3D laser characterization of Silicon detectors using Two Photon Absorption Transient Current Techniques

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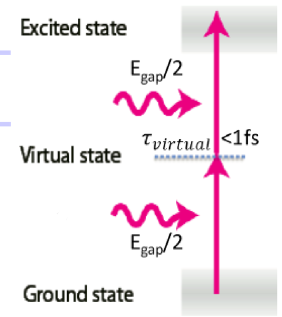
The problem: spatial resolution of laser tracks

In **Transient Current Techniques**, silicon detectors are characterized injecting charge carriers produced by short **pulsed lasers** (normally working in the visible to infrared). In this wavelength range, one absorbed photon produces one electron hole pair. The **wavelength** of the laser determines the **length** of the light track in Si and the **focusing optics** the **spot size** and the **divergence** of the beam.

Visible laser tracks can be focused to small spots (≤ 1 μm) but penetrate only few μm inside Si (very good spatial resolution at the surface), while infrared lasers can be collimated to ~5 μm over several mm (no spatial resolution along the beam).

We propose a **new technique [1,2]** that yields small spot size over short length **at any depth inside the detector**.

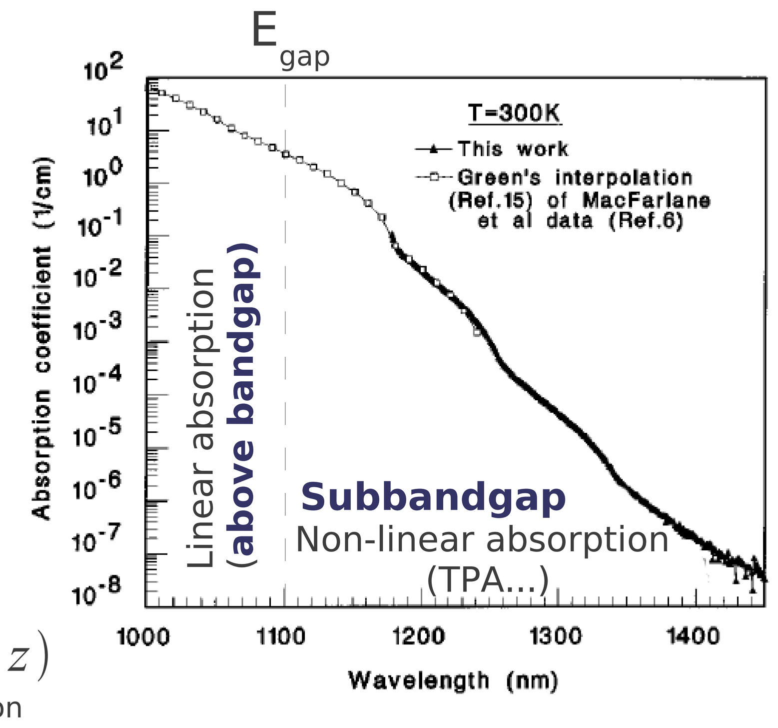
This technique is based on the **simultaneous** absorption of **two photons**.

