Report on studies of a semiconductor sensor.

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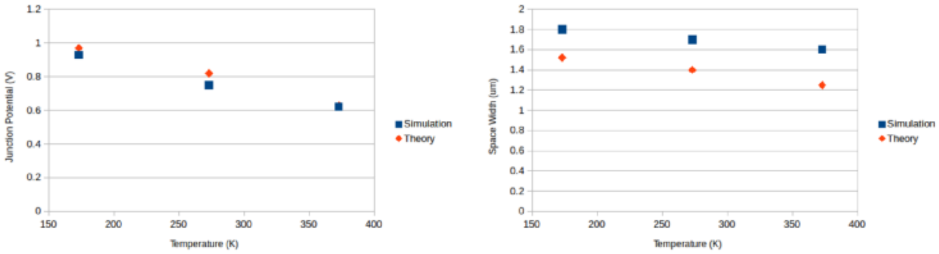
1 Exercise Section

1.1 Study of PN-Junction

Using GSS Ver 0.46.07 the results of the simulated pn-junction for different parameters are presented. For the simulation Silicon was used as a bulk material with $10^{16} cm^{-1}$ donor concentration. There are no effects on the electrons-holes density for these parameters so it remains at $10^{16} cm^{-1}$ for each of the temperatures. In Figures 1a and 1b we can appreciate how both the simulated and the theoretical values of the junction potential and space width decrease with temperature similarly enough for saying that they are in good agreement. It can be noticed that the deviations between them are small enough for the junction potential, however the deviation in the case of the space width is appreciable to up to 20% for the temperature $373K$.



(a) Simulation and theory effects of temperature vs junction potential.

(b) Simulation and theory effects of temperature vs space width.

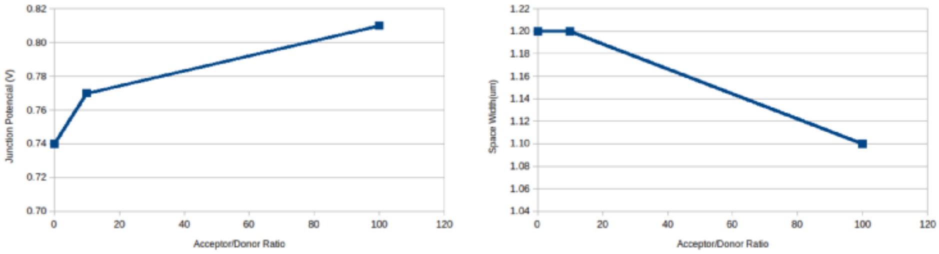
Figure 1

Again using silicium as the bulk material the effect of the $\frac{acceptor}{donor}$ ratio was investigated. The temperature used for the simulation was $300K$. The ratios used in Figures 2a and 2b are the ones shown in Table 1. It is appreciable that there is an increase of the junction potential with the increase of the donor/acceptor ratio while the space width diminishes.

The simulations were made for Germanium with the same $\frac{acceptor}{donor}$ parameters and the results were comparable with each other. It could be seen a slightly different behaviour for different concentrations only for the junction potential.

$\frac{acceptor}{donor}$	Electron Density (cm^{-3})	Hole Density (cm^{-3})
10^{-1}	10^{17}	10^{16}
10^{1}	10^{16}	10^{17}
10^{2}	10^{16}	10^{18}

Table 1: Electron density and hole density vs $\frac{acceptor}{donor}$ ratio



(a) Simulation of donor/acceptor ratio vs junction potential.

(b) Simulation of donor/acceptor ratio vs space width.

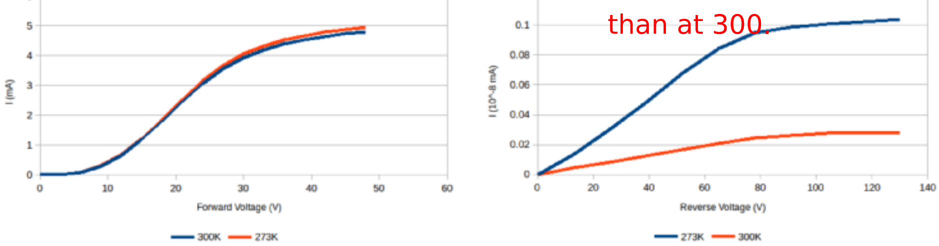
Figure 2

Comparison for $10^{16}cm^{-1}$ electron/holes density is shown in Table 4, there it can be seen how the junction potential for Germanium, simulated at the same temperature with the same electron/holes density, is a little bit less than half of the Silicium. It can be concluded that the effect of the material becomes obvious since Germanium has lower junction potential and a smaller space width than Silicium. From the simulations the space width for the same acceptor/donor concentration tends to be symetrical and higher, at the same time for unequal concentrations it becomes asymetrical.

