Radiation Damage + Towards a Rad-hard Sensor Design

E.Fretwurst, R.Klanner, H.Perrey[1], I.Pintilie[*], A.Srivastava, T.Theedt, J.Xiao[2]

(Univ. Hamburg, [*]National Inst. Materials, Romania)

1. **Reminder:** Summary of radiation damage measurements and parameter extraction for simulation
2. **Sensor simulation:** Sensor model, inclusion of radiation effects, first results
3. **Next steps:** Measurements and simulations

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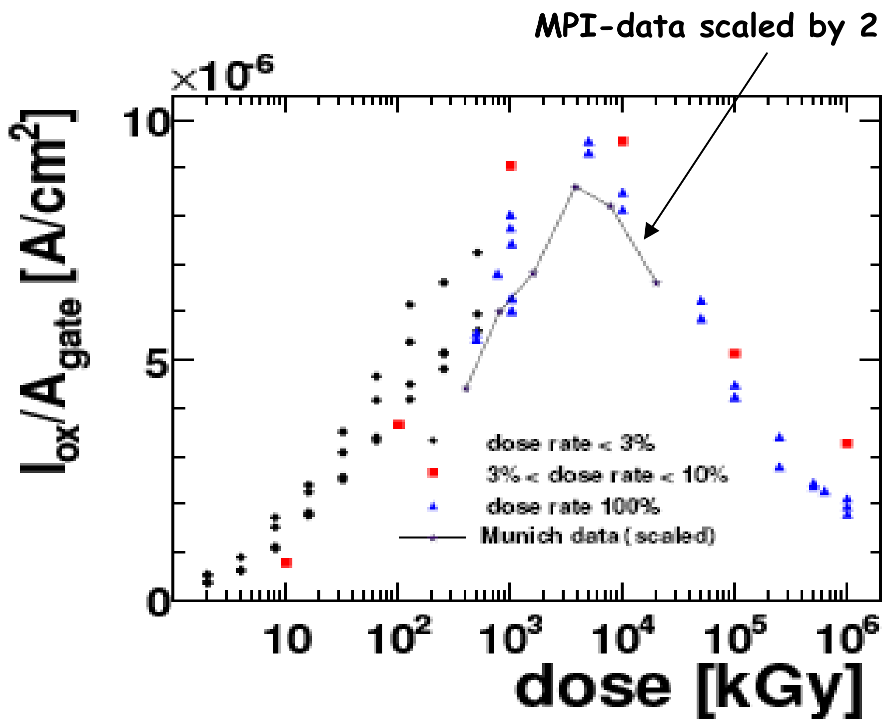
[1] has "left" radiation damage → moved early 2009 to 2nd thesis topic: precision measurement of the proton structure (as planned and promised at start of thesis)

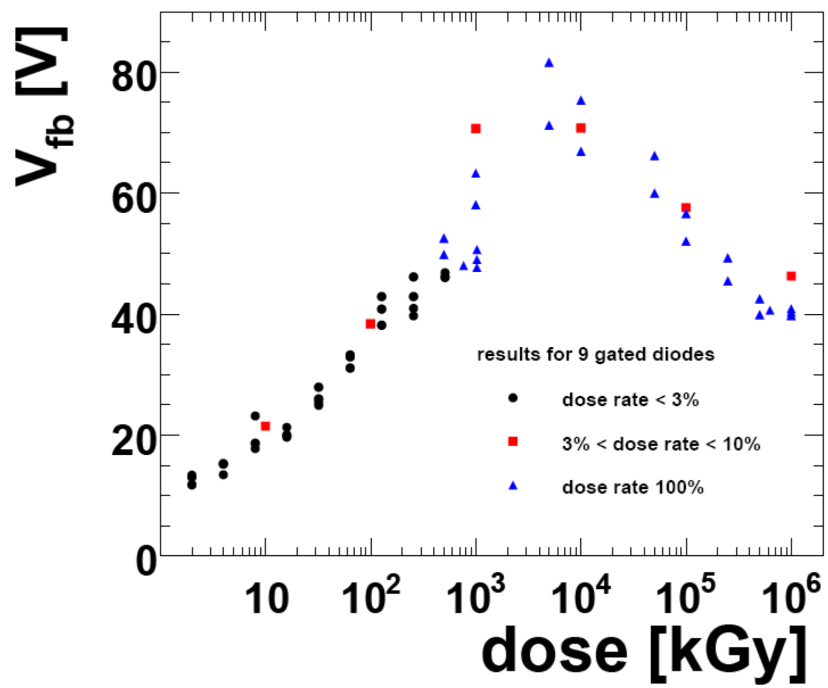
[2] new (16.7.09) PhD student from China – supported by EU (Marie Curie-ITN: MCPAD)

Summary Radiation Damage

1. Summary of radiation damage measurements and parameter extraction for simulation (from gated diode measurements)

Surface generation current vs dose + "Flat-band voltage" vs dose (immediately after irradiation)





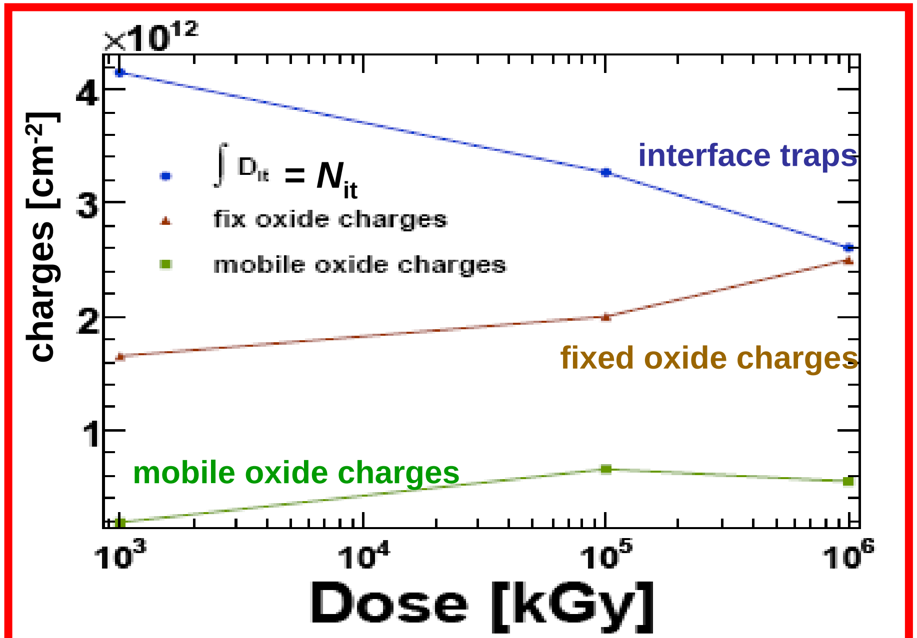
→V_{fb} [N_{Ox}+N_{it}] and I_{Ox} [N_{it}] reach maximum at few MGy – then decrease

(tentative conclusion: decrease due to N_{it} at high doses – reason not clear)

