Status Report: Multi-Channel TCT

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2. Set-up and measurement techniques
3. Measurements on pad diodes
4. Conclusion and next steps
Introduction

Aim and main goal:

- Determination of pulse shape of individual pixels with XFEL type irradiation.
- Agreement of experimental reference data and simulations

Relevant XFEL-specification: Photon fluxes of $10^0 - 10^5 \gamma$/pixel/pulse (12 keV)

Properties of the charge cloud are not well understood for more deposited energy than mips (~25000 e,h Pairs). Possible effects include:

- **Plasma effects**: Distortion of pulses.
- **Charge Cloud expansion**: Charge sharing in neighboring pixels due to diffusion and electrostatic repulsion.
- **Recombination losses**: Signal loss due to electron-hole recombination (can most probably be neglected).

A Multi-Channel TCT setup records pulse shapes and therefore allows to study these effects in a structured device (strip or pixel detector) -> experimental reference data
**Set-up and measurement techniques**

TCT (Transient Current Technique) records the time-resolved current of the device under test.

⇒ **Pulse shape**

measured from:
- Distortion of pulse shape
- Charge sharing of pixels (pulse on adjacent pixels)
- Pulse height or integrated charge

property:
- Plasma effect
- Charge cloud expansion
- Recombination losses

![Image of a multi-channel TCT setup with labels for electronics, optics, linear tables, high intensity sub-ns laser, pad diode under test]
Multi-Channel TCT Setup for Charge Cloud Studies

Current set-up (standard TCT)

- Laser
- Laser Controller
- HV Supply
- 2.5 GHz Oscilloscope
- Bias-T: 18 GHz 45 ps
- Attenuator: 4 GHz 85 ps
- Oscilloscope: 2.5 GHz 115 ps
- Amplifier*: 1.8 GHz 180 ps

2.5m cable

Element Bandwidth Risetime
Bias-T: 18 GHz 45 ps
Attenuator: 4 GHz 85 ps
Oscilloscope: 2.5 GHz 115 ps
Amplifier*: 1.8 GHz 180 ps

Pulse shape is electronically smeared!

* only necessary with low intensity injection
Example of a recorded waveform

**Transient for 660 nm injection at -100 V**

- **Signal risetime limited by system risetime**
- **750 MHz noise coupling to the system**
- **End of charge carrier drift indicated by the change of slope**
- **“Slow” discharge of detector capacitance**
- **Small reflection due to impedance mismatch at bias-t**
- **Reflection due to impedance mismatch at amplifier**
- **Positive current drawn**
- **2x cable length**
- **Negative current drawn**

**Notes:**
- $N_e(x) = 2.23e+100$, FWHM = 361 nm, PD = 4.53e+012 [cm$^2$]
- Time [ns]: 0 - 60
Key features of the setup

- Red and IR lasers with short pulses (~100 ps)*
- range of injection from $0.5 - 30 \times 10^6$ e,h pairs (red laser) $\Rightarrow 150 - 9000$ 12 keV-$\gamma$ (absorbed)
- minimum spotsize of $\sim 75 \, \mu m$ (FWHM) at maximum intensity (down to $11 \, \mu m$ FWHM at reduced intensity)
- position steps with 0.1 $\mu m$ repeatability
- mounts for (standard) 10x10 mm$^2$ and 5x5 mm$^2$ diodes

Available in the near future:
- space for device of 13x26 mm$^2$
- 4 readout channels (expandable), 32 channels total
- backside injection (hole signal with 660 nm laser)
- temperature control (30°C to -10°C)

* Red laser $\lambda=660nm$ $\Rightarrow 3\mu m$ absorption length
IR laser $\lambda=1052nm$ $\Rightarrow 900\mu m$ absorption length
Beam characteristics

Determination of FWHM by fitting \( \text{erf}(x) \) to photocurrent (assumes gaussian beam spot) but beam profile shows a non gaussian beam spot!
Laser system (red)

- Minimum energy:
  - $\approx 22 \text{ pJ/pulse}$
  - $\approx 70 \text{ ps pulse width}$

- Maximum energy:
  - $\approx 140 \text{ pJ/pulse}$
  - $\approx 800 \text{ ps pulse width}$
Measurements on pad diodes

- medium ($2 \times 10^6$ e,h $\Rightarrow$ 600 absorbed 12 keV $\gamma$) and high ($3 \times 10^7$ e,h $\Rightarrow$ 9000 absorbed 12 keV $\gamma$) electron injection with 660nm laser
- Pulse distortion clearly visible

 transient for 660 nm injection at -50 V

CG1233 FZ-n-Si 280 $\mu$m, $N_{\text{eff}} = 8 \times 10^{11}$ cm$^{-3}$, $U_{\text{dep}} = 48.5$ V, $C_{\text{dep}} = 9.5$ pF, $\rho = 5.3$ k$\Omega$cm
Measurments on pad diodes
Transient for 660 nm injection at -100 V

Plasma effects strongly dependent on local charge carrier density and bias voltage

