Quality assurance

for the

radiation hard ATLAS pixel sensors

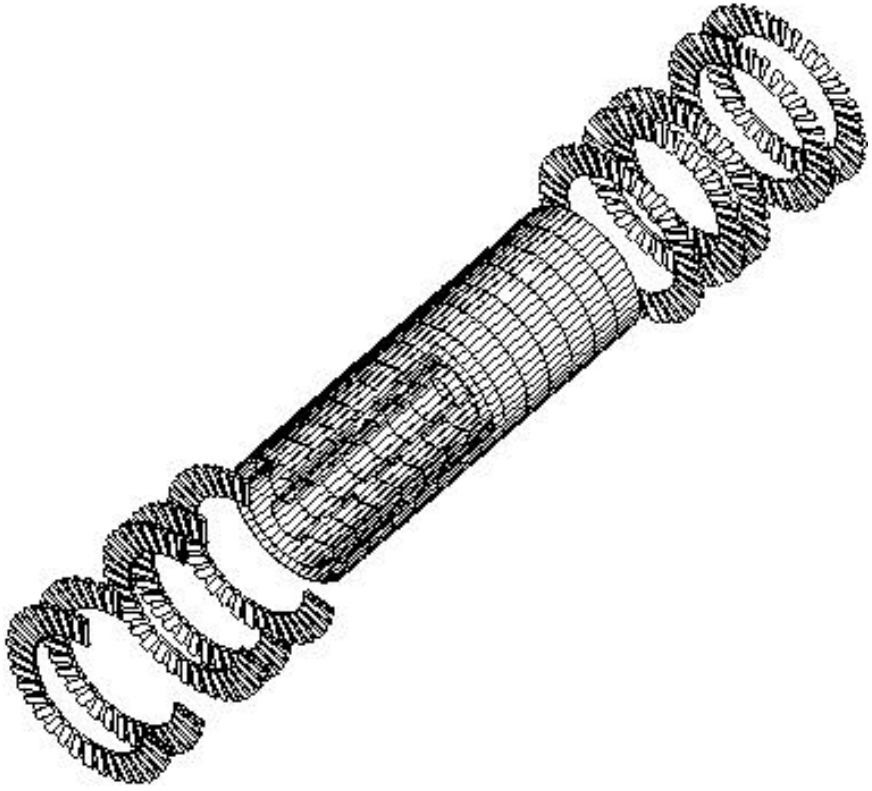
Contents:

- *Why is systematic QA necessary?*
- *Procedures and design features*
- *Measurements before irradiation*
- *Measurements after irradiation*

Introduction

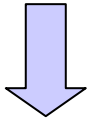
Why systematic quality assurance for the ATLAS pixel sensor?

- *large number of detector parts (2228 modules fitted with one sensor tile and 16 front-end chips each)*
- *parts not easily accessible after assembly (central position, cooling and radiation)*
- *every bad pixel degrades performance*
- *» $1.4 \cdot 10^8$ pixel channels in total*

