STOCKHOLM UNIVERSITY

Semiconductor Task

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1 THEORY

Silicon detectors are commonly used in particle physics due to the fast response and small size In high energy physics this gives high energy and spatial resolution. The principle behind a diode is that in the interface between two semi-conducting materials with different electrical affinities, electrons will diffuse from the region with high electron affinity (N-type) into to the region which have holes as charge carriers (P-type) until equilibrium is reached. This will result in electric field and a potential in between these two interfaces. The charge affinity of a material can changed adding small amounts of different elements. A material that has had it's charge affinity change in this way is called doped. In the case of acceptor (holes) concentration, N_a and donor (electrons) concentration N_d follows $N_a >> N_d$ the potential (built-in potential) between the two interfaces is given by

$$\psi_0 \frac{k_B T}{e} \ln\left(\frac{N_a N_d}{n_i^2}\right), \tag{1.1}$$

where k_B is the Boltzmann constant, T is the temperature in Kelvin, e is the electron charge, N_a is the number of acceptor ions per volume, N_d is the number of donor ions per volume and n_i is the number of intrinsic charge carriers per volume for the material. In the region between the two materials we the electrons and holes are captured creating a so called *depletion region* with no free charges. An expression for the potential over the diode given a the width,d, of a depletion region is given below

$$V_r + \psi_0 = \frac{ed^2 N_d}{2\epsilon_0 \epsilon_r}\left(1 + \frac{N_d}{N_a}\right) \tag{1.2}$$

Table 2.1: The properties and geometry of the pn-diode.

Region	Type	X[μm]	Y[μm]	N	Distribution
A	P+	0-50	0-3	varied	Gaussian
bulk	P-	0-50	3-97	$3 \cdot 10^{13}$	Uniform
C	N+	0-50	97-100	varied	Gaussian

where ϵ_0 is the vacuum permittivity, ϵ_r is the relative permittivity for the particular material used in the diode and V_r is an applied external revere bias potential. This expression can of course also be solved for d which yields:

$$d = \sqrt{\frac{2\epsilon_0\epsilon_r(V_r + \psi_0)}{eN_d\left(1 + \frac{N_d}{N_a}\right)}} \tag{1.3}$$

These three equations will be used to compute theoretical values to compare with our simulations.

2 SIMULATE PN-JUNCTION

The simulation was done using the free of charge program GSS.

The geometry of the simulated pn-diode is given in table 2.1. The doping of the interfaces P+ (A) and N+ (C) was varied between 10^{14} and 10^{18}, while the bulk is kept at $3 \cdot 10^{13}$. The width of the device was 50 μm. The temperature of the diode was also varied between 100 and 600 Kelvin. Two diode materials, Silicon and Germanium, were simulated with this geometry.

2.1 RESULTS

A pn-diode with varied parameters was simulated using the geometry from table 2.1. The width of te depletion region was estimated from the central 90% of the electric field, E_y, as a function of y. The built in potential was determined by the maximum potential difference in the diode after reaching equilibrium.

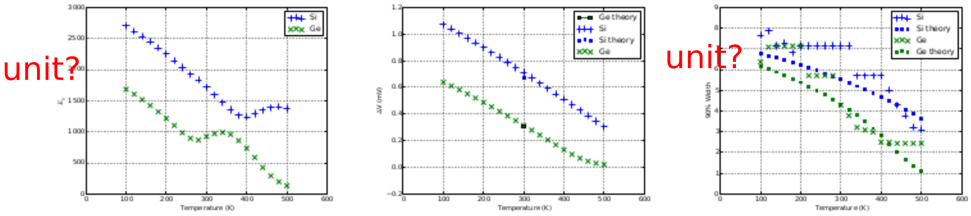
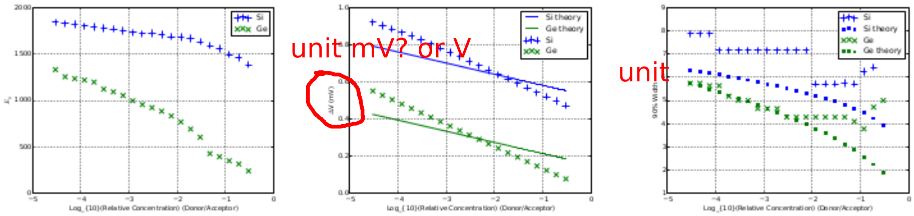


Figure 2.1: Effects of varying the temperature on the electric field, voltage and width of the depletion width for both Silicon and Germanium diodes. The discrete features of the depletion width is due to the finite grid of the simulation.

what doping was used?

Figure 2.1 shows the effects of varying the temperature. The electric field is in general decreasing with increasing temperature. However peaks are seen for both the Germanium diode (350 K) and the Silicon diode (500 K) which are probably due to the onset of new vibration modes which increases the number of charge carriers. The voltage decreases with increasing temperature as the diode becomes more conductive. The theoretical values for the potential and the depletion width were calculated with eq. 1.1 and eq. 1.3, respectively. The voltage (built in potential) directly depends on the temperature and the intrinsic number of charge carriers, n_i, in the material which also depends on the temperature. However, we only know the value of n_i at 300 K, therefore the voltage is only calculated for one temperature. For the depletion width the measured ψ_0 is used and $V_r = 0$.

For other temperatures can be found in litterature....



unit mV? or V

unit

Figure 2.2: Effects of varying the the doping concentration in the A and B region (see 2.1) while the donor concentration of the bulk is fixed.

The effects of varying the doping are shown in figure 2.2. As the relative concentration between the bulk and the implants decreases the electric field, the built in potential and the width decreases. This is expected as the number of charge carriers diffusing increases with a larger ratio of N_a/N_d.

Lastly the leakage current is shown for a reverse bias voltage for Germanium and Silicon diodes in figure 2.3 and for a forward bias in figure 2.4. The theoretical calculation of the depletion voltage matches well with the simulation.

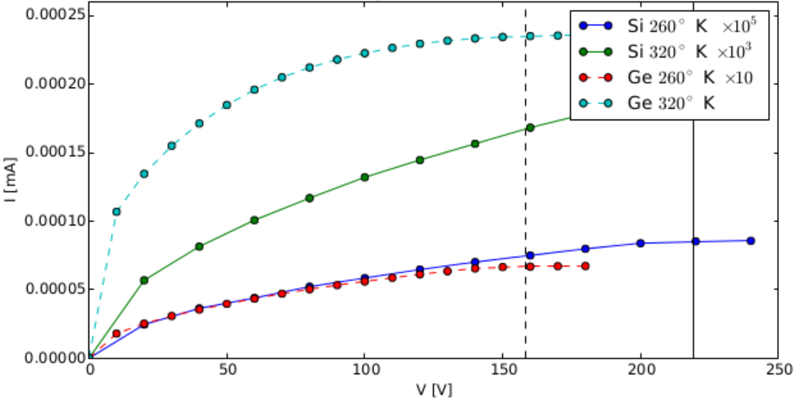
3 SIMULATE SCHOTTKY JUNCTION

The Schottky junction has simpler geometry that the pn-diode. The size of the diode is still 50 μm in x and 100 μm in y and it consists of one region of uniformly doped Silicon as an acceptor. The boundary is changed, however. At the anode side a Schottky contact is added.

3.1 RESULTS

The results of the of the Schottky junction while varying the simulation parameters were in general similar to the pn-diode. Unfortunately the varying the workfunction did result in rather unstable results, which is the reason why they are not shown. For the bias simulation the bulk had an acceptor concentration $N_a = 10^{11}$ at a temperature of 273 K and workfunction value of 4.2. In figure 3.1 the leakage current for reverse and forward bias voltages are shown. One can see that the Schottky junction depletes quite fast but both the forward and reverse bias currents are small.

Nd=10^?



Unless sign
is wrong for Si
then the
current is
very
strange!
-> too high
current

Figure 2.3: IV-curves for a Germanium and Silicon diode at two different temperatures. Note the different scalings of the leaking current stated in the legend. The theoretical value for the depletion voltage is shown as a dashed vertical line for the Germanium diodes and as a solid line for the Silicon diodes. The theoretical value was calculated with eq. 1.2.

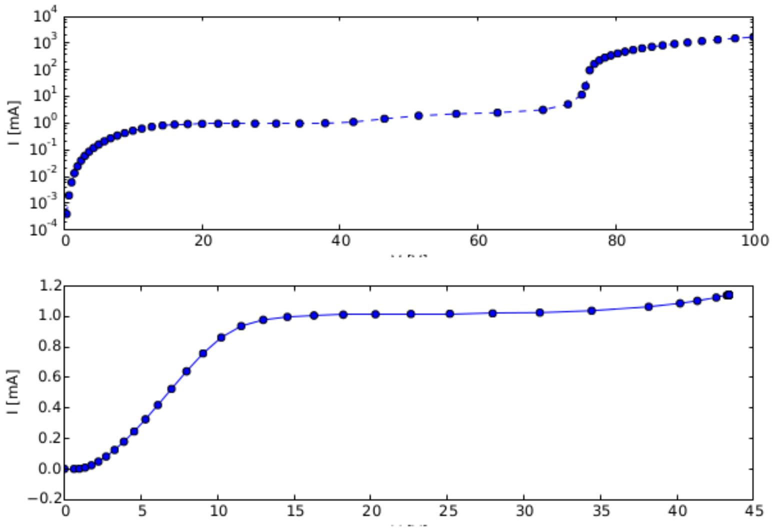


Figure 2.4: Forward bias for Germanium diode (top) and a silicon diode (bottom).

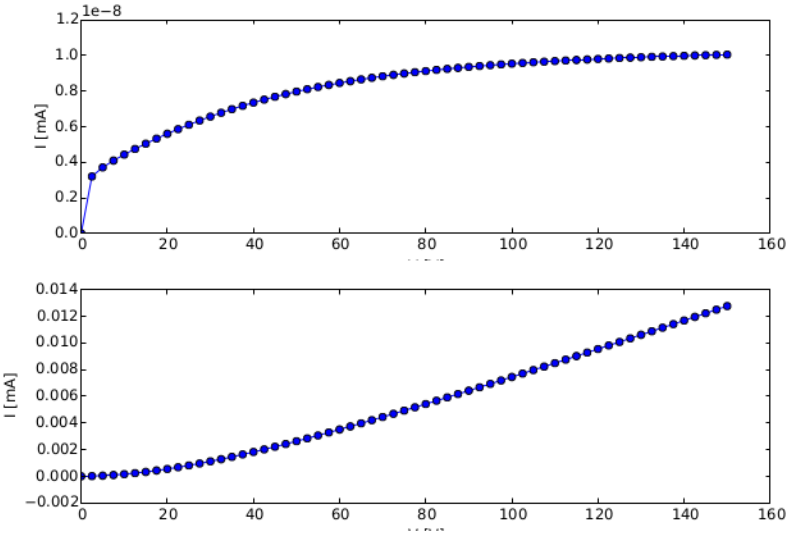


Figure 3.1: Reversed bias (top) and forward bias (bottom). The leakage current for the revers bias can be seen plateauing after 100 V indicating that the depletion voltage for this Schottky junction should be around 80-100 V.