Plasma effects in silicon sensors for the XFEL and impact on imaging performance

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1. Introduction XFEL

The European XFEL will push the limits of brilliance farther than any light source today. Examples of foreseen applications include the study of structures of complex biomolecules, resolving tiny structures like viruses and investigations of the evolution of fast chemical processes.

The expected dynamics, from single photon counting to 10^5 12keV photons/pixel/pulse, is a challenge for the design of silicon sensors and front end electronics.

Three beamlines differing in photon energy are foreseen: SASE 1: 12.4keV, SASE 2: 3.1 - 12.4keV and SASE 3: 0.8 - 3.1keV

2. Transient Current Technique (TCT)

The Transient Current Technique records the time current pulse of a sensor.

Photons have an energy dependent attenuation length in silicon (2.8µm for 1keV γ, 250µm for 12keV γ) and create electron hole pairs by ionization along their path. These charge carriers drift in the electric field and thus cause current.

3. Electron hole plasmas

When many photons are absorbed the charge carrier density can exceed the bulk doping O(10^{12}cm^{-3}) and e,h plasmas with following properties are created:

- The generated charge carriers modify the electric field which is no longer negligible at high densities, this is the dominating effect for high densities.
- Field free regions inside the plasma lead to ambipolar diffusion as dominant transport process. The plasma dissolves slowly which has an effect on the pulse shape (plasma delay).
- Charge repulsion results in further increased charge carrier spread.

4. Measurement setup

Multi Channel TCT key features:

Short laser pulses (~100ps) of high energy (up to 10^5 12keV γ equivalent). 660nm, 1015nm, 1052nm wavelength available corresponding to 1keV γ, 12keV γ and mips, respectively. Front and rear side injection possible.

32 readout channels with <100ps risetime

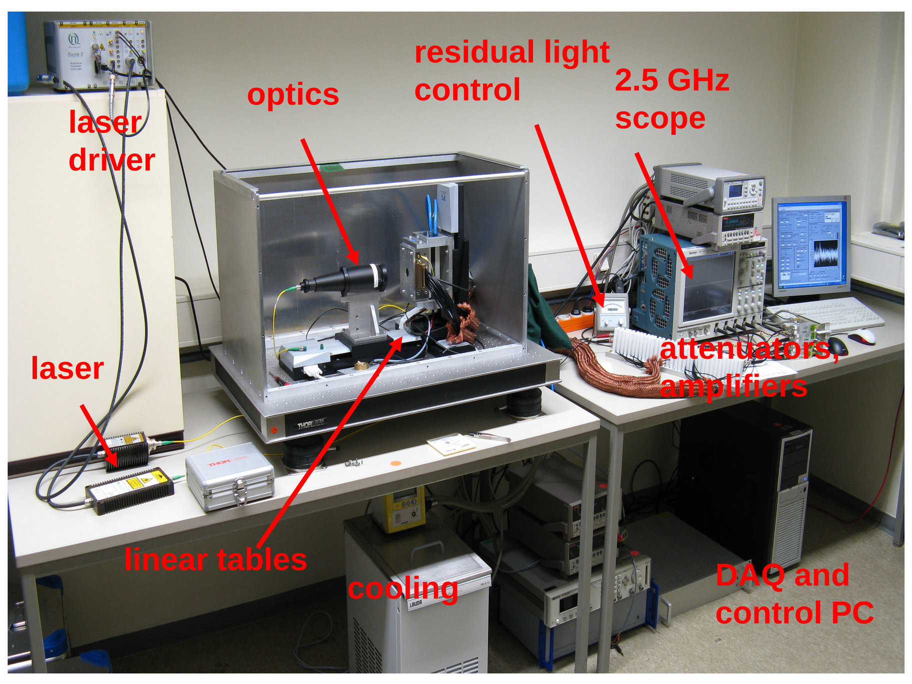

Fig. 1: Photograph of the setup used for the measurements. The setup can be closed and flushed with dry air to allow measurements at low temperatures (down to -35°C).

