The PIN structured Si sensor for the ALICE FoCal / APD structure into the pixels for the LS3 upgrade

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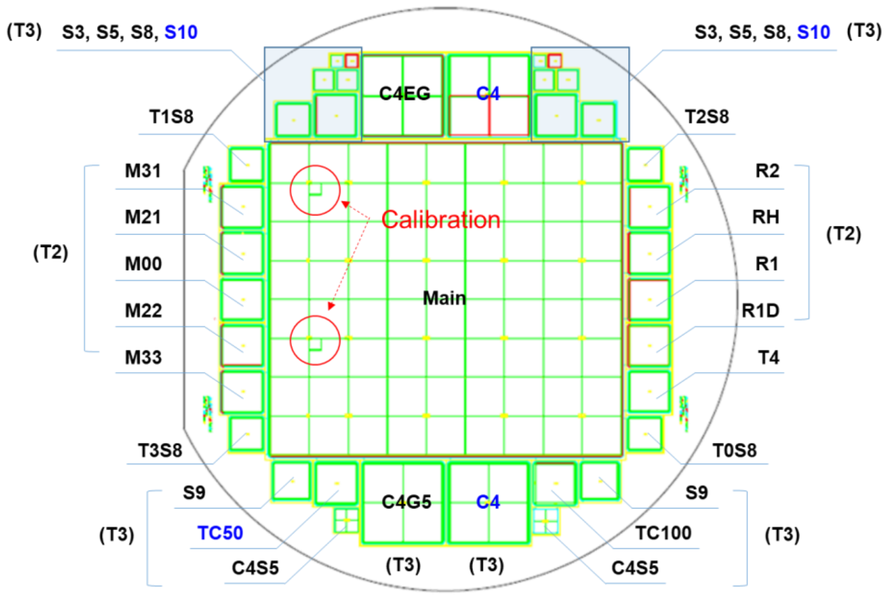
The PIN structured Si sensor for the ALICE FoCal

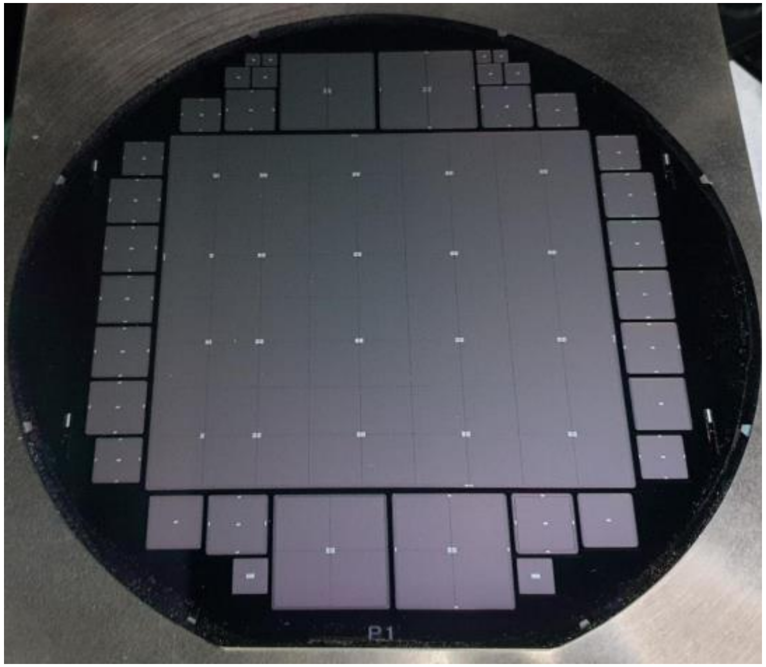
Processed Submission

As a plan we announced at previous workshop, we proceed submission with design considered



