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Preliminary study of electrical characteristics of microstrip sensors

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(Started on 16th July, 2009; topic: optimized design of hybrid pixel sensors)

Introduction

The European X-ray free electron laser (XFEL) will generate ultra short, coherent extremely intense X-ray flashes. It will open up new research topics for scientists, such as mapping the atomic details of viruses, deciphering the molecular composition of cells and movies of molecular transitions.

The XFEL beam will result in a radiation exposure of the detectors of up to 1 GGy from 12 keV photon, which represents a major challenge.

The task is to study the performance of different structured silicon detectors under high X-ray doses. We present first results on the characteristics of microstrip sensors.

Investigated structures

Microstrip sensors:

- high resistivity n-type silicon substrate of 2-5 kΩ·cm
- Diffusion oxygenated float zone material
- <100> orientation
- thickness of 285±10 μm
- 98 readout p$^+$-strips, with strip pitch of 60 μm, width of 20 μm and length of 7.8 mm

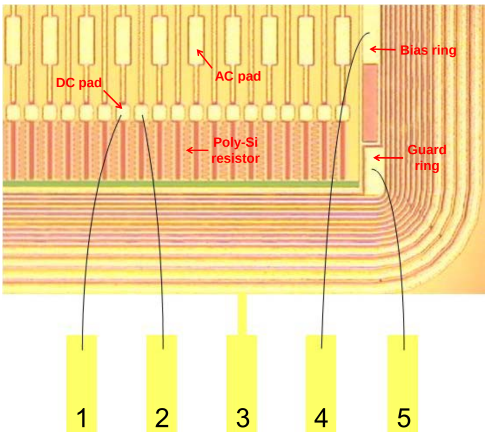
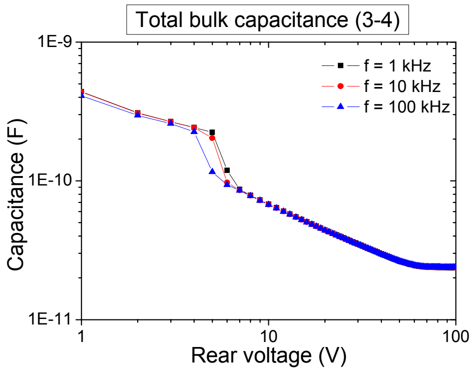


Fig. Photograph of microstrip sensor
Contacts:1&2 – adjacent strips; 3 – rear plane; 4 – bias ring; 5 – 1st guard ring.

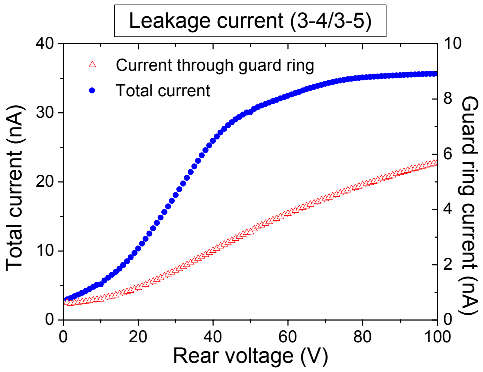
Measurements

- total bulk capacitance
- total leakage current
- poly-Si resistance
- inter-strip resistance
- single strip capacitance

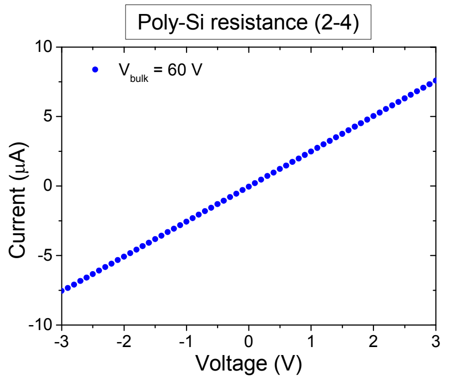
Results for microstrip sensors



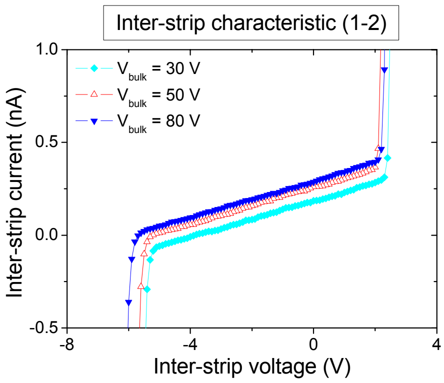
- V_{dep} = 57 V → N_{eff} = 9.2×10^{11} cm^{-3}
- V = 6 V → single strip depletion merges



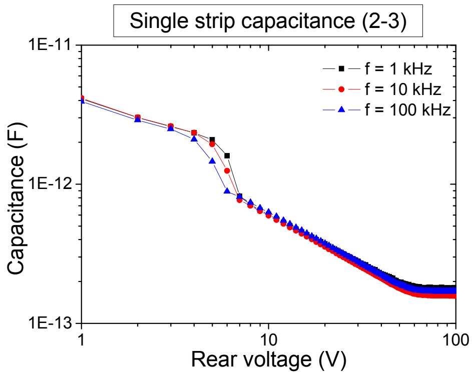
- I_{leak} = 35 nA (at 100 V), nearly an order of 10 greater than the guard ring current



