Irradiation and annealing study of 3D p-type strip detectors

- CNM double-sided 3D
- Measurements pre-irradiation
  - Bulk capacitance
  - Leakage current
  - Interstrip capacitance
  - Interstrip resistance
- Post-irradiation and annealing
- Future 3D work and other activities

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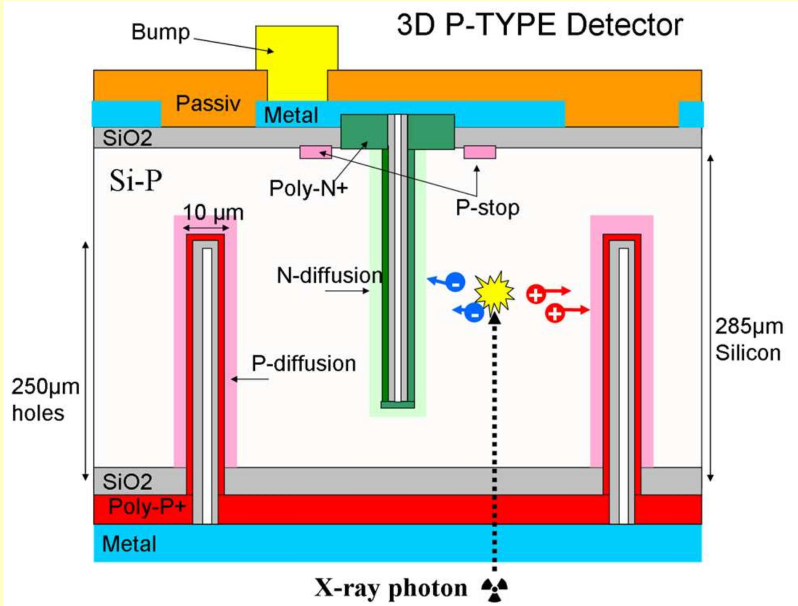
Double-sided 3D at CNM

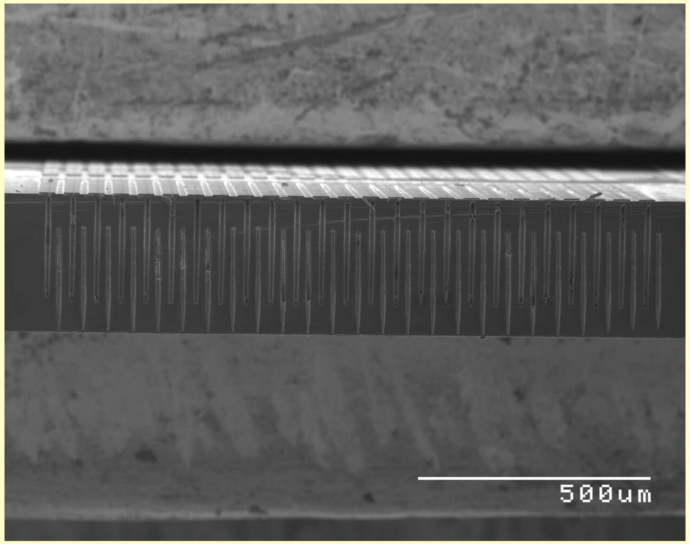
- **Columns etched from opposite sides of substrate and don't pass through full thickness**
- **All fabrication done in-house**
- **ICP is a <u>reliable and repeatable</u> process (many successful runs)**

Electrode fabrication:

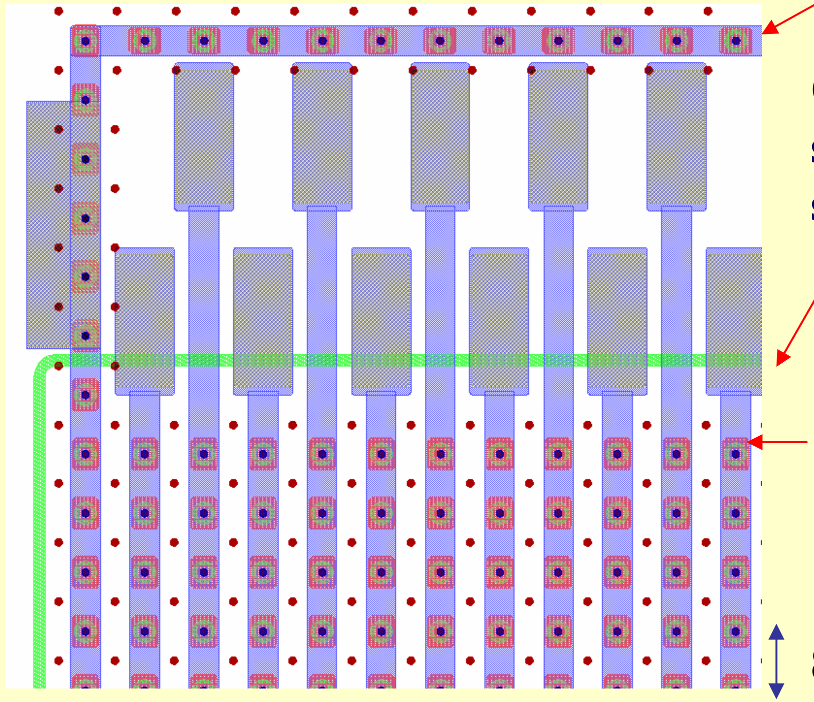
1. **ICP etching of the holes: Bosch process, ALCATEL 601-E**
2. **Holes partially filled with 3 µm LPCVD poly**
3. **Doping with P or B**
4. **Holes passivated with TEOS SiO_2**

Hole aspect ratio 25:1
10µm diameter, 250µm deep
P- and N-type substrates, 285µm thick