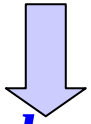


Important steps for QA

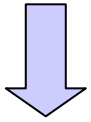
Setting technical specifications



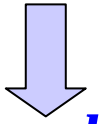
Designing according to specifications



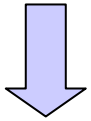
Identifying relevant qualities



Defining reliable measurement procedures



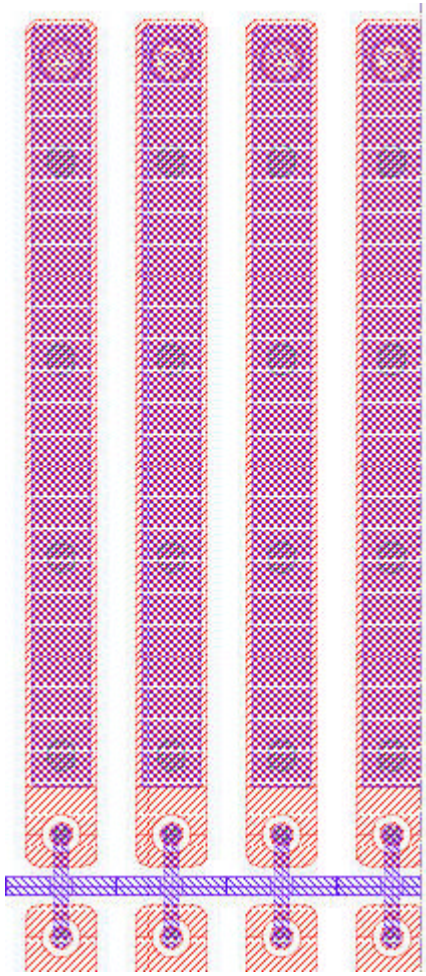
Calibrating involved test sites



Archiving measurement data in data base

Pixel design requirements

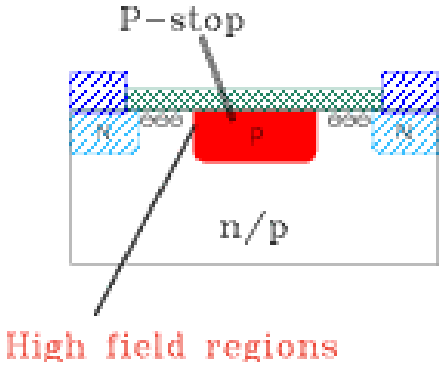
- *pixel size 50µm x 400µm*
  - *50 µm pitch*
  - *12µm diameter bump connection*
- *total active area 2.3m^2 (2228 modules)*
  - *high yield*
  - *testability*
- *10 years operation*
  - *fault tolerance*
- *harsh radiation environment*
  - *up to 10^{15} cm^{-2} (1 MeV neutron eq.)*
  - *radiation hard technology and design*



