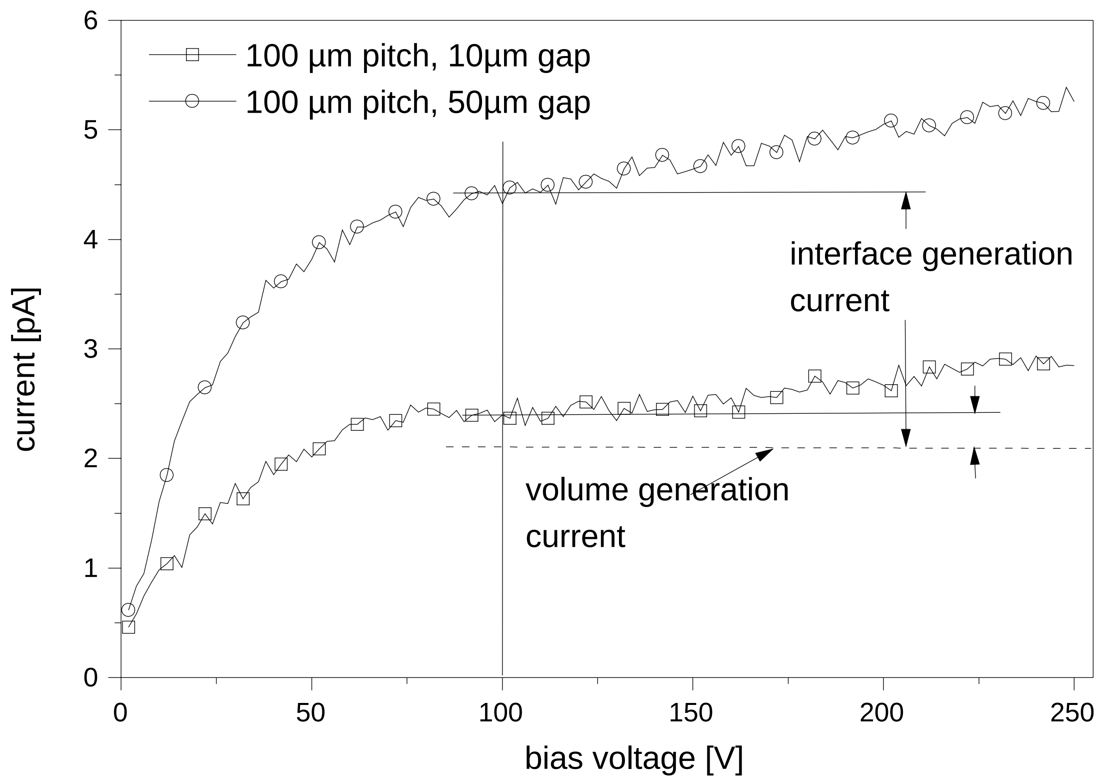
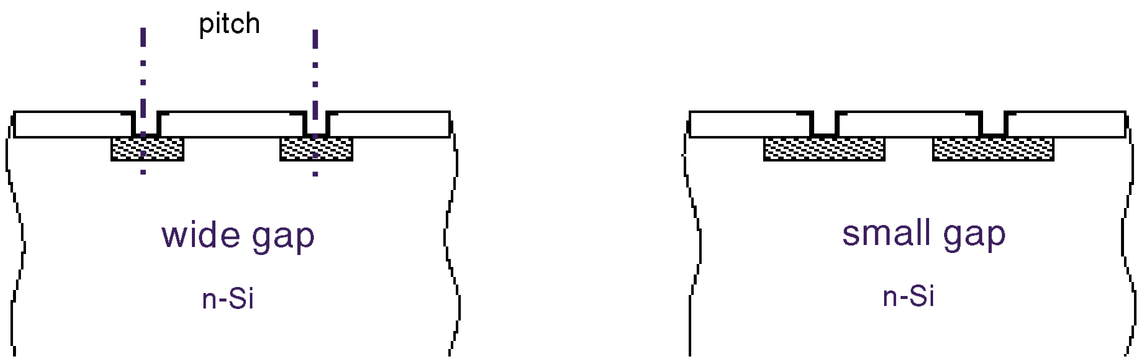
IV curves of different pixel cells





both pixels have identical pitch and length

→ equal volume generation currents expected

but wide gap pixel shows higher current !

surface effect ??

→ wide gap -> large surface area

→ small gap -> small surface area

Crucial growth parameters

goal : grow oxide films of well defined thickness
and quality (low defect densities)

→ control oxidation rate

→ control ambient composition / contamination

radiation hardness depends on the process

water vapour

* increases oxidation rate

high dopant surface concentrations (> 10^19/cm²)

* dopants diffuse into oxide film or pile-up at crystal surface
* increased oxidation rate
* local variations in film thickness