Summary Radiation Damage

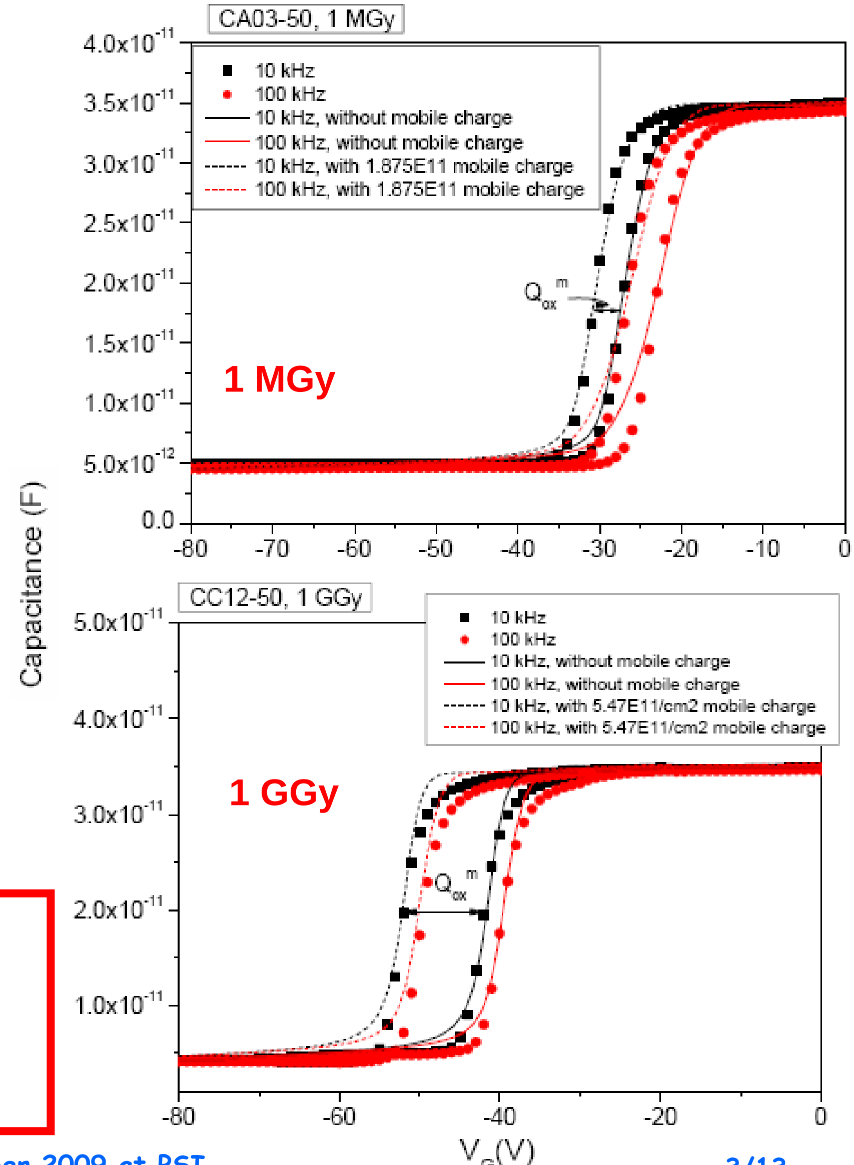
Relevant parameters:

1. N_{Ox}(fix) fixed oxide charges
2. N_{Ox}(mob) mobile oxide charges – recent studies show introduction under biasing with long (hours) introduction time const.
3. D_{it}[$cm^{-2}\cdot eV^{-1}$] interface trap density



→ summary:
→ data can be described by microscopic model → parameter extraction → → for use in simulations

Comparison to measurements



Summary Radiation Damage

→ Impact of parameters on sensor performance

1. $\boxed{N_{Ox}^{fix}}$ fixed positive oxide charges ← shift of ideal CMOS-C/V-curve
   → accumulation layer below oxide
   → strong electric fields causing breakdown

2. $\boxed{N_{Ox}^{mob}}$ mobile oxide charges (close to interface) ← hysteresis C/V-curve
   → same effects as above; dependence on time + surface potential!

3. $\boxed{D_{it}}$ interface traps (integral N_{it}) ← TSC (Thermally Stimulated Current)
   → current generation, if interface is exposed to E-field
   → contribution to surface charge density depends on
   - position of Fermi level
   - type of states
     → acceptors compensate positive oxide charges
     → donors enhance effect of positive oxide charges

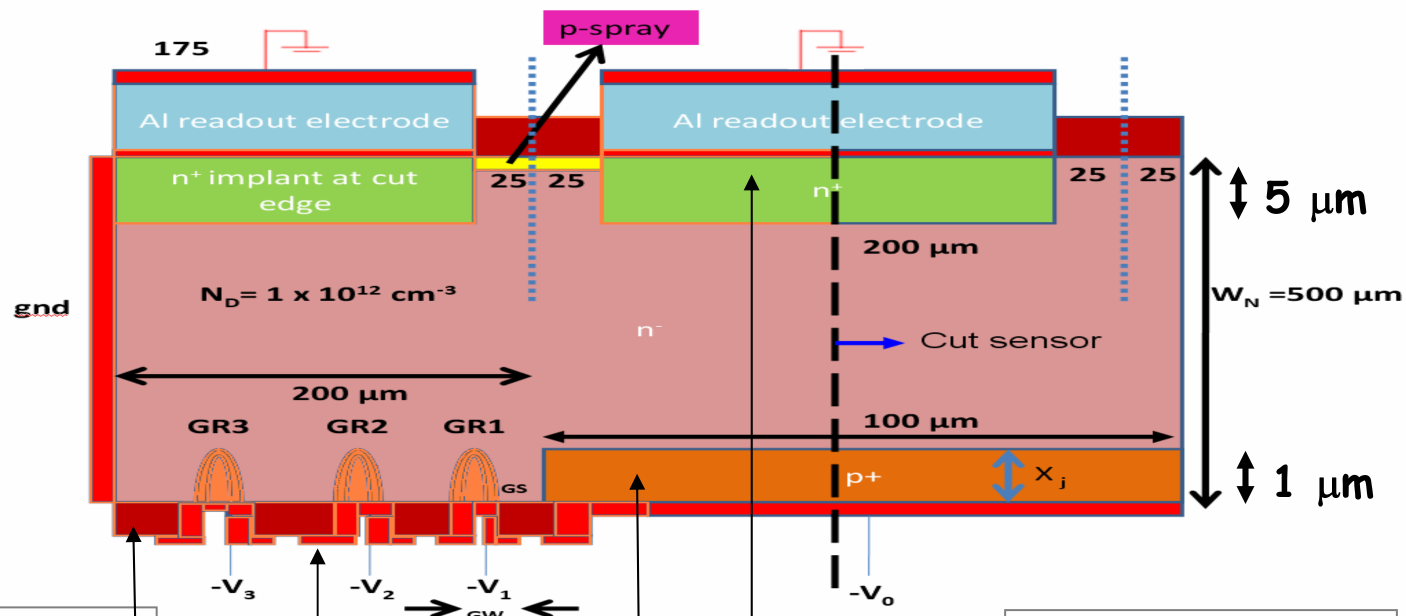
→ reliable simulation is not a simple task !

