Upgrade of ATLAS silicon semiconductor tracker for the SLHC

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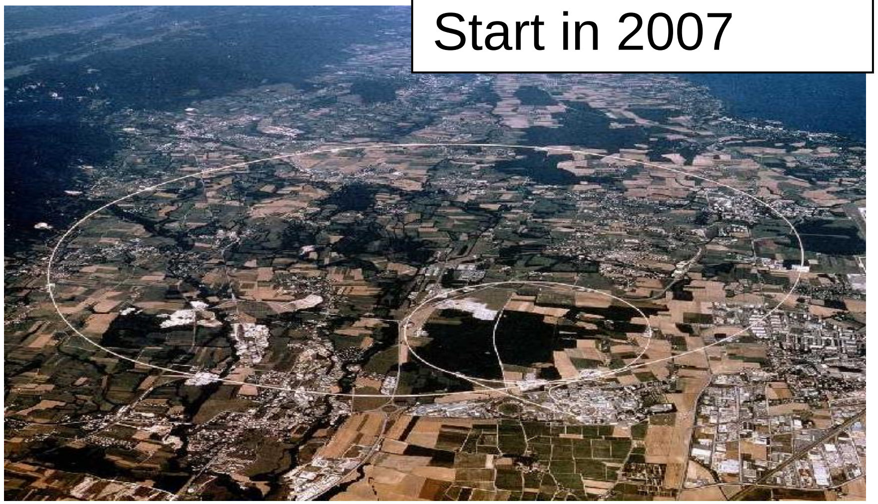
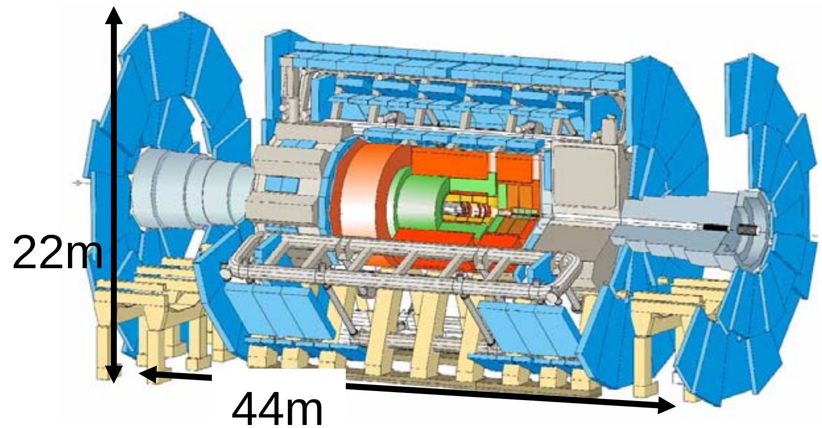
1. LHC experiment and ATLAS detector
2. super LHC
3. P-bulk test samples and irradiation
4. IV, CV/CCE, isolation measurement results
5. Summary

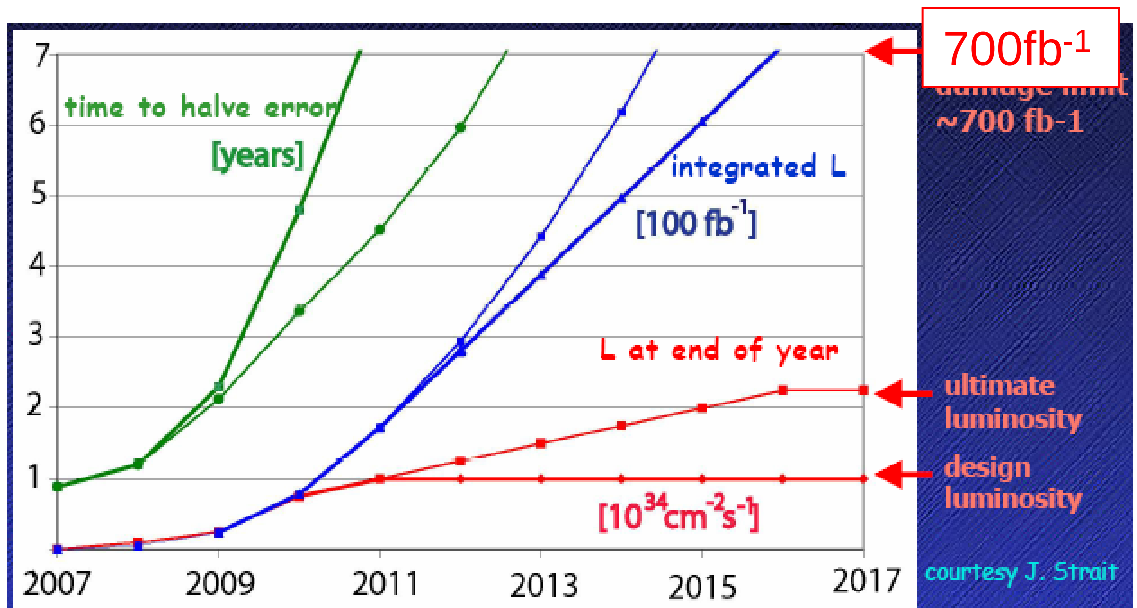
LHC experiment and ATLAS detector



Start in 2007

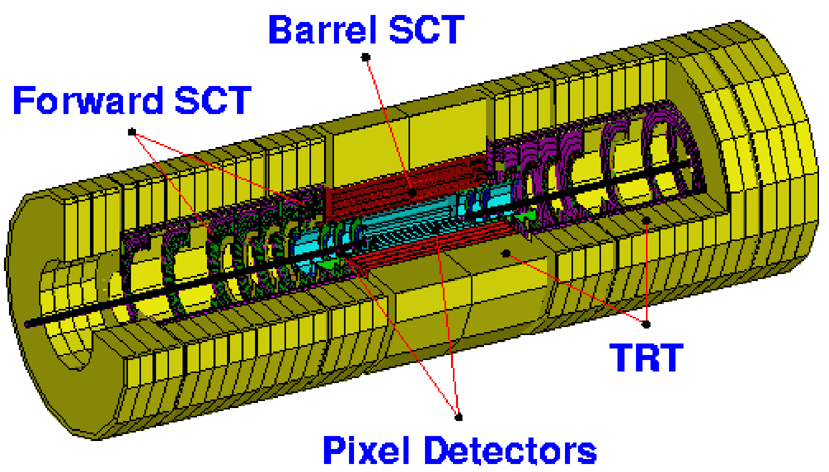


- Proton-Proton collider
- CM energy : 14 TeV
- Luminosity : 10^{34} $cm^{-2}s^{-1}$
- Collision interval : 25 nsec
- 700 fb^{-1} by 2014~2016

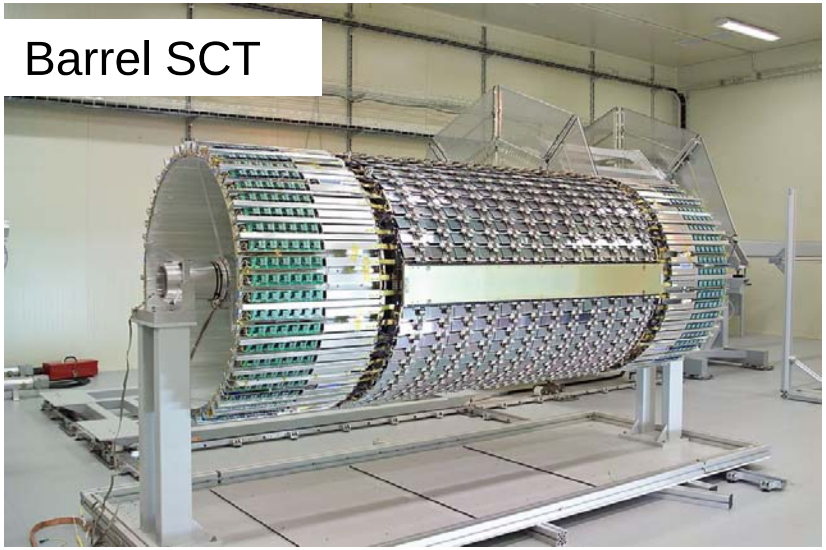


Inner detector and semiconductor tracker

Inner detector



Barrel SCT



SCT Radiation tolerance

~< 2×10^{14}(1MeV-n-eq/cm^2)

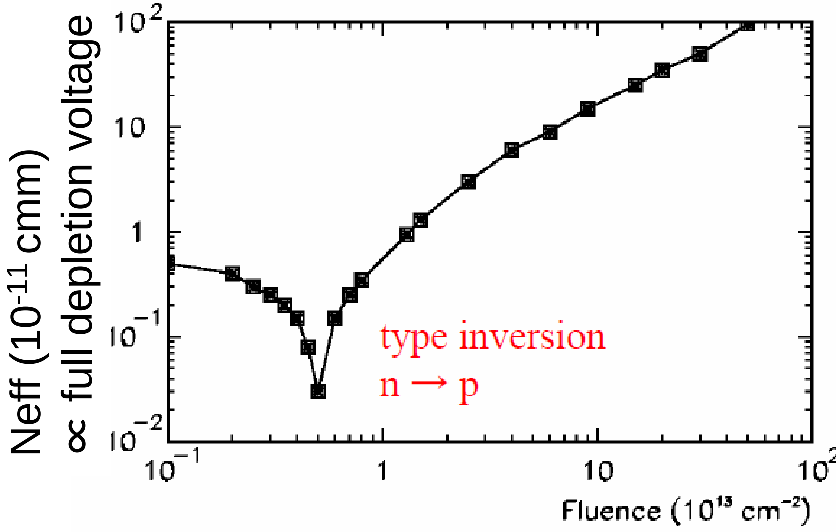
(10 years of LHC experiment)

SCT property

- N-type sensor

  be fully depleted for signal readout

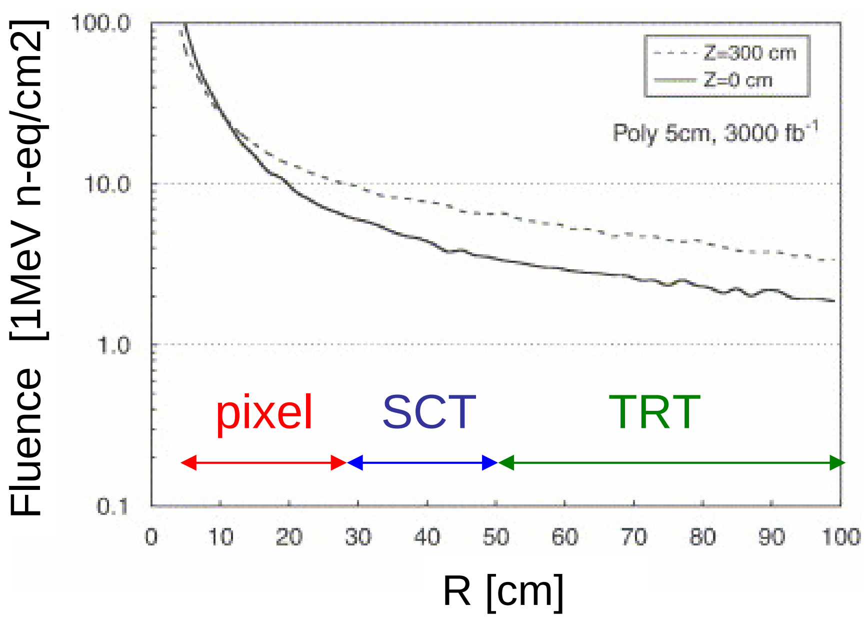
- With fluence, full depletion voltage increase.
- Operation Voltage limits the lifetime



Super-LHC

SLHC parameters

- Luminosity : 10^{35} /cm2/s
- Integrated luminosity : 3000 fb^{-1}
- Collision interval : 12.5 ns
- Particle fluence



~1×10^{15} (1MeV n-eq/cm^2) @R=30 cm

ATLAS Inner Detector needs re-designed

- •Replace TRT with silicon detector
- •Need more rad-hard silicon detector

→ Developing P-type sensor

Advantage of N^+-on-P sensor :

✓Signal can be accumulated even under partial depletion (operational at reduced HV).