crystal orientation

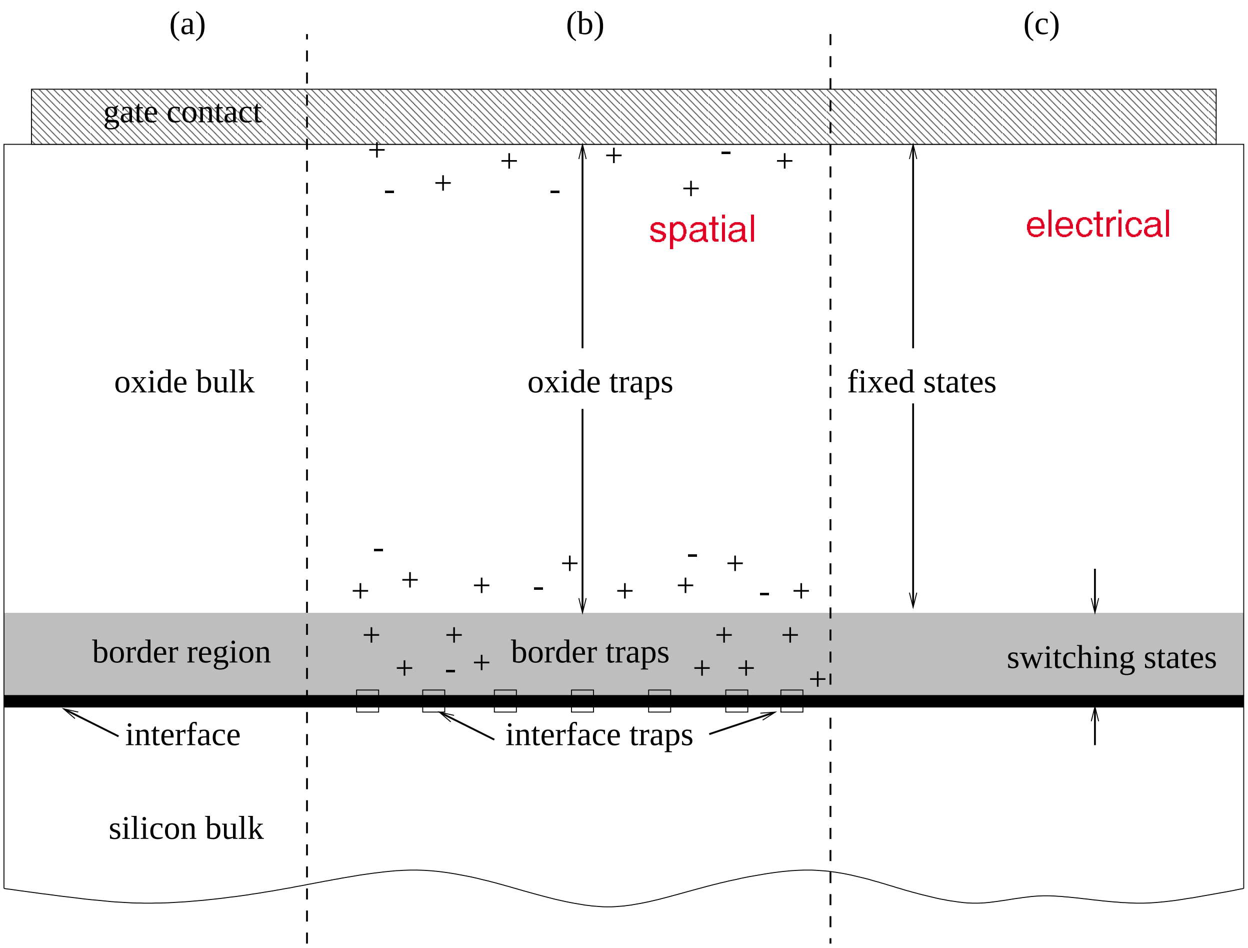
* density of available bonds
* activation energy depends on bonding angle
* defect density

chlorine additives (HCl,TCA, TCE)

* reduce mobile oxide charges
* reduce stacking faults
* lower defect densities
* increased minority carrier life-time at silicon surface (MOSFET)

3. Microscopic radiation effects

nomenclature



oxide bulk consists of stoichiometric silicon dioxide

border region is characterised by high bond stress

it extends over ~30 Angstroem

high defect densities

interface: transition region

~5 Angstroem thickness

3 layers of Si_2 , Si_2O_2 and SiO_2

where do we stand ?

- surface effects are correlated to the sensor design
- radiation induced surface damage occurs in the silicon oxide and at the interface
- surface effects are process related before and after radiation exposure

the process related data is often not accessible by the customer

- quality assurance during large scale production
- process monitoring
- monitoring of radiation hardness

↓

set of macroscopic parameters required

4. Macroscopic surface parameters

N_{ox} density of positive oxide charges

→ flat-band voltage

oxide thickness

$$U_{fb} = U_{fb0} + \frac{e * d}{\varepsilon_{ox} * \varepsilon_0} * \Delta N_{ox}$$

permittivity of oxide

S_0 surface recombination velocity

→ interface generation current

$$I_{ox} = q_0 * n_i * A_{gate} * S_0$$

intrinsic carrier concentration

D_{it} interface state density (midgap)

→ determines surface recomb. velocity

$$S_0 = \sigma_{eff} * v_{th} * \pi * k_B T * D_{it,mg}$$

effective capture cross-section

thermal velocity

→ causes "stretch out" of high frequency

CV curve of MOS devices

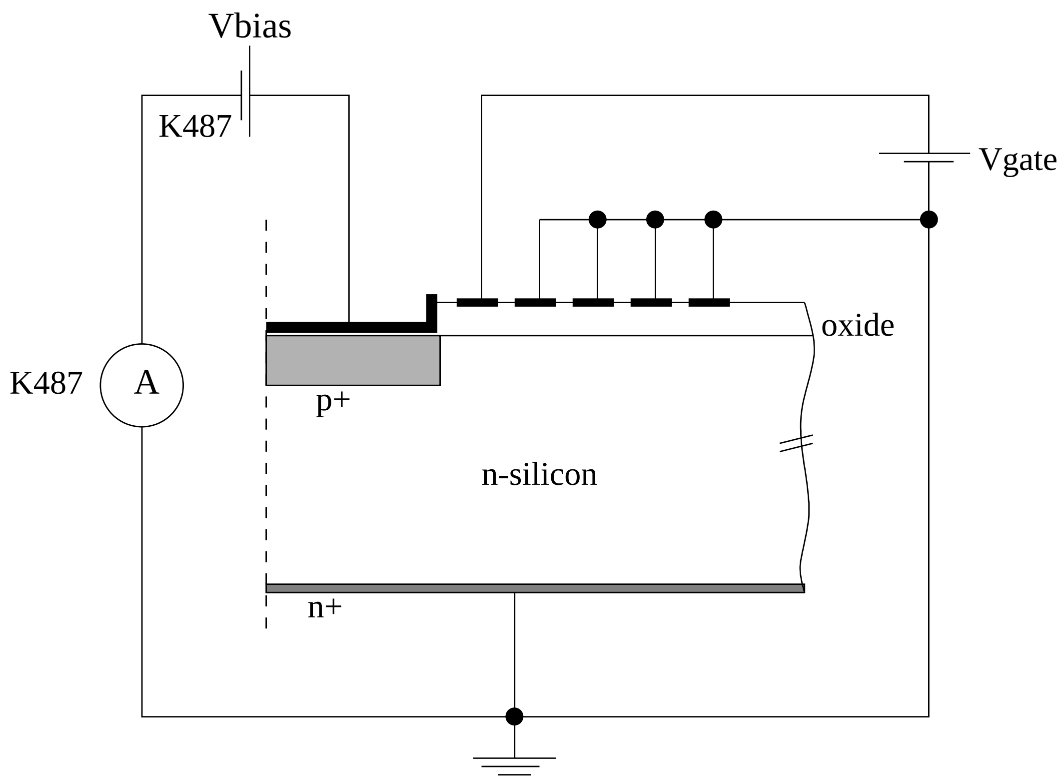
interface generation current (I_{ox})