- poly-Si resistance R ≈ 0.4 MΩ



- inter-strip resistance R_{in} ≈ 20 GΩ
- Interstrip breakthrough voltage: -5~-6 V/ 2~3 V

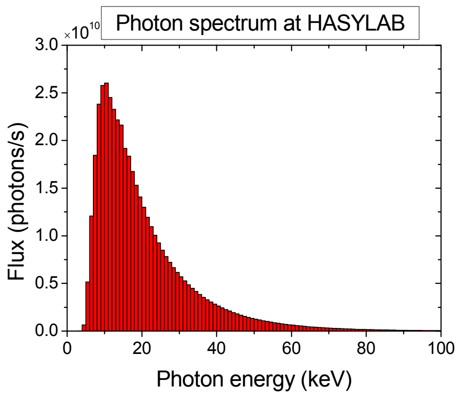


- ~1/100 total capacitance → strip number

Outlook

Irradiation will be performed at HASYLAB beamline F4:

- dose rate variable from 0.5-150 kGy/s
- Beam spot 2×5 mm^2



Next work:

- Above measurements as function of dose D

Acknowledgements

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European XFEL

MC PAD

Contribution submission to the conference Bonn 2010

Characterization and spice simulation of a single-sided, p+ on n silicon microstrip detector before and after low-energy photon irradiation — •Jiaguo Zhang[1,2], Robert Klanner[1], and Eckhart Fretwurst[1] — [1]Institute for Experimental Physics, Detector Laboratory, University of Hamburg, Hamburg 22761 — [2]Marie Curie Intial Training Network (MC-PAD)

As preparation for the development of silicon detectors for the harsh radiation environment at the European XFEL (up to 1 GGY 12 keV X-rays) p+ on n silicon microstrip detectors were characterized as function of dose. The measurements, which include dark current, coupling capacitance, interstrip capacitance and interstrip resistance, are compared to a detailed SPICE model, so that the performance for particle detection can be estimated.

Part:	**T**
Type:	**Vortrag;Talk**
Topic:	**3.04 Halbleiterdetektoren: Strahlenhärte, neue Materialien und Konzepte**
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GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

European XFEL

MC PAD

Characterization and spice simulation of a single-sided, p^+ on n silicon microstrip sensor before and after 12 keV X-ray irradiation

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Outline

- Introduction
- Test sensor and photon irradiation
- Macroscopic characteristics
- Spice simulation
- Summary

Introduction

Next generation light source European X-ray Free Electron Laser (XFEL):

- **Opportunities:** single molecule imaging, movies of chemical reactions, exploration of material science, etc.
- **Challenges:** ***integrated dose ~ 10^9 Gy for E_{photon} ~ 12 keV.***

Main effects on silicon sensors @XFEL:

- **No bulk damage** for E_{photon} < 300 keV.
- ***Surface damage: oxide charges + interface traps***

  ⟶ high electric field → breakdown

  ⟶ increase of leakage current → noise + power dissipation

Will standard Si sensors work in XFEL environment?

- Check performance of available sensors and compare to simulations
- Perform microscopic studies on surface radiation damage, with the aim to understand sensor properties on basis of microscopic radiation effects

