DESIGN OF PLANAR P-ON-N PIXEL SENSOR WITH AN OPTIMIZED ACTIVE-EDGE REGION FOR THE NEXT GENERATION OF FEL

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Outline

- Introduction
  - XFEL project overview
  - PixFEL Collaboration
- Device Structure & Design issues
- TCAD Simulation results
- Conclusion and perspectives

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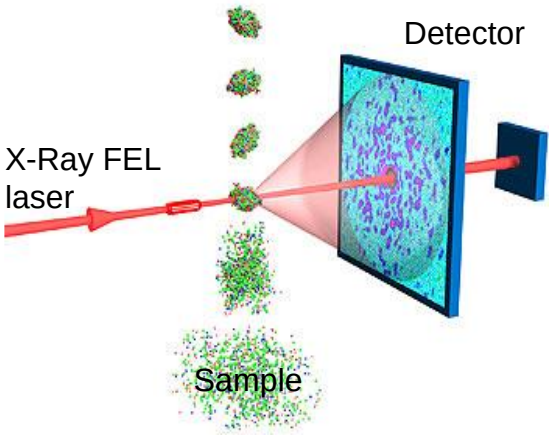
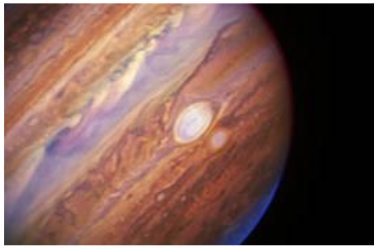
INTRODUCTION

The X-Ray Free Electron Laser
The next generation light source



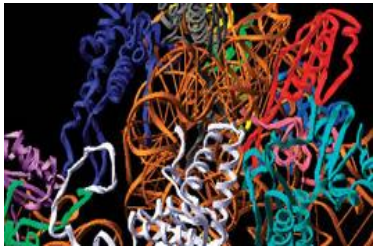
Applications

- physics,
- chemistry,
- biology,…



Investigating extreme states of matter

Filming chemical reactions



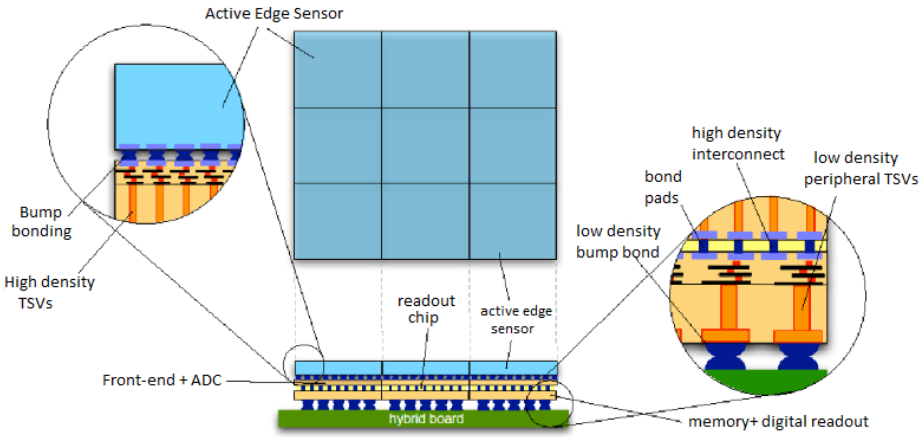
Deciphering the structure of biomolecule

❑ The use of radiation-hard **Pixel Detectors :**

- ❖ **L**arge **P**ixel **D**etector (**LPD**)
- ❖ **D**EPFET **S**ensor with **S**ignal **C**ompression (**DSSC**)
- ❖ **A**daptive **G**ain **I**ntegrating **P**ixel **D**etector (**AGIPD**)

PixFEL project overview

- Goal of the project: High performance X-ray imaging instrumentation for experiments at the next generation FELs



The four-side buttable module for the assembly of large area detectors

Participating groups:

- INFN University Pavia & Bergamo
- INFN University Pisa
- INFN University Trento:

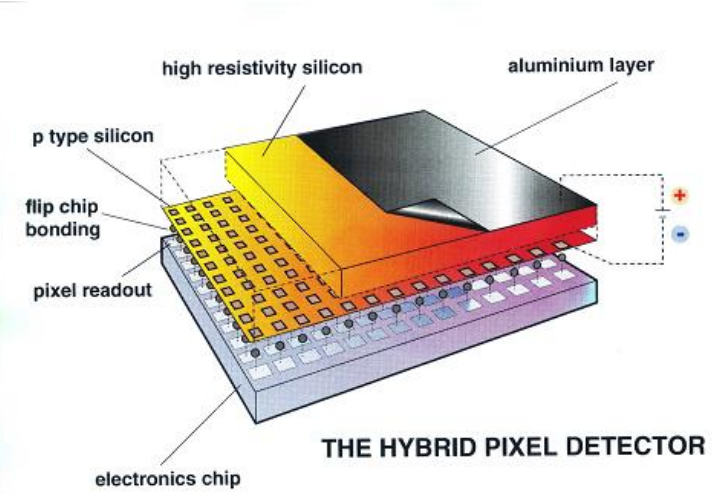
M.A Benkechkache – G-F Dalla Betta – L. Pancheri

The enabling technologies :

- ✓ Small pitch **Active Edge** Pixel sensors
- ✓ **65 nm CMOS** technology
- ✓ **3D integration** technique

X-Ray FEL detector challenges

- **X-Ray FEL detector challenges or requirements**



Sensor chips of 64x64 Pixel Array ⟷ (Bump-bonded) Readout ASICs

Requirements

- **Dynamic Range** from 0,1 photons up to more than 10^4 photons of 12keV/Pixel/Pulse
- **Frame Rate** 5MHz
- Operating voltage above V_{bias}>>400-500V
- **Radiation Tolerance** 10 MGy-1GGy per 3years of operation
- No or minimum **dead area** 2%

