Description of SD task 4
-
depletion voltage and charge carrier mobility measurements using the TCT

Short description

In this task, you will measure the depletion voltage and the charge carrier mobility in a silicon strip sensor using the Transient Current Technique. As an option, you will additionally measure the position dependence of the current signal.

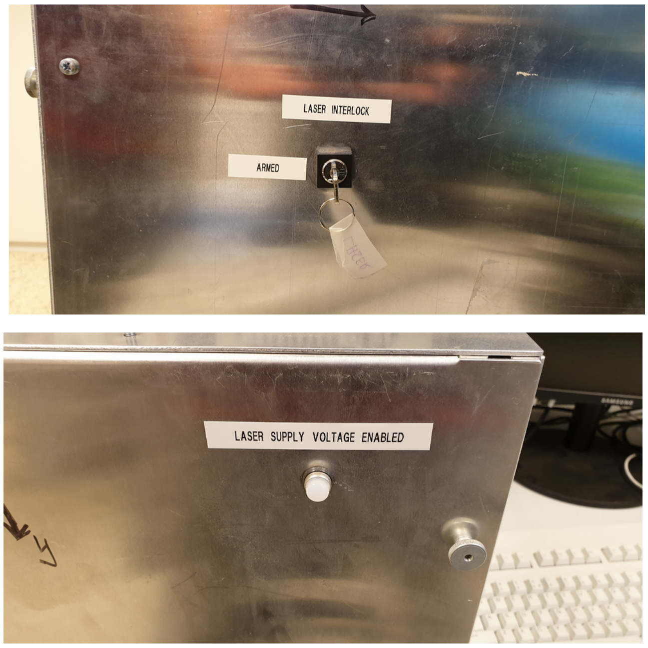
To this end, you will use two lasers, red and infra-red, to create free electron-hole pairs in the sensor. You will apply an external bias and measure the induced current for various voltages. Using the in-built functionalities of the oscilloscope, the analysis of the current pulses allows you to extract the depletion voltage and drift times. If time allows: Scan over the sensor surface and discuss the position dependence of the current pulse.

A) Safety first

Laser:
- Never look into the laser. This set-up uses class 3B lasers.
- Always close the lid of the TCT box before turning the laser key.
- If the red LED is on, the laser is powered.
- If in doubt, ask your facilitator.

Laser class:

Key interlock and LED:

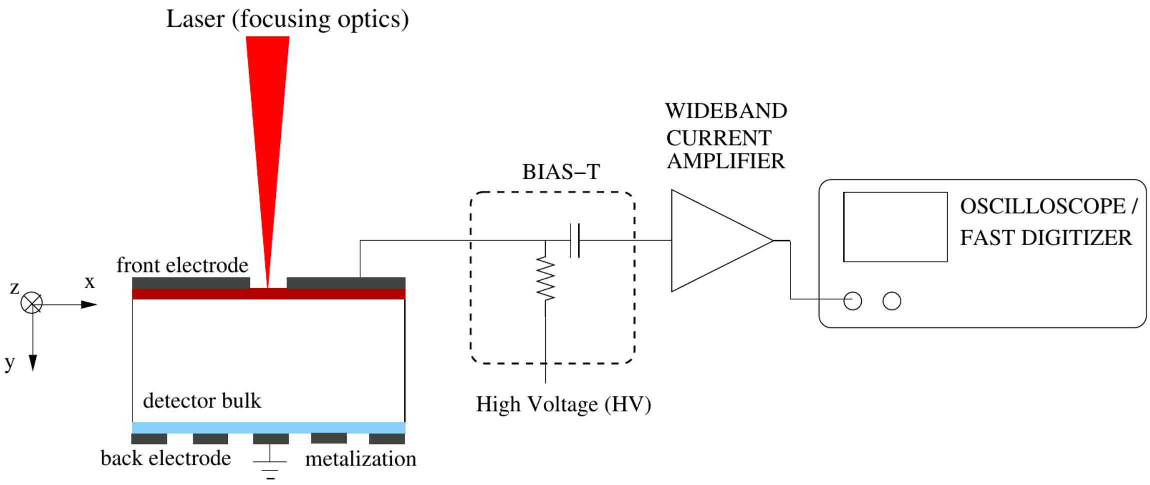


High-voltage:
- You might use voltages above 50 V. Handle with care.
- Check all cables and understand the connection before switching on the HV.
- Always understand the polarity you want to apply before switching on the HV.
- If in doubt, ask your facilitator.

Oscilloscope:
- Handle the oscilloscope with care. No voltages > 5V should by applied to its input.
- If in doubt, ask your facilitator.