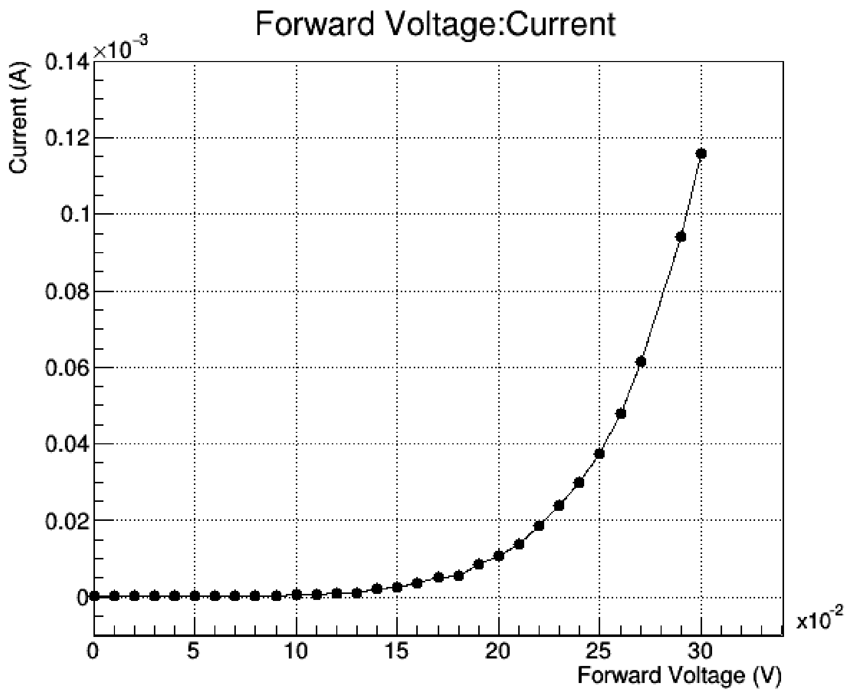
Fixed version of Mask design

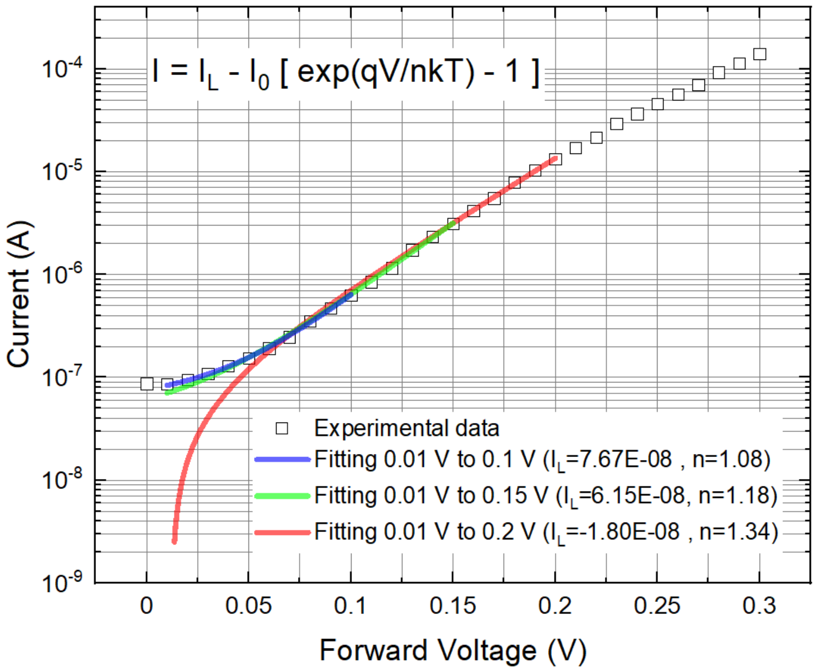
With various types of test patterns



Fabricated sensor

Characteristic of fabricated sensor

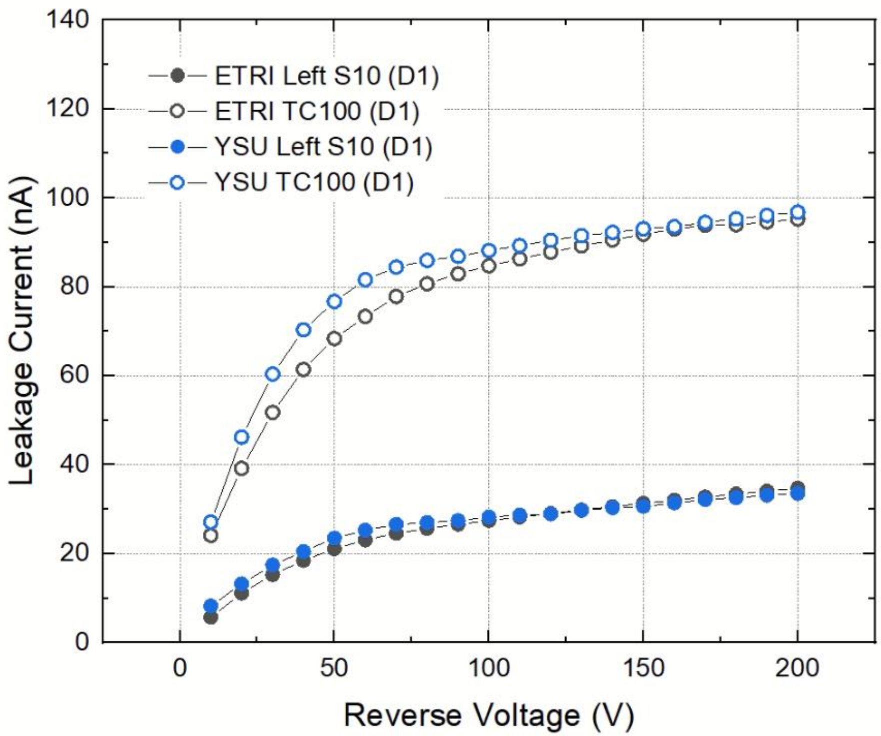


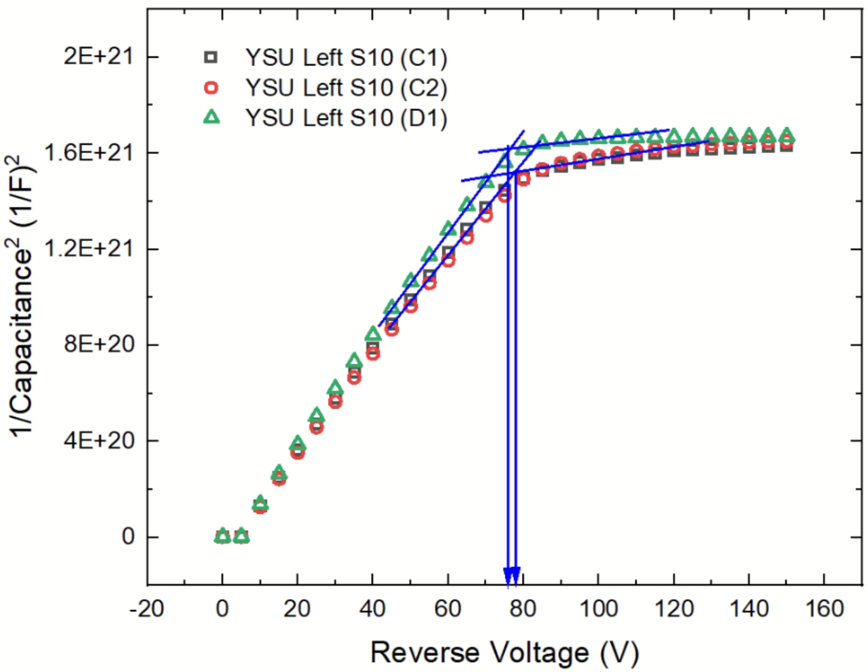


Device show turn on at 0.2V, general forward characteristic of diode

Device's ideality factor was measured as 1.21, so we could confirm device show enough quality of being diode