5. Investigated sensors

- produced by CiS/Erfurt
- high resistivity Wacker n-type silicon
- diffusion oxygenated float zone material (DOFZ)
- <100> orientation
- thickness of 280µm
- effective doping of 7.8x10^{11}cm^{-3}
- depletion voltages of 45V / 63V for planar diode/microstrip sensor
- strip pitch of 80µm and a strip width of 20µm.
- ≥5 strips neighboring the investigated strips where grounded

6. Results for planar diodes

Measurements (except curves showing no plasma effects) were done with a spot size of ~2.5µm. All pulses are normalized to same integral (charge). A reflected signal is starting at 50ns due to an impedance mismatch at the amplifier.

No-plasma-effect curves were recorded with a defocused laser beam and show no plasma effects as the charge carrier density is one order of magnitude lower than the bulk doping

Injection at the junction produces less pulse distortions, thus using n-in-n technology in the final AGIPD sensor is recommended.

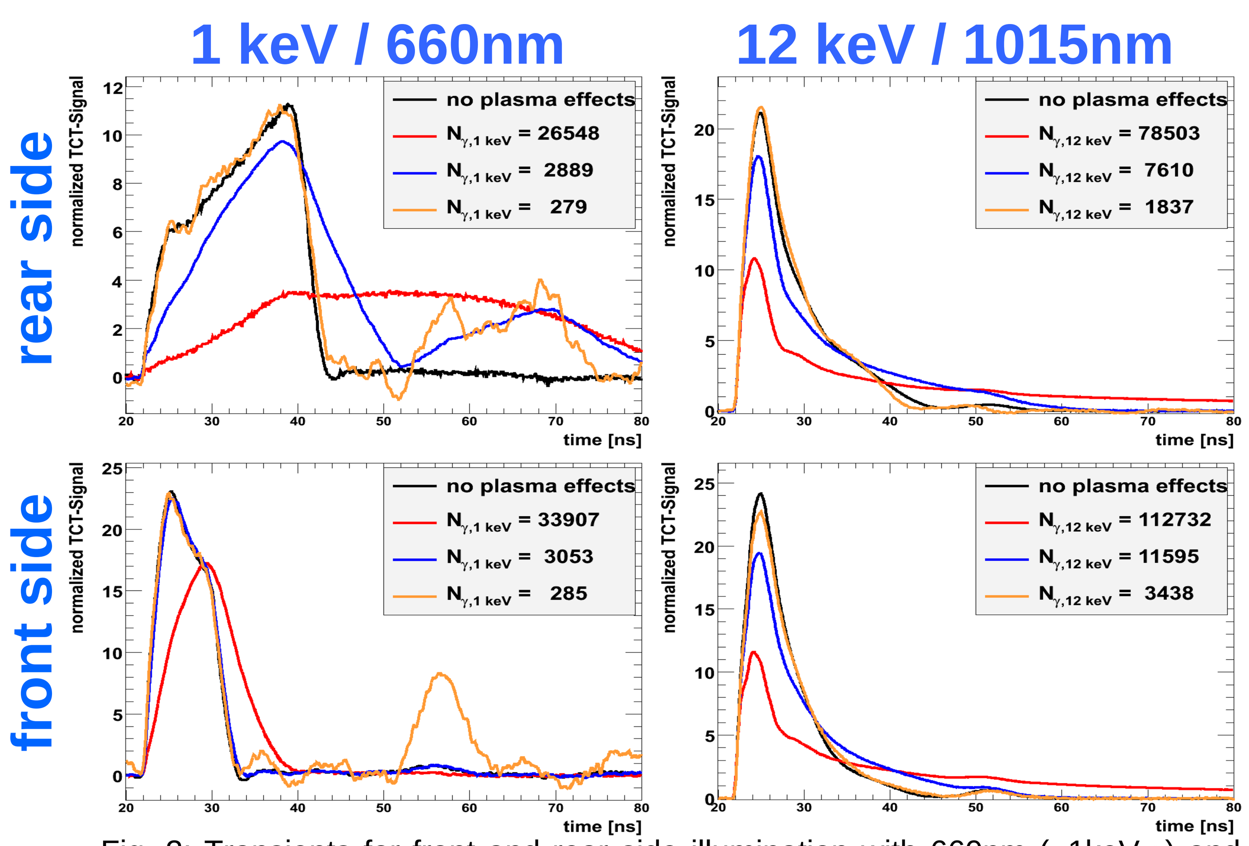

Fig. 2: Transients for front and rear side illumination with 660nm (~1keV γ) and 1015 nm (~12keV γ) light showing plasma distortions when more than roughly 1000 photon equivalents are injected. The applied bias voltage is 100V.