Material	Junction Potential (V)	Space Width (μm)
Silicium	0.71	1.79
Germanium	0.31	1.40

Table 2: Comparison of junction potential and space width between Si and Ge at $300K$ with $10^{16}cm^{-1}$ electron/holes.

The IV curves were simulated for a p-type bulk sensor with concentration $10^{13}cm^{-1}$ and geometry $100\mu m X 50\mu m$ and implanted $3\mu m$ sides with $10^{15}cm^{-1}$. Simulations for Silicium at temperatures $273K$ and $300K$ are presented in Figure 3a for the forward and reverse bias and in Figure 3b. In the case of Germanium simulations only for $273K$ are presented in Figure 4a and 4b. It can be said that the Germanium sensor is depleted at lower voltages than Silicon sensors. This can be noticed from the depletion voltage table (3) obtained from the IV curves.

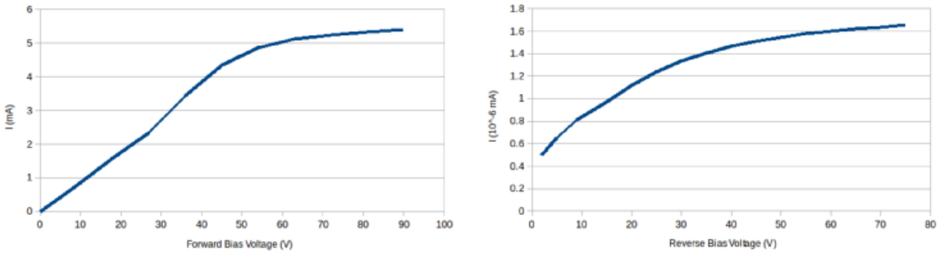


? I guess the legend is wrong
current at 273 should be less
than at 300.

(a) IV curve for Silicium forward Bias at 273K and 300K.

(b) IV curve for Silicium reverse Bias at 273K and 300K.

Figure 3: IV simulations for Silicium



(a) IV curve for Germanium forward Bias at 273K.

(b) IV curve for Germanium reverse Bias at 273K.

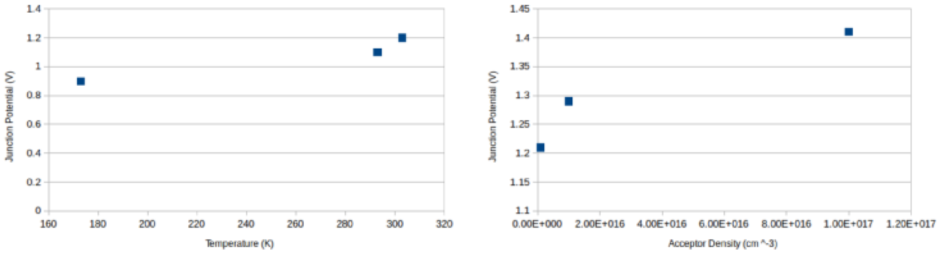
Figure 4: IV simulations for Germanium

Material	Temperature (K)	Depletion Voltage (V)
Silicium	273	73
Silicium	300	78
Germanium	273	46

Table 3: Depletion Voltages for Silicium and Germanium.

1.2 Study of Schottky contact

The same simulations were also performed for a Schottky contact. In Figure 5a it can be seen that the increase of the temperature leads to a slight increase in the junction potential. In the case of the space width, it remained constant in 3.0 μm for all the temperatures and also for the different acceptor densities simulated in 5b.



(a) Simulation of temperature vs junction potential for electron density of $10^{18}cm^{-1}$ and hole density of $10^{15}cm^{-1}$.

(b) Simulation of acceptor density vs junction potential.

What do you mean??? What is the bulk material of and charge carrier concentration of the detector?

Figure 5: Schottky contact simulations.

It looks that the geometry is not correct....