B) Get to know the set-up

Schematics of the set-up



Schematic view of the optics:

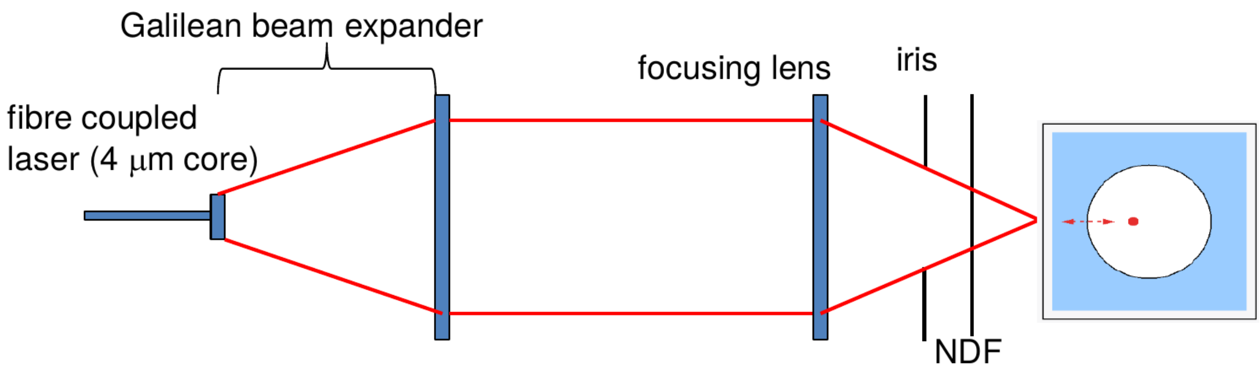
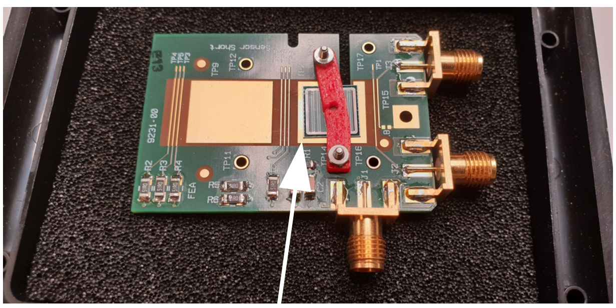
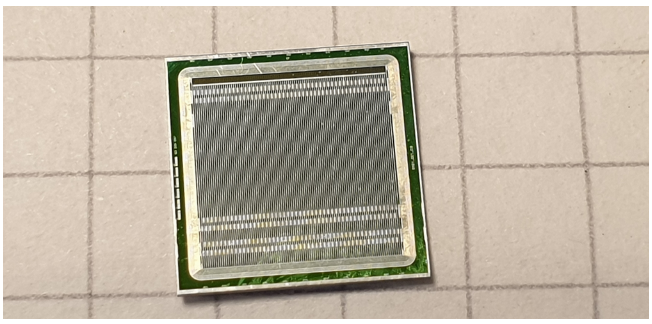


Photo of the PCB:



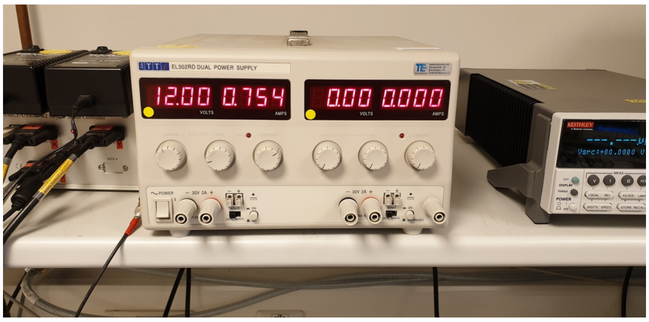
HV-Pad

Photo of the sensor:

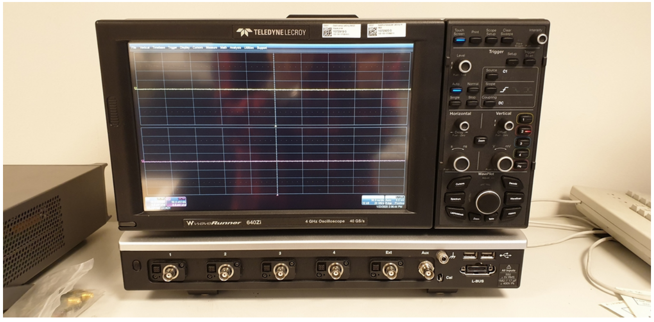


HV supply:

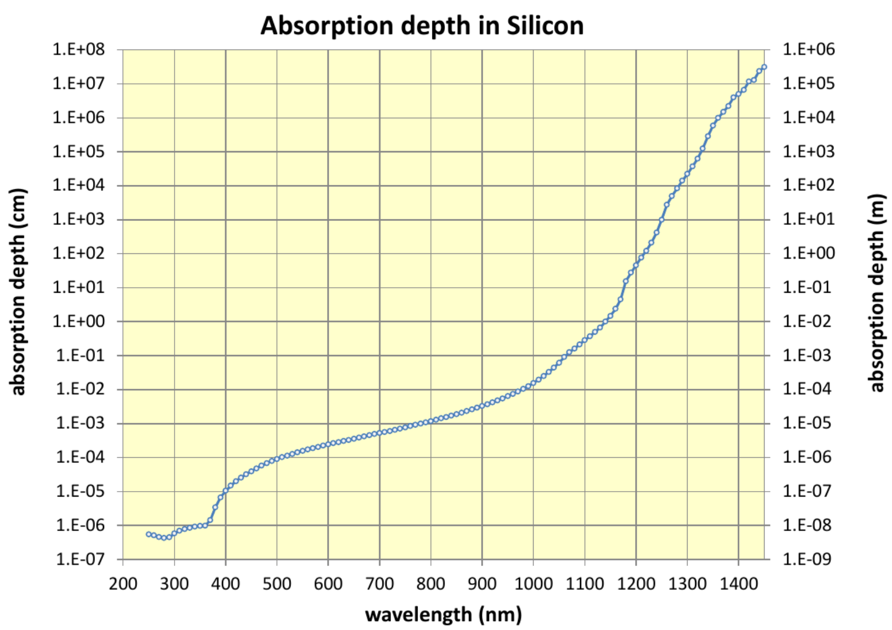
Low voltage supply for the amps:



Oscilloscope:



Review the absorption length of light in silicon. Wavelength of red and infra-red?



With your facilitator, also have a look at the laser GUI and the stages GUI.

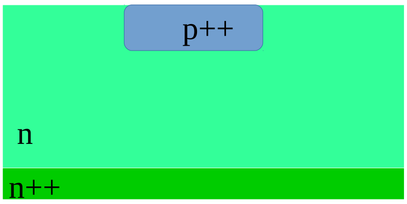
Some questions for you:

1. How is the sensor biased? Follow the cables.
2. How is the sensor read out? Follow the cables.
3. The sensor is a “p-in-n” strip sensor. Draw a cross section sketch of the implant and the sensor. Which polarity of the HV should be used to reverse-bias (i.e. to deplete) the sensor?
4. There are two lasers. Which one is connected?
5. Convert the absorption length to micrometre. What is the intensity as a function of depth?
6. Understand the set-up of the stages. Which functionality is provided by this choice?

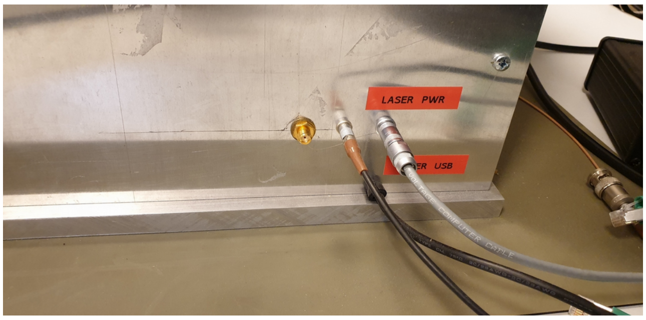
Answers:

1. Keithley 2410 → box → feed through → HV filter → PCB/HV-Pad → Backside of strip sensor

2. AC current from sensor top side → wire bond → PCB → Amplifier → Oscilloscope
3. If unsure, ramp the voltage in 0.1 V steps in both directions. Observe the current. Remember the IV behaviour of a diode. Finally, use POSITIVE BIAS.



4. Infra-red. Shown below are the inputs and outputs to the laser.



5. λ = ~3 um at 640 nm, λ = ~200 um at 1060 nm; $I(z) = I\_0 * \exp(-z / \lambda)$
6. X-Y to choose where the laser enters the sensor. Z to focus the laser on the sensor.

C) Measurements with an infra-red laser

By analysing the current signals for various voltages, find out the depletion voltage.

Laser setting:
100 Hz, 440 ns, Enable DAC: 39.5%, SET DAC. Go back to first tab: “SET”
Axis: -22250, -11000, 0. Scan from -22000 upwards in reasonable steps and find the position with maximum signal.

Some thoughts first:

1. HV range to scan?
2. Oscilloscope axis settings? (voltage and time)
3. Triggering?
4. Averaging?

Switch on the power supply for the laser. Enable the laser interlock.
Apply the HV. Apply the LV for the amplifiers. Integrate the current with the scope.