* contributing surface region must be well defined

$$I_{ox} \sim A_{gate}$$

* switch Iox on and off to separate it from bulk contributions

→ use gate-controlled diode

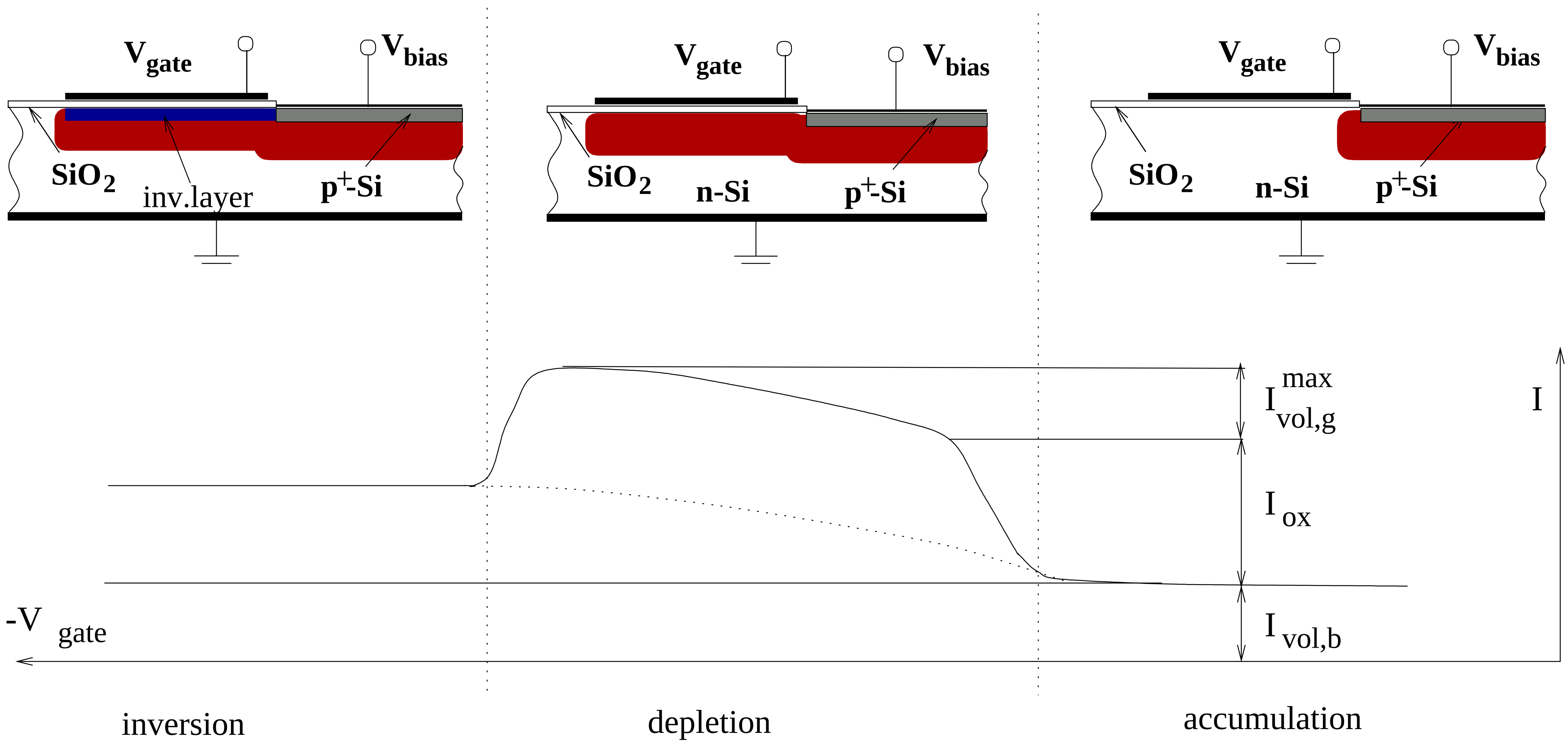


* measure current through the diode

* by adjusting gate potential I_{ox} can be turned on and off

* outer gates accumulated to define region
  → contributing surface region well defined

