Design of the AGIPD Sensor for the European XFEL

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1. Introduction

For experiments at the European XFEL the Adaptive Gain Integrating Pixel Detector (AGIPD) system is currently under development. The requirements are a high dynamic range of 0, 1 – to more than 10^4 12.4 keV photons per pixel within a XFEL pulse duration of < 100 fs and a radiation tolerance of doses up to 1 GGy for 3 years of operation.

The sensor will have 1024 × 1024 p^+-pixels with a pixel size of 200 µm × 200 µm and will be manufactured on 500 µm thick n-type silicon. The design value for the operating voltage is 500 V, however, for special applications an operation at above 900 V should be possible.

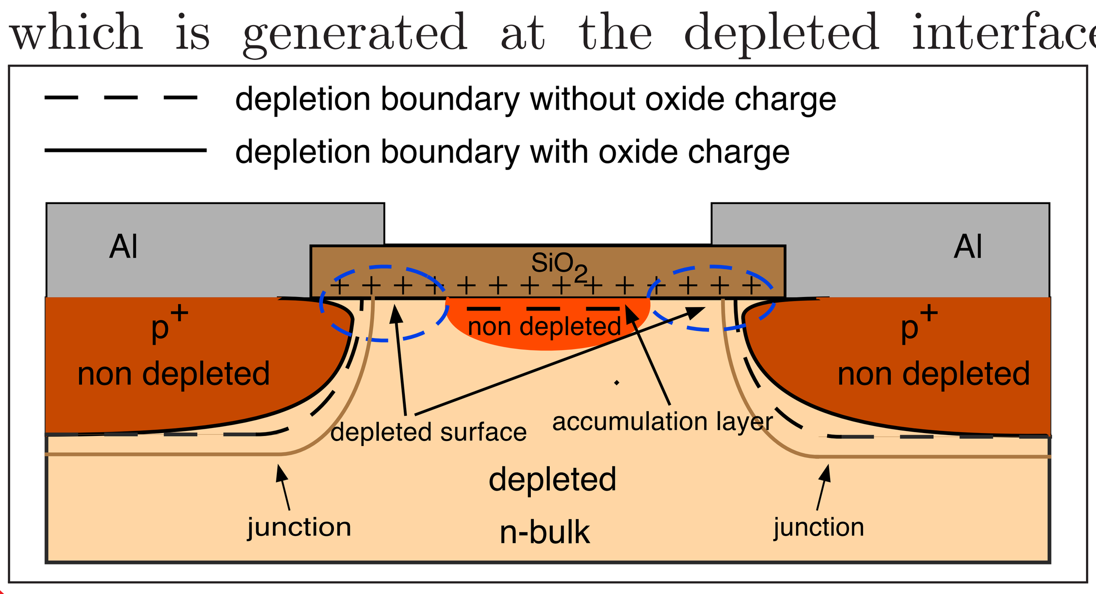
The design for the AGIPD sensor is optimized using TCAD simulations which take into account surface damage. A layout which fulfills the specifications is presented.

2. Impact of surface damage

For 12.4 keV photons no bulk damage is expected, but surface damage.