Test sensor and photon irradiation

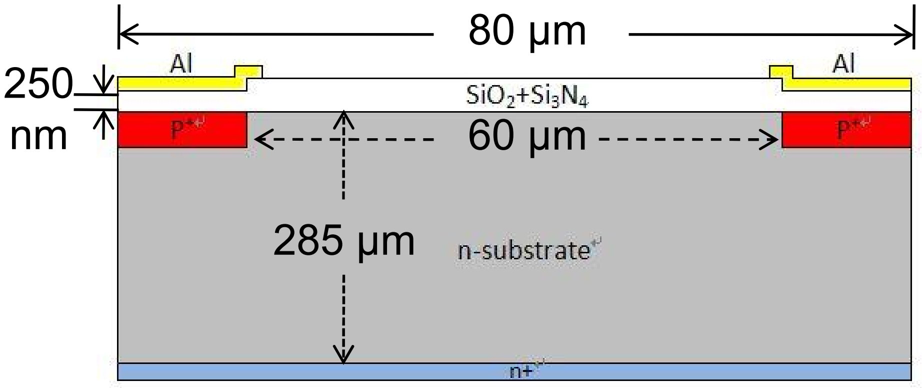


Fig 1. Side view of the test sensor

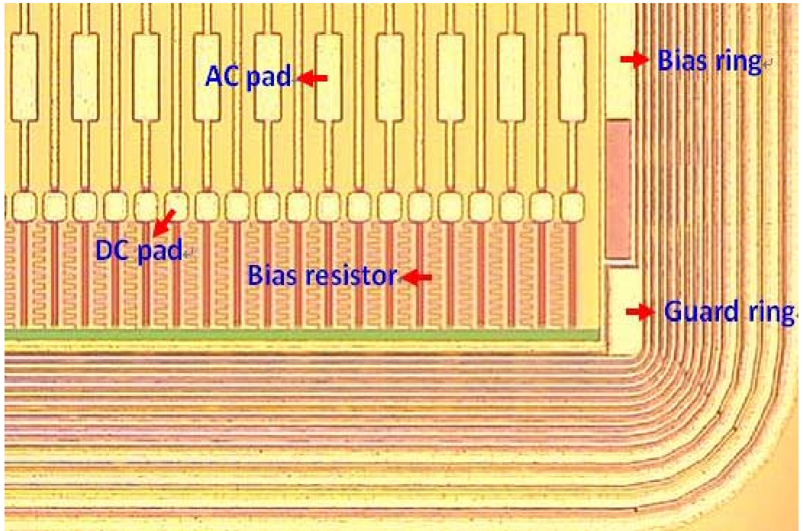


Fig 2. Top view of the test sensor

p^+ on n Si strip sensor:

- <100> n-substrate
- High resistivity: 2 - 5 kΩ·cm
- Thickness: 285 ±10 µm
- Active area: 0.62 cm^2
- “Oxide”: 200 nm SiO_2+50 nm Si_3N_4
- Strip length: 7.8 mm
- Strip pitch: 80 µm
- Strip number: 98

Photon irradiation:

- @DESY DORIS III beamline F4
- ***Typical energy is 12 keV*** (Γ ~10 keV)
- Dose rate in SiO_2: 200 kGy/s
- ***Results for doses:***
  1 MGy, 10 MGy, 100 MGy

Macroscopic characteristics: Total capacitance

CV curve analysis - three stages:

① $V_{bias} < V_{merge}$ (≈ 6V), strips are depleted individually

② $V_{merge} \leqq V_{bias} \leqq V_{dep}$, sensor partially depleted, $1/C^2$ increases linearly with V_{bias}

③ $V_{bias} > V_{dep}$, fully depleted, C ≈ constant.