R&D goals :

✓evaluate high resistive p-type wafers →stability against radiation

✓electrical isolation between N^+ readout strips.

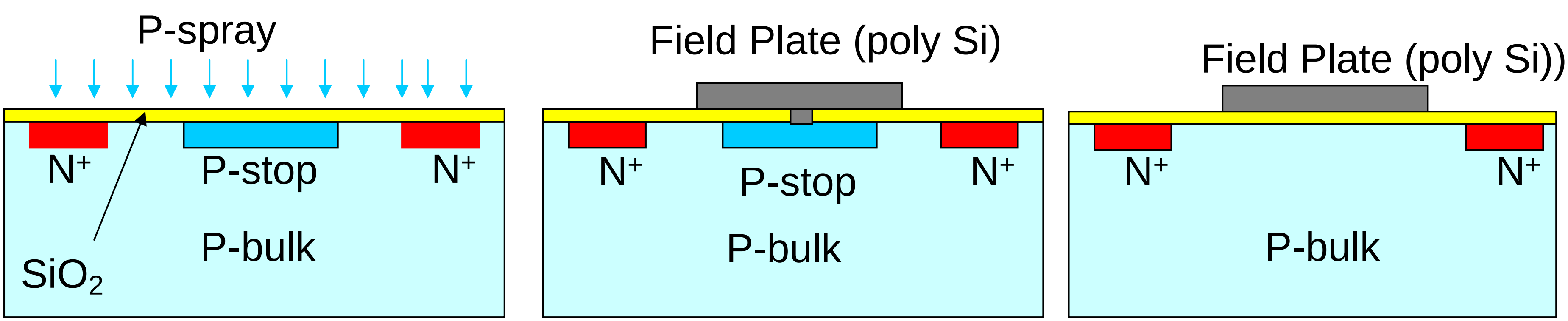
P-bulk test Samples
for rad-hard silicon

40 samples

- wafer types: Floating Zone (FZ), Magnetic Czochralski (MCZ) → Next page
- 5 p-stop structures
  (IPSTP,CPSTP,IPSTPDF,CPSTPDF,AF)
- 2 p-stop/p-spray concentrations →
- 2 fluences

concentrations

wafer No	p-stop	p-spray
7,8	1E+12	1E+12
17,18	2E+13	---



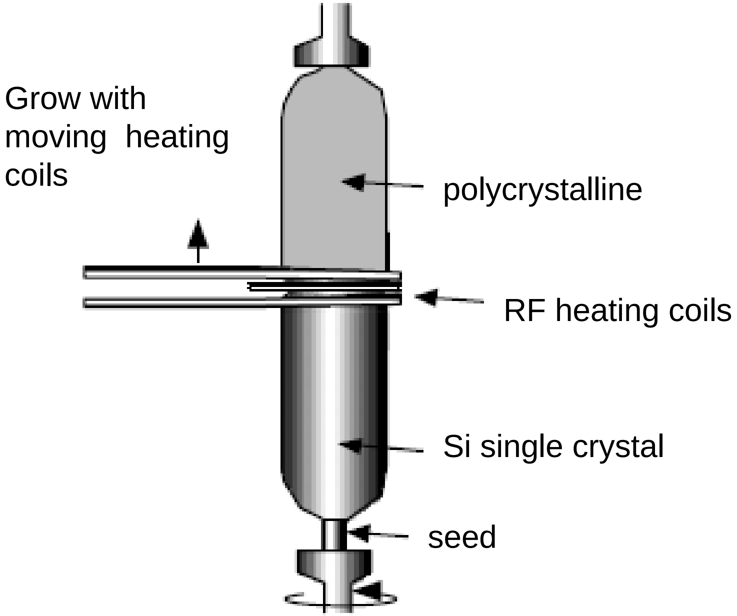
P-stop (Common, Indiv.)　　P-stop + DC Field Plate (Common, Indiv.)　　AC Field Plate

wafer 7/17: irradiated to 0.7×10^{14} /cm2 (low fluence)
wafer 8/18: irradiated to 0.7×10^{15} /cm2 (high fluence)

P-bulk test Samples
for rad-hard silicon

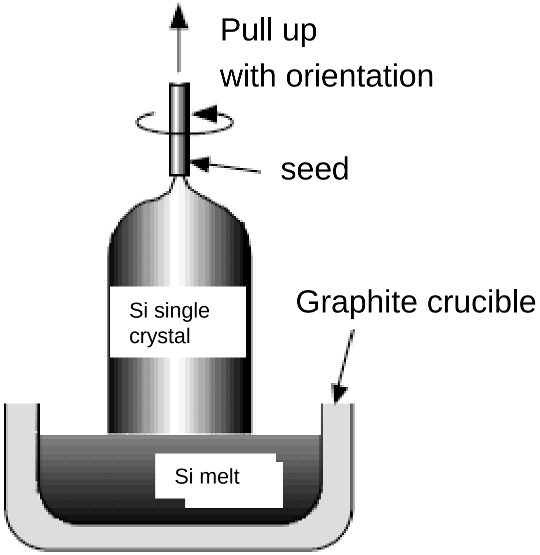
Floating Zone (FZ) crystal growth

- Resistively ~1.5k Ω･cm
- Very low impurity



Magnetic Czochralski (MCZ) crystal growth

- Resistively ~1k Ω･cm
- Oxide rich
  (expected to decrease full depletion voltage for any irradiation)

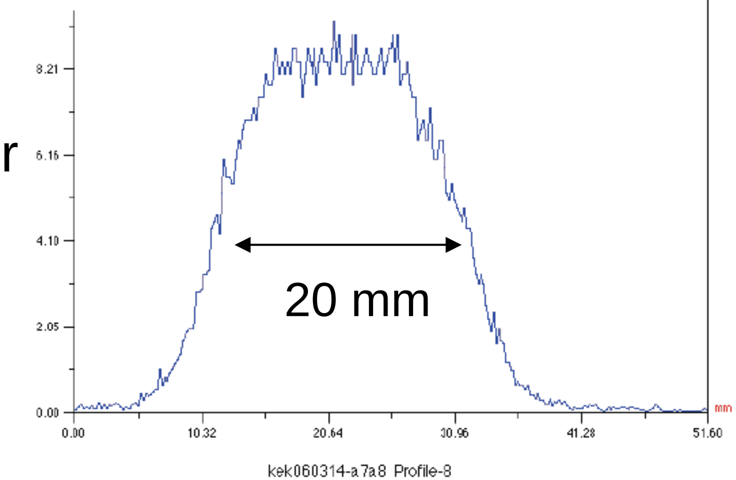


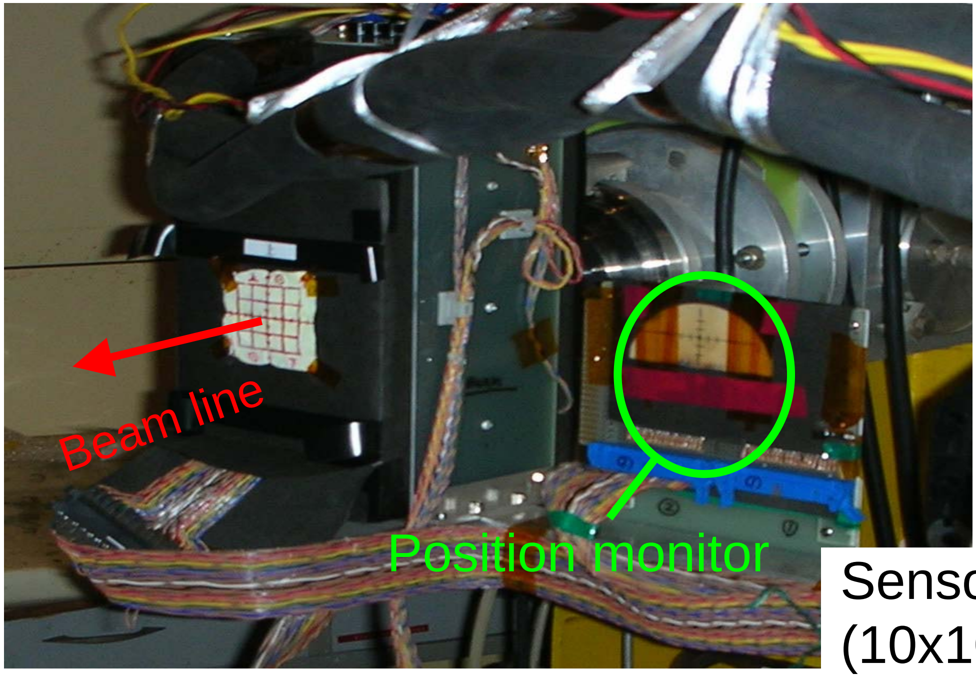
Full depletion voltage/Micro discharge/Strip isolation are compared for FZ and MCZ samples.

