

APPENDIX A – Experimental set-ups

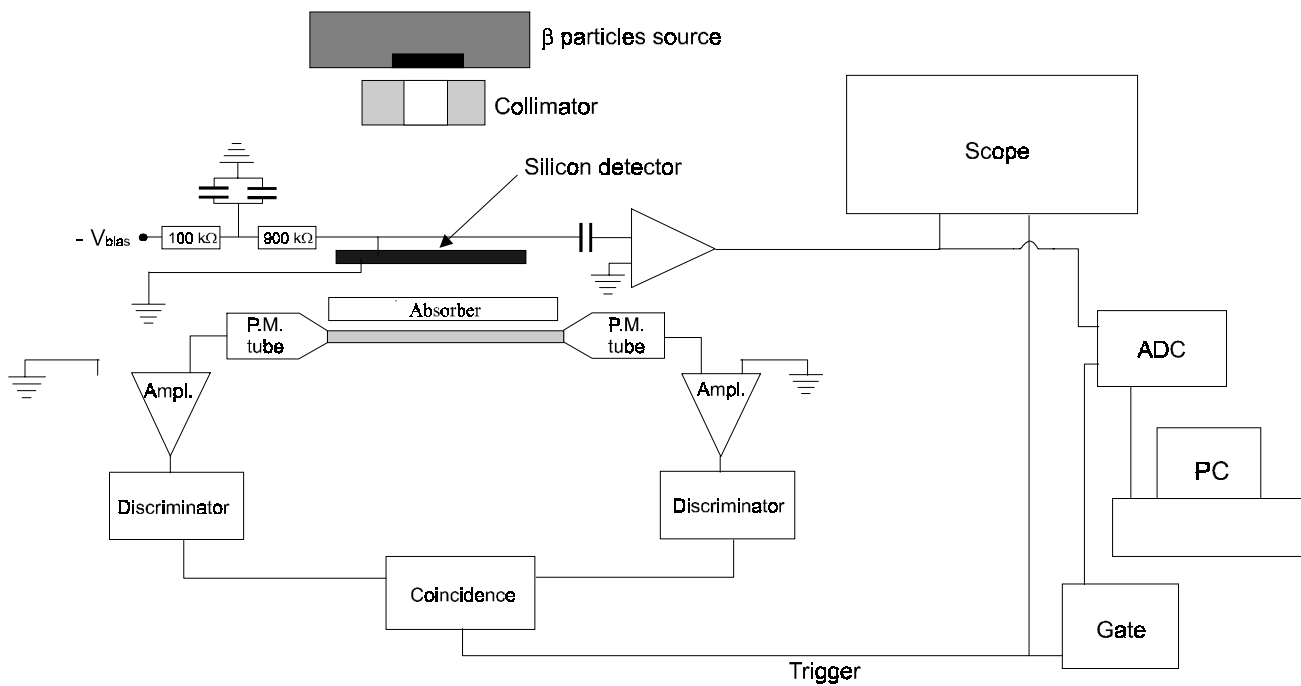


Fig. A.1 *Set-up for the charge collection measurement with β particles injection. The signal can be averaged with the scope when a fast current amplifier is used. The spectrum is recorded by an ADC connected with a PC when a charge-sensitive amplifier is used.*

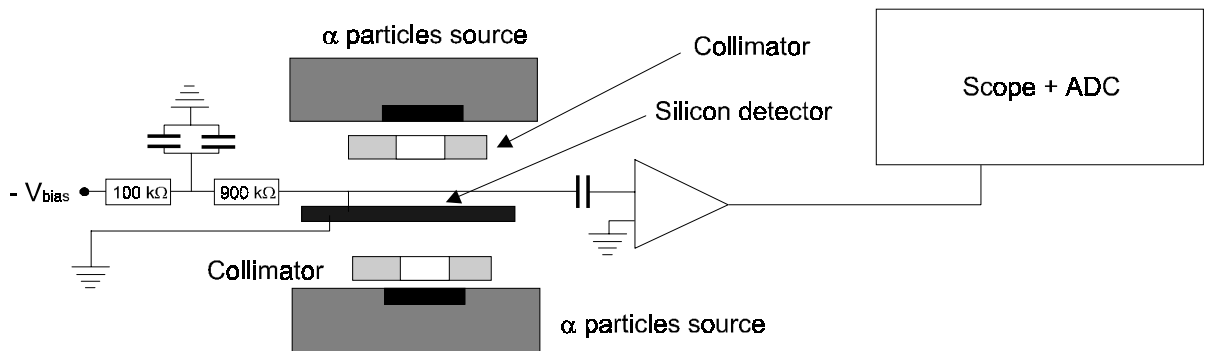


Fig. A.2 *Set-up for the charge collection measurement with α particles injection. The signal can be averaged with the scope when a fast current amplifier is used or the spectrum is recorded by the internal ADC of the scope when a charge-sensitive amplifier is used. The set-up allows the positioning of the α source on both sides of the detector.*