3D p-type strip detectors



Devices:
» n^+ strips
» p^- bulk
» p^+ back contact

50 strips
DC coupled
50 electrodes/strip
4mm long strips

Yield for strip detectors in 2008 production = 86%

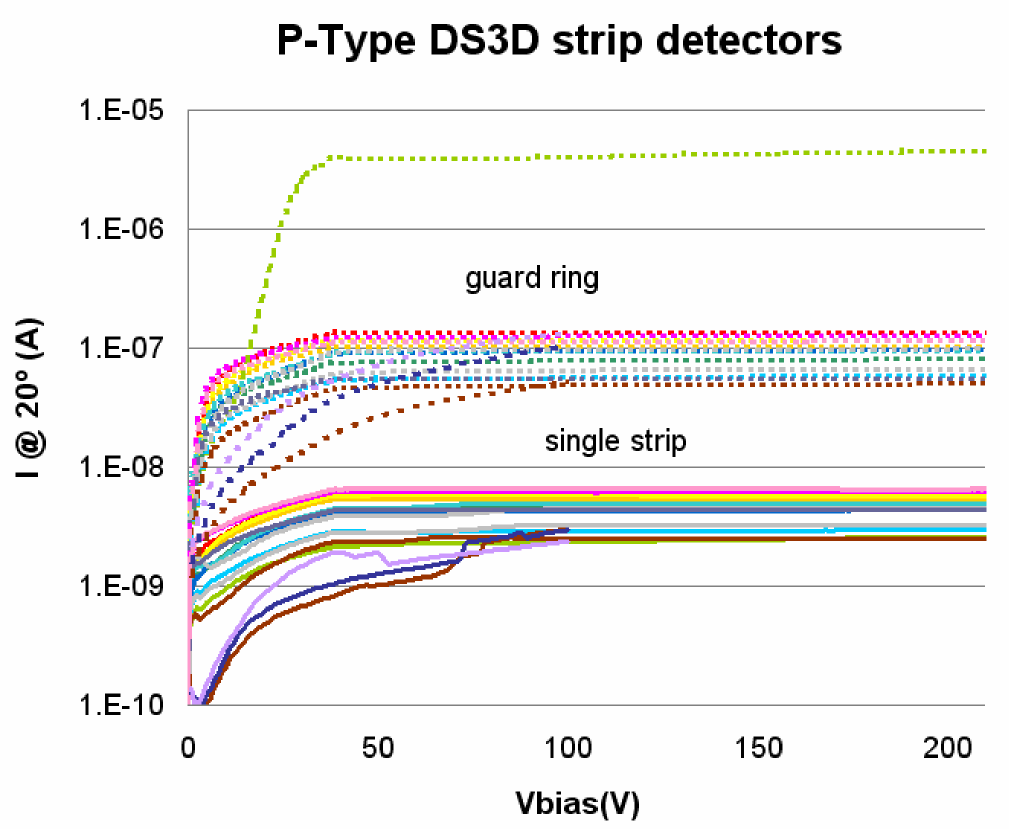
$$Yield = \frac{tested\ good\ sensors}{wafers\ started \times sensors\ per\ wafer}$$

Leakage current

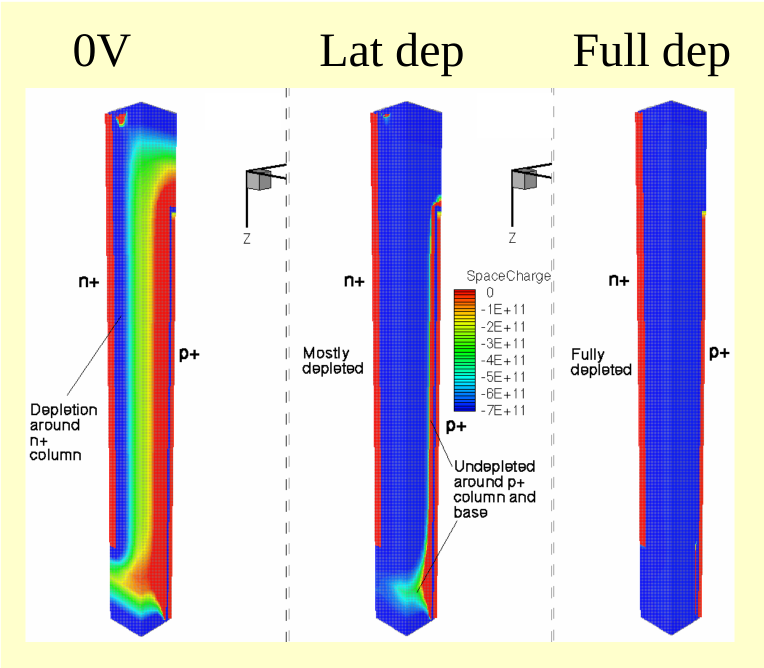
Before irradiation, T = 20ºC

Backside biased, strip and guard ring grounded

- **Can see VFD ~ 40V**
- **2 – 6 nA/strip (40 – 120 pA/column)**
- **Only 2 detectors, of 19 tested, bad (not shown)**
  - **Breakdown at less than 5V (catastrophic defect?)**
  - **All others work far beyond full depletion**