7. Results for strip sensors

As expected, increasing the bias voltage resulted in reduced plasma effects (more narrow point spread function). **Recommendation of using 1000V bias voltage in the final AGIPD detector.**

	660 nm (1keV γ)	1015nm (12keV γ)
intensity (absorbed γ equivalent)	32760	90000
max/min collection time (100V/500V)	100ns / 11ns	>200ns / 22ns
expected collection time (no plasma) (100V/500V)	20ns / 5.5ns	20ns / 5.5ns
plasma delay at 100V	15ns	none
peak current at 500V (<1ns)	0.24mA	8mA
sigma of charge spread (100/500V)	55µm / 28µm	54µm / ~25µm

Table 1: Results from the evaluation of position sensitive scans on the strip detector.

Results for 1keV γ / 660nm

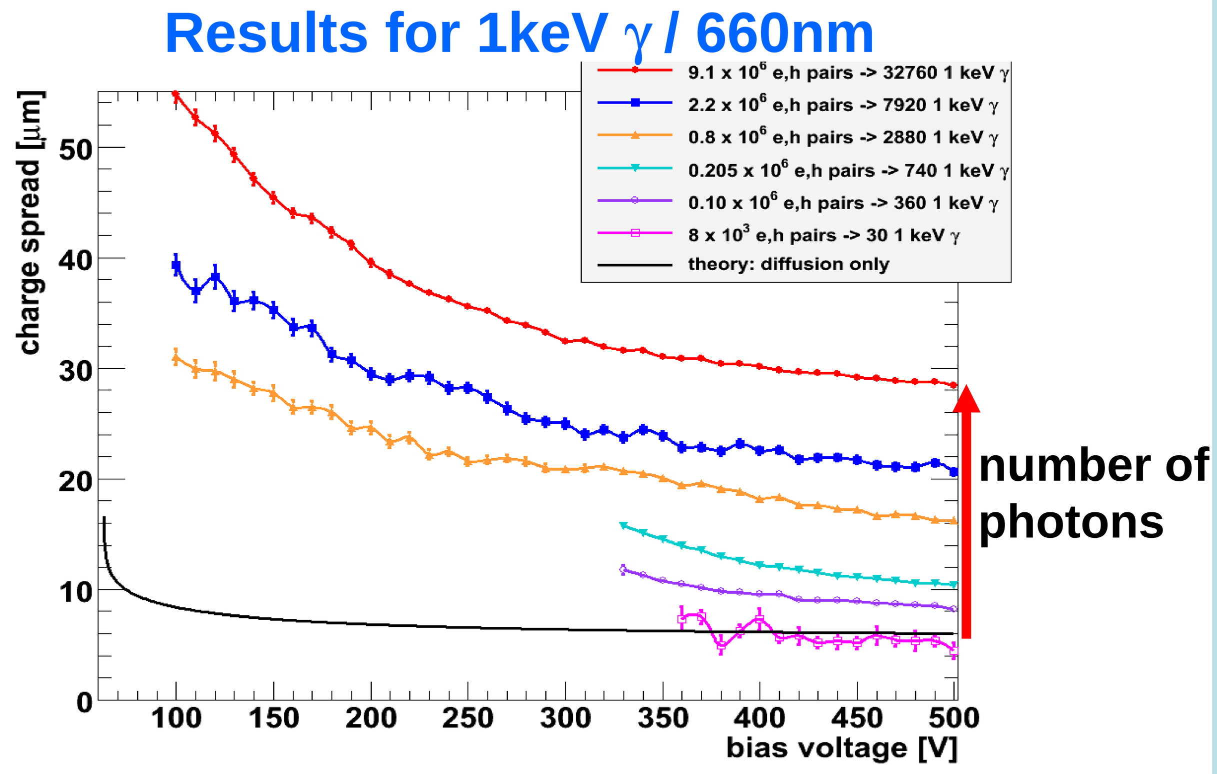

Fig. 3: Sigma of Gaussian point spread function as function of the applied bias voltage. Increased charge spreading is already observed for as few as 360 1keV photons. The sigma of the injected light is < 3µm.

