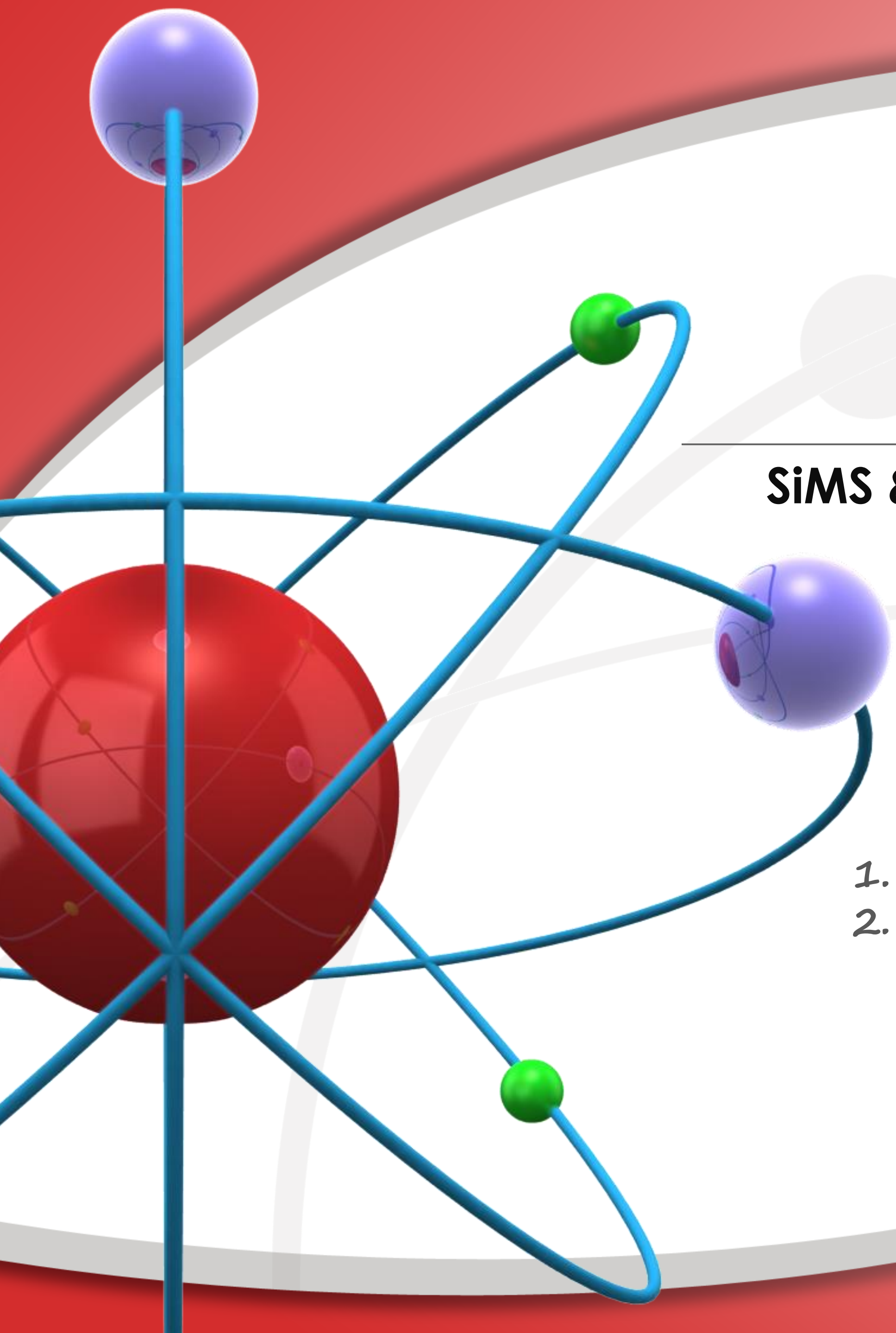

Doping Profile

SiMS & SRP Measurements & Irradiations

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RD50 Workshop - CERN

Overview

Introduction

Concept and Goals
A complete comprehensive development method

SiMS

SiMS principle and test run
Test wafer production and measuring

n-in-n test wafers

CiS n-in-n test wafers production
Measurements, modeling and oxide simulations

n-in-p test wafers

ADVACAM n-in-p test wafers
Measurements and through oxide tests

P-spray wafers

P-spray low resistivity wafers
Through oxide measurements and resolution issues

SRP measurements

First SRP measurements
First results on high and low resistivity wafers

Conclusion and plans

Further plans and future updates

•Concept and Goals

3D Simulated doping profiles

Uniformly doped wafers:

- **Controlled parameters**
  1. **Implantation dose and energy**
  2. **Screen oxide thickness and annealing**
- **Simplicity in simulation and study**
  1. **No geometrical effects**
  2. **Single implant and oxide layer**

Simulations

√ SYNOPSYS TCAD simulator

√ Fabrication and implantation process simulation

√MC full cascade and damage calculation

√Exact processing parameters from foundries

√Thermal stresses and diffusion

√ Cross-check with different models and simulators

Measurements

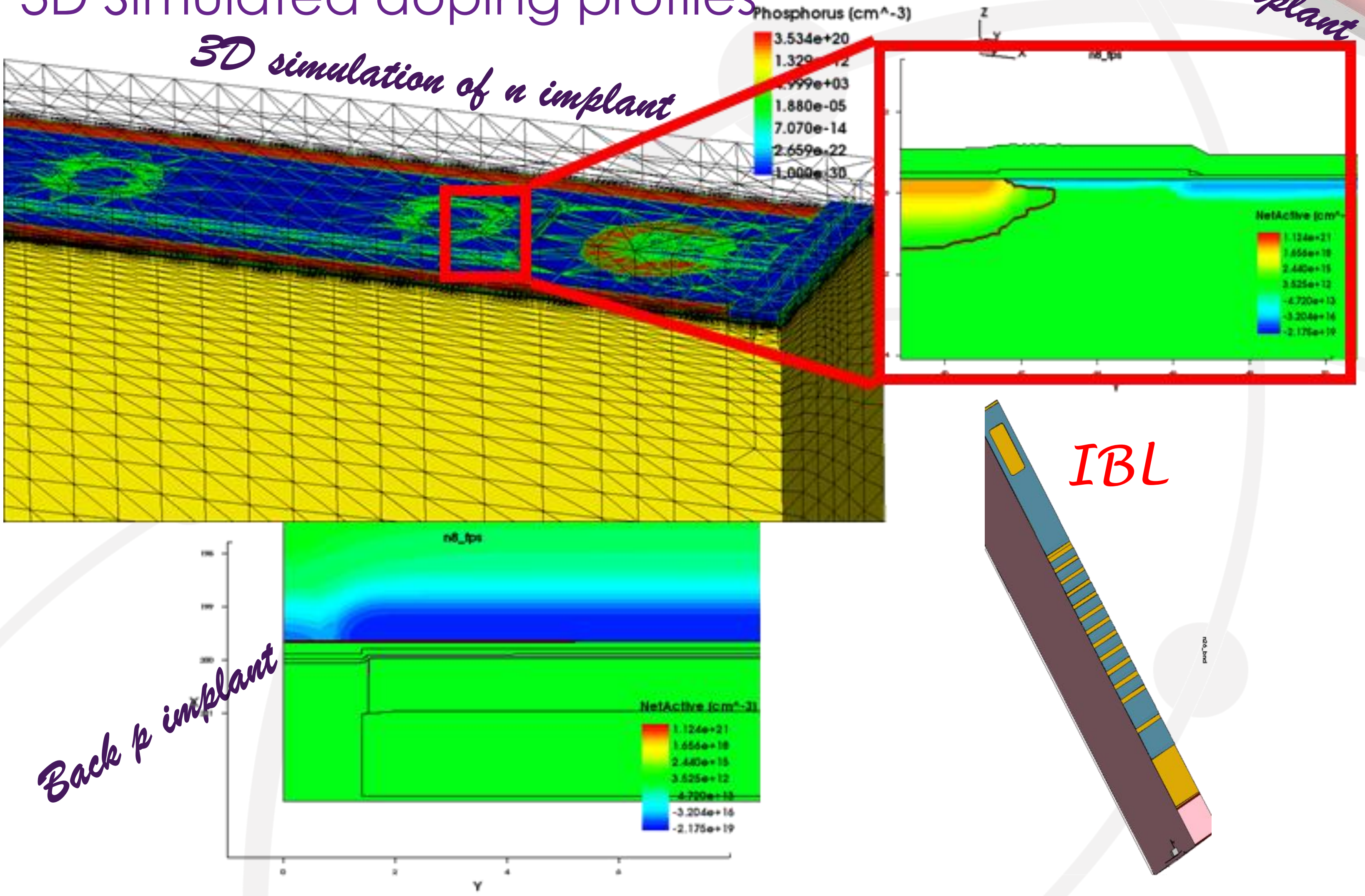
√SiMS—Secondary ion mass spectroscopy

√SRP—Spreading Resistance

√ SSRM—Scanning Spreading Resistance Microscopy

•Concept and Goals

3D Simulated doping profiles



3D simulation of n implant

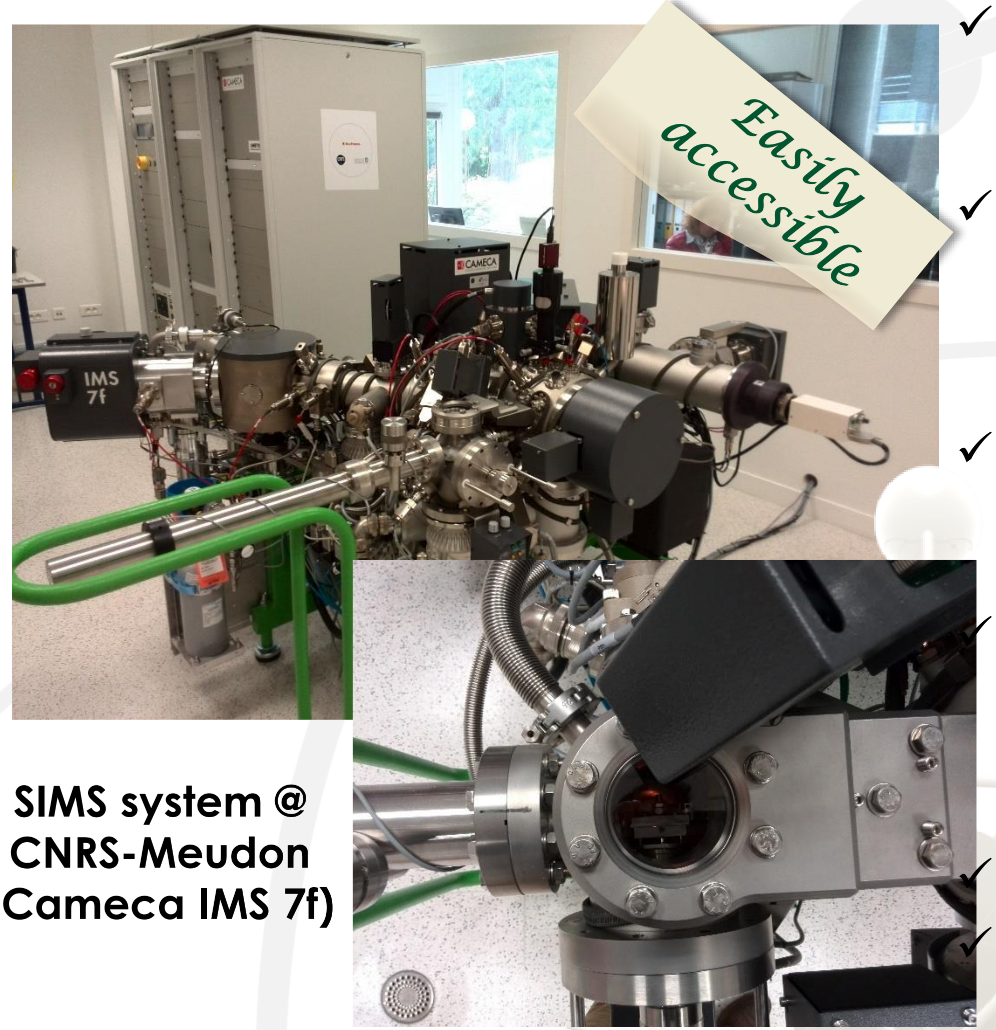
Front n implant

Back p implant

IBL

•SiMS

SiMS Method @ Versailles



SIMS system @ CNRS-Meudon (Cameca IMS 7f)

- ✓ Analytical technique to *characterize the impurities in the surface and near surface (~10μm) region*
- ✓ Relies on sputtering of a *primary energetic ion beam (0.5-20 keV)* on sample surface and analysis of produced ionized secondary particles by mass spectrometry
- ✓ Good detection sensitivity for many elements: *it can detect dopant densities as low as 10^{13} cm^{-3}*
- ✓ Allows multielement detection, *has a depth resolution of 1 to 5 nm* and can give a lateral surface characterization on a scale of several microns
- ✓ Destructive method,
- ✓ It determines the *total dopant density profile*

•SiMS

Sample preparation

Sample preparation

- Sample preparation
  - Wafer Dicing (Uniformly doped wafers of 4" and 6", not thinned)
  - Chemical oxide etching for non pure bulk measurements
  - No etching for through-oxide measurements
- Future plans
  - Investigation of oxide layer thickness with respect to etching rates and time
  - AFM Measurements
  - SiMS on the High resistivity Wafers

Sample preparation and measurements

- Nicoleta Dinu
- Sorin Dumitriu
- Francois Jomard

•SiMS

CiS and ADVACAM wafer test runs

N in N

N in N, CiS production, <100> orientation														
Oxide thickness	100 nm							200 nm						
P implantation doses	10^{13} cm^{-2}		10^{14} cm^{-2}		10^{15} cm^{-2}		10^{16} cm^{-2}	10^{13} cm^{-2}		10^{14} cm^{-2}		10^{15} cm^{-2}		10^{16} cm^{-2}
Implantation energy (keV)	130	240	130	240	130	240	130	130	240	130	240	130	430	130
Annealing	4hours, 975 °C													

- ✓ $\rho = 0.25$ Ω/cm (3 x10^{16}/cm^3) 380μm thickness
- ✓ $\rho > 4$ kΩ/cm (1,1 x10^{12}/cm^3) 525μm thickness

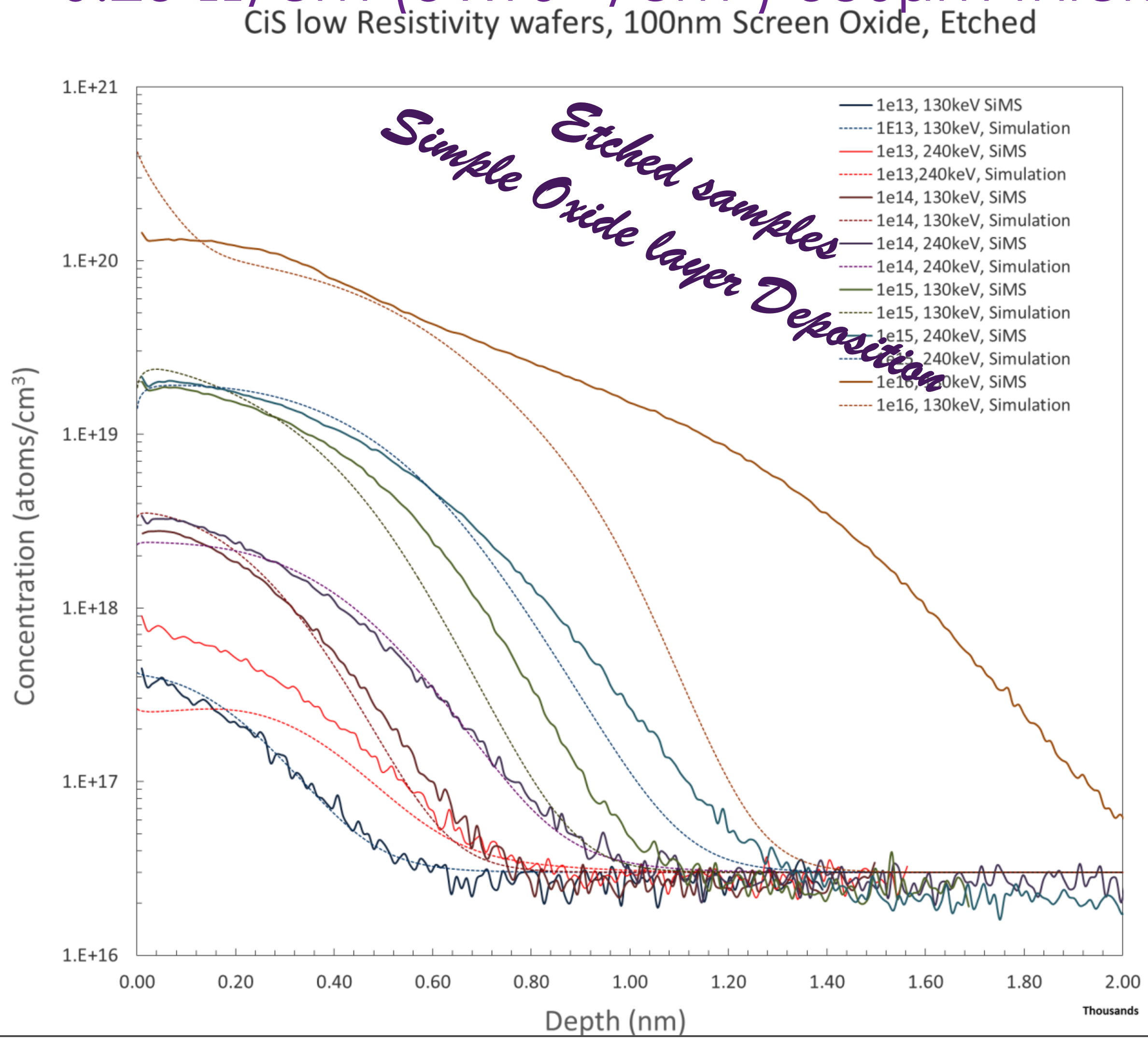
N in P

N in P, ADVACAM production, <100> orientation, thickness of 675 μm or less,																
Oxide thickness	100 nm								200 nm							
P implantation doses	10^{13} cm^{-2}		10^{14} cm^{-2}		10^{15} cm^{-2}		10^{16} cm^{-2}		10^{13} cm^{-2}		10^{14} cm^{-2}		10^{15} cm^{-2}		10^{16} cm^{-2}	
Implantation energy (keV)	130	240	130	240	130	240	130	240	130	240	130	240	130	240	130	240
Annealing	3hours, 1000 °C (1h annealing + 1h wer oxidation +1h dry oxidation)															

- ✓ $\rho = 10$ kΩ/cm (1.1 x 10^{12}) - 525μm thickness
- ✓ $\rho = 0.2 – 0..25$ Ω/cm (2.5 – 3 x 10^{16}) – 675μm thickness

•n-in-n test wafers

ρ = 0.25 Ω/cm (3 x10^{16}/cm^3) 380µm thickness (n in n)

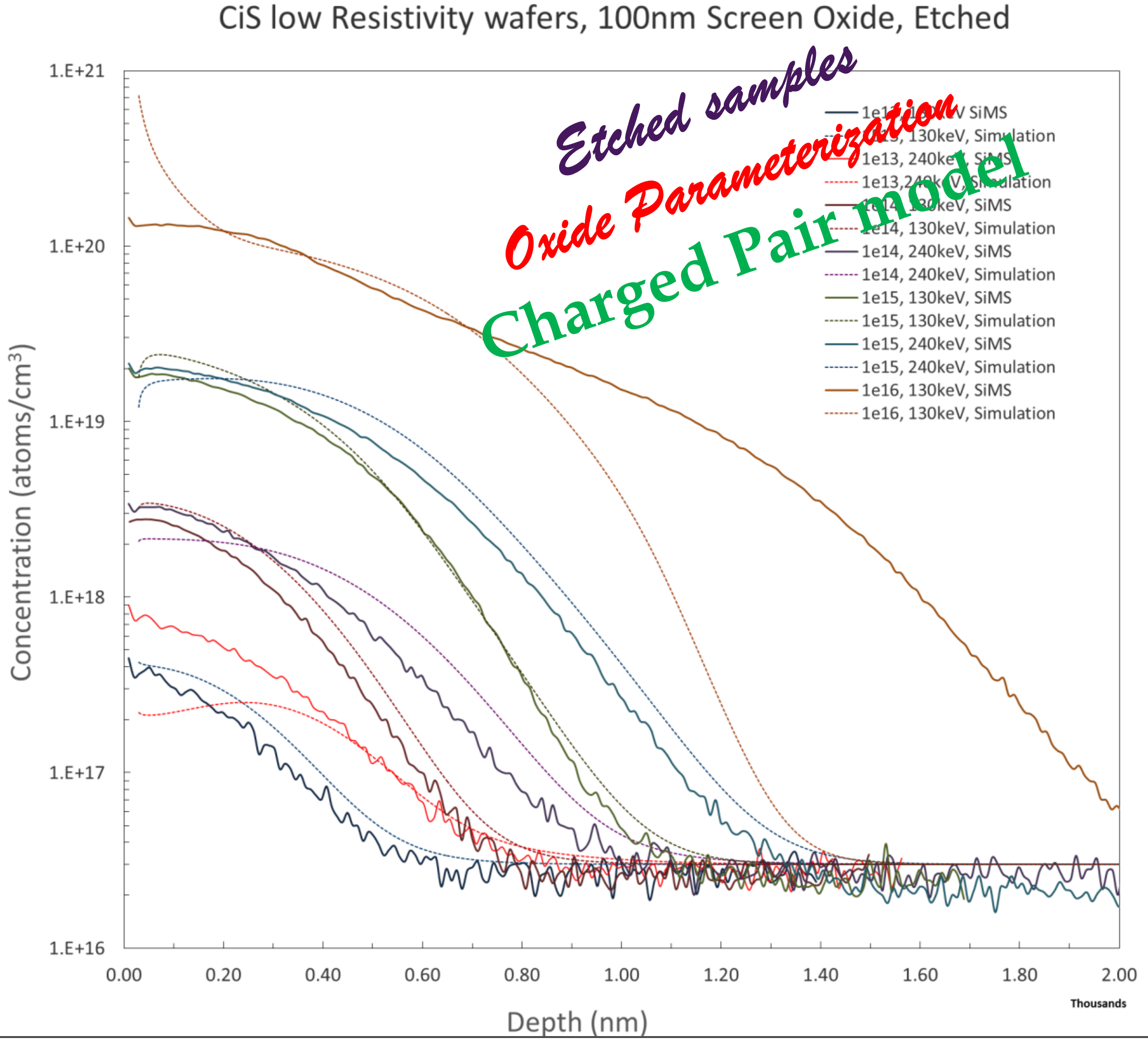


1. **Synopsys MC Crystal TRIM full cascade simulator**
2. **Final oxide layer etching step implemented**
3. **Normal thermal annealing for implant activation**

- Overall good agreement for low doses
- Pronounced systematic deviations in measured implant depth for higher dose samples
- Simulation shows shallower profile than actual samples
- Surface Effects

•n-in-n test wafers

$\rho = 0.25\ \Omega/\text{cm}\ (3 \times 10^{16}/\text{cm}^3)$ 380µm thickness (n in n)



Etched samples

Oxide Parameterization

Charged Pair model

1. **No oxide deposition but real oxidation process simulation**
2. **Exact steps implemented from CiS process flow**
3. **MC Crystal TRIM implantation**

!!!!!!!!!!!!!!!!!!!

- No systematic deviations
- Statistical disagreements of same order for all samples
- An effect with highest dose sample
- Second dose sample possible measuring or homogeneity effect

•n-in-n test wafers

Synopsys and SILVACO diffusion Modeling

- ❖ **Disagreements on high dose profiles**
- ❖ **Small deviations in lower doses, which become significant with dose increase**

Diffusion Model tuning

SILVACO

- Fermi Model
- 4 CPL Model (clustering consideration)
- PLS Solid State Model

Synopsys

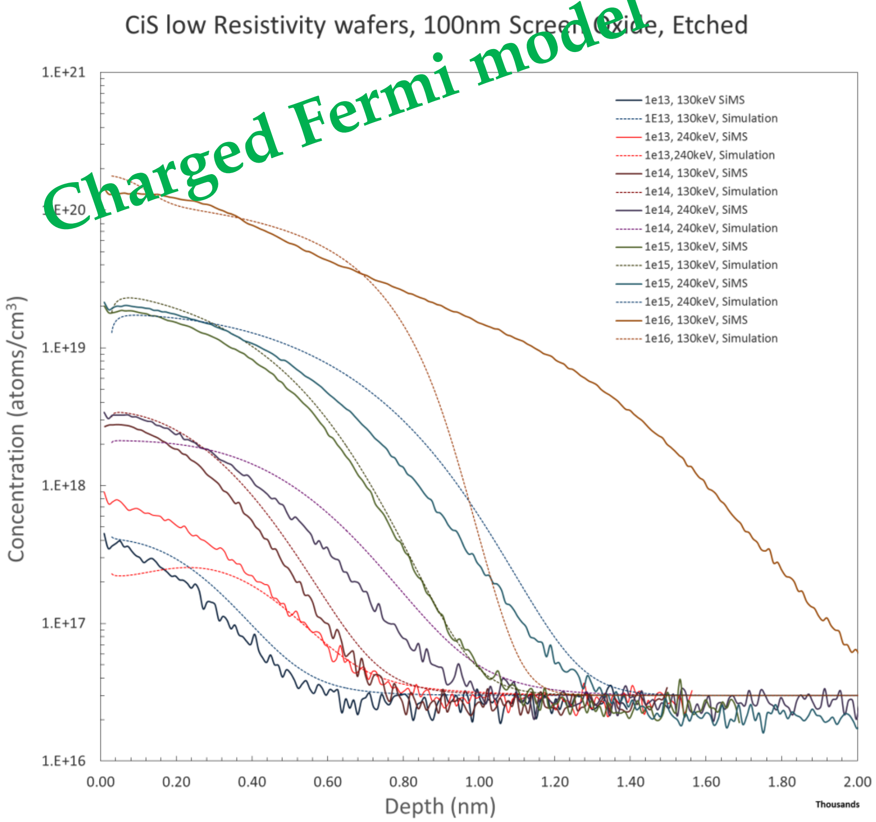
- Charged Fermi model
- Charged Pair Model
- Constant Model
- Charge React Model

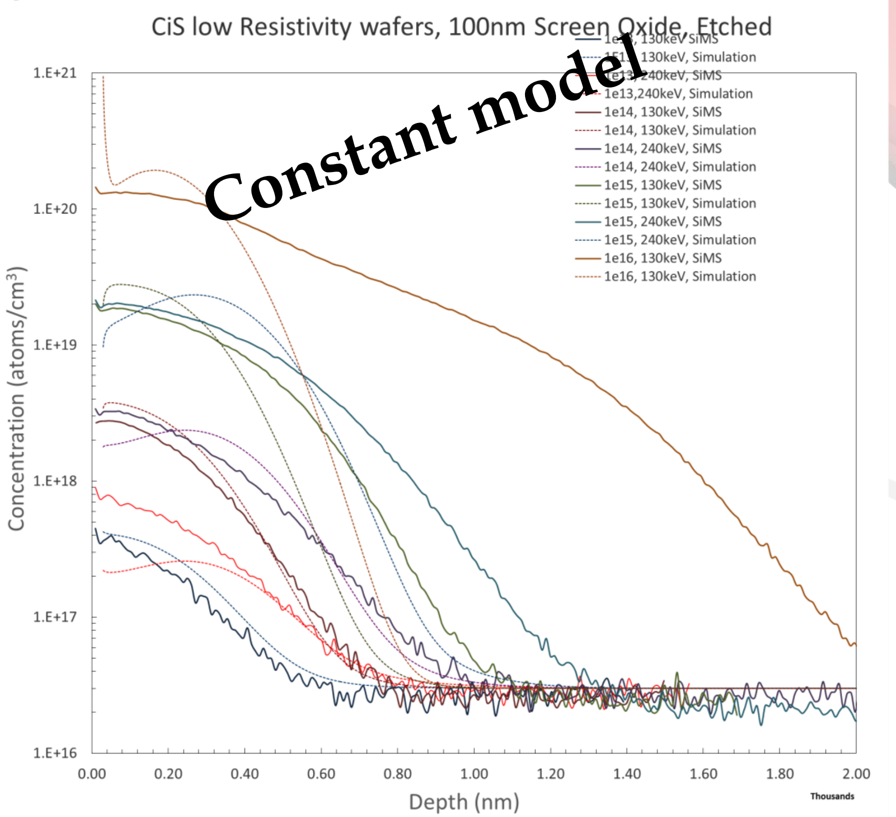
Notes:

Default Synopsys model is Charged Pair while default SILVACO is Fermi
Synopsys-SILVACO comparison only for the highest dose

•n-in-n test wafers

Synopsys Diffusion models comparison

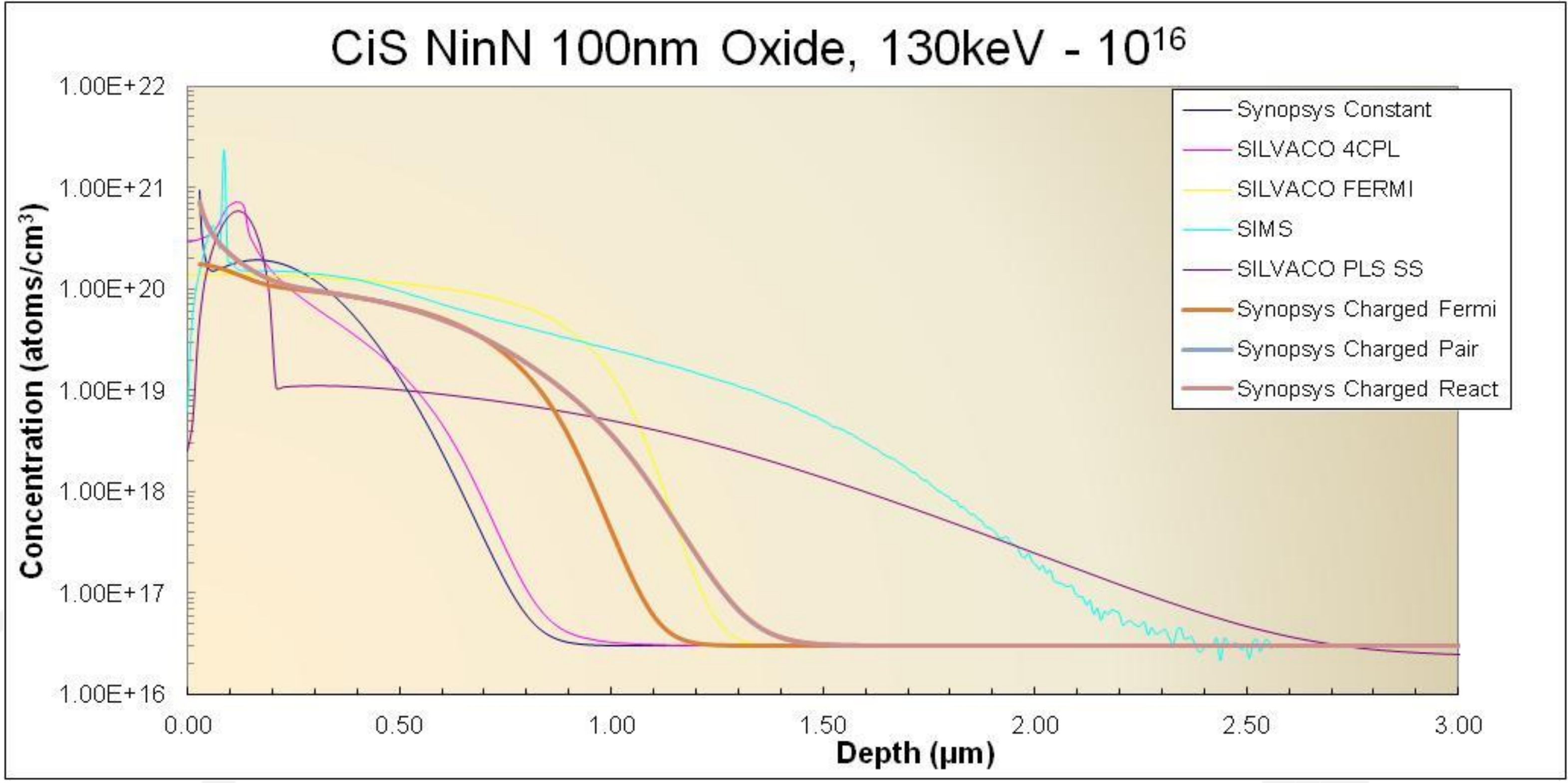

Charged Fermi model


Constant model

- Charged Pair and Charged React model in these conditions give similar results
- No model gives adequate agreement for highest dose
- Standard model seems to quite good for intermediate and low doses

•n-in-n test wafers

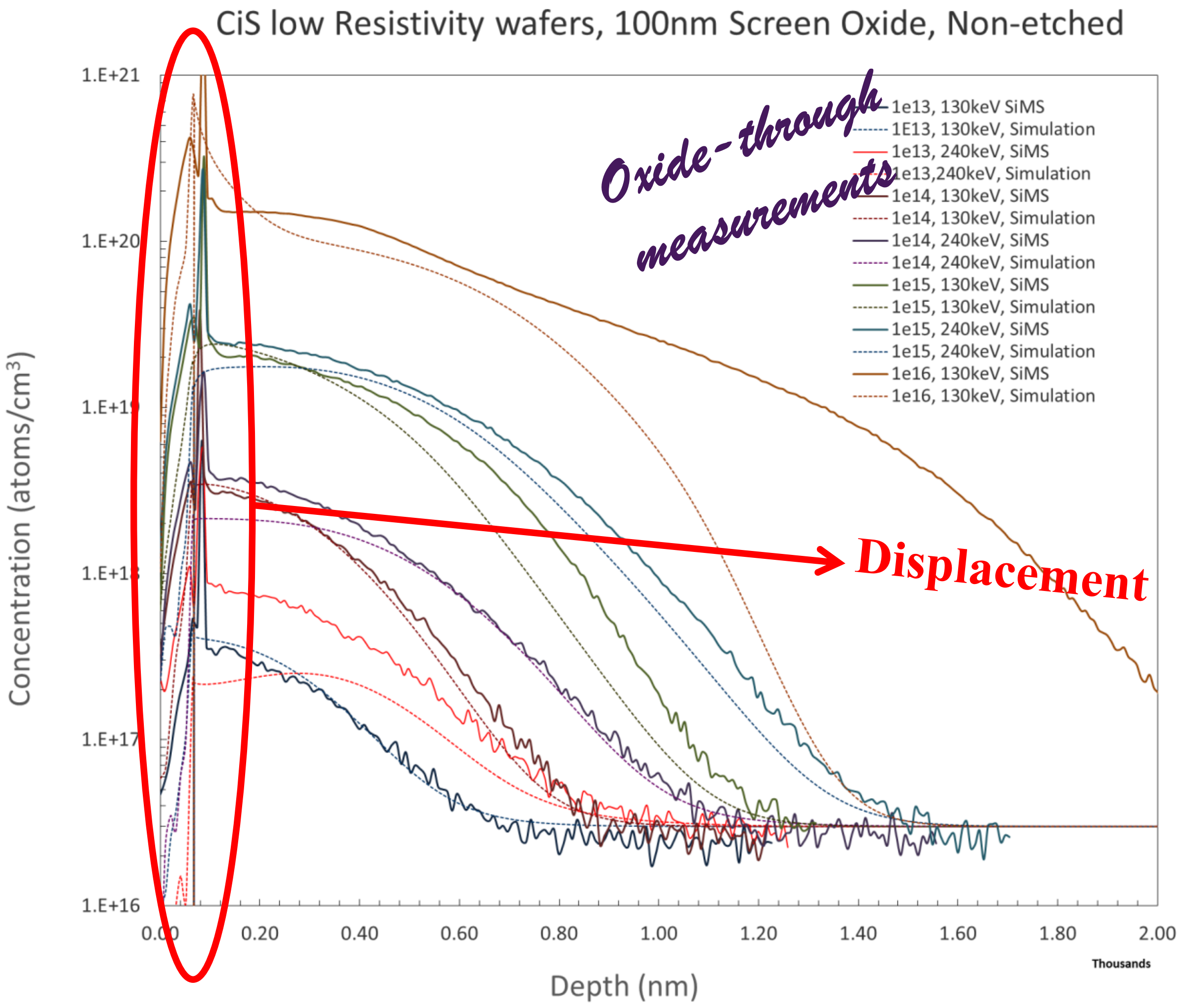
Synpsys-SILVACO high dose comparison



- No single model validated for doses over 10e15
- All frameworks give significantly shallower profiles than measurements
- SILVACO seems to give a better in depth description but needs adjustments in surface

•n-in-n test wafers

ρ = 0.25 Ω/cm (3 x10^{16}/cm^3) 380μm thickness (n in n)



CiS low Resistivity wafers, 100nm Screen Oxide, Non-etched

Oxide-through measurements

Displacement

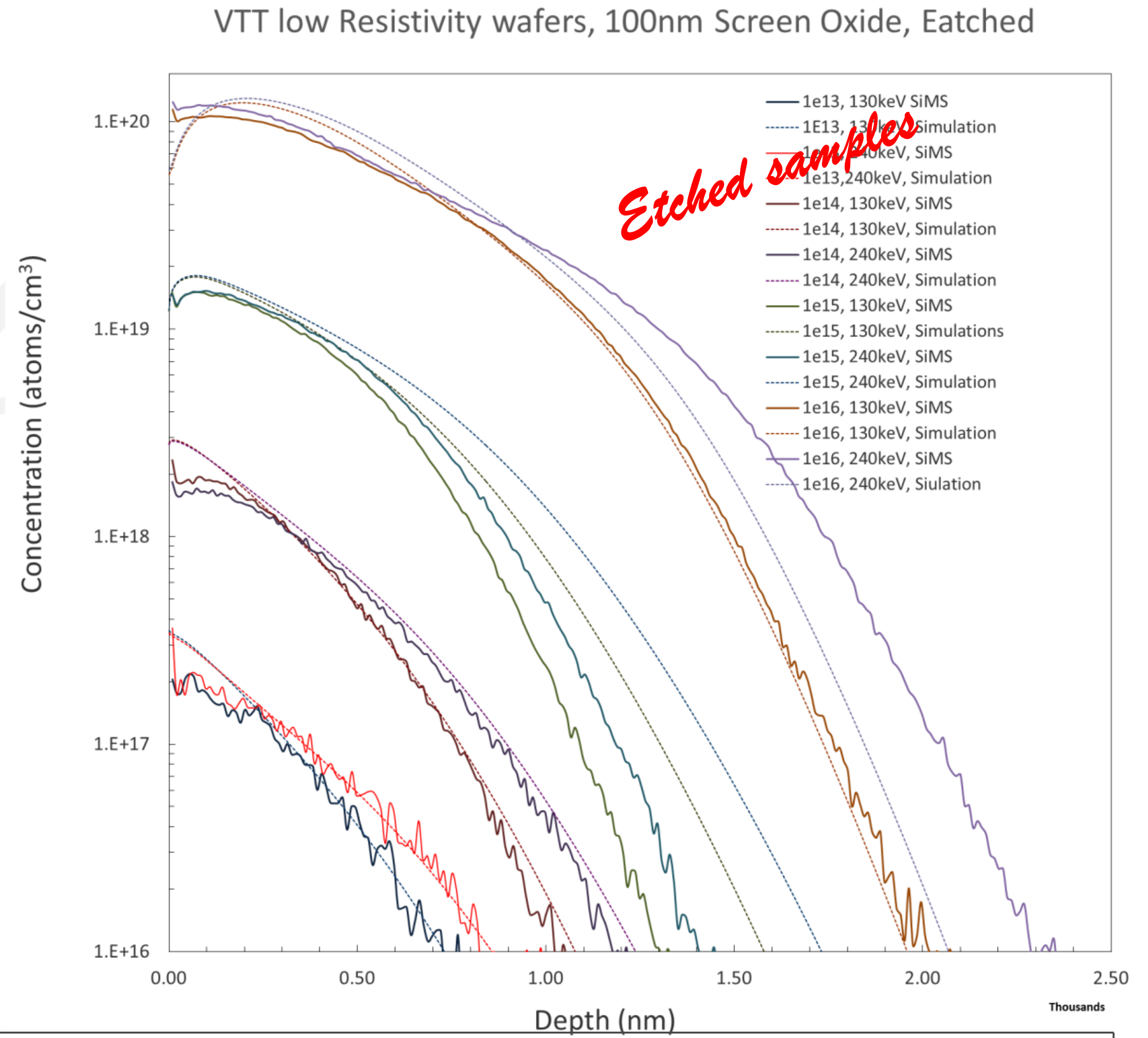
- ✓ Same profile form as in the etched samples validates measurements
- ✓ Displacement of the oxide peak between SiMS-Simulations

- ▪ **Ion beam velocity different in oxide and Silicon**
- ▪ **Difference not taken into account**
- ▪ **Correction to be applied**

•n-in-p test wafers

ρ = 0.25 Ω/cm (3 x10^{16}/cm^3) 675µm thickness (n in p)

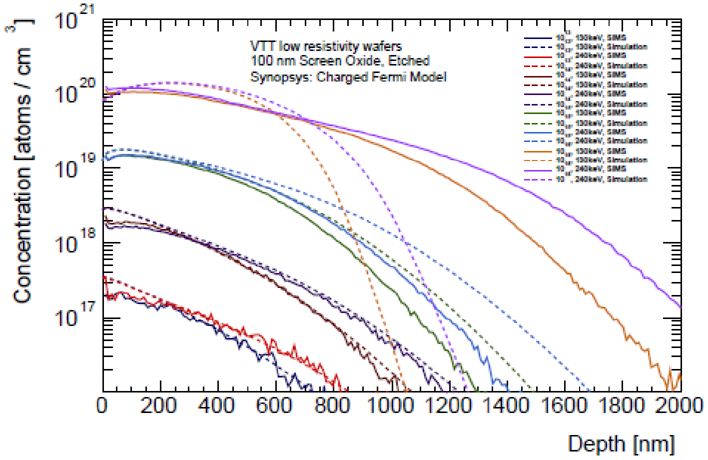
- ❑ Simulations have been displaced towards 0 to compensate for oxide growth
- ❑ Advacam uses annealing through oxidation
- ❑ Dry + wet oxidation that really ‘eats-up’ dopant
- ❑ Oxide removed for SiMS
- ❑ Simulated oxide diffusion and complete oxidation

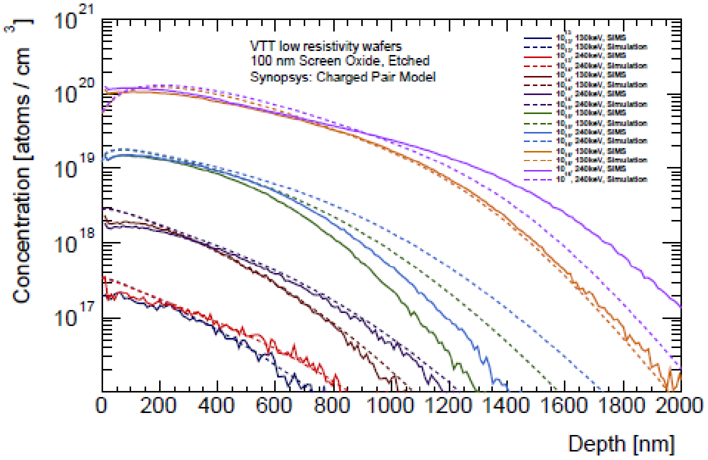


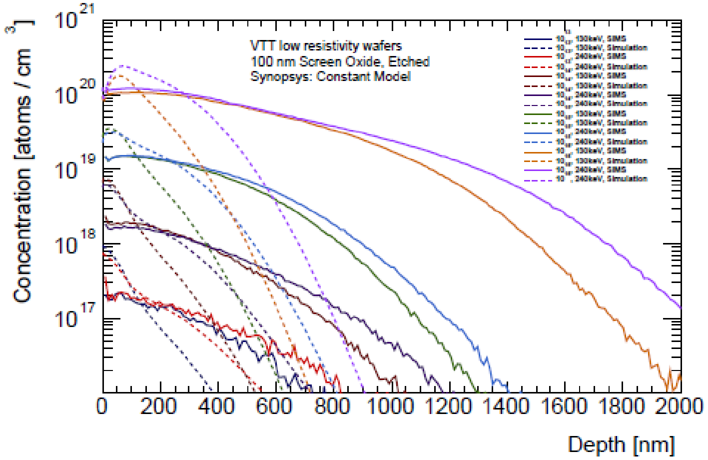
Etched samples

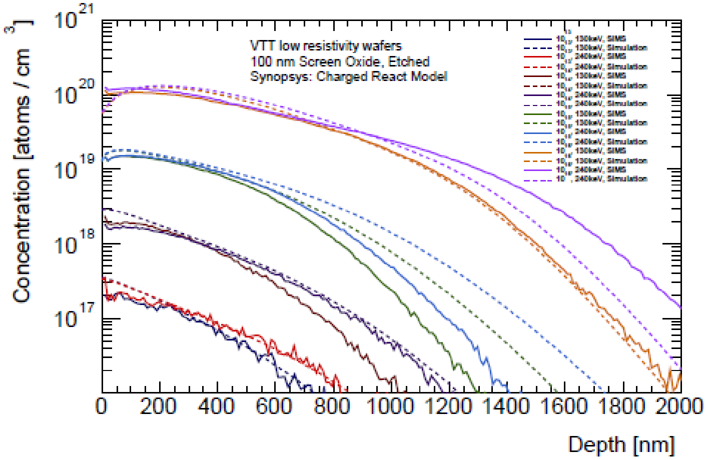
•n-in-p test wafers

ρ = 0.25 Ω/cm (3 x10^{16}/cm^3) 675μm thickness (n in p)









•n-in-p test wafers

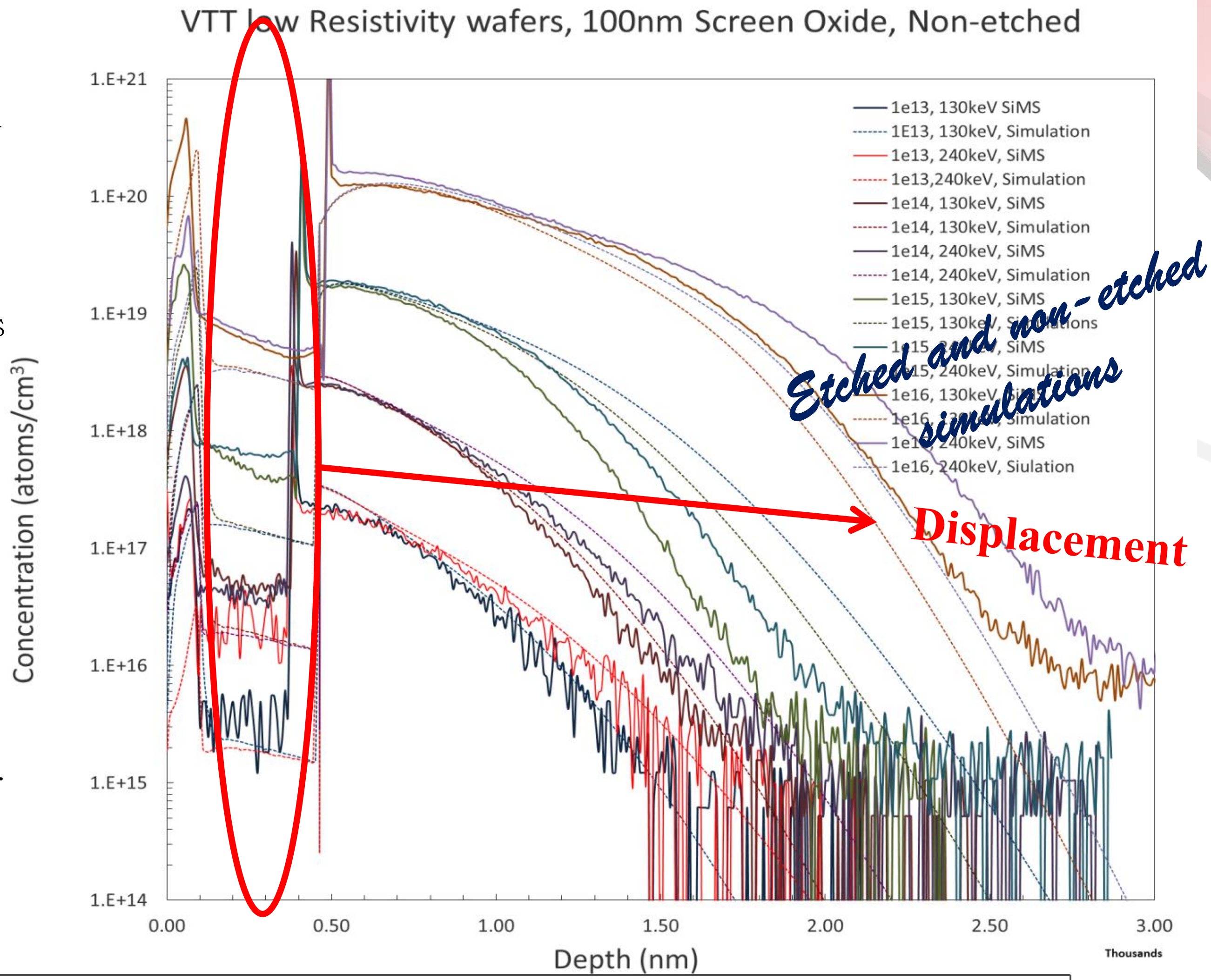
ρ = 0.25 Ω/cm (3 x10^{16}/cm^3) 675μm thickness (n in p)

Remarks

- Overall good agreement on the low and intermediate doses
- Disagreement on the profile distribution for the higher- intermediate doses but almost perfect agreement for one of the highest ones
- Deviation trend between simulation – SiMS exhibits contradicting behavior

Wafer – annealing uniformity??

- No difference expected for etched – non-etched samples



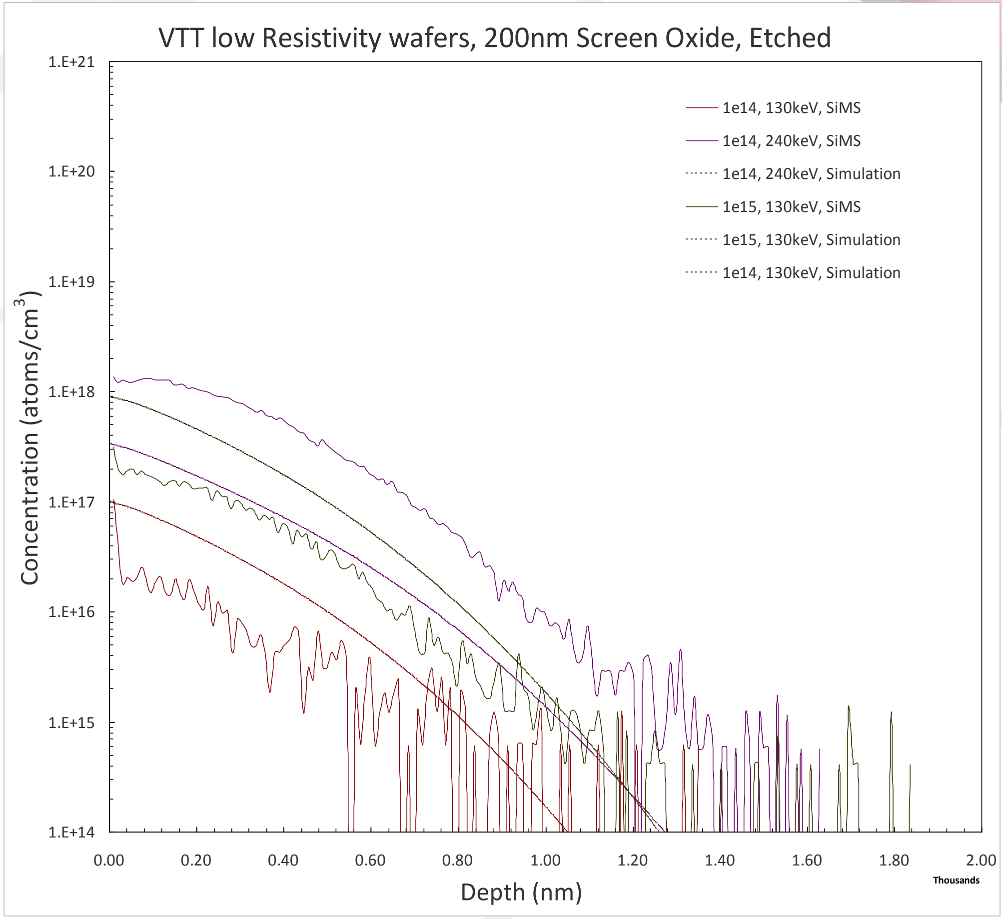
Etched and non-etched simulations

Displacement

•n-in-p test wafers

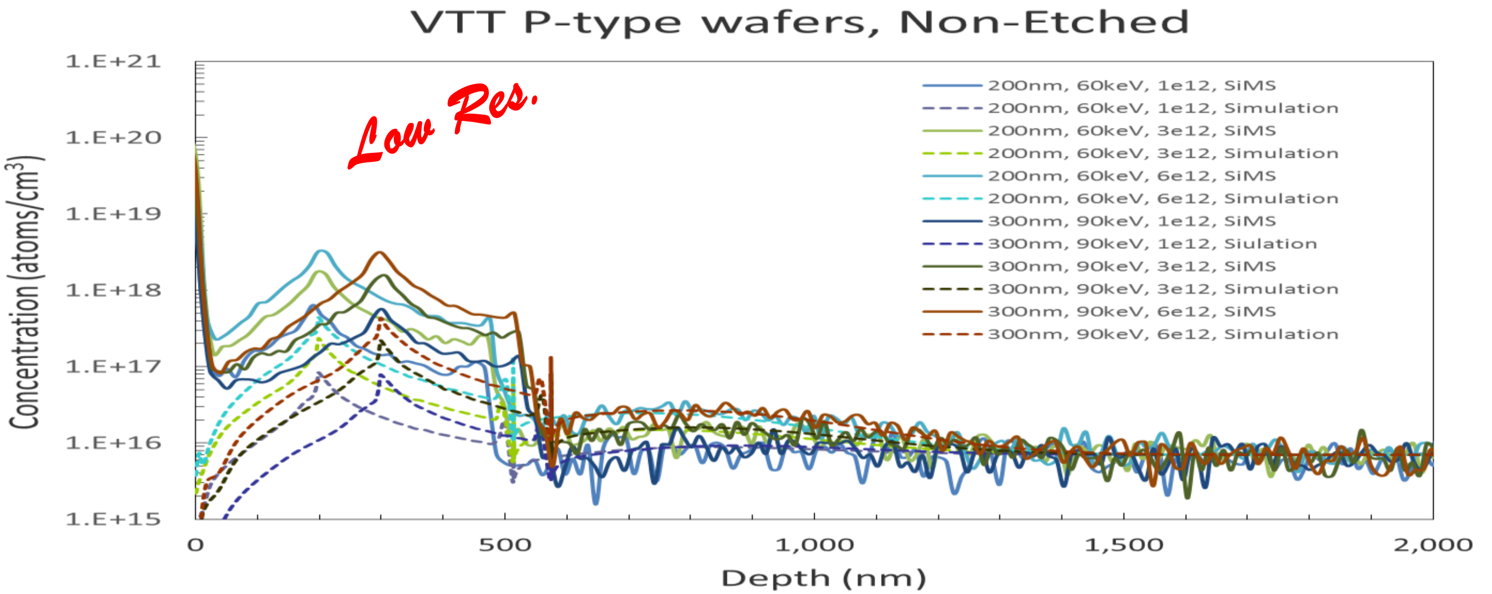
ρ = 0.25 Ω/cm (3 x10^{16}/cm^3) 675μm thickness (n in p)

- Measurements for 200nm screen oxide
- At the limit of detection capabilities
- One can observe the 10^{14}/cm^3 imposed limit for silicon wafers
- No oxide present, was not deemed necessary for this study



•P-spray low resistivity wafers

ADVACAM p spray Calibration Wafers



N in P, VTT production, <100> orientation						
Oxide thickness	200nm			300nm		
P implantation doses	$1X10^{12}$ cm^{-2}	$3X10^{12}$ cm^{-2}	$6X10^{12}$ cm^{-2}	$1X10^{12}$ cm^{-2}	$3X10^{12}$ cm^{-2}	$6X10^{12}$ cm^{-2}
Implantation energy	60 KeV			90 KeV		
Annealing	3hours, 1000 °C					

✓ $\rho = 2\ \Omega/cm\ (7 \times 10^{15})$ – 380μm thickness

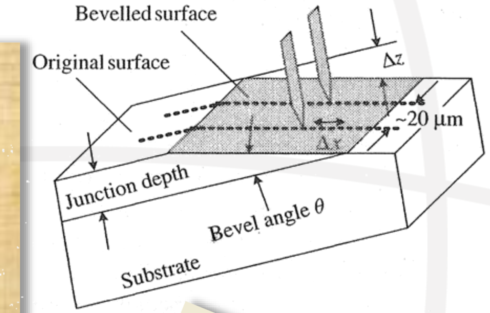
•SRP Measurements

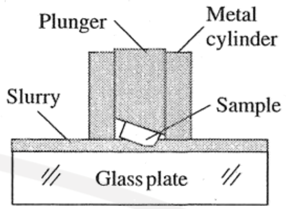
Method principles

Analytical technique to characterize the majority carrier and active dopant concentration profiles in semiconductor structures

Procedure

1. Pair of specially conditioned point contact probes which are stepped across the bevel surface of the semiconductor sample
2. Resistance between two probes is measured at each step
3. Resulting data computer processed into detailed carrier concentration and resistivity profiles from which dopant concentration profiles can be deduced





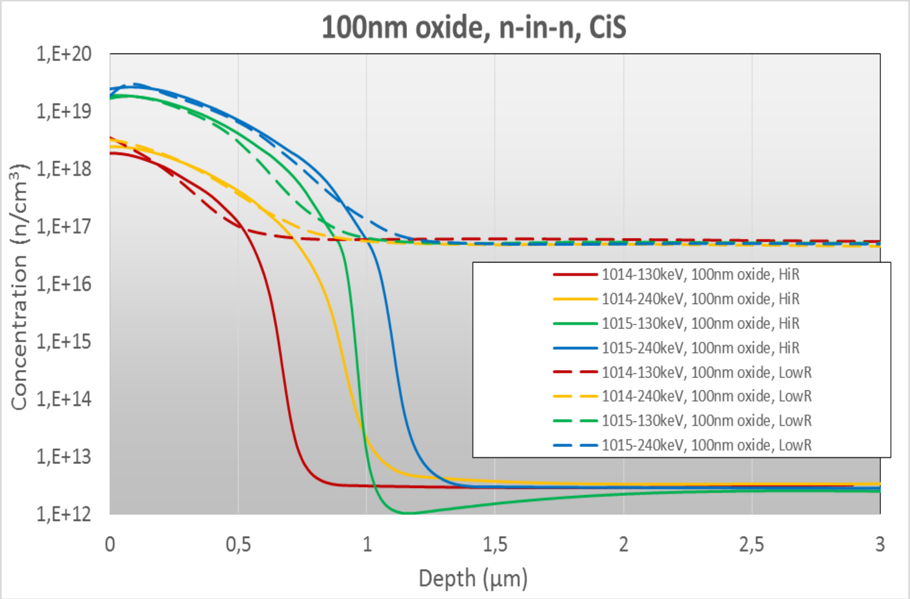
- ✓ Costly Technic carried out by Evans Analytical Group
- ✓ No full control of used parameters
- ✓ Development of in-house alternatives

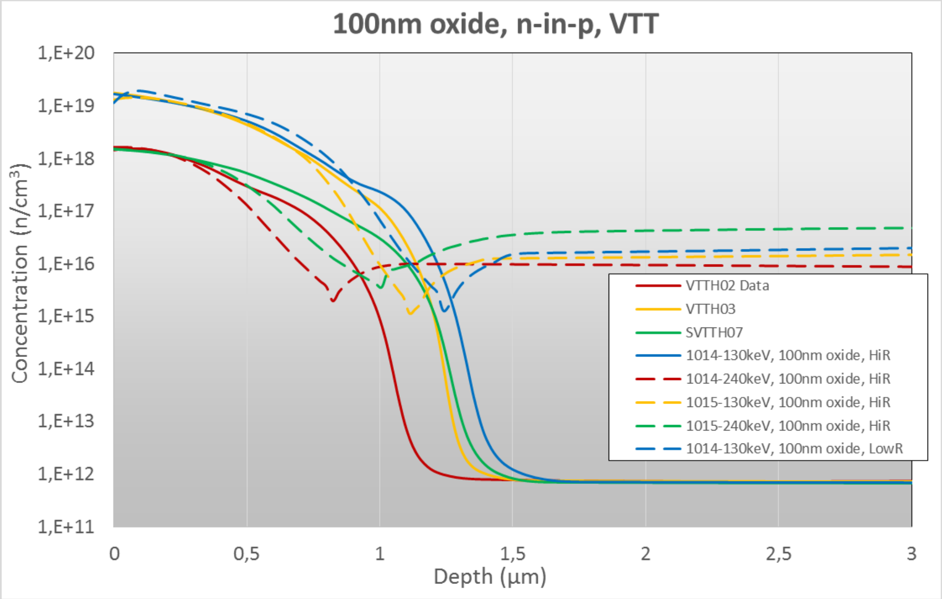
Pros: Very high dynamic range (10^{12} - 10^{21} cm^{-3})
Capable of profiling very shallow junctions (nm regime)

Conns: Destructive method

•SRP Measurements

High and low resistivity results





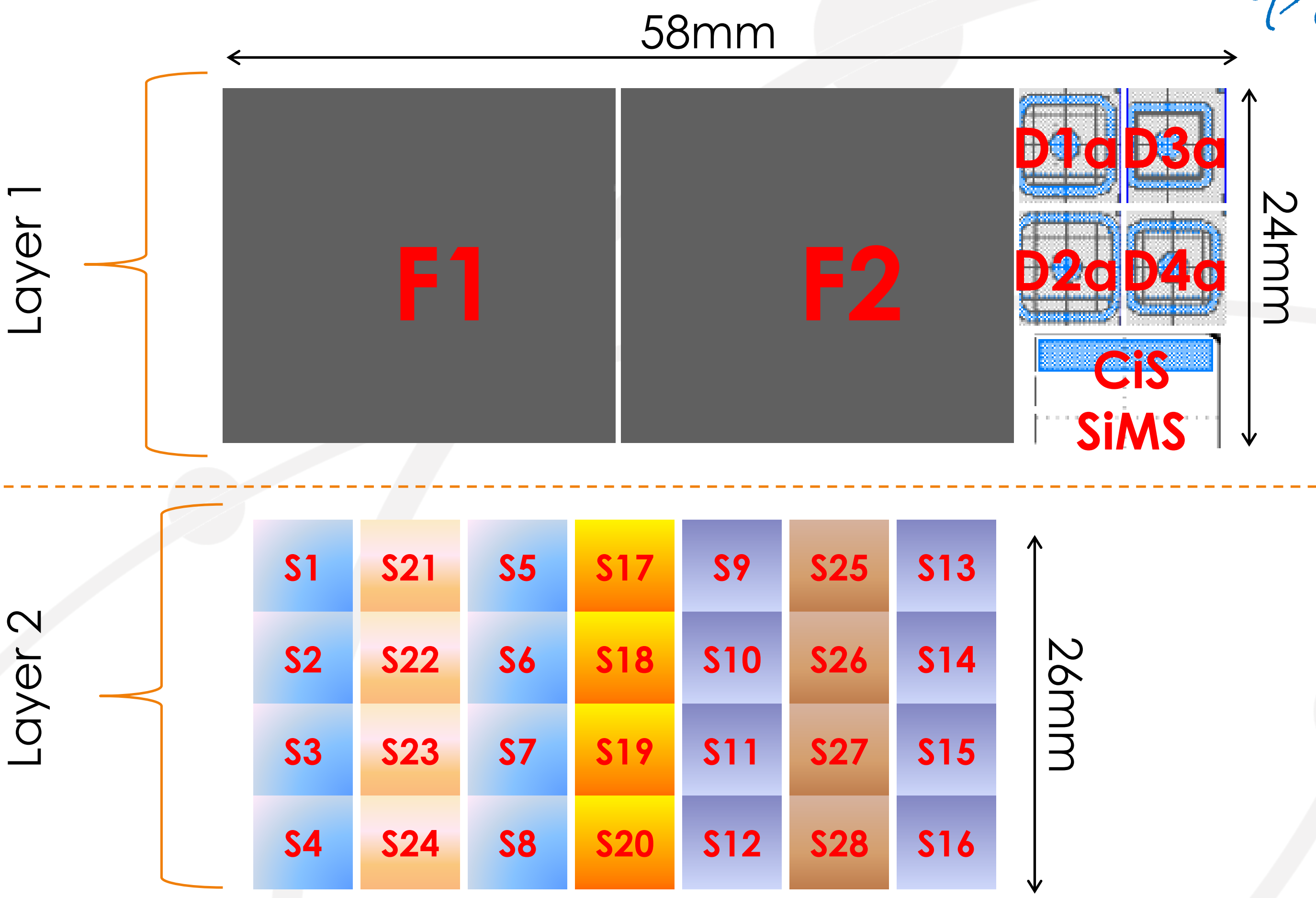
- Cis High and Low resistivity n-in-n test wafers with 100nm screen oxide
- Only n-type carriers

- ADVACAM High and Low resistivity n-in-p test wafers with 100nm test oxide
- N-type carriers that convert to p-type at max implantation depth

•Irradiations at KIT

Irradiation Scheme

Expected flounce
10^{16} neq/cm^2

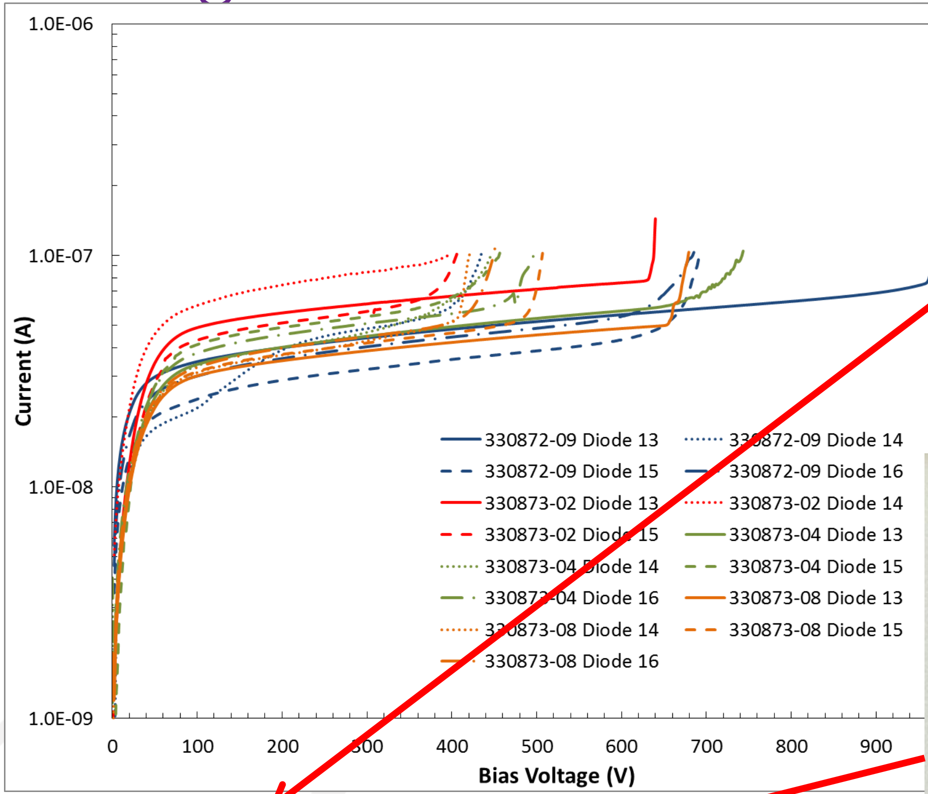


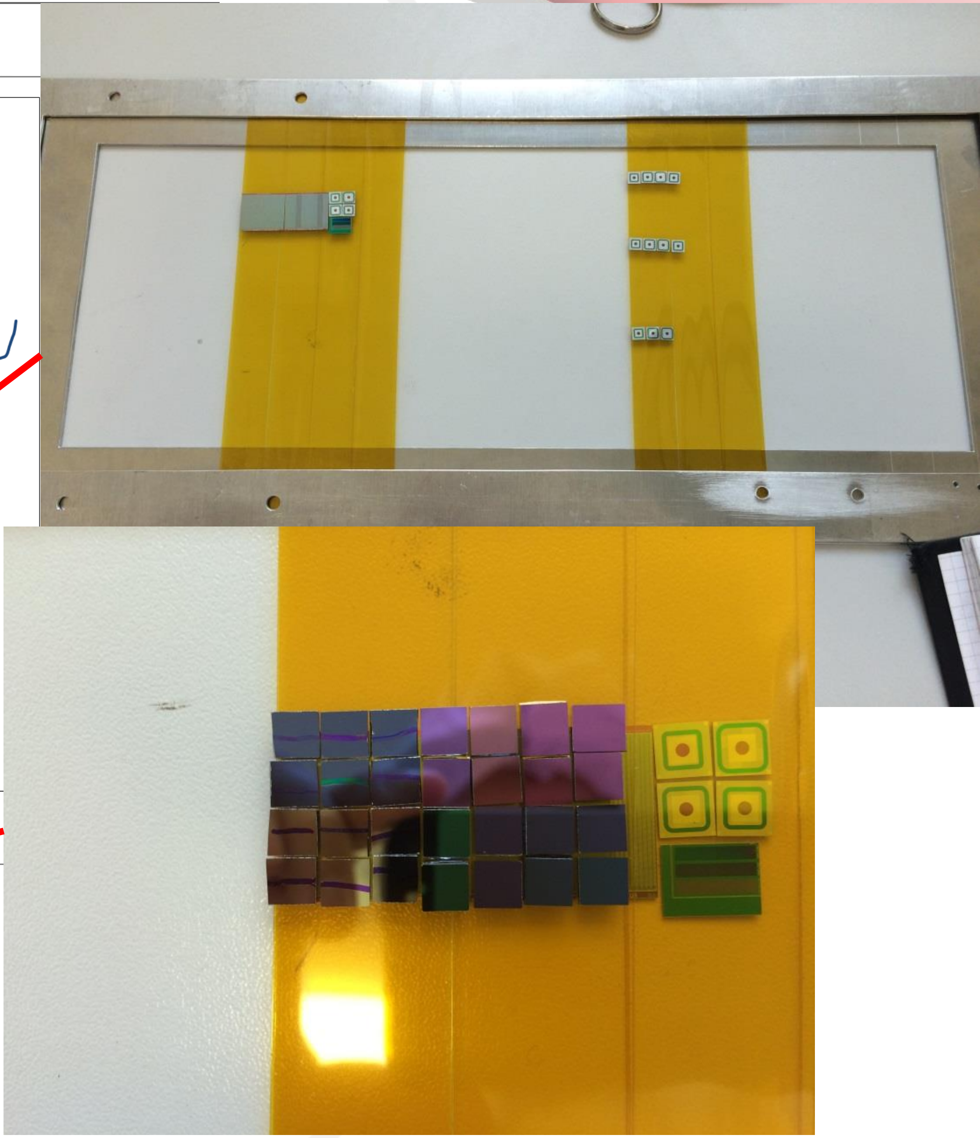
Legend

🟦	CiS n-in-n high resistivity samples
🟪	ADVACAM n-in-n high resistivity samples
🟧	ADVACAM p-Spray low resistivity samples
🟨	CiS n-in-n low resistivity samples
🟫	ADVACAM n-in-n low resistivity samples
FX	CiS NinN FE-i4 structures
DXx	CiS n-in-n diodes
CiS SiMS	CiS n-in-n wafer SiMS test structure

•Irradiation at KIT

Placing and Selection





Layer 1

Layer 2

Diodes for each dose were selected accordingly to their quality and breakdown voltage

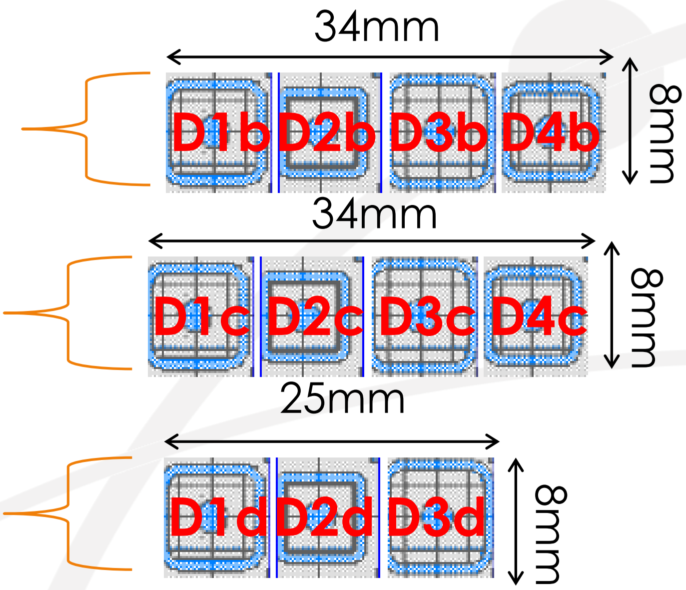
•Irradiation at KIT

Irradiation Scheme

Irradiation to
$5 \cdot 10^{15}$ neq/cm^2

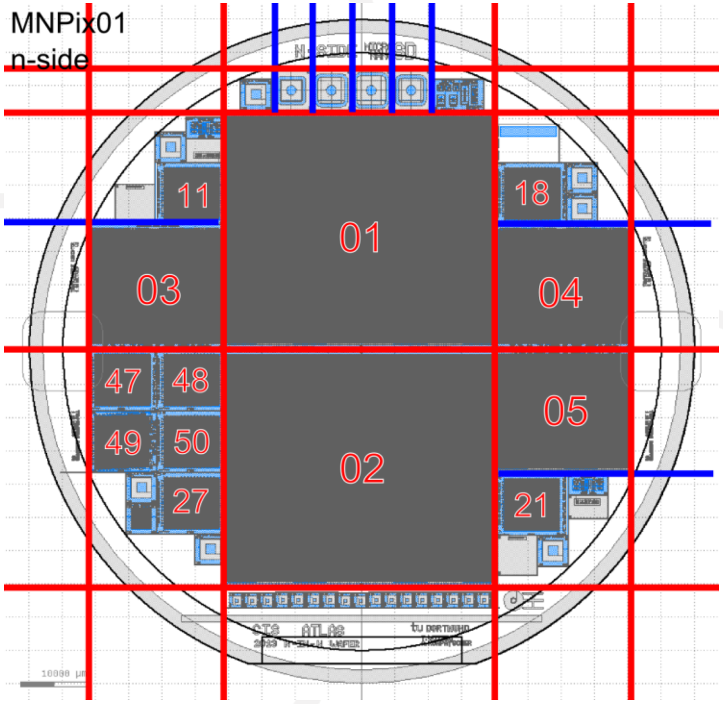
Irradiation to
10^{15} neq/cm^2

Irradiation to
$5 \cdot 10^{14}$ neq/cm^2



Legend

DXx CiS n-in-n diodes



- Diodes with 1,2,3 and 4 guard rings
- FE-I4 matrices with standard and varied bias rail geometry
- CiS n-in-n 4” wafer production last year
- Ivs, CVs and Guard ring potential measurements performed to all diodes before irradiatons
- CVs and Ivs to FE-I4s before irradiation performed

•Future Plans

SiMS –SRP – AFM Calibrations and closure

- ☐ Proven good agreement between measurements and simulations
- ☐ Technical competences and experience in doping profile and simulation

- ☐ Future Plans
  - ☐ Conclude SiMS oxide measurements before irradiatio
  - ☐ Maximum likelihood fits in bi-directional controls
  - ☐ SiMS on selected irradiated samples
  - ☐ Simulation description of radiation damage
  - ☐ SRP measurements on irradiated samples

THANK YOU FOR YOUR ATTENTION!!