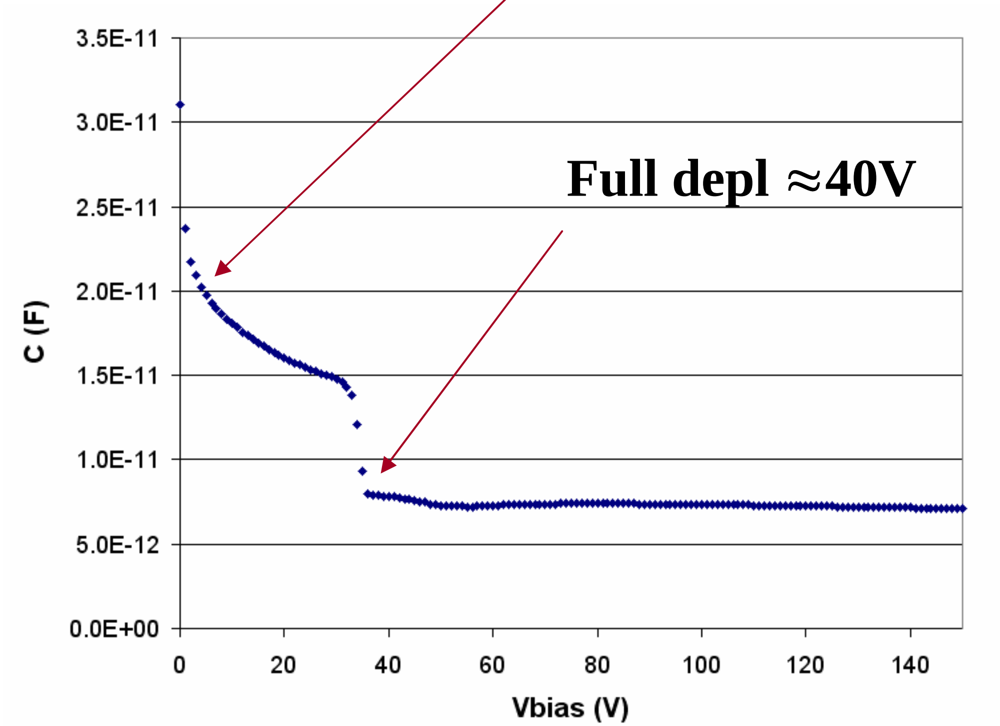


Bulk capacitance



Simulation by D. Pennicard, Glasgow

~4V lateral depletion



Capacitance between strip and backside, neighbours also biased, 20ºC, 10 kHz

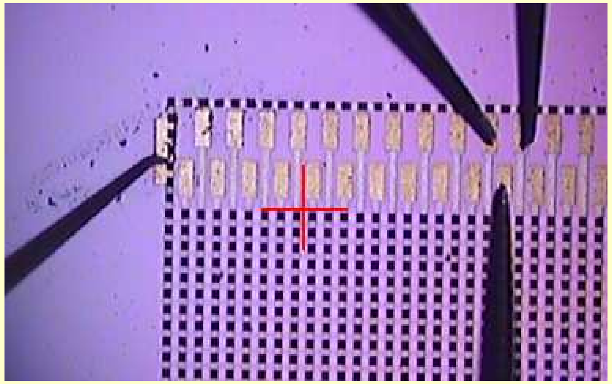
C = 3 — 7 pF/strip depending on sensor

Interstrip resistance

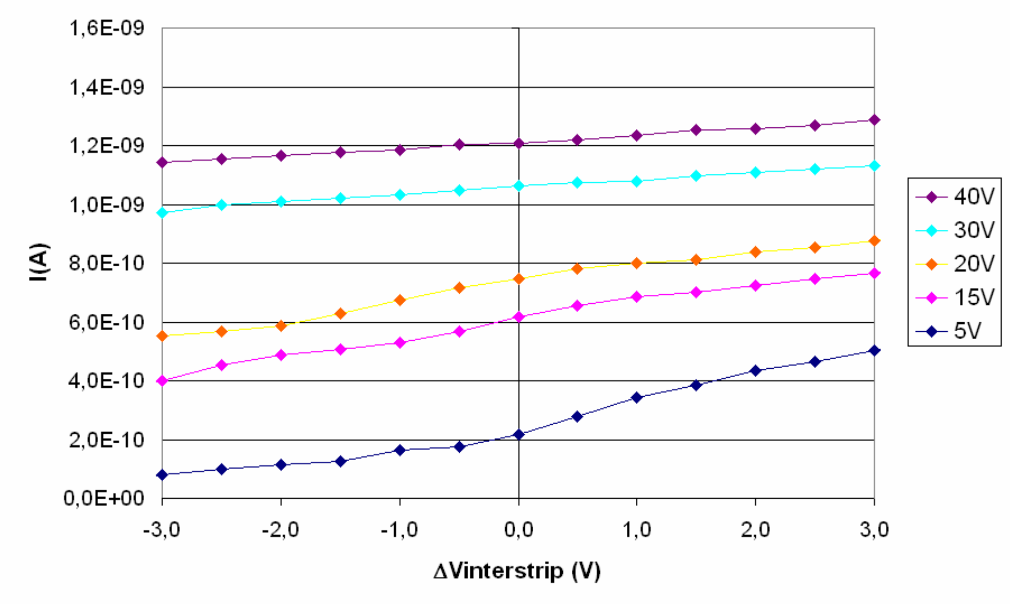
Use two K2410 Sourcemeters:

1. **Bias in backside, guard ring to ground**
2. **Sense test strip, varying voltage, keeping neighbours at ground**

Rint = 2/slope



Non – irradiated I-V interstrip at 20ºC



Vbias (V)	Rint (GΩ)
5	28
15	50
20	52
30	99
40	94

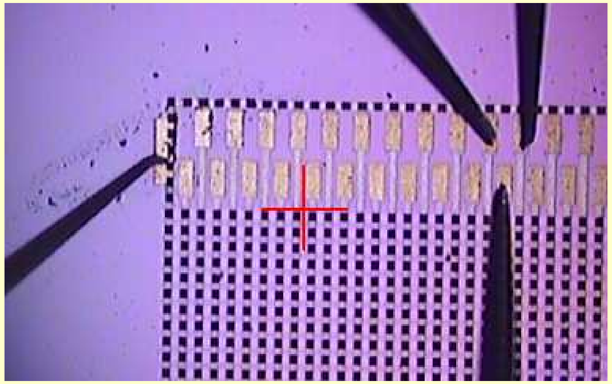
Good P-stop isolation before irradiation

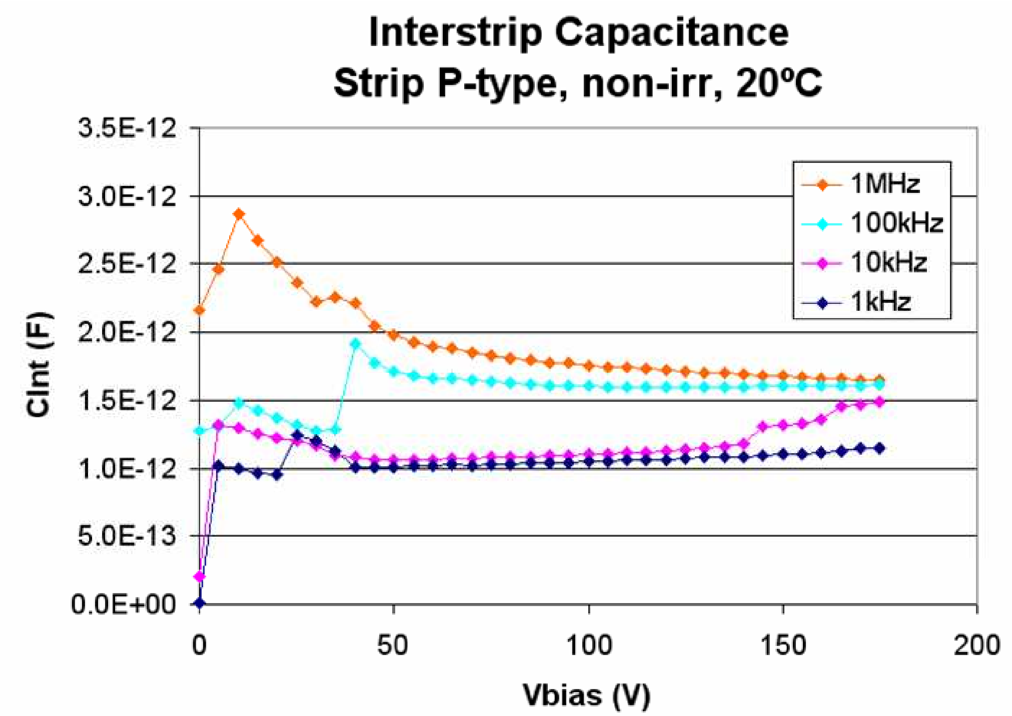
Interstrip capacitance

Use K2410 Sourcemeter and HP4284A LCR meter:

- **K2410: Bias in backside, guard ring to ground**
- **4284A: test strip HIGH, neighbours LOW**

3 probes + guard ring





- **Test Cint as function of frequency**
- **Values converge for higher frequencies**
  - **Will use 1 MHz for tests**

Irradiations
(with thanks to Karlsruhe, Freiburg)

- N- and P-bulk short strip detectors were irradiated at Karlsruhe with 26 MeV protons.
  - Irradiated cold, not biased
- No intentional annealing
  - Max 5 days room temperature
- Distributed to test in Glasgow, Freiburg, CNM.

