Status Report: Charge Cloud Explosion

J. Becker, D. Eckstein, R. Klanner, G. Steinbrück
University of Hamburg
Detector laboratory

1. Introduction and Motivation
2. Set-up available for measurement
3. Measurements on pad diodes
4. Comparison to Simulations
5. Measurements on strip detectors
6. 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 (WIAS)

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

recent upgrade featuring the following improvements:

• Smaller spotsize due to improved optics
• Defined set-up allowing to investigate structured devices
• Improved electronics with multi GHz bandwidth
Multi-Channel TCT Setup for Charge Cloud Studies

Multi TCT setup

- Laser
- HV Supply
- 2.5 GHz Oscilloscope
- Laser Controller
- 2m cable
- structured device (strip detector)
- Amp
- Attenuator
- Amp
- Attenuator
- signal lines 2.5m each to delay reflections
- Amp
- trigger line
- structured device (strip detector)
Some words on electronics

**Element** | **Bandwidth**
--- | ---
Attenuator: | DC - 4 GHz
Oscilloscope: | DC - 2.5 GHz
Amplifier*: | 10 kHz - 1.0 GHz
2.5 m Cable | ??
Stray C’s | ??

Pulse shape is electronically smeared!

=> SPICE Model

* only necessary with low intensity injection
Multi-Channel TCT Setup for Charge Cloud Studies

Beam characteristics

660 nm laser, derivative of photocurrent [μA/μm], 15mm iris, $N_{e,h} = 14.8 \times 10^6$

- $Z=75$ μm, $\sigma=14.9$ μm
- $Z=150$ μm, $\sigma=10.2$ μm
- $Z=275$ μm, $\sigma=4.7$ μm
- $Z=425$ μm, $\sigma=1.9$ μm

Minimum spotsize

- Higher density possible at larger spotsize

Beam profile colored lines -> measurement black lines -> gaussian fit

Minimum Spotsize vs. Iris Size

Number of electron hole pairs vs. Iris Size

Maximum electron hole density vs. Iris Size

WIAS Meeting 6.2.2009 Julian Becker Uni-Hamburg
System calibration

**Calibration:** injecting a step function (V) over a known capacitance (C) into the system

\[ C \times V = \int U_{osc}(t) / R_{osc} \, dt \]

\[ K = \frac{Q_{meas}}{Q_{inj}} \]

\[ K_{avg} = 0.984 \]
Measurements on pad diodes

CG1234 FZ-n-Si 280 μm, $N_{\text{eff}} = 7.8 \times 10^{11} \text{ cm}^{-3}$, $U_{\text{dep}} = 45 \text{ V}$, $C_{\text{dep}} = 11 \text{ pF}$, $\rho = 5 \text{ k}\Omega\text{cm}$

SIDE VIEW
- no to scale

TOP VIEW
- no to scale
Multi-Channel TCT Setup for Charge Cloud Studies

Measurements on pad diodes

injection from frontside $0.116 - 16.5 \times 10^6$ e,h Pairs, scaled to same integral

Transient for 660 nm injection at 100 V

2x $U_{dep}$

Transient for 660 nm injection at 500 V

10x $U_{dep}$

pulse distortion clearly visible

pulse distortion mostly suppressed
Comparison to Sim. from WIAS

Laser timing structure not taken into account
Hints of slight deviation in effective doping
Comparison to Sim. from WIAS

Laser timing structure taken into account
“Speed” of transients does not agree
=> Mobility wrong?
Comparison to simple Sim. (HH)

frontside (electron) injection

Laser timing structure taken into account
exponential injection decrease taken into account
non focused laser beam
no carrier interactions taken into account
no diffusion taken into account
Comparison to simple Sim. (HH)

backside (hole) injection

Laser timing structure taken into account
exponential injection decrease taken into account
non focused laser beam
no carrier interactions taken into account
no diffusion taken into account
Mobility in simple Sim. (HH)

\[ \mu = \frac{\mu_0^*}{(1 + \left(\frac{\mu_0^* E}{v_{sat}}\right)^\beta)^{\frac{1}{\beta}}} \]  \quad \text{Jacoboni}

\[ \mu_0^* = \mu_{\text{min}} + \frac{\mu_0 - \mu_{\text{min}}}{1 + \left(\frac{N_{\text{eff}}}{C_{\text{ref}}}\right)^\alpha} \]  \quad \text{Selberherr}

for holes \( \mu_0^* \) was multiplied by 1.075 to produce transients of the right time