Characteristic of fabricated sensor

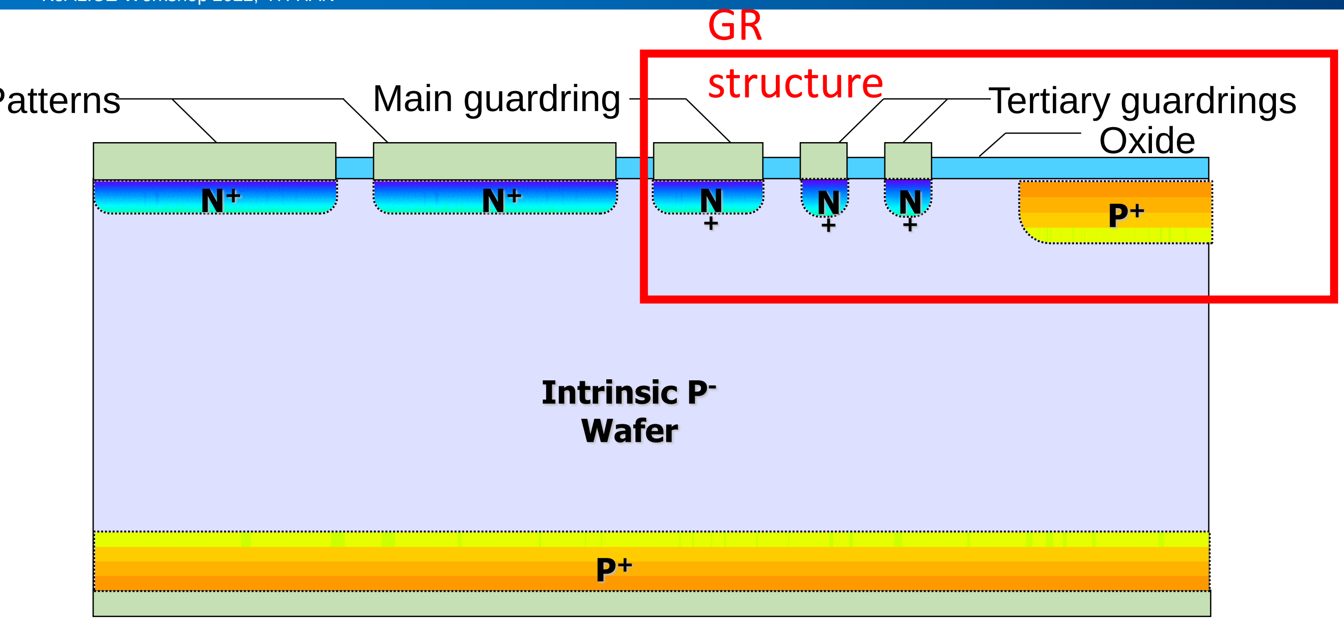


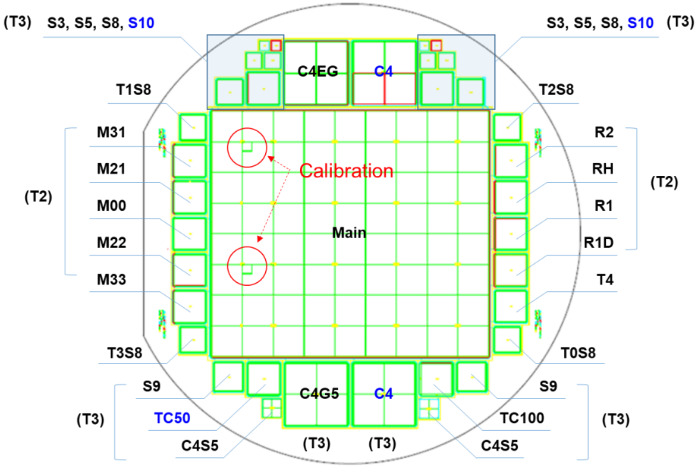


There exist some variation at leakage level, but nearly all pattern show leakage level under 1μA, which was our limitation to use for detector

By measuring capacitance, we find that full depletion is achieved at under the half of breakdown voltage, so we concluded it can be operated for ALICE E-FoCal