2. Sensor Simulation

Aim: optimise design for radiation hardness using the results of test structure measurements as input

1st project: breakdown and current for p⁺-n guard-ring structure

"generic sensor for first simulation"



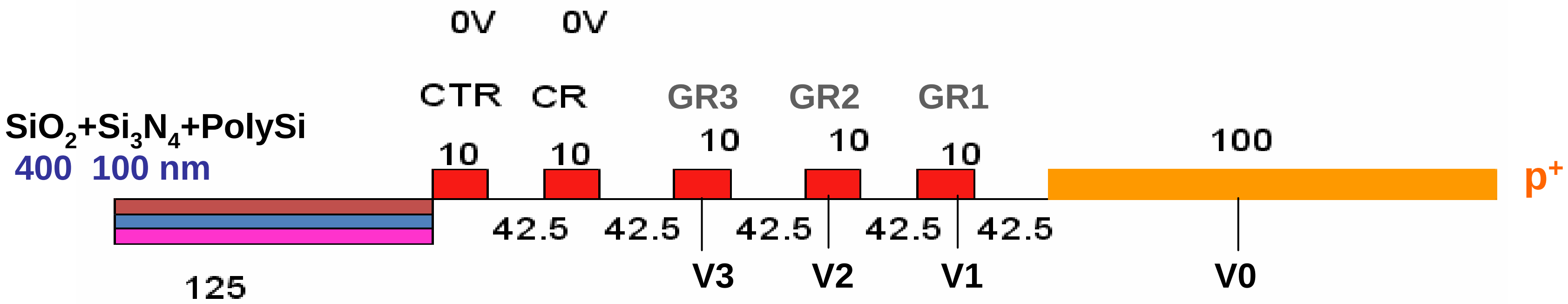
$SiO_2+Si_3N_4$: 400+100 nm
p⁺-implant: 1 µm
n⁺-implant: 5 µm
metal overhang: 5 µm

n-doping: 10^{+12}cm^{-3}
thickness: 500 µm
full depletion: 196 V
I_{bulk}: 31 nA

"X-ray-entrance (p^+)-side of generic sensor"

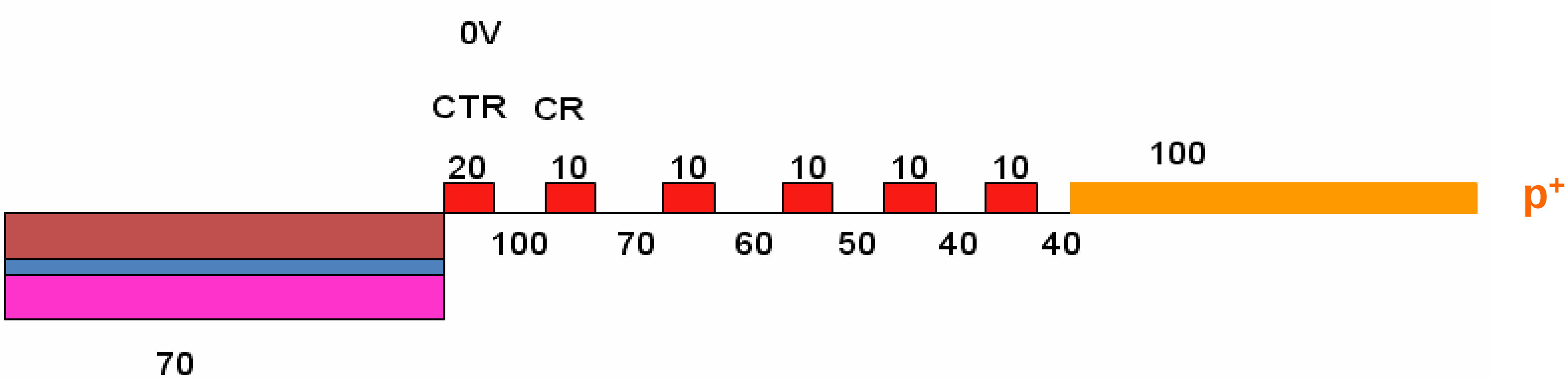
Layout of sensor model I

Simulation of 2-dim. cell of 487.5 x 500 μm²



Layout of sensor model II

Simulation of 2-dim.bcell of 600 x 500 μm²



CTR: **C**urrent **T**erminating **R**ing
CR: **C**urrent **R**ing
GRi: **G**uard **R**ing **i**

Program used: ISE-TCAD from Synopsis

Physical models used:

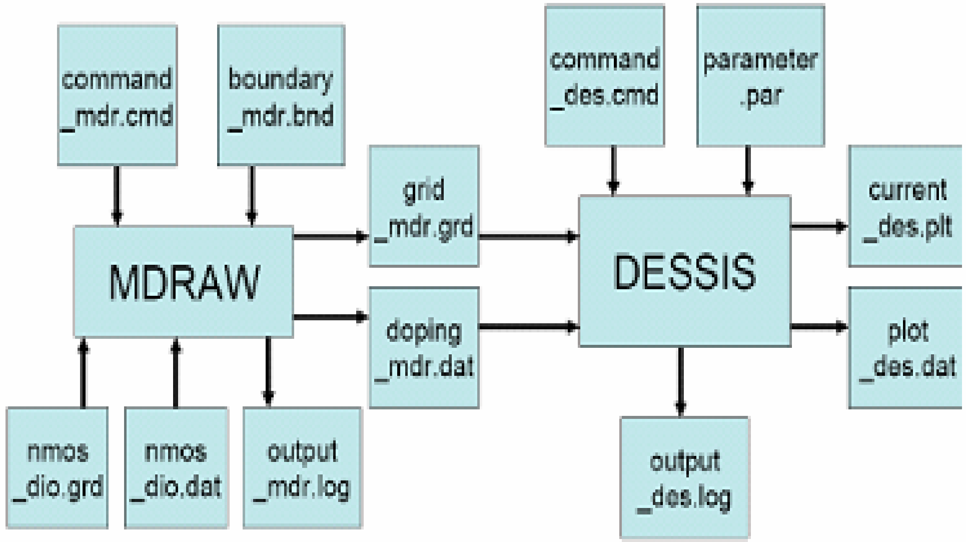
- SRH (Shockley-Read-Hall) recombination
- Auger recombination
- impact ionization
- trap models
- doping dependent mobility and high field saturation model, band to band tunneling
- surface recombination model

CPU time: 100 min
no. grid points: 60 000

Simulation procedure:

Procedure

1. Design structure in MDRAW
2. Feed results into DESSIS
3. Combine simulation of device (DESSIS) and circuit (SPICE)

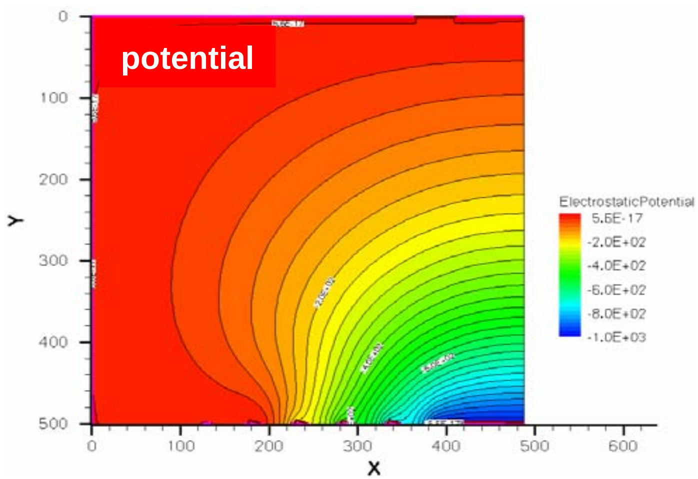


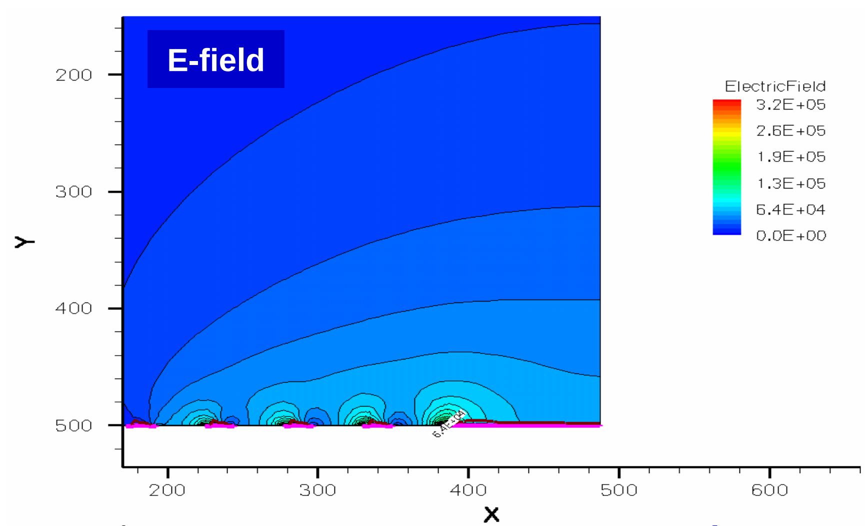
Break-down voltage vs. radiation damage

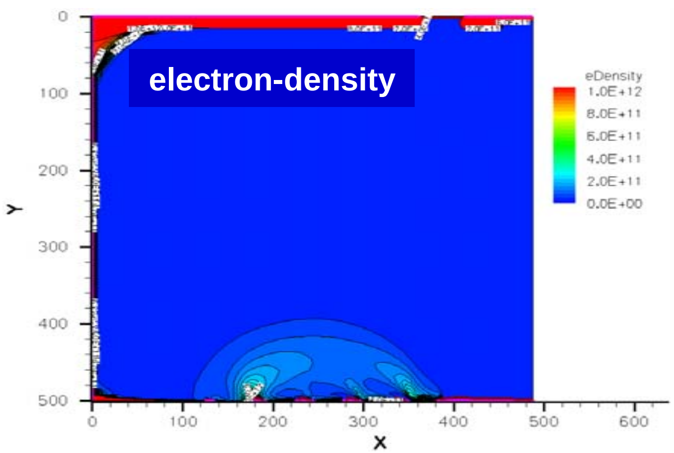
- "ideal case": $N_{Ox}=N_{it}=0$ (to understand optimisation – sensor model I)

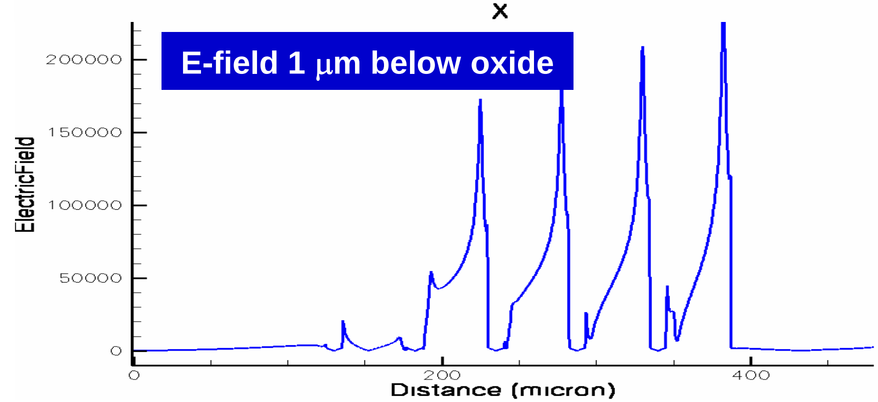
bias=V_0, $V_1=0.75\cdot V_0$, $V_2=0.5\cdot V$, $V_3=0.25\cdot V$ →