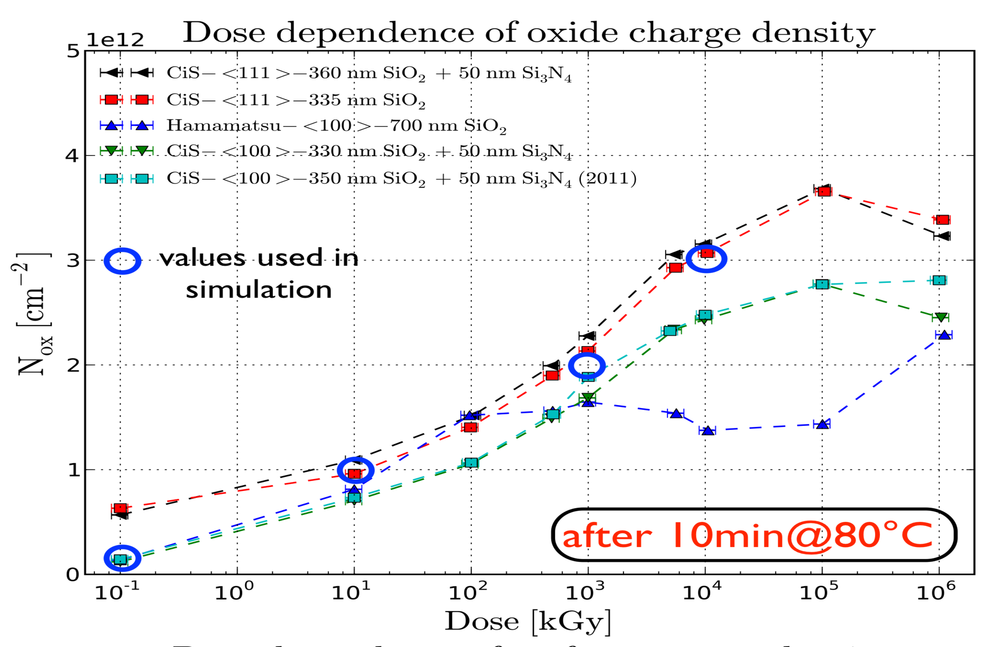
Radiation induced positive oxide charge will produce a strong bending of the depletion boundary near the interface which will results in a high electric field and a lower breakdown voltage. In addition, an electron layer forms which prevents the fully depletion of the surface and leads to a increase of the inter-pixel capacitance and charge losses.

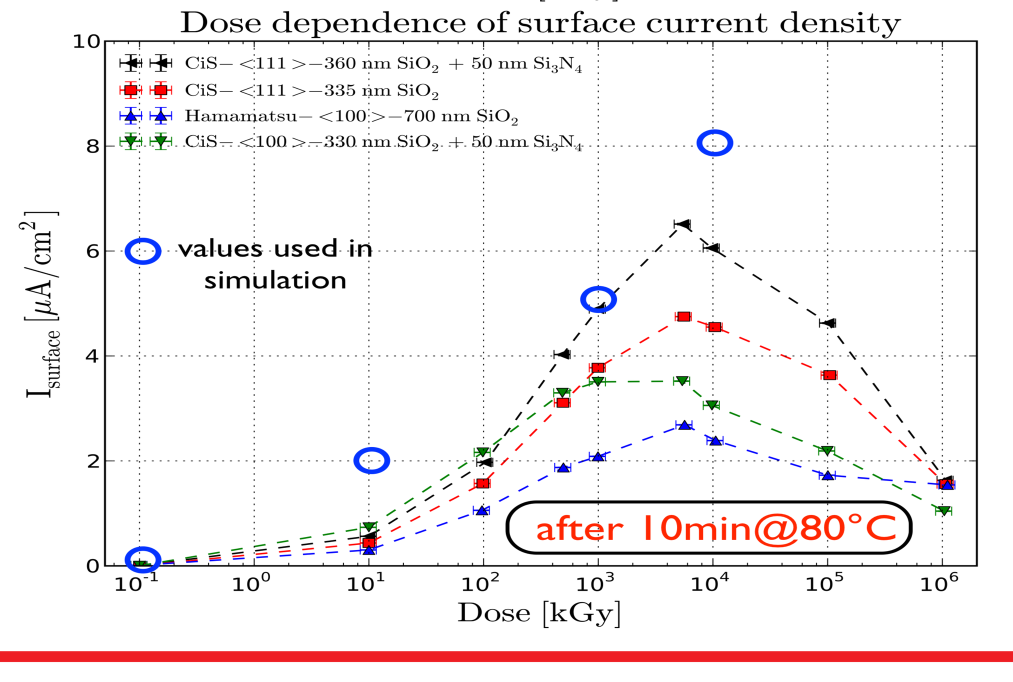
The Si-SiO_2 interface traps are distributed within the Si band gap and their charge states depends on the type, energy and Fermi level. They are responsible for the surface current, which is generated at the depleted interface.