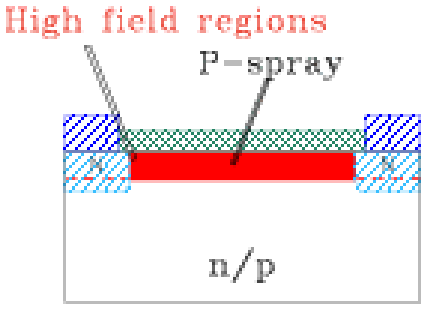
Isolation techniques

Optimizing performance before and after type-inversion and ensuring testability

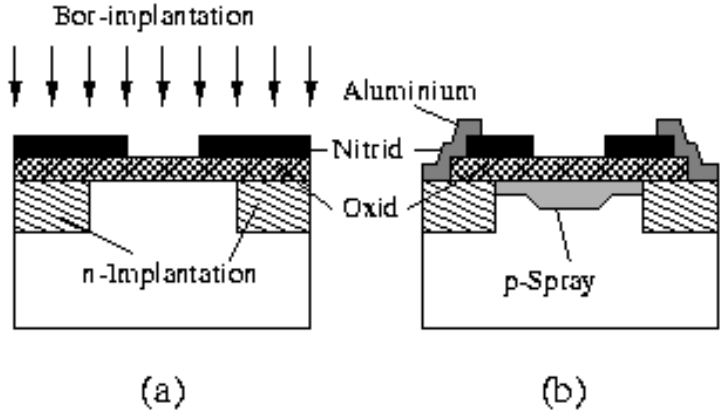
p-stop



p-spray



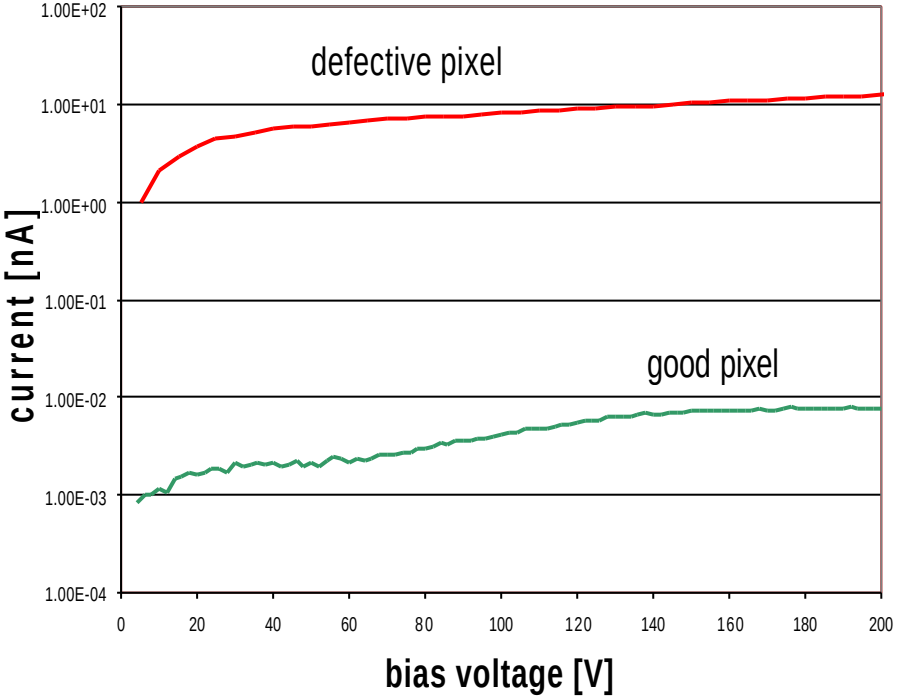
moderated p-spray