Fluence (n_{eq}/cm^2)
5E14
1E15
2E15
5E15
1E16
2E16

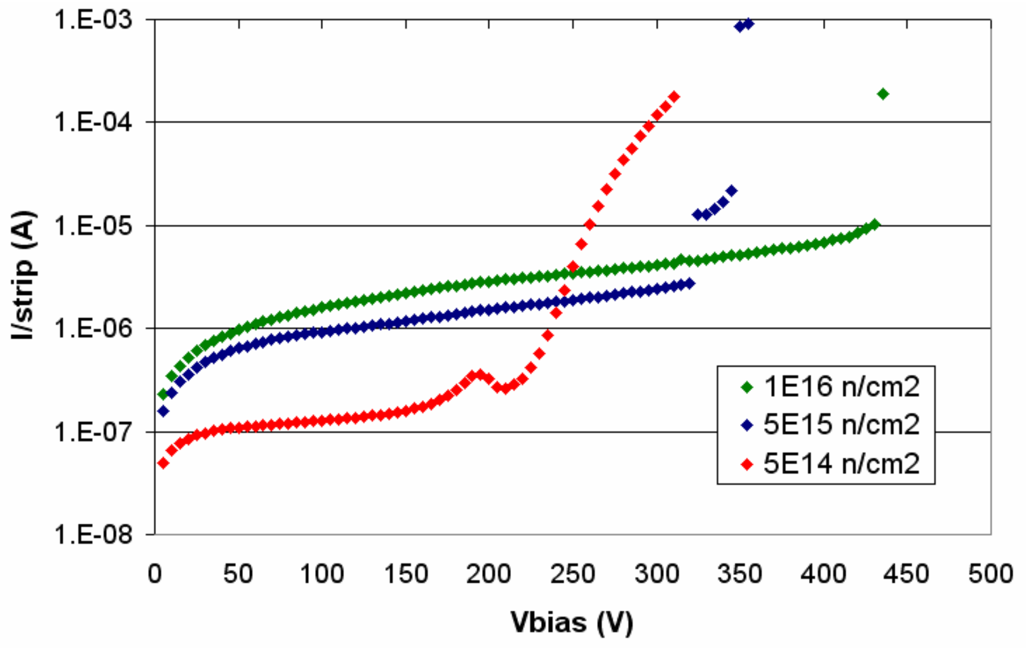
26 MeV protons scale to 1 MeV neutron equivalent fluence with a hardness factor of 1.85

Annealing

- P-type strip detector irradiated to 10^{16} neq/cm^2
- Accelerated annealing at 80ºC
  - Acceleration factor of 7400 for the reverse annealing with respect to RT
- All tests at -10ºC in probe station

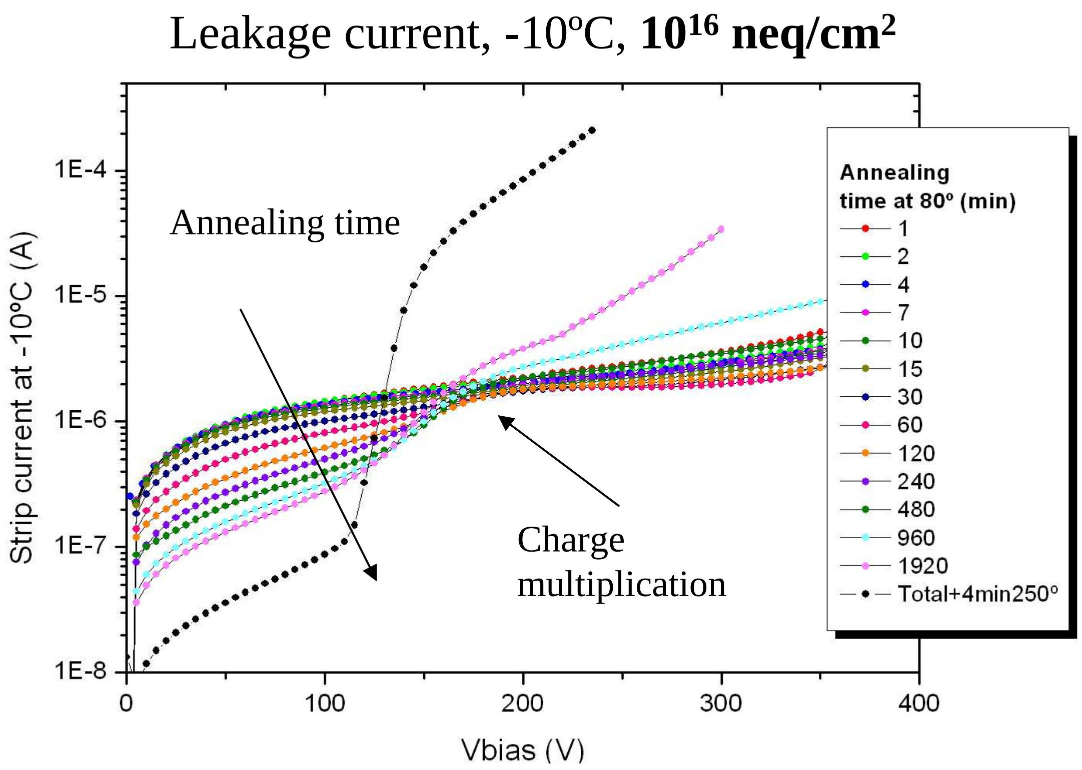
Leakage current after irradiation

Irradiated p-type, no annealing, -10ºC



- **Leakage current increases with irradiation dose**
- **Difficult to estimate damage constant alpha (difficult to calculate Vdep)**