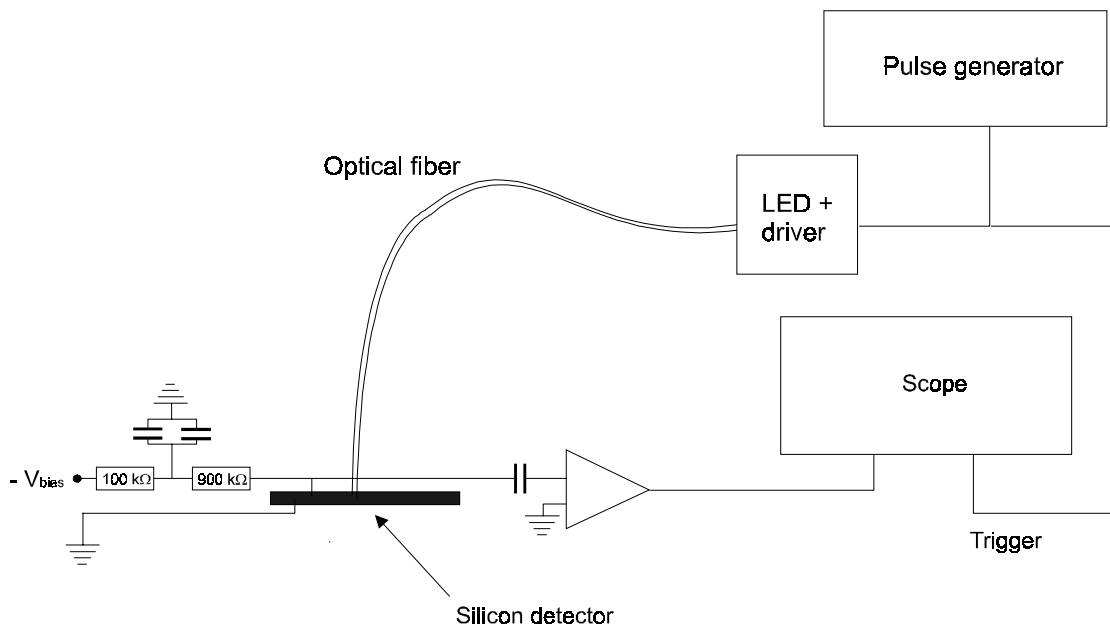


Fig. A.3 *Set-up for the charge collection measurement with red LED light illumination. The signal pulse is amplified by a fast current amplifier and recorded by the scope. The waveform generator drives the LED pulses and provides the trigger to the scope.*

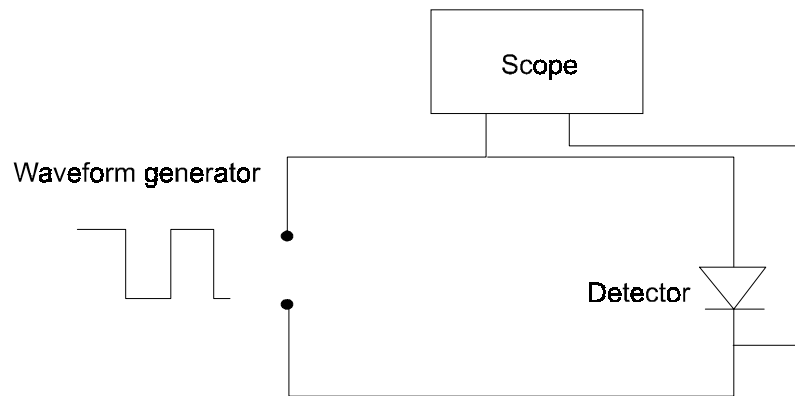


Fig. A.4 *Set-up for the carrier lifetime measurement (Reverse Recovery method).*

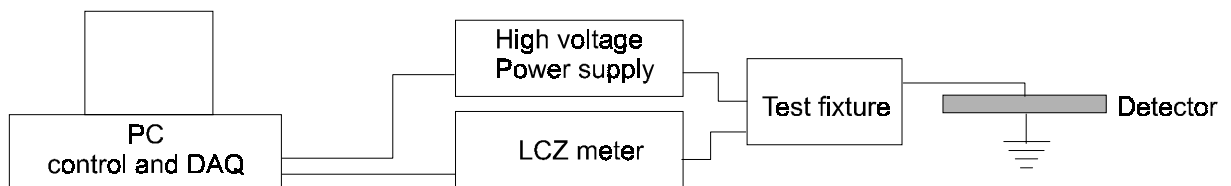


Fig. A.5 *Set-up for the capacitance-voltage (C-V) and current voltage (I-V) measurement.*

CERN/EP/MIC laboratory equipment (Fig. A.1, A.2, A.3, A.4):

Charge-sensitive preamplifier: CANBERRA 2003BT.