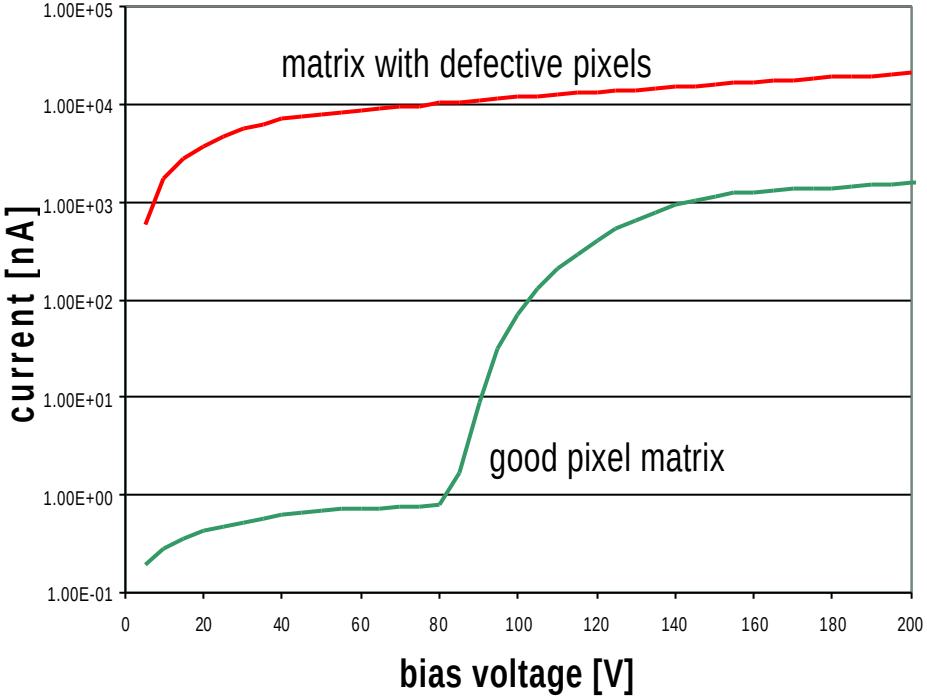


For p-spray testing of worst case of breakdown before irradiation

Testability

I-V tests on test pixels using punch-through





current through single pixel

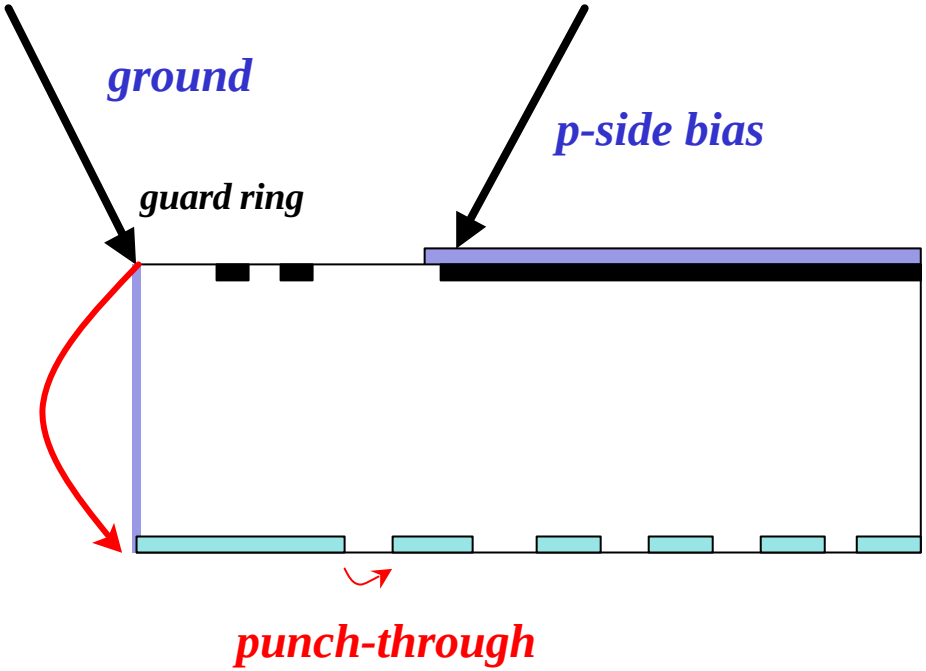
current through punch-through array

