Preliminary Results of the CiS-HH SRD Project

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- **Optimization of DOFZ for manufacturing process**
- **Cost effectiveness, how much [O] is enough?**
- **<111> vs. <100>, influence on surface properties**
- **Hidden parameters affecting radiation hardness**
  (example: HCl vs. TCA)
- **Czochralski silicon, a possible alternative?**

Material: FZ: Wacker, Cz: Sumitomo

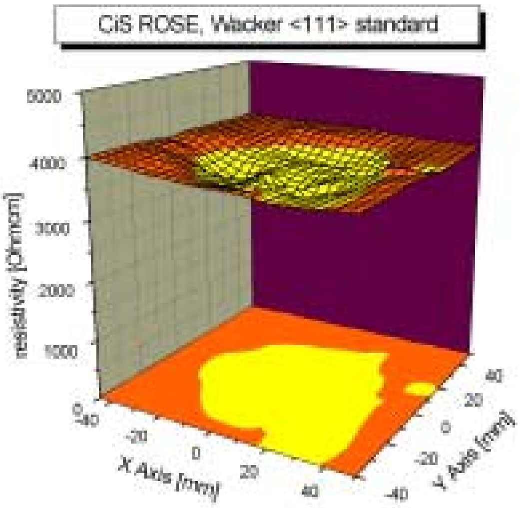
Processing: CiS Erfurt, process very similar to ATLAS wedge
Test diodes multi g.r.(HH) + test fields(Dortmund)

Material characterization:
IR: ITME Warsaw, B. Surma
SIMS: SIMS Lab Warsaw, A. Barcz
4-point probe and management: ITME, E. Nossarzewska
DLTS, C/V + I/V: Uni-HH

Radiation damage studies (Uni-HH):
Irradiations with p (PS-CERN), n (TRIGA-Ljubljana),
Co-60 Gamma (BNL, collab. with Z. Li, E. Verbitskaja)
Tools: DLTS + Laplace-DLTS, TSC, TCT, C/V + I/V-annealing, Simulation-studies

Project started: November 2000
First irradiations: p (July + Sept. 01), n (Oct. 01), γ (Sept. 01)

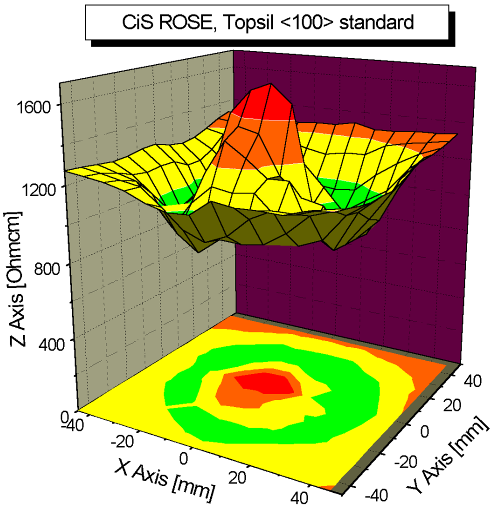
Resistivity profiles on 4" CiS wafers
Wacker <111> and Topsil <100>
measured from depletion voltage on diodes



Wacker <111>

Standard process

<ρ> = 3.71 kΩcm
± 4%



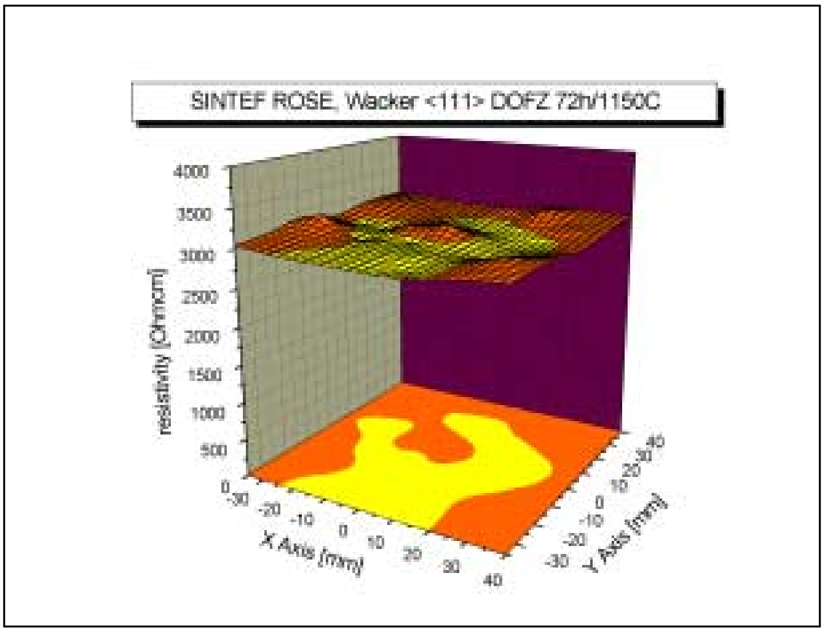
Topsil <100>

Standard process

<ρ> = 1.12 kΩcm
± 16%

Wacker <111>
exhibits less radial dispersion than
Topsil <100>

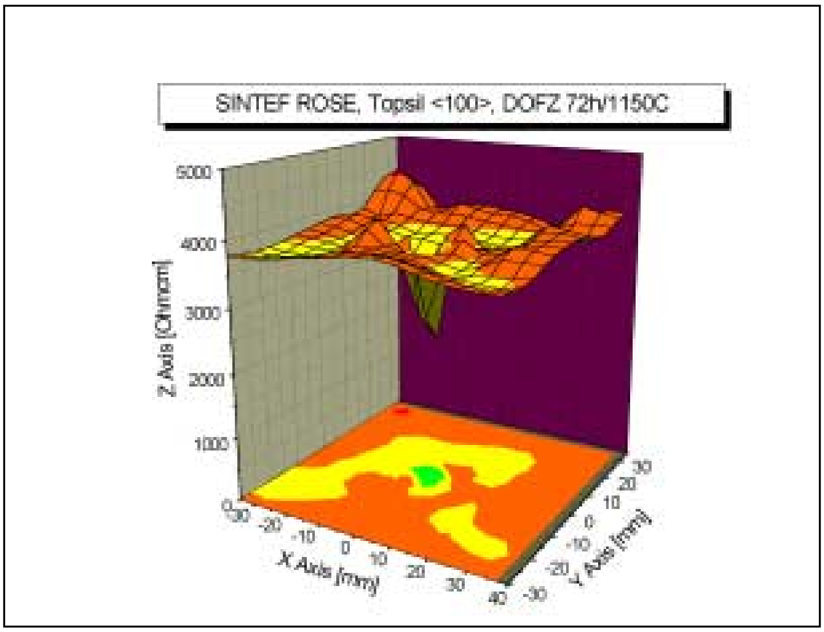
Resistivity profiles on 4" SINTEF wafers
Wacker <111> and Topsil <100>
measured from depletion voltage on diodes



Wacker <111>

DOFZ 72h/1150C

<ρ> = 3.02 kΩcm
± 3%



Topsil <100>

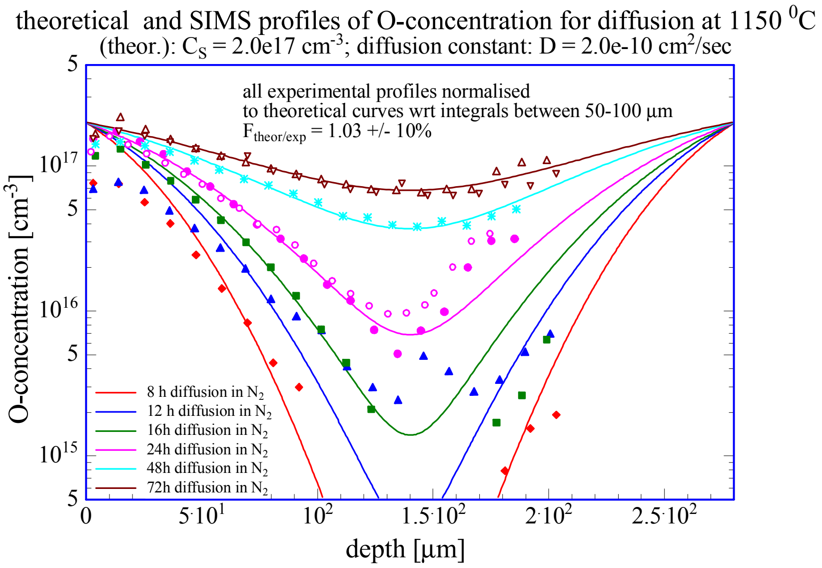
DOFZ 72h/1150C

<ρ> = 3.85 kΩcm
± 9%

- **Also for SINTEF process and after DOFZ:**
- **Wacker <111>**
- **exhibits less radial dispersion than**
- **Topsil <100>**

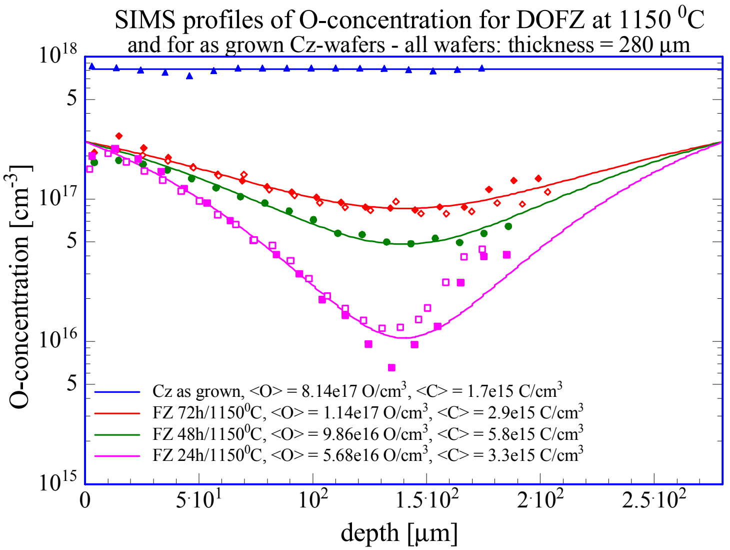
Depth profiles of Oxygen concentration
DOFZ: 8 – 72 h at 1150°C
measured with improved SIMS on bevelled samples

1. A first survey:



SIMS-COMPARISON-CIS REPORT 31-JAN-01 | 31.1.2001

2. The final choice:

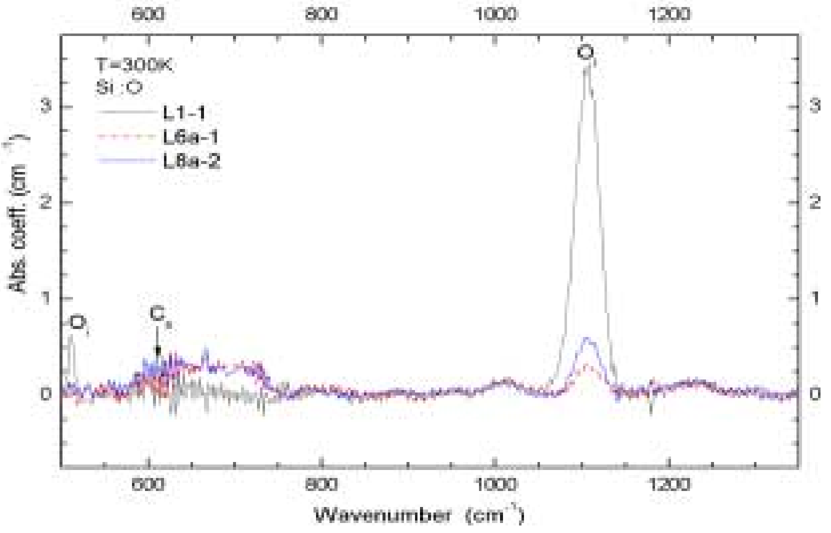


SIMS-PROFILES FZ AND CZ FOR RAINER | 2.4.2001

- ➢ **SIMS profiles reliable, symmetric wrt 140 µm !**
- ➢ **Theory predictions excellent**
- ➢ **[O] in Cz extremely homogeneous as expected**

Depth profiles of Oxygen concentration
DOFZ: 8 – 72 h at 1150°C
Integrated SIMS compared to IR absorption results

Examples of IR absorption spectra



IR and SIMS results in comparison:

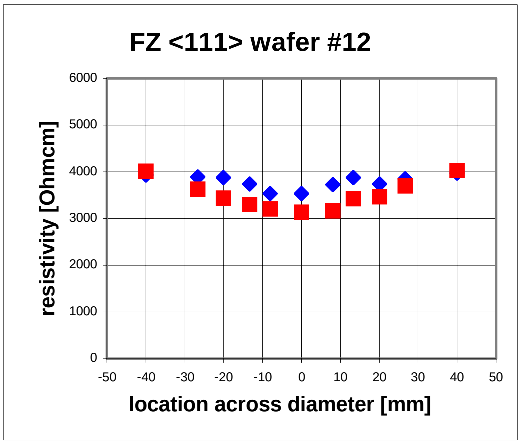
Sample#	$t_{diffusion}$ [h]	$[O]_{SIMS}$ [1/cm³]	$[O]_{IR}$ [1/cm³]	IR/SIMS
1	None, (Cz)	8.13e17	8.55e17	1.052
2	8	3.68e16	3.65e16	0.992
3	12	5.00e16	4.51e16	0.902
4	16	4.74e16	5.72e16	1.207
5	24	5.50e16	6.97e16	1.267
6	24	5.86e16	6.59e16	1.125
7	48	9.86e16	1.04e17	1.055
8	72	1.14e17	1.30e17	1.140
9	72	1.13e17	1.34e17	1.186

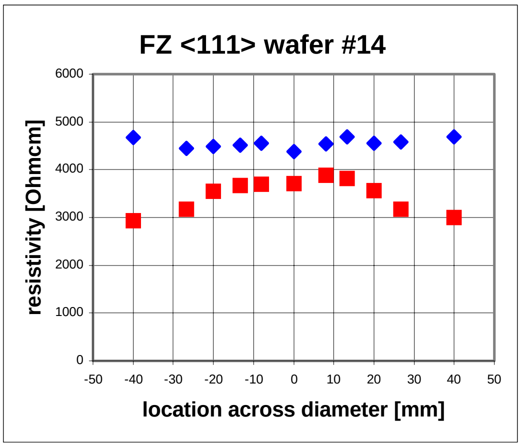
SIMS results: integrated average between d= 0 and 140 µm
IR results: averages of 4 measured samples in each case

$$\langle [O]_{IR}/[O]_{SIMS} \rangle = 1.10 \pm 10\%$$

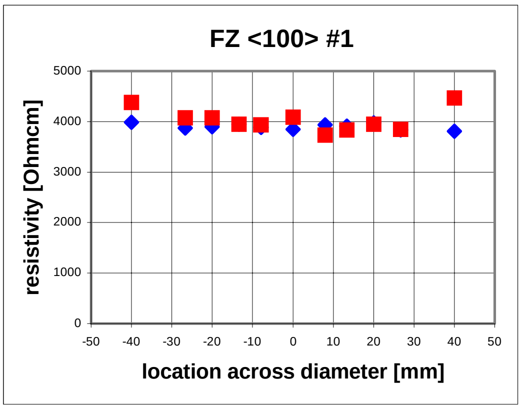
- **Agreement between SIMS and IR excellent**

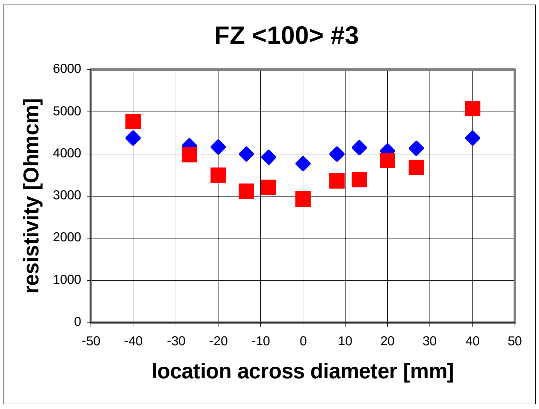
Resistivity profiles on 4" wafers
Change due to oxidation?
measured with 4-point probe





Wacker <111> ρ = 2 – 5 kΩcm, 🟥before, 🔷 after oxidation



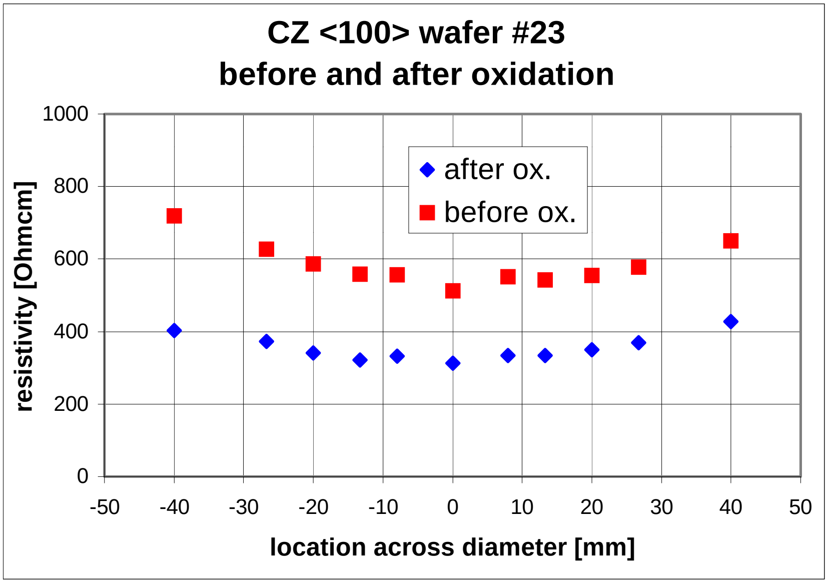


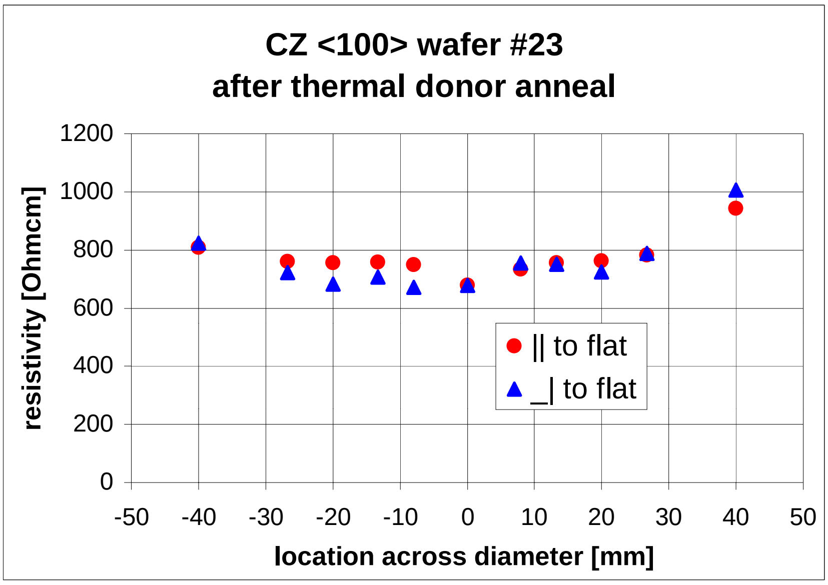
Wacker <100> ρ = 1 – 6 kΩcm, 🟥before, 🔷 after oxidation

- ➢ **Little change in resistivity after oxidation**
- ➢ **slight improvement of radial dispersion**

Resistivity profiles on 4" Cz-wafers
Influence of thermal donors
ρ measured with 4-point probe

Cz Sumitomo <100>, ρ ≥ 600 Ωcm


CZ <100> wafer #23
before and after oxidation


CZ <100> wafer #23
after thermal donor anneal

Before oxidation:
<ρ> = 590 Ωcm
± 11%

After oxidation:
<ρ> = 355 Ωcm
± 11%

Comparison:

After oxidation and TD kill:
<ρ> = 820 Ωcm
± 12%

- **Thermal donor kill essential for final process**
- **1h/800°C + 1min ramp to RT sufficient (?)**
- **final ρ larger than on as grown wafer**

Resistivity of Cz-wafers
Influence of thermal donors
Results from DLTS

Cz Sumitomo <100>, ρ ≥ 600 Ωcm

DLTS and N_{eff} by V_{dep} on test diodes:

Diode #12:

$N_{eff} = 6.88e12\ cm^{-3}$ ⇒ **625 Ωcm**
$N_{thD} = 1.32e12\ cm^{-3}$ (double charged!), measd. by DLTS
effective concentration: $2.64e12\ cm^{-3}$
Net doping conc.: $(6.88-2.64)e12\ cm^{-3}$ =
$N_{eff,corr.} = 4.24e12\ cm^{-3}$ ⇒ **1014 Ωcm**

Diode #35:

$N_{eff} = 9.10e12\ cm^{-3}$ ⇒ **472 Ωcm**
$N_{thD} = 2.16e12\ cm^{-3}$ (double charged!), measd. by DLTS
effective concentration: $4.32e12\ cm^{-3}$
Net doping conc.: $(9.10-4.32)e12\ cm^{-3}$ =
$N_{eff,corr.} = 4.78e12\ cm^{-3}$ ⇒ **900 Ωcm**

After thermal donor correction: 960 Ωcm ± 6%

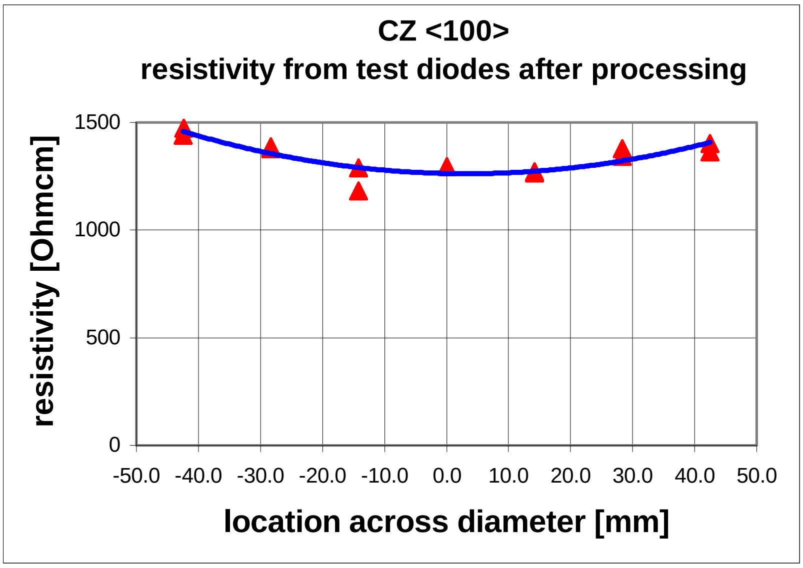
4-point probe measurements:

(on different wafer!)
ρ after oxidation: 360 Ωcm ± 11%
ρ after oxidation and TD kill: 820 Ωcm ± 11%

- **TD-concentration measured by DLTS can fully explain the change of resistivity**
- **proper TD killing needed in process**

Resistivity profiles on 4" CiS-Cz-wafers
ρ measured from depletion voltage on processed diodes

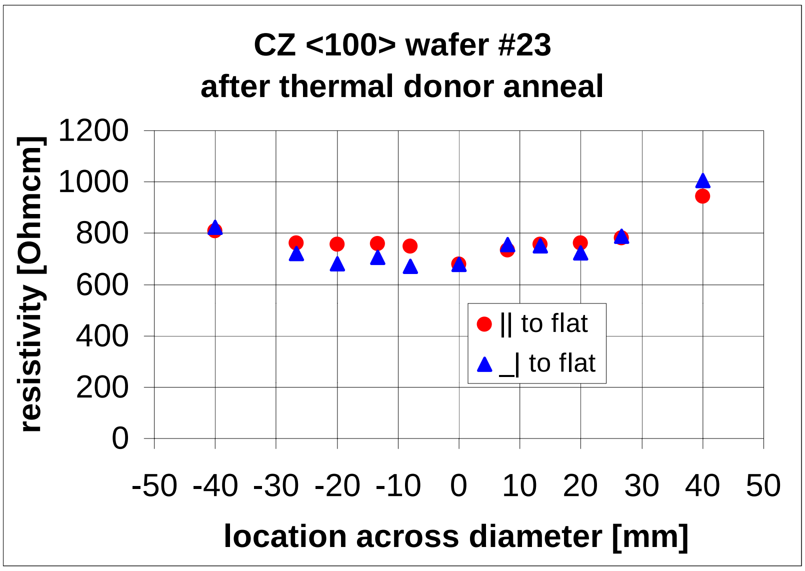
Cz Sumitomo <100>, ρ ≥ 600 Ωcm



After processing including TD kill:

<ρ> = 1.34 kΩcm ± 6%

Comparison:



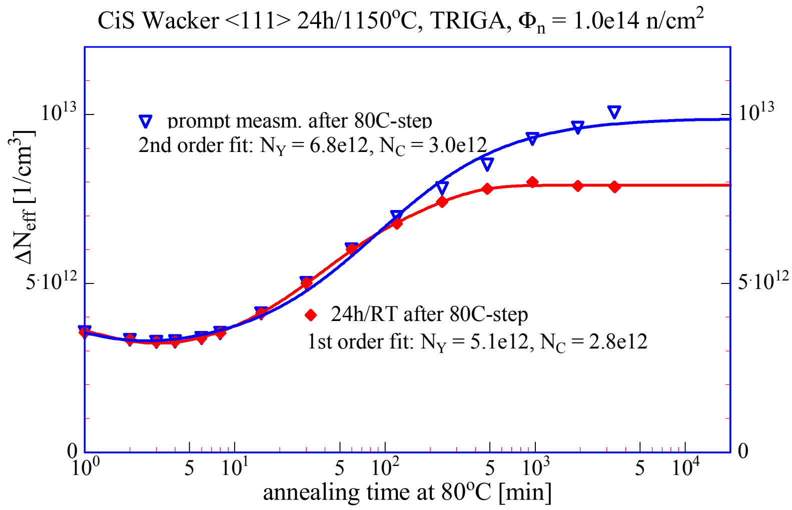
Before processing But after oxidation
+ TD kill
(4-point probe)

<ρ> = 0.82 kΩcm ± 12%

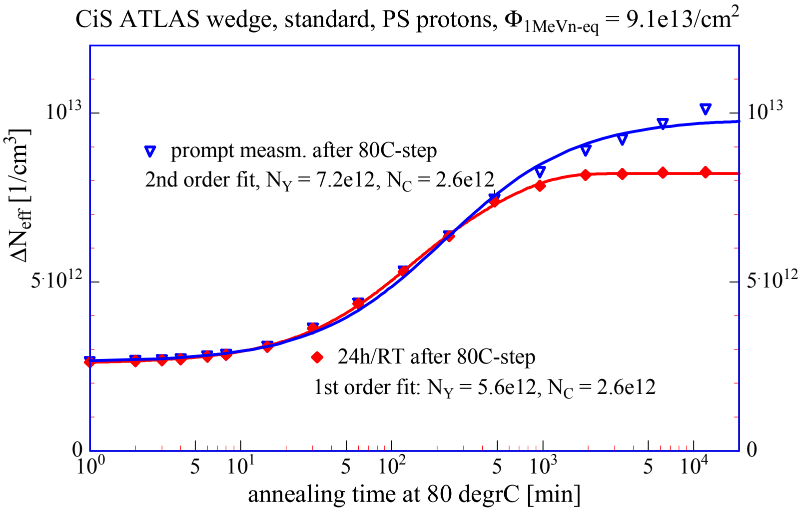
- **Final process including TD kill is working !**
- **homogeneity of ρ excellent**
- **difference in V_{dep} and 4-point probe not understood**

Reliability of annealing experiments at elevated temperatures

the "bistable defect" and 1st order vs. 2nd order



C12102-DNEFF-COMPARISON | 25.11.2001



CW09A3-DNEFF-P | 25.11.2001

➢ **Bistable effect both appreciable for n- and p-irradiation**

24 h/RT relaxation after each 80C step necessary (τ_{relax} = 8h @ RT)

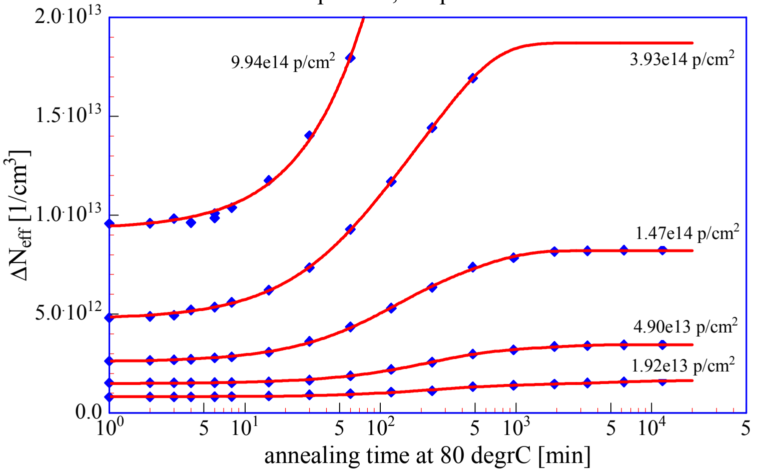
➢ **Resulting annealing curves can only be fitted with 1st order**

Large differences in N$_Y$ between prompt/2nd order and relaxed/1st order

Proton Irradiation of Test Diodes from CiS ATLAS Wedge Wafers, E_p = 24GeV/c

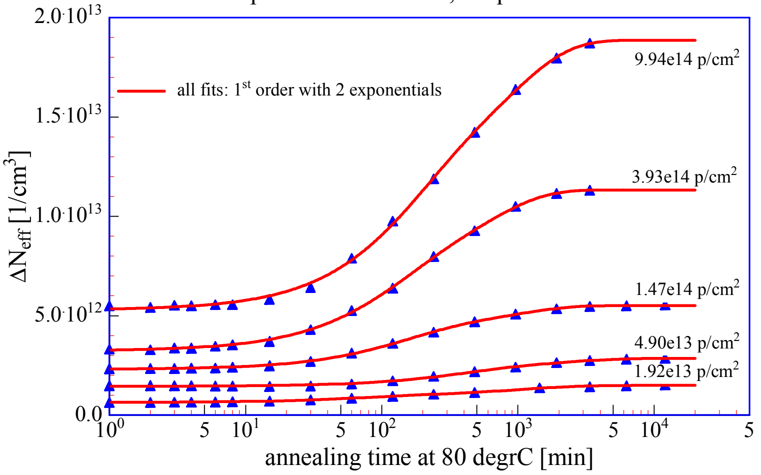
-Annealing Results at 80°C-

CiS ATLAS wedge test diodes Wacker <111> ρ = 3.4 kΩcm
standard process, PS-proton irradiation



CW-STANDARD-DNEFF-P | 23.11.2001

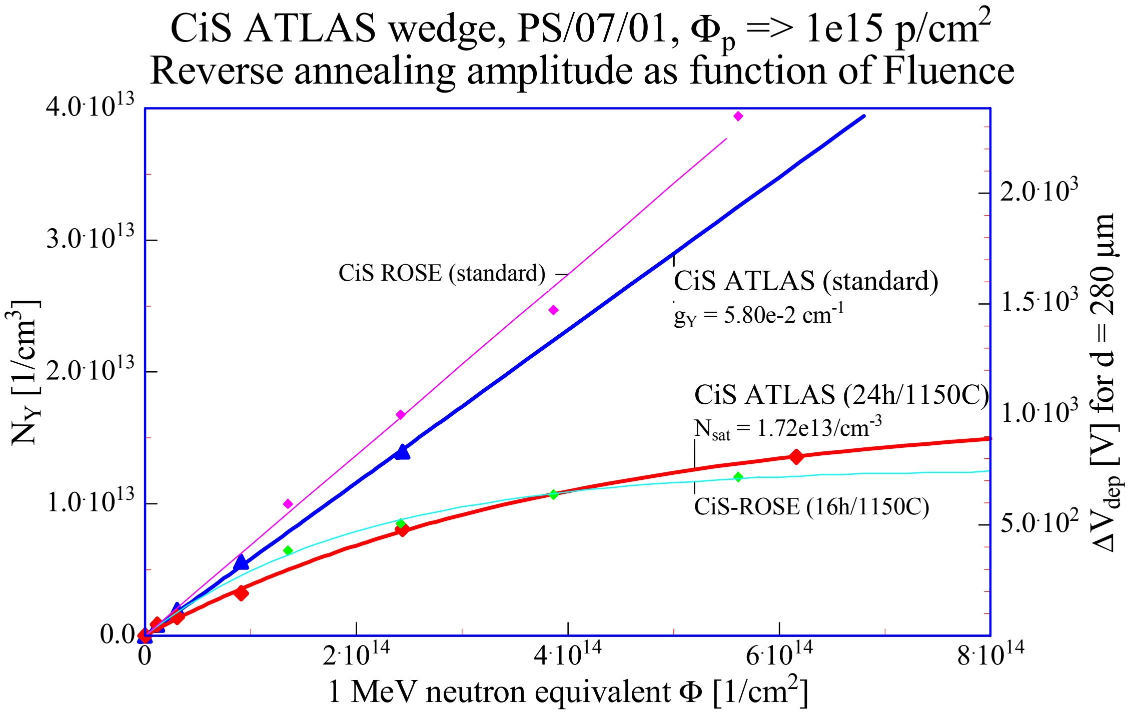
CiS ATLAS wedge, test diodes Wacker <111> ρ = 3.4 kΩcm
DOFZ process: 24h/1150C, PS-proton irradiation



CW-DOFZ-DNEFF-P | 23.11.2001

- **Test Diodes with Identical Mask Design and Process as ATLAS Wedge Strip Detectors, Manufactured on Same Wafer**
- **For Reliable Analysis Relaxation of Bistable Effect Important (24h RT after Each HT Annealing Step)**
- **Annealing Functions only to be fitted by 1st order fits**

Reverse annealing amplitude for CiS ATLAS wedge test diodes in comparison to ROSE results after 24GeV/c p-irradiation with $\Phi_p = 5\cdot10^{13} - 1\cdot10^{15}$ p/cm²


CiS ATLAS wedge, PS/07/01, Φ_p => 1e15 p/cm^2
Reverse annealing amplitude as function of Fluence

N_Y-COMPARISON | 23.11.2001

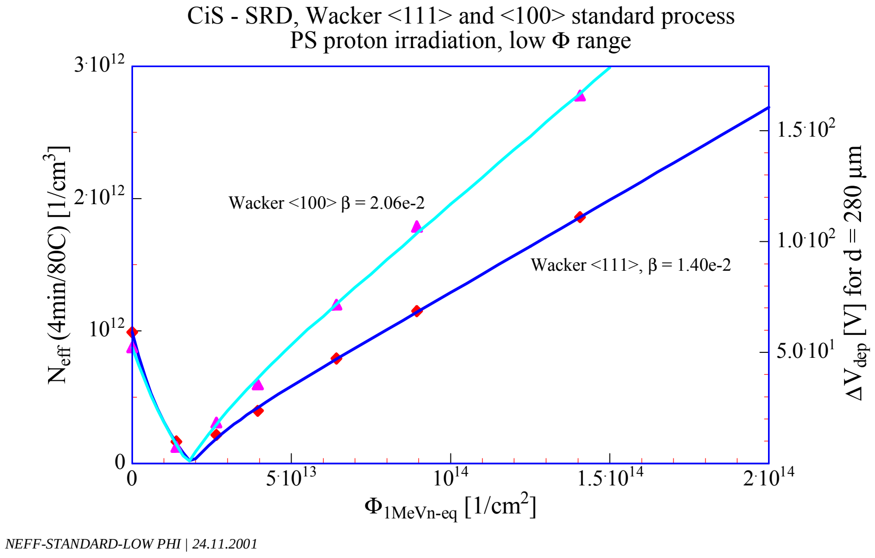
- **ROSE results are reproduced in ATLAS wedge**
  for similar material (Wacker <111>) & oxygenation

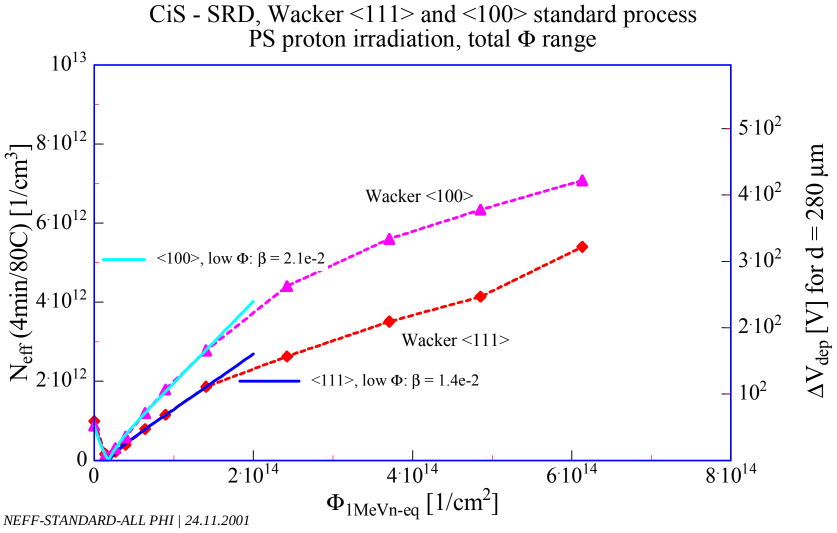
- **DOFZ process => saturation of N_Y for $\Phi_p > 10^{15}$ p/cm²**
  change in V_{dep} < 1000V independent of Φ_p and annealing

CiS – SRD test diodes

Wacker <111> and <100> standard process

CERN scenario for $\Phi_p = 2\cdot 10^{13}$-$1\cdot 10^{15}$ p/cm²





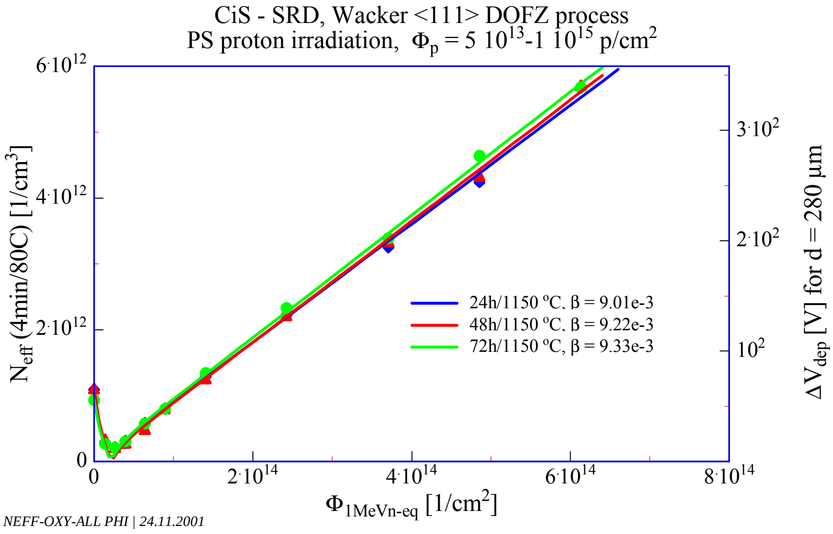
- **Model description only possible for low Φ range**
  Total donor removal, β compatible with ROSE results
- **Change of N_{eff} for <100> larger than for <111>**

CiS – SRD test diodes

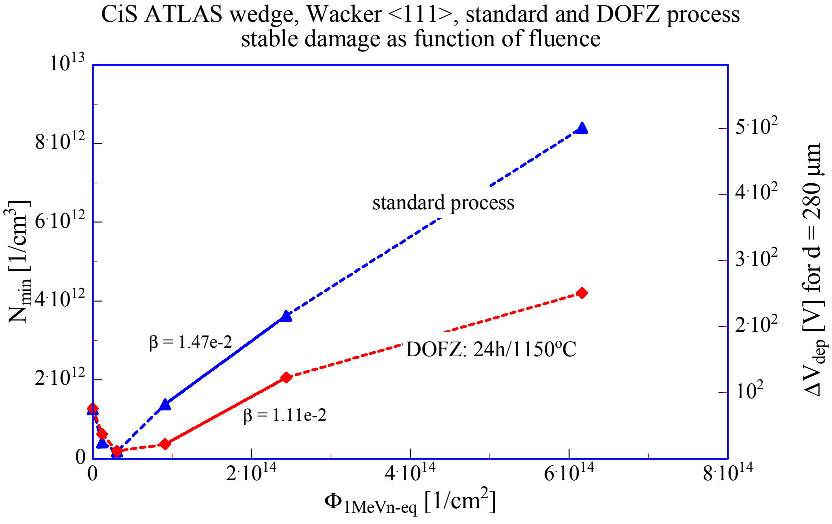
Wacker <111> DOFZ process

CERN scenario for $\Phi_p = 2\cdot10^{13}\text{-}1\cdot10^{15}$ p/cm²

Comparison with ATLAS wedge stable damage


CiS - SRD, Wacker <111> DOFZ process
PS proton irradiation, $\Phi_p = 5\ 10^{13}\text{-}1\ 10^{15}$ p/cm^2

NEFF-OXY-ALL PHI | 24.11.2001


CiS ATLAS wedge, Wacker <111>, standard and DOFZ process
stable damage as function of fluence

N-MIN-COMPARISON | 24.11.2001

- **CERN scenario: model description possible for total Φ range**
  β compatible with ROSE results, independent of [O] for 24 to 72 h/1150°C

- **Comparison with ATLAS wedge reasonable, ? for high Φ**
  Measurements: $N_{min} = <N_{eff}>$ for t_{anneal} = 4-8 minutes

Summary

This talk:

- SRD project is getting under way!
- Wacker FZ shows less ρ dispersion than Topsil
- Resistivity not affected by DOFZ process
- New SIMS technique reliable, [O]-results ≡ IR
- Reliable annealing only after relax of bistable defect
- Analysis reveals 1st instead of previous 2nd order
- Extracted parameters compatible with ROSE results
- Cz can be used for processing taking care of TD

Many thanks to: M.Moll, M.Glaser (CERN), V. Cindro (JSI); E. Nossarzewska, B. Surma (ITME), A. Barcz (ITE) and M. Zielinski (SIMS Lab, Warsaw)

Further Results:

- SIMS, see talk given by A. Barcz
- Characterization of unirradiated diodes: J. Stahl
- Co-60 gamma irradiation macroscopic: E. Fretwurst
- Co-60 gamma irradiation microscopic: I. Pintilie