GR structure study using test pattern



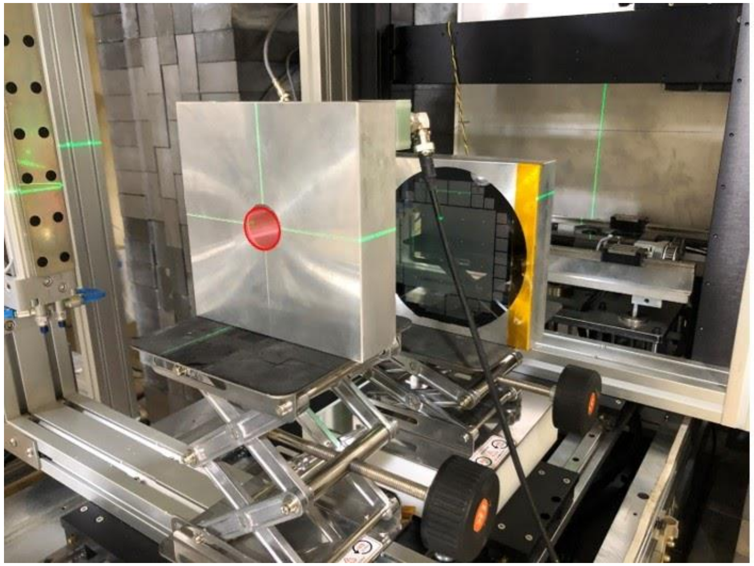


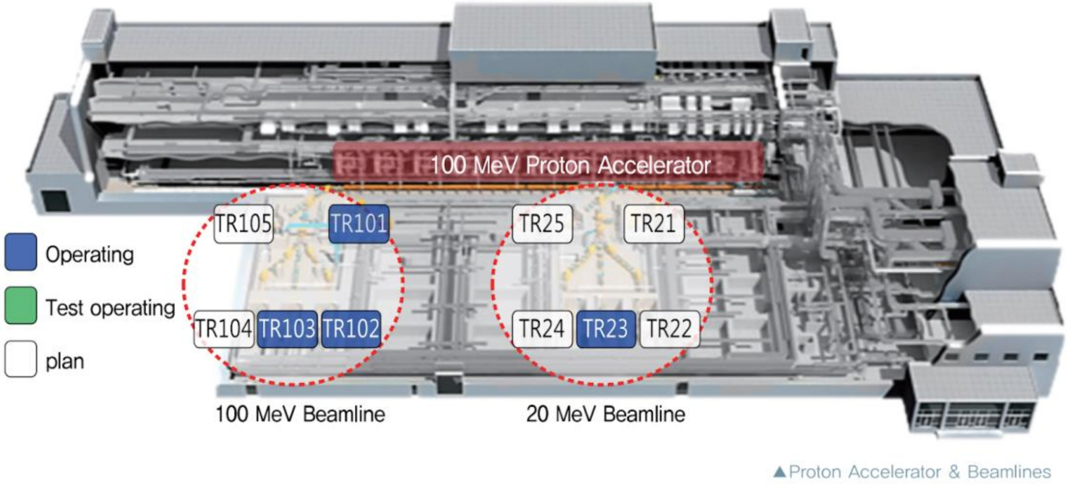
Give some variances at GR

structures using test pattern

GR numbers, width, rounding.. etc

Radiation test





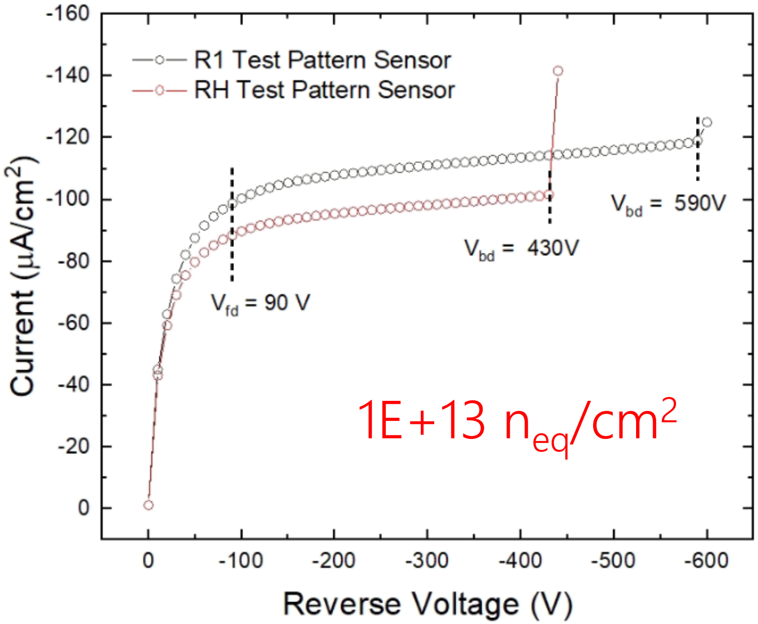
In order to study radiation hardness issues, we perform experiments at KOMAC.

We use two beam line to do research about type-inversion

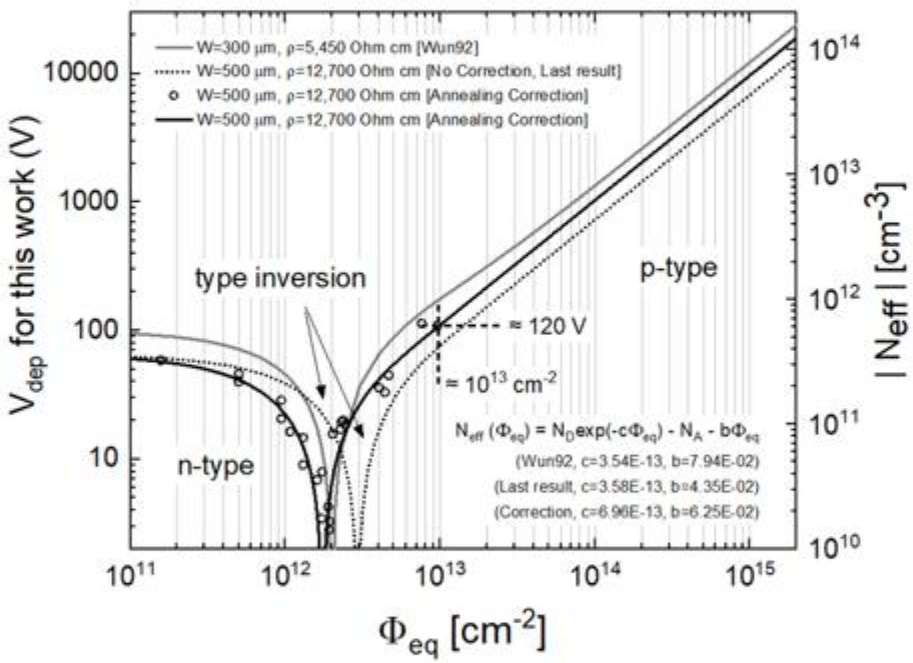
and leakage current variations due to irradiation