Linear-shaping amplifier: ORTEC 450 Research Amplifier.

Fast current amplifiers: Phillips scientific Model 6954, Gain = 100 or Gain = 10.

Oscilloscope: LeCroy 9361 - 300 MHz, 2.5GS/s.

LCZ meter: Hewlett-Packard 4276A.

Power supply: Keithley 237.

Test fixture: modified external voltage bias fixture HP-16065A.

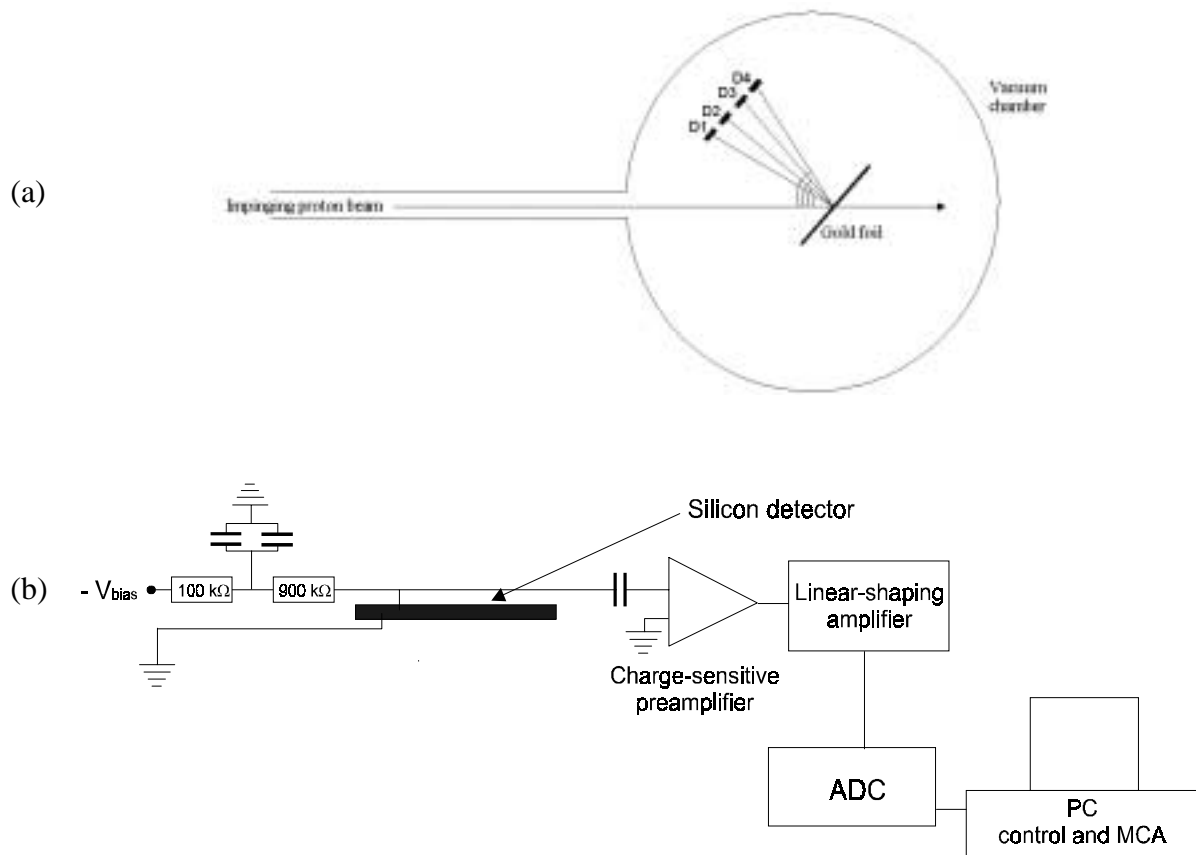


Fig. A.5 *Set-up for the low-range protons measurements at the Charles University Van de Graaf accelerator [6.1] (a) detector position (D1, D2, D3 and D4) into the Van de Graaf vacuum chamber (b) signal spectra recording set-up.*

Charles University-Van de Graaf accelerator equipment (Fig. A.5):

Charge-sensitive preamplifier: CANBERRA.

Linear-shaping amplifier: TENELEC TC 244.

Fast ADC: CANBERRA 8077

Multi Channel Analyser (MCA): CANBERRA S100.