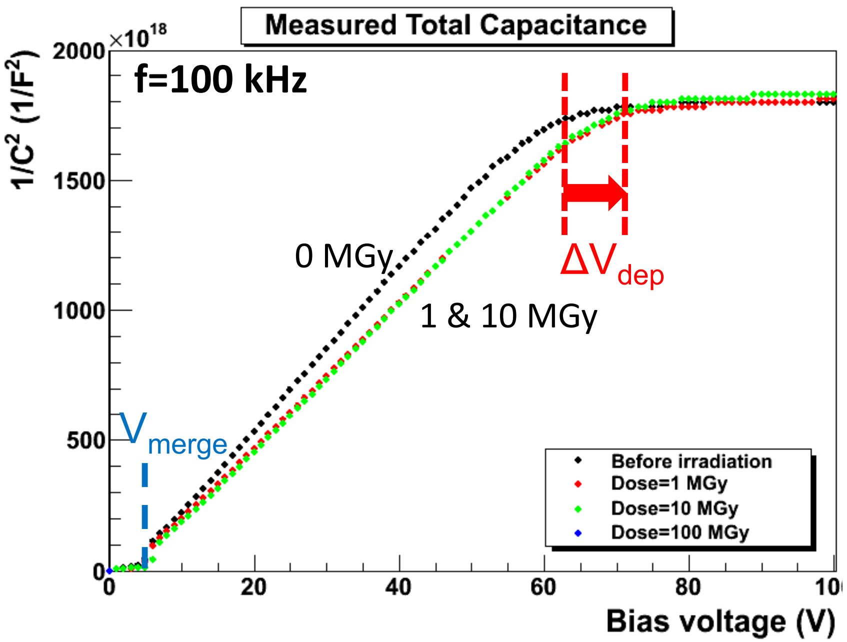


Fig 3. Measured CV curves for different doses

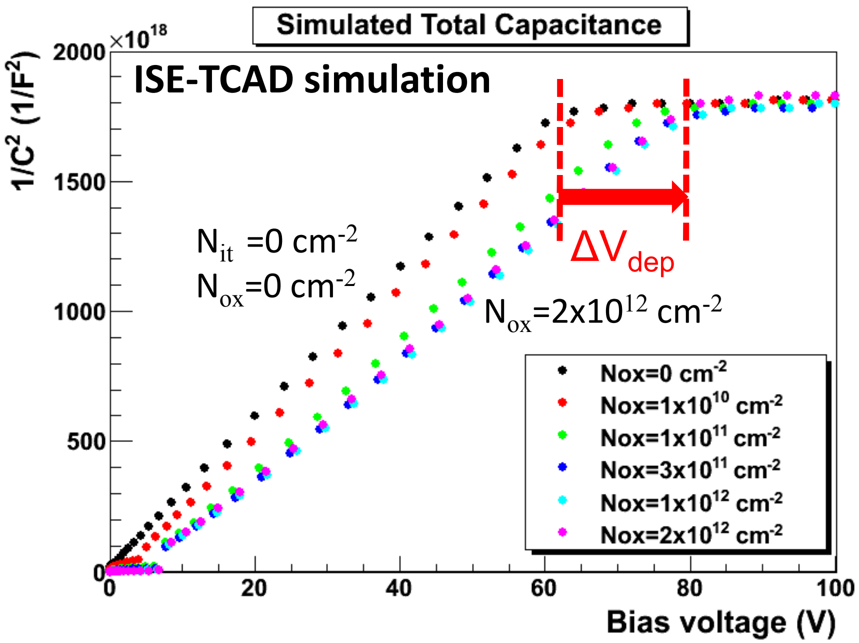


Fig 4. Simulated CV curves for different oxide charge densities

- ***Because of surface charges, V_{dep} increases after irradiations!***
- From simulation, V_{dep} changes with increasing oxide charge density N_{ox}

Macroscopic characteristics: Total capacitance

Accumulated electrons delay increase of depletion depth.

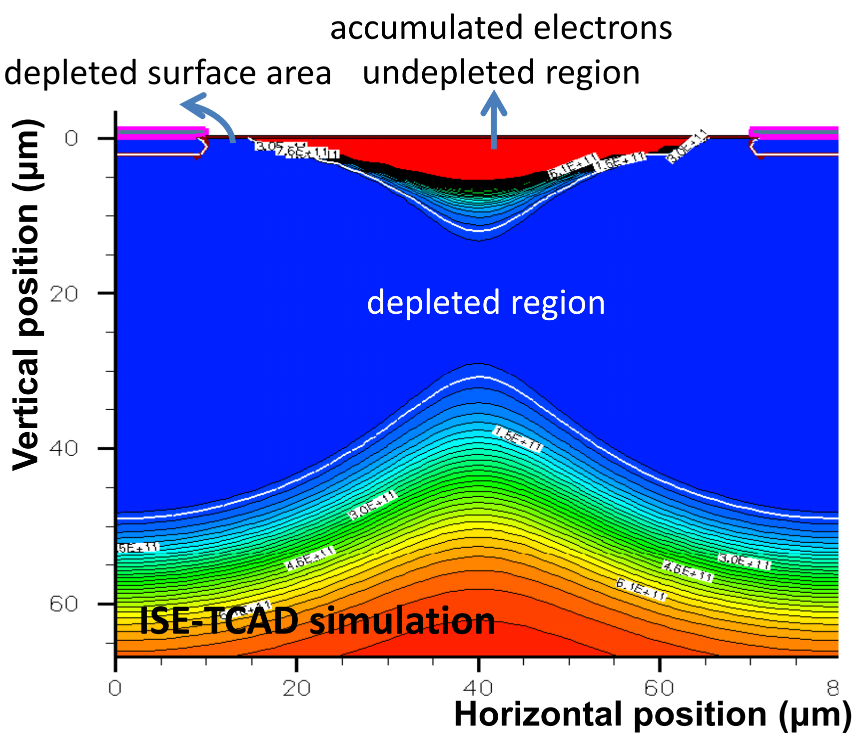


Fig 5. Simulated electrons density distribution

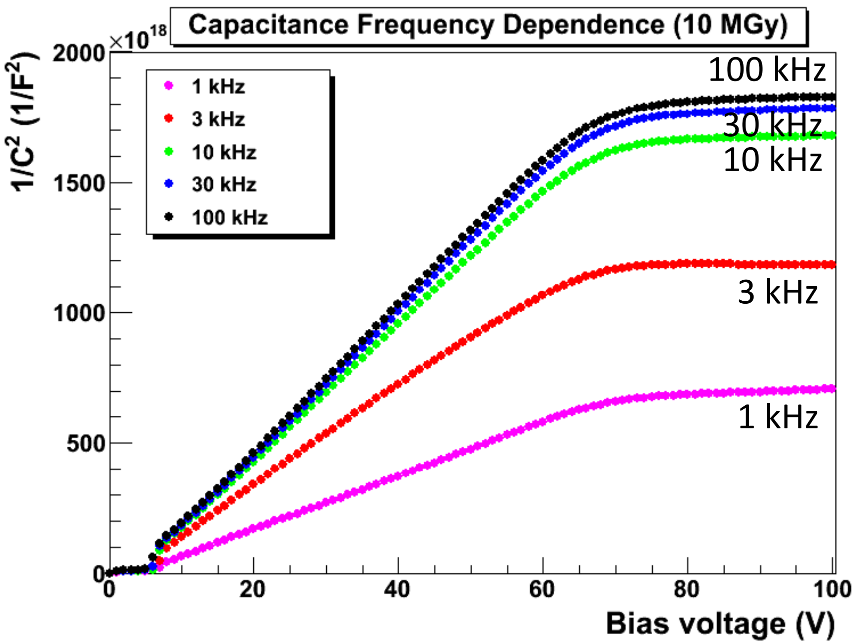


Fig 6. Measured CV curves frequency response

- High frequency → low capacitance
- ***Interface traps are responsible for the change of C with frequency***

Macroscopic characteristics: Leakage current

$I_{leakage} = I_{bulk} + I_{surface}$:

After irradiation → $\Delta I_{leakage} = \Delta I_{surface}$

I_{bulk} depends on ***depleted volume*** of the sensor, and

life time of charge carriers in bulk

No change due to X-ray irradiation.