- V_{bd} (break-down) > 1000 V
- optimized V(GR) → increase by ~10%









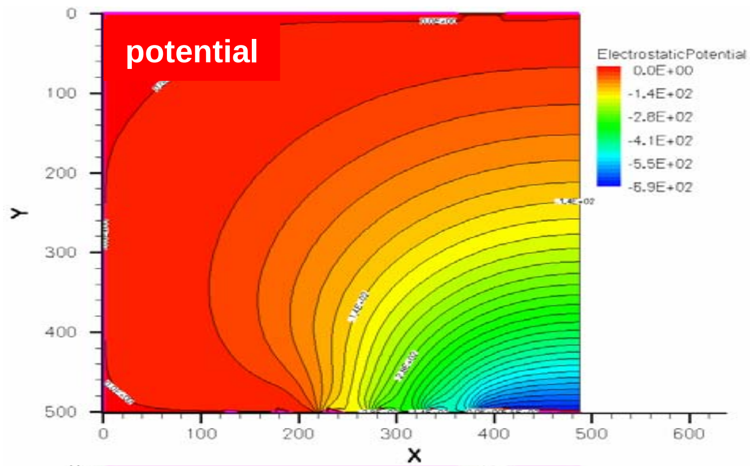
GR3 GR2 GR1 p^+ diode

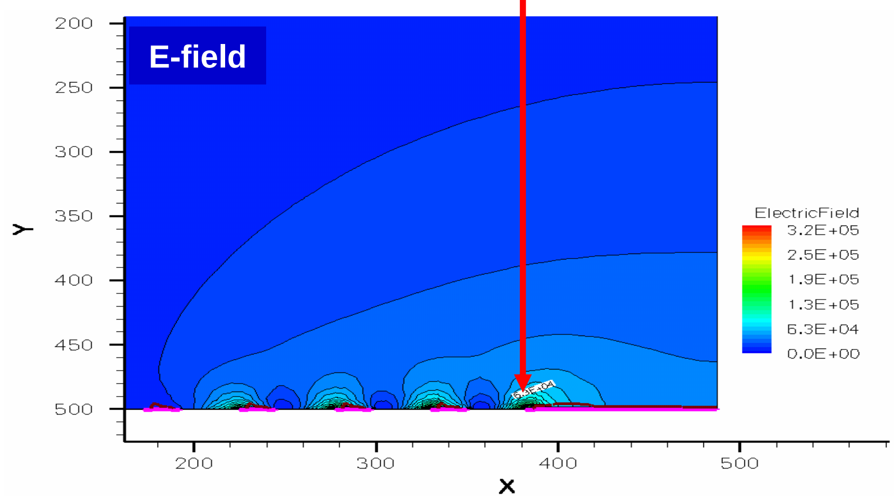
Break-down voltage vs. radiation damage

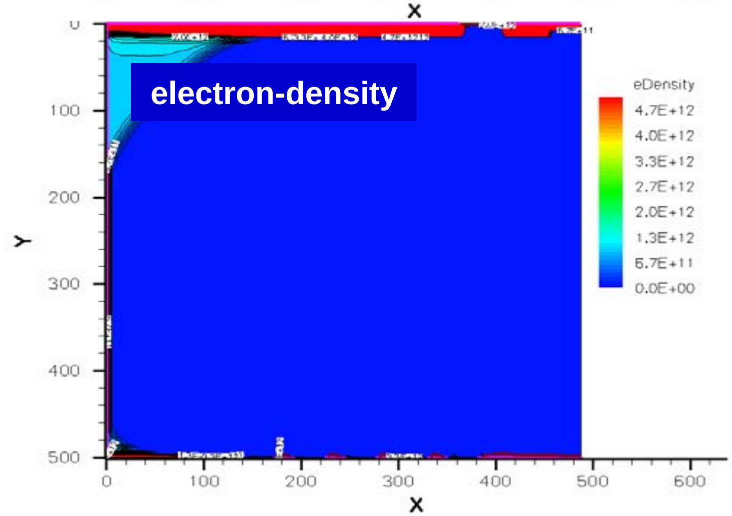
$N_{Ox}=4\cdot10^{11}cm^{-2}$ $N_{it}=0$ (sensor model I)

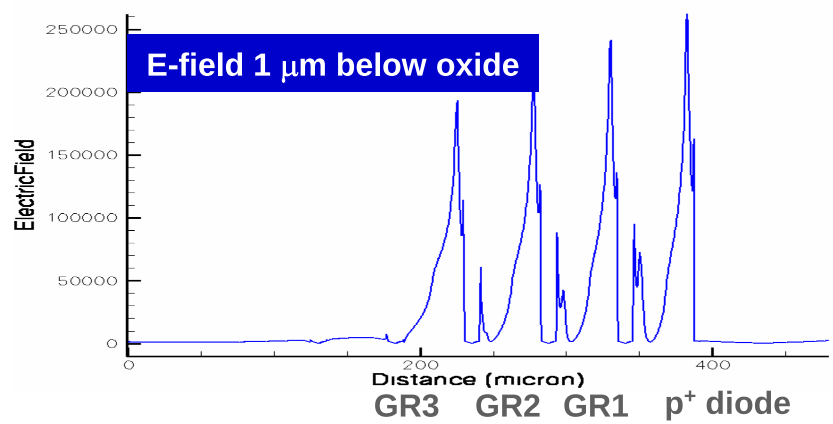
bias=V_0, $V_1=0.75\cdot V_0$, $V_2=0.5\cdot V$, $V_3=0.25\cdot V$ →

- V_{bd} (break-down) = 690 V
- E_{max} below metal overhang (p^+)