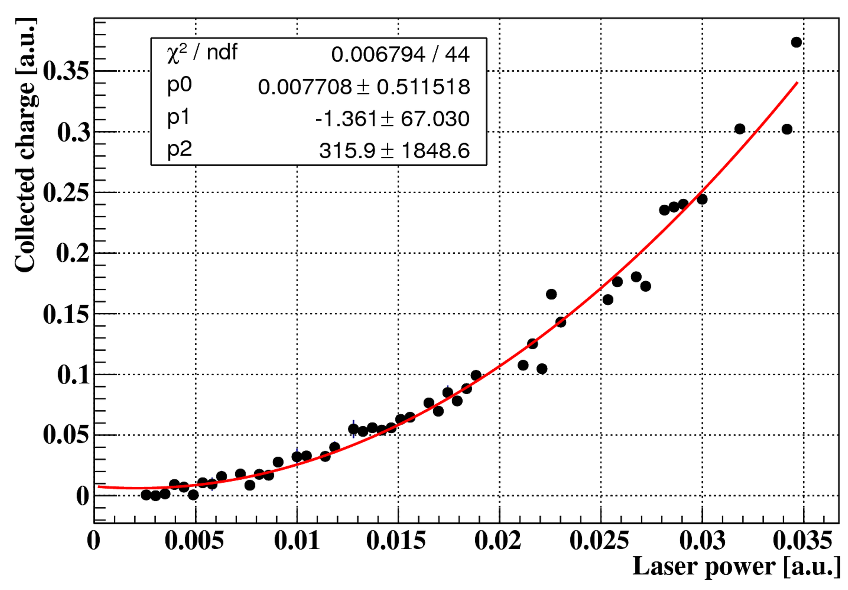


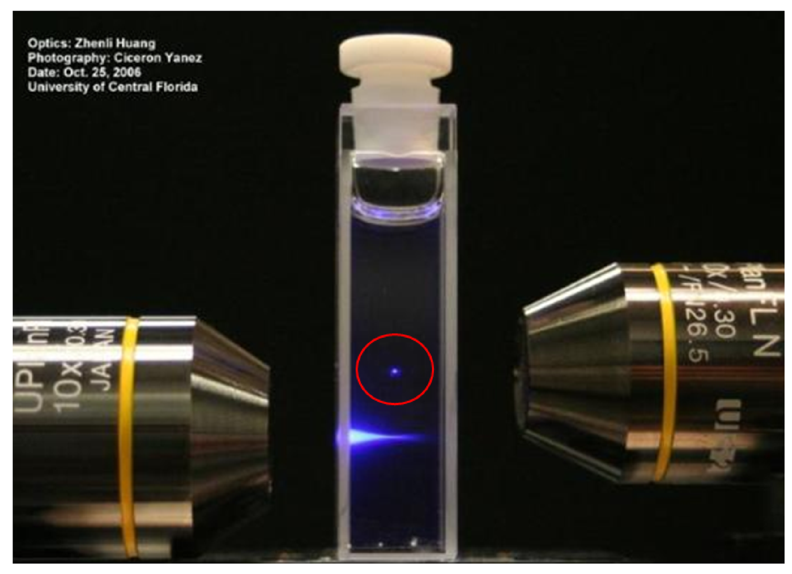
Two Photon Absorption (TPA)

The absorption spectrum of silicon shown in the (left figure), illustrates the **very low absorption** in the **subbandgap region**. At sufficiently high intensities, however, the material can absorb two photons simultaneously to generate a single electron–hole pair. Because the material is "transparent" to the incident irradiation in the linear regime, the Beer's law exponential attenuation due to such absorption is absent.

$$\frac{dI(r,z)}{dz} = \underbrace{-\alpha I(r,z)}_{\text{Beer's law}} \underbrace{-\beta_2 I^2(r,z)}_{\text{TPA}} \underbrace{-\sigma_{ex} N(r,z) I(r,z)}_{\text{Free carrier absorption}}$$







Carrier **generation** in the two-photon process is proportional to the **square** of the laser pulse **intensity** (shown in the center figure for one of our measurements). Significant **carrier generation** therefore occurs only in the high intensity **focal region** of the focused laser beam. Both facts enable charge injection at any depth in the structure, permitting 3D mapping of the sensitivity of a device (see experimental illustration via fluorescence on a solution). To obtain high intensity, very short laser pulses (~fs) are used.

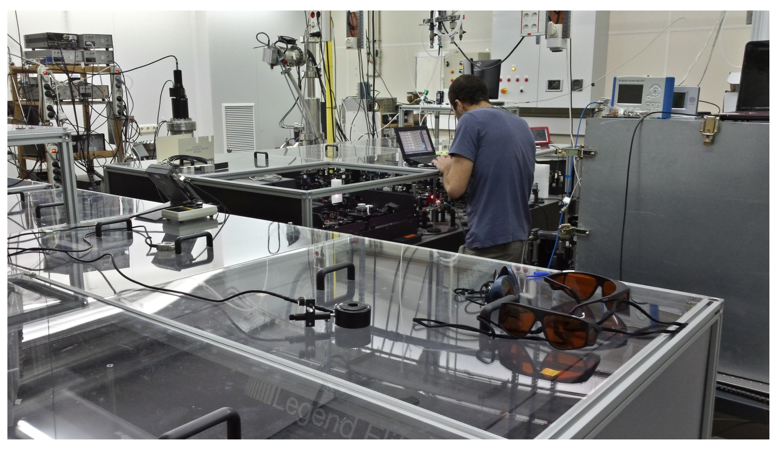
TPA characterization of HVCMOS

HVCMOS are partially depleted silicon sensors produced in commercial CMOS processes. Deep N-wells (DNW) in a moderately p-doped bulk (10 Ω·cm) are used to insulate the built-in electronics (preamp, discriminators...) from high voltages (≤100 V). The expected depletion depth is below 10 μm at 100 V. These detectors have been chosen to study the resolving power of the TPA technique.