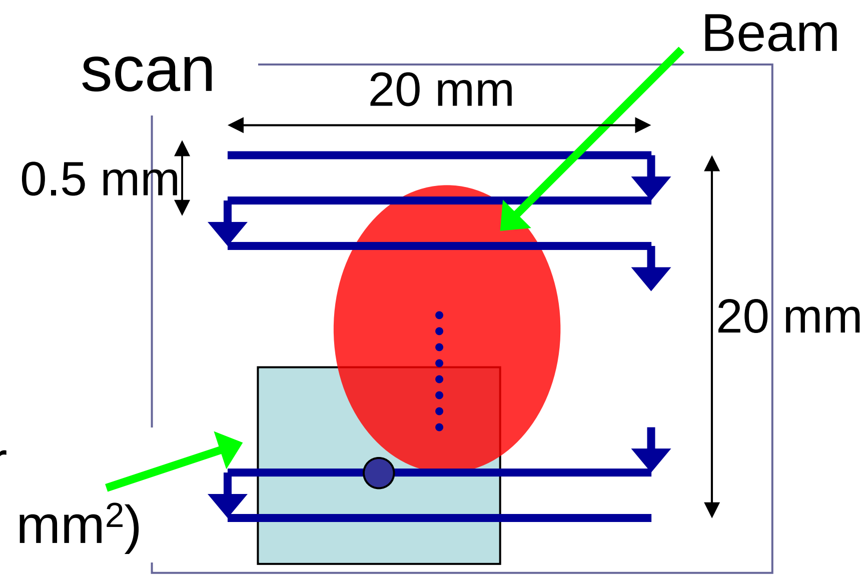
Irradiation@Tohoku Univ. CYRIC

- 70MeV protons
- center position determined by position monitor
- Irradiate evenly by scanning the sensors
- Fluence evaluated by Al activation

Beam profile







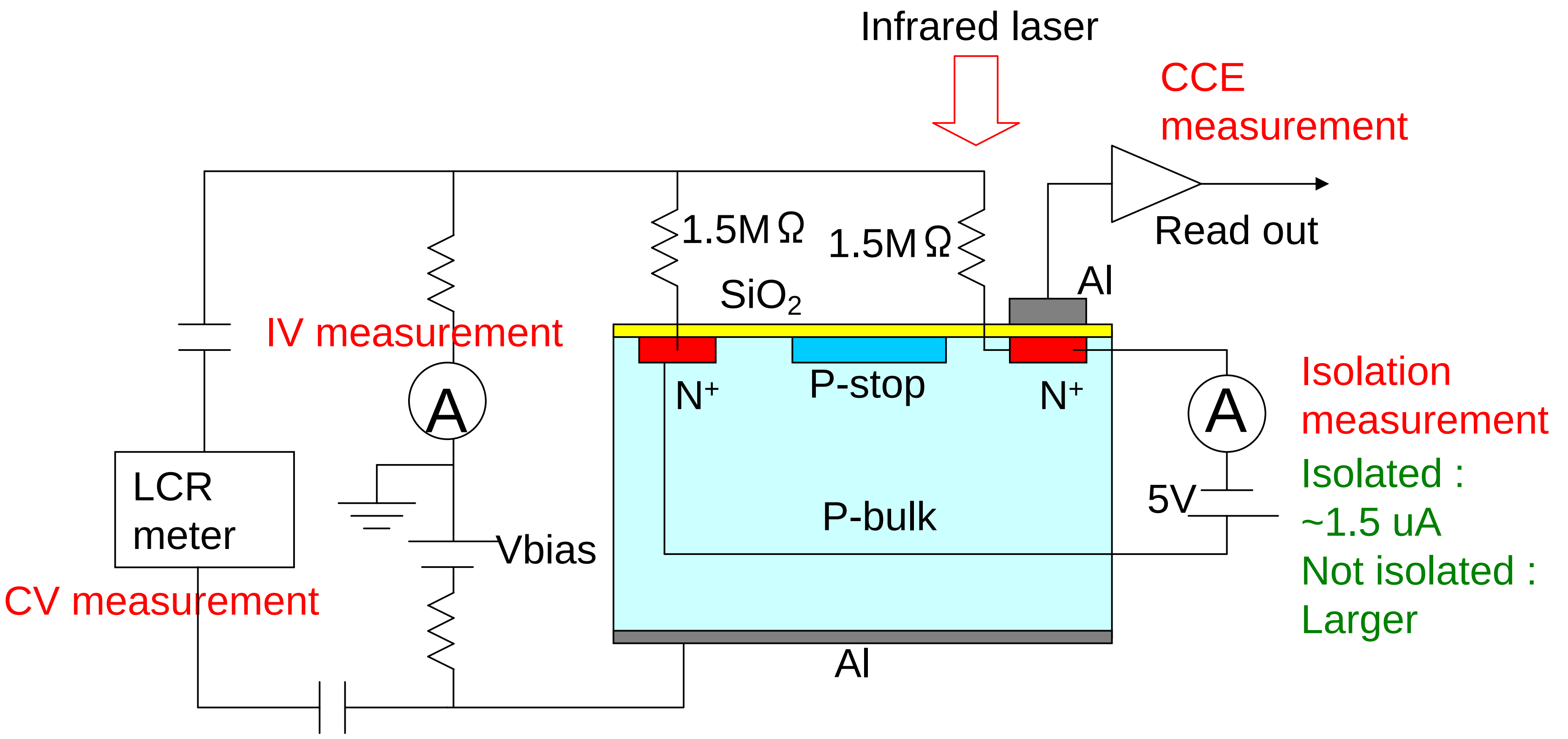
Sensor
(10x10 mm^2)

Measurements of sensor characteristics

I-V ･･･ micro discharge ?

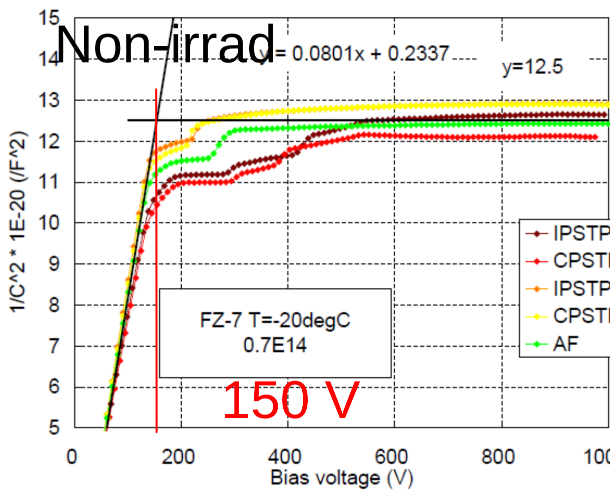
C-V/ CCE (Charge Collection Efficiency) ･･･ evaluate full depletion voltage

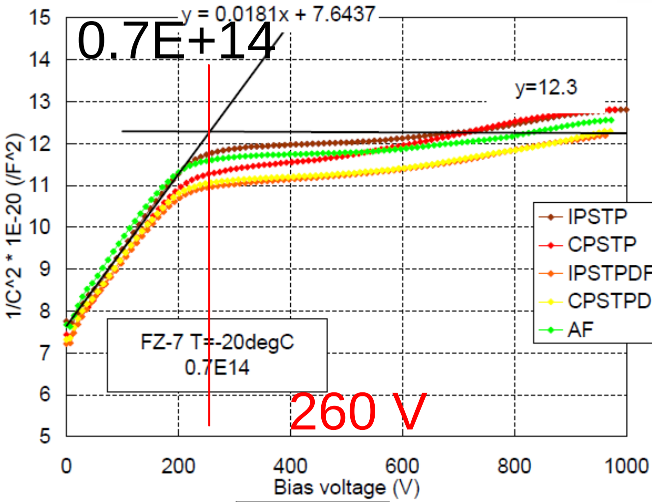
Isolation ･･･ evaluate electrical isolation between readout strips

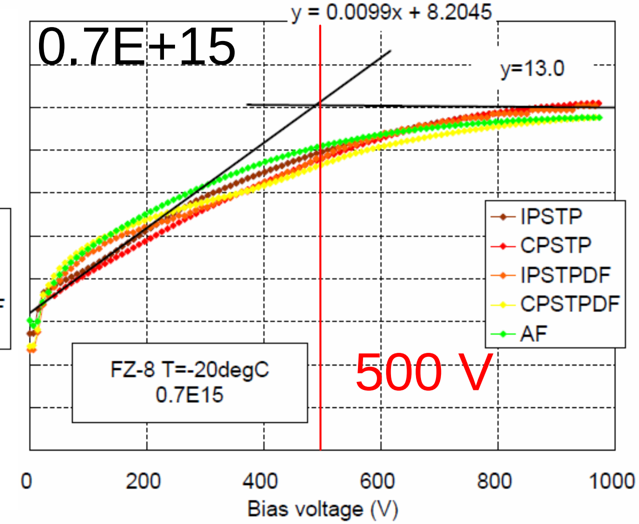


Full depletion voltage (FZ)

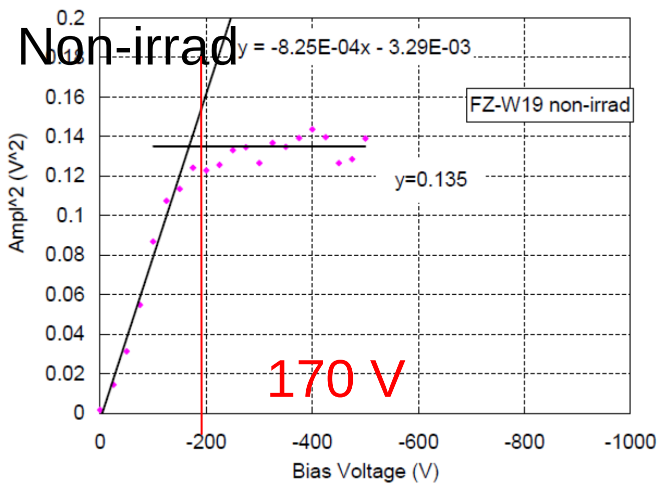
C-V $1/C^2$: plot $1/C \propto d \propto \sqrt{Vbias}$