Peak e,h density assuming gaussian beam shape \(10^{13}\text{--}10^{15}\)

\[
\begin{align*}
\text{CG1233 FZ-n-Si} & \\
d & = 280 \, \mu\text{m} & \\
N_{\text{eff}} & = 8 \times 10^{11} \, \text{cm}^{-3} & \\
U_{\text{dep}} & = 48.5 \, \text{V} & \\
C_{\text{dep}} & = 9.5 \, \text{pF} & \\
\rho & = 5.3 \, \text{k}\Omega\text{cm}
\end{align*}
\]

Measurements on pad diodes:
High (3 \times 10^7 e,h \Rightarrow 9000 absorbed 12 keV \gamma) electron injection
Measurements on pad diodes

Transient for 660 nm injection at -400 V

CG1233 FZ-n-Si
- \(d = 280 \, \mu m\)
- \(N_{\text{eff}} = 8 \times 10^{11} \, \text{cm}^{-3}\)
- \(U_{\text{dep}} = 48.5 \, \text{V}\)
- \(C_{\text{dep}} = 9.5 \, \text{pF}\)
- \(\rho = 5.3 \, \text{k} \Omega \text{cm}\)

high bias voltage (here 8.3x \(U_{\text{dep}}\)) suppresses pulse elongation

high \((3 \times 10^7 \, e/h \Rightarrow 9000 \, \text{absorbed 12 keV } \gamma)\) electron injection
Multi-Channel TCT Setup for Charge Cloud Studies

Measurements on pad diodes

- Number of charge carriers injected
  - 2.42x10^6 e,h pairs
  - 2.85x10^7 e,h pairs

Injection ratio: 8.5% ≈ 9% optical attenuation

=> no evidence for recombination losses

Beam profile (derivative of photocurrent)

FWHM determined from photocurrent

Common artifact due to range switching during measurement

Z = 600 μm, FWHM = 349 μm
Z = 1200 μm, FWHM = 272 μm
Z = 1800 μm, FWHM = 198 μm
Z = 2400 μm, FWHM = 122 μm
Z = 3000 μm, FWHM = 74 μm
Available parameter space

- wavelength of laser (660nm, 1052 nm)
- bias voltage (up to 1000 V)
- laser intensity (0.5 – 30 x10^6 e,h pairs*)
- spotsize of injection (75 µm FWHM minimum at maximum intensity, smaller ~10 µm at lower injection)

soon also:

- position sensitive scan on structured device
- temperature (-10°C – 30°C and up)

*10,000 e,h pairs ≥ 3 γ (12 keV)
Conclusion and next steps

• TCT setup running for pad diodes (multi-TCT in preparation)
• agreement on device to be studied
  -> Strip detectors are available (80 μm pitch) and easier from experimental side.
• agreement on measurement parameters (voltage, charge injection, beam profile)
• measurement campaign with agreed parameters
• comparison to simulations of device with agreed parameters
Backup
M-TCT ceramics

- 13x26 mm$^2$ space for d.u.t
- 32 Pads -> individual channels
- 2x 16 landing zones for wire bonds
- Separate pads for ground contact
- Separate pads for HV contact
- 90° rotation symmetry
- Flip symmetry (vias at pads) and central hole for backside injection
Measurements on pad diodes

- medium \((2 \times 10^6 \, \text{e,h} \Rightarrow 600 \, \text{absorbed 12 keV } \gamma)\) and high \((3 \times 10^7 \, \text{e,h} \Rightarrow 9000 \, \text{absorbed 12 keV } \gamma)\) electron injection with 660nm laser
- Pulse distortion clearly visible

Transient for 660 nm injection at -100 V

\[
\begin{align*}
\text{CG1233 FZ-n-Si 280 } \mu\text{m, } N_{\text{eff}} &= 8 \times 10^{11} \, \text{cm}^{-3}, \ U_{\text{dep}} &= 48.5 \, \text{V, } C_{\text{dep}} = 9.5 \, \text{pF, } \rho &= 5.3 \, \text{k}\Omega\text{cm}
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Measurements on pad diodes

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CG1233 FZ-n-Si 280 $\mu$m, $N_{\text{eff}}$ = $8 \times 10^{11}$ cm$^{-3}$, $U_{\text{dep}}$ = 48.5 V, $C_{\text{dep}}$ = 9.5 pF, $\rho$ = 5.3 k$\Omega$cm
Laser system (IR)

minimum energy:
≈ 44 pJ/pulse
≈ 70 ps pulse width

maximum energy:
≈ 275 pJ/pulse
≈ 700 ps pulse width
**Goal:** Experimental verification of charge collection in silicon at large charge carrier densities: Can use heavy ions instead of high intensity γ's: Large dE/dx due to Z²-dependence in Bethe-Bloch Formula.

Ongoing analysis of data from test beam at GSI by UHH students.

Some preliminary results (for Neon: Z=10):

*S-side:*
- r/o pitch 110 µm

Next steps:
- Understand proton-signal (also present).
- Analysis of data taken with other ions to investigate Z-dependence: B (Z=5), C (Z=6), Mg (Z=12), P (Z=15) and Ar (Z=18).