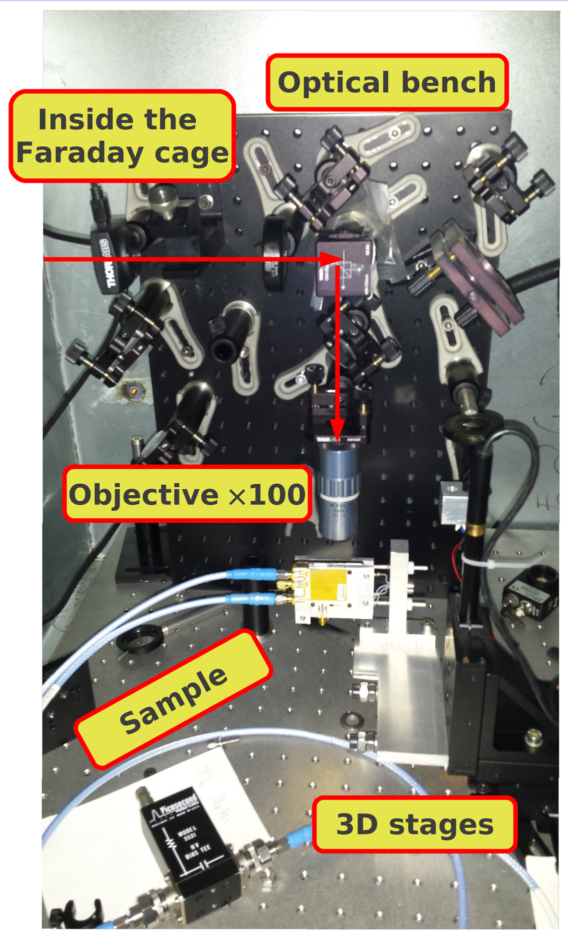
The diode formed by the DNW and p-bulk was measured using a **femtosecond** laser **XYZ scan**, operating in TPA mode. **Illumination was done from the edge of the detector.** Time resolved Transient Currents were recorded using an oscilloscope. The leftmost figure below shows the map of collected charge (in 10 ns). The apparent **depletion depth** of the detector (FWHM$_y$ of charge map) is ~ 25 μm. The collection time(lapse until 98% of total charge is integrated), center figure **spatially resolves** the implant, depleted region and undepleted bulk. This is the first time implants can be resolved using Transient Current Techniques.

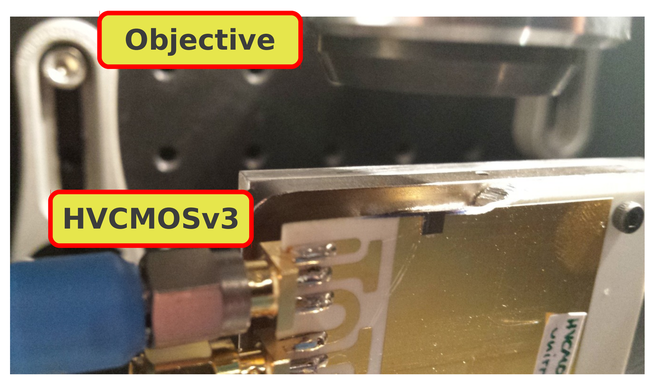
TPA facility

Measurements conducted at the Singular Laser Facility of the UPV (Bilbao, Spain).