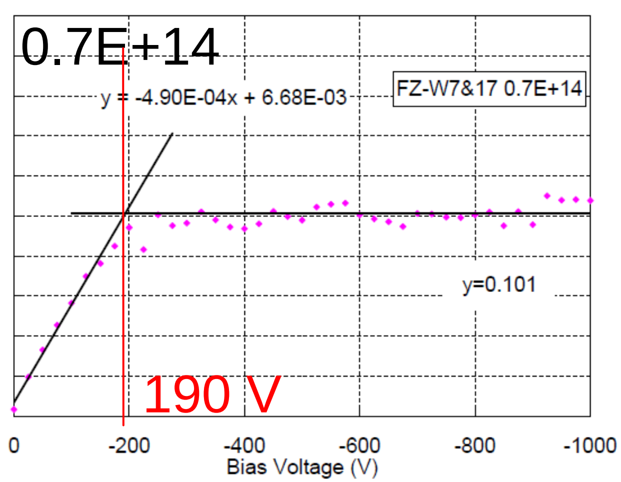


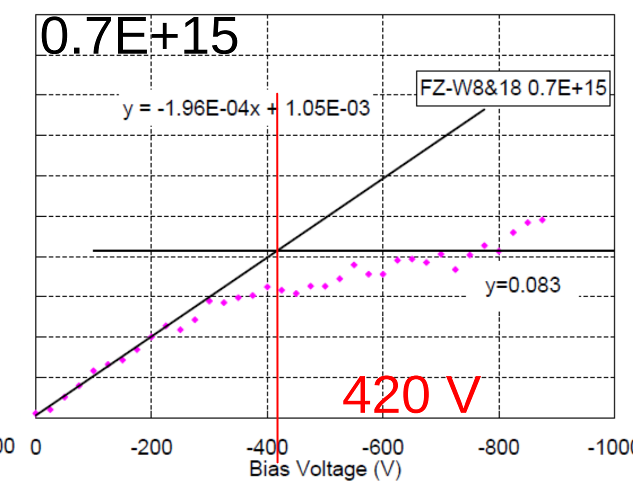




CCE : $ampl^2$ plot $ampl \propto d \propto \sqrt{Vbias}$

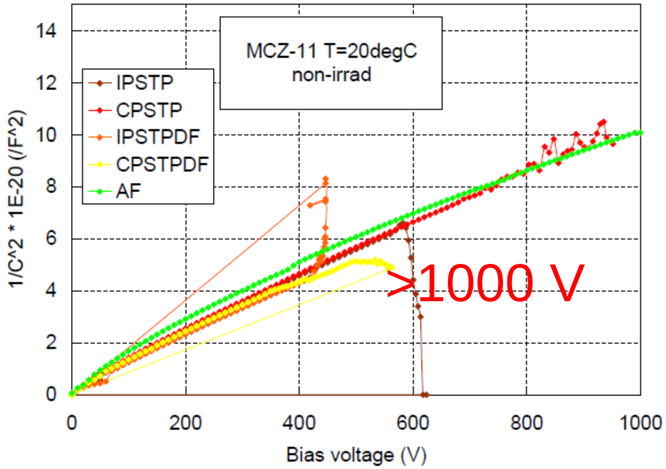




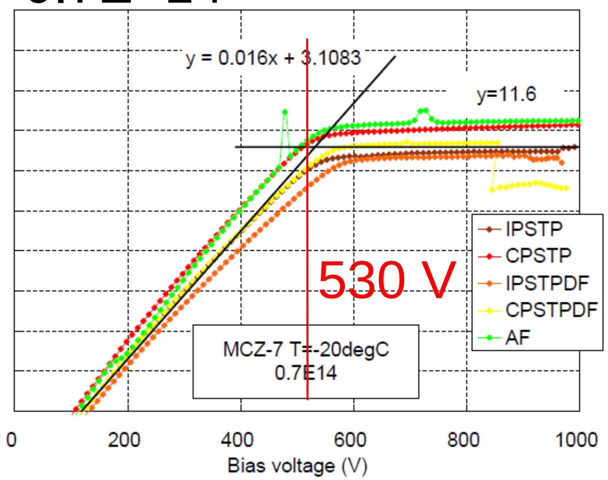


Full depletion voltage (MCZ)

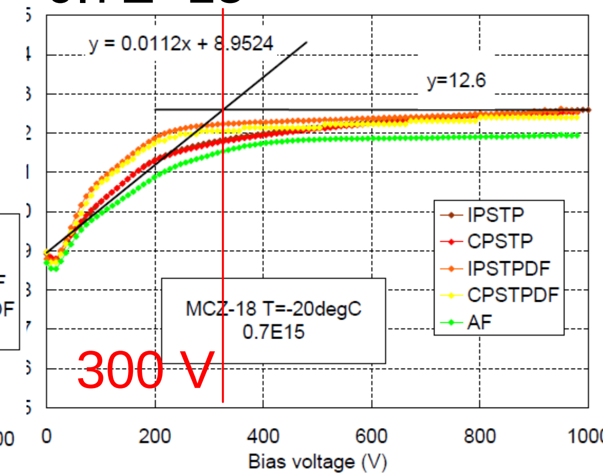
Non-irrad



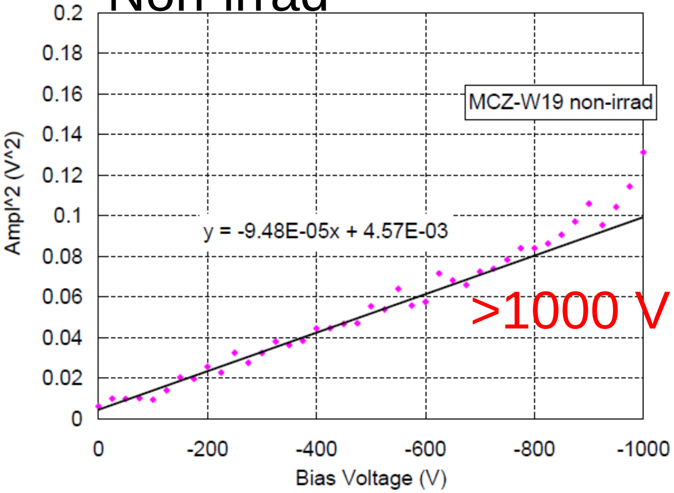
0.7E+14



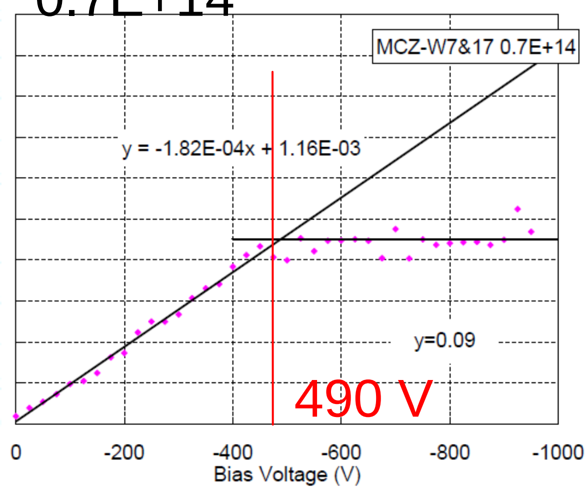
0.7E+15



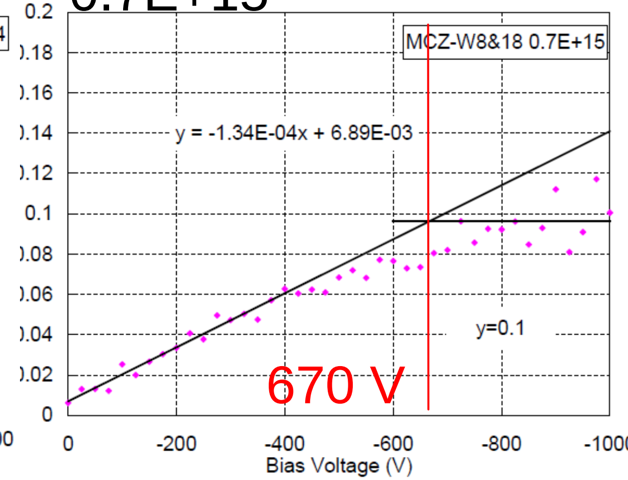
Non-irrad



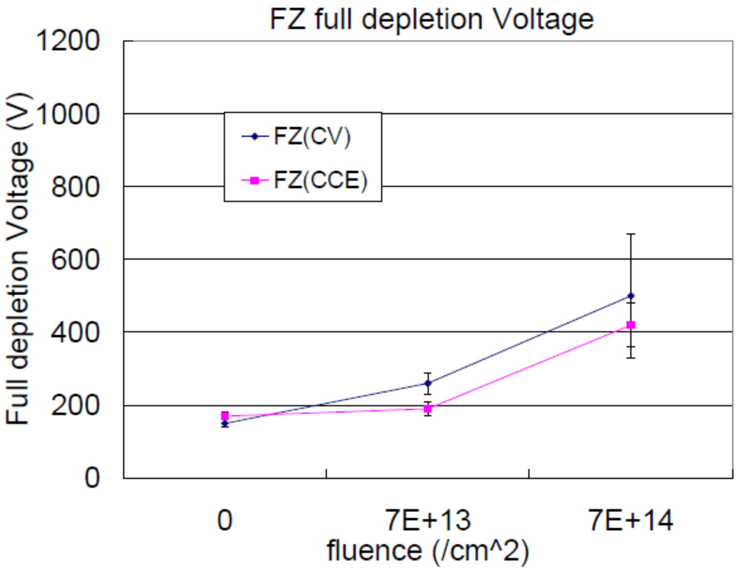
0.7E+14



0.7E+15



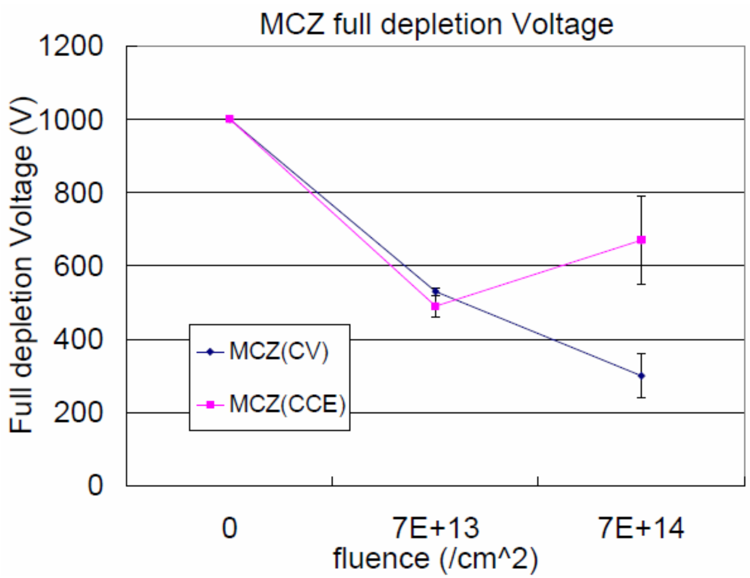
Full depletion voltage dependence on fluence



- **FZ**

~150 V before irradiation

Increases to ~500V after 0.7E+15



- **MCZ**

~1kV before irradiation

Decreases to ~500 V after 0.7E+13

Vfd after 0.7E+15 ?

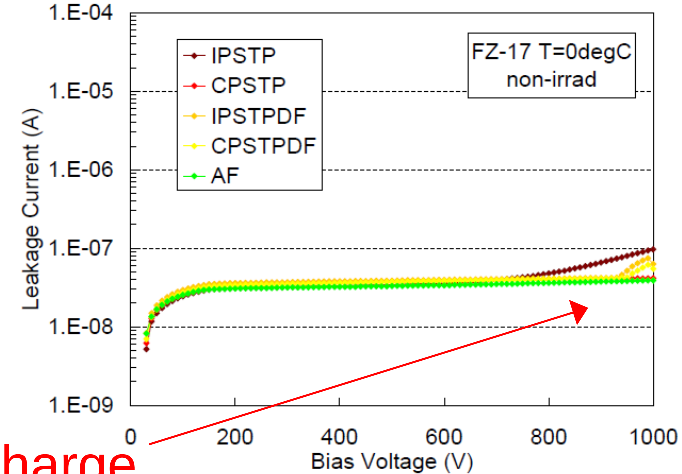
We have conducted more systematic irradiation:

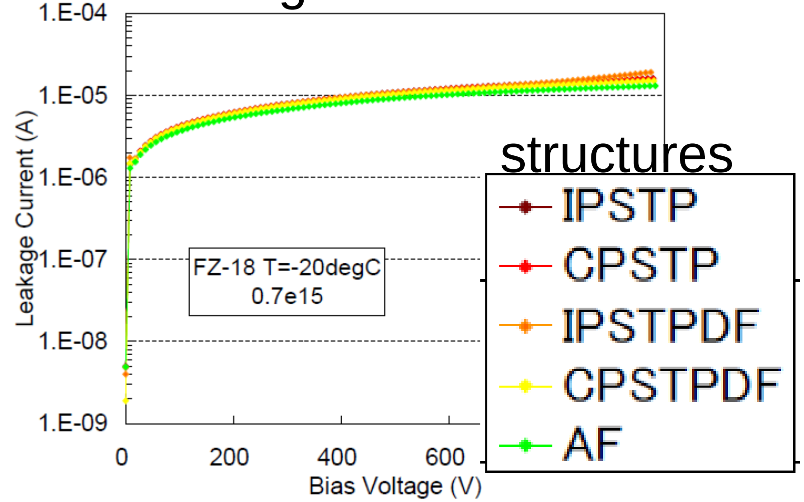
Data to be ready in a month.

I-V Curve before/after irradiation

Non-irrad | High fluence

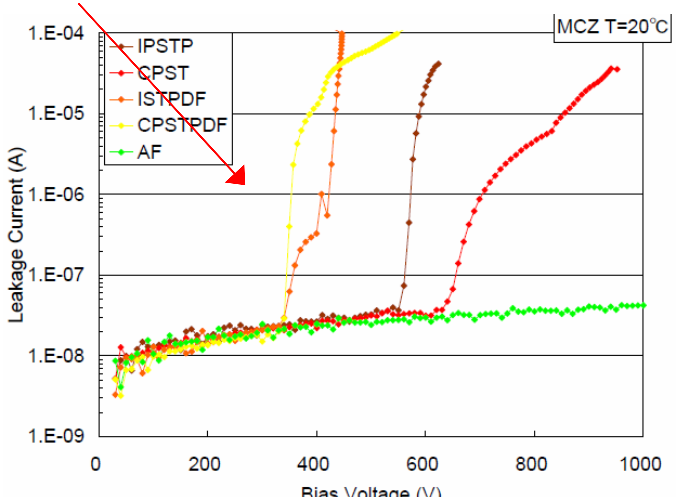
FZ

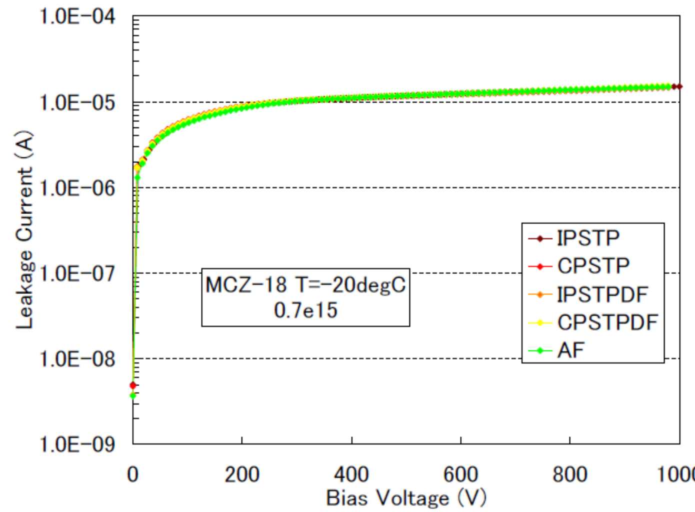




Micro discharge

MCZ





After irradiation,

micro discharge disappears.

current is about 10 uA at T= -20℃ (1 cm^2 sensor).

Strip Isolation of FZ

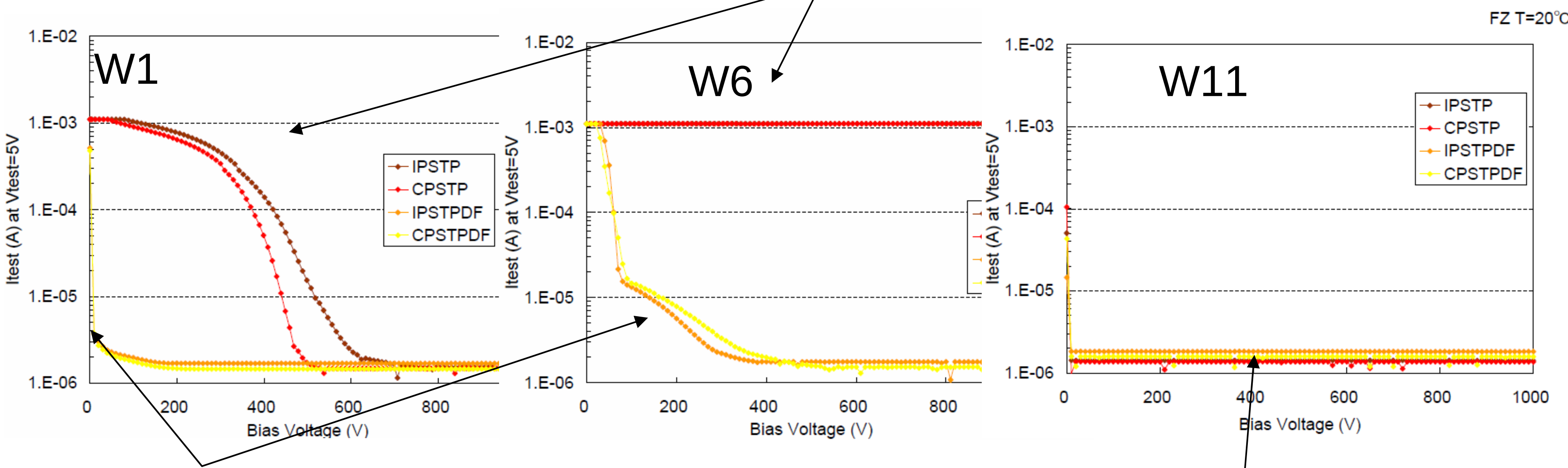
dependence on p-stop concentration (before irradiation)

wafer No	p-stop	p-spray
1	2E+12	2E+12
6	5E+12	---
11	2E+13	---

structures

- IPSTP
- CPSTP
- IPSTPDF
- CPSTPDF

with P-spray is better than without.



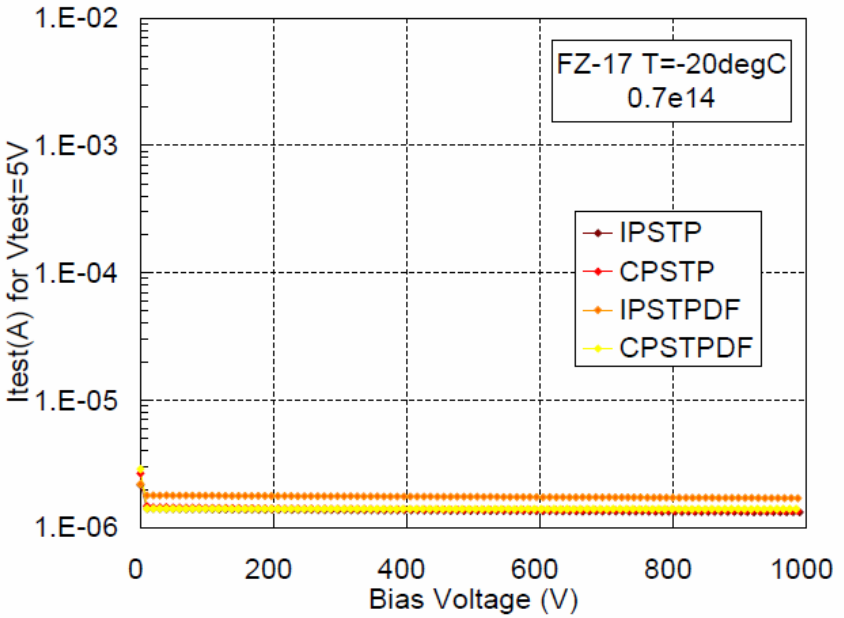
P-stop with DC Field Plates is better than without.

Need ~2E+13 p-stop (W11) to isolate (concentrations for W1/6 are not enough)

Strip Isolation of FZ

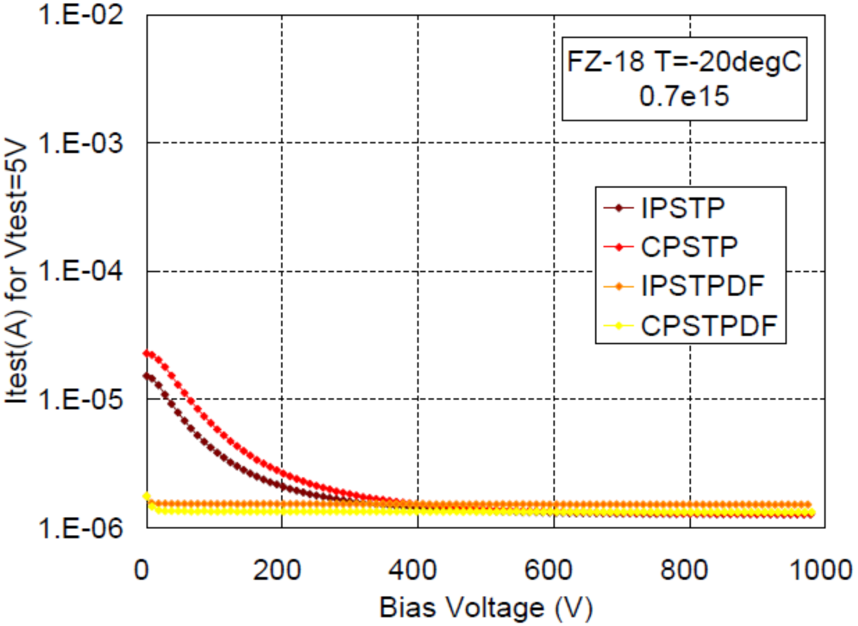
after irradiation (P-stop concentration: 2E+13)

Low fluence



At low fluence,
isolation is still good.

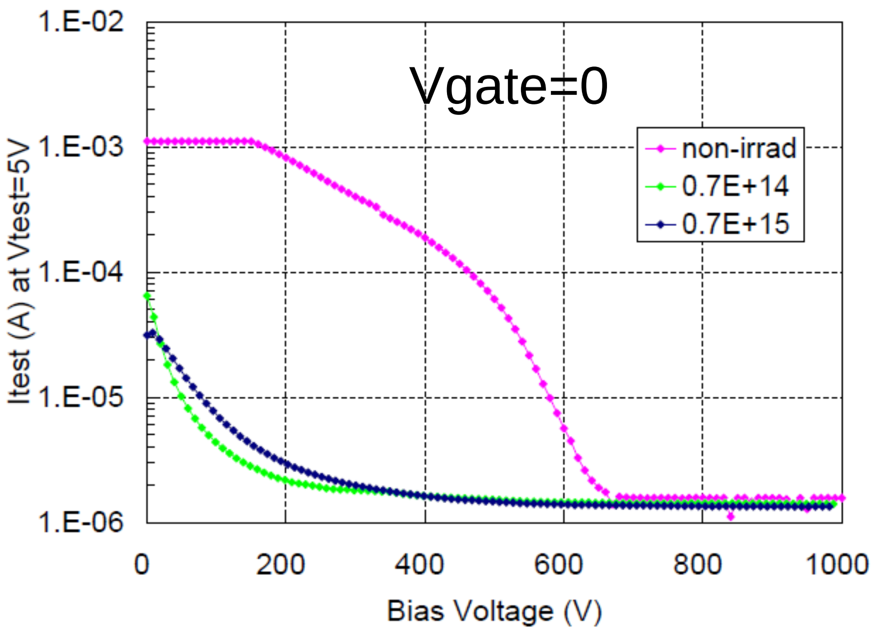
High fluence

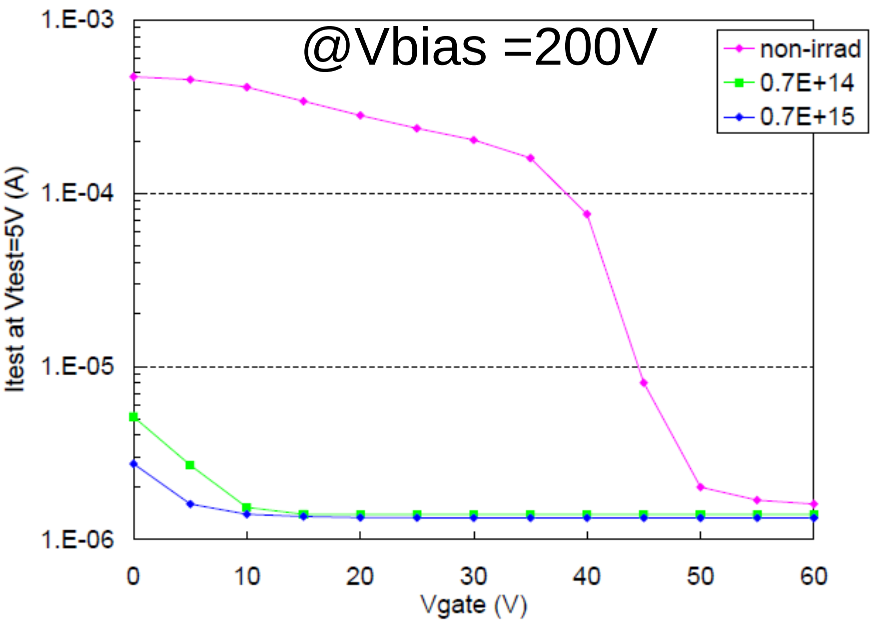


At high fluence,
IPSTP/CSTP becomes worse.
DC field plate remains OK.

Strip Isolation of FZ

effectiveness of AC Field Plate





AF samples are not isolated at Vgate=0 and
HV below ~650V (non-irrad)
HV below ~300V (irradiated)

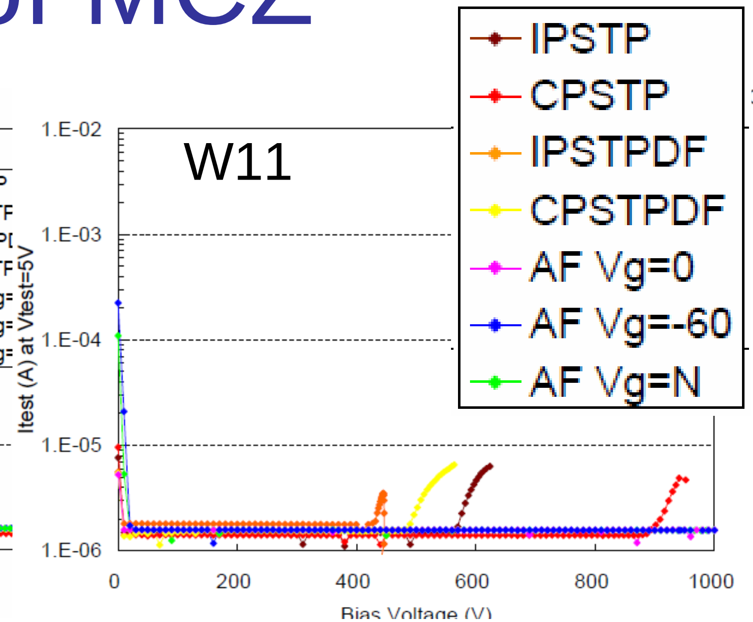
Isolation is achieved at
Vgate~ -50V (non-irrad)
~ -10V (irradiated)

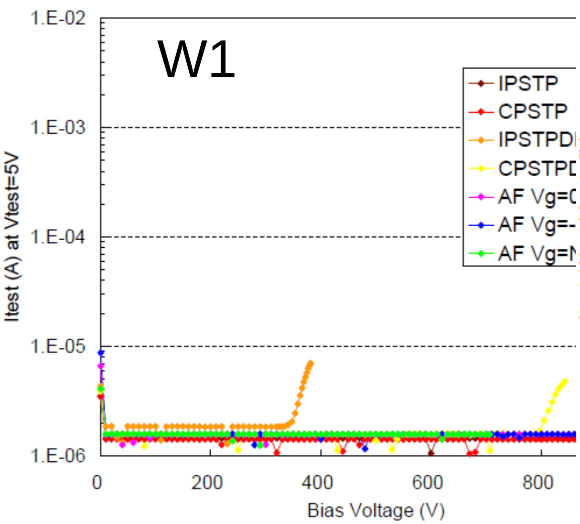
irradiation relaxes the isolation conditions

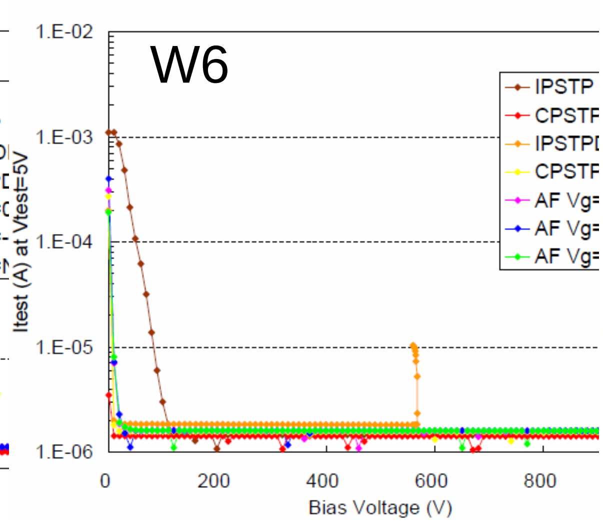
Strip Isolation of MCZ

(before irradiation)

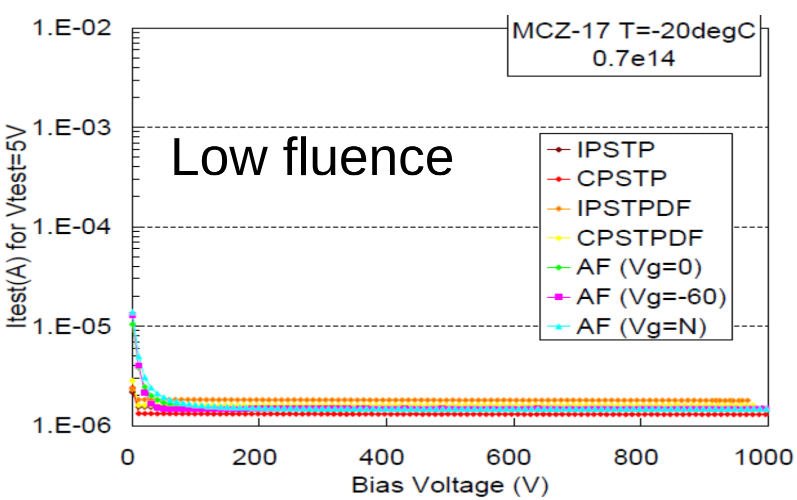
structures

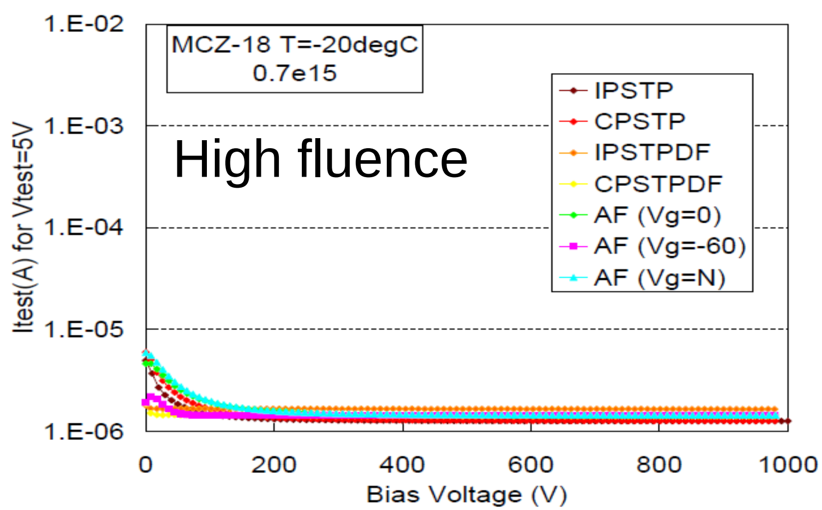






MCZ samples are all OK. Also for AC Field Plate with Vgate=0





Summary

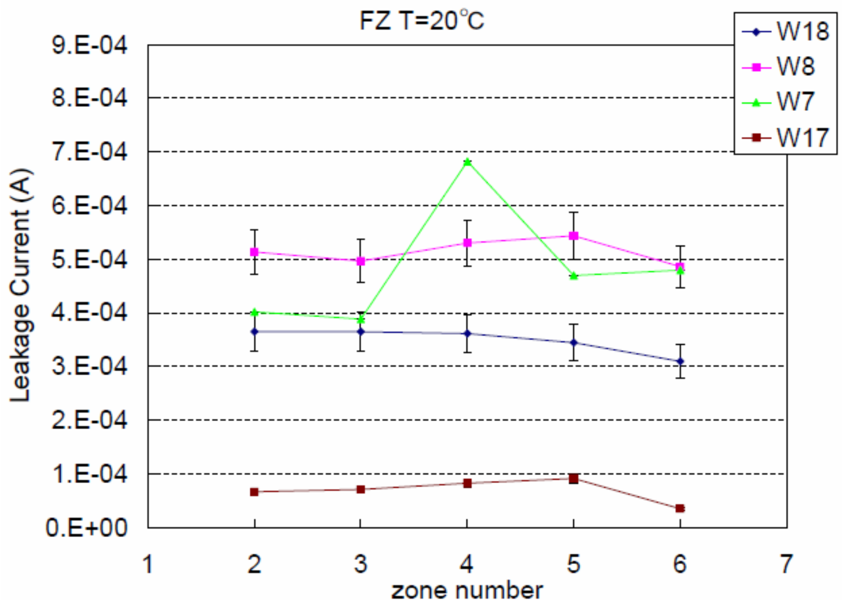
- We have been developing radiation tolerant silicon sensors for the SLHC.
- MCZ wafer is better at present data.

