A table-top Two Photon Absorption – TCT system: measurements of irradiated and non-irradiated silicon sensors

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Motivation: Two Photon Absorption-Transient Current Technique (TPA-TCT) is a tool to characterize unirradiated and irradiated silicon sensors with 3D resolution by generating charge at the focal point of a laser [1,2].

The fundamentals

Two Photon Absorption is based on the **simultaneous absorption of two photons** to excite a single electron into the conduction band. Compared to Single Photon Absorption, even photons with energies well below the band gap energy, can excite charge carriers.

TPA depends **quadratically on the intensity** of the light source, therefore strongly focused light excites the majority of charge carriers via TPA only in a small volume around the focal point.

Picture (modified) taken from: Ciceron Yanez, University Florida

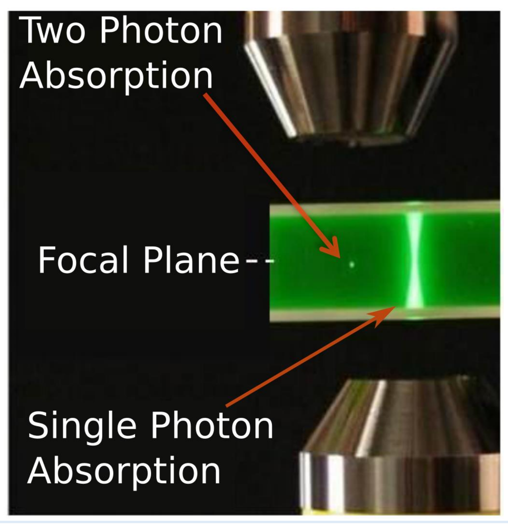

Figure 1: Comparison between TPA and SPA on a fluorescence specimen.

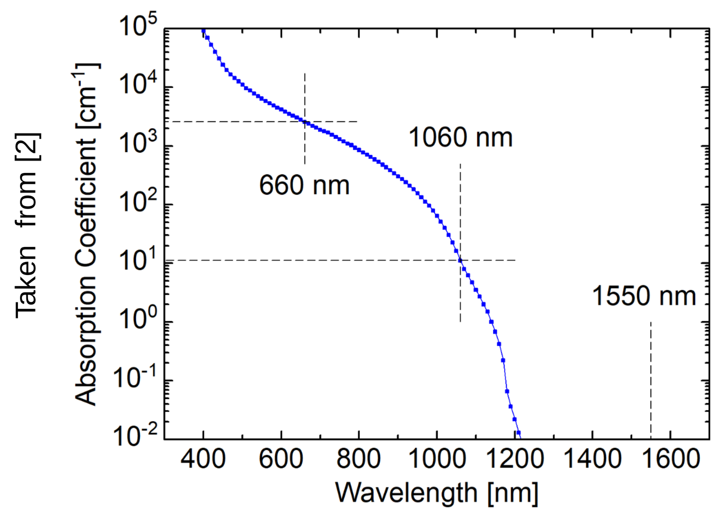

Figure 2: Absorption coefficient for different wavelength of silicon.

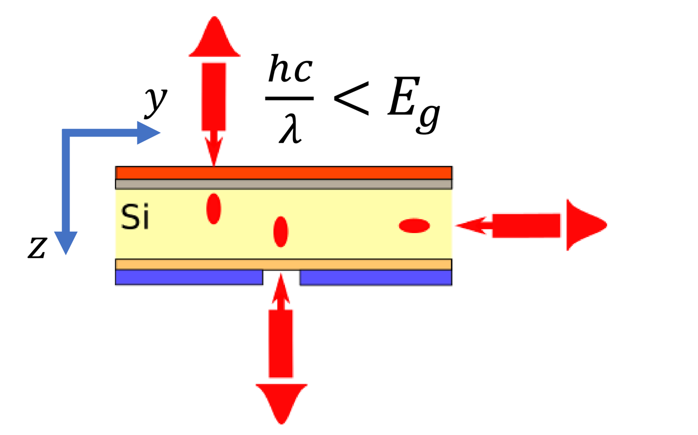

Figure 3: Schematic emphasising the available configurations for TPA-TCT (top, bottom, and edge).

