**EDIT 2011** **Excellence in Detectors and Instrumentation Technologies**
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# Silicon Strips and Pixel Technologies

## Hands-on: Laser induced signals

### Aim

Get familiar with the techniques of laser based detector analysis using the laser-induced charge as a probe. Learn about the electric field shape inside a silicon detector and the differences between electron and hole drift velocities.

### Introduction

The silicon detector is basically a p-n diode with a given thickness (somewhere around 300$\mu$m, usually) which is reverse biased by means of an external power supply to a voltage V. The active region of the detector is given by the depleted volume of the detector, which is proportional to$\sqrt{V}$. Of course we would like to operate the detector at full depletion i.e. apply a bias voltage, which is sufficient to fully deplete the detector volume from the intrinsic charge carriers. The charge carriers generated inside the detector by the laser are drifting in the direction of the electrodes under the effect of the applied voltage (i.e. the electric field generated inside the detector). Of course, the length of the signal and the pulse shape generated by the drifting charge are directly related to the electric field strength the carriers encounter throughout their drift. For low electric field strengths, the drift velocity $\nu$ is proportional to the local electric field strength E with the mobility $\mu$ of the charge carrier as proportionality factor ($\nu=\mu E$).

### Fundamentals of Transient Current Techniques (TCT)

To study the field profile within the detector, we can use laser generated carriers to “probe” the detector volume and to give us information about the field they have encountered within the detector. Of course, we are looking for local information so we are also going to need a “localized” probe. Laser pulses provide an easy mean to produce localized charge clouds inside the detector bulk, which then drift under the action of the applied electric field. At each time they will induce a current given by

$$j = \frac{nqv}{d}$$

Again, for low electric field strength, the drift velocity is proportional to the applied electric field , resulting in

$$j = \frac{nq\mu E}{d}$$

In TCT techniques we are not interested in knowing the exact value of j, but just to know how it evolves with the drift time. Moreover, drift velocity and field profile can be extrapolated by imposing boundary conditions over the drift time and the total voltage drop on the detector, though the process in not trivial, as we will explain when discussing about the charge trapping issue.