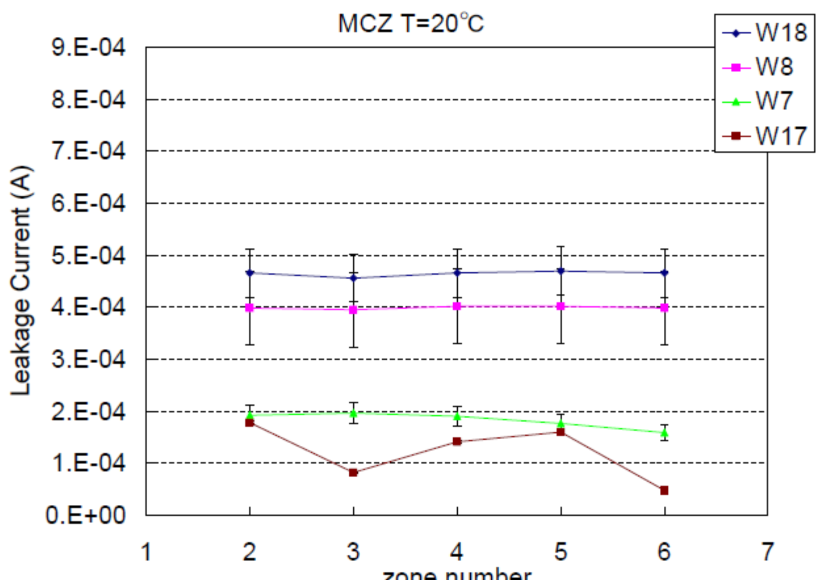
Wafer type	Full depletion voltage	Micro discharge	Strip isolation
FZ	~150 V (non-irrad) ~500 V (0.7E+15)	At 800 V (non-irrad)	•Need 2E+13 P-stop concentration •AC Field Voltage = -50 V
MCZ	~1k V (non-irrad) ~500 V (0.7E+14) to be re-evaluated (0.7E+15)	At 400 V (non-irrad)	All samples are good

- We have new data, covering fluence of 5E15 with 6 fluence points

Back up

Leakage Current @ Vfd





Leakage current are,

For FZ,

$Ileak_{18} = 3.5 \times 10^{-4} \pm 5\ \%\ A$

$Ileak_{8} = 5.1 \times 10^{-4} \pm 8\ \%\ A$

$Ileak_{17} = 0.69 \times 10^{-4} \pm 15\ \%\ A$

$Ileak_{7} = 4.8 \times 10^{-4} \pm 12\ \%\ A$

For MCZ

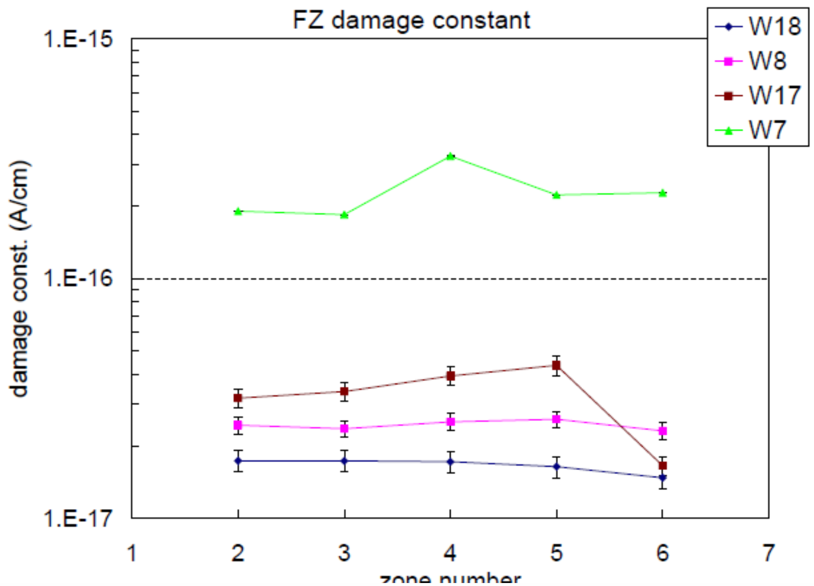
$Ileak_{18} = 4.7 \times 10^{-4} \pm 5\ \%\ A$

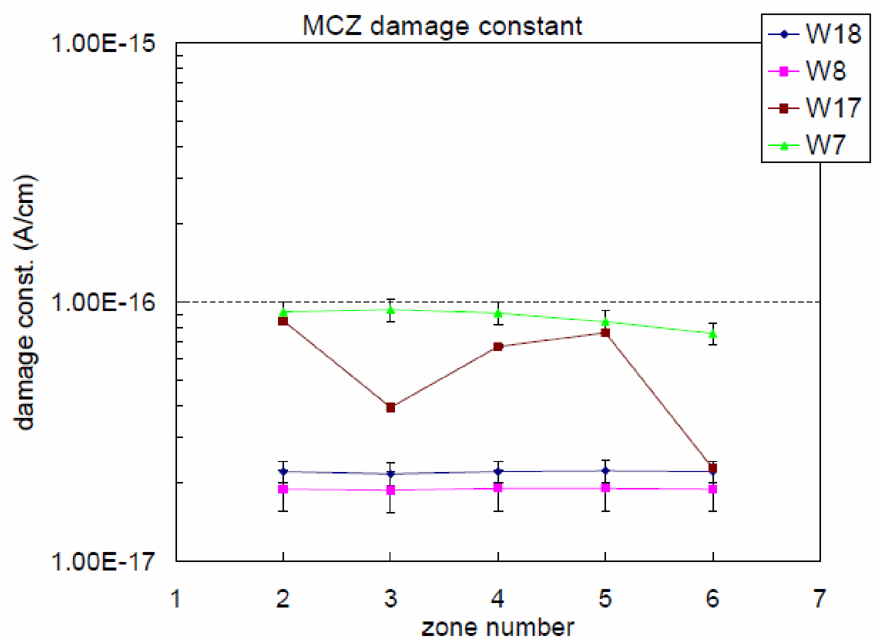
$Ileak_{8} = 4.0 \times 10^{-4} \pm 4\ \%\ A$

$Ileak_{17} = 1.8 \times 10^{-4} \pm 20\ \%\ A$

$Ileak_{7} = 1.2 \times 10^{-4} \pm 6\ \%\ A$

Damage constant





$$\Delta I / Volume = \alpha\Phi$$

Damage constant α are,

For FZ,

$\alpha_{18} = 1.7 \times 10^{-17} \pm 5\ \%$ (A/cm)

$\alpha_{8} = 2.5 \times 10^{-17} \pm 8\ \%$ (A/cm)

$\alpha_{17} = 3.3 \times 10^{-17} \pm 15\ \%$ (A/cm)

$\alpha_{7} = 23 \times 10^{-17} \pm 10\ \%$ (A/cm)

For MCZ,

$\alpha_{18} = 2.2 \times 10^{-17} \pm 5\ \%$ (A/cm)

$\alpha_{8} = 1.9 \times 10^{-17} \pm 5\ \%$ (A/cm)

$\alpha_{17} = 5.8 \times 10^{-17} \pm 20\ \%$ (A/cm)

$\alpha_{7} = 8.7 \times 10^{-16} \pm 5\ \%$ (A/cm)

Fluence evaluation from Al activation

$$P + Al \longrightarrow {}^{7}Be + X$$

$$\Phi \cong \frac{N_{mes} \exp(\lambda \Delta t)}{N_t \sigma \lambda E_{eff} \Gamma}$$