8. Impact on sensor performance

From the point spread function the minimum angular resolution (angle at which two points can just be separated, lower is better) for two points of the same intensity was calculated using the Rayleigh criterion. In the final experiment the angular resolution will depend on the pixel size, the distance to the experiment, the intensity ratio of the two points and other parameters.

minimum intrinsic resolution at 2m distance [µrad]

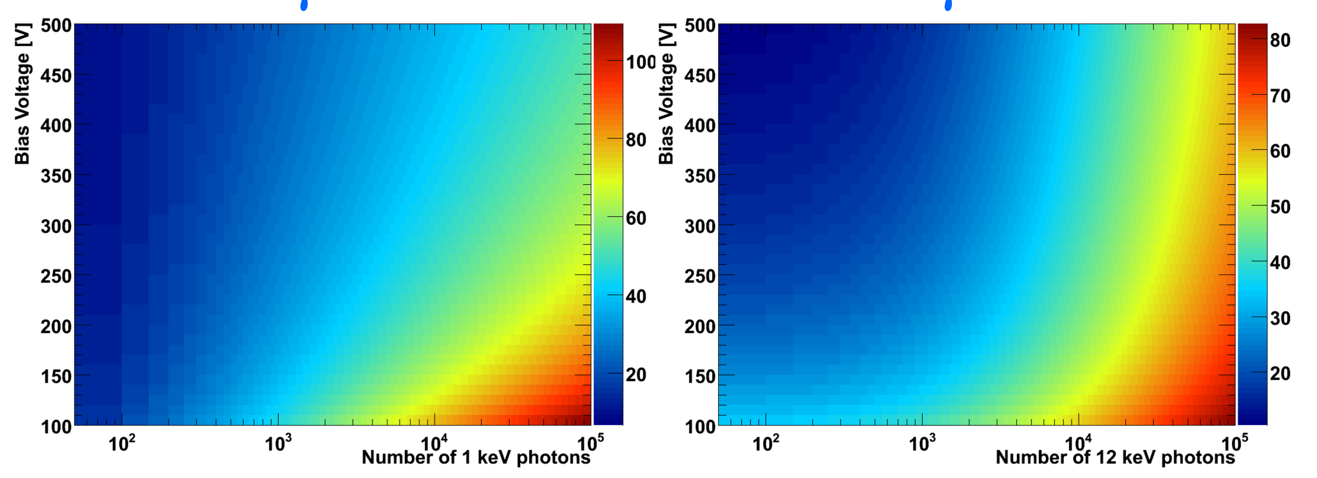

Fig 4: Minimum angular resolution for two points of the same intensity as function of point intensity and applied bias voltage for a distance of 2 meters (experiment-detector). A detector of 280µm thickness was used. The intrinsic resolution of thicker detectors will be worse.

9. Summary

Plasma Effects in silicon sensors were observed and studied using a multi channel TCT setup.

Conclusions for XFEL sensors are:

- A suppression of plasma effects was observed when injection is done from the junction side.
  - ➢ **The use of n-in-n technology is recommended**
- High bias voltages counteract plasma effects.
  - ➢ **Aiming for 1000V bias voltage in the final AGIPD detector.**
- Measurements on a strip sensor allowed the reconstruction of the point spread function (PSF) as function of the number of photons and the applied bias voltage. Following properties were deduced:
  - ➢ **The PSF can be approximated by a Gaussian function.**
  - ➢ **The sigma of the PSF is a function of the number of photons and the applied bias voltage.**
  - ➢ **A sigma of up to ~55µm was measured.**
- The reconstructed PSFs were used to calculate the intrinsic minimum angular resolution of the sensor for 660nm/1keV γ and 1015nm/12keV γ.
  - ➢ **Significant charge sharing will occur but the measured minimum angular resolution stays below the geometric resolution for injections of up to 10^5 γ (injection with Gaussian spot and sigma < 3µm).**

10. Outlook

- Detailed comparisons of measurements and simulations done by WIAS-Berlin. Possibility to study the influence of different transport properties from literature on simulations.
- Measured datasets serve as input data for the design of the AGIPD ASIC and measured parameters will be included in the AGIPD detector simulation package HORUS.
- New measurement campaign with test structures of different thickness to study the influence on the point spread function and intrinsic resolution.
- Better description of the point spread function for 12keV photons / 1015nm light. Currently described as Gaussian distribution.

11. Acknowledgements

This work was partly funded by the Helmholtz Alliance 'Physics at the Terascale', the Federal Ministry of Education and Research and the European XFEL Consortium.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung