Evaluation of lateral depletion in the edge region and evaluation of punch-through-protection in the strip ends before and after irradiation

S. Mitsui, Y. Unno (Sokendai/KEK), Y. Ikegami, Y. Takubo, S. Terada (KEK), K. Hara, Y. Takahashi (Univ. Tsukuba), O. Jinnouchi, R. Nagai, T. Kishida (Tokyo Inst. Tech.), K. Yorita (Waseda Univ.), K. Hanagaki (Osaka Univ.), R. Takashima (Kyoto Univ. Edu.), S. Kamada, A. Ishida, K. Yamamura (Hamamatsu K.K.)

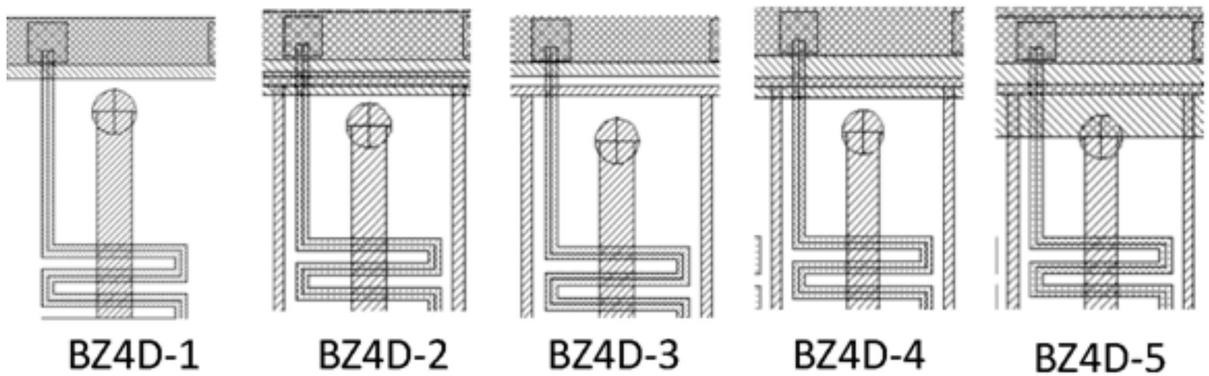
Proton irradiation

- Irradiation
  - 70 GeV protons irradiated at CYRIC
  - 5.7e12, 1.1e13, 1.2e14, 1.2e15 n_{eq}/cm^2
- Samples
  - fabricated by Hamamatsu K.K.
  - Punch Trough Protection
    - miniature strip sensor (1cm x 1cm)
  - Slim Edge
    - diode (4mm x 4mm)
  - Multi Guard
    - diode (4mm x 4mm)

New Punch Through Protection

Samples

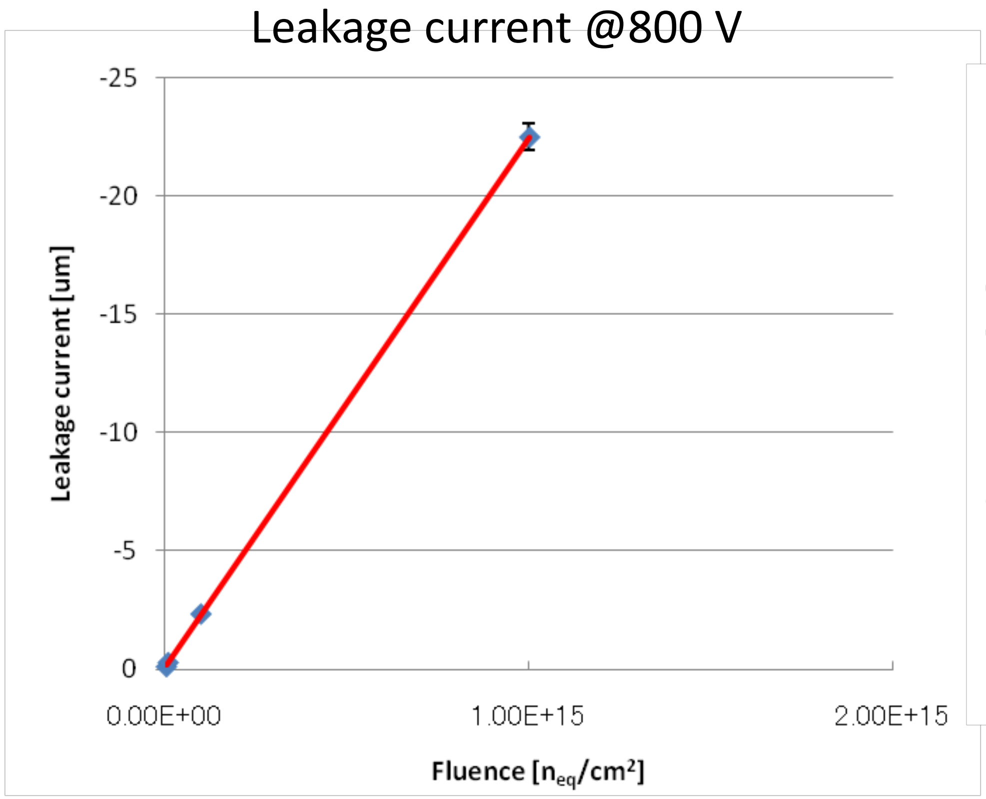
- p-sub (W11,W12,W13,W14)
- Bias ring Al extension
- BZ4D
  - 1: No p-stop
  - 2: Up to p-stop
  - 3: No extension
  - 4: Over p-stop
  - 5: Full extension