Figure 1 shows TPA in a fluorescent sample. The top objective focuses light on the specimen and only at the focal point fluorescence is visible. The bottom objective in **Figure 1** demonstrates the absorption by SPA, where a position independent florescence along the beam is observed.

We use TPA-TCT to characterize silicon detectors, using a $1550\ \mathrm{nm}$ fs-pulsed laser [3]. The wavelength corresponds to an absorption coefficient where SPA is negligible, as shown in **Figure 2**. Spatial resolutions of approximately $\mathbf{1{\times}1{\times}20\mu m^3}$ are typical for TPA-TCT.
Like ordinary TCT, TPA-TCT is available in **top, back, or edge** illumination configuration, as emphasized by **Figure 3**.

The setup

The central piece of the setup is the laser source. The laser supplies a pulse length of $\boldsymbol{\Delta\tau \approx 430\ \mathrm{fs}}$ with a central wavelength of $\boldsymbol{\lambda = 1550\ \mathrm{nm}}$. The frequency can be varied from **single pulses up to 8 MHz** with pulse energies adjustable from **10 pJ to 10 nJ**.

The optical setup is shown in **Figure 4**. There are three different lines shown: one for the laser that illuminates the DUT and the reference sensor, one for an **infrared microscope**, and one for an alignment laser. The path of the laser is shown by the solid red line. The thick, transparent red line shows the IR microscope setup, and the dashed red line shows the path of the alignment laser.

The DUT is mounted on a copper chuck, which can be moved by a 6-axis Hexapod. The strongly focusing objective (NA 0.5 to 0.7) is right above the DUT. An additional silicon sensor (**Figure 4** top left corner) is used to monitor the laser energy.
The IR microscope consists of an IR lamp to illuminate the DUT, an IR camera, and optical components to guide the light.
The alignment laser is a simple laser diode in the visible red, which is used for the coarse alignment of the DUT.

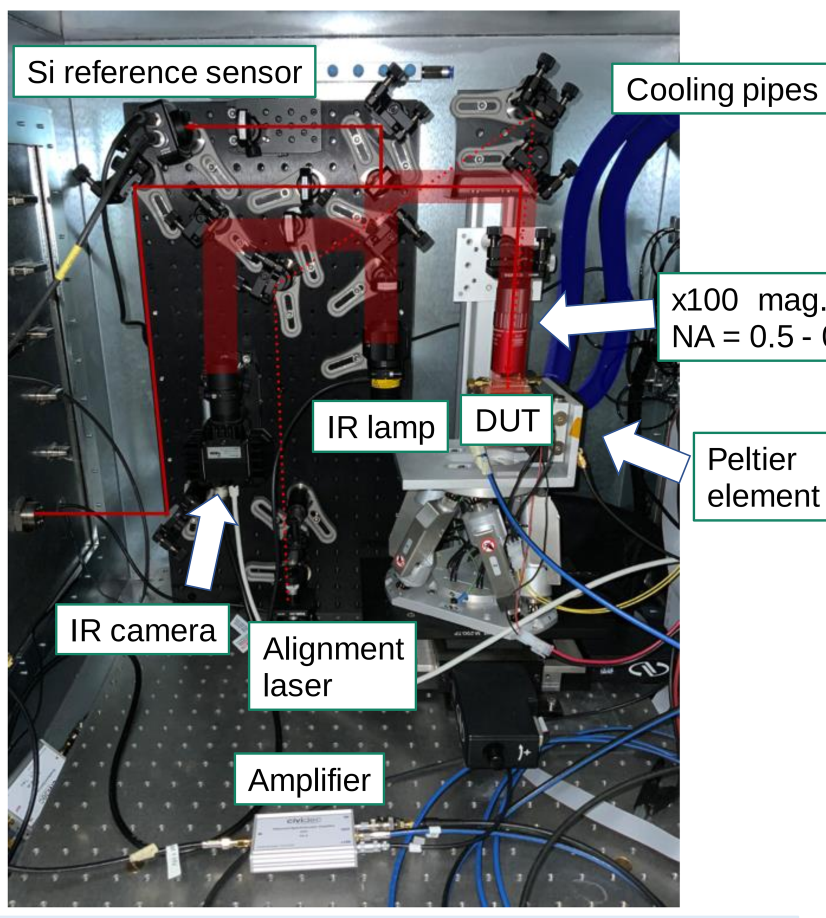

Figure 4: The optical setup inside a Faraday cage.