$I_{surface}$ depends on ***interface trap density*** N_{it}, and

Si-SiO₂ interface depleted area S_{dep}

Changes with X-ray irradiation.

Macroscopic characteristics: Leakage current

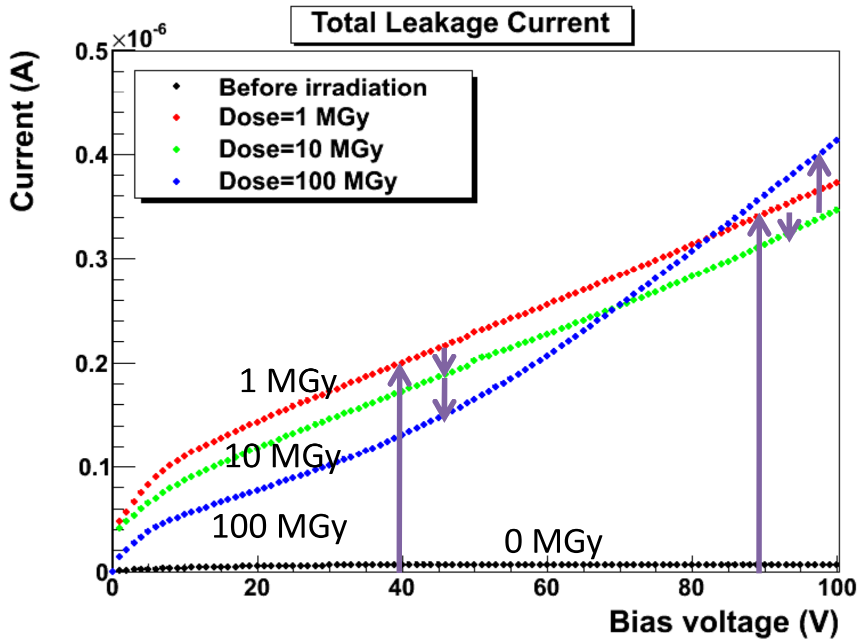


Fig 7. Measured IV curves for different doses

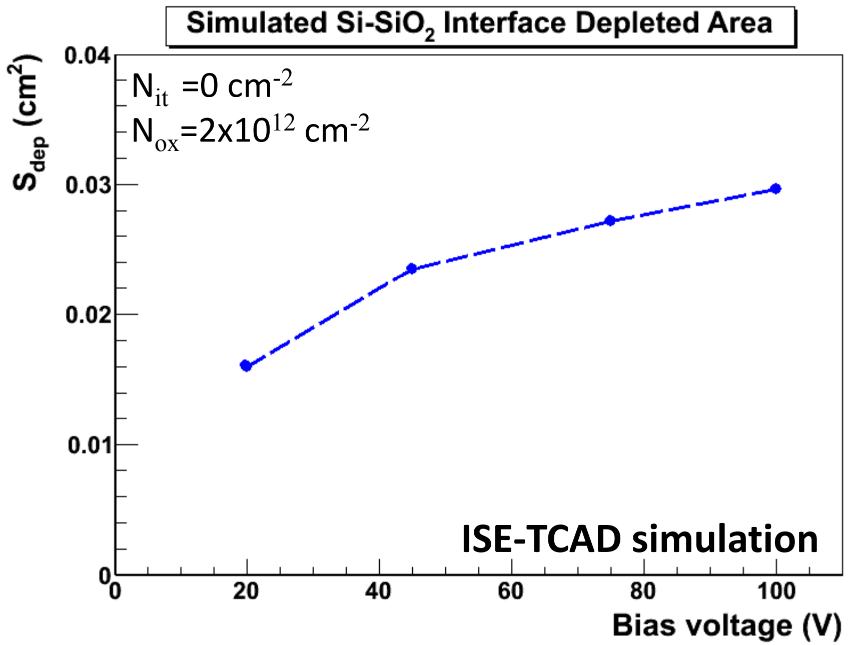


Fig 8. Simulated $Si\text{-}SiO_2$ interface depleted area

- Decrease of $I_{leakage}$ with dose → ***interface trap density N_{it}***
- Increase of $I_{leakage}$ with bias voltage → ***$Si\text{-}SiO_2$ interface depleted area S_{dep}***
- $I_{leakage}/S_{dep} \approx 10\ \mu A/cm^2$ agrees with measurements on gated diodes

More details on TCAD simulation please refer to Ajay's talk.