Radiation test

IV Plot



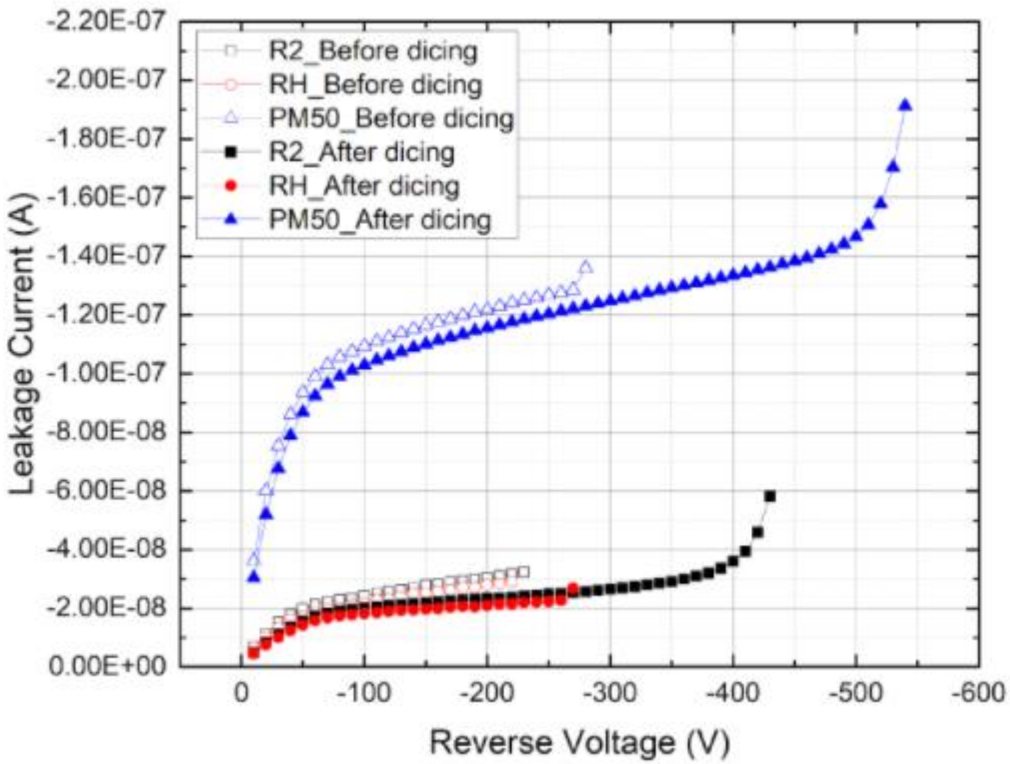
A2 Wafer

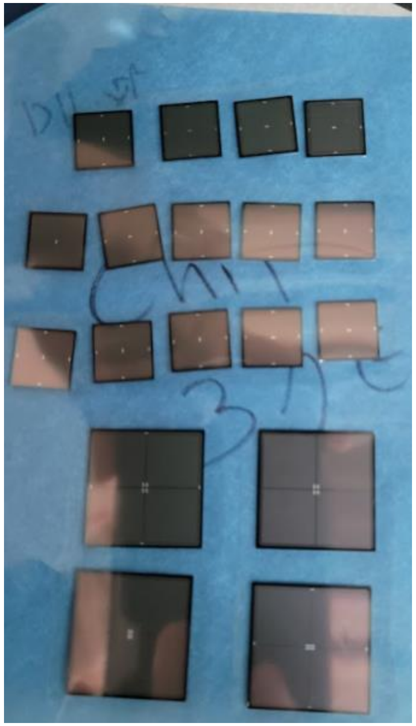


Proton flux injected was choosed by ALICE FoCal radiation criteria

We check type inversion and increased leakage current

Dicing study

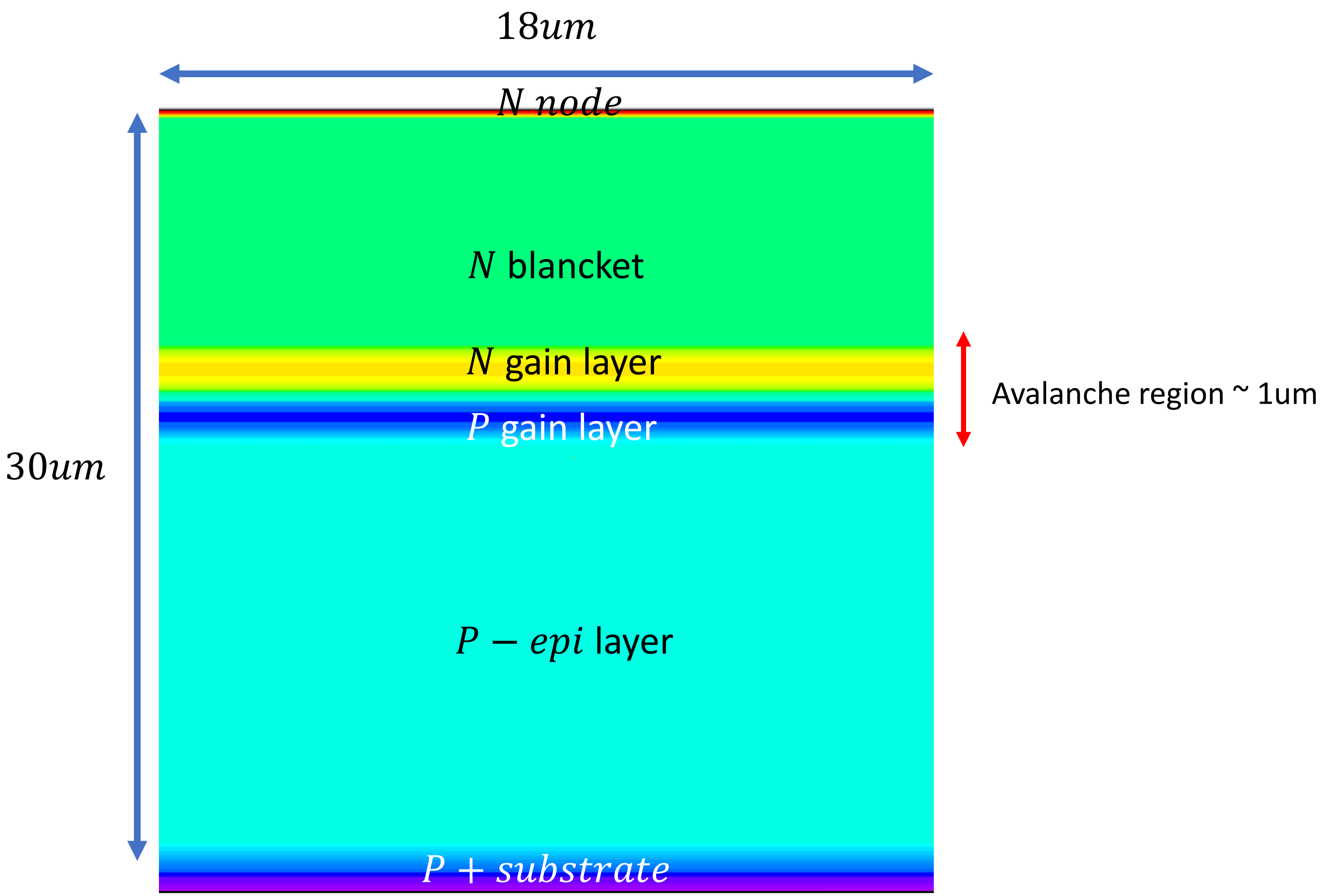




Dicing improved leakage current of sensor

APD structure into the pixels for the LS3 upgrade

Considered APD structure



Considered technology of ‘Epitaxial growth’