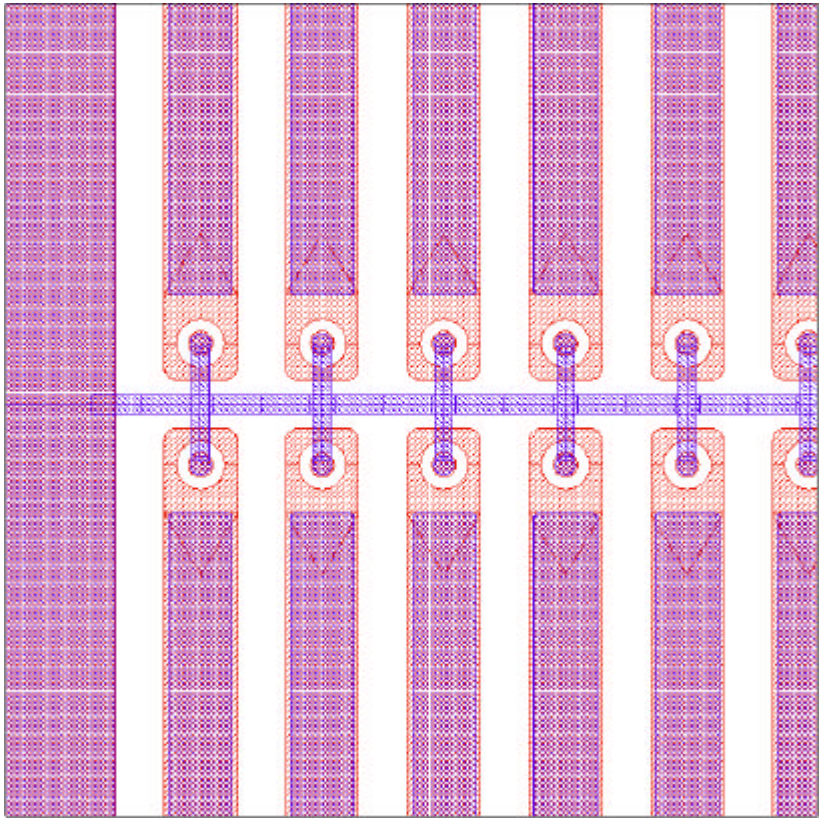
Leakage current indicative for quality of every pixel

Testability

I-V tests before bonding using bias grid

- *Punch-through effect across a bias grid allows testing of all pixels using only two probes on wafer p-side*