Leakage current vs annealing time

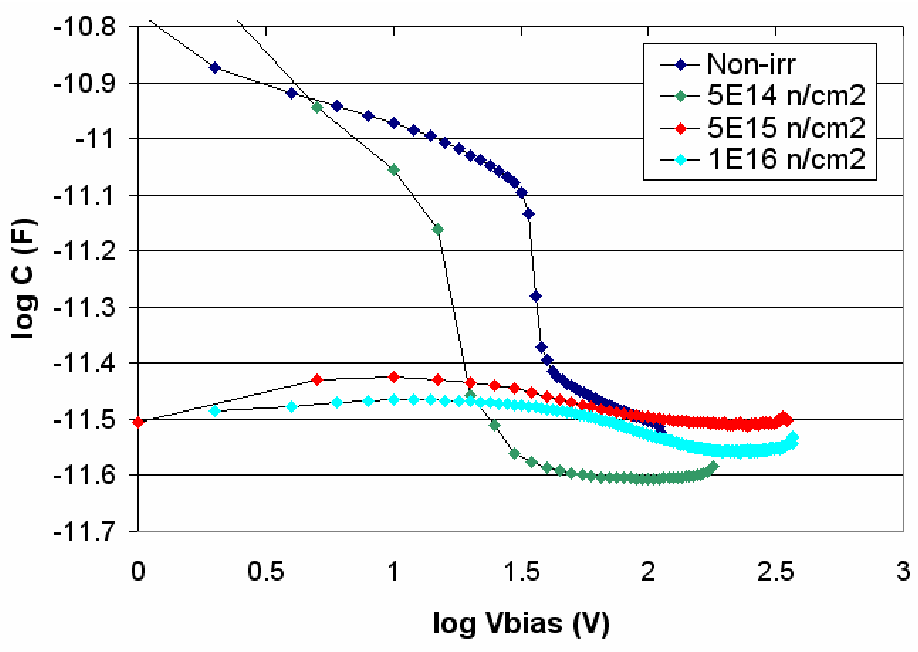


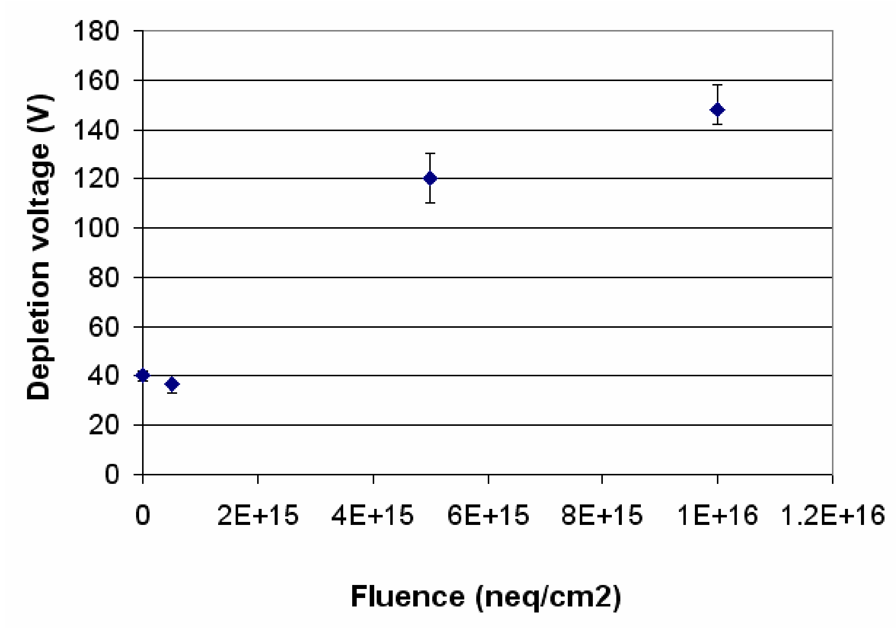
Two competing effects in annealing curves:

- **Annealing of leakage current at low V**
- **Charge multiplication at V ~ 200V. More pronunced and earlier for longer annealing times**

Bulk capacitance vs fluence

Irradiated p-type sensors, no annealing, -10ºC



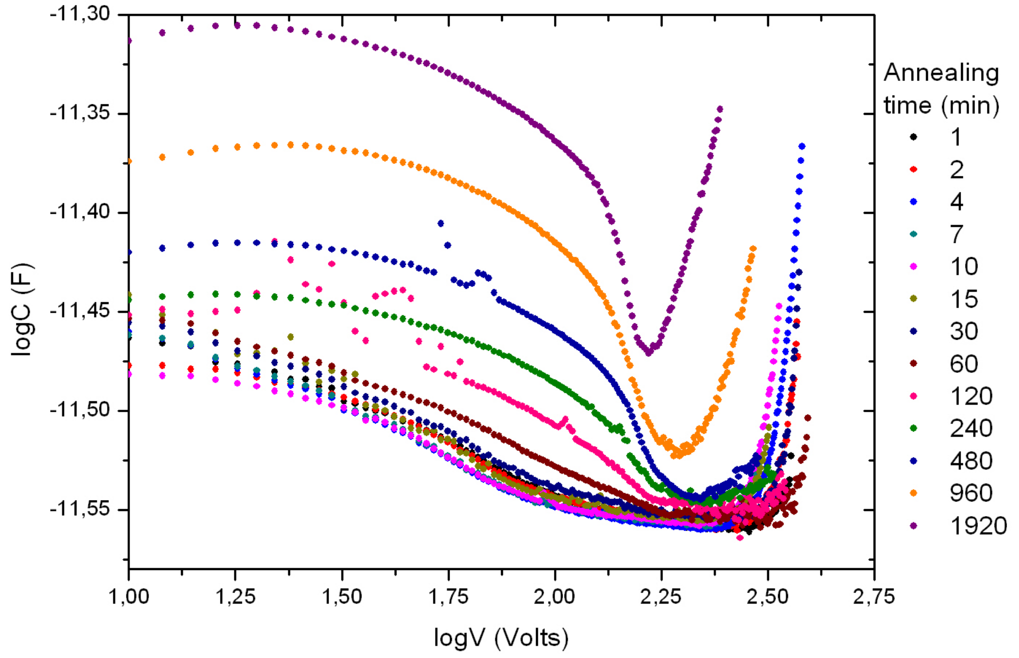


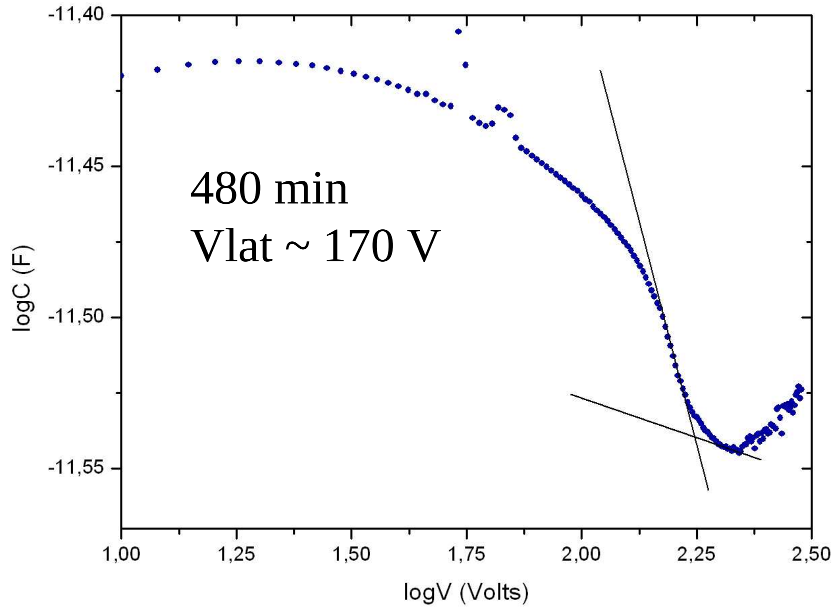
Lateral depletion voltage estimated from log-log plot, error bars take into account choice of points for lines fitting