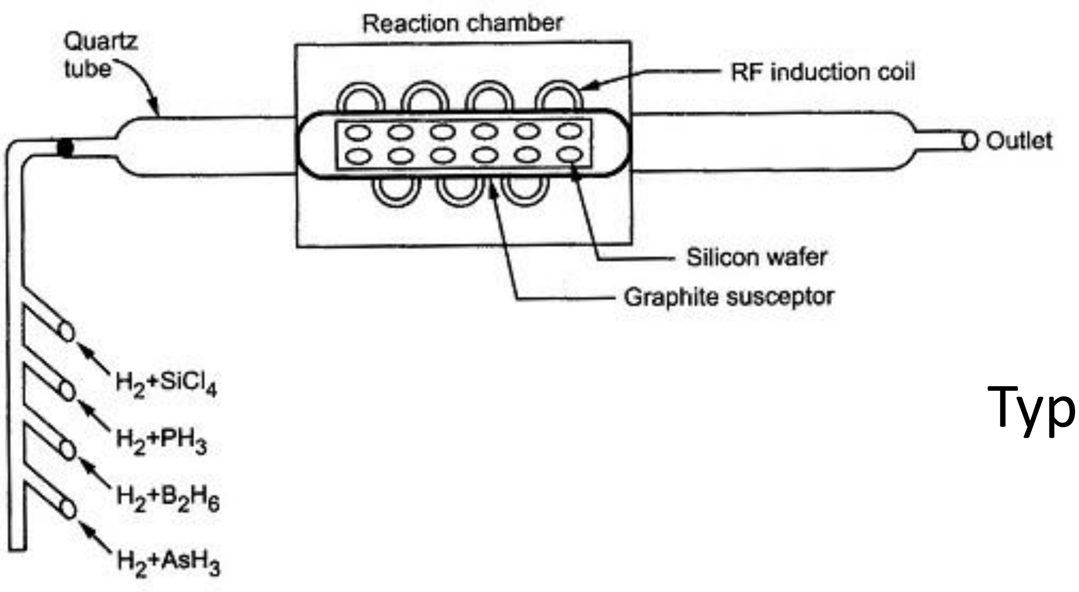


Fig. 1.3 Schematic representation of vapour phase epitaxy process

Typical growth rate: 1 $\mu m/hour$

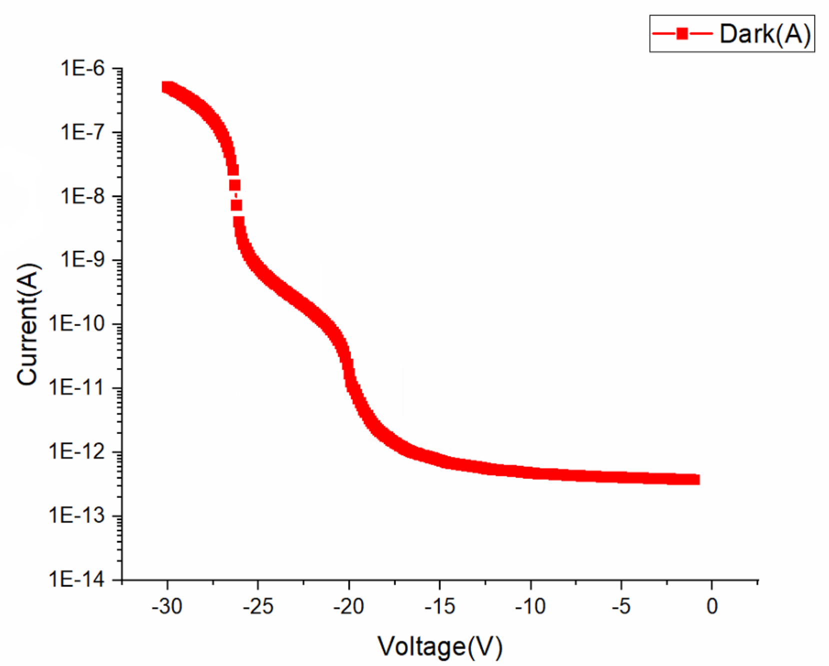
Dopant: P, As, B

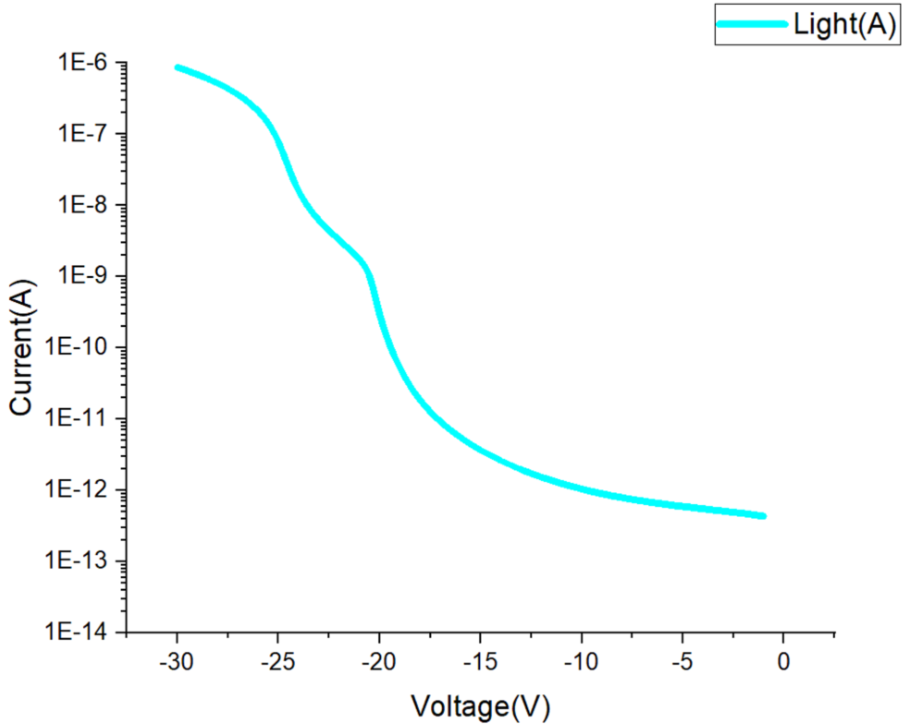
$0.01 - 1200\ \Omega \cdot cm$ ($N_D = 10^{18} - 10^{13} cm^{-3}$) with thickness $1 - 150\ \mu m$