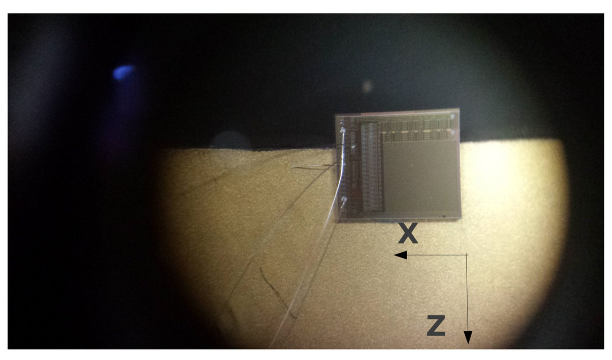


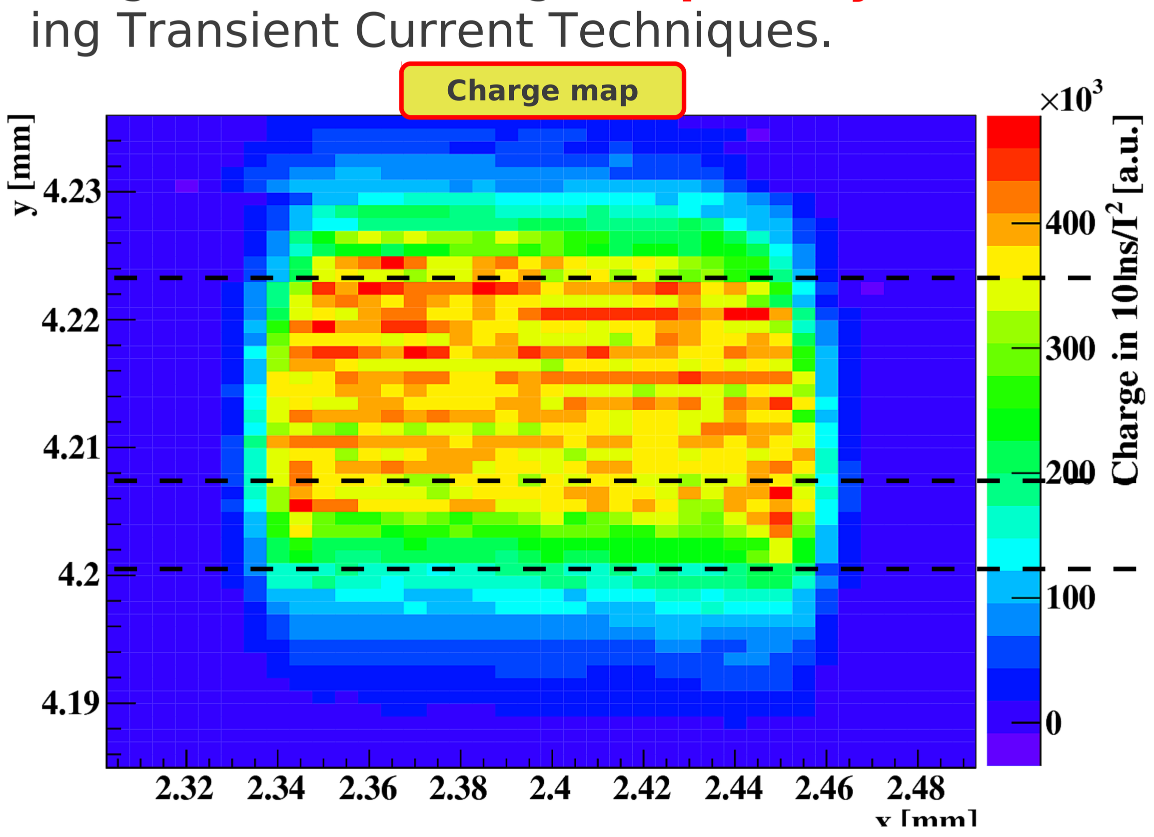
λ=1300 nm, Δt=240 fs

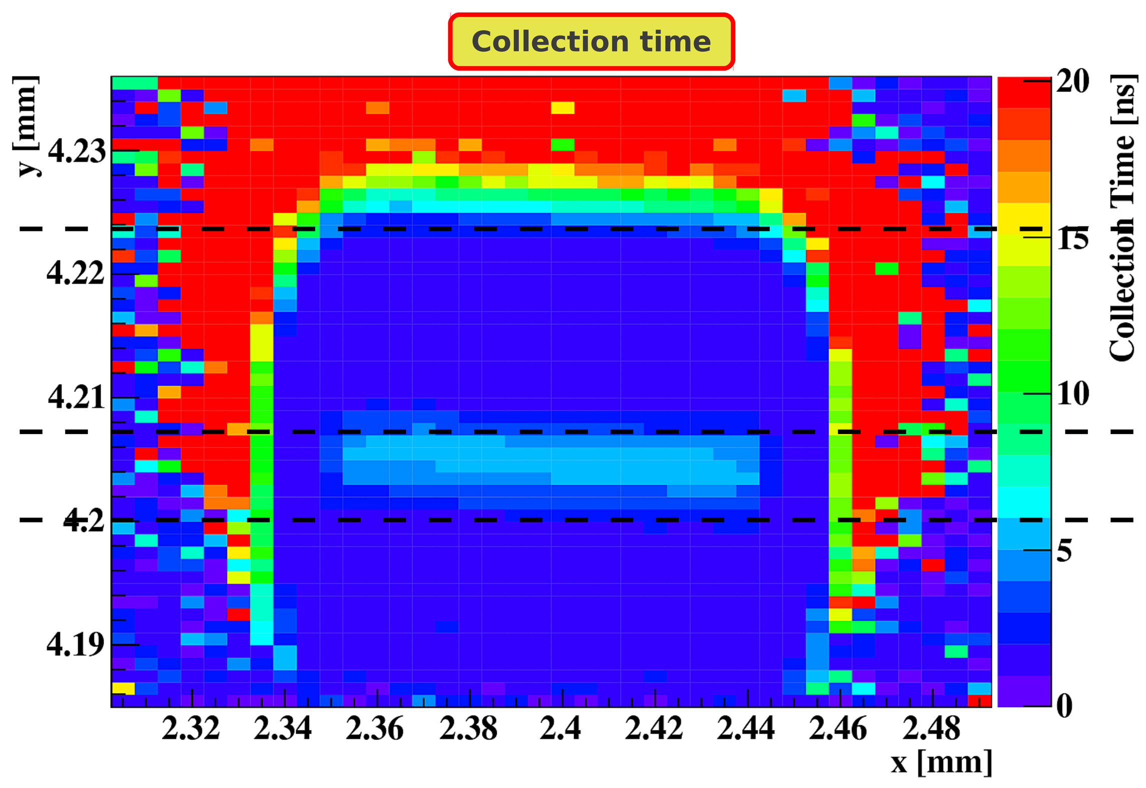




