G71. Elementary Particle Physics Lab Session

Introduction to semiconductors radiation detectors:
Transient Current Technique characterization of a PIN semiconductor diode using a 670 nm laser.

Summary

A detailed study of the current generated by a $\mathcal{O}(10)$ pico-second, $\lambda = 670\,nm$ laser pulse in a **n-in-p** diode is performed. This laser is used to emulate the diode response when a particle with a low penetration range fall upon the surface of the Silicon, i.e. alpha particles. Electron and holes response are studied by illuminating the laser beam either on the bottom or on the top of the diode.

1 Experiment description and setup

The physical and electrical properties of a semiconductor detector can be studied with the so called Transient Current Techniques (TCT), A detector is illuminated by a laser, used as localized charge carrier generator, and by measuring their transient current in a wide band oscilloscope and comparing with the predicted one, which can be calculated with the *Shockley-Ramo* theorem, several properties, such as the depletion width, the depletion voltage, the level of impurities, etc...; can be infered.

In this experiment, we study a **n-in-p** diode (Fig. 1) using a $\lambda = 670\,nm$ laser. A red laser penetrates just a few microns into the Silicon, releasing energy to create electron-holes only near the surface is illuminating. That behaviour mimicks the energy deposition of a low penetration particle, such as alpha particles for instance, and it is equivalent to inject electrons or holes, depending the illuminated surface. The experimental setup is shown in Fig. 2

2 Theoretical basis

Ionization detectors Basic elements of a gaseous ionization chamber detectors: ionization medium, drift field, collecting electrodes. *Specific references* [LEO1994, sections 6.1, 6.2 and 6.3], [KNO2000, sections 5.I and 5.II]

Semiconductors as ionizing medium Energy band in semiconductors, intrisic semiconductors, doped semiconductors. Charge carriers transport: drift, movility, difusion

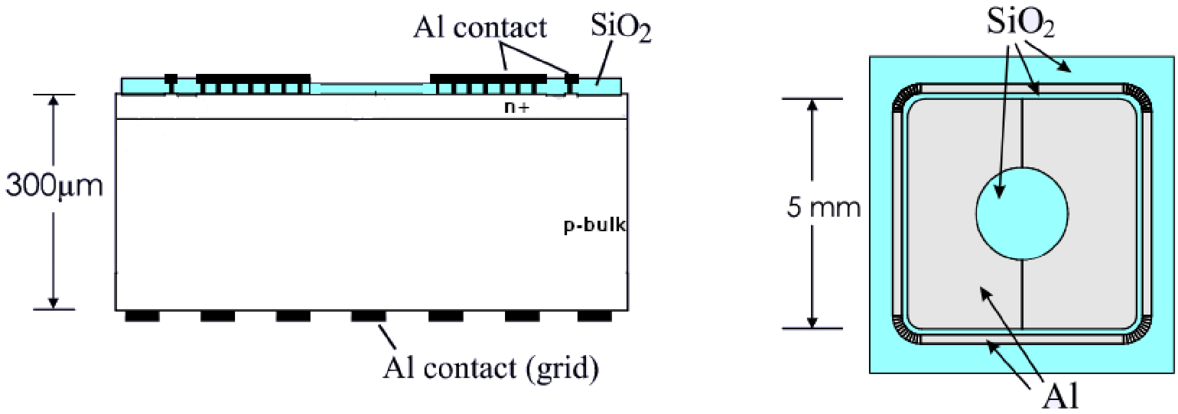

Figure 1: Geometry of the characterized n-in-p diode.

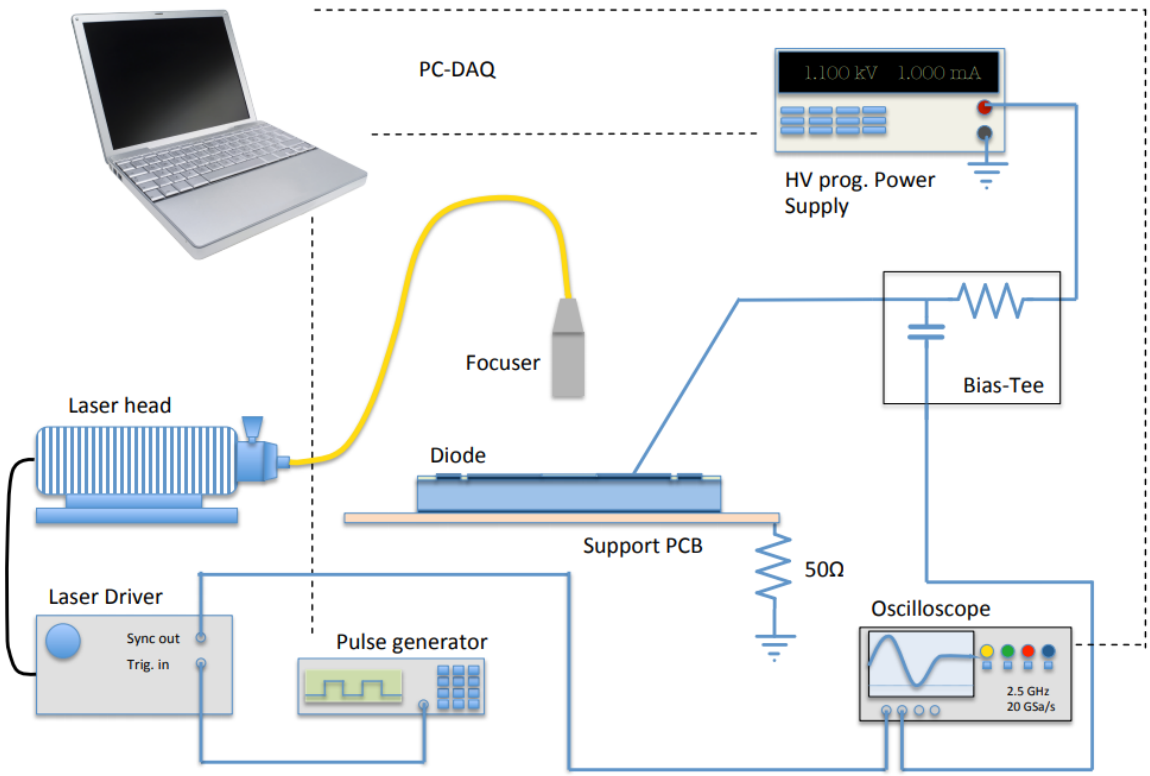

Figure 2: Schematic experimental setup used in the lab (Image from N. Pacifico, PhD Thesis, Bari University 2012).

and recombination. Semiconductor junctions: analitic resolution of a pn junction; reverse biasing operation of a pn junction, charge carriers depletion region, junction charge distribution, junction capacitance. *Specific references* [LEO1994, sections 10.1, 10.2, 10.3 and 10.4], [KNO2000, sections 11.I, 11.II and 11.III] and [KRA2001, section 2.1]

Signal generation in capacitive electrodes Shockley-Ramo Theorem: weighting field as a measure of the electrostatic coupling between a charge and an electrode. Analitic calculation of the signal generated at an ionization chamber and in a p-n junction. *Specific references* [KNO2000, Appendix D], [KRA2001, section 2.2.1 and 2.2.2]

3 Data formats

I-V characteristic (extension .txt file)

- First column: Voltage in Volts
- Second column: Inverse current in Amperes.

Transient voltages (extension .dat file)

- File Header: 3 first lines
  - **t0: 3.580000E-007 *** Transient initial time, it is arbitrary
  - **dt: 2.500000E-011 *** Temporal separation between consecutive sampling points in the osciloscope, in seconds
  - **Samples: 2000 *** Number of samples
- 4th line contains the voltages used to acquire the data
- Columns: as much as adquired voltages, profile stored by the oscilosocope in Volts

Questions and data analysis

1. Explain why illuminating with a red laser in a PIN diode "is equivalent to inject electrons and holes, depending which surface the laser is illuminating"? In what surfaces there is hole and electron injection?

2. Assuming a p-n junction, with a n^+ region much more doped with impurities than the p-bulk region (see Fig. 3), i.e. $N_{donors} >> N_{acceptors}$. Determine

a. The electric field in the semiconductor junction.

b. The depletion depth in the region n^+ (x_n) and in the region p (x_p) given a bias voltage (V_{bias}) and the doping concentrations in each region (N_a, N_d).

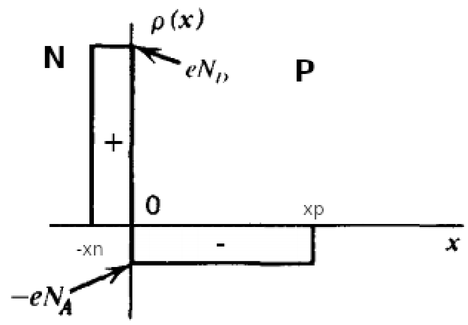

Figure 3: Charge density in a pn junction

c. The bias voltage needed to fully deplete the junction, assuming a 300 μm diode thickness. You can use a hole mobility of 450 $cm^2/(V \cdot s)$ and a resistivity of the doped P-region of about 30 K$\Omega \cdot cm$.

3. Plot the inverse current versus the bias voltage (I-V characteristic). Estimate the inverse corrent per volume unit.

4. Explain qualitatively the profile of the generated current when illuminating the diode by a red pulsed laser. Draw a schematic induced current vs. time graph and explain the different components of the graph. Do it for the two cases studied in the lab: electron and hole injection.

5. Graphical representation of the ionized charge in front of the bias voltage. The osciloscope input impedance is 50 Ω and the amplifier gain 60 db (x1000). Estimate:

a. The fully depleted bias voltage

b. The doping density (resistivity) of the semiconductor material **p**. Obtain an estimation of the doping density for the n type as well.

c. The energy of the laser pulse

References

[LEO1994] William R. Leo. *Techniques for nuclear and particle physics experiments: a how-to approach.* Springer, 1994 (Biblioteca Ciencias: F29 3, F29 3a, F29 3b)

[KNO2000] Gelnn F. Knoll. *Radiation detection and measurement* 3rd ed., Wiley 2000 (Biblioteca Ciencias: F29 6c I)

[KRA2001] Gregor Kramberger. *Signal development in irradiated silicon detectors* CERN-THESIS-2001-038, 2001; `http://cds.cern.ch/record/1390490?ln=es`