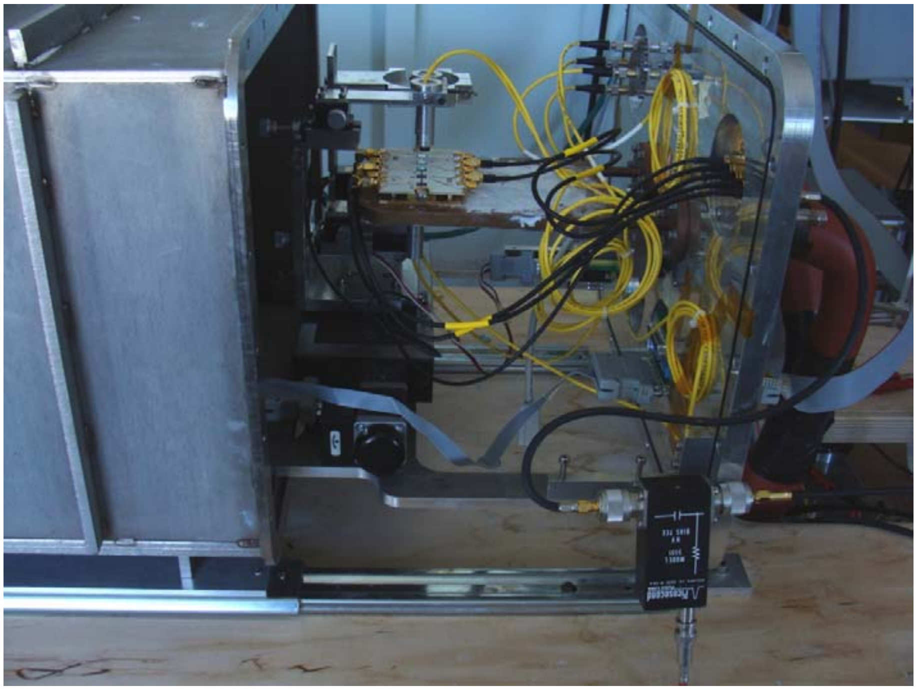

**Figure 1: Global view of the TCT setup**

## Red Laser TCT

In red laser TCT, we use a laser with a visible wavelength (λ=660 nm) injected on one of the implantation sides of the detector (we talk in this case about front and back illumination). The absorption length in silicon for this wavelength is of the order of 3 µm, hence the charge generated will be drifting as a localized cloud. In case of front illumination, the majority carriers (electrons in n-type silicon) are the one drifting in the bulk away from the junction side where they were generated, while the minority carriers (holes in n-type silicon) are immediately collected at the nearby electrode and are thus not contributing to the signal. The carriers will thus drift towards the low field region and the signal is thus expected to get lower as the charge drifts towards the rear electrode. A schematic picture and a series of laser induced pulses under different reverse bias conditions is given in Figure 2.

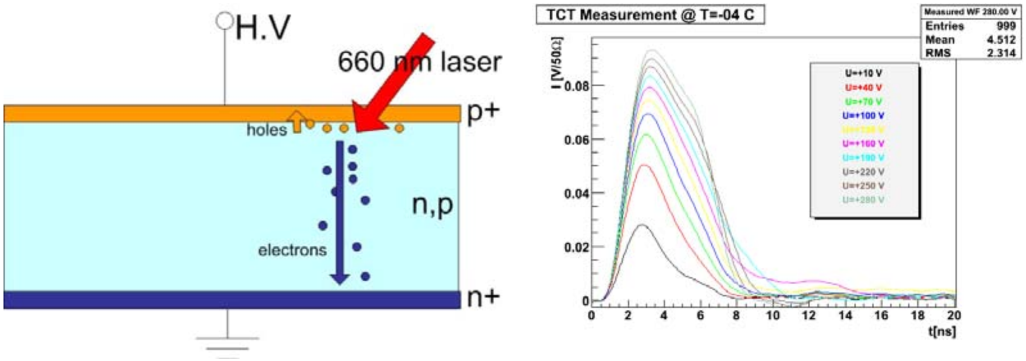

**Figure 2: Signal formation in TCT with front-side illumination**

On the other hand, in case of backside injection, the minority carriers are the ones drifting towards the junction side (front electrode), where the field is higher. As they drift, the induced current will increase, until they are finally collected by the front electrode. This is shown in Figure 3 below.

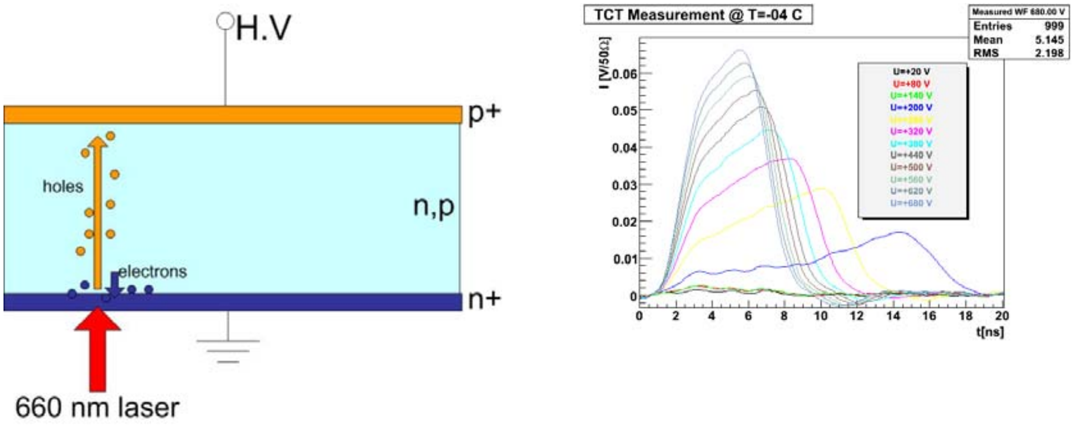

**Figure 3: Signal formation in TCT with back-side illumination**

## Lab Activity: TCT.

You are going to measure red laser induced pulses for five different diodes:

1. 1 mm thick diode with n type bulk – unirradiated
2. 300 µm thick diode – irradiated to $3 \cdot 10^{13}$ p/cm$^2$
3. 300 µm thick diode – irradiated to $1 \cdot 10^{14}$ p/cm$^2$
4. 300 µm thick diode – irradiated to $3 \cdot 10^{14}$ p/cm$^2$
5. 300 µm thick diode – irradiated to $1 \cdot 10^{15}$ p/cm$^2$

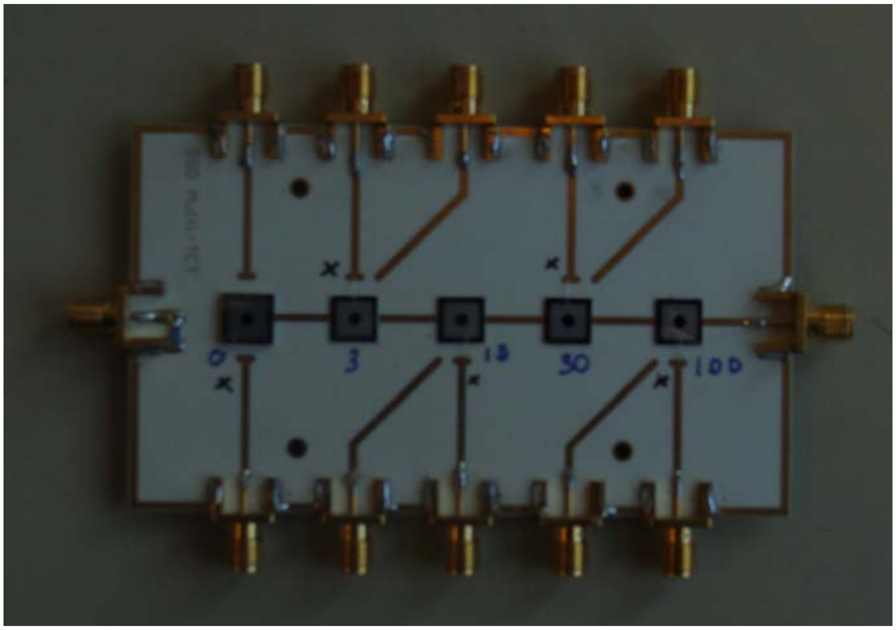

**Figure 4: TCT Board with diodes mounted**

Setting up the experiment:
1 – Connect scope channel 2 to the signal output of the Bias-Tee
2 – Connect the bias voltage supply (Keithley 2410) to the bias voltage input of the Bias-Tee
3 –Connect the signal+bias coupled output of the bias-tee to the junction-side of the detector you want to measure
4 – Connect a 50 Ω resistor to the back-metallisation of the detector to ground.

Switch on the front laser focuser – the coincidence with the trigger line has been already set up for you.

Now, position the laser spot on the unirradiated detector (position 0) and start ramping up the voltage in steps of 10 volts. Mark down the pulse maximum height at $V_{bias}$=10V.
Is it possible to figure out what the depletion voltage of the detector is? Also mark down the value for the drift time at V=200V. Try to estimate the drift velocity for this type of charge carriers (are they electrons or holes?)

Now repeat the same procedure switching this time the laser focuser on the back side of the detector. Try applying again the 10V and measure the pulse height. Can you explain the difference? Do you notice any difference in the drift time of the carriers with respect to the previous case?

For the unirradiated diode the charge trapping is negligible. Hence the pulse shape reflects well enough the electric field profile inside the detector. For irradiated detectors there are two effects coming into the play to affect the pulse generated in the TCT:

- Charge trapping comes into the play: lifetime decreases considerably, down to values in the ns-range at fluences of ˜$1 \bullet 10^{15}$ n/cm$^2$ thus decreasing the number of carriers as they drift in the bulk.
- Change in the effective doping concentration within the silicon bulk. In particular, in standard FZ silicon there is an increase in the number of acceptor-like defects, thus turning a n-type detector to an effective p-type detector. The change in the concentration of effective dopants in an n-type irradiated silicon can be to a first degree of approximation modelled as:

  $$\Delta N_{eff} = |g_c \cdot \phi - N_D|$$

  where ⍰ is the irradiation fluence expressed in neutrons equivalent, $g_c$ is a constant factor and $N_D$ the initial concentration of n-type dopants. Since the front and the back implant, due to their high doping concentration, are relatively unaffected by this change, type inversion only affects the bulk of the detector, resulting in the main junction that moves on the side with the n$^*$ implant (ohmic contact). Of course also the depletion voltage will change, since it's proportional to $N_{eff}$.