Claim for commercial service:

https://svmi.com/service/epitaxial-wafer-service/

Key features of design





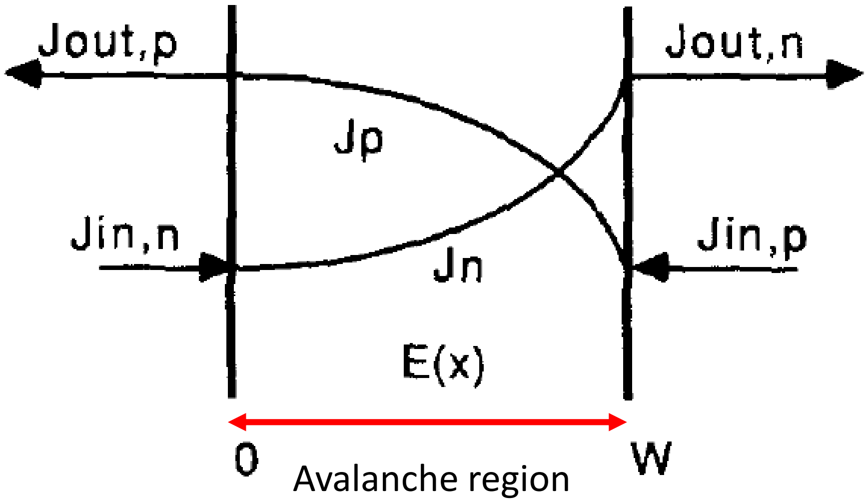
As a reverse bias is applied to P sub, avalanche PN junction region start to be depleted

Full depletion is achieved at 23V with gain of near 93 and we have margin about 3V

As shown at Dark current feature, Light current characteristic follow avalanche behavior due to depletion at junction

Hands estimation of APD gain

REF: IMPACT IONIZATION IN SILICON: A REVIEW AND UPDATE W. MAES, K. DE MEYER* and R. VAN OVERSTRAETEN IMEC vzw, Kapeldreef 75, 3030 Hevedee, Belgium Solid-State Electronics Vol. 33, No. 6, pp. 705-718, 1990



$$\nabla J_{n,p} = \pm q(G_{n,p} - R_{n,p})$$

$$M_{n,p} = \frac{J_{out\ n,p}}{J_{in\ n,p}}$$

$$M_n = \frac{1}{1 - \int_0^W \alpha_n \exp\left(-\int_0^x (\alpha_n - \alpha_p)dx'\right) dx}$$

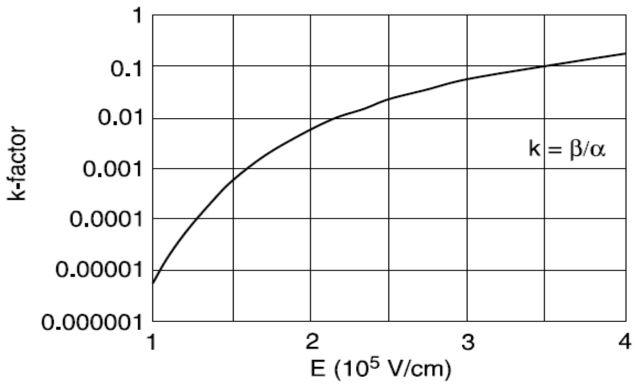


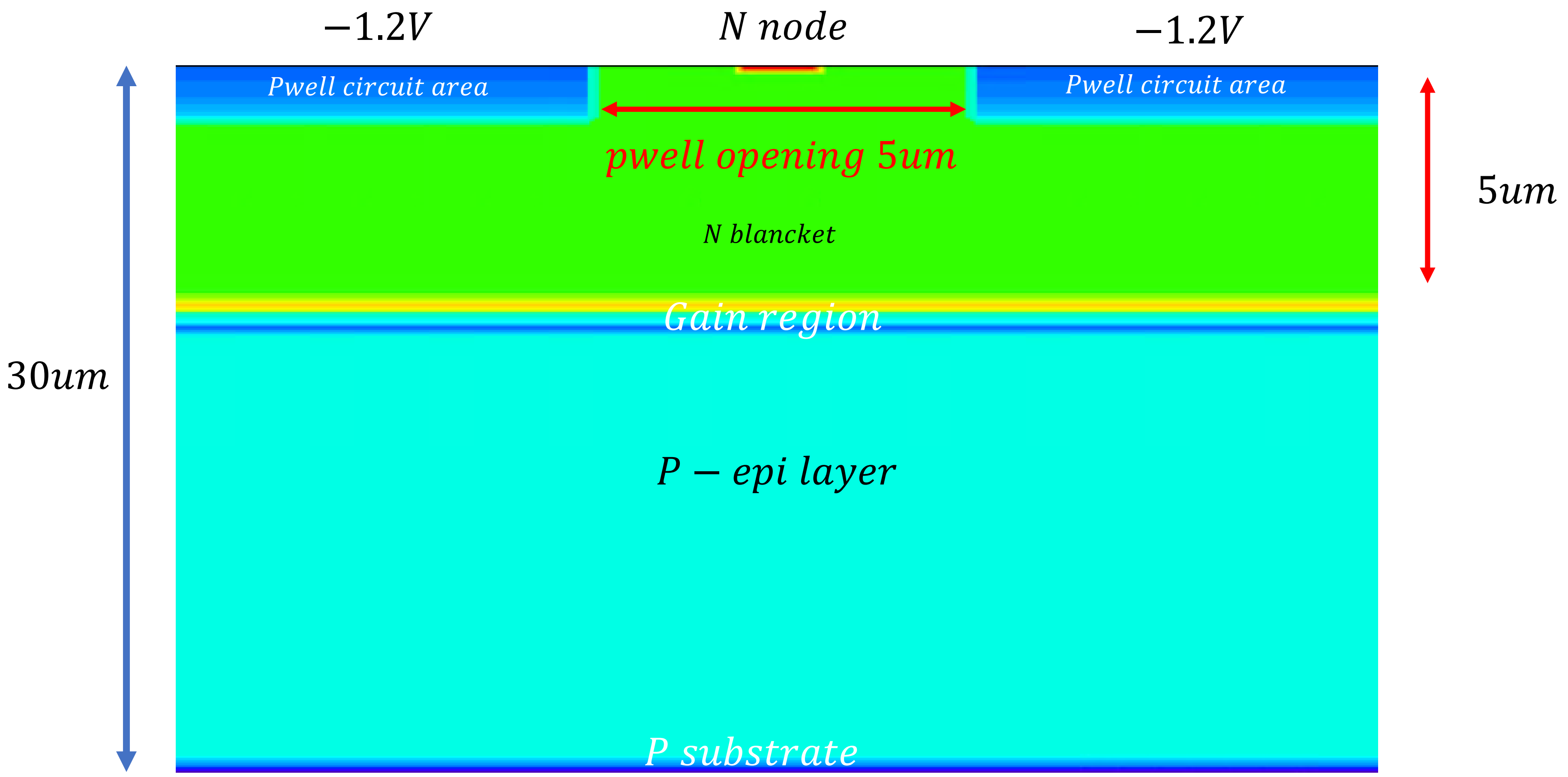
Fig. 3. Ratio of ionisation coefficients (k-factor) as a function of electric field (after Ref. 2).

Use k-factor (ratio between electron and hole ionization coefficients) to estimate formula

$$M_n = \frac{1}{1 - \int_0^W \alpha_n \exp\left(-\int_0^x (\alpha_n - \alpha_p)dx'\right) dx}$$

$$\approx \frac{k-1}{k - \exp\left((k-1)\int_0^W \alpha_n dx'\right)} = M_n(N_{a0}, c_a)$$

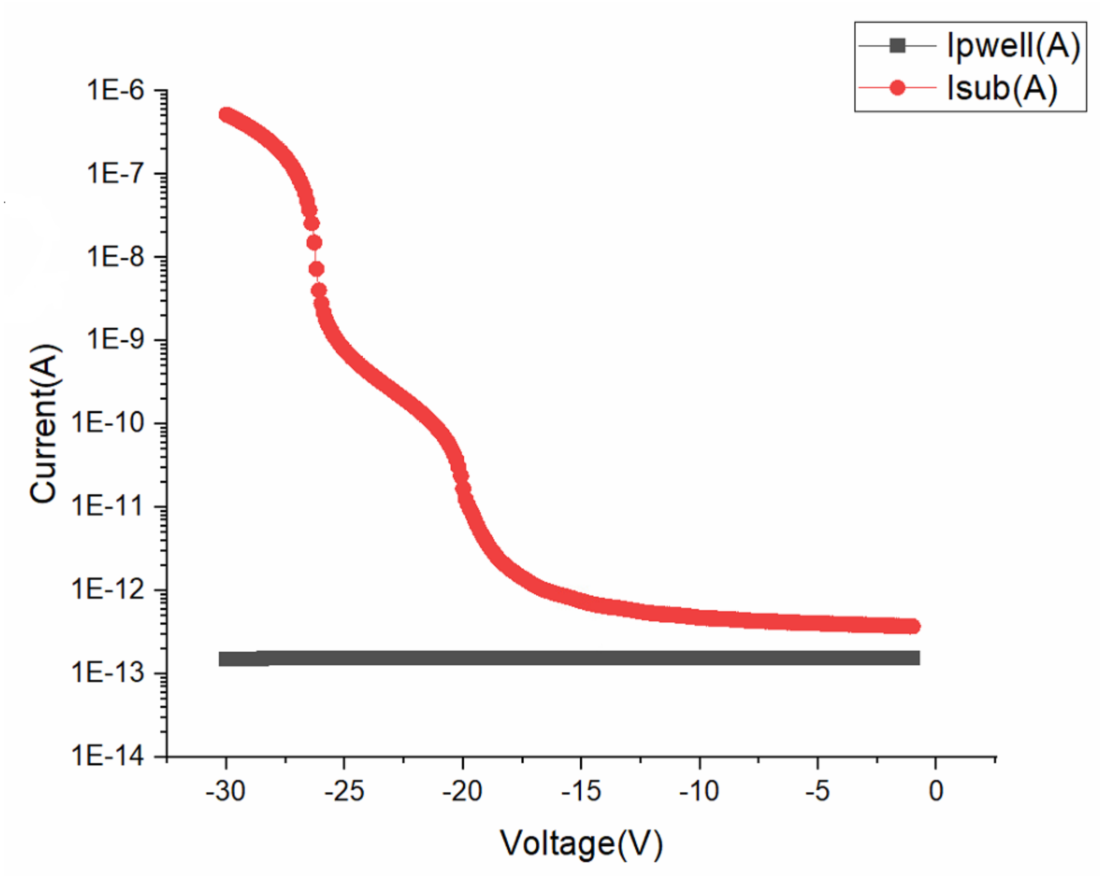
APD into the pixel



Insert previous APD structure into ALPIDE pixel

Reverse bias of 1.2V is applied at each deep P-well region

Key features persist!



There were no big differences at current feature when we implant APD structure into the ALPIDE pixel structure

No punch through until system breakdown occur

Summary

- **As a plan, We processed submission and check characteristics of sensor**
  - ✓ Sensor's characteristic was concluded enough to be used for ALICE E-FoCal
  - ✓ Guardring structure study through test pattern
  - ✓ Radiation hardness test was processed
- **APD structure study using Tcad was processed**
  - ✓ Inserting APD structure into the pixel doesn't make change at avalanche behavior

Thank you for attention