For the effects of the material used, simulations with Germanium were done similar to how it was done for the PN-Junction. It becomes obvious again the influence of the material in the junction potential values. It happens differently in the case of the space width which remains constant. Compared to the PN-Diode both magnitudes are higher in the Schottky contact.

Material	Junction Potential (V)	Space Width (μm)
Silicium	1.31	3.0
Germanium	0.29	3.0

Table 4: Comparison of junction potential and space width between Si and Ge at $273K$ with $10^{16}cm^{-1}$ acceptor density.

Schottky contact was built in the same way as the pn diode model used in the previous exercise. GSS seems quite unstable in Schottky contact because the simulations almost never converged. For simulating the IV curve for the Schottky contact the software breaks at $60V$. It was possible to obtain the IV curve of the reversed voltage for Germanium at the temperature of 273K as shown in Figure 6. It could be really interesting to obtain the values for voltages $> 60V$, so that the behaviour of the IV curve could be more visible . More time and familiarization with the GSS software would have made possible to tweak the paramaters or get a better understanding of them so the simulations could be carried in a better way.

High field under the contact, a typical short comming of Scottky

Schottky do not have comparable characteristics with
a pn-juction hence one should not expect curves to look similar.

What work function was used in the simulation?

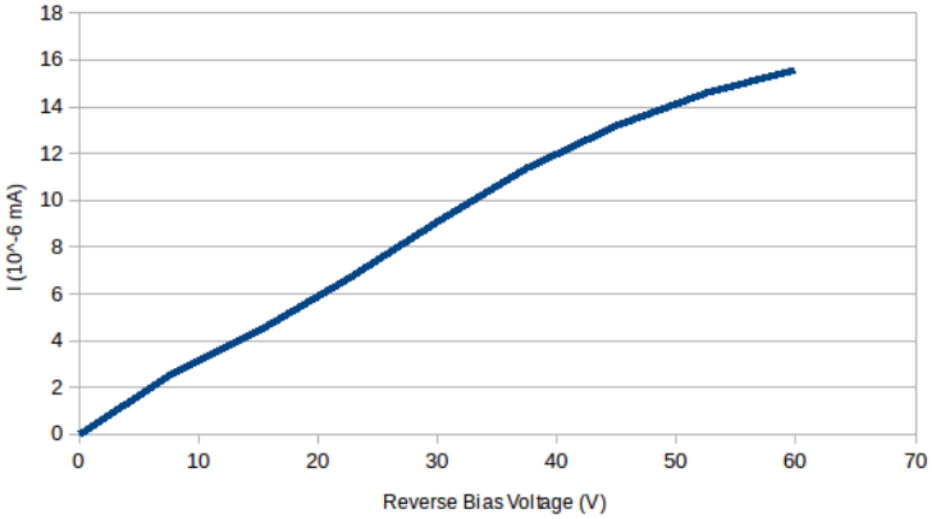
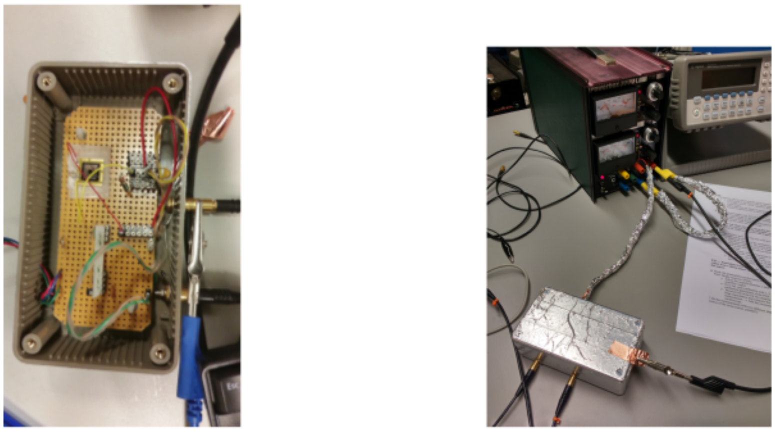


Figure 6: Simulation for Schottky contact IV curve using Germanium.

2 Laboratory Section

A custom board shown in Figure 7a was used for the electronics for connecting the diode named "vero board". After all the electronics were soldered and the connections tested, the calibration and noise measurements were permfored. It was broadly noticed the importance of propper grounding for the noise reduction as well as the importance of the use of aluminum wrap paper and tape for covering the electronics. The electronic noise if those two factors were not taken into consideration was big enough to entirely disrupt the signals. All the electronics around, meaning light bulbs, power supplies, power line, etc contributed to this noise that was attenuated by covering circuitry with aluminium foil as shown in Figure 7b and mentioned before.