5. Where are the “measure” modes?
6. Convert nWeber (nWb) to nC.
7. Plot in ROOT: Q vs U_bias.
   Identify the depletion voltage
   Verify d ~ sqrt(U_bias).
8. Store a waveform in a buffer at 100 V.

Answers:

1. HV from 0 to 140 V.
2. ~200 mV/scale, 5 - 10 ns/scale
3. Trigger on laser trigger signal (C4). Could you self-trigger on C1?
   What, if a beta-source is used?
4. Yes or no? Depends on what you want ;)
   Try it: C1 → Pre-Processing → 100 sweeps.
5. Measure → My measure→ e.g. P1 → select source and measure. “Gate” appropriately.
6. x nWb / 50 Ohm = x/50 nC.
7. Plot in ROOT or make a sketch:
   a) Q vs U_bias, reach maximum at 100 V.
   b) Q vs sqrt(U_bias), fit straight line from 0 – 100 V.
8. Math → Memory setup → e.g. M1 → copy WF

D) Measurements with the red laser

Ramp down the HV. Turn off the laser. Turn off LV. Turn off laser power supply.

Switch to use the red laser. Put everything back on.

Laser settings:

100 Hz, 440 ns, Enable DAC: 45.5%, SET DAC. Go back to first tab: “SET”
Axis: as before, -11000, 1100: Change x-axis to find maximum again.

C4: Where did the trigger go? Trigger now goes up. Trigger accordingly.

Measure a pulse at 100 V. Compare to infra-red.

1. Discuss and explain the change in shape. Use averaging over 100 sweeps.
   Which charge carrier type dominantly induces the current, electrons or holes or both?
   FYI: The sensor is a “p-in-n” strip sensor. Thickness = 300 um, pitch = 80 um.
2. Measure drift time at 100 V. Convert to drift velocity.
   Assume weighting field =1 for first 30 um, and =0 afterwards.
   (= assume 30 um effective drift path)
3. Calculate mobility: μ = v_drift / E
   Compare with literature value. GIYF ;)

Answers:

1. Check answer B5.
   → Infra-red: long MIP-like charge cloud
   → red: near-surface charge cloud
   → Using Shockley-Ramo theorem (GIYF): → it is complicated for strip sensors ;) You see two components for IR (e + h) and one component (e) for R. For R, think of a point like charge cloud drifting along sharply decreasing weighting field.

2. Measure → P2 → negative width (nwidth).
   v_drift = d / t_drift = 30 um / 1.2 ns = 0.25e7 cm/s

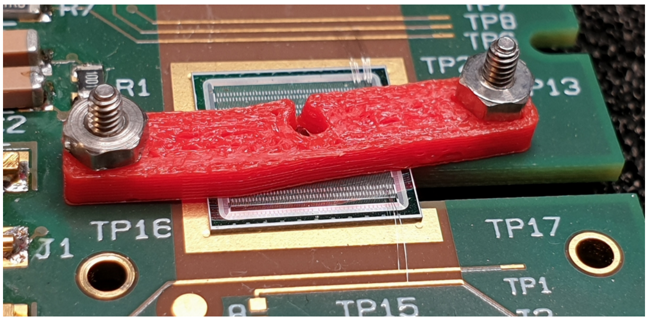
3. E = U_bias / d = 100 V / 300 um = 3333 V / cm
   μ (100 V) = v_drift / E = 750 cm^2/Vs

   Electrons:
   μ_0 = 1400 cm^2/Vs
   v_sat = 0.8e7 cm/s
   μ (100 V) = μ_0 / (1 + μ_0 E / V_sat) = 880 cm^2/Vs (close enough to 750 cm^2/Vs)

$$\mathrm{v}_{\mathrm{drift}}(E) = \mu(E)E = \frac{\mu_0 E}{1 + \dfrac{\mu_0 E}{\mathrm{v}_{\mathrm{sat}}}}$$

E) Further measurements with the red laser

1. Read-out a second strip. Both are wire-bonded as shown below.



2. Note the current position of the laser.

3. Scan from strip to strip (top axis), using the SMC Viewer.
4. Discuss pulse shape as function of position.

Answers:

1. Connect the SMA cable for the second strip.
2. Do it :) Write down the current position from the viewer.
3. 5 um steps are OK. Not too small, not too large.
4. Discuss :)

F) Cleaning up!

Turn of the HV.
Turn of the LV.
Restore stage position: -22000, -11000, 0.
Turn of laser interlock.
Switch off laser power supply.
Connect the IR laser again.