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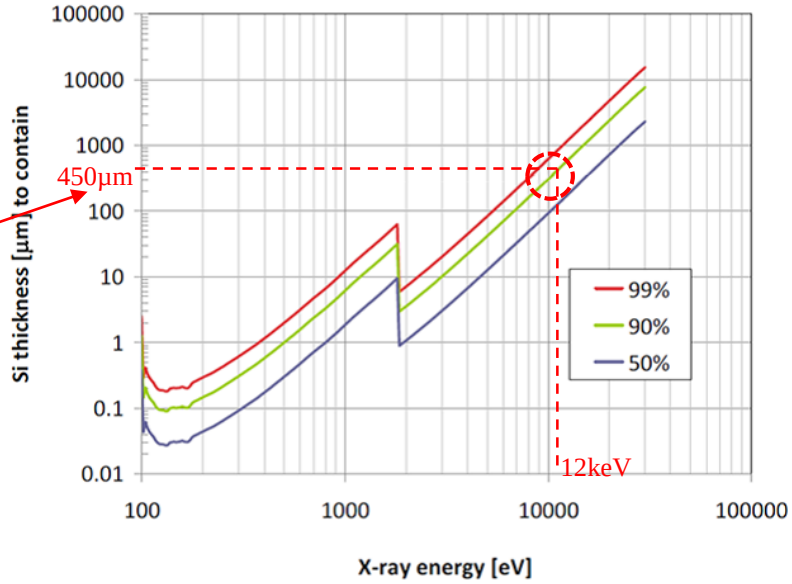
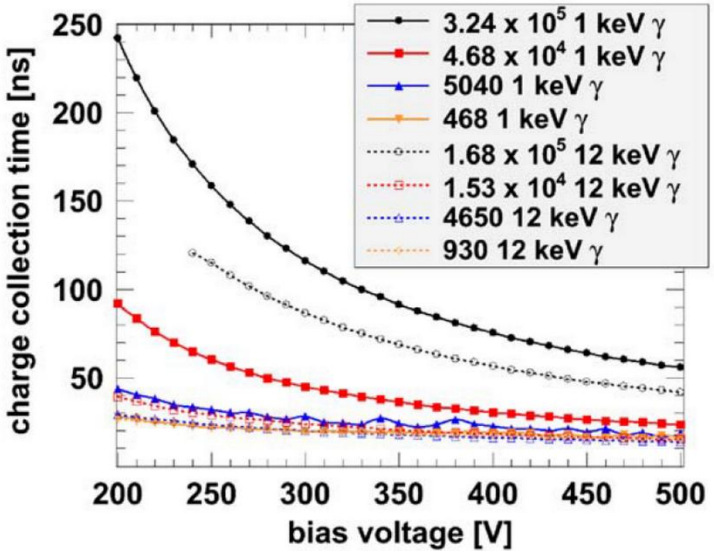
Design Issues

- **Thick substrates** to have **high detection efficiency** at high X-Ray energies , causing larger depletion voltages.
  - ~90% at **12 keV energy** for **450 µm thick**)





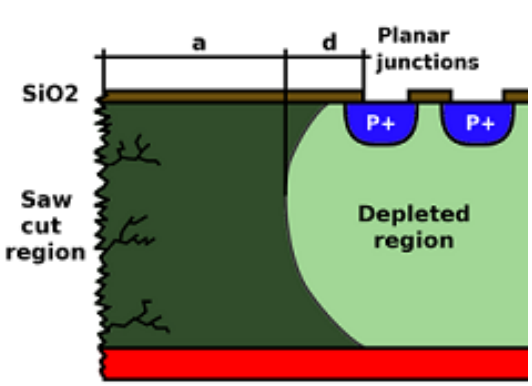
- **Plasma effects** due to **many photons** hit one pixel at a time, resulting in **high carrier densities**
  - High V_{bias} required

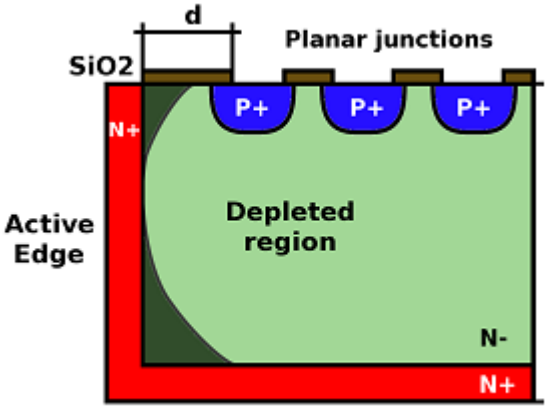
J. Becker, et al., NIM A, vol. 615, pp. 230-236, 2010

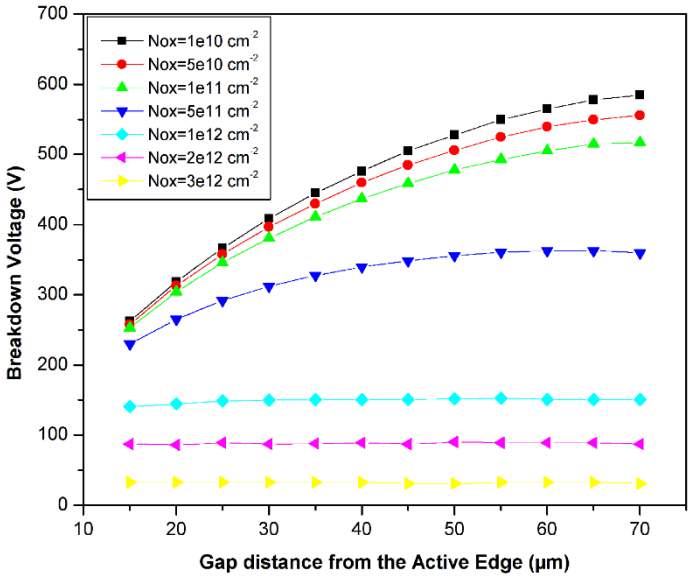
Design Issues

- **Active edge Planar sensor**
  - **Pros:**
    - Reducing the inactive area in the Edge of the sensor
    - Eliminate parasitic currents
  - **Cons:**
    - **Early Breakdown Voltage**

Edge region has to be optimized







Device simulation

Objective:

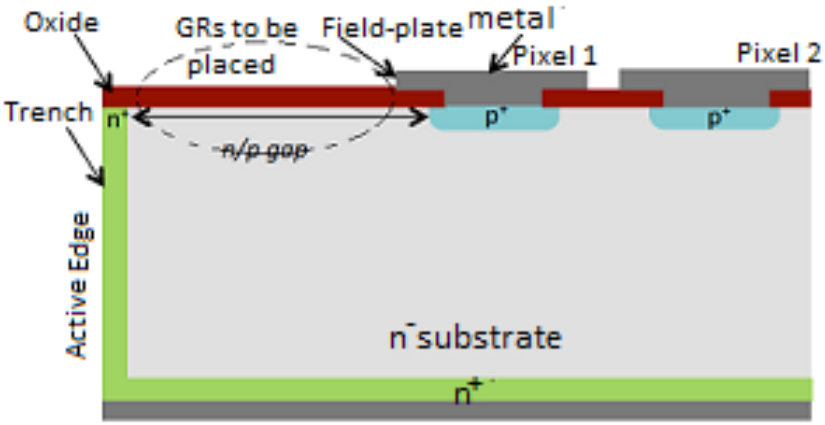
- **Design Optimization** by TCAD simulations.
- Charge collection properties, to predict the most suitable operation voltage, and the breakdown voltage characteristics

The aim :

Best **trade-offs**

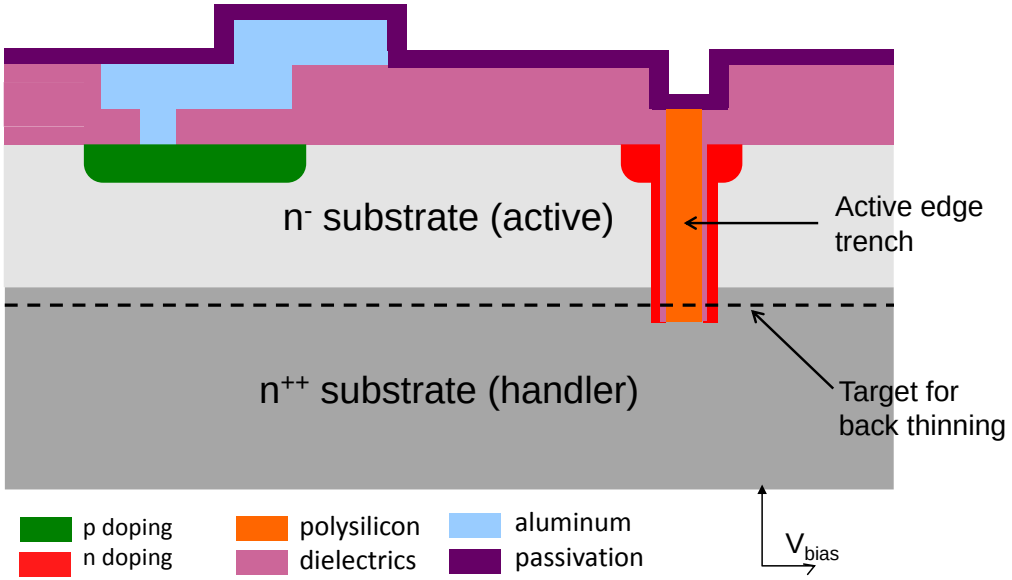
The edge region **Vs.** **Breakdown voltage**

Parameters Fixed	Parameters Varied
➢ Guardring width ➢ Field-plate	➢ The oxide thickness ➢ Junction depth ➢ Number of Guardrings ➢ Guardrings Spacing



Sensor design

Active edge Planar sensor p^+-on-n



M. Povoli et al., NIMA 658 (2011) 103.

List of geometrical parameters for the p-on-n sensor

Sensor parameter	value
Substrate thickness	450µm
Substrate doping	2e11cm^{-2}
Pixel width	80µm
Pitch	100µm
Field Plate	5µm
SiO_2 thickness	300nm
Guardring width	15µm

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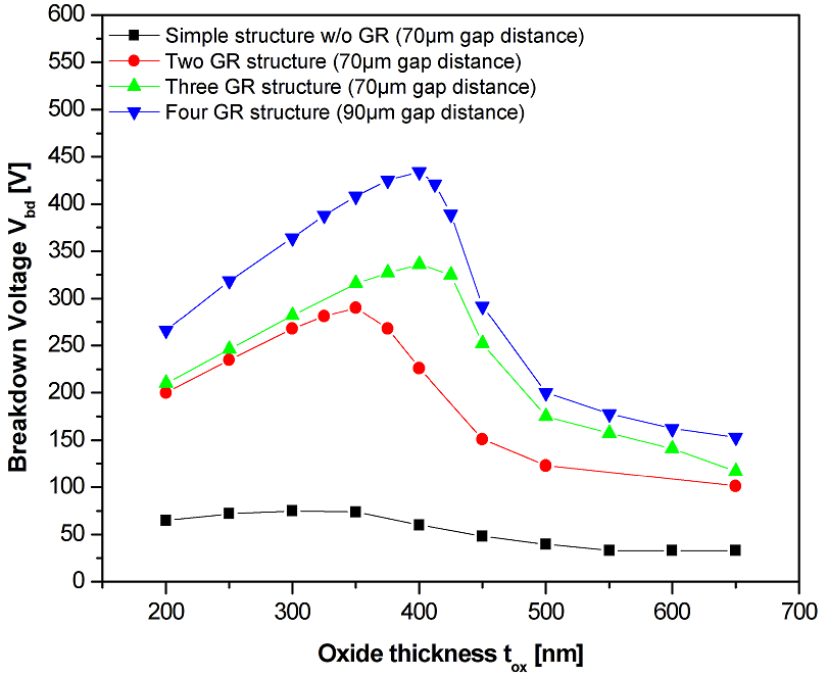
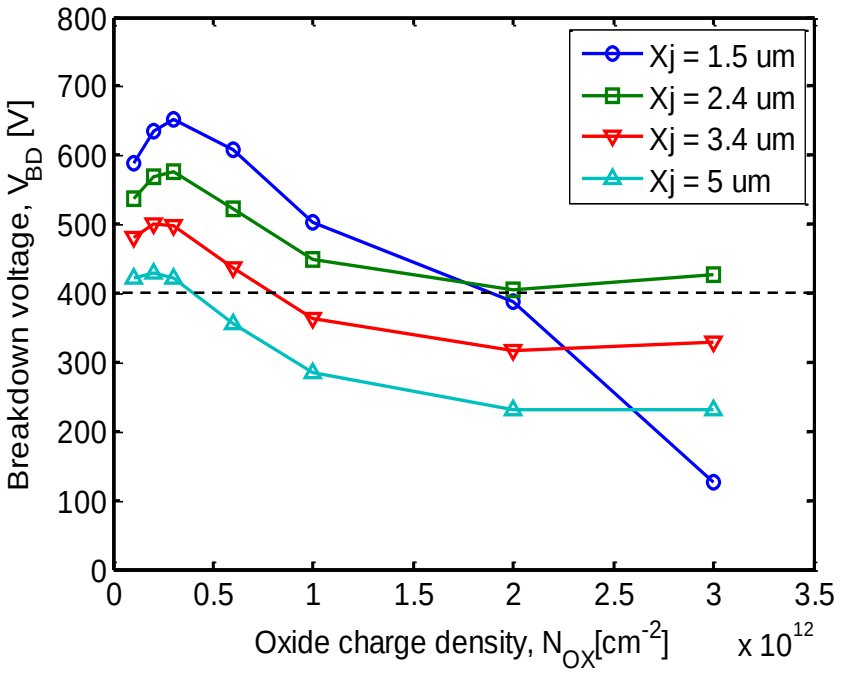
Simulation Results