(a) Vero board.

(b) Electronic connections.

Figure 7: Vero board and electronic connections.

2.1 Preamplifier Characteristics

In order to measure the preamplifier characteristics the vero board was connected to a pulse generator and a power supply. The signals from the pulse generator and from the pre-amplifier were shown on the oscilloscope screen. The properties of the preamplifier were determined experimentally by injecting a charge Q using a defined calibration capacitance ($C_c = 0.4pF$) and input voltages (V_i). From equation 1 it can be obtained that 10 mV (1 minimum ionizing particle) corresponds to about $16500e^-$.

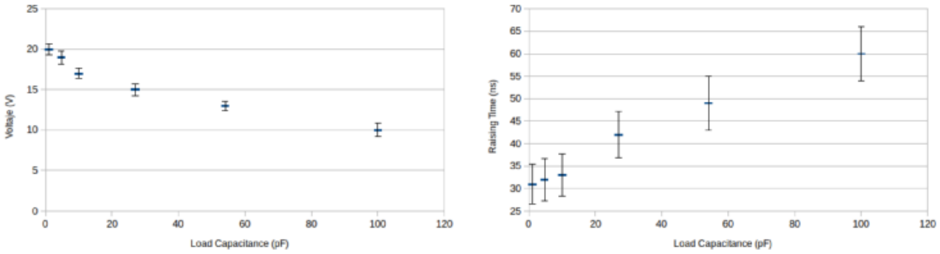
$$Q = \frac{C_c V_i}{ln(2)} \tag{1}$$

In Table 5 it can be seen the amplitude (V_o), gain (G), rise time (t_r), V_{RMS} and he equivalent noise charge (Q_{ENC}) behaviour for different load capacitances (C_l). These values were obtained from the oscilloscope so there are errors introduced in the reading process estimated to be $< 10\%$. The equivalent noise charge (Q_{ENC}) calculated by means of Equation 2 taking into consideration $Q_{MIP} = 16500e^-$.

$$Q = \frac{V_{RMS}}{V_o} Q_{MIP} \tag{2}$$

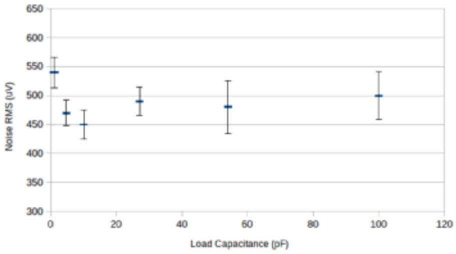
$C_l(pF)$	G	$V_o(mV)$	$t_r(ns)$	$V_{RMS}(\mu V)$	$Q_{ENC}(electrons)$
1	2.99	20	31	540	445
4.7	2.84	19	32	470	408
10	2.54	17	33	450	436
27	2.24	15	42	490	539
54	1.94	13	49	480	609
100	1.49	10	60	500	825

Table 5: Preamplifier characteristics taken with a square $6.5V$ long period signal.



(a) Voltage Amplitude for different load capacitances.

(b) Raising time for different load capacitances.



(c) Voltage RMS for different load capacitances.

Figure 8: Preamplifier characteristics.

2.2 Spectroscopy amplifier performance and measurement of ^{137}Cs

A spectroscopy amplifier and a pulse height analyzer were used in order to verify the pre-amplifier performance. A three point gain calibration for two shaping times of the spectroscopy amplifier was performed by using 10 mV, 20 mV and 30 mV test pulses. The test pulses correspond to 1, 2, 3 minimum ionizing particles (MIP) respectively.

