Test-beam evaluation of newly developed n⁺-in-p planar pixel sensors aiming for use in high radiation environment

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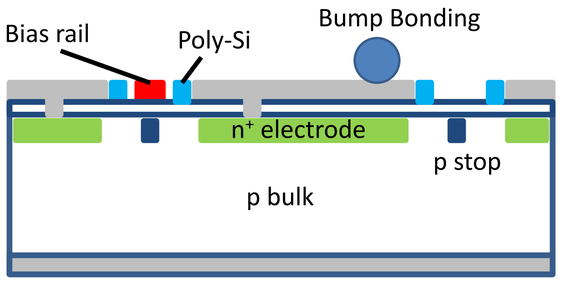
n⁺-in-p planar pixel sensor R&D with HPK

Since the pixel detectors in high energy application have been developed with the aim of detecting and tracking short-lived particles, pixel sensors are placed close to the collision point.
e.g. ATLAS detector (LHC) ~ *O*(1 - 10 cm)

Due to the high radiation environment, pixel sensor is required to satisfy the following conditions:

- Highly radiation tolerant
  e.g. 3×10^{15} 1MeV n_{eq} / cm^2 for ATLAS outer pixel layer
- Fast readout speed



n⁺-in-p silicon sensors have following advantages:

- Bulk type-inversion tolerant
- Operational without fully depleted
- Fast response since the collected carrier is electron

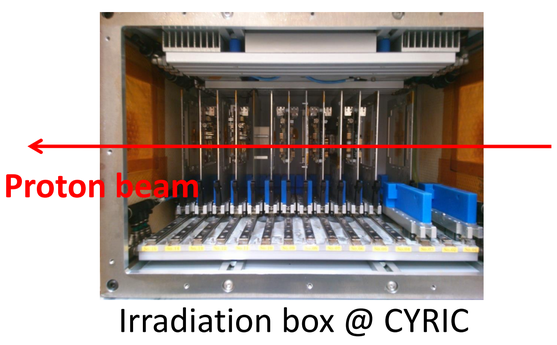
Indication from previous R&D studies and new sensor structures

Previous studies pointed out that the efficiency drop was especially obvious under the biasing rail structure. To minimize the efficiency drop, new sensor structures has been developed.

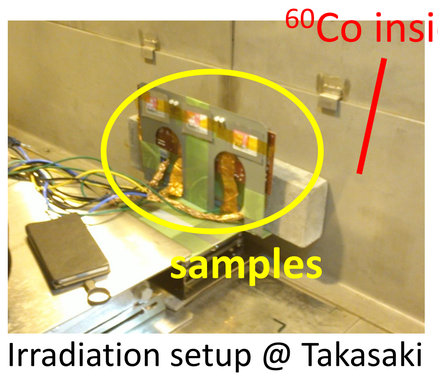
- **Larger offset structure:** hiding bias rails under the electrode
- **Wide p-stop:** broadened p-stop hiding bias rails

Evaluation of hit efficiency after irradiation

In order to test the new structures, sensors were irradiated with proton beam at Cyclotron Radio-Isotope Center (CYRIC) in Tohoku University and with γ's at Takasaki Advanced Research Institute.



Irradiation box @ CYRIC

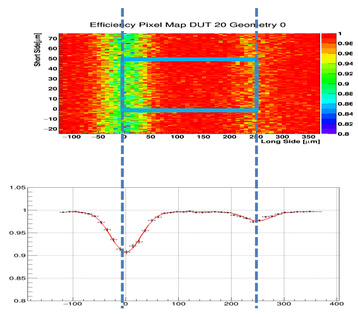


Irradiation setup @ Takasaki

The effect of **bulk damage** and **surface charge-up** has been evaluated with data taken with particle beams at CERN (120GeV pions, pointing resolution ~ 8-9μm) and DESY (4GeV electrons, pointing resolution ~ 30-35μm).

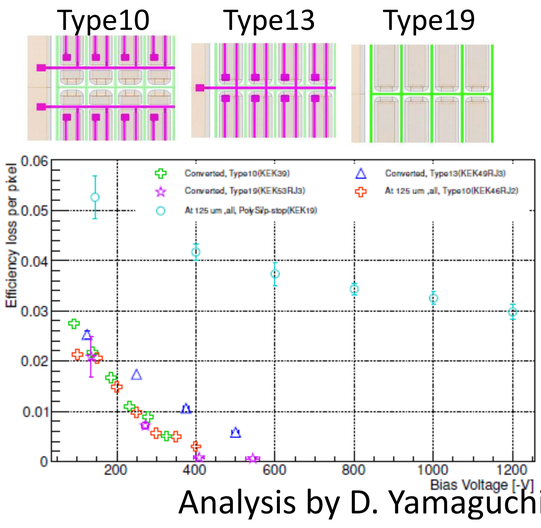
To evaluate the efficiency drop quantitatively, a numerical value, "efficiency loss per pixel" is calculated with the following procedure:

1. Project the pixel efficiency maps (2 × 2 pixel size) to XY axis to get "Pixel center efficiency" and "Pixel edge inefficiency".
2. Fit the projected histogram with **double-Gaussian + offset func.**
3. Calculate the area of each Gaussian, and divide the value with 2-pixel length (**averaging the inefficiency among pixels**).
4. Normalize with the offset value.



