The study on the radiation hardness of CIGS semiconductor

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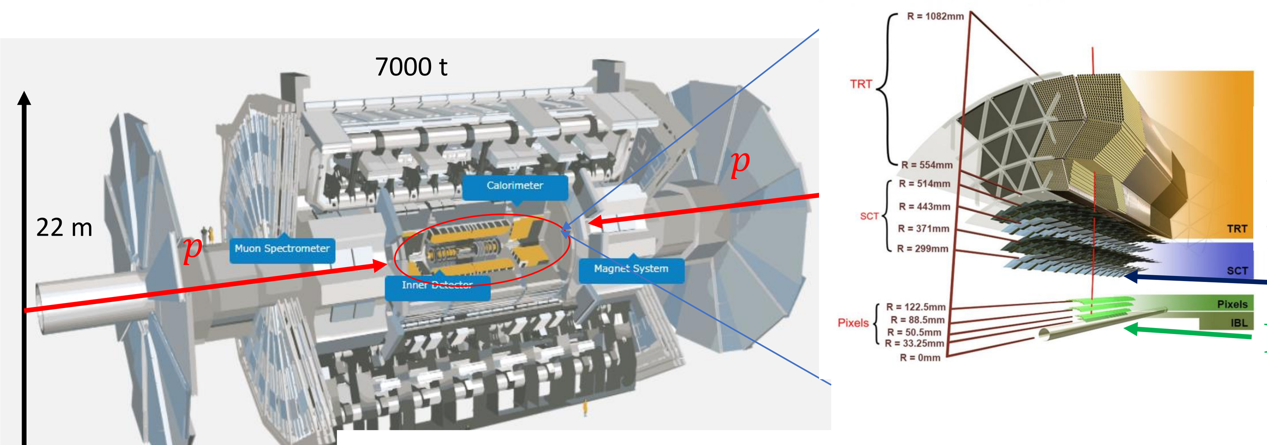
1. ATLAS detectors

ATLAS detector is one of the huge detectors installed at CERN.
→ Equipped three types of inner detectors.



Transition Radiation Tracker (TRT)
- Particle identification

Semiconductor Tracker (SCT, Pixel)
- Tracking
- Momentum measurement

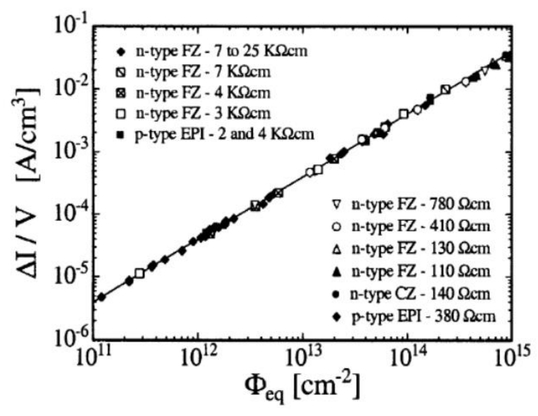
SCT
Pixel

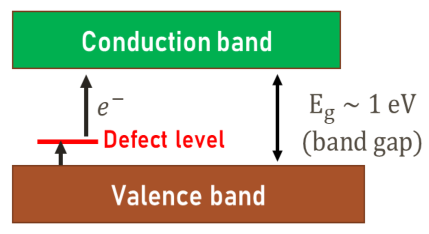
The ATLAS detector detects the charged particles produced by collision reactions. → To give critical damage to Si semiconductor detectors

2. Radiation damage for semiconductors

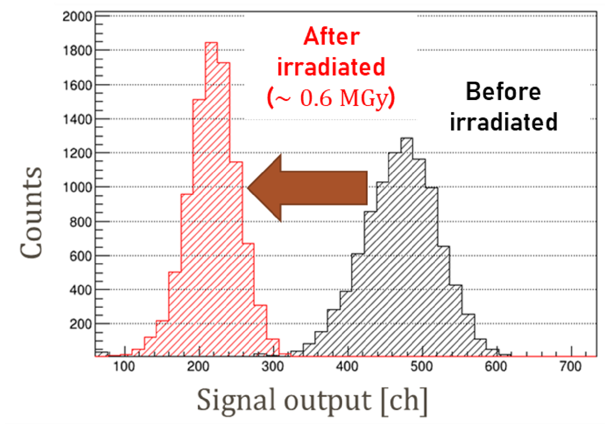
Radiation particles (proton, neutron, etc.) are knocked out atoms in the lattice (NIEL).Heated ionic atoms restored defective lattices.

Increasing leakage current [1]





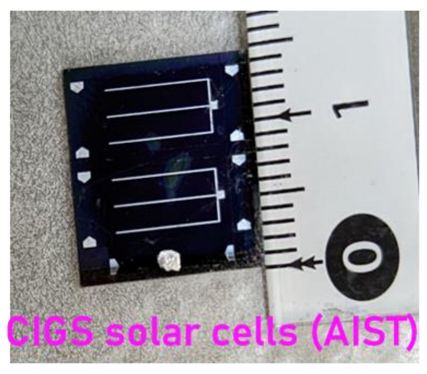
Decreased amount of signal collected charge.

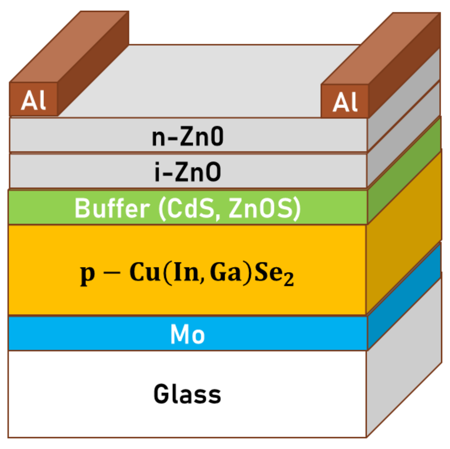


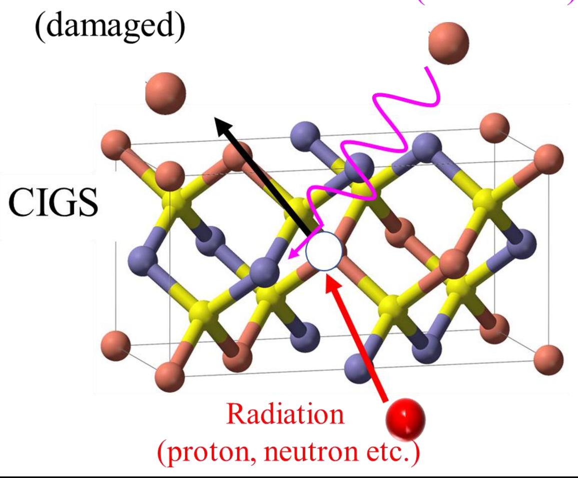
3. CIGS ($Cu(In,Ga)Se_2$)

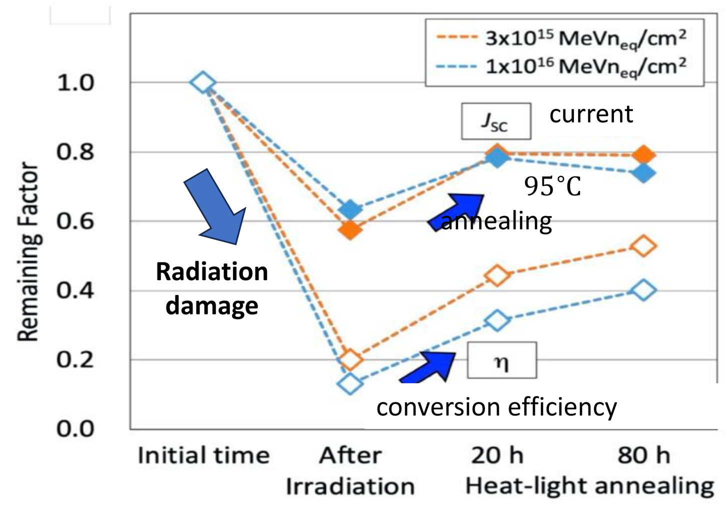
A CIGS is an alloy semiconductor of $CuInSe_2$ and $CuGaSe_2$.

- Energy gap : 1.01 – 1.64 eV (depends on fraction of In and Ga)
- Absorption wavelength : 300 – 1200 nm
- P-type semiconductor
- High radiation resistance
- Good light sensitivity





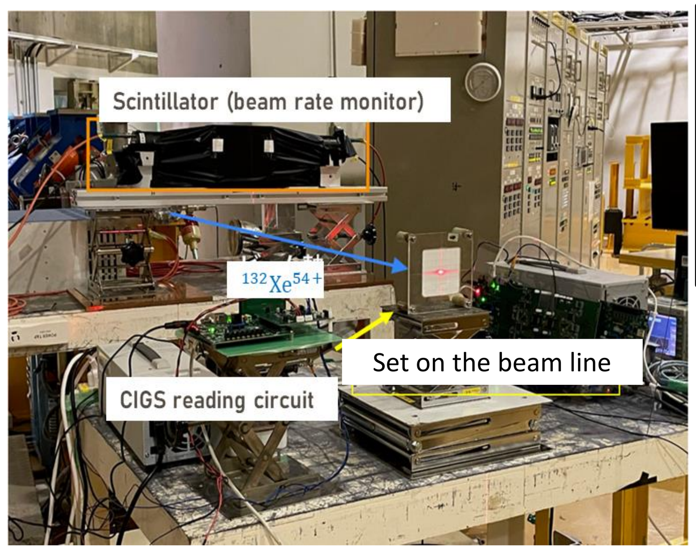




CIGS has recovered mechanism by heat annealing
Heated ionic atoms restored defective lattices → Expected to recover leakage current and collected charged decreasing by radiation damage.

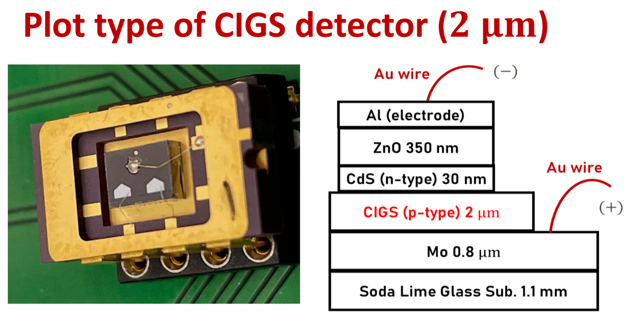
4. Heavy ion irradiation experiment at HIMAC

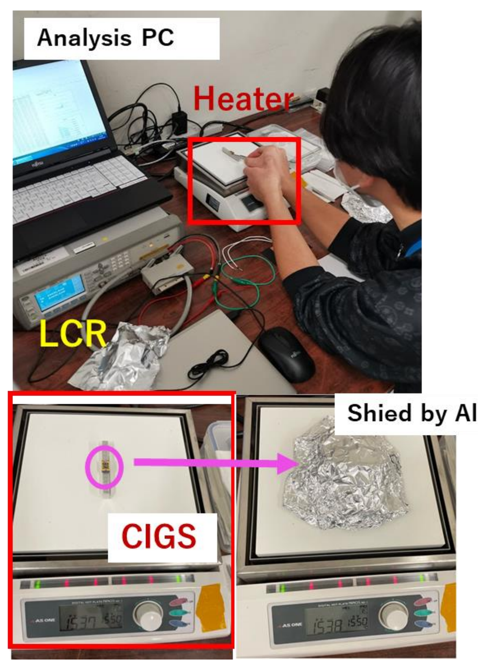
HIMAC is a heavy-ion cancer therapy device in National Institute of Quantum Science and Technology (QST) in Chiba, Japan.

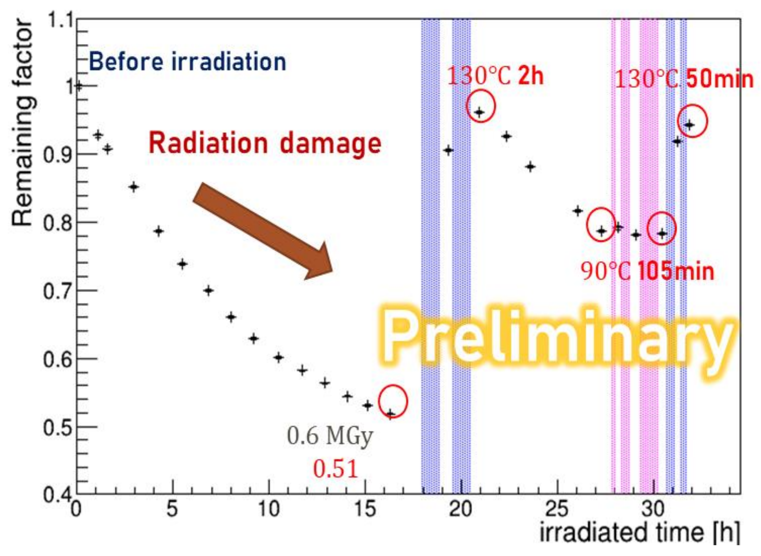


HIMAC test beam condition (Nov. 2022)
Beam : ^{132}Xe ion
Energy : 400 (MeV/u)
Beam size (ϕ) : 3-5 mm
Fluence : 10^7 cm^{-2}/3.3 s (ppp)

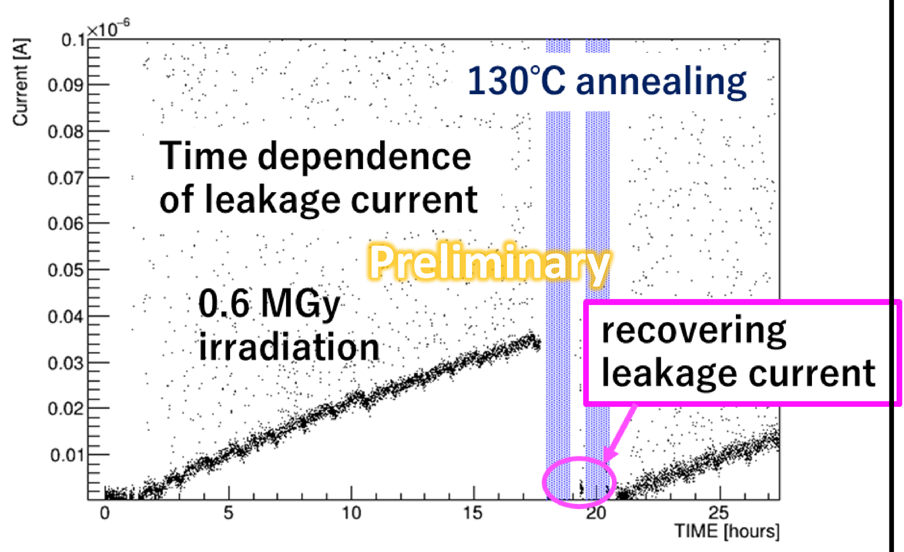
Plot type of CIGS detector (2 μm)







- Continuously recovery (130°C annealing)
- strong temperature dependence

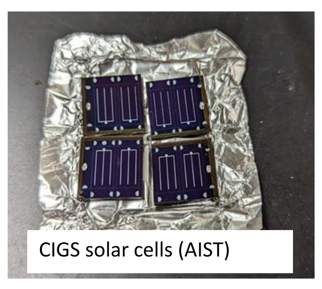


Recovered leakage current by 130°C annealing
→ Decreasing defect level

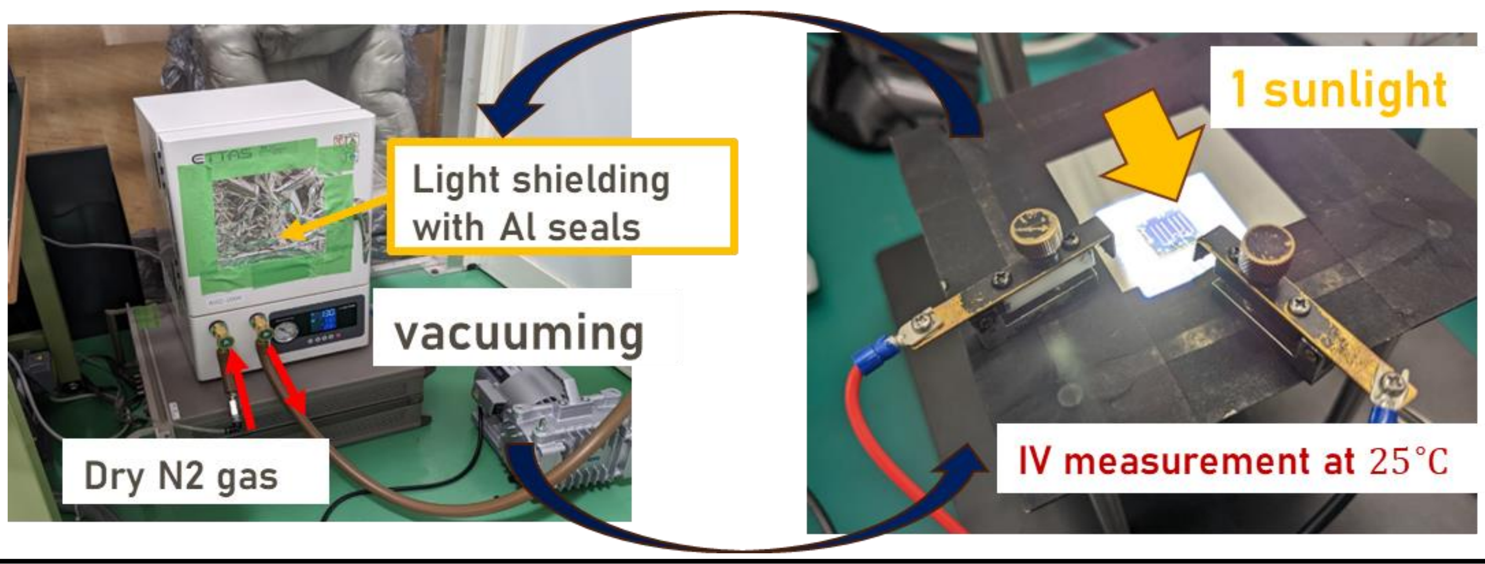
5. Proton irradiation experiment at CYRIC

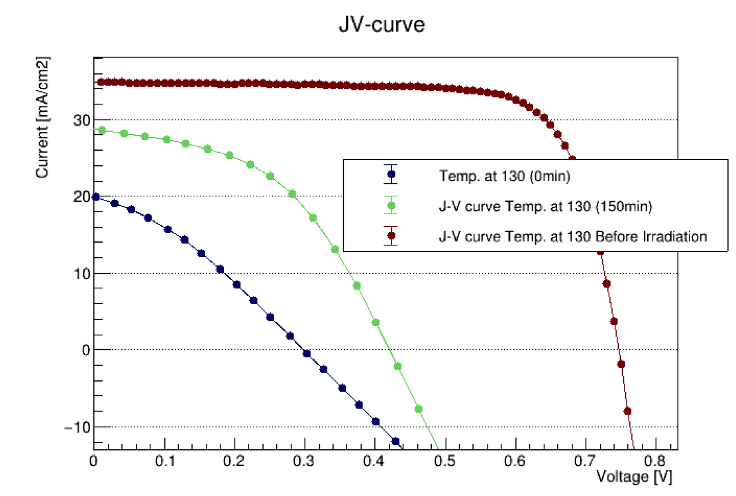
We irradiated 70 MeV proton to CIGS solar cells (7×10^{15} $MeV \cdot n_{eq}$) at Cyclotron and Radioisotope Center (CYRIC) in Tohoku University.

Irradiated samples

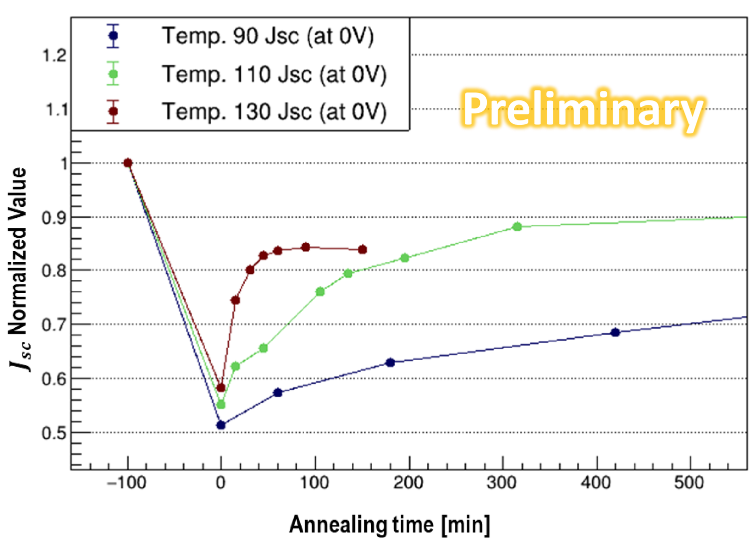


For study of the annealing temperature and time dependence of current, we measured short-circuit current (J_{sc}) and conversion efficiency (η) with 1 sunlight.





IV curve of CIGS solar cells
- J [mA/cm^2] decreased due to proton irradiation
  $J_{sc}(0V)$: 35 → 20 mA/cm^2
- Recovered J by thermal annealing (2.5 h) at 130°C
  $J_{sc}(0V)$: 20 → 28 mA/cm^2



Heating temperatures (90, 110, 130°C)

- 130°C annealing : J_{sc} = 0.58 → 0.83 (1h)
- 90°C annealing : J_{sc} = 0.51 → 0.56 (1h)

Recovery time is greatly depending on heating temperature.

These results are consistent with HIMAC experimental results

6. Summary

LHC at CERN plans major upgrades for the high energy and luminosity.
- The development of detectors with high radiation tolerance (70 MGy) is necessary.

CIGS has the ability to recover from the radiation damage by annealing.
- high radiation tolerance semiconductor

We performed heavy ion irradiation experiment for study the thermal annealing at HIMAC.
- CIGS recovered the radiation damage in terms of leakage current and signal output by the heat annealing at 130 °C.

For study of the annealing temperature and time dependence of J_{sc}, CIGS solar cells were irradiated with 70 MeV proton (7×10^{15} $MeV \cdot n_{eq}$) at CYRIC.
- We observed strong temperature difference of J_{sc} recovery speed, and this results is consistent with recovery speed of collected charge in HIMAC experiment.

7. Future research plan for CIGS

Toward the practical application of CIGS detectors
- Development of thick depletion layers for single-charged particles detection
- Development of the CIGS detector as a pixel and strip type.

Reference

[1] G. Lindstrom Nucl. Phys. And Meth. In Phys. Rese. A 512 (2003) 30-43.