3. Surface damage in TCAD

Values for oxide charge N_{ox} and surface recombination velocity s_0 are taken from measurements on test structures irradiated up to 1 GGy.



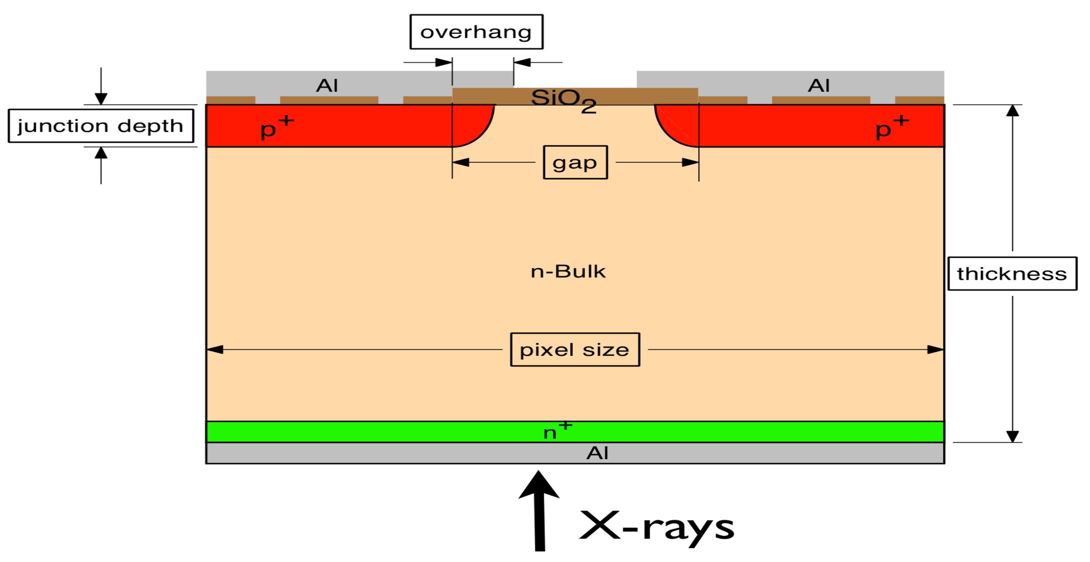


4. Sensor specs (0 – 1 GGy)

Parameter	Value
mechanical thickness	500± 20 μm
distance pixel edges to cut edges	1200 μm
n doping	3–8 $k\Omega \cdot cm$
pixel dimensions	200 × 200 µm^2
operating voltage	500 V
breakdown voltage	> 900 V
coupling type	DC
inter-pixel capacitance@500V	500 fF
total dark current sensor@500V	50 µA

5. Parameter optimized

Pixel: gap, Al overhang, radius of implant and Al at corners



Guard ring: number of rings, implantation width, spacing, Al overhangs

Process: junction depth, oxide thickness

6. Optimization strategy

- Performance to be optimized:

  Pixel: breakdown voltage, surface current, inter-pixel capacitance

  Guard: V_{bias} (1000V?) over 1.2 mm for doses between 0 and 1 GGy, bulk should not be depleted at scribe line

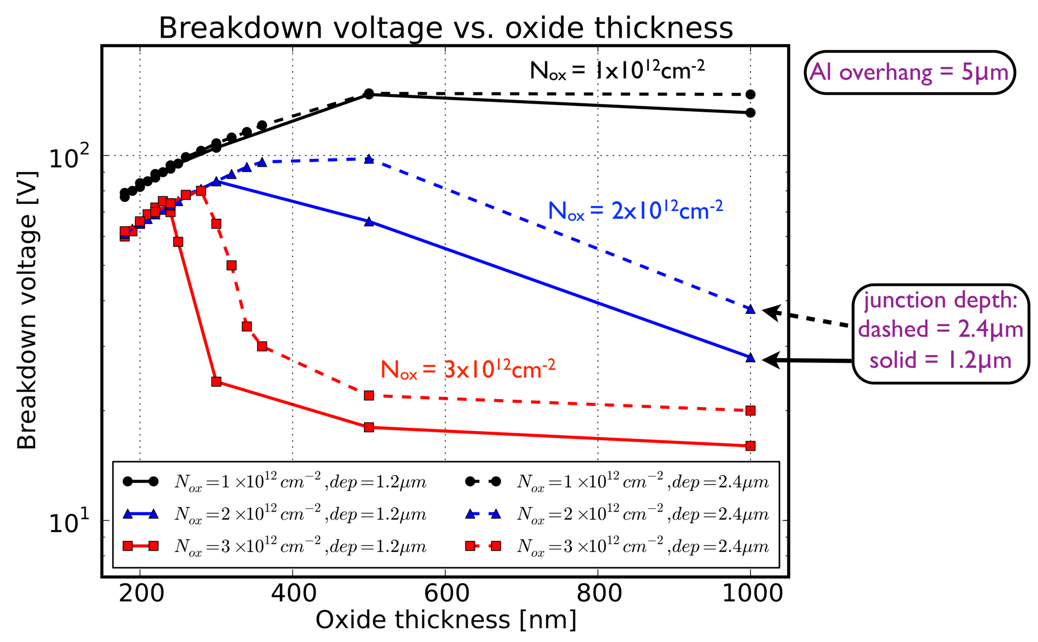
- Guard-ring optimization (2D in (x,y) & (r,z)):
  1. Study breakdown behavior of 0 GR (CCR only) for different N_{ox} as function of oxide thickness and Al overhang
  2. Estimate No. of floating GRs for 1000V
  3. Vary spacing between rings, implant width and overhang to achieve maximum V_{bd} ≈ equal electric field at each GR
  4. Minimize space required

- Pixel optimization (2D):
  1. Optimize oxide thickness, Al overhang, gap and implantation depth with respect to breakdown voltage, dark current and capacitance
  2. Extrapolation of dark current and capacitances to "3D values"
  3. Check breakdown voltage + dark current with 3D simulation (only 1/4 pixel used)

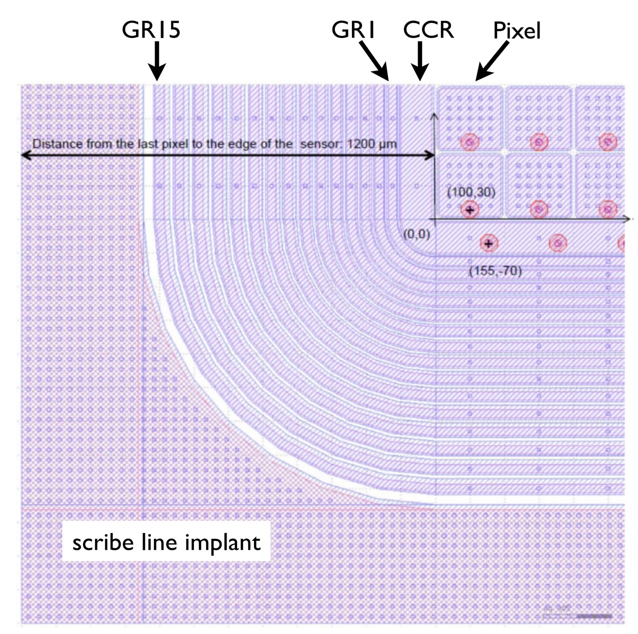
7. Results

Guard ring

For 0 GR and $N_{ox} = 3{\times}10^{12} cm^{-2}$ the breakdown voltage is ≈ 70V for 230-270nm oxide thickness.



