EDIT 2011 **Excellence in Detectors and Instrumentation Technologies**

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Silicon Strips and Pixel Technologies

Hands-on: Silicon Pad Detectors

Aim

Observe the change in the depletion depth versus bias voltage measured by the capacitance voltage relationship and measure the charge collection versus bias voltage for front and back side illumination.

Introduction

This part of the lab illustrates the operation of a reversed bias pn-junction as detector for ionising particles. The first measurement shows how the depleted region grows as a function of bias voltage, and the change in capacitance that it implies. The second measurement shows how the signal size varies with bias voltage for front and back side illumination.

Apparatus

Detector: The detector used in this part of the lab is a simple pad detector as shown in Figure 1. The detector is a p-in-n diode which is 300µm thick with implants less than 2µm thick. The front implant is heavily doped p-type, the bulk is n^- and the back implant is n^+. The front side implant is covered with an aluminium layer to enable electrical contact to the implant. This has a circular hole at the centre to facilitate light illumination. The back side is covered by an aluminium grid for electrical contact and light illumination. The front pad is surrounded by a p^+ guard ring to reduce edge currents. The active area of the device is approximately 0.5 x 0.5 cm^2.

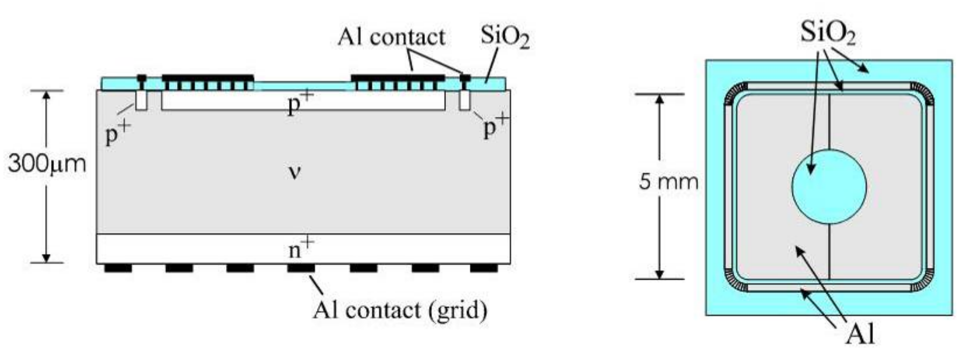

Figure 1 : The pad detector

Test box: A box containing the pad sensor mounted on a PCB with the necessary passive components has been developed for this lab. The schematic of the circuit is shown in Figure 2. It has an LP filter at the input of the HV supply (R1, R3, C1, C2) and AC coupling capacitors to screen the LCR meter and the preamplifier from the high voltage (C3, C4, C5). The box also contains two LED used to generate signals in the pad detectors. They are mounted at the top and bottom of the sensor, to make it possible to illuminate from both the back and the front of the sensor. The wavelength of the light emitted from the LEDs is 624 nm, which gives a penetration depth of approximately 10 µm. Figure 3 shows the content of the test box.

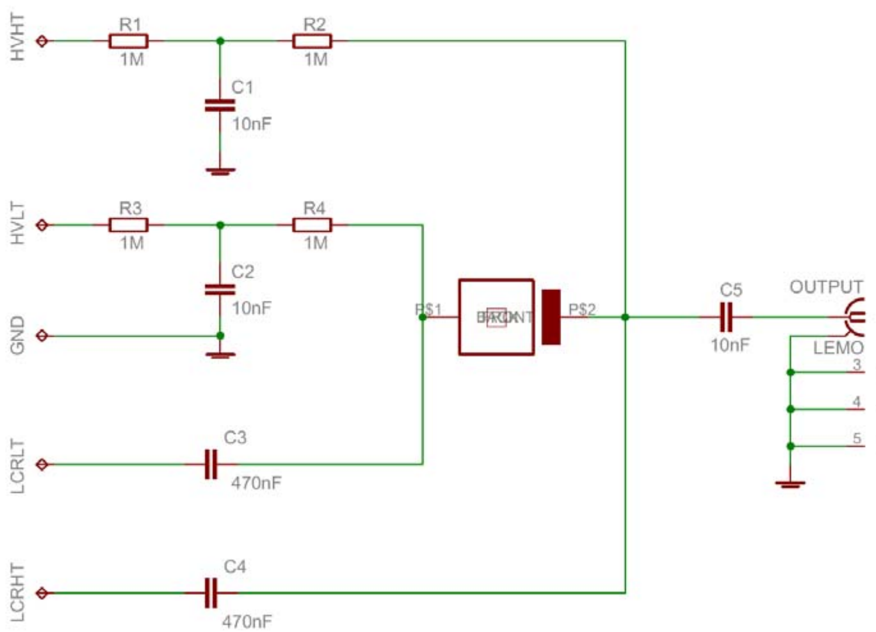

Figure 2: Schematic of the circuit in the black test box.