- **Not possible to distinguish full depletion in plots**

Bulk capacitance vs annealing time

Bulk capacitance, -10ºC, 10 kHz, **10^{16} neq/cm^2**



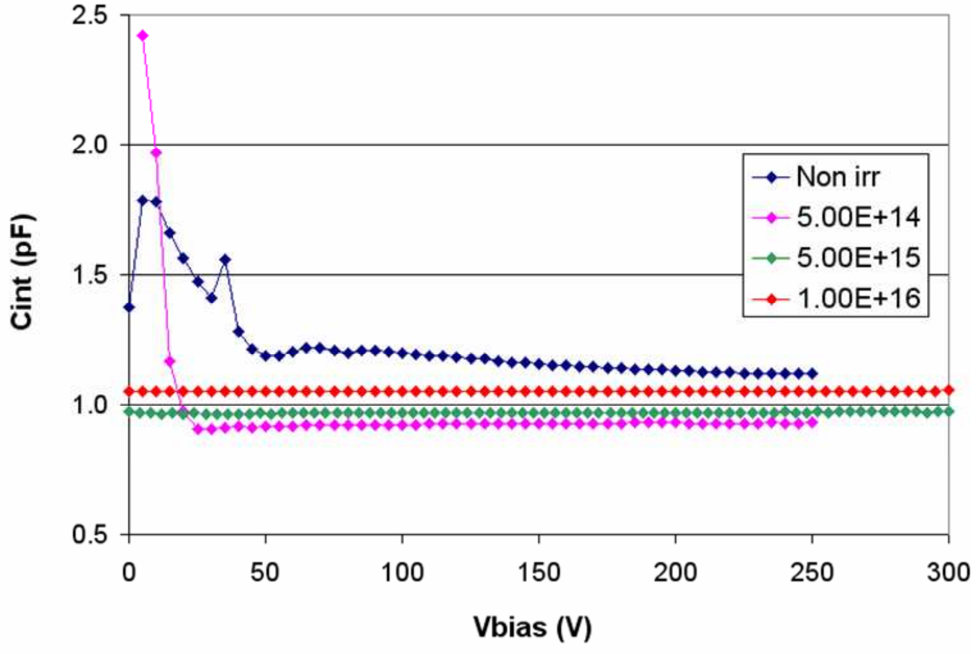


Vlat increases with annealing time at 80ºC

– **Vlat (0 min) ~ 148V, Vlat (480 min) ~ 170V**

Interstrip capacitance vs fluence

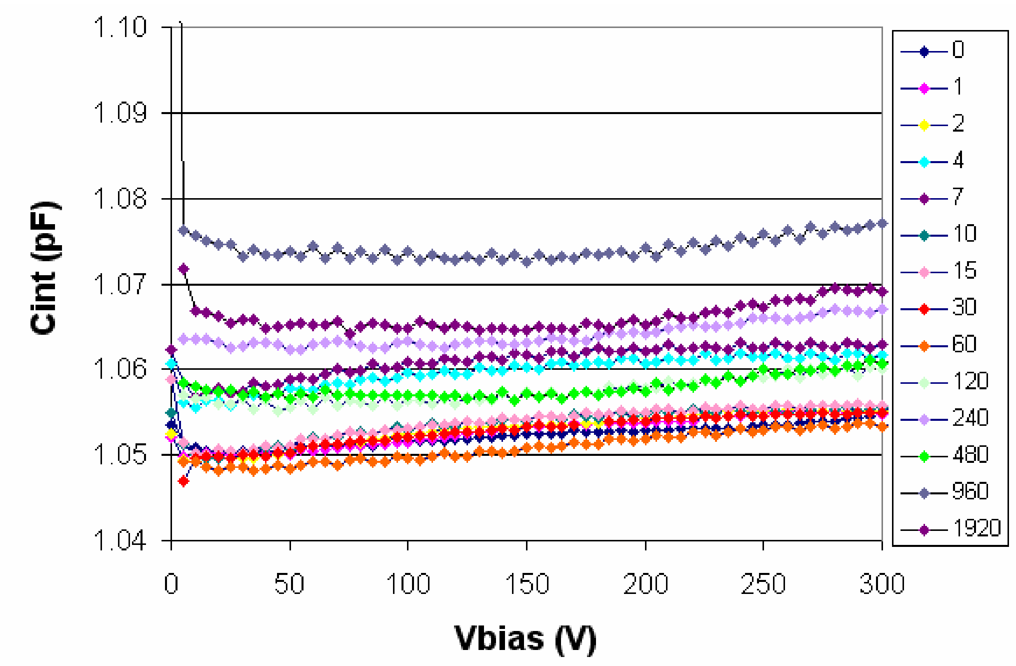
Irradiated p-type sensors, no annealing, -10ºC, 1MHz

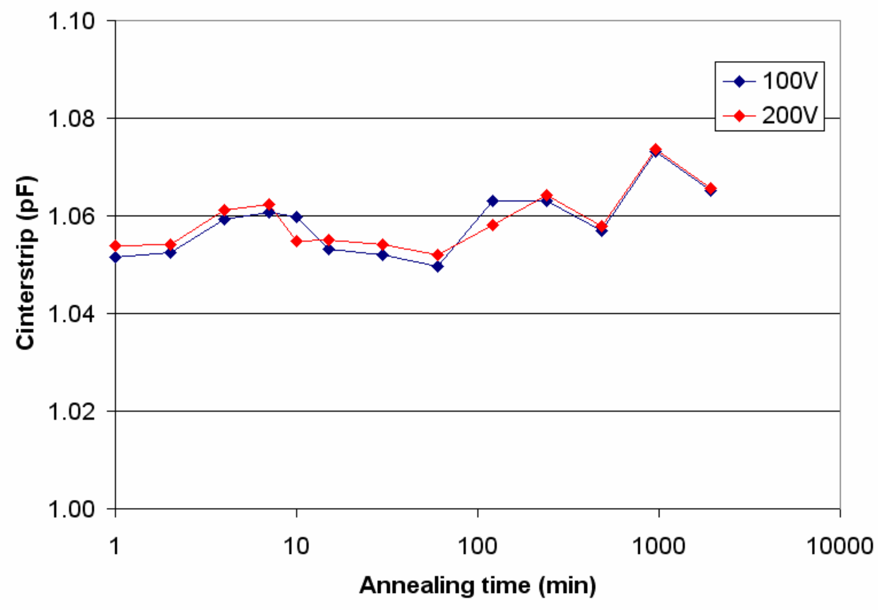


- **Cint saturates at lower voltages for irradiated sensors**
- **Cint seems to decrease with initial irradiation, then increase again with dose.**
  - **Might just be difference between sensors (one for each dose only)**

Interstrip capacitance vs annealing time

Interstrip capacitance, -10ºC, 1 MHz, **10^{16} neq/cm^2**



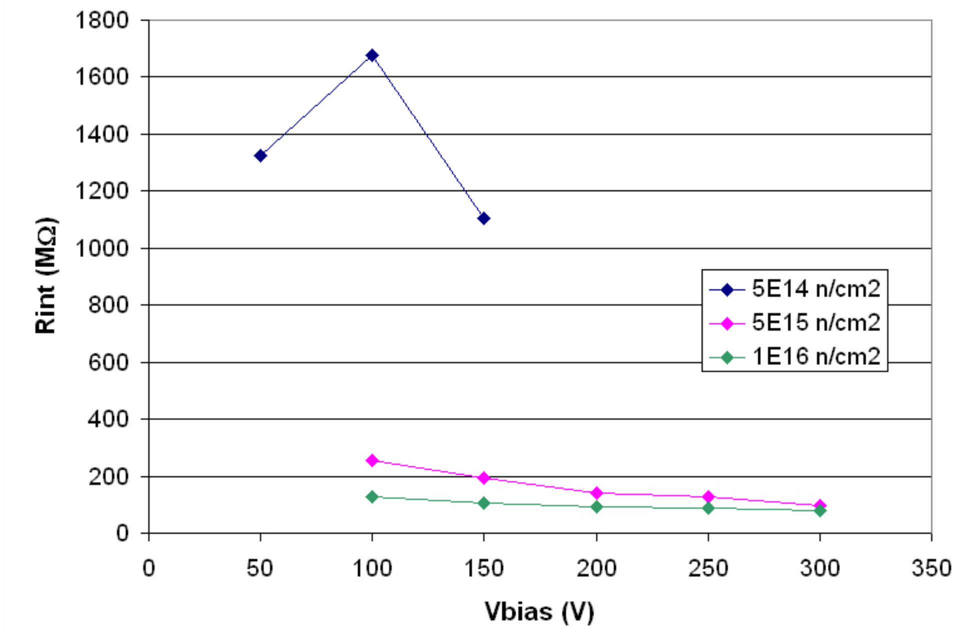


Interstrip capacitance changes very little with annealing time at 80ºC.