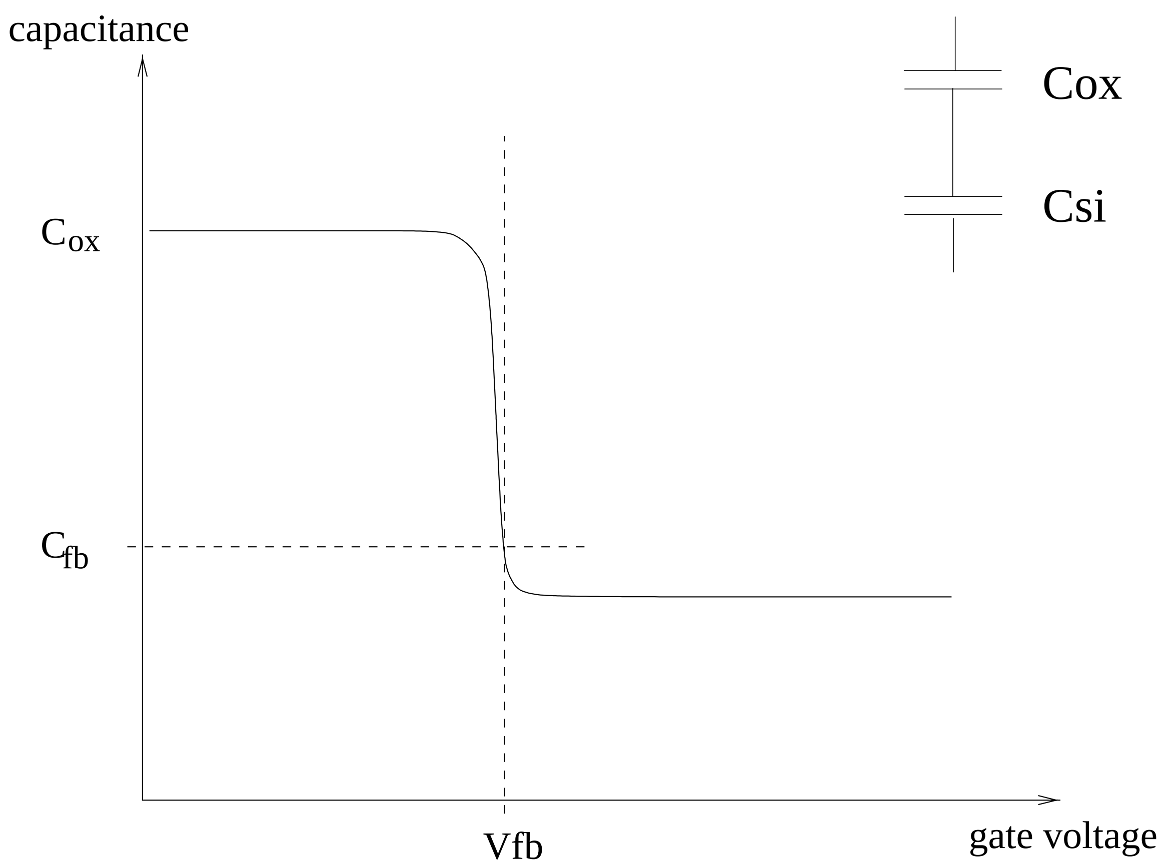
current measurements with gate -controlled diodes



J. Wüstenfeld, Universität Dortmund

flat-band voltage (Vfb)

measure capacitance of a MOS device
versus gate voltage @ high frequencies



flat-band condition :

$$C_{si}(V_{fb}) = A_{gate} * \frac{\varepsilon_{ox}\varepsilon_0}{\lambda}$$

λ extrinsic Debye length

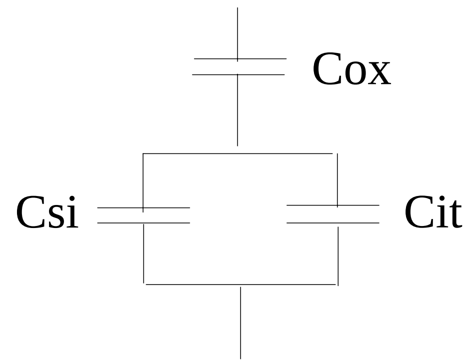
- ➤ find gate voltage corresponding to Cfb
- ➤ Neff needed to determine flat-band voltage

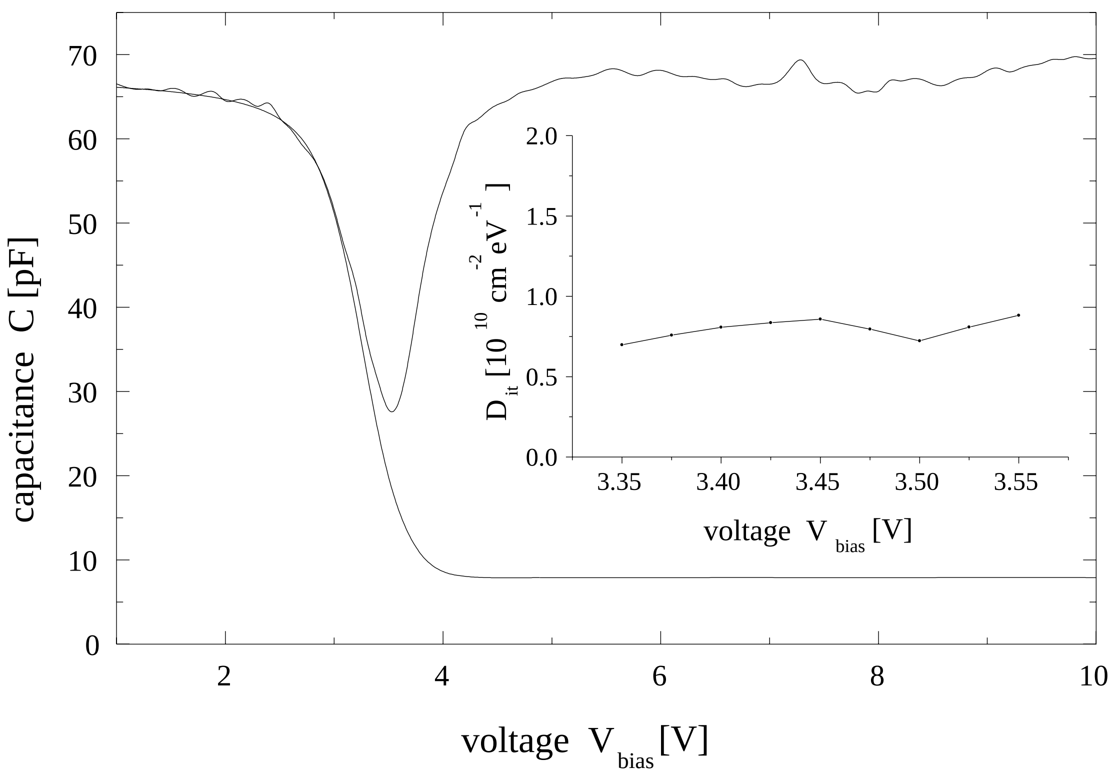
(correction for serial resistors and stray capacitances may be necessary)