Unirradiated detectors

To obtain the charge profile in depth (z) of a DUT, the current transients for every z-step are integrated.
The charge profile, of an unirradiated physically $285\ \mu\mathrm{m}$ thick p-type PIN produced by CNM [3], is shown in **Figure 5**, as well as the Time-over-Threshold (ToT) below.

Two exemplary situations are marked, where the position of the focal point is schematically shown.
Marker 1 refers to the entering of the focal point inside the active volume and marker 2 refers to the exiting of the focal point and the arising of the beam reflection from the backside (interface Si/air).
Between marker 1 and 2 the focal point traverses the active volume, whereby the drift of electrons and holes can be distinguished.
At **marker 1** the **hole signal** dominates the ToT. Holes need to cross the whole sensor volume to reach the collection electrode at the backside. At **marker 2 electrons** dominate the ToT. Behind marker 2 the focal point is outside of the active volume, but the reflected beam at the Si/air interface is collected inside the detector.
The contribution of the reflection can be clearly seen in the ToT plot, because the **ToT-profile appears to be mirrored by this effect**. The reflection traverses the active volume in the opposite direction as the focal point.

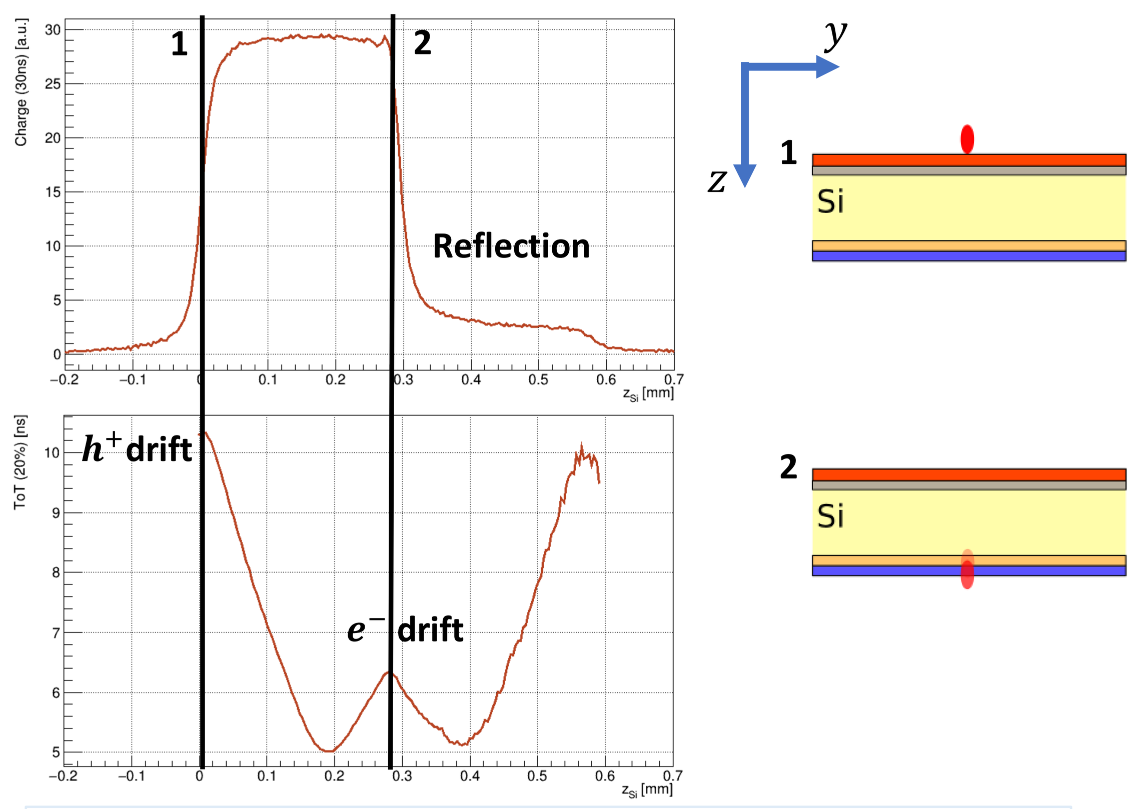

Figure 5: Collected charge and ToT of a PIN diode. The two markers refer to the right figures, where the corresponding position of the laser's focal point is shown.