http://www.ehu.es/SGIker/es/laser/







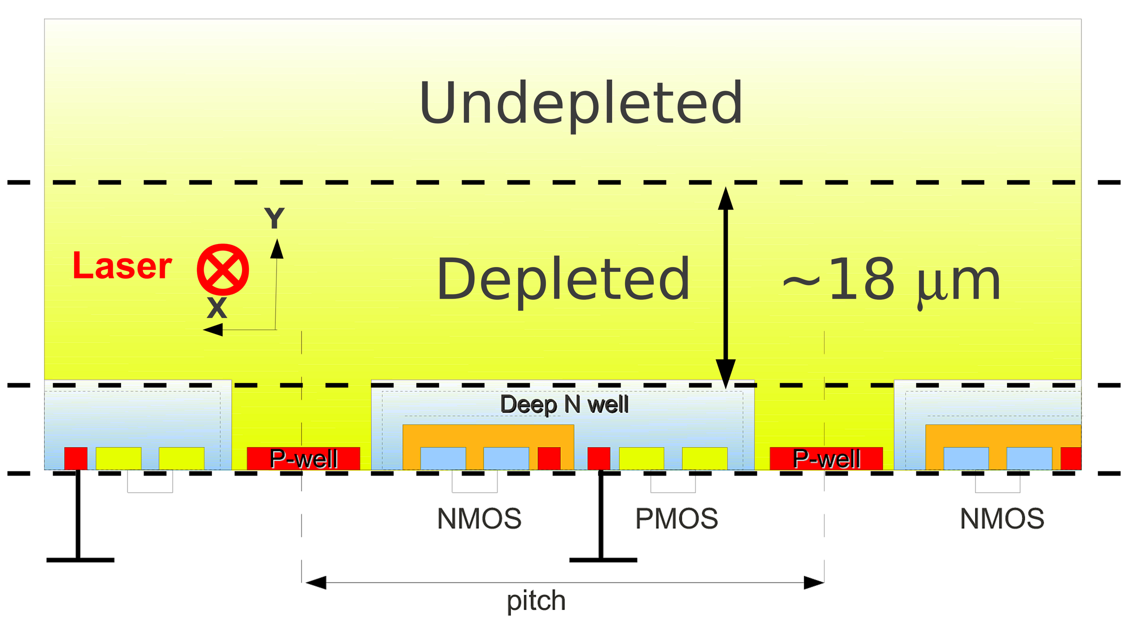
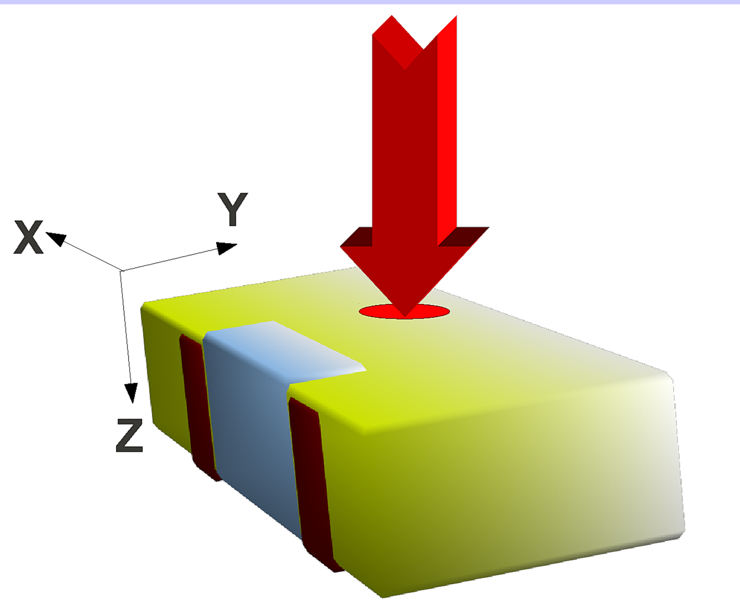