interface state density

* use (for example) a combined high/low frequency CV measurement

* equivalent circuit for very low frequencies



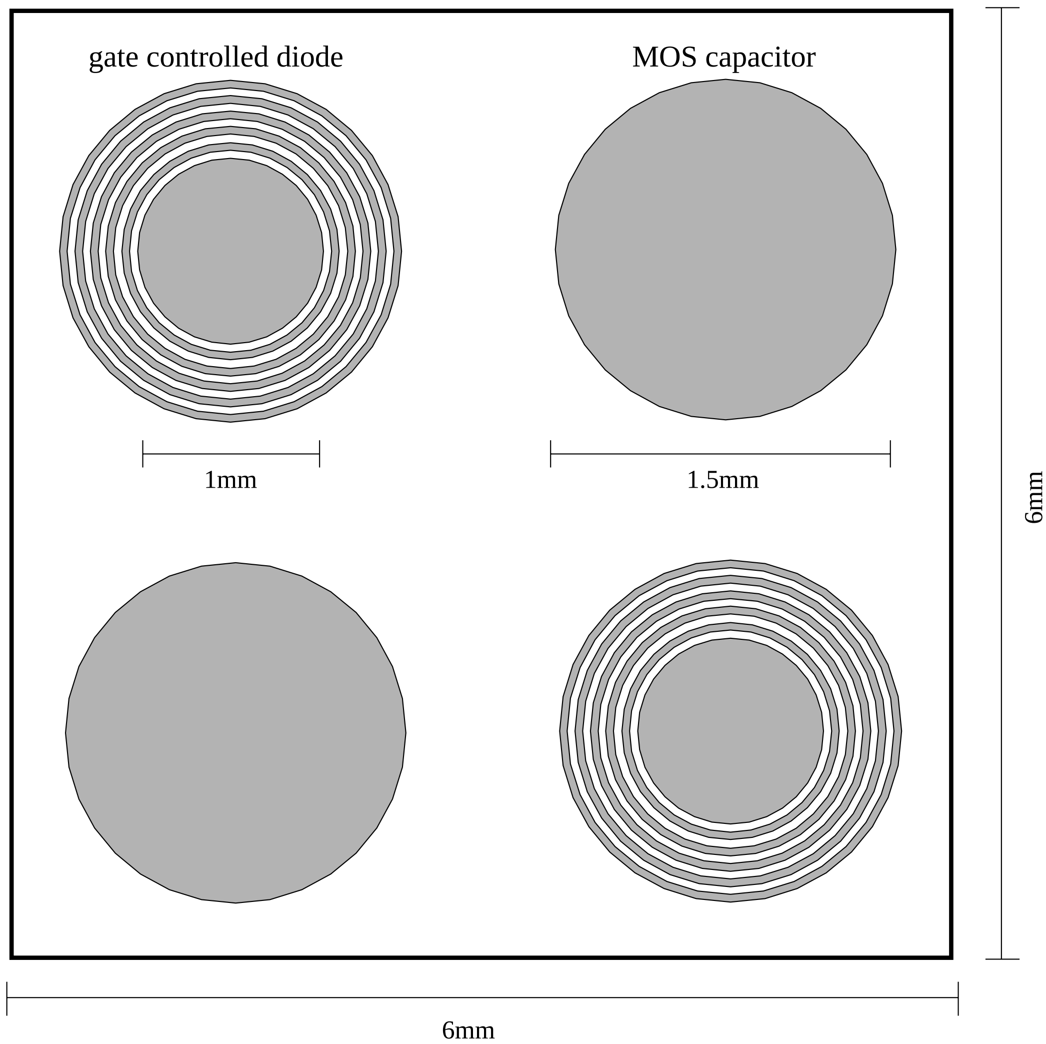


$$D_{it} = \frac{C_{lf} - C_{hf}}{q} * \left(1 - \frac{C_{lf}}{C_{ox}}\right)^{-1} \left(1 - \frac{C_{hf}}{C_{ox}}\right)^{-1}$$

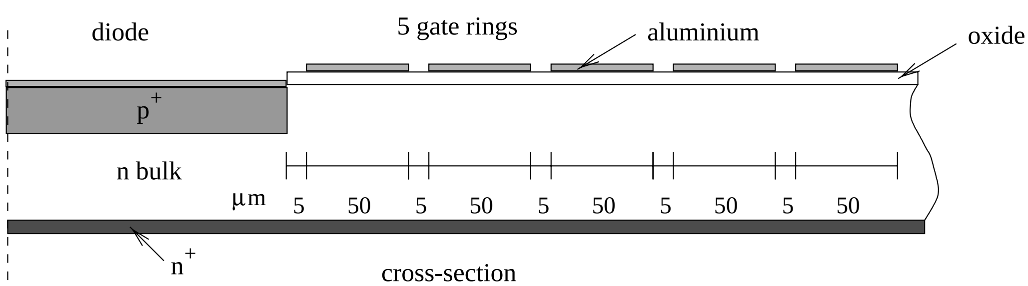
interface traps respond to "ac" gate voltage
-> C_{it} (stretch-out)

minority carrier response

schematic drawing of a test-field (CERN2, APIX...)