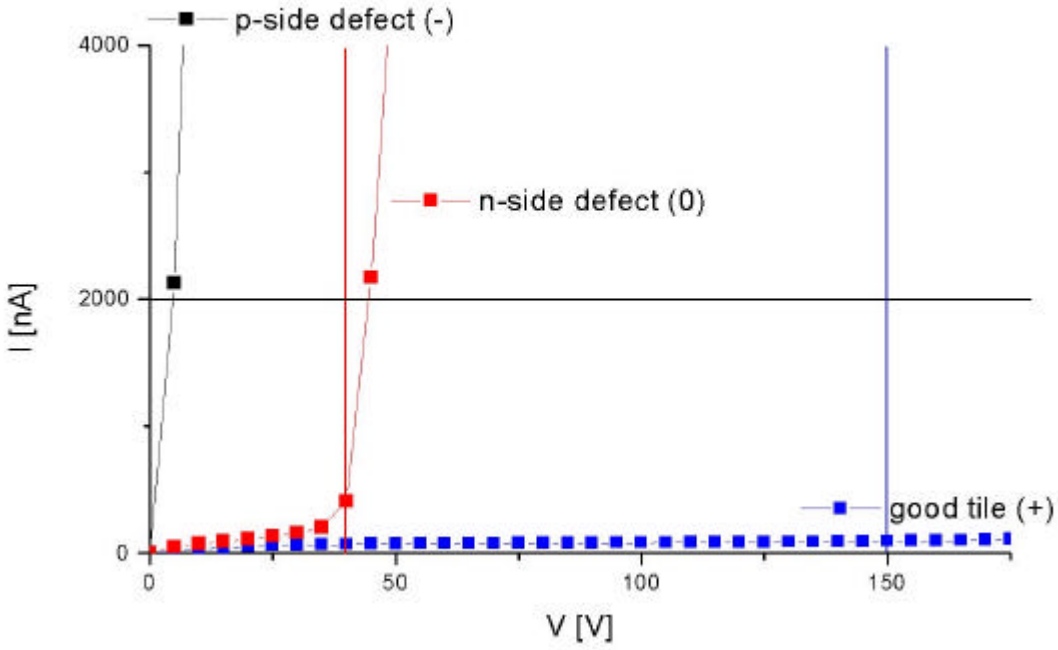




Leakage current

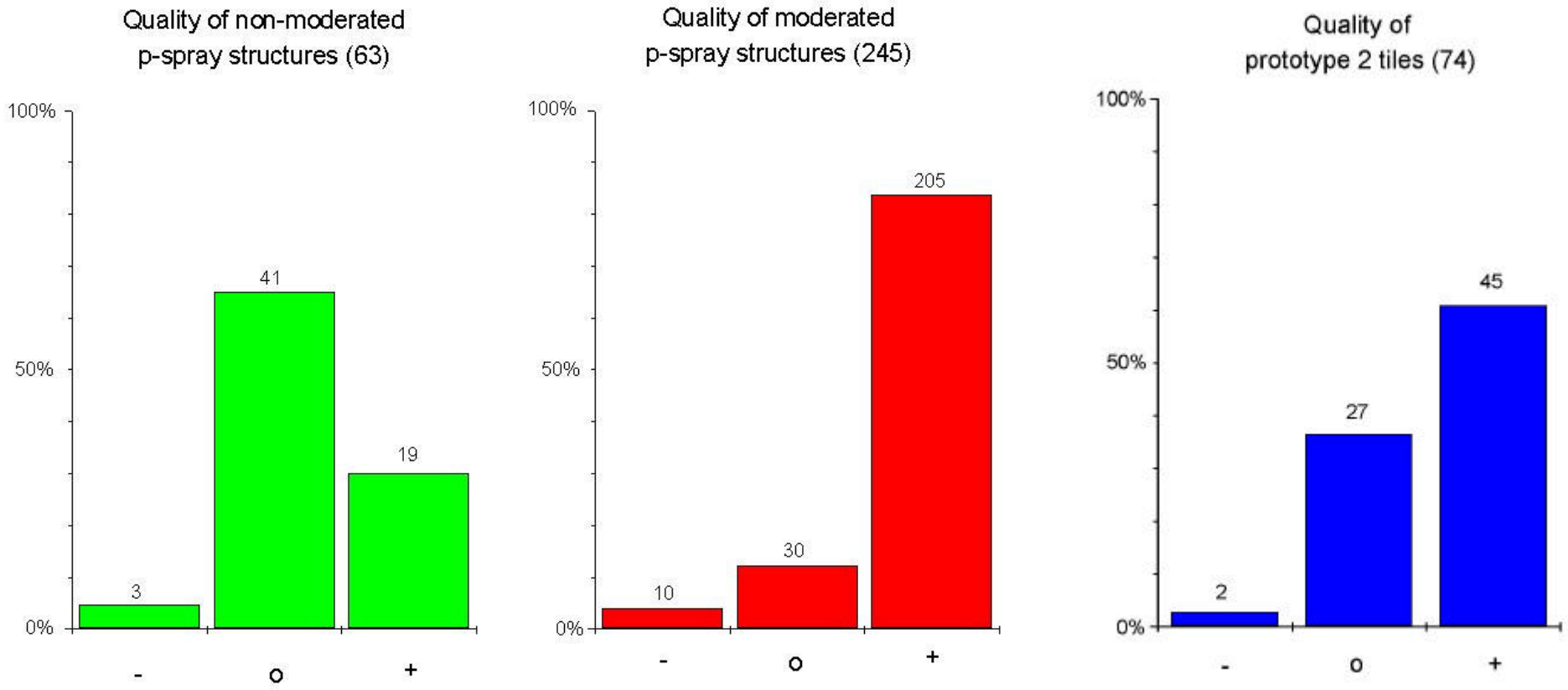
Tile classification by pixel quality

- *I-V measurements of leakage current show pixel quality*
- *breakdown voltage indicates type of defect*
- *tile classification possible*



Leakage current

Yield analysis based on I-V curves

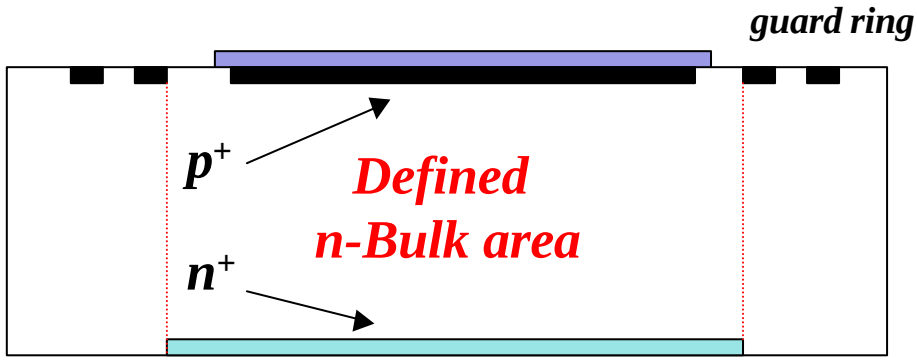


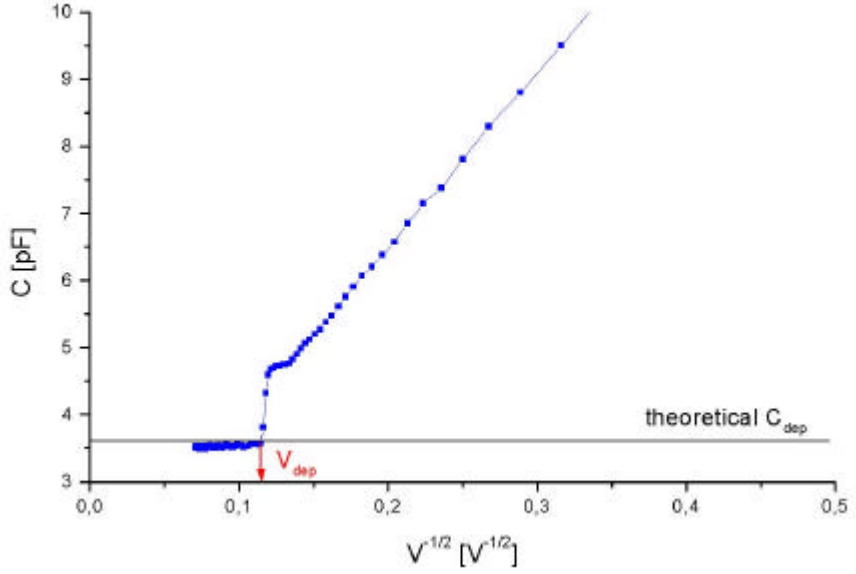
Sensor depletion

Diagnostic measurement by diode capacitance

- *Test diodes on production wafer for well defined capacitance measurements*

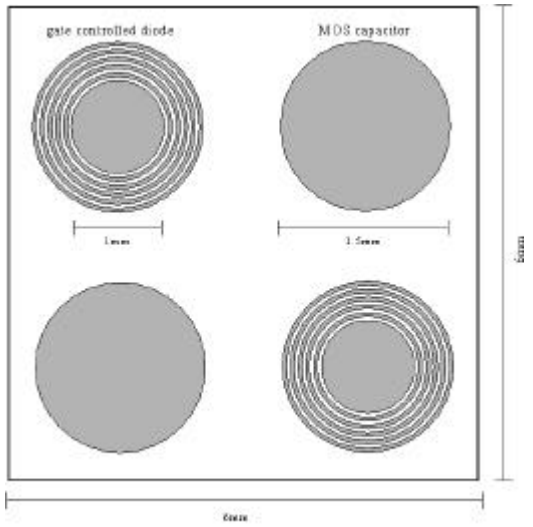
- *Full depletion visible by levelling out of C vs. $V^{-1/2}$ curve (suppression of possible constant stray capacitances)*





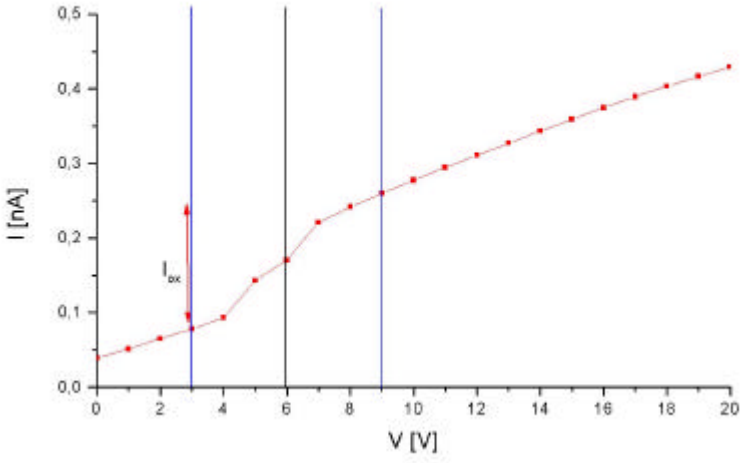
Oxide characteristics

Diagnostic measurements on MOS and GCD



- *oxide breakdown and capacitance measured in I-V and C-V curves on MOS pads*

- *interface generation current measured on gate controlled diodes as I-V curve around flat-band case with identical gate and diode voltage*

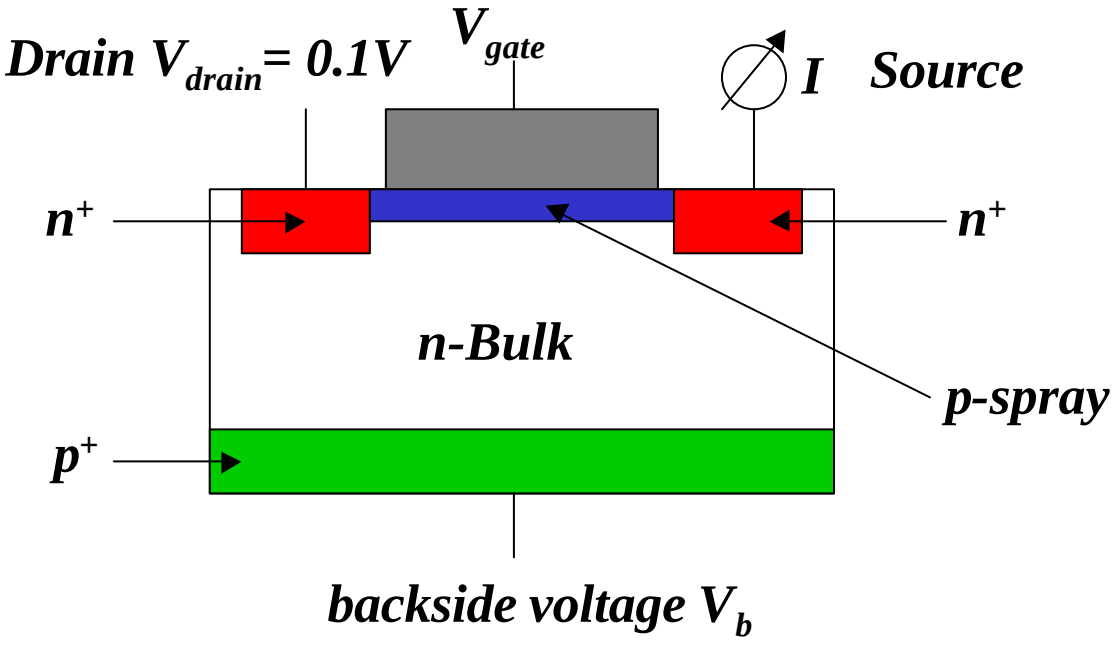


- *current step indicates charge density on interface*

P-spray dose

Method of measurement

- source - drain measurement on MOSFET on depleted bulk
- p-spray inverts at higher gate voltage: threshold V_{th}
- source-drain current rises rapidly at V_{th}



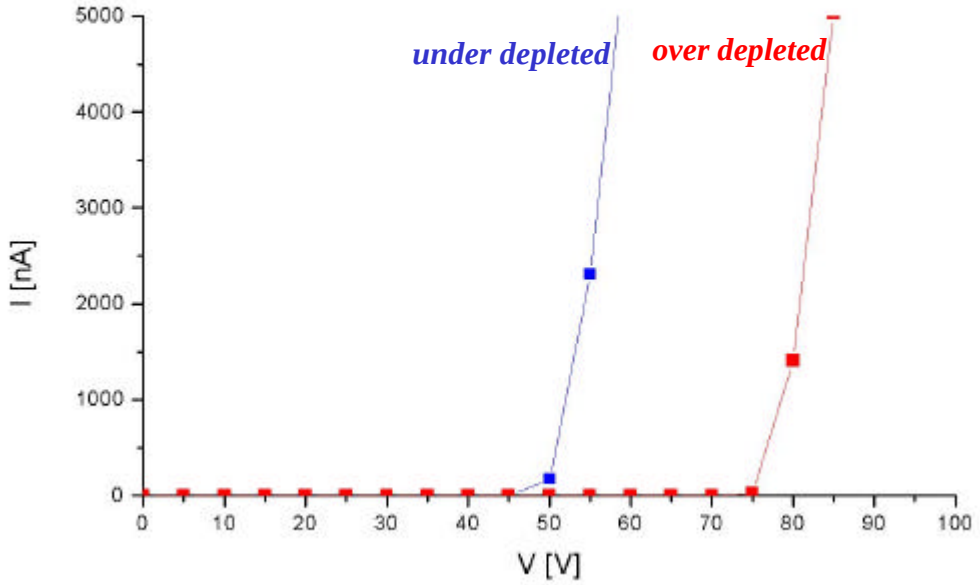
P-spray dose

Analysis

• after V_{th} is identified p-spray dose is given by

$$f_{p\text{-}spray} = C_{ox} \cdot (V_{th} - V_{fb}) / e$$

using flat-band voltage and oxide capacitance from MOS C-V



Radiation hardness tests

Bulk damage testing

- after irrad. with $3.1 \times 10^{14} cm^{-2}$ neutron equivalent protons
  - depletion measurement on diode
- after irrad. with $10^{15} cm^{-2}$ neutron equivalent protons (design fluence)
  - I-V measurements on mini chip and diode (small structures)

Surface damage testing

- after irrad. with 500 kGray low energetic electrons (design dose)
  - interface generation current measurement on GCD
  - p-spray measurement on MOSFET

Testing responsibilities

vendor

- providing process data
- testing pixel quality on sensor tiles on wafer level
- performing diagnostic tests on wafer level for depletion, oxide quality and capacitance, and p-spray dose

ATLAS institutes

- checking process data
- testing pixel quality on sensors tiles, single chips and mini chips
- performing all diagnostic tests on wafer level and on diced test structures
- measuring irradiated structures

Summary

Progress of quality assurance process

• technical specifications	completed and approved
• sensor design	completed and approved
• quality test for every pixel on sensor	defined and demonstrated
• diagnostic tests for relevant qualities	defined and demonstrated
• cross calibration of test sites	in progress
• data base for test results	under construction