The calibration spectrum for shaping times of $2\mu s$ and $8\mu s$ can be observed in Figure 9. The calibration the functions $F(ch)$ were determined for each peak time, respectively 3 and 4.

$$F_{2\mu s} = 50.1e^{-} + N_{channel}29.6e^{-} \tag{3}$$

$$F_{8\mu s} = 47.6e^{-} + N_{channel}27.2e^{-} \tag{4}$$

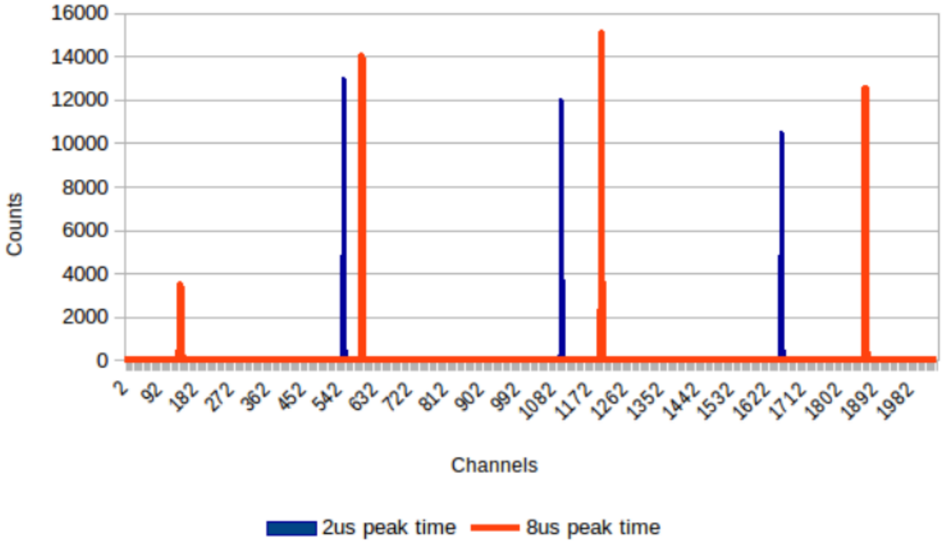


Figure 9: Calibration spectra.

The spectrum of a ^{137}Cs radiation source was measured during the laboratory exercise. The measurements were performed and the peaks were detected. The data was saved in a memory stick that regretfully was lost making it impossible to report the snapshots of the peaks from the scope as well as the data for the Cs spectra.

3 Comparison with with clean room measurement

The GSS program was used to simulate the silicon chip used in the laboratory to find the IV-curve and compare to the results obtained in the clean room exercise. The processing parameters were:

- Diode thickness: $300mm$
- Active area: $5mm\ X\ 5mm$
- Bulk concentration n-type: $*10^{12}cm^{-3}$
- Implant concentration p-type: $5*10^{18}cm^{-3}$
- Implant depth: $2mm$
- Thickness of Al metallisation: $0.5mm$ (Not simulated)

From Picture 10 it is possible to establish a depletion voltage around $63V$ which compared to the $30V$ that measured with the data from the clean room. There might be some parameters that were not properly established in the simulation. One paramater worth mentioning is the metallisation contact which was not included in the simulation.

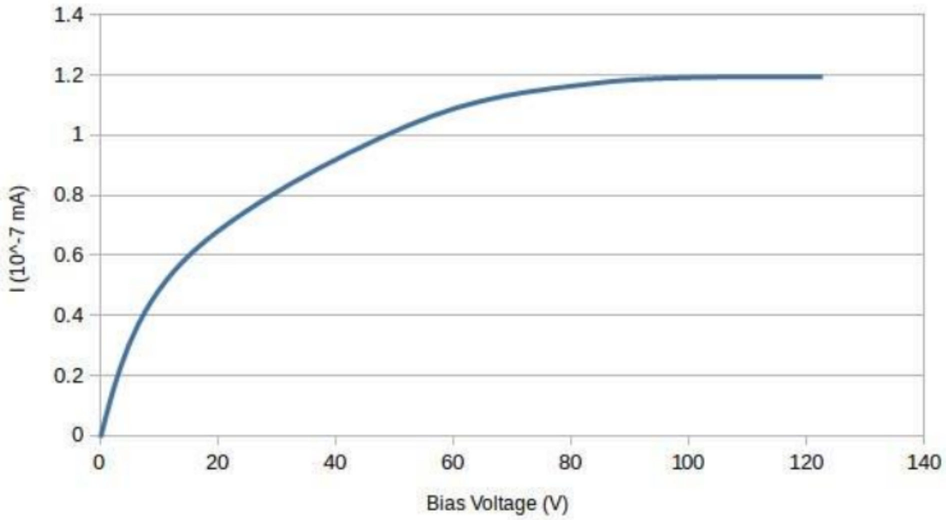


Figure 10: Simulated chip IV curve.