Figure 6 to **Figure 8** show a measurement of the interpad region of an unirradiated 5x5 Multipad LGAD manufactured by HPK. The implantation scheme is shown in **Figure 6** and the result of a xz-scan of the interpad region as well as a microscope image of the scanned region are shown in **Figure 7**. A cut along x at the backside of the DUT for different bias voltages is shown in **Figure 8**. It can be seen that **TPA-TCT resolves** three different **implant regions**, which can be related to: the p-stop, the JTE, and the pad region.

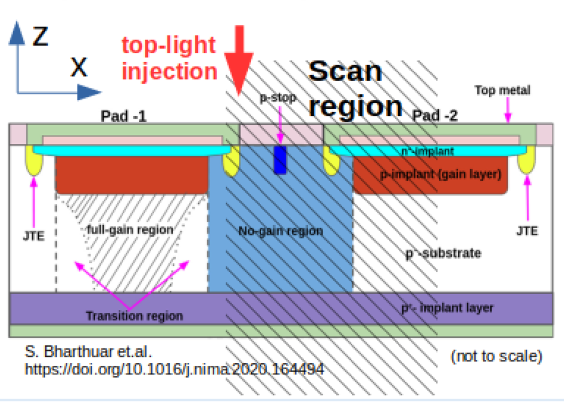

Figure 6: Schematic implantation of a HPK 5x5 Multipad LGAD.

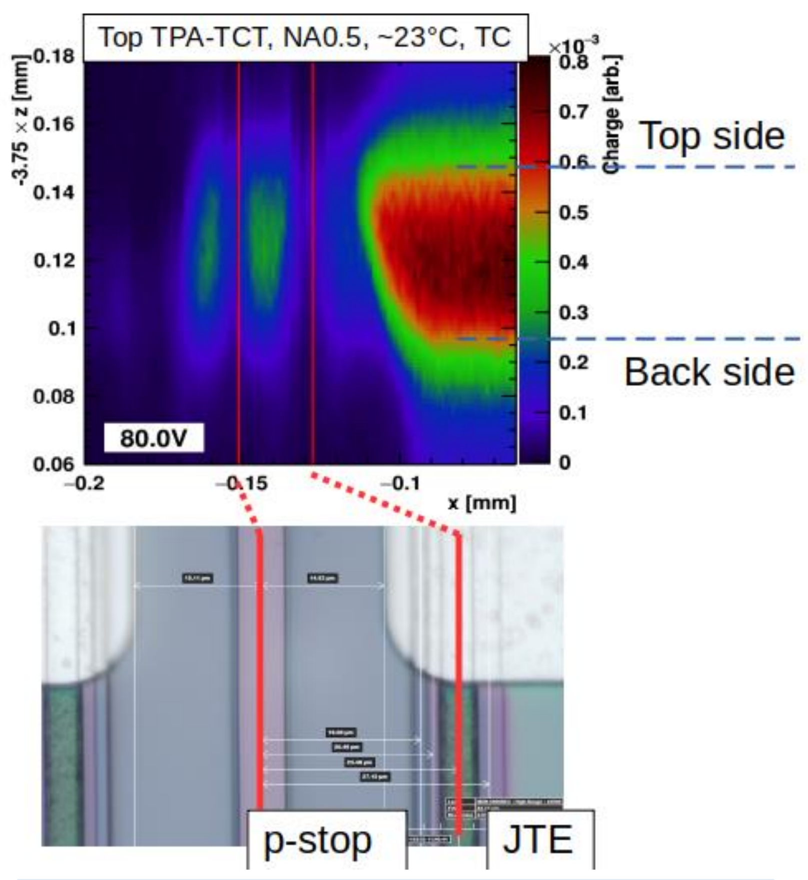

Figure 7: xz-scan of the region shown in Figure 6 of a HPK 5x5 Multipad LGAD.
A microscope picture of the interpad region is shown below the measurement data.