electric field was assumed linear and independent of charge carriers

\[ \alpha = 0.72 \left(\frac{T}{300K}\right)^{0.065} \]

\[ C_{\text{ref},e} = 1.12 \times 10^{17} \left(\frac{T}{300K}\right)^{3.2} \]

\[ C_{\text{ref},h} = 2.23 \times 10^{17} \left(\frac{T}{300K}\right)^{3.2} \]

\[ \mu_{0,e} = 1430 \frac{\text{cm}^2}{\text{Vs}} \left(\frac{T}{300K}\right)^{-2.0} \]

\[ \mu_{0,h} = 460 \frac{\text{cm}^2}{\text{Vs}} \left(\frac{T}{300K}\right)^{-2.18} \]

\[ \mu_{\text{min},e} = 80 \frac{\text{cm}^2}{\text{Vs}} \left(\frac{T}{300K}\right)^{-0.45} \]

\[ \mu_{\text{min},h} = 45 \frac{\text{cm}^2}{\text{Vs}} \left(\frac{T}{300K}\right)^{-0.45} \]

\[ v_{\text{sat},e} = 1.45 \times 10^7 \sqrt{\tanh\left(\frac{155K}{T}\right)} \]

\[ v_{\text{sat},h} = 9.05 \times 10^6 \sqrt{\tanh\left(\frac{312K}{T}\right)} \]

\[ \beta_e = 2.57 \times 10^{-2} \left(\frac{T}{1K}\right)^{0.66} \]

\[ \beta_h = 0.46 \left(\frac{T}{1K}\right)^{0.17} \]
Measurements on Strip detectors

CG1017 Strip detector
same Wafer as CG1233
FZ n-type Silicon
Thickness 280 µm
$U_{\text{dep}} \sim 50$ V
$N_{\text{eff}} \sim 8 \times 10^{11}$ cm$^{-3}$
$\rho \sim 5$ kΩ cm
Pitch 80 µm
Width 20 µm
Position sensitive measurements

position scan with spotsize sigma ~2 µm

injection of 660 nm light from backside (holes)

hole drift is slower than electron drift -> more time for expansion
Position sensitive transients

central hit on readout

neighbor strip

bipolar pulse non-zero integral
Multi-Channel TCT Setup for Charge Cloud Studies

Charge cloud profile

• Fitting done with assumption of gaussian charge carrier distribution and box integration along strip pitch

• Expected sigma for pure diffusion in the range of 5-10 µm

\[ C(x) = c_0 + N_0 \int_{x-rac{p}{2}}^{x+rac{p}{2}} \exp\left(-\frac{(y-\mu)^2}{2\sigma^2}\right)dy \]

\( C(x) \) collected charge
\( x \) position of injection
\( c_0 \) contribution of noise
\( N_0 \) total number of injected carriers
\( p \) strip pitch
\( \mu \) position of strip center
\( \sigma \) spread of charge carrier distribution
Position sensitive transients

- Central hit on readout
- Neighbor strip
- Bipolar pulse non-zero integral

0.18 MeV
Multi-Channel TCT Setup for Charge Cloud Studies

Charge cloud profile

- Fitting done with assumption of gaussian charge carrier distribution and box integration along strip pitch
- Assumption of gaussian distribution not valid below ~350 V

\[ C(x) = c_0 + N_0 \int_{x-p/2}^{x+p/2} \exp\left(-\frac{(y-\mu)^2}{2\sigma^2}\right) dy \]

- \( C(x) \): collected charge
- \( x \): position of injection
- \( c_0 \): contribution of noise
- \( p \): strip pitch
- \( \mu \): position of strip center
- \( \sigma \): spread of charge carrier distribution
- \( N_0 \): total number of injected carriers
Effects at different intensities

significant increase in charge spread already for low intensities
Next steps

- improvement of setup
  (eliminate stray C’s, reduce noise)
- investigations with new 1015 nm laser
  (absorption length ~250 µm ~ 12 keV photons)

Note

The AGIPD (former HPAD) consortium wants to go for sensors as thick as 700 µm.

Estimates on the charge collection time and charge spreading for such thick sensors might be useful for the consortium to fix the actual sensors thickness.
Backup
Timing structure of 660 nm laser

660 nm linear

660 nm log

provided by manufacturer
Multi-Channel TCT Setup for Charge Cloud Studies

M-TCT ceramics

- 13x26 mm² 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
Transient little plasma effects