Now, continue measuring the irradiated devices, applying the same procedure. Observe the change in the pulse shape and in the depletion voltage. Is the depletion voltage increasing or decreasing with irradiation fluence? Keep comparing the pulse heights immediately after the initial rise of the pulse. How are they developing in function of the irradiation fluence?

## Infrared Edge-TCT

TCT is a powerful technique for field investigation in silicon detectors. However it only allows charge generation at two fixed points of the detectors, i.e. either front-side or back-side contact. Charge trapping results in the signal shape to be determined not only by the electric field encountered but, as well, from the charge trapping, that decreases the drifting charge accordingly to:

$$q(t) = q_0 \cdot \exp\left(-\frac{t}{\tau}\right)$$

where q(t) is the charge drifting at time t, $q_0$ is the initial amount of charge induced into the bulk by the laser and τ is a constant named °trapping constant° and accounts for the average carrier lifetime in the bulk. On highly irradiated silicon detectors, where the τ ends up to be of the same order of magnitude as the total drift time, the signal might be dumped to the extent of not allowing to see that, i.e. the field is higher on the opposite side with respect to the injection side. It would be ideal to be able to generate a charge in a given depth of the detector. This can be performed by using a highly focused infrared laser injected on a side of the detector (the infrared laser has a penetration depth in silicon of the order of some mm). Since an infrared laser cannot be physically collimated to dimensions in the order of ˜10 µm due to the relativily big wavelength, it is only possible to obtain a focused laser beam, within a Reyleigh length that can be, depending on the optics adopted, of some 100s µm. For this reason, a strip detector is used instead of pad detector, having an electrode width in the order of ˜20 µm. The approach is better described in Figure 5:

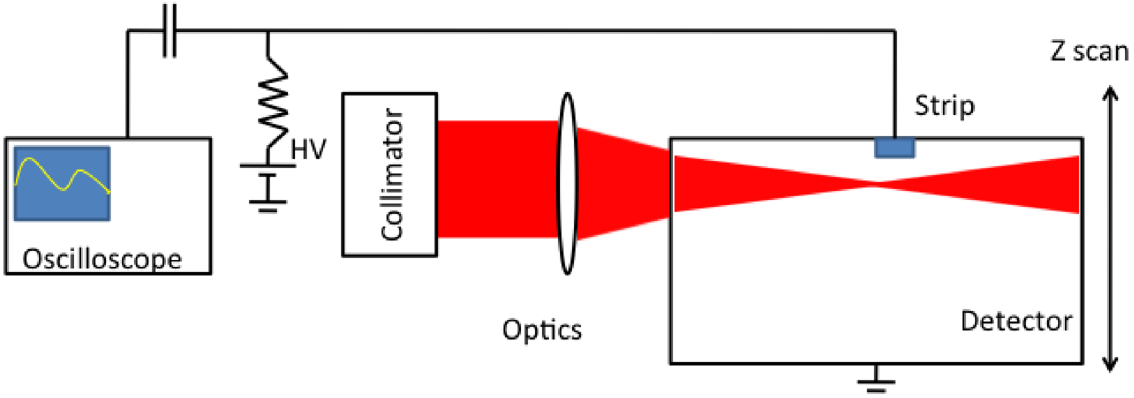

**Figure 5: Schematic view of the Edge-TCT setup**

You will be now given the opportunity to experience with the Edge-TCT setup. The system is normally controlled by a computer, but you will be given the change to manually displace vertically the detector with a very fine pitch. Observe the behaviour of the pulse as you change the vertical position of the laser. Can you explain change you obtain in the pulse shape? Moreover, try to repeat the measurement at different bias voltages. You will be able as well to see how the active region of the detector increases in depth.