topview



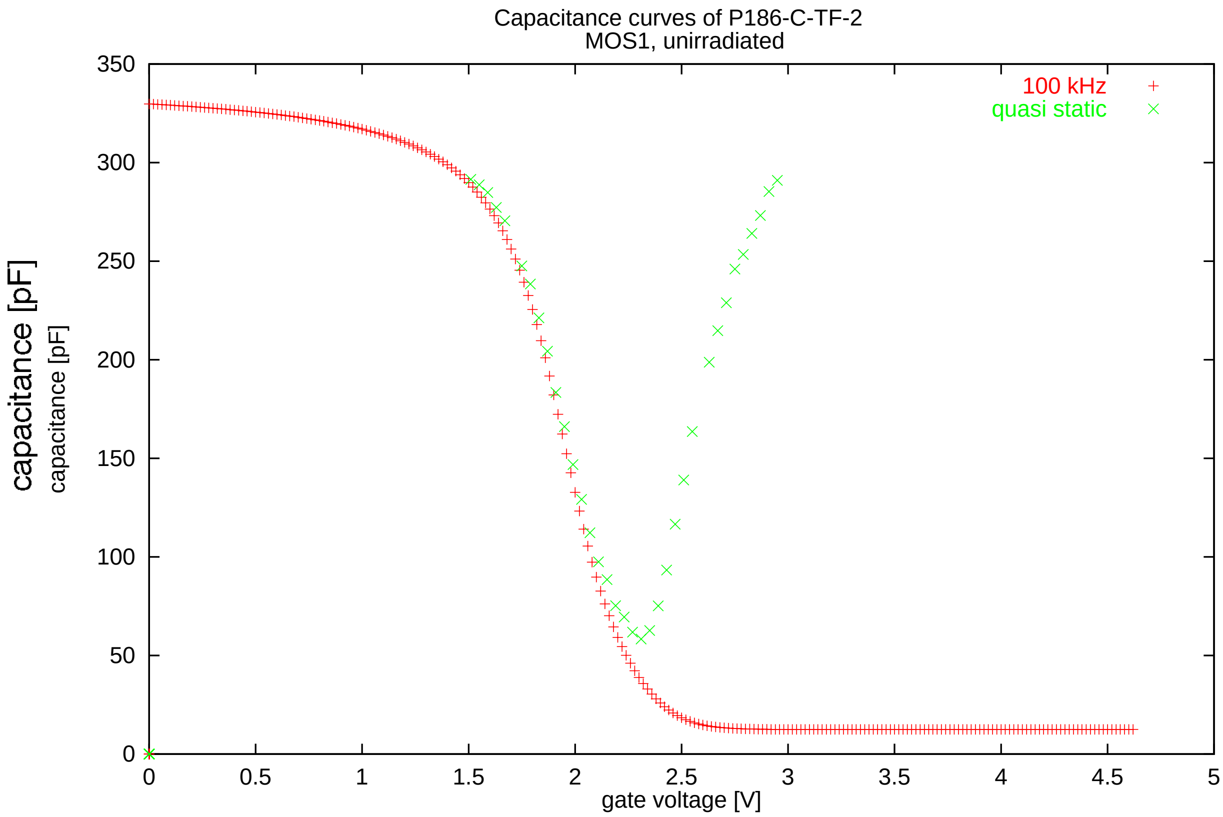
cross-section

the advanced test field provides current measurements as well as capacitance methods on the same device

more details in Wunstorf et al., NIM A444 (2000) 605-613

Results before irradiation

Polovodice <111> DOFZ, Canberra



CV measurement on diode :

$$N_{eff} = 7.2 * 10^{12} cm^{-3} \qquad \rho = 0.6 k\Omega cm$$

CV curve of MOS :

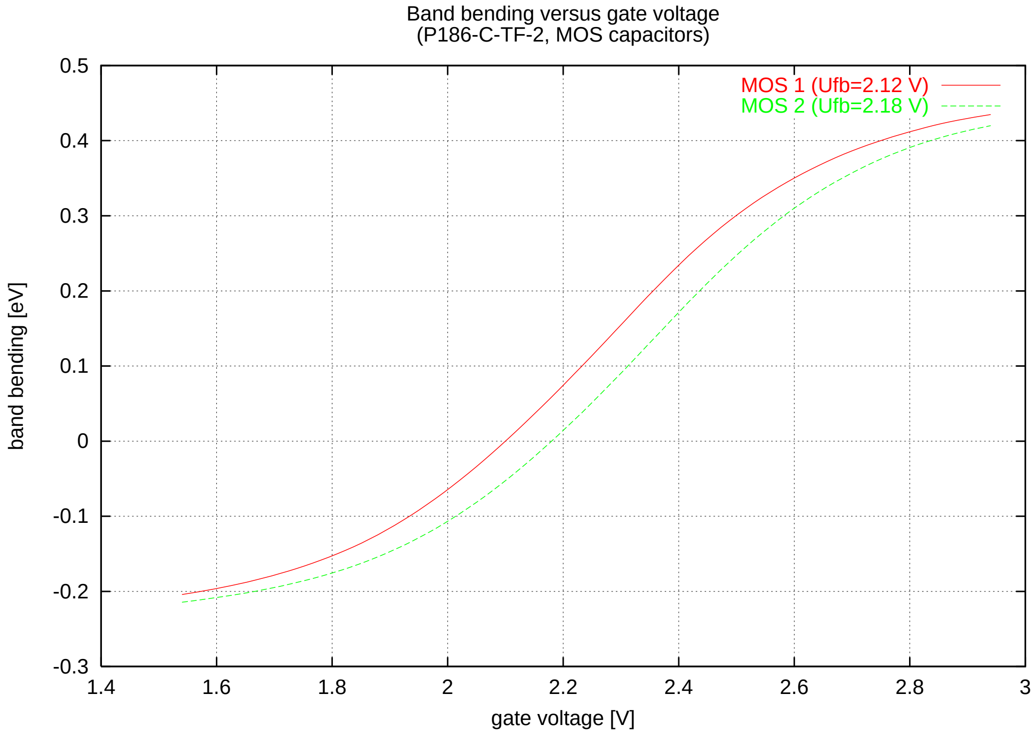
$$C_{ox} = 330 pF \longrightarrow d_{ox} = 160 nm$$