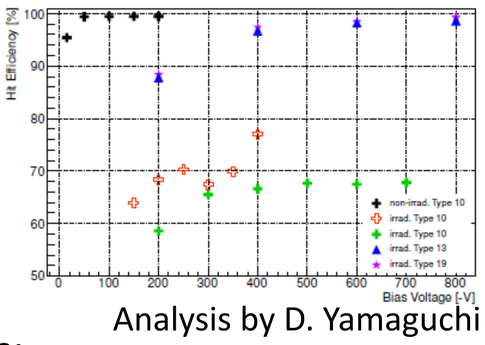
Inefficiency analysis results

Samples:
- OLD type sensor
- Poly-Si rail, Large offset structure (Type10)
- Poly-Si rail, Wide p-stop structure (Type13)
- No bias rail reference structure (Type19)



Analysis by D. Yamaguchi

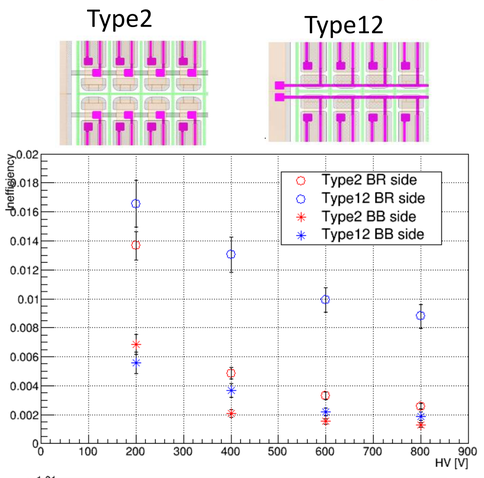
*No reference plane analysis
overall efficiency is low ~ 70%



Analysis by D. Yamaguchi

Efficiency loss per pixel:
OLD ≫ Type13 > Type10 ≧ Type19

Type10 is almost equivalent to no bias rail structure (Type19)



Samples:
- Al rail, Large offset structure (Type2, 3.03×10^{15} MeV n_{eq}/cm^2)
- Poly-Si rail, Small offset structure (Type12, 3.08×10^{15} MeV n_{eq}/cm^2)

*analysis with reference plane
good overall efficiency > 90%

Efficiency loss per pixel:
Type12 ≧ Type13 > Type2

Larger offset structure presented least efficiency loss

Investigation into surface damage effect

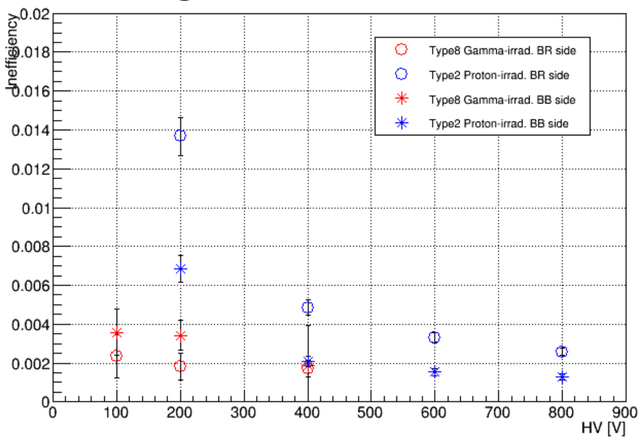
TCAD analysis indicates possible causes of the efficiency drop

- **Surface damage from gamma-ray exposure**
- Investigation of the effect of Oxide-Si interface charge-up

Irradiation with gamma-ray is to decouple the effect of surface damage from that of bulk damage

Samples:
- Proton-irrad(150μm thick, 3.03×10^{15} MeV n_{eq}/cm^2)
- Gamma-irrad (320μm thick, 2.4 MGy)

Efficiency loss in the gamma-irrad. sensor is remarkably small compared with proton-irrad. sensor.



Conclusion and future plan

New sensor structures are under development based on the previous studies, and have been evaluated with particle beams.

- Improvement in efficiency was observed
- Large offset structure has the least efficiency loss
- Still need to compare Poly-Si and Al bias structure

Gamma-irradiation was carried out to investigate the effect of surface damage

- The contribution from surface damage is much smaller than that of bulk damage
- Samples were proton-irradiated further. Going to see if they reproduce the results of proton-irrad. modules