Spice simulation

Spice model: based on RC network [1)]

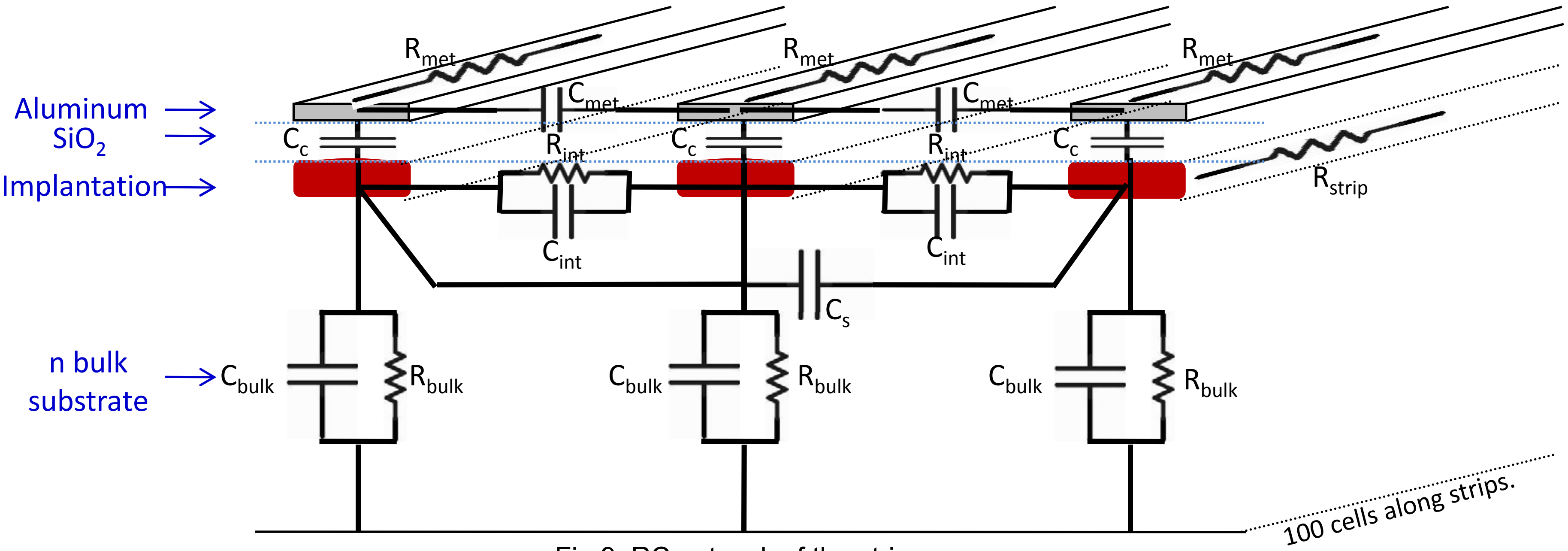


Fig 9. RC network of the strip sensor

- 10 parameters: C_{bulk}, R_{bulk}, C_{int}, R_{int}, C_c, R_{strip}, C_{met}, R_{met}, C_s, R_{bias}
- Able to simulate capacitance and resistance ***frequency response – C(f) & R(f)***
- In this simulation, 5 strips and 100 cells are used ~ 80 µm/cell

1) M.M. Angarano, et al. Nucl. Instru. & Methods, Vol. 428, No.2, 1999

Compare spice simulation to measurements

Total bulk, interstrip and coupling impedances *) :