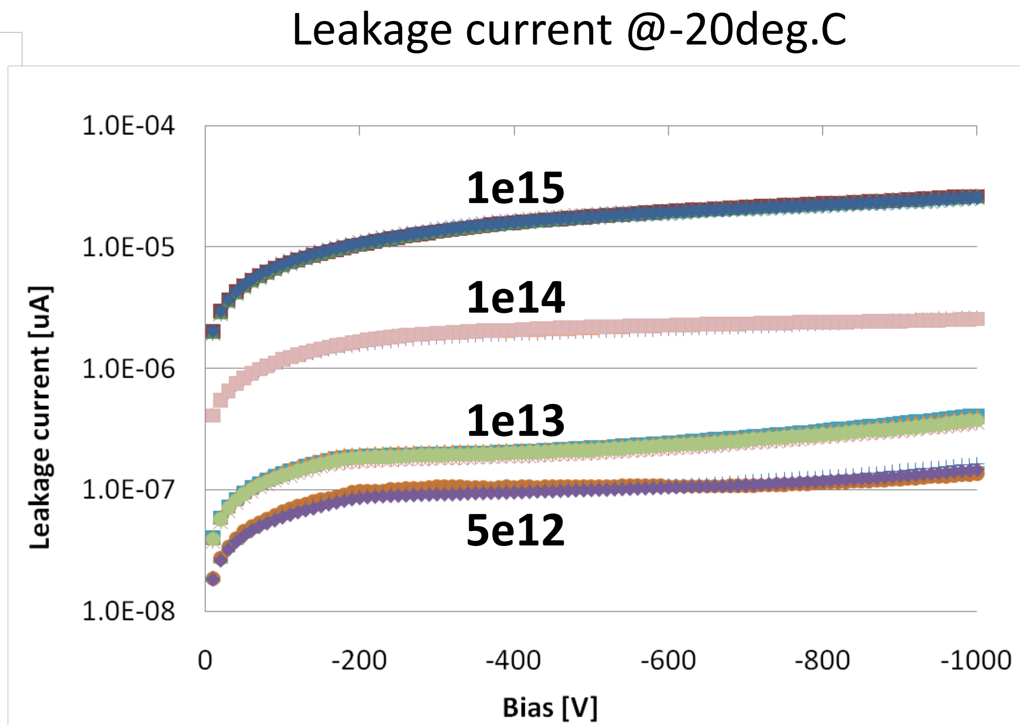


Measurement

- before annealing (after anneal is preliminary), temperature at -20deg.C
- IV measurement
  - measure the leakage current
- CV measurement
  - measure the body capacitance
  - evaluate the Full Depletion Voltage
- PTP measurement
  - measure the resistance applying voltage between bias ring and DC pad (strip implant)
  - Vbias = -300 V constant

