Evaluation of KEK n-in-p planar pixel sensor structures for very high radiation environments with testbeam

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1. N-in-P Planar Pixel Sensor

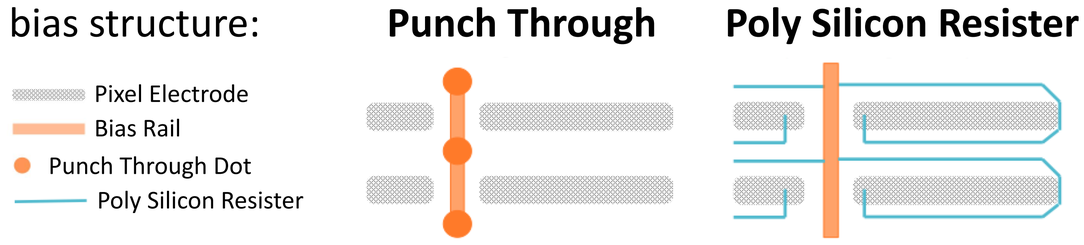
In collider physics, the pixel is usually used as an innermost sub-detector of a multi purpose detector, such as ATLAS and CMS. The pixel is located at short distance from the interaction point, *O*(1-10 cm). Hence, it is required the pixel is high radiation tolerant. N-in-P planar pixel sensor is one of the candidates for the future high luminosity experiments. N-in-P type has following advantages:

- **no type inversion after irradiation**
  - + pn junction is formed at readout side
    - -> operational w/o full depletion
  - + lithograph processing only on one side
    - -> low cost
- **readout n^+ pixel collects electron (not hole)**
  - -> good timing performance

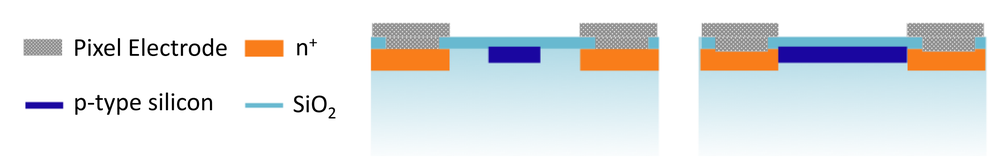
2. Devices Under Test

Evaluated **7** DUTs (**4**: un-irradiated, **3**: irradiated [$\mathbf{1 \times 10^{16}}$ $\boldsymbol{n_{eq}}$**/cm²** **from reactor neutron**]). All sensor modules were produced by **HPK** (Hamamatsu). Sensors are connected with R/O chips, FE-I4A, using bump bonding technique. 4 (= 2 x 2) structures were compared.

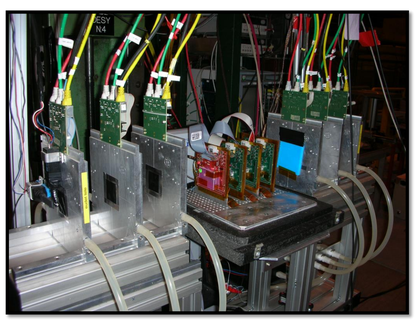
- bias structure: **Punch Through** **Poly Silicon Resister**



- pixel isolation type: **p-stop** **p-spray**



3. Testbeam at CERN SPS



The testbeam was held in September 2012 at CERN SPS to evaluate the change of sensor performance after irradiation

- beam : 120 GeV/c Pion
- tracking telescope : MIMOSA26
  - 18.6 µm pitch pixel sensor
  - Spatial resolution is a few µm