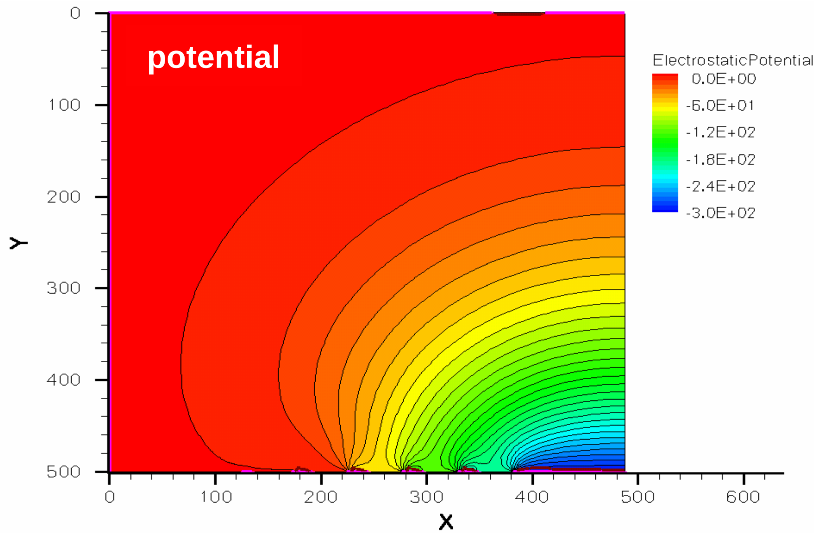


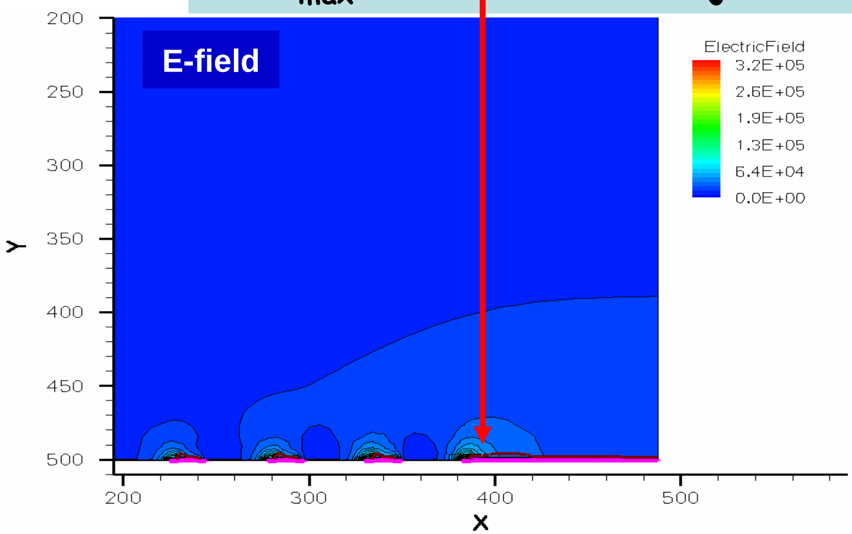


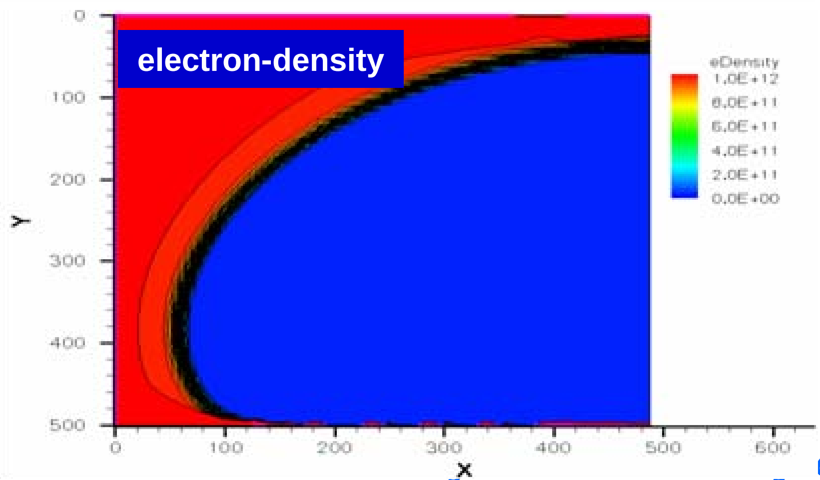
Break-down voltage vs. radiation damage

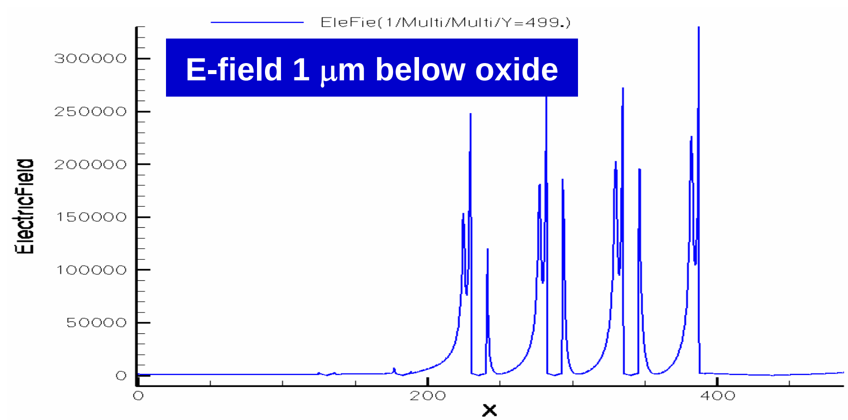
$N_{Ox}=2\cdot10^{12}cm^{-2}$ $N_{it}=0$ (~saturation value of N_{Ox} – sensor model I)

bias=V_0, $V_1=0.75\cdot V_0$, $V_2=0.5\cdot V$, $V_3=0.25\cdot V$ →
- V_{bd} = 300 V
- E_{max} @ curvature of junction









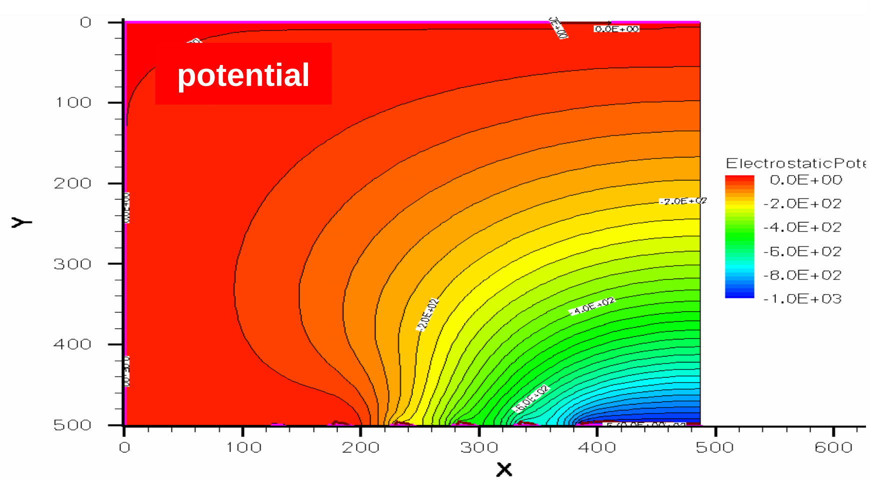
GR3 GR2 GR1 p^+ diode

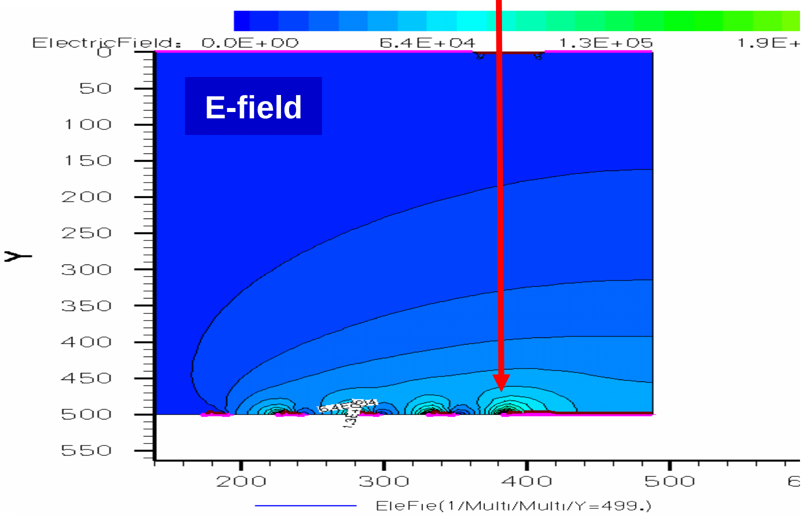
Break-down voltage vs. radiation damage (values found for high doses)

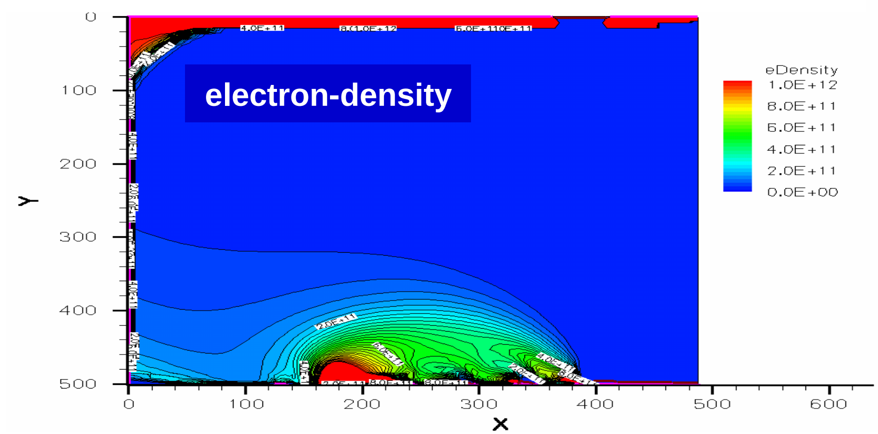
$N_{Ox}=2\cdot10^{12}cm^{-2}$; $\boxed{N_{it}=4\cdot10^{12}cm^{-2}}$ @ $E_c-E_{it}=0.35eV$ and $\boxed{4\cdot10^{13}}$ @ 0.6 - acceptors)