More likely due to strip to strip variation than annealing effect

Interstrip resistance vs fluence

Irradiated p-type sensors, no annealing, -10ºC



- **Interstrip current too low (pA) to obtain Rint of non-irradiated sensor at -10ºC (~100 GΩ at 20ºC)**
- **Measured resistance decreases with irradiation dose as surface isolation decreases**
- **P-stop works well even for highest irradiation**
  - **Rint >100 MΩ for 10^{16} neq/cm^2**

Interstrip resistance vs annealing time

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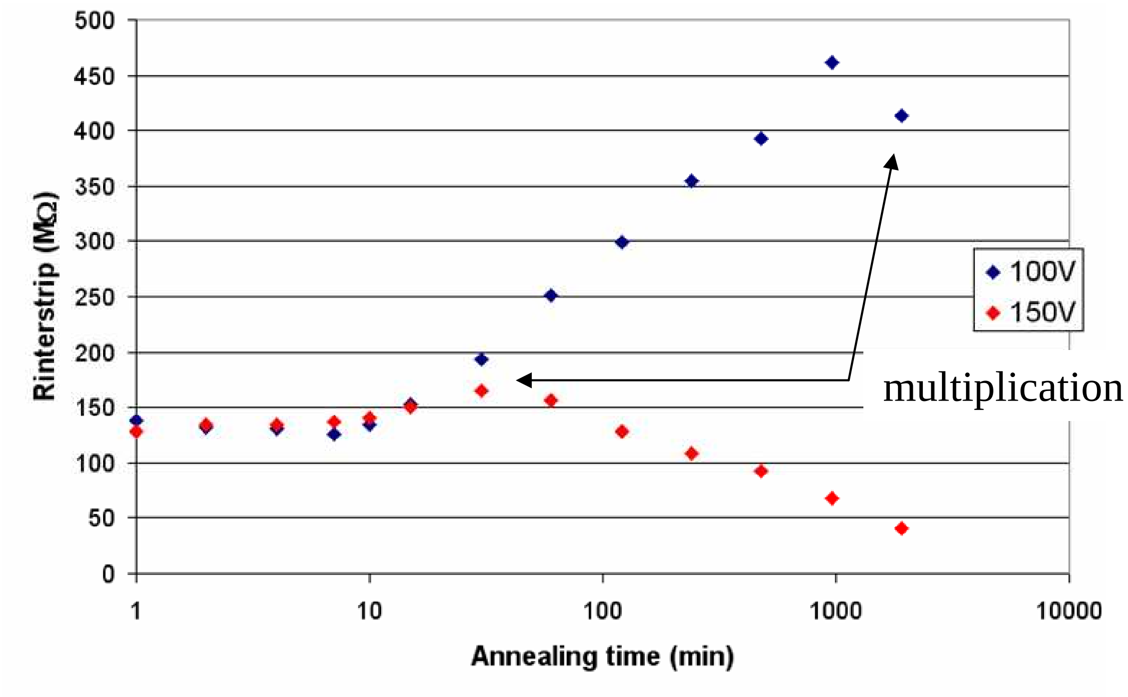
Interstrip resistance, -10ºC, **10^{16} neq/cm^2**

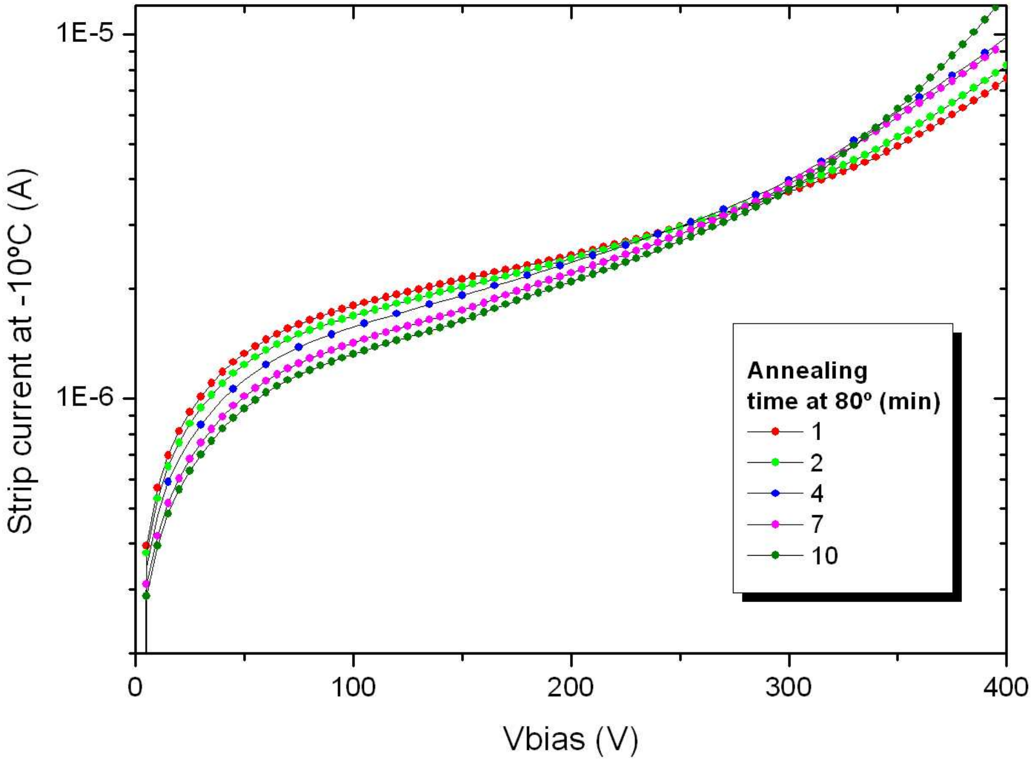


- **100V: interstrip resistance increases with time as substrate becomes more p-type and compensates negative charge in surface**
- **150 V: Rint measured decreases for t > 15 min →charge multiplication**

N-type detector (preliminary)

- **1E16 neq/cm2**
- **Multiplication behaviour similar to p-type sensor**
  - **Starts at higher voltages: ~200V for ptype, ~300V for ntype**