Figure 3: Photo showing the content of the test boxes.

Note: *The 4 test stands have partly different equipment (different pulse generators and LCR meters) and – to make the program more interesting – are using different silicon Pad Detectors. The tutor at the test stand and a paper sheet next to it will provide detailed information about particularities and small deviations from the below given descriptions.*

Measurements 1: Capacitance versus voltage characteristics

- Connect the box containing the pad detector and LEDs to the HV supply and the LCR meter. The pulse generator and amplifier should not be connected for this part of the lab. Configure the LCR meter to measure capacitance in parallel mode, at 10 kHz frequency. To eliminate stray capacitance, the LCR meter has to be calibrated to define the zero point. This is done by connecting one of the leads to the box and leaving the other just connected to the meter. Switch on HV supply and the LCR meter then press and hold the CAL button on the meter, OPn should appear in the top right corner then press the same button again. The meter should now show a value close to 0 pF.
- Connect both LCR leads to the box; the reading will increase to a few hundred pF. Now scan the bias voltage and measure the capacitance at each value. Appropriate values for the scan is displayed on the sheet next to the box.
  NB: it will take a long time for the measurement value to settle at each point. To get a consistent curve in a reasonable time, wait *exactly* the same time between changing the voltage and reading the value, e.g. 20 seconds
- Plot the capacitance against the voltage, then plot $1/C^2$ against V. Fit two straight lines to the graph, one to the first sharp rise and the other to the plateau value. The depletion voltage is conventionally defined as the intersection of these two lines

Question: Which polarity of bias do you apply and why?
Question: What is the role of the capacitor C3 and C4?
Question: Why do the capacitors C3 and C4 not influence the measurement?
Question: What is the depletion voltage of the device?

Measurements 2: Signal generated by front and back side illumination

- Disconnect the LCR meter and connect the amplifier to the output, make sure that the power supply for the amplifier is on and providing the voltage indicated on the amplifier.
- Connect the pulse generator to connector labelled *Front* on the box. This will generate short light pulses on the front-side of the detector. You can spy on signal sent to the LED on Channel 1 on the oscilloscope.
- Look at the output of the pre-amplifier on channel 2 on the oscilloscope.
- Note immediately what you can see on the oscilloscope when there is 0V applied. Scan the voltage from 0 to +2 V and observe the signal on the oscilloscope. Then decrease from 0V to -100V, initially from 0 to -5V in 1V steps then from -10 to -150V in steps of 10V. Note the signal height and peak position as a function of voltage.

Question: Why do you see a signal at 0 V?
Question: Explain the behaviour of the signal between 0 and +2 V
Question: Explain the variation of signal size versus bias voltage.

- Reduce the bias voltage to 0 V and connect the pulse generator for back side illumination and observe the signal on the oscilloscope.
- Decrease the voltage from 0V to -150V in steps of 10V. Note the signal height and peak position as a function of voltage.

Question: Why does the device behave so differently in front and back-side illumination?
Question: Why is the first observed signal delayed with back-side illumination?
Question: What is the depletion voltage of the device?

NB: The wavelength of the LED is 624 nm and light at this wavelength has a penetration depth of approximately 10 µm in silicon.

Additional exercises and calculations (if time allows)

1: The doping density N_{eff} and the resistivity of the silicon can be determined from the depletion voltage. The depletion depth can be expressed as $w = \sqrt{\frac{2\varepsilon_r \varepsilon_0 V(w)}{qN_{eff}}}$. The depletion voltage is the voltage at witch the depletion depth is equal to the thickness of the device (300µm). The resistivity can be calculated from the effective doping concentration using $\rho = \frac{1}{q\mu_N N_{eff}}$. This value in normally in the order of a few kΩcm.

Quantities:

$\varepsilon_{Si} = 11.9$

$\varepsilon_0 = 8.854 \times 10^{-14} \rho / cm$

$q = 1.602 \times 10^{-19} C$

$\mu_N = 1500\ cm^2 V^{-1} s^{-1}$

Question: What is the effective doping concentration?

Question: What it the bulk resistivity of the device?