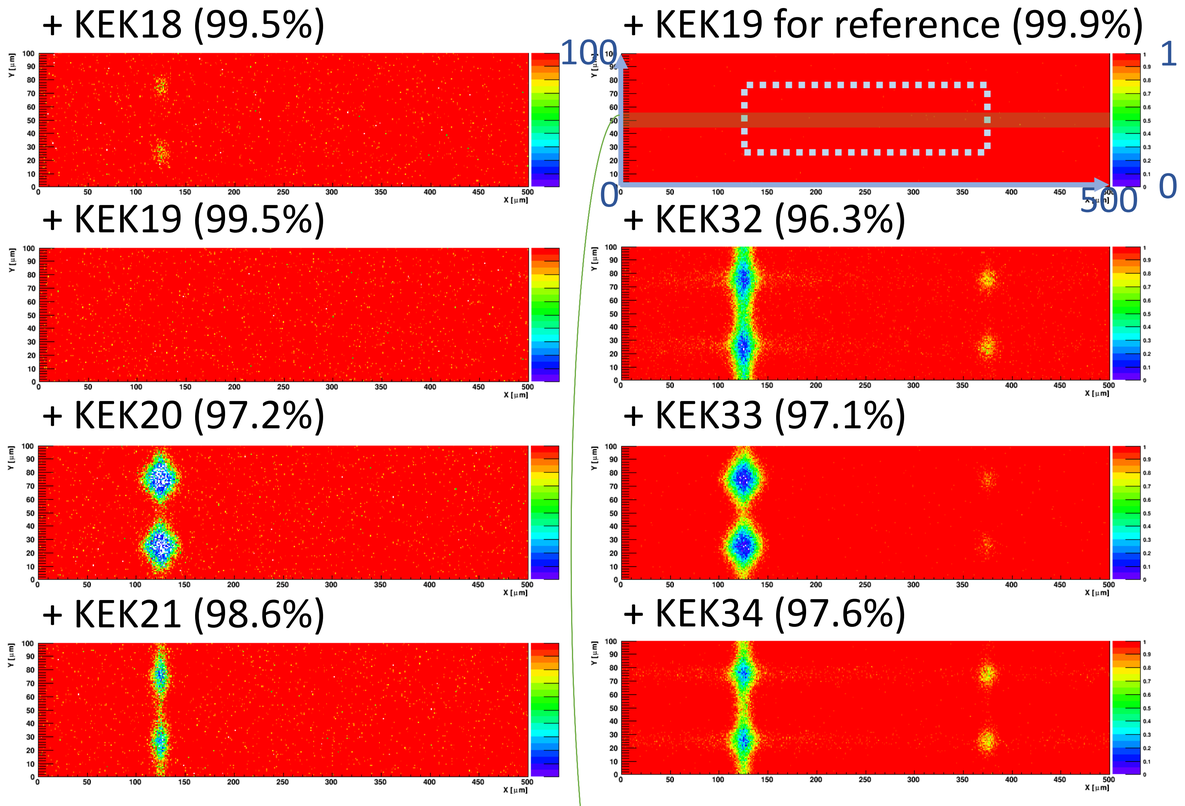
There are 2 batches in this testbeam:

- **Batch1 for un-irradiated:**
  - + KEK18 (PT, p-stop)
  - + KEK19 (PolySi, p-stop)
  - + KEK20 (PT, p-spray)
  - + KEK21 (PolySi, p-spray)
- **Barch2 for irradiated:**
  - + KEK19 (PolySi, p-stop) for ref
  - + KEK32 (PolySi, p-stop)
  - + KEK33 (PT, p-spray)
  - + KEK34 (PolySi, p-spray)

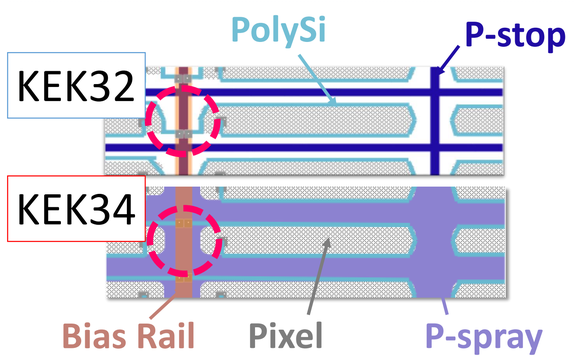
4. DUT Hit Efficiency

Hit Efficiency Map in Pixel shows differences of each structures

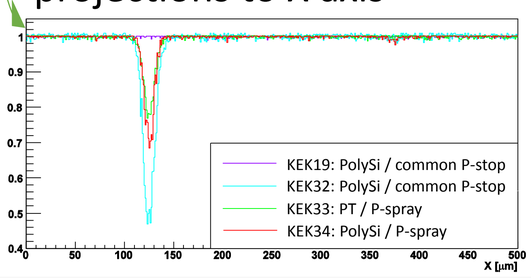
- **Batch1 (HV = -400 V):**
  - + KEK18 (99.5%)
  - + KEK19 (99.5%)
  - + KEK20 (97.2%)
  - + KEK21 (98.6%)
- **Batch2 (HV = -1200 V):**
  - + KEK19 for reference (99.9%)
  - + KEK32 (96.3%)
  - + KEK33 (97.1%)
  - + KEK34 (97.6%)



P-spray causes inefficiency region under bias rail before irradiation



projections to X axis



Region under **PolySi** become inefficient after irradiation

5. DUT Charge Collection Efficiency

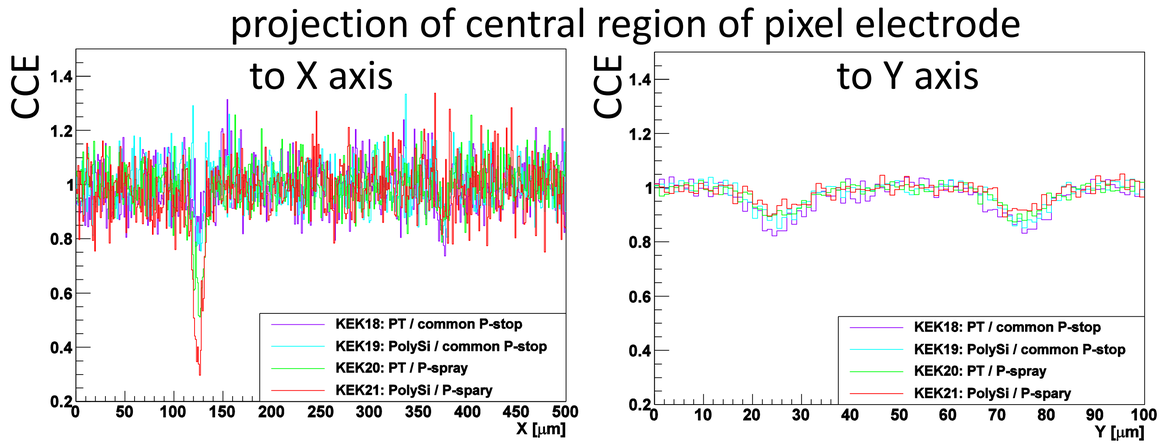
Look into the charge collection efficiency map to investigate whether bias/isolation structures cause any inefficiency.
The definition of charge collection efficiency is:

$$\mathrm{CCE} = \frac{\mathrm{Vcal_{obs}}}{\mathrm{Vcal_{ave}}}$$

Vcal is DAC value which is linear to amount of collected charge.

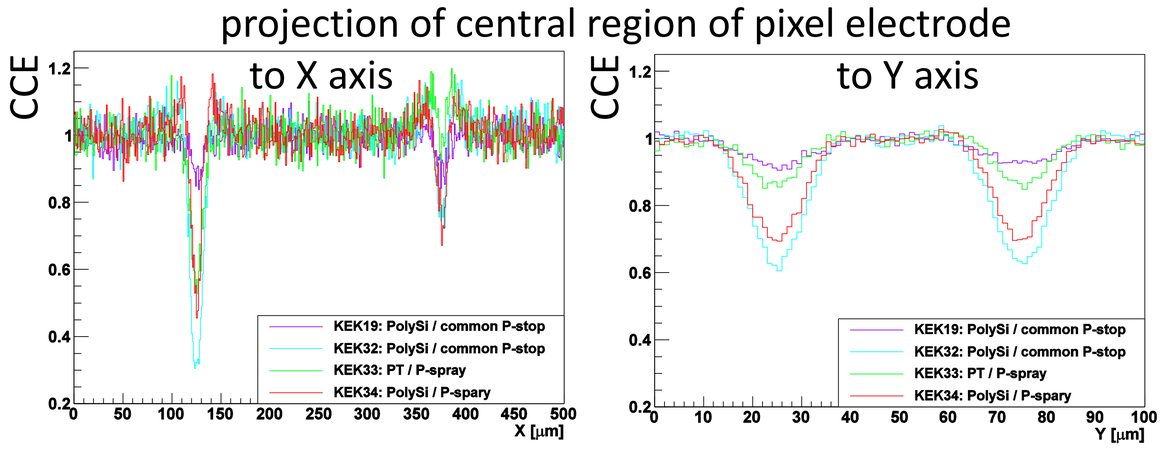
- **Batch 1 (HV = -400 V)**

projection of central region of pixel electrode



- **Batch 2 (HV = -1200 V)**

projection of central region of pixel electrode



Region under **PolySi** causes charge loss after irradiation

6. Conclusion & Outlook

Newly developed n-in-p pixel sensors were evaluated using testbeam at CERN SPS. 4 structures were compared.
Overall hit efficiency of 97.6% was confirmed at 1200 V after irradiation of 1 x 10^{16} n_{eq}/cm^2.
It is found that

- p-spray has caused the inefficiency region under bias rail even before irradiation
- PolySi resister has caused the inefficiency and charge loss after irradiation

In the next production, several new designs are prepared.
In some of them, PolySi is placed on top of the pixel electrode to avoid the inefficiency.