Leakage current





$$\Delta I = \alpha \times \Phi \times V$$

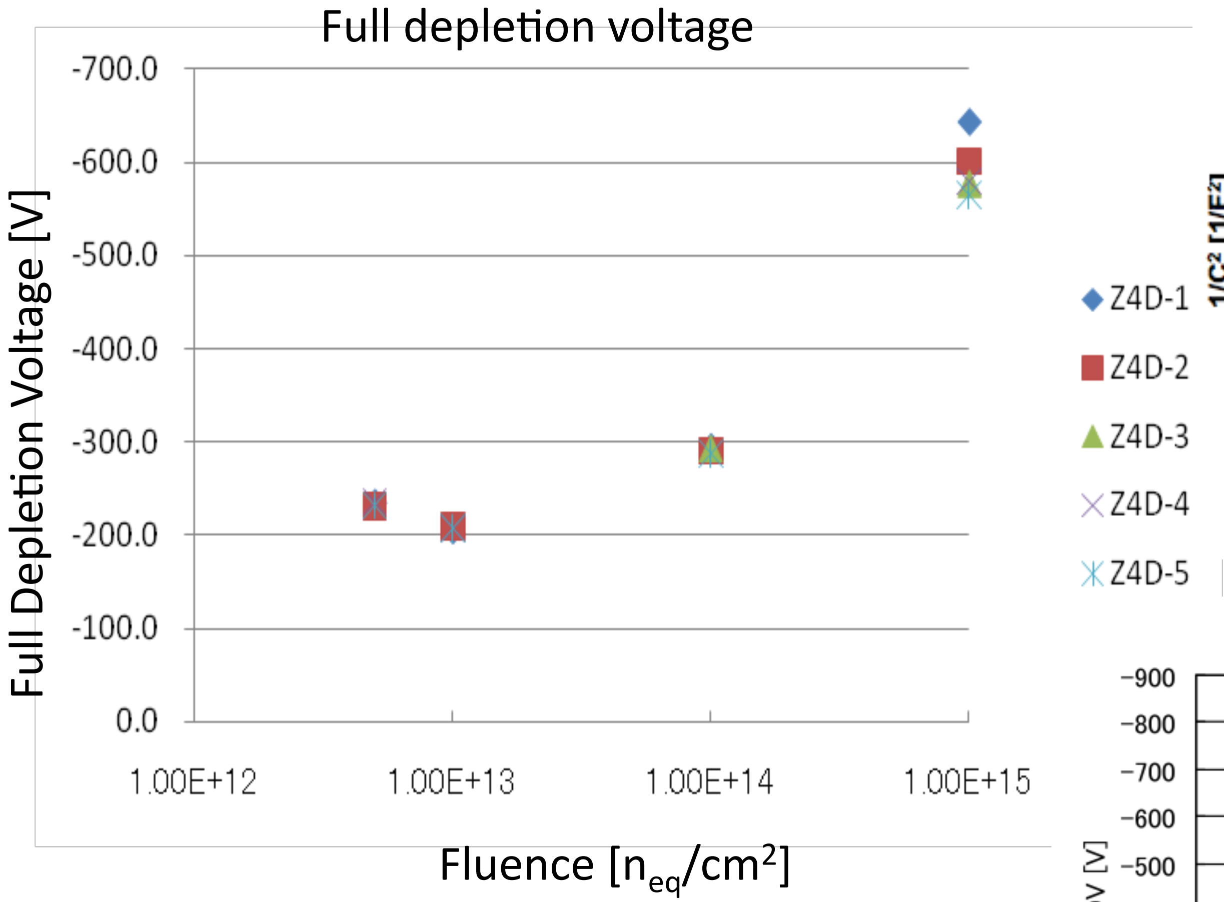
No onset of microdischarge up to 1000 V

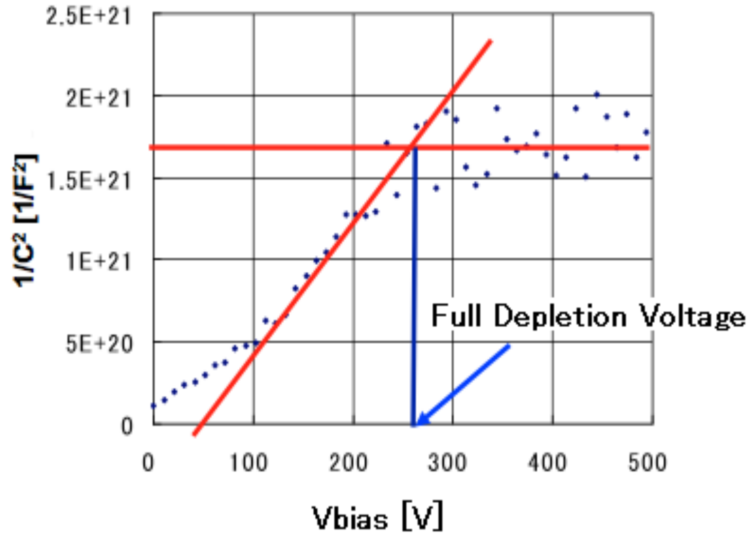
⊿I = current, α = damage constant, Φ = fluence, V = sample volume

damage constant = 4.1 x 10^{-17} A/m

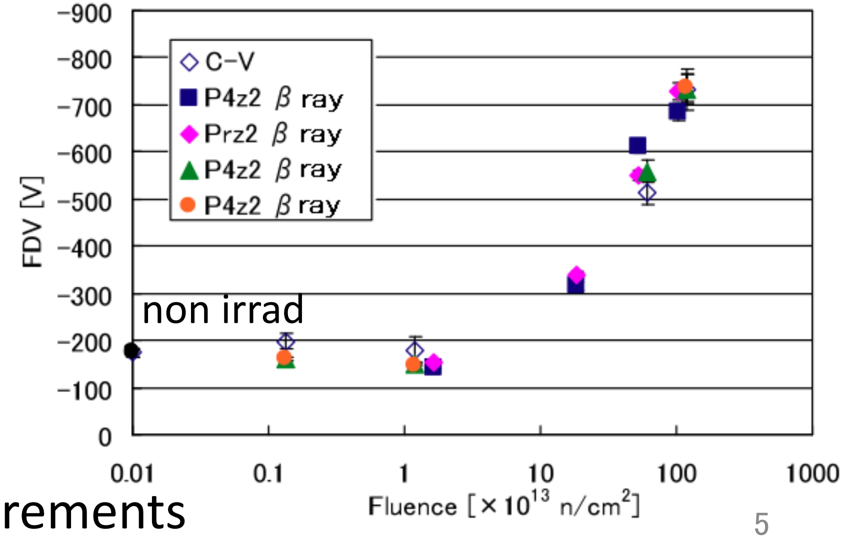
=>consistent with known value 3.99 x 10^{-17} A/m