APPENDIX B – The diffusion theory in silicon

The diffusion is the passage of an atom in silicon through vacancy or interstitial sites. Each passage of the impurity atom in a new interstitial or substitutional position is called a “single jump”. The isotropic diffusion process is described in term of diffusion coefficient D , as defined by the first Fick’s law

$$\vec{j} = -D\nabla N \quad (\text{B.1})$$

where N is the impurity concentration. The silicon devices are plane and parallel structures, therefore the analysis can be limited to the simple one dimensional case. By applying the continuity equation to eq. B.1 we obtain:

$$\frac{\partial N}{\partial T} = \nabla \cdot (D\nabla N)$$

and, for the one-dimensional case:

$$\frac{\partial N}{\partial T} = D \frac{\partial^2 N}{\partial x^2} . \quad (\text{B.2})$$

The characteristics of a diffusion process are the concentration as a function of the depth (x) of the diffusing impurity, the flux of matter through an arbitrary surface and the quantity of material introduced or removed from the body. The boundary conditions specify the various concentrations at the beginning and the concentration or the flux at fixed layers at a given time. Here are summarised some solutions of eq. B.2 concerning different boundary conditions.

B.1 Semi-infinite body with constant surface concentration

This is the case describing an infinite impurity source. The diffusing impurities enter the body through the plane $x = 0$ so as to maintain a constant concentration N_0 at the surface. The boundary conditions are:

$$N(x > 0, t = 0) = 0 , \quad N(x = 0, t \geq 0) = N_0 \quad (\text{B.3})$$

and the solution of eq. B.2 is:

$$N(x, t) = N_0 \operatorname{erfc} \frac{x}{2\sqrt{Dt}} .$$

(B.4)

This solution describes reasonably well an impurity diffusing in silicon from a gas or a vapour phase. If N_0 exceeds the solubility limit of the diffusing specie then the model is not adequate.

The rate of impurity passing through the surface at $x = 0$ is given by:

$$j(t) = \left[-D \frac{\partial N}{\partial x} \right]_{x=0} = \left[\frac{DN_0}{\sqrt{\pi Dt}} \exp \left\{ - \left(\frac{x}{2\sqrt{Dt}} \right)^2 \right\} \right]_{x=0} = N_0 \sqrt{\frac{D}{\pi}} .$$

(B.5)

The total amount of material having entered the solid at time t is:

$$Q = \int_0^t j(t') dt' = 2N_0 \sqrt{\frac{Dt}{\pi}} .$$

(B.6)

B.2 Out diffusion from a constant impurity concentration

This is the case of a body with uniform impurity distribution at $t = 0$ The boundary conditions are:

$$N(x > 0, t = 0) = N_0 , \quad N(x = 0, t \geq 0) = 0$$

(B.7)

and the solution is

$$N(x, t) = N_0 \left(1 - \operatorname{erfc} \frac{x}{2\sqrt{Dt}} \right) .$$

(B.8)

1.3 Diffusion from a limited source

The boundary condition is that of an impermeable surface:

$$\left[\frac{\partial N(x, t > 0)}{\partial x} \right]_{x=0} = 0.$$

(B.9)

This configuration can describe the case when the dopant is introduced into the solid before the diffusion, forming a “rectangular” box in a semi-infinite body. This is the case of a silicon wafer oxidised and annealed at high temperature in an inert (N₂) atmosphere.

The impurity concentration at the beginning is:

$$N(x, t = 0) = \begin{cases} N_0 & 0 \leq x \leq h \\ 0 & x > h \end{cases}$$

(B.10)

where h is the depth of the initial impurity distribution. The solution of eq B.2 with the boundary conditions expressed by eq. B.10 is:

$$N(x, t) = \frac{N_0}{2} \left[\operatorname{erfc} \left(\frac{x-h}{2\sqrt{Dt}} \right) - \operatorname{erfc} \left(\frac{x+h}{2\sqrt{Dt}} \right) \right].$$

(B.11)

The surface concentration decreases according to:

$$N(0, t) = N_0 \left(1 - \operatorname{erfc} \frac{x}{2\sqrt{Dt}} \right).$$

(B.12)

The Taylor’s series expansion of 12 about $\frac{x}{2\sqrt{Dt}}$ is:

$$N(x, t) = \frac{Q}{\sqrt{\pi Dt}} \exp \left[- \left(\frac{x}{2\sqrt{Dt}} \right)^2 \right] \left[1 + \frac{1}{3!} \left(\frac{h}{2\sqrt{Dt}} \right)^2 H_2 \left(\frac{x}{2\sqrt{Dt}} \right) + \frac{1}{5!} \left(\frac{h}{2\sqrt{Dt}} \right)^4 H_4 \left(\frac{x}{2\sqrt{Dt}} \right) + \dots \right]$$

(B.13)

where H_n are the Hermite polynomials of order n and $Q = N_0 \cdot h$ is the total number of impurities in the solid at all times.