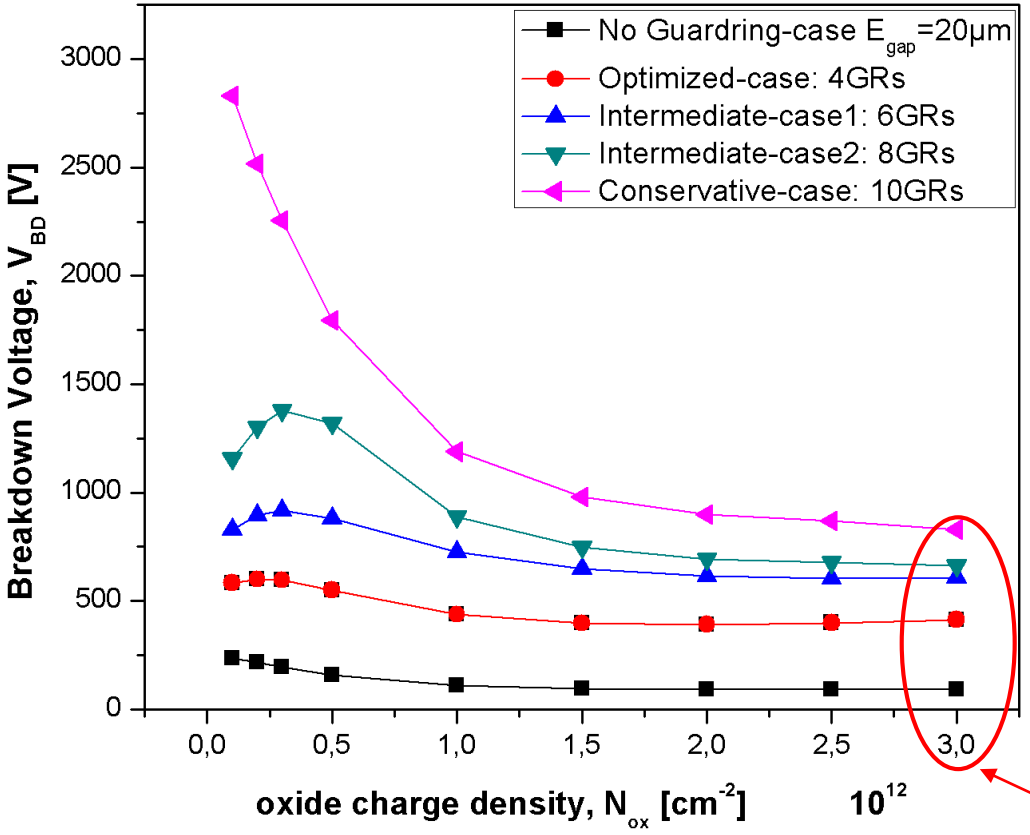
❑ Parameter optimization





- ✓ Higher **V_{BD}** with more **Guardrings**
- ✓ **Optimum** value for **tox ~ 300-400nm**
- ✓ **Xj=2,4µm** Junction depth allow for higher **V_{BD}** at high **radiation doses (>400V)**

Different border termination



- **No GR case**: Edge distance 20μm
- **The 4GRs case**: Edge distance ~150μm.
- **The 6GRs case** : Edge distance ~ 240μm
- **The 8GRs case** : Edge distance ~ 320μm
- **The 10GRs case** : Edge distance ~380μm

High Radiation doses

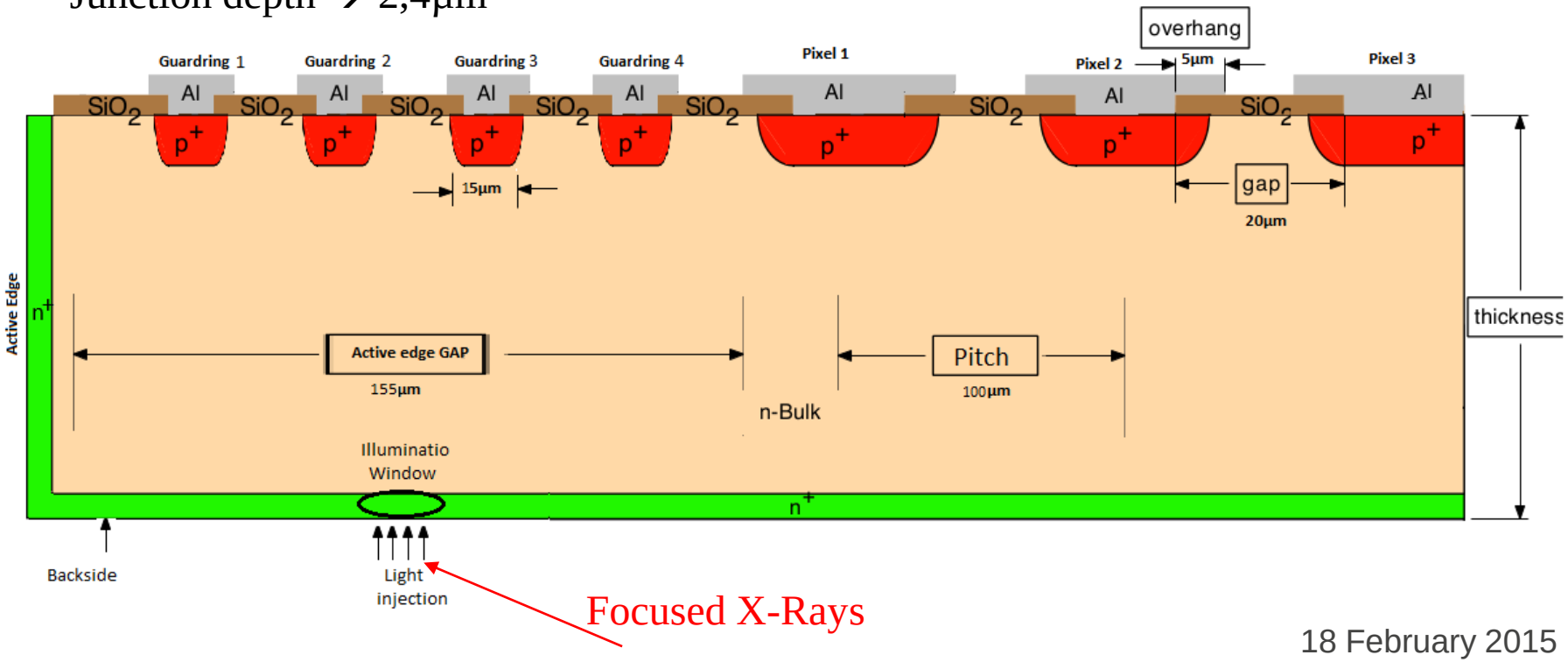
Charge collection properties

Optimized Structure

- 4GRs structure
- Edge distance of 155µm
- Oxide thickness→300nm
- Junction depth → 2,4µm

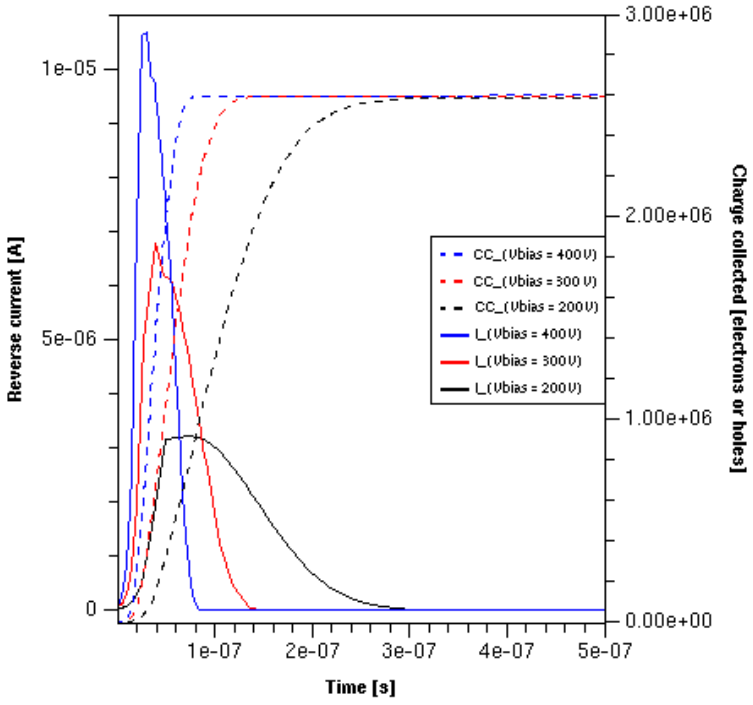
- **Optical generation** of photons impinging the backside with **TCAD** "optbeam" model

Parameters: - Illumination window ~ 10µm
- Gaussian pulse <100fs - Tuned Intensity

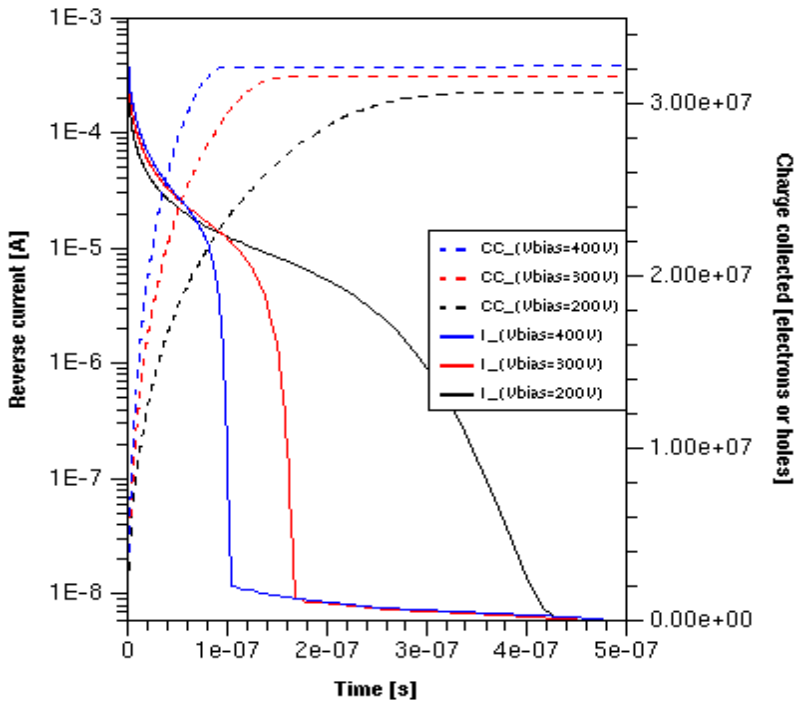


Charge collection results

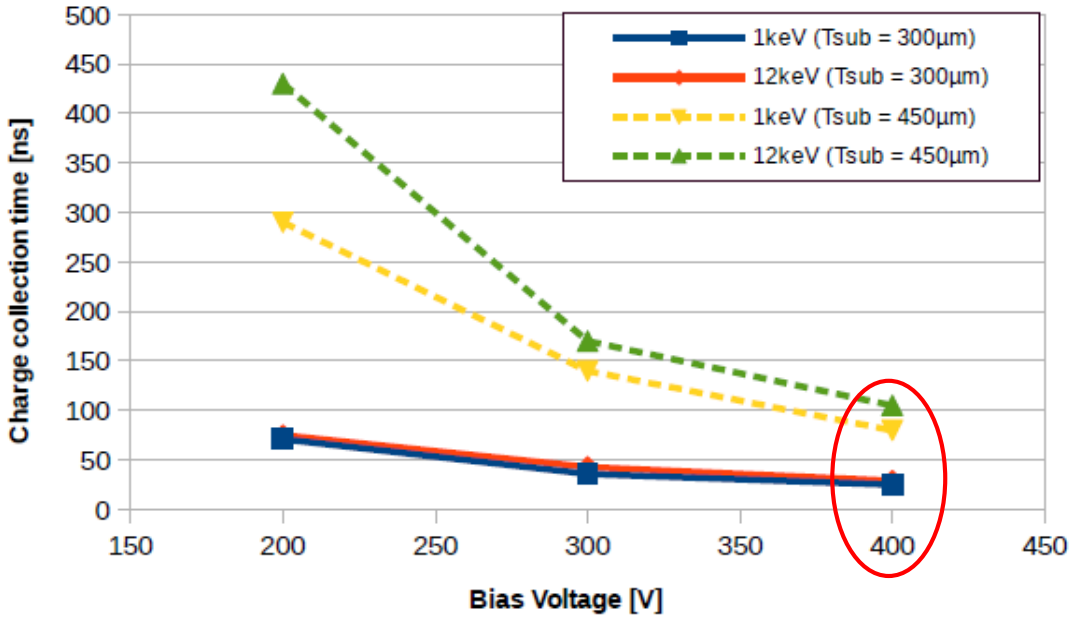
Focused **660nm** light of an intensity of **10^4 1keV** photons energy



Focused **1015nm** light of an intensity of **10^4 12keV** photons energy



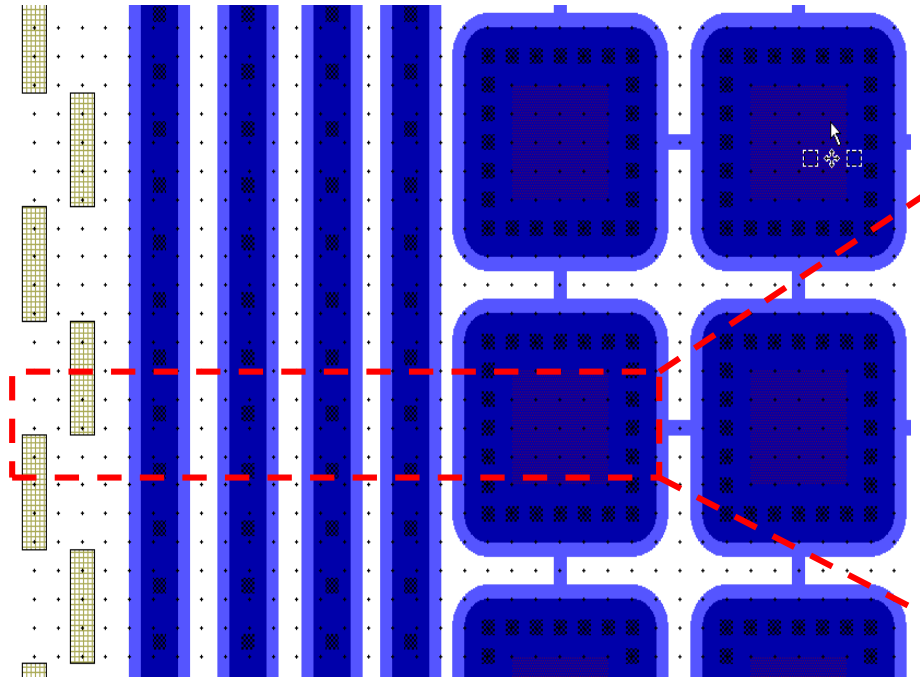
Charge collection results



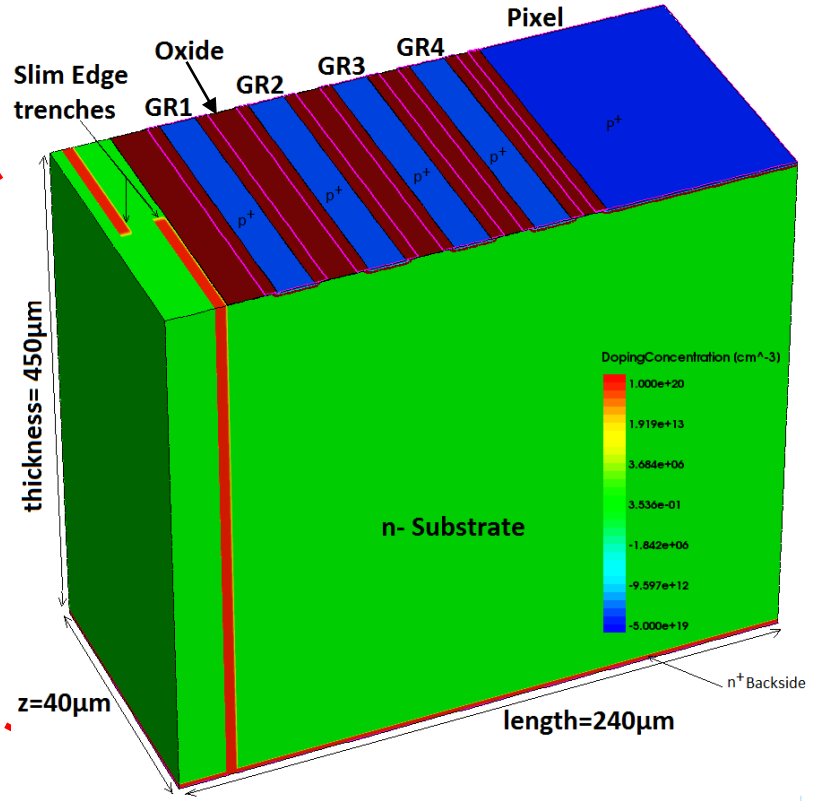
- Faster charge collection as bias voltage is increased, as expected
- **In brief: collection times less than 100ns can be obtained at 400 V bias for a charge generated near the Edge**
- These values would meet PixFEL specifications in terms of frame rate and spatial resolution

The Slim Edge Approach

Structure Layout



TCAD 3D structure



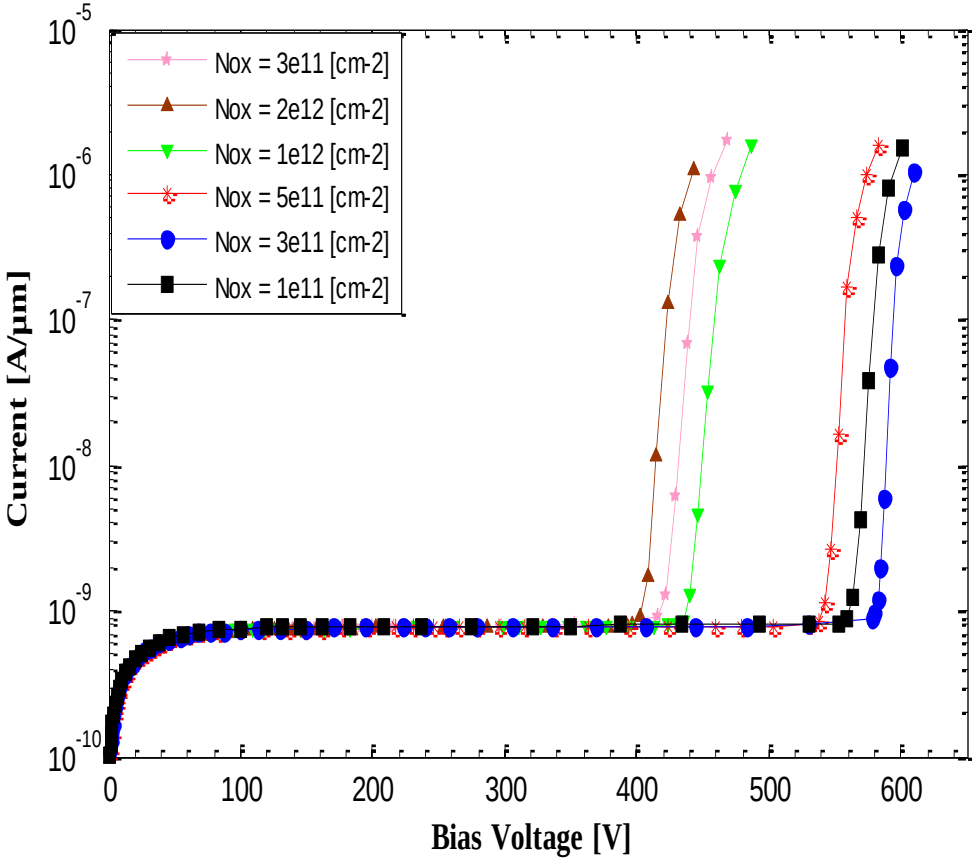
Simulation results

Advantages:

- get rid of the support wafer
- Entrance window at low energy can be optimized

Disadvantages and risks

- Additional dead space at the border
- Possible reduction of breakdown voltage



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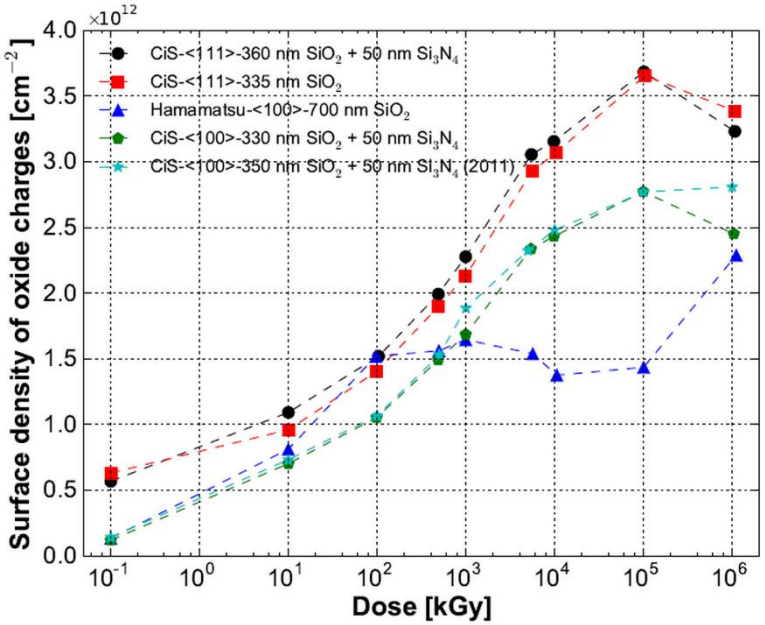
Conclusion

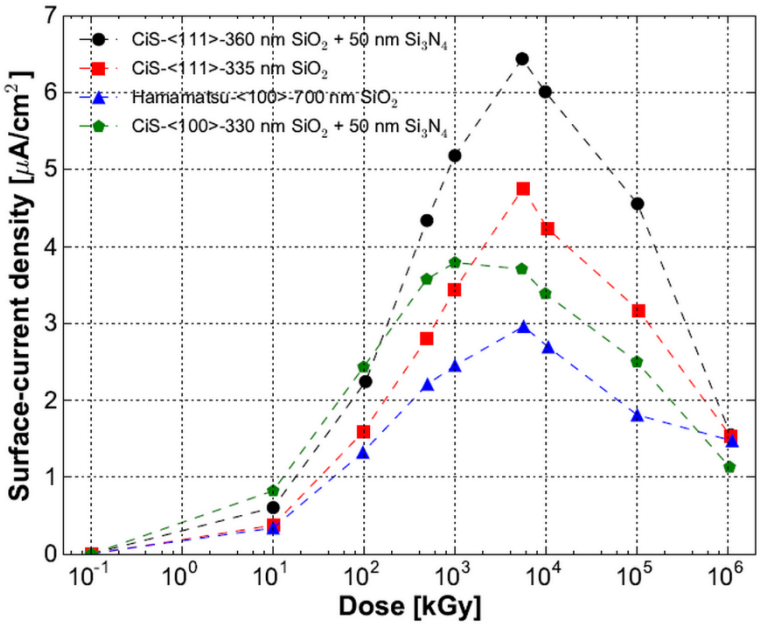
- TCAD simulations were used to design active-edge pixels for FEL applications
- From simulations, a 4-GR termination and an edge size of ~150 μm, withstanding more than 400 V in all oxide charge conditions, seems feasible.
- The Slim Edge approach for Pixel sensor
- The wafer layout of the first PixFEL sensor batch is under way, first prototypes are expected for summer 2015.

Back up

Dose dependence



*J.Zhang "**Investigation of X-ray induced radiation damage at the Si-SiO2 interface of silicon sensors for the European XFEL"***
09/Nov/2012



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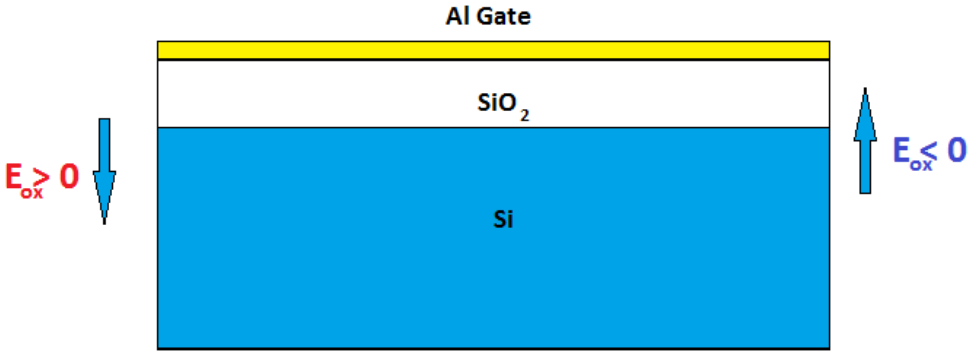
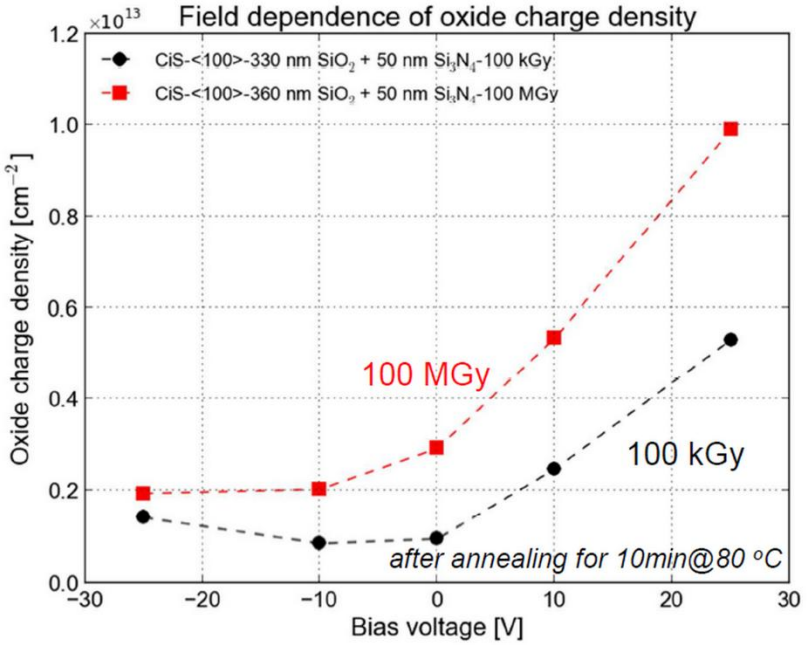
Bias dependence



Conclusions:

- *Nox* and *Isurface* increase for *Eox* > 0
- No strong *Eox* dependence for *Eox* < 0
- **p⁺n** sensor: *Eox* < 0 → not a problem



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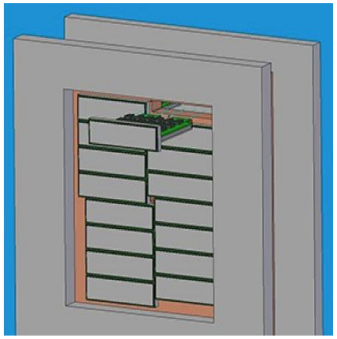
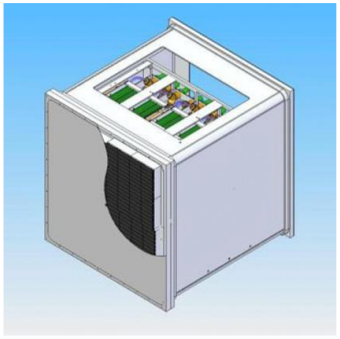
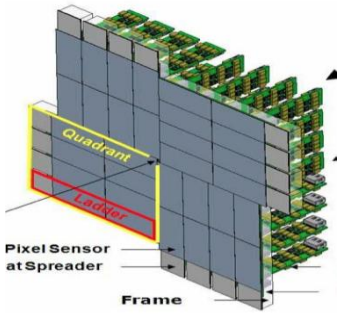
Eu-XFEL imaging detectors







AGIPD – Adaptive Gain Integrating Pixel Detector:

- energy range: 3-13 keV
- dyn. range: 10_4 photon @12 keV energy
- single photon sensitivity
- storage cells (analog): ~300
- pixel pitch: 200 um

LPD – Large Pixel Detector

- energy range: 1-25 keV
- dyn. range: 10_5 photon @12 keV energy
- single photon sensitivity
- storage cells (analog): ~512
- pixel pitch: 500 um

DSSC – DEPFET Sensor with Signal Compression

- energy range: 0.5-6 keV
- dyn. range: 6000 photon @1 keV energy
- single photon sensitivity
- storage cells (digital): ~640
- pixel pitch: 236 um

❑ PixFEL aims to improve on memory depth, spatial resolution and dead area

X-ray FEL detector challenges

- FEL Pulse Structure
  - Single shot imaging (<100fs pulse, 200 ns readout)
  - Frame Storage Of complete

Bunch train (2700 pulses) for Eu-XFEL or fast readout for continuous machine (up to 1MHz)

- Dynamic Range
  - Single photon counting
  - Up to 10_4 ph/pixel/pulse

- Sensitive Energy Range
  - 0.25---25 keV ideally with the same system
- Radiation Hardness
  - 10 MGy---1 Ggy over 3 years operation
- Pixel size:
  - 700---20 µm, depending on distance & angular resolution required
- Large area coverage:
  - multiple tiles with no dead area