Full Depletion Voltage



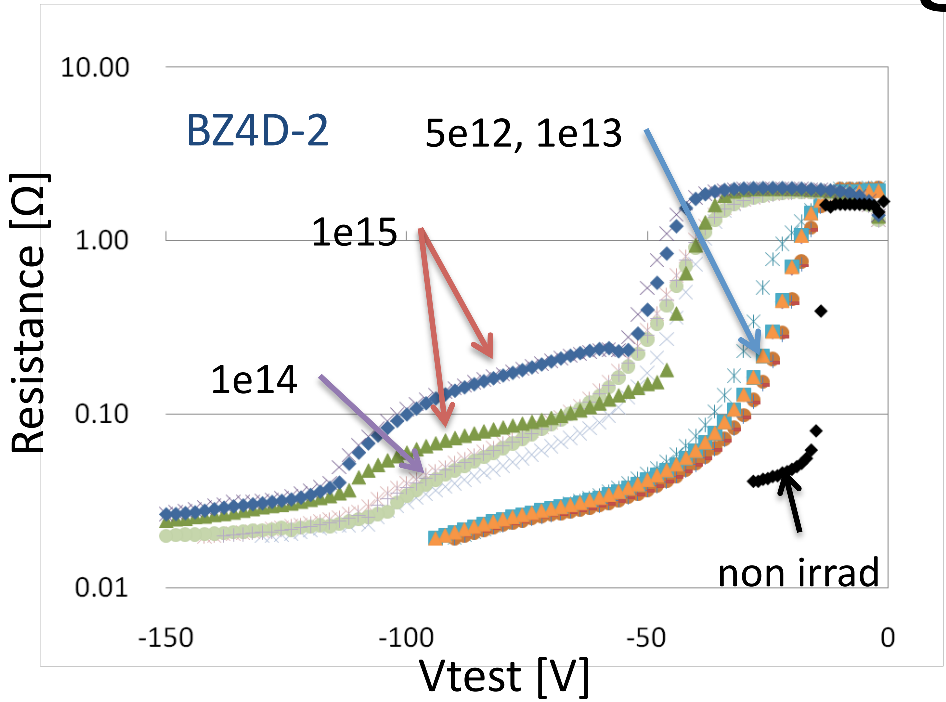


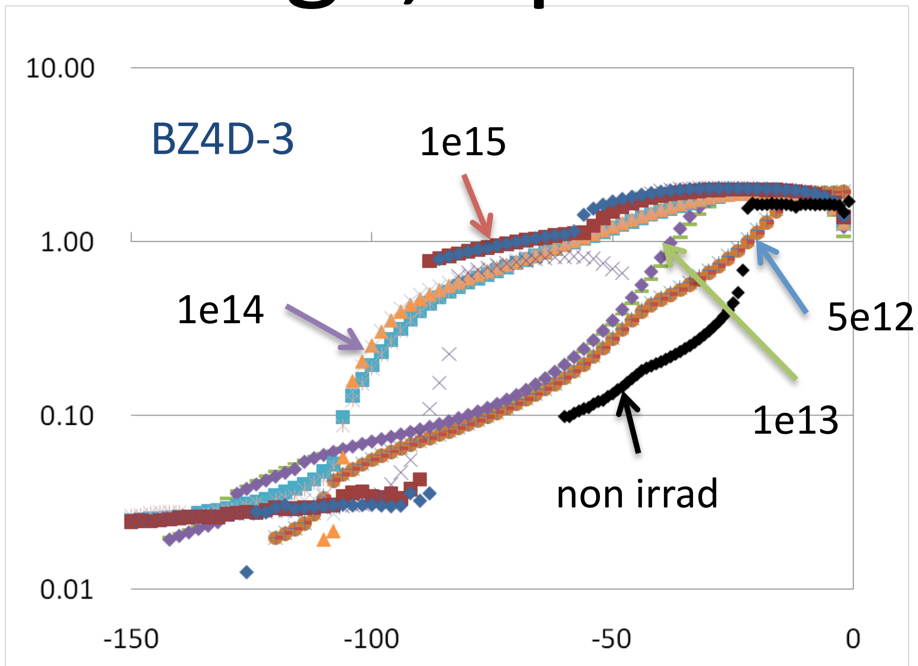
Previous measurements

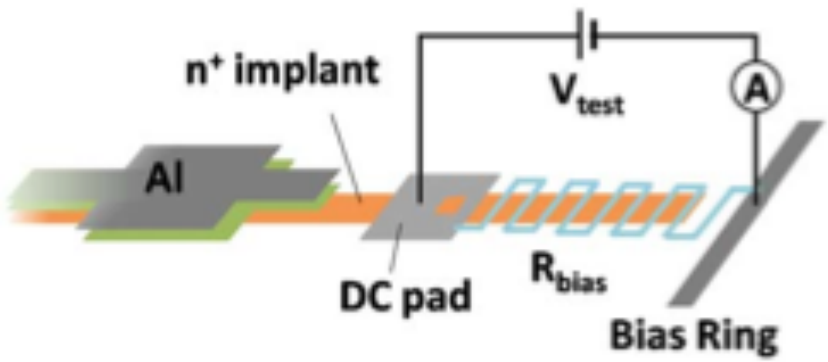


- $1/C^2$ is linearly dependent on Vbias
  after full depletion, $1/C^2$ is constant
- FDV reach -600 V at 10^{15} n/cm^2
  =>FDV is consistent with previous measurements