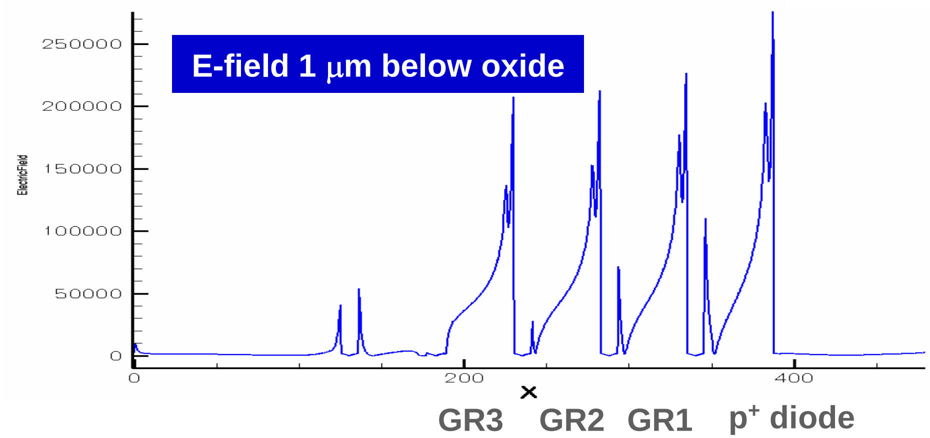
bias= V_0, $V_1=0.75\cdot V_0$, $V_2=0.5\cdot V$, $V_3=0.25\cdot V$ →

- V_{bd} (break-down)= 995 V
- E_{max} @ curvature of junction





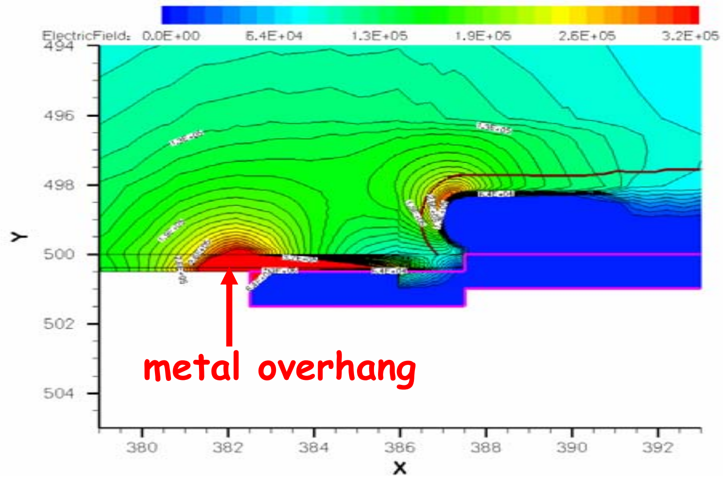




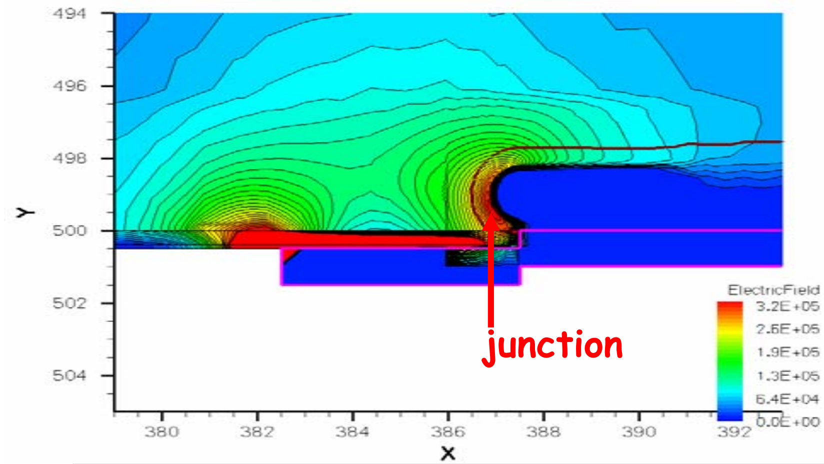
Sensor Simulation

details of breakdown regions: E-field

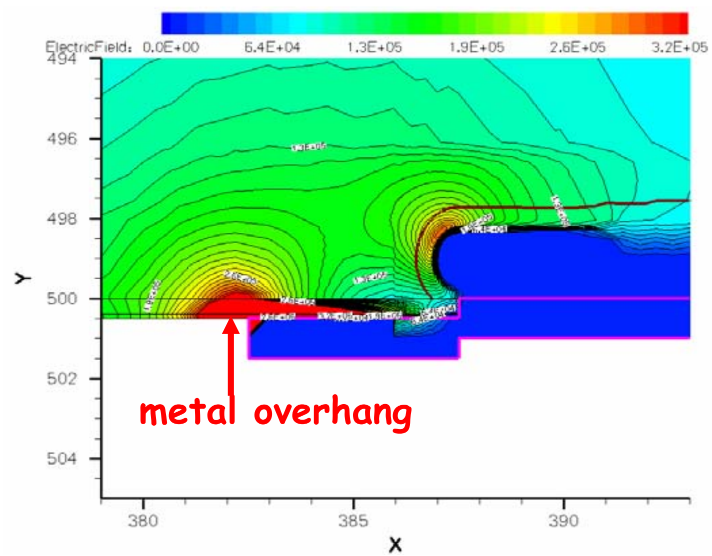
N_{ox}=0, N_{it}=0 → V_{bd} > 1000 V



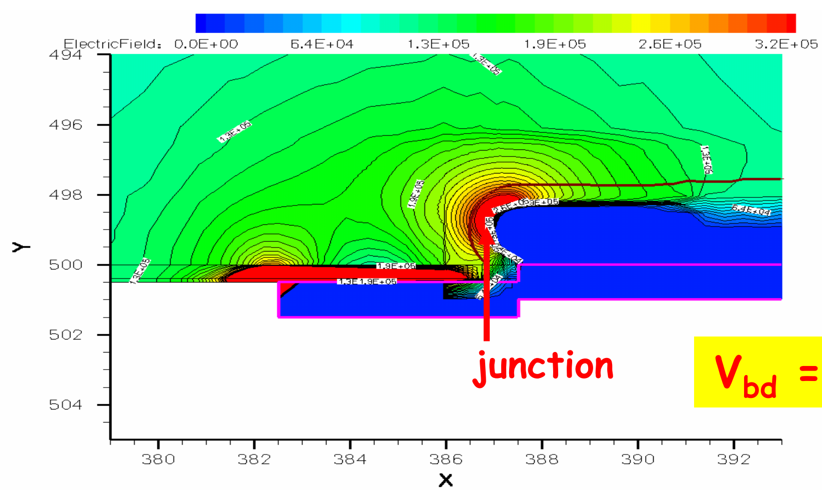
$N_{ox}=4\cdot10^{12}$ cm^{-2}, N_{it}=0 → V_{bd}=300 V



$N_{ox}=2\cdot10^{12}$ cm^{-2}, N_{it}=0 → V_{bd}=690V



$N_{ox}=2\cdot10^{12}$ cm^{-2}, N_{it}=acceptor ($4\cdot10^{12}$, E_t=0.35eV), acceptor ($4\cdot10^{13}$,E_t=0.6eV)



V_{bd} = 995 V

3. Next steps: Radiation damage and sensors simulations

3.1 Radiation damage measurements

- gated diodes under bias (under way)
- finish annealing studies (under way)
- segmented p^{+}-n-sensor (characterization of unirradiated detector completed); ready for irradiation