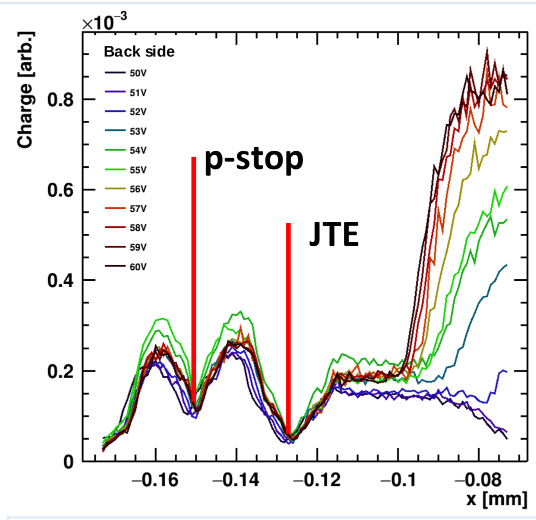

Figure 8: Collected charge of a cut along x of Figure 7 for different bias voltages.

Irradiated detectors

Radiation damage in silicon leads to additional energy levels inside the band gap. The intermediate levels trap carriers and make them available for **SPA**. SPA only depends on the intensity and not on the position of the focal point and therefore, appears as a **constant background** in a z-scan. The effect is well understood and methods to correct for it were established [2].
An exemplary uncorrected measurement of a $120\ \mu\mathrm{m}$ thick n-type float zone PIN with a deep diffused wafer produced by HPK is shown in **Figure 9**.The constant background due to SPA is clearly visible. The drift velocity of the charge carriers inside the PIN is extracted from the current transients using the prompt method [5]. The drift velocity is directly proportional to the electric field. The electric field inside the irradiated detectors differs strongly from the one of unirradiated PINs. The **highest electric field is found at the backside** due to space charge sign inversion [6].

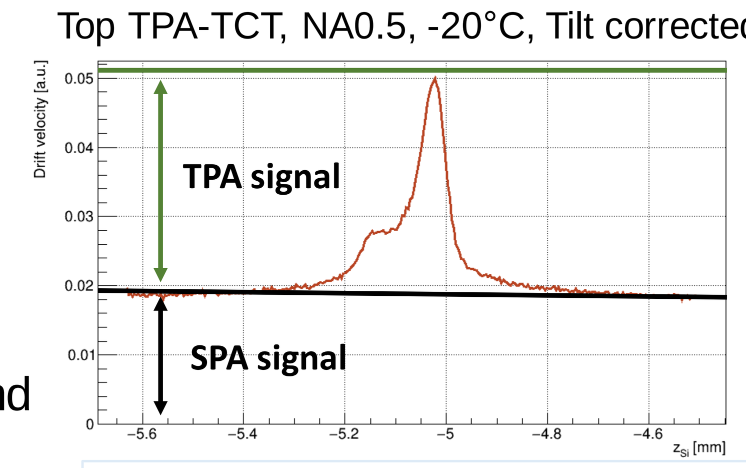

Figure 9: Measurement of an irradiated PIN diode.

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Sebastian Pape (technische universität dortmund), Marcos Fernández, Iván Vila (IFCA Instituto de Física de Cantabria), Raúl Montero (UPV EHU), Michael Moll (CERN), Moritz Wiehe (Uni Freiburg), Rogelio Palomo (Universidad de Sevilla)

Author's E-Mail: sebastian.pape@cern.ch

[1] M. Fernandez Garcia et al.: High resolution 3D characterization of silicon detectors using a Two Photon Absorption Transient Current Technique
[2] M. Wiehe et al.: Development of a Tabletop Setup for the Transient Current Technique using Two Photon Absorption in Silicon Particle Detectors
[3] FYLA: https://www.fyla.com
[3] CNM: http://opter6.cnm.es/index.php/en
[4] HPK: https://www.hamamatsu.com
[5] G. Kramberger: Advanced Transient Current Technique Systems
[6] M. Moll: Displacement Damage in Silicon Detectors for High Energy Physics

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