Punch Through Voltage, Vpt



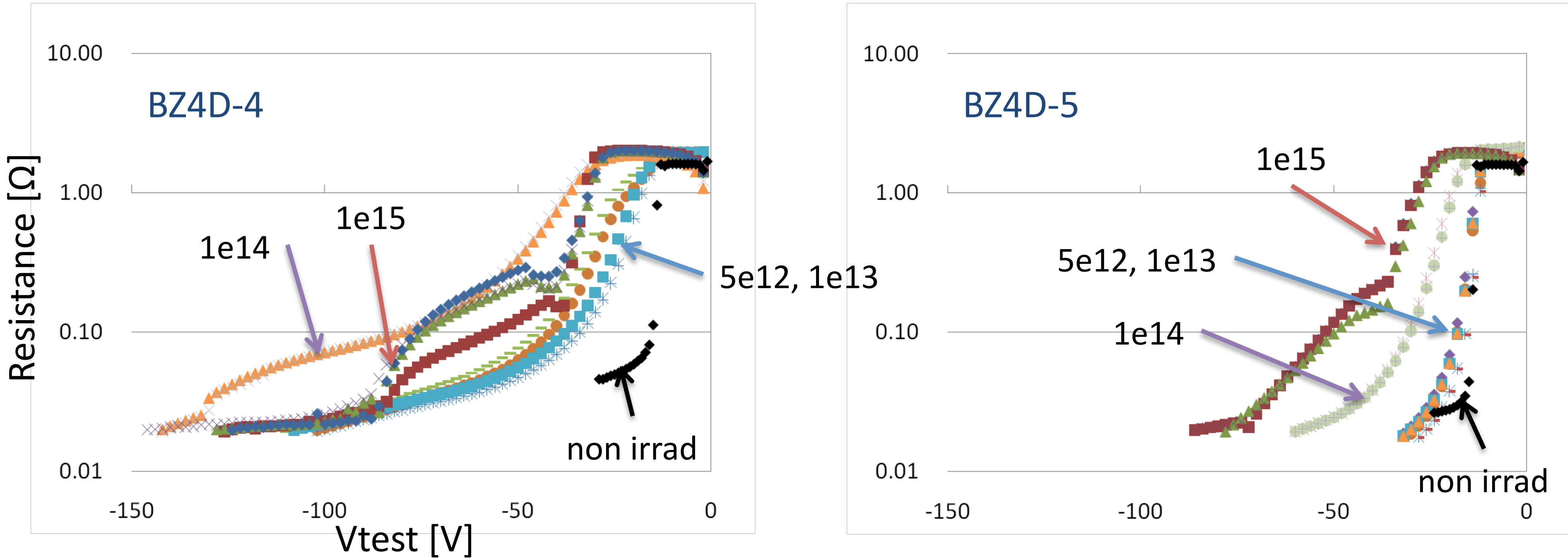




- Apply Vtest up to -150 V
- measure resistance between bias ring and DC pad

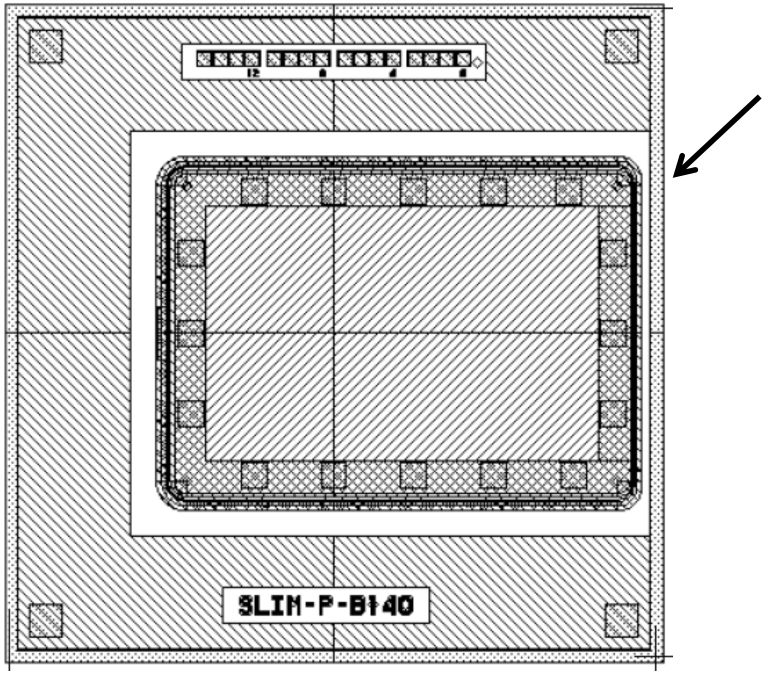
- Onset voltage, Vpt, increases as fluence increases
- BZ4D-2 is better than -3 caused by extended Al
    - Lower Vpt
    - Sharper cutoff
    - Lower saturation resistance

Punch Through Voltage



- Punch through voltage depend on Al extension
- BZ4D-5 is the best amongst the types
  - Saturation Vpt < 100 V and resistance ≤ 20 kΩ
    - ~5 mA! per strip (≡ ~10 kMIPS/25ns/strip)
  - It would protect the AC coupling insulator of breakdown ~120-150 V

Slim Edge Study



- Only in one side, the distance-to-edge is varied from 80 to 1000 μm
- Our goal is to deduce the required width for operating the silicon sensor up to 1000 V