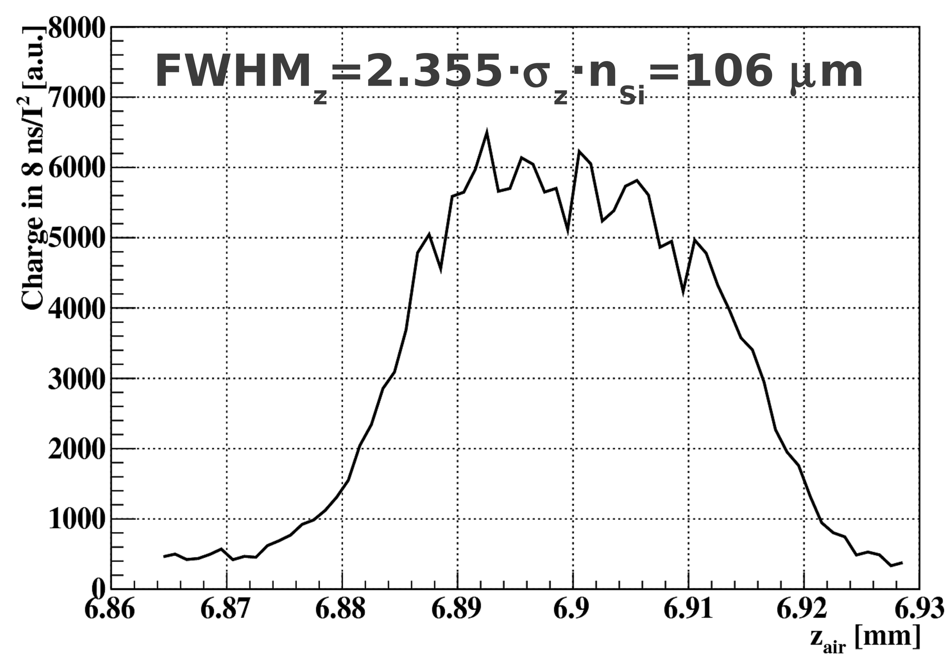
Figure: 2D XY maps. Left: charge map. Center: collection time (center) and detector sketch. All shown in a plane XY

Resolving structures along the beam

The dimension of the implant and the depletion zone along the 3rd **coordinate (Z)** can be calculated scanning the beam along the Z direction. When the focus intercepts the depleted region, carriers produced by TPA nearby this point will be collected. Far from the focus TPA absorption will cease because of lower intensity.



Edge incidence on the bulk of the detector



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[1] R. Palomo, Two Photon Absorption and carrier generation in semiconductors, 25th RD50 workshop (CERN)
[2] I. Vila, TPA-TCT: A novel Transient Current Technique based on the Two Photon Absorption (TPA) process