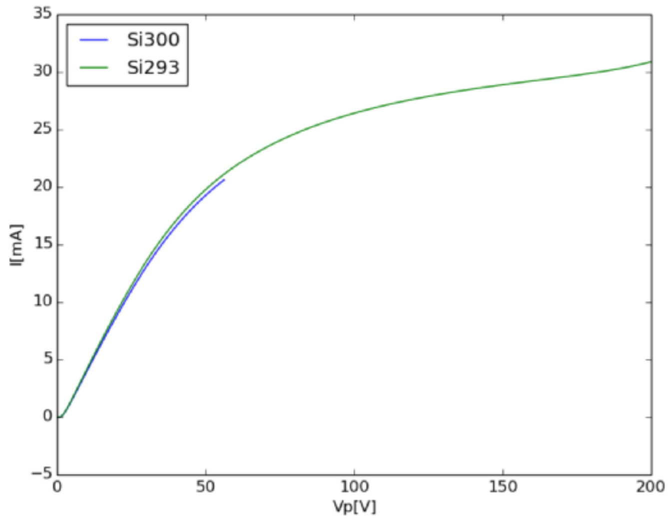
Material	Ψ [V]	Ψ_{theo} [V]	W [μm]	W_{theo} [μm]
Si	0.59	0.574	1.366	8.618
Ge	0.1239	0.312	0.623	7.427

Table 3: Comparison between simulated built in potentials and depletion widths for Silicon and Germanium for a temperature of 300 K.

Task 2: Schottky

Varying different parameters like the charge carrier concentration, temperature and material lead to quite similar results as for the pn-diode. When changing the WorkingFunktion from 4.2 to 4.8 the voltage decreased, other changes have not been noticed. The IV-curves with reversed bias applied and the same default values as for the pn-junction exercise are displayed in figure 3. The device takes higher voltages to deplete.

what work function was used?



Rather high current.
Are you sure the contact
is reverse biased?

Figure 3: IV-curves for Silicon with the same default values as for the pn-diode for 300 K and 293 K.

The simulation software for the Schottky device seems to be more unstable than for the pn-junction. The leakage current breaks up around 60 V for 300 K for no obvious reason. Similar behaviour has been observed for the Germanium as well.

Conclusion

With the software gss it is possible to simulate different semiconductor devices and get realistic results. The comparison to theory for the pn-diode showed that the results are at least in the same order of magnitude, and with more time these simulations can be improved. The simulation for the Schottky device were not that successful, but also here more time with the simulation program would probably lead to better results.

REFERENCES

[1] Glenn F. Knoll. Radiation detection and measurement. Wiley, 1979.

[2] gss. General-purpose Semiconductor Simulator. URL `http://gss-tcad.sourceforge.net/`.