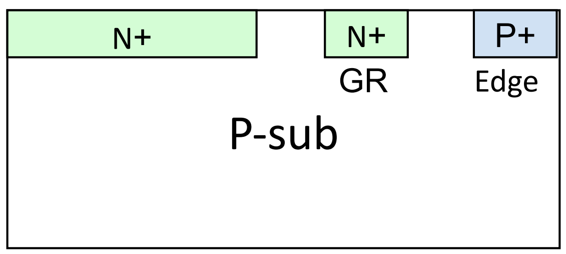
Samples

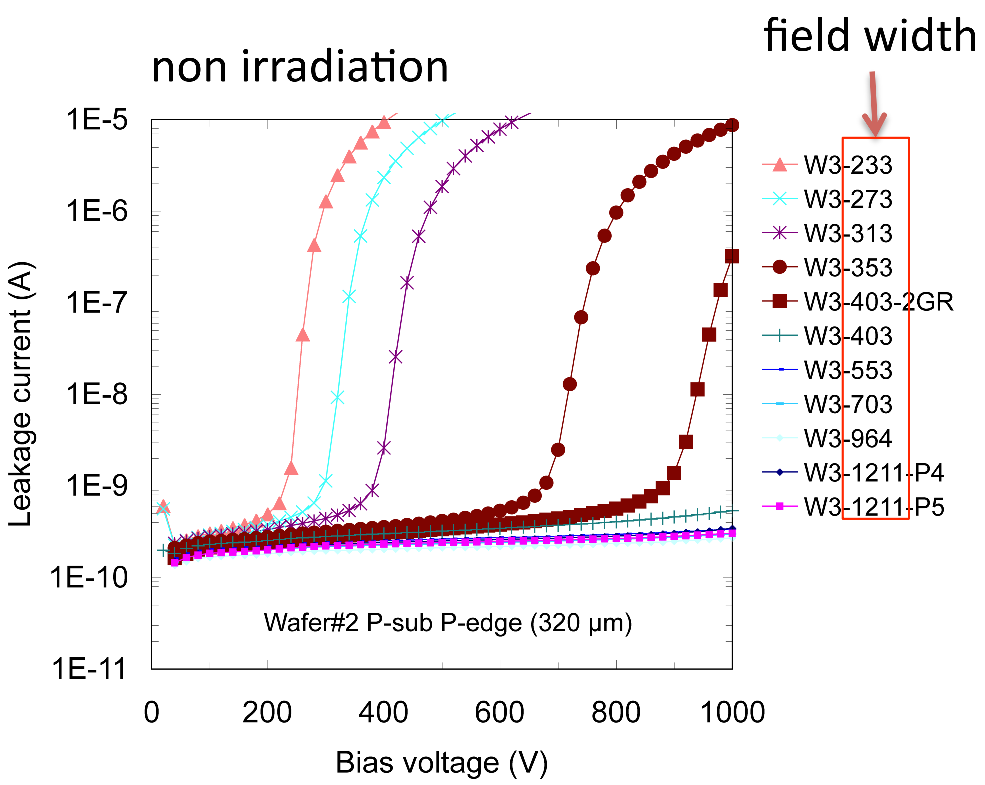
- p-sub : preliminary
- n-sub : 320 and 200 μm thickness, p-edge or n-edge
- Fluence : 5.7e12, 1.1e13, 1.2e14 n/cm^2
- Annealed: at 60deg.C for 80min

- "Field width" is the width without implantation between the edge implant and the bias ring implant
  – 34, 64, 94, 124, 214, 244, 334, 374, 534, 574 μm

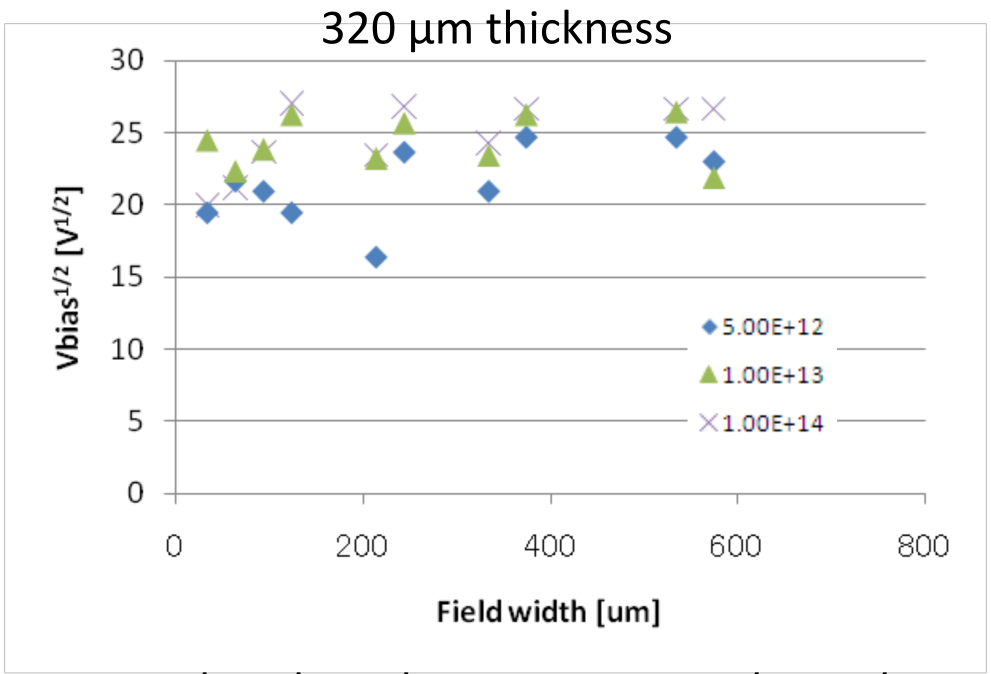
Slim Edge Study – Lateral Depletion

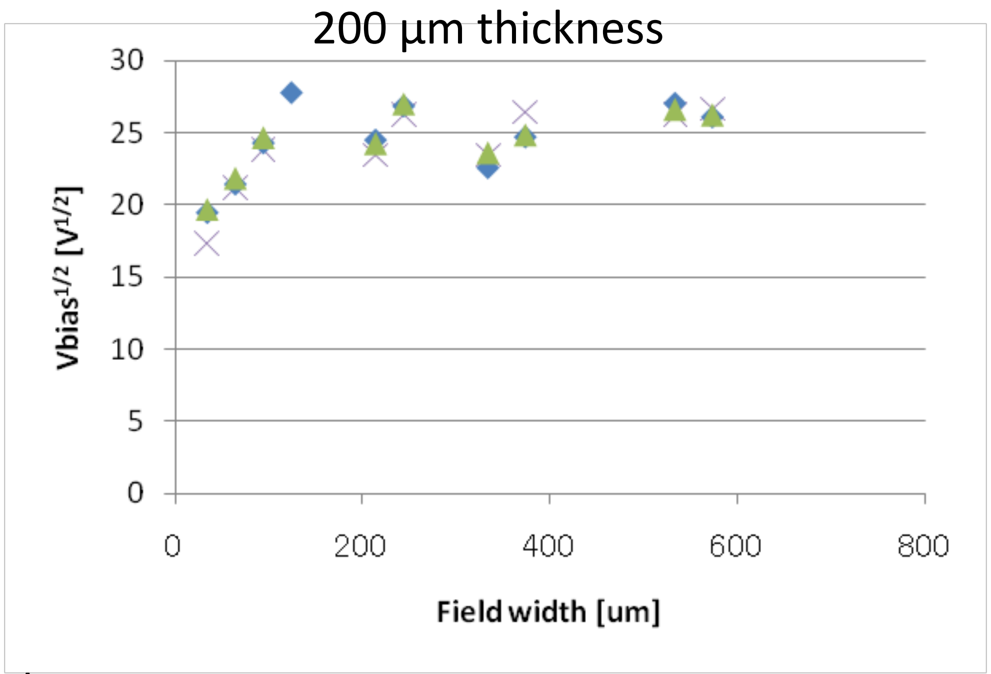
- Evaluating the relation between the edge space and the bias voltage to hold
  - Lateral depletion along the surface
- onset of microdischarge increase as field width is wide



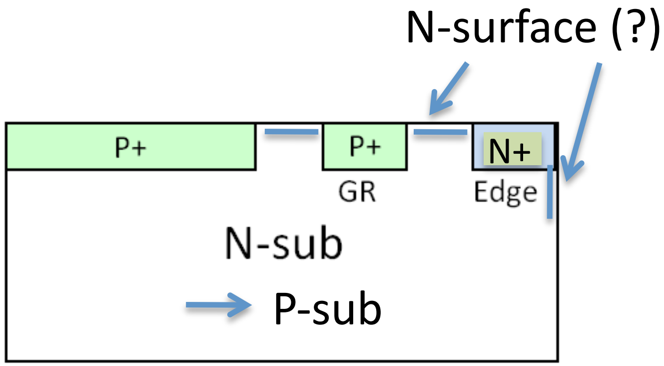


Slim edge N-sub N-edge



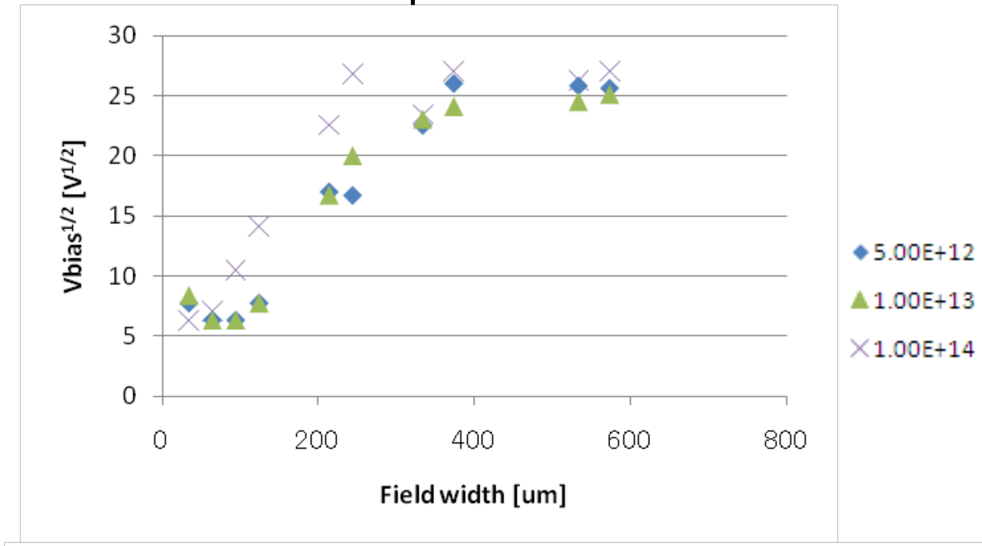


- Note that the substrate type may have changed to p-type by irradiation over 10^{14} n/cm^2
- No difference in the fluences
  - Surface is N-type even with 1e14 …
  - Thus, no p-n junction at the edge
- All show good bias voltage tolerance
  - Too good for the study
  - Although the onset voltages were all ~600 V