Leakage current, -10ºC, **10^{16} neq/cm^2**



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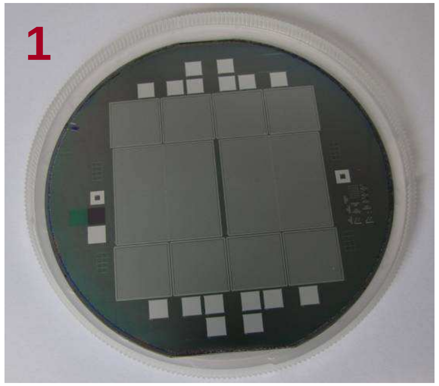
Conclusions

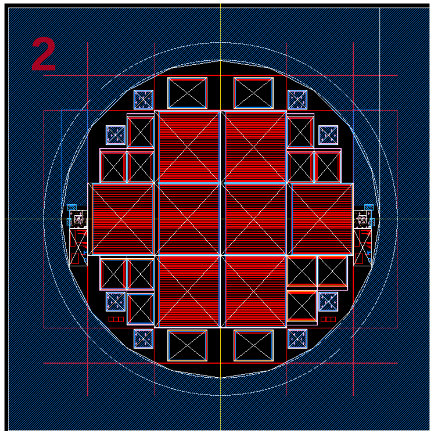
- I have presented an irradiation and annealing study of 3D P-type strip sensors from CNM irradiated with 26 MeV protons up to 1E16 neq/cm2
- Depletion voltage increases with irradiation dose and annealing time. V(lat depl) lower than 150 V for 1E16 without annealing
- Leakage current increases with dose, shows typical annealing behaviour for low voltages. Charge multiplication appears at higher voltages, earlier for longer annealing times
- Strip isolation decreases with dose, p-stop works well even for higher irradiation
- Multiplication effect also seen in annealing curves of interstrip resistance
- Interstrip capacitance doesn’t change much with irradiation or annealing
- Annealing study of n-type sensor irradiated to 1E16 neq/cm2 started: Multiplication observed but at higher voltages than p-type.

Future 3D Work

Centre Nacional de Microelectrònica IMB

- New run of 3D-Medipix3, standard (2 cm^2) and quad area (16 cm^2). Collaboration with Diamond Light Source and Glasgow Uni (1)
- Irradiation and test beams with Medipix (Timepix) detectors for LHCb VELO upgrade.
- ATLAS pixels FE-I3 and new FE-I4 fabrication, irradiation and test beam. For the IBL, in the framework of the ATLAS 3D Collaboration (http://test-3dsensor.web.cern.ch/test-3dsensor/). (2)
- Design and fabrication of CMS pixels: single chips and 8x2 module. In collaboration with PSI. (3)
- Design and fabrication of 3D strip detectors for TOTEM (CERN) (4)





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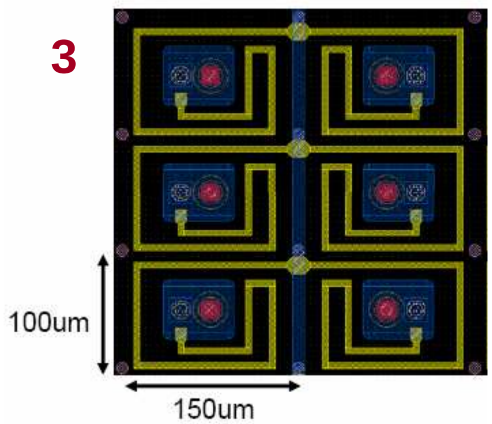

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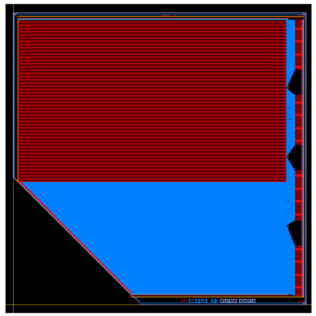

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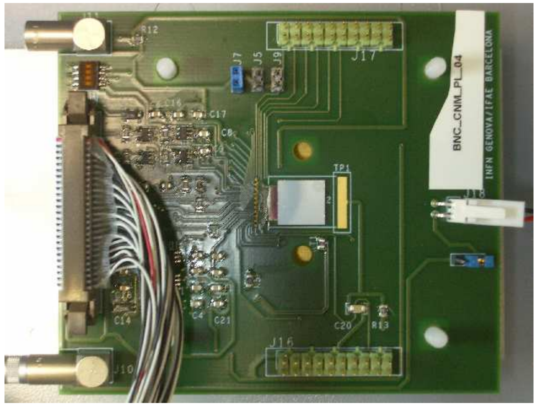
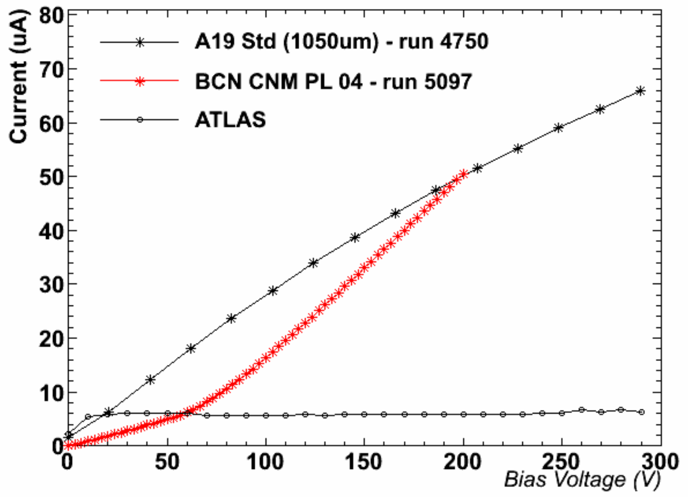
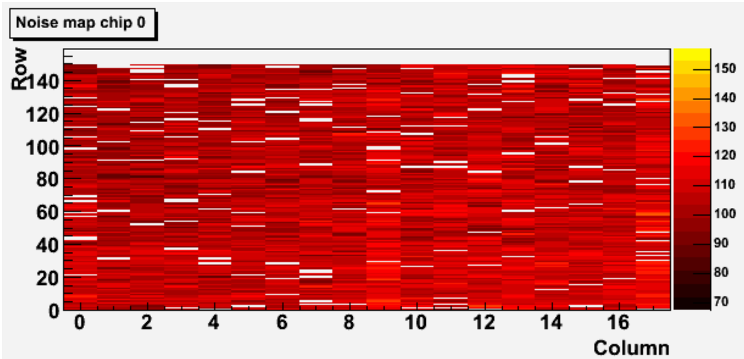
Other Activities

- **Full production/testing chain at Barcelona**
  - **Sensor production**
  - **Sensor/Front-end chip integration (bumpbonding to wirebonding)**
  - **Device characterization**



I. Leakage Current (FE-I3)





II. Noise Map: most pixels working

III. Ionization test (Am^{241})