Nmes : # of γ per second

λ : $^{7}Be \rightarrow \gamma$ (477KeV) decay rate

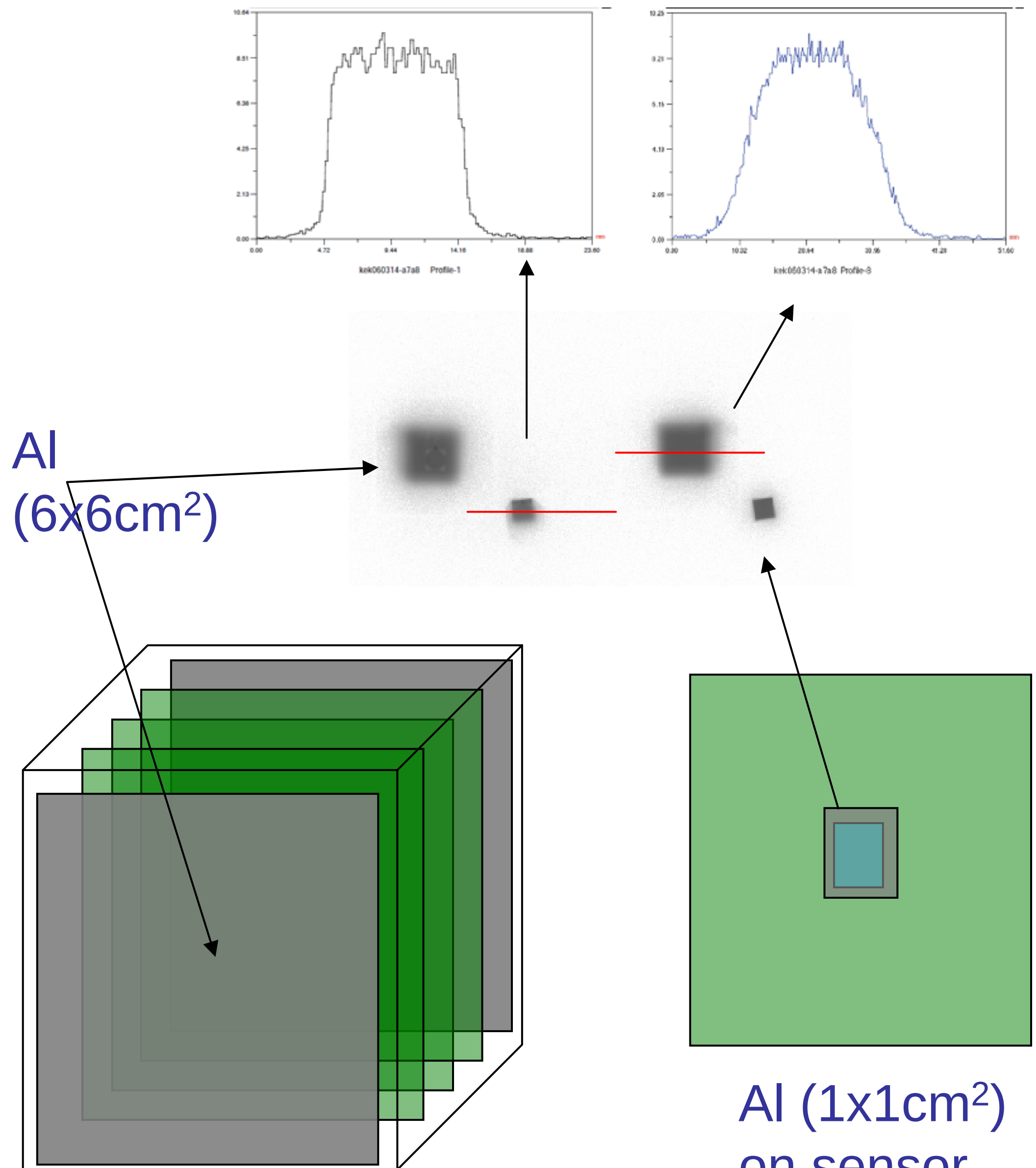
Δt : time from beam off to measurement

N_t : # of Al atom

Γ : $^{7}Be \rightarrow \gamma$ (477KeV) Branching ratio

σ : cross section

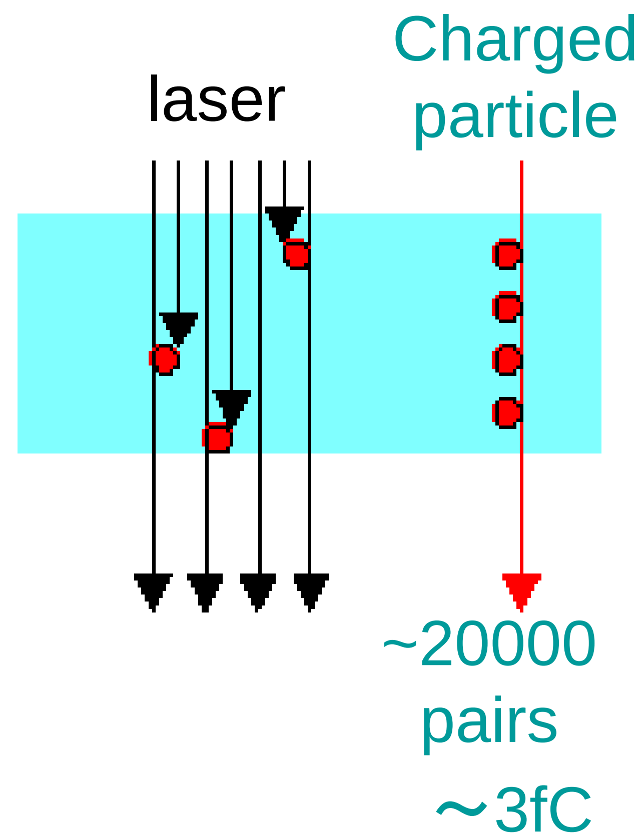
Eeff : SSD efficiency



Silicon detector and laser

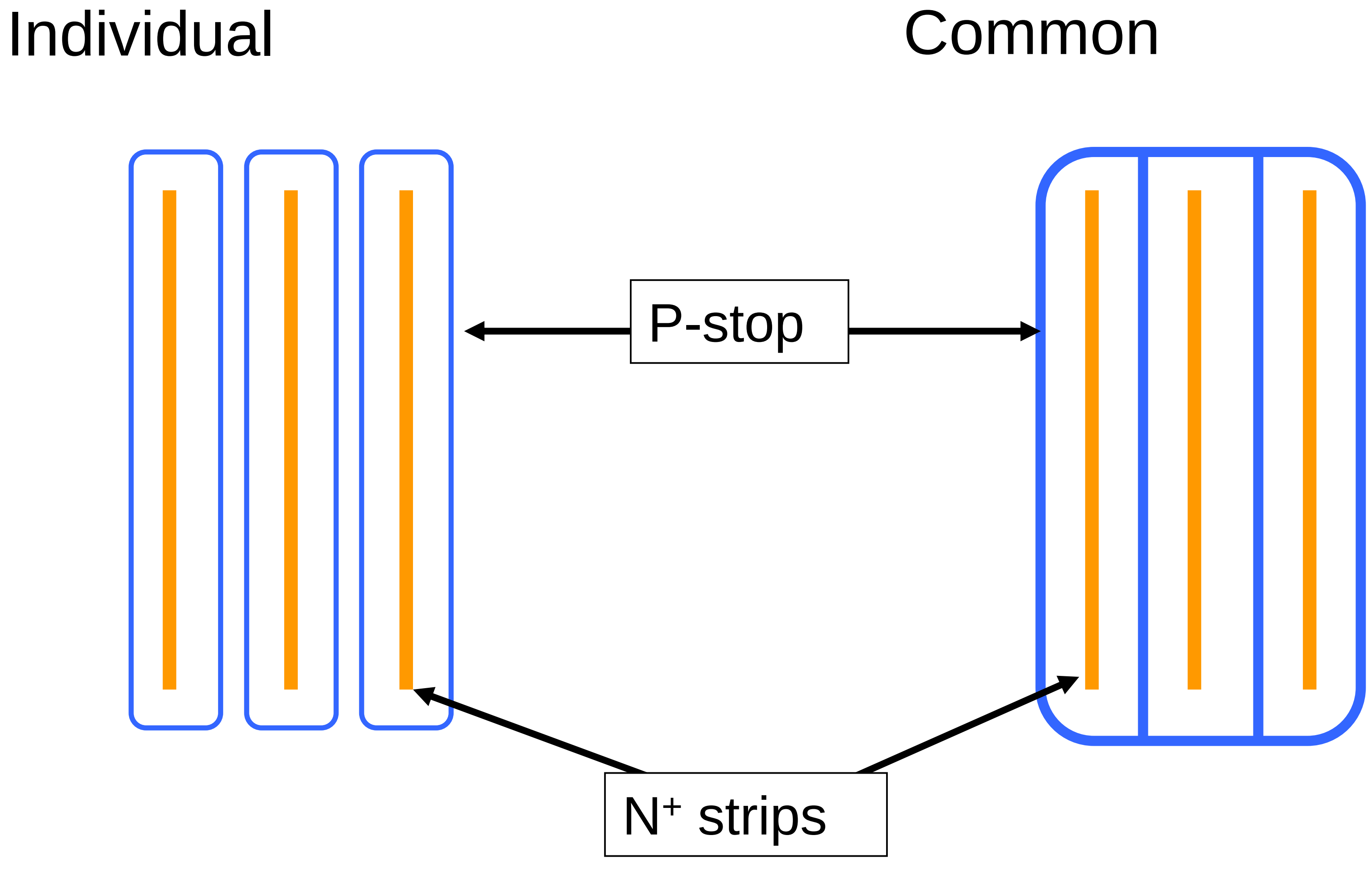
The laser in this measurement is solid-state laser which cavity is YAG（yttrium、aluminum、garnet）crystal doped Nd (neodymium).
1064nm laser is emitted by excitation and transition of Nd^{3+} ion.

Nd:YAG laser	1064nm=1.16eV
Silicon energy gap	=1.12eV

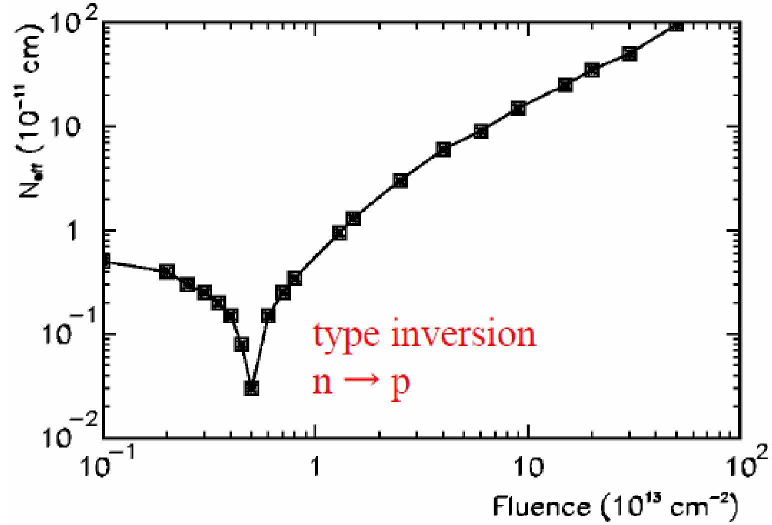


- Although almost laser pass through the silicon, can create electron-hole pair in a probability. Evenly for the silicon depth.
  - Can control number of creation by adjusting light quantity.

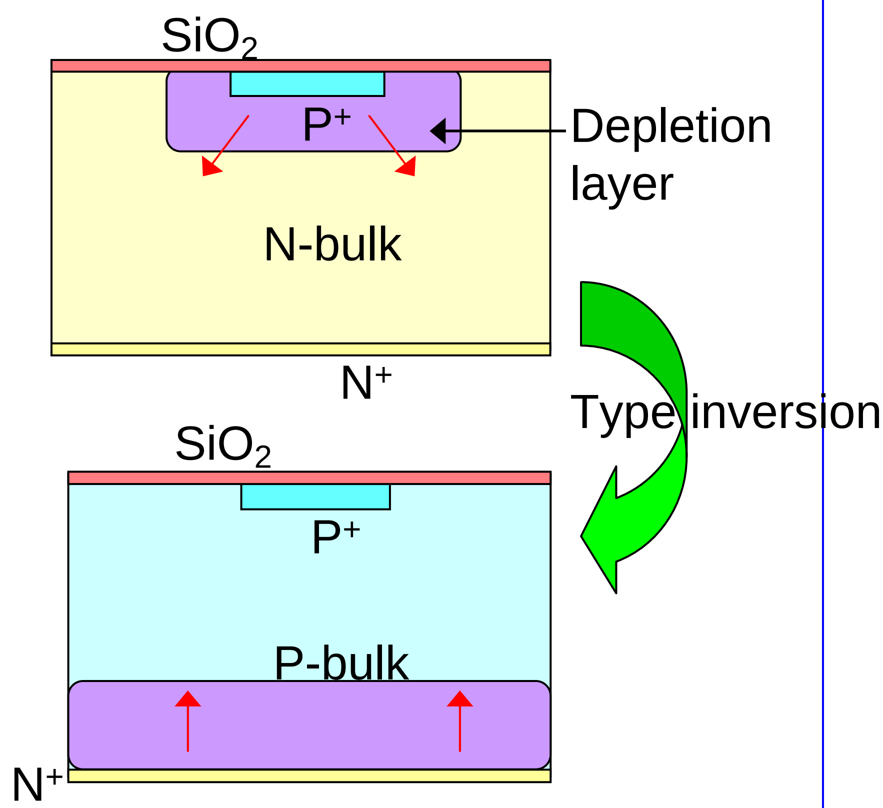
P-stop shape



The advantage of P-bulk sensor



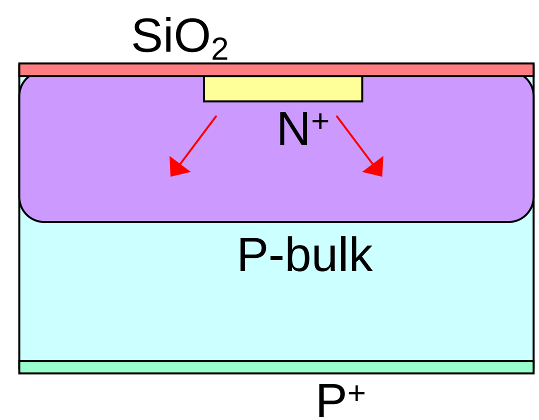
P-on-N sensor (present SCT)



- Need to be fully depleted to read out signal.

N-on-P sensor

No Type inversion



- Signal can be read out even under partial depletion