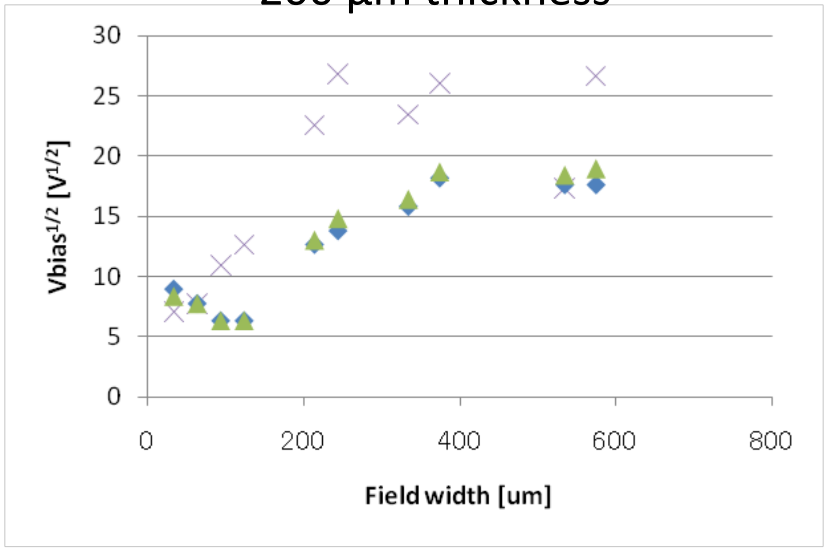


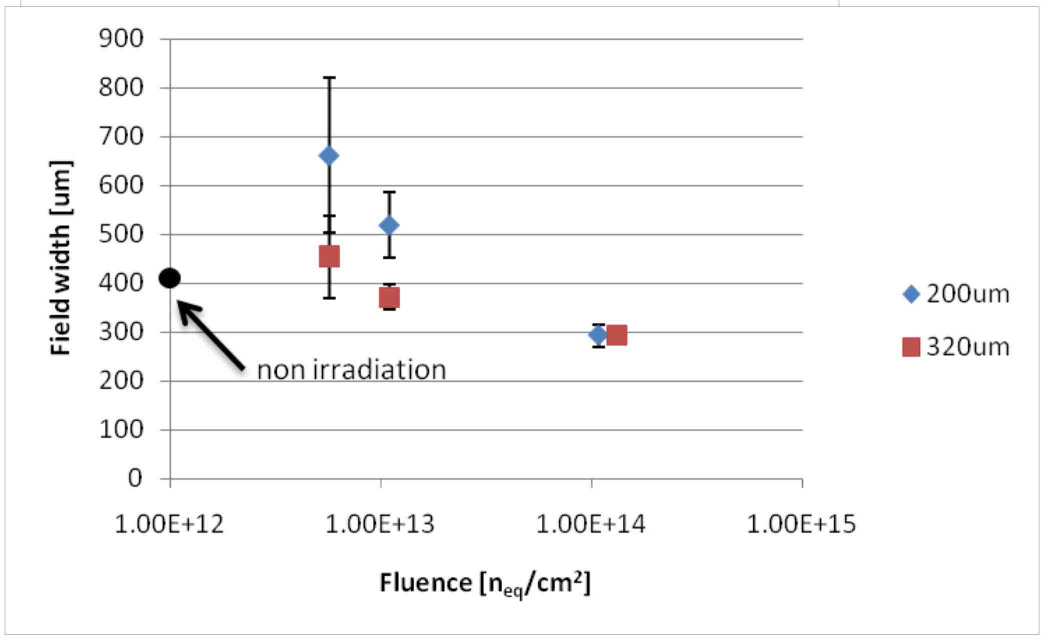
Slim edge N-sub P-edge

320 μm thickness



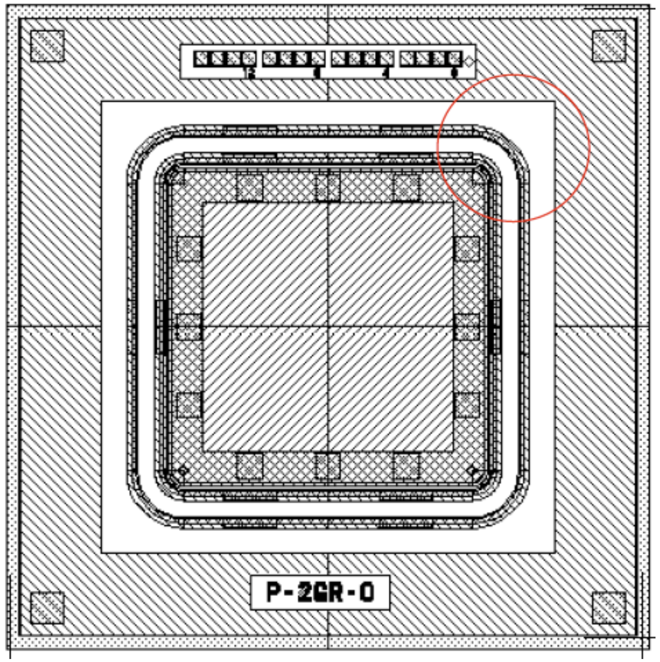
200 μm thickness