The optimized guard-ring structure consist of CCR and 15 floating rings with a junction depth of 2.4µm and 250nm oxide thickness.

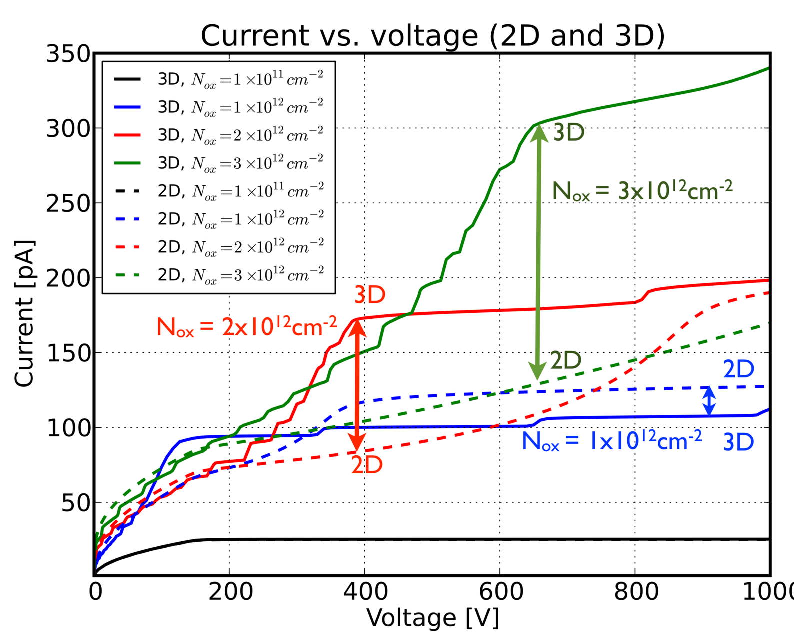


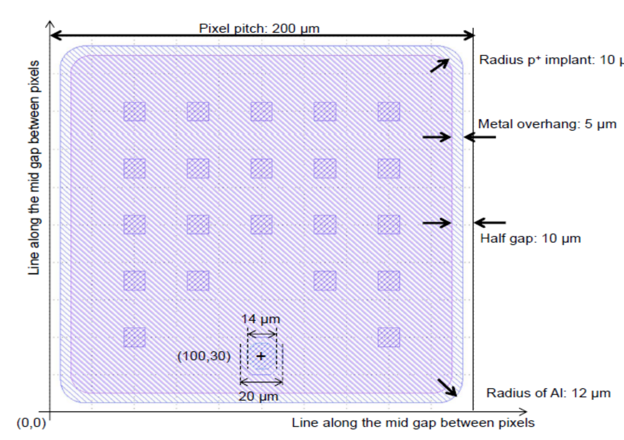
Breakdown voltage as function of N_{ox}

N_{ox} $[cm^{-2}]$	5 kΩ·cm 2D (x,y)	5 kΩ·cm 2D (r,z)
$1 \cdot 10^{12}$	> 1100 V	> 1100 V
$2 \cdot 10^{12}$	1080 V	910 V
$3 \cdot 10^{12}$	> 1100 V	910 V

Pixel

The I-V of the optimized pixel shows no breakdown below 1000V. The different voltage dependence in 2D and 3D are due the accumulation layer at the corners.





Simulated performance at 500V

N_{ox} $[cm^{-2}]$	I_{surf} $[\mu A/cm^2]$	I_{Sensor} $[\mu A]$	I_{CCR} $[\mu A]$	C_{int} [fF]
$1 \cdot 10^{12}$	2	7.4	0.6	120
$2 \cdot 10^{12}$	5	12.7	0.9	270
$3 \cdot 10^{12}$	8	14.4	1.2	312

All values are within the specifications!

8. Summary

Experimental results on X-ray radiation damage have been used in Synopsys TCAD in oder to optimize the design of the pixel and the guard ring layout of the AGIPD sensor.