Semiconductor simulation

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1 Theoretical Overview

The intrinsic potential in an asymmetric junction is given by

$$U = \frac{k_B T}{q} \ln \left(\frac{N_a N_d}{n_i^2} \right) \tag{1}$$

where k_B is the Boltzmann constant, T is the temperature, N_a and N_d are the concentration of acceptors and donors and n_i is the concentration of charge carriers in the bulk. For a temperature value of 300 K $k_B T/q = 26$ mV, the concentration of charge carriers for Silicium and Germanium are $n_i^{Si} = 1.5 \times 10^{10}$ cm^{-3} and $n_i^{Ge} = 2.4 \times 10^{13}$ cm^{-3}. Due to the intrinsic potential at the junction, there is a region with width given by

$$W = \sqrt{\frac{2\epsilon_R \epsilon_0 U}{q} \left(\frac{1}{N_a} + \frac{1}{N_d} \right)} \tag{2}$$

with free charge carriers, where ϵ_R is the relative permittivity and $\epsilon_R^{Si} = 11.7$ and $\epsilon_R^{Ge=16.0}$.

2 Effect of the different parameters

What N_d and N_A did you use in your simulation?

The effect of varying the temperature, the concentration of donors and acceptors and the semiconductor material on the junction potential, the width of the charge carriers and the electric field was studied.

Values calculated for Silicon from the theory were available only for a temperature of 300 K thus this value was the reference one. For this temperature the potential value is $U \approx 0.7$ V while the width is $W \approx 0.42$ μm. Lowering the temperature increased a little bit the potential and the electric field while the width remained constant. The results for a simulated temperature of 270 K are $U \approx 0.7$ V which is compatible with the theoretical prediction and $W \approx 0.9$ which is not compatible with the calculated result.

Lowering the acceptor and donor concentration had in general the effect of lowering the potential and the electric field while increasing the width. For a concentration of 10^{15} donors, the simulated results for the potential $U \approx 0.6$ V, the electric field $E \approx 0.9 \times 10^4$ V/cm with a width of $W \approx 3$ μm. Comparison with the theory, again shows that the value simulated for the width are not compatible with the calculated one ($W \approx 1.2$ μm).

Correct! High doping -> high filed

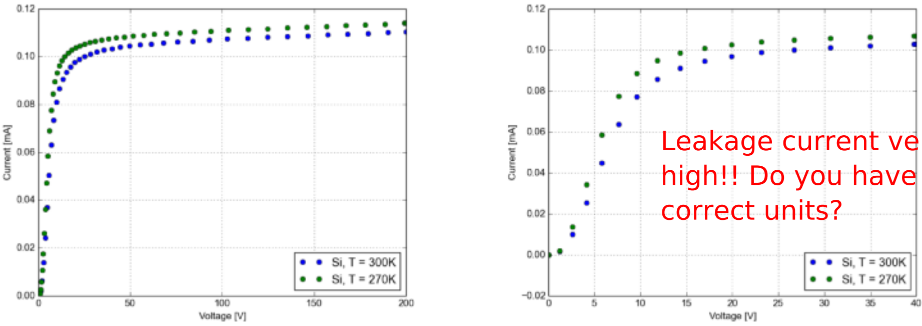
Finally a diode was simulated with the same parameters for Silicon and Germanium. In general the value of the potential and the electric field in a Germanium semiconductor are lower compared to a Silicon one while the width are comparable for the two. Also in this case the simulated values were compared to the theory and while the potential and the electric field were in agreement, the width was not compatible between simulation and theory.

3 IV curve

A 100 μm thick sensor with a highly doped 3 μm thick implant on a low doped bulk was used to study the IV curve. The donor concentration of the donors in the bulk was 10^{13} while on the acceptor side it was 10^{15}. The total width of the sensor was 50 μm and two temperatures were studied for both Germanium and Silicon. Figure 1 reports the IV curves for Silicon for a reverse and forward bias. The current is higher for lower temperature for both biases though the voltage required is much higher for a forward bias. The depletion current can be found by fitting two straight lines to the linearly increasing regions of the IV curve and determining the intersection point, in both cases full depletion occurs at $\approx$ 10 V. Figure 2 reports the simulation for a Germanium semiconductor with a reverse bias applied for two temperatures, the results are quite similar to what was obtained for a Silicon diode and also in this case the full depletion voltage is $\approx$ 10 V.

The depletion voltage is very low.
Are you sure the correct geomtry was simulated?

should be the reverse!



Leakage current very high!! Do you have correct units?

(a) IV curve for a Silicon semiconductor for two different temperature values with a forward bias applied.

(b) IV curve for a Silicon semiconductor for two different temperature values with a reverse bias applied.

Figure 1

4 Schottky semiconductor

When a metal is put in contact with a semiconductor, a Schottky contact is formed. The metal-semiconductor interface causes a barrier to form which is responsible for controlling the current conduction and the capacitance behavior.

A Schottky contact was simulated using the same parameters as in the pn-junction and the effect on the junction potential, the electric potential and the junction width of changing the temperature, the concentration of acceptors and donors and the semiconductor, were studied.

The results of the simulation are pretty similar to those obtained for the pn-junction. Lowering the temperature had the effect of increasing the junction potential

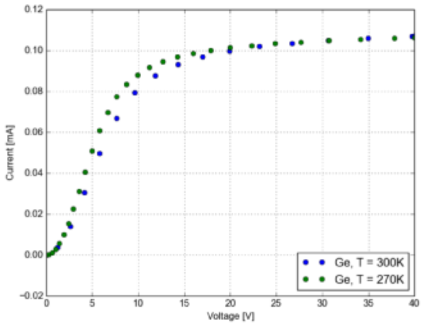


Figure 2: IV curve for a Germanium semiconductor for two different temperature values with a reverse bias applied.

and the electric field while the width stayed constant.

Increasing the concentration of donors and acceptors, increased both the junction potential and the electric field while the width decreased.

Changing the semiconductor element from Silicon to Germanium had the effect of lowering the junction potential, the electric field and the width.

Figure 3 shows the simulated IV curve for the Schottky contact for a Germanium semiconductor. It can be seen that the voltage is quite similar to those obtained for the pn-junction though the current is some orders of magnitude lower. It is not clear from this plot where the leakage currents brakes out and at which voltage the diode is fully depleted.

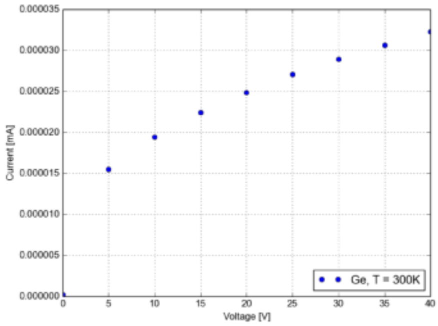


Figure 3: IV curve for a Germanium Schottky semiconductor for a temperature value o 300K with a reverse bias applied.

Suprisingly low current compared to pn-juntion!
More information om geometry and doping and work function welcome.

5 Conclusions

The GSS simulation program, proved to be quite unstable and hard to use. This was most probably due to lack of experience and with more time to get familiar with it, is a quite powerful tool. In particular the simulation of the Schottky contact proved to be quite hard to achieve.

Overall the results obtained with the simulations agreed with the literature at least for the junction potential and electric field. For some reason the width was always overestimated.