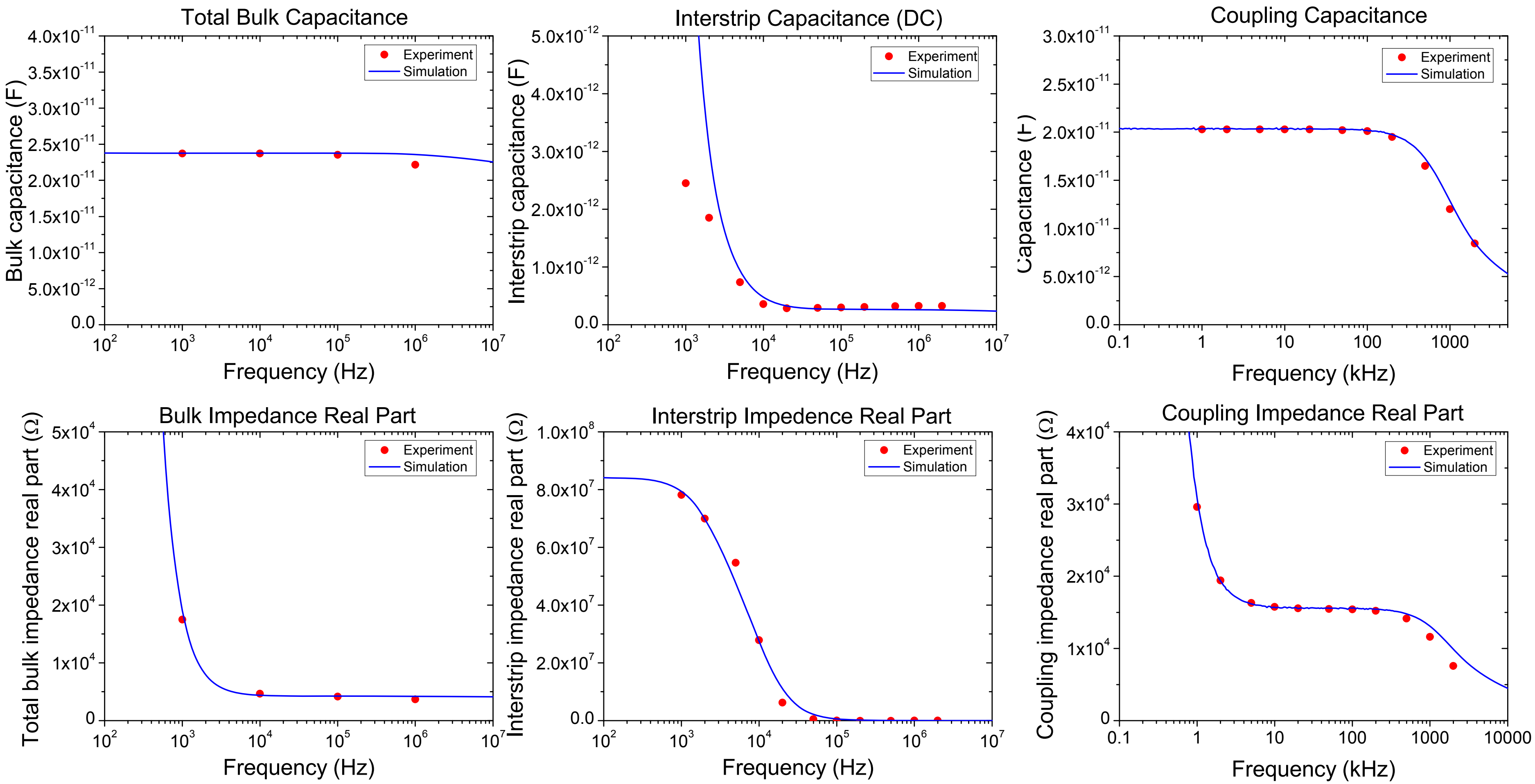


Fig 10. Comparison between spice simulation and experiment

Because of the presence of interface traps, this simple model won't work for irradiated sensor.

*) Series mode

Summary

Summary:

• Detailed characterization of p^+ on n Si strip sensor for 0, 1, 10 and 100 MGy

— Data described by Spice model for 0 MGy

— Irradiation

$\Longrightarrow$ Increase of N_{ox} → Change of depletion voltage

$\Longrightarrow$ Change of N_{it} → Change of leakage current

Changes can be described by ISE-TCAD simulation

• Tentative conclusion: p^+ on n sensor can work up to dose ~ 100 MGy

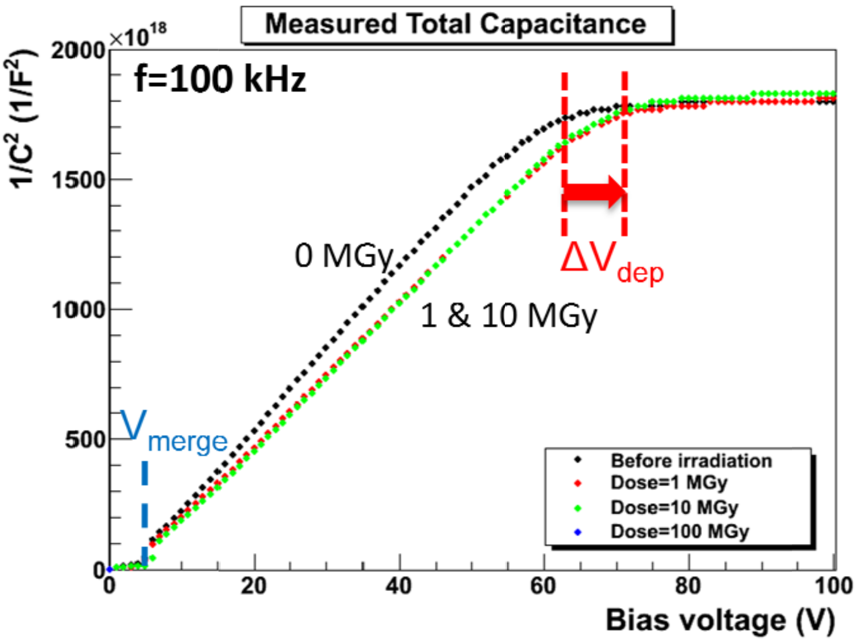
Thanks for your attention!

Proposal for DORIS III beamline F4

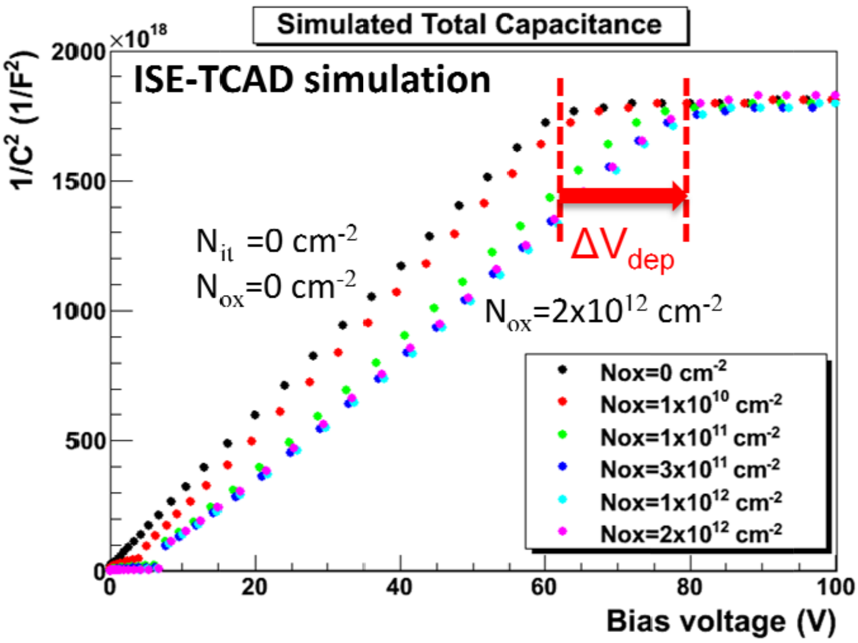
The next generation light source European X-ray Free Electron Laser (XFEL) provides a lot of opportunities for scientific research, for example, deciphering the molecular composition of cells, taking three-dimensional images of the nano world, filming chemical reactions and studying the processes in the interior of planets, and so on. Science at European XFEL requires precise pixel detectors which need to withstand an integrated dose of up to ~ 1 GGy of 12 keV X-ray (10^{16} photons/pixel) for three-year operation [1, 2]. The final goal of the present work is to develop radiation hard silicon pixel sensor for Adaptive Gain Integrating Pixel Detector (AGIPD) at XFEL [3].

In XFEL environment, no bulk damage happens to the silicon sensor of Adaptive Gain Integrating Pixel Detector for photon energy lower than 300 keV. Surface damage dominates the change of properties of silicon sensor. Oxide charges and interface traps will be built-up in the SiO_2 and $Si\text{-}SiO_2$ interface, respectively. The former induces high electric filed in the sensor, which may lead to breakdown; whereas the latter increases leakage current, which may generate power dissipation and introduce noise in the read-out signal. Therefore, both microscopic radiation damage study and macroscopic property investigation should be performed for sensor design of AGIPD.

For the last past year 2009, we finished systematic study of a p^+ on n silicon microstrip sensor. This microstrip sensor was irradiated by 12 keV X-ray (imitation of XFEL environment) with 1, 10 and 100 MGy high doses at DESY DORIS III beamline F4. The results have been analyzed and compared to TCAD simulation. The experimental results can be reproduced by simulation, which gives us confidence to “predict” macroscopic behaviors of silicon sensor for other designs.



Measured CV curves for different doses



Simulated CV curves for different oxide charge densities

The above totally new (at least beyond our imaginations) example is the measured and simulated CV curve of the silicon microstrip sensor before and after irradiations. An obvious behavior – increase of full depletion voltage – can be observed, which may indicate an increase of substrate doping concentration by normal formulas. But surface charges have no the ability to change “bulk” doping concentration from the understanding of surface radiation damage. TCAD simulation reproduced the measured CV curve and gave the answer why the full depletion voltage changes with irradiation doses (one un-depleted region close to the Si-SiO_2 interface forms due to the attraction of positive oxide charges in the SiO_2 dielectric layer).

After the detailed investigations of p^+ on n silicon sensor, a study on n^+ on n silicon sensor is expected. The will-be tested n^+ on n structures include NMOS transistors and 6 by 6 pixel sensors. The NMOS transistors are used to observe p-spray charges as function of dose, which probably give an indication that how large dose to use for the design of new AGIPD detector if n^+ on n sensor is chosen as the final fabricated sensor; the 6 by 6 pixel sensors will be used to investigate inter-pixel isolation – including inter-pixel resistance and capacitance (if possible, it is hard to measure due to very small value).

After completely comparing advantages and disadvantages of p^+ on n and n^+ on n silicon sensors, a conclusion on sensor design will be draw from radiation hardness point of view. And suggestion on sensor fabrication can be provided according to these studies.

References:

[1] E. Fretwurst, et al, *“Study of the Radiation Hardness of Silicon Sensors for the XFEL”*, poster presented at IEEE NSS 2008, Dresden, Germany, Conference record N30-400.

[2] E. Fretwurst, et al, *“Radiation damage studies for silicon sensors for the XFEL”*, conference paper accepted by Nucl. Instr. And Meth. A.

[3] P. Göttlicher et al. (AGIPD collaboration), *“The Adaptive Gain Integrating Pixel Detector (AGIPD): A Detector for the European XFEL: Development and Status”*, poster presented at IEEE NSS 2009, Orlando, Florida, USA, N25-239.