$$C_{si}(V_{fb}) = 124 pF$$

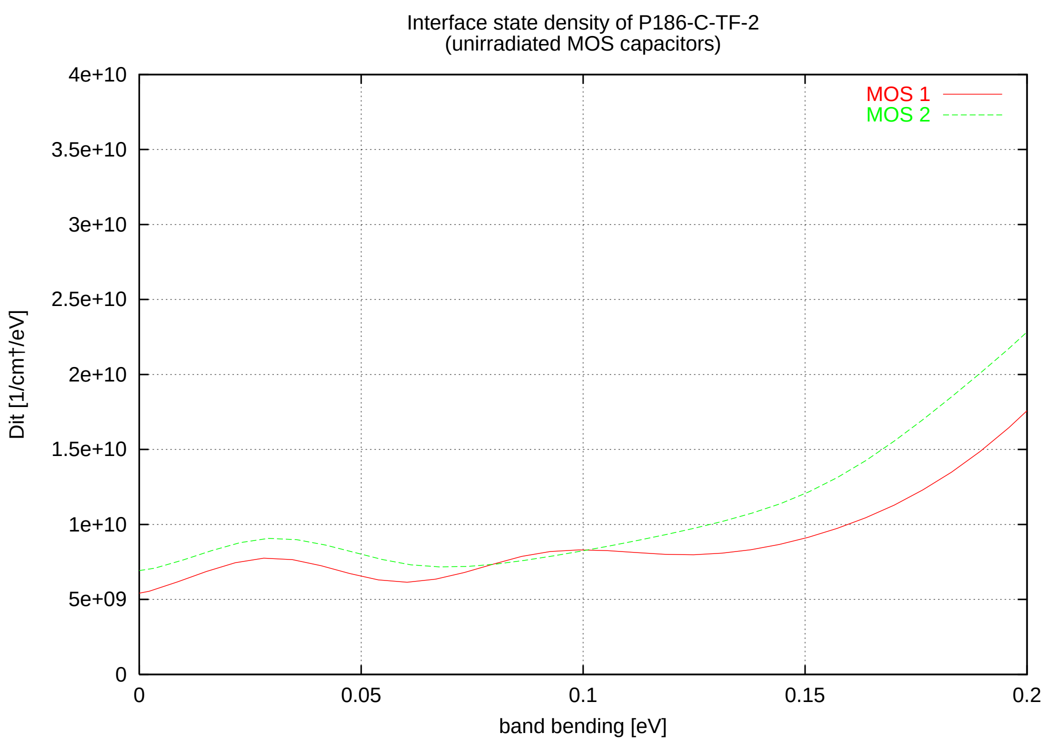
$$C_{fb} = 90 pF$$

$$\rightarrow V_{fb} = 2.2 V$$

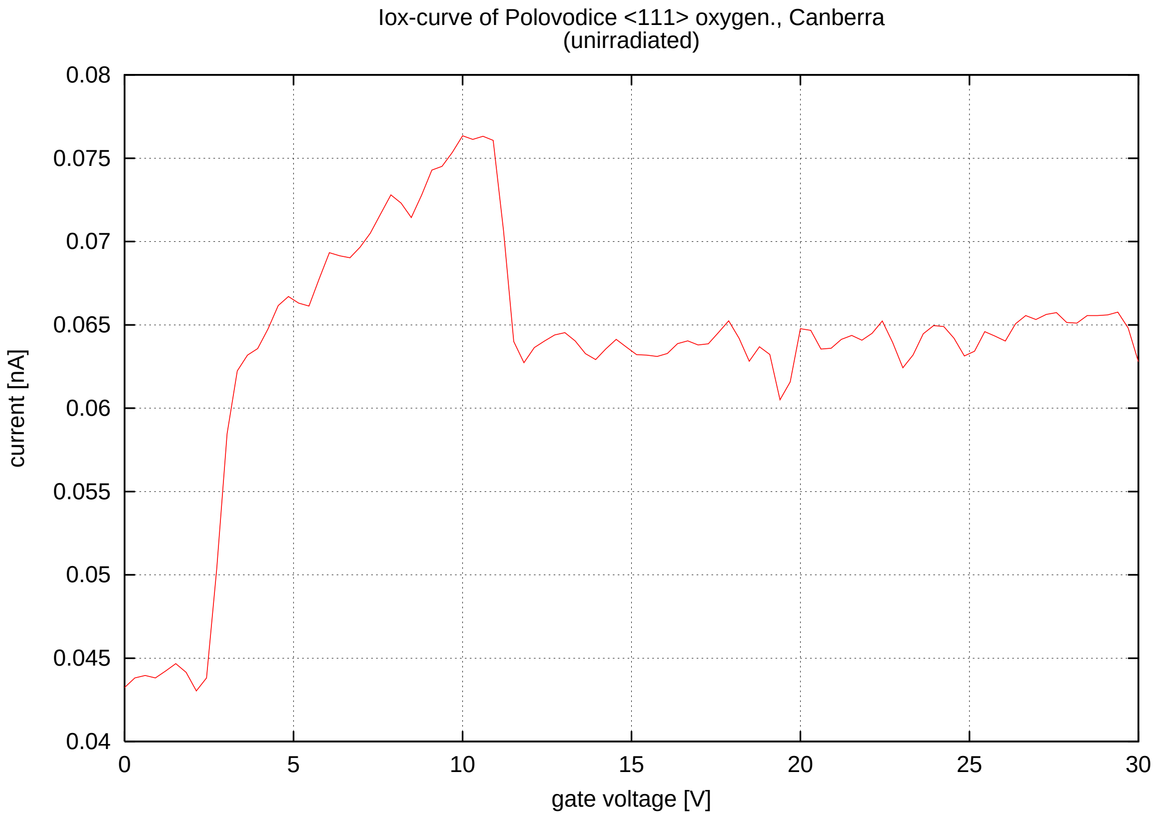
$$N_{ox} = 2.5 * 10^{11} cm^{-2}$$



band bending $$\psi(V_{gate}) = \int_{V_{fb}}^{V_{gate}} \left(1 - \frac{C_{lf}(V)}{C_{ox}}\right) dV$$



$$\psi_{midgap} = 0.17eV \qquad D_{it,mg} \approx 1.5 * 10^{10} eV^{-1} cm^{-1}$$



Iox = 0.016 nA

S0 = 7 cm/s

comparison of unirradiated devices

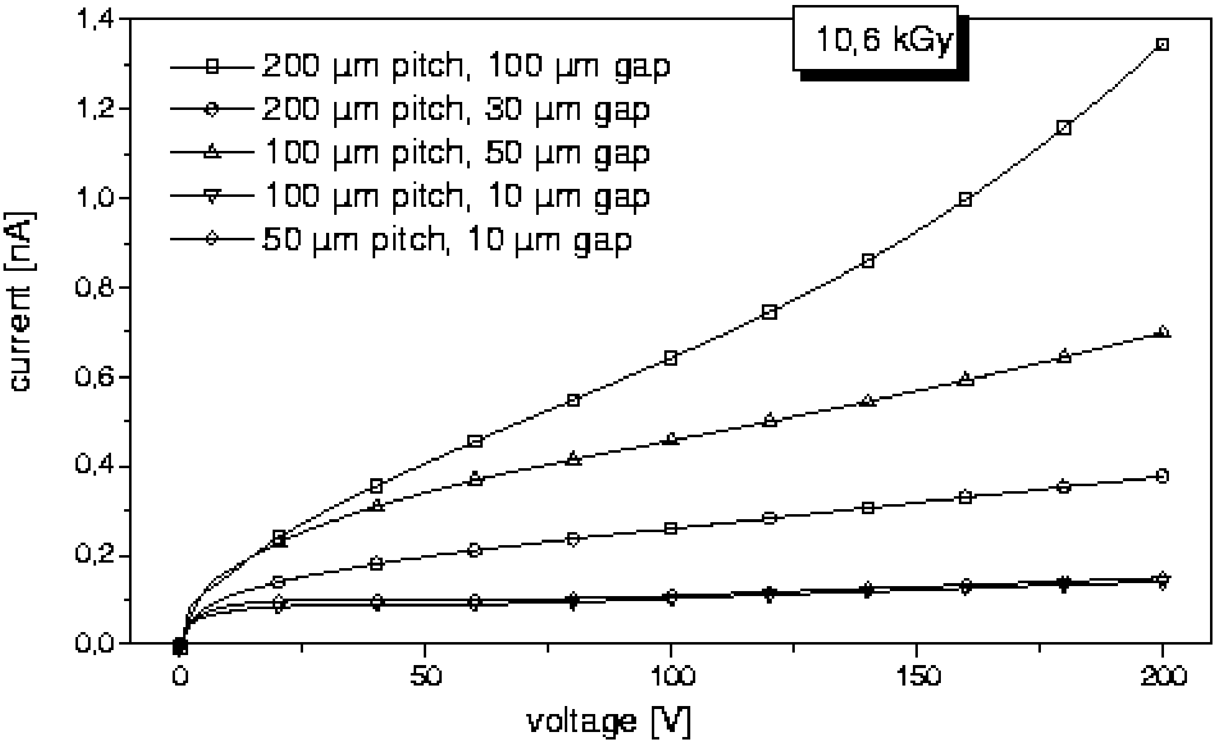
substrate / vendor	$N_{ox}[10^{11}/cm^2]$	$S_0[cm/s]$	$D_{it,mg}[10^{10}/eV/cm^2]$	$\sigma_{eff}[10^{-16}/cm^2]$
Polovodice, DOFZ Canberra	2.5	7.0	1.5	2.9
Topsil, <100>, DOFZ CiS	2.1	?	1.7	?
Topsil, <100>, Std. FZ CiS	2.1	8.0	0.9	5.6
Wacker, <111>, Std.FZ CiS	5.6	8.0	1.7	2.8
Wacker <111> 16h DOFZ CiS	5.6	7.6	1.7	2.8
Wacker <111> 24h DOFZ CiS	5.5	8.0	1.8	2.8
Wacker <111> Std.FZ IRST	3.9	<4.4	<1.1	2.5
Wacker <111> 24h DOFZ IRST	4.2	12.0	12.0	0.6
Topsil <111> 72h DOFZ Sintef	0.6	1.7	0.4	2.5
Wacker <111> 72h DOFZ Sintef	0.6	1.7	0.4	2.5

value calculated
input for calculation

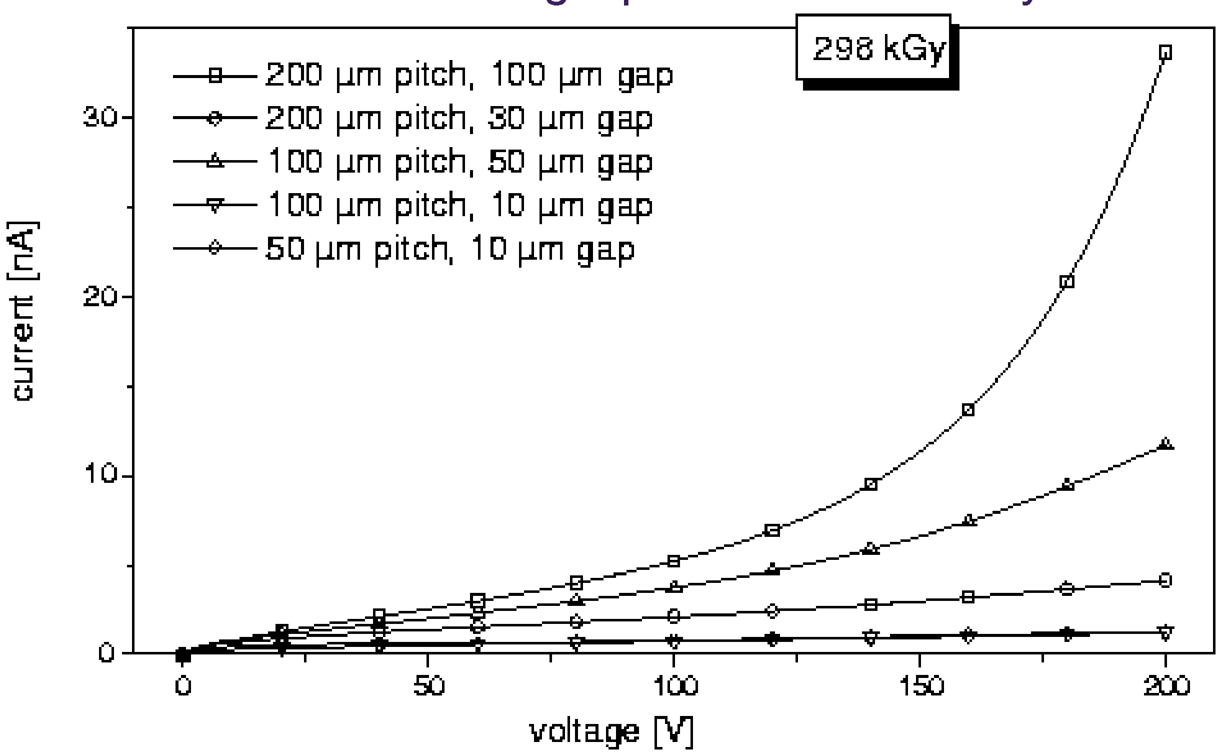
- high quality oxidation
- effective capture cross-section in agreement with commonly used values
- the performance of <111> silicon is as good as for <100> crystals
- no difference between DOFZ and Std.FZ !

a) current

IV curves of single pixels after 11 kGy *)



IV curves of single pixels after 300 kGy



- current increase compared to current before irradiation
- exponential shape of the curves !
- gap dependent

*) Wüstenfeld et al., Il Nuovo Cimento, Vol. 112A, N. (1999)