Aim to complete work by end 2009

3.2 Simulations

- complete detailed comparison gated diodes ⇔ simulations
- compare breakdown simulations for segmented detector(s) with measurements
- sensor design based on above experience

Aim to complete work by mid 2010

Characterisation segmented sensor

Characterisation segmented sensor:

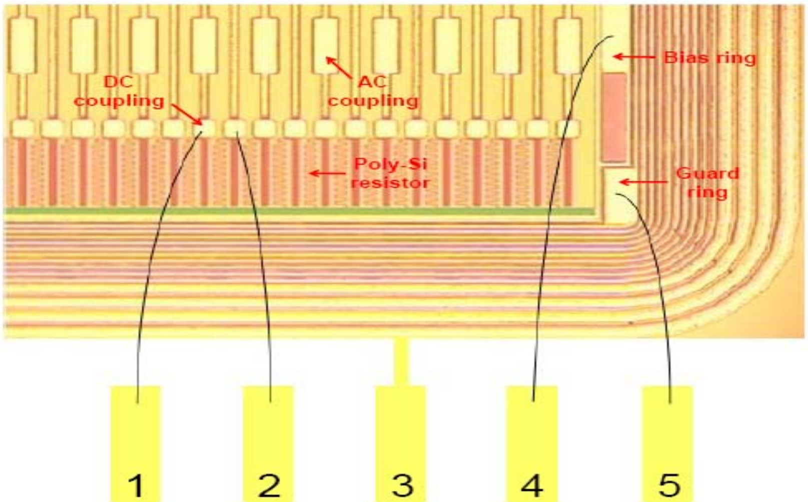
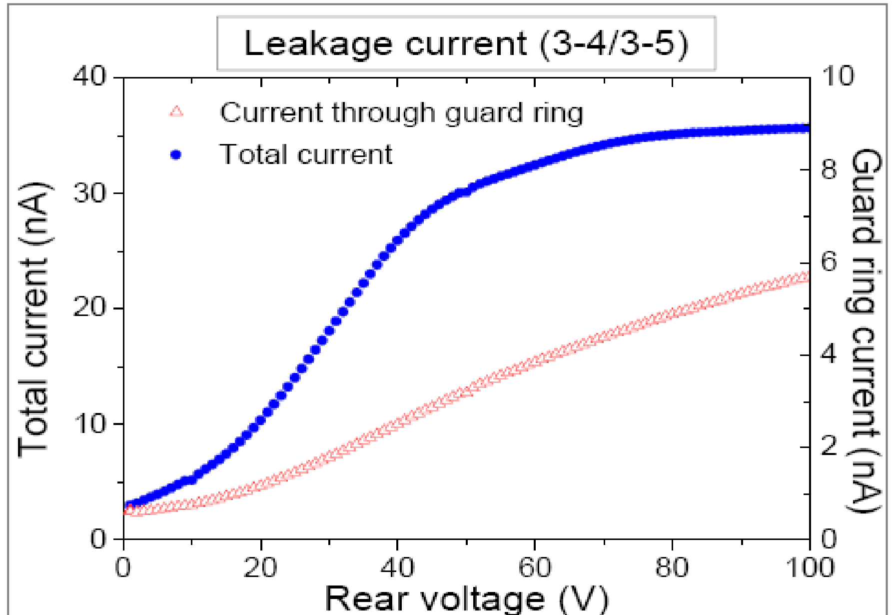
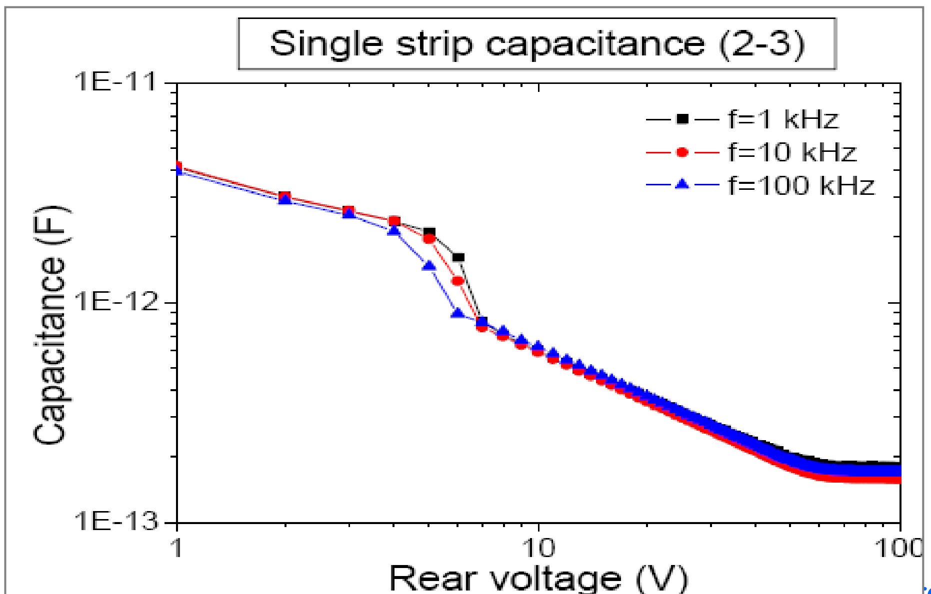
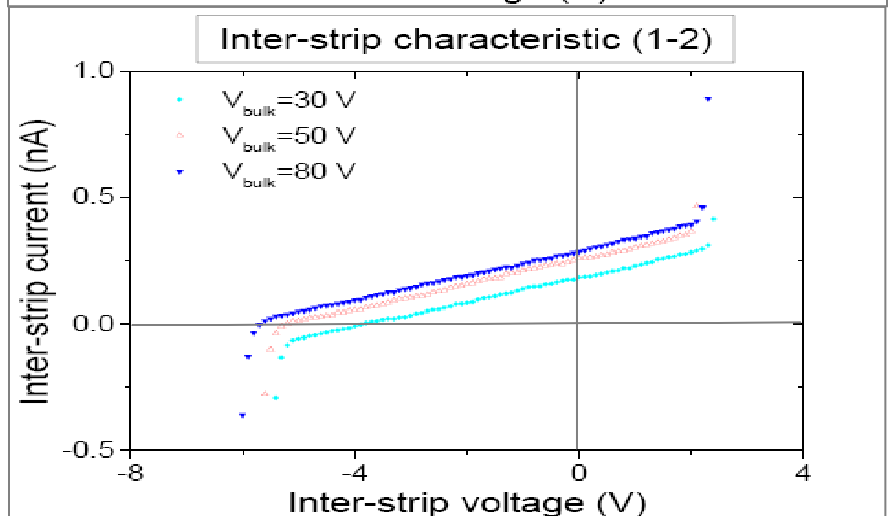


Fig. Photograph of microstrip sensor
Contacts:1&2 – adjacent strips; 3 – rear plane; 4 – bias ring; 5 – 1st guard ring.







- inter-strip resistance $R_{in} \approx 20\ G\Omega$
- Interstrip breakthrough voltage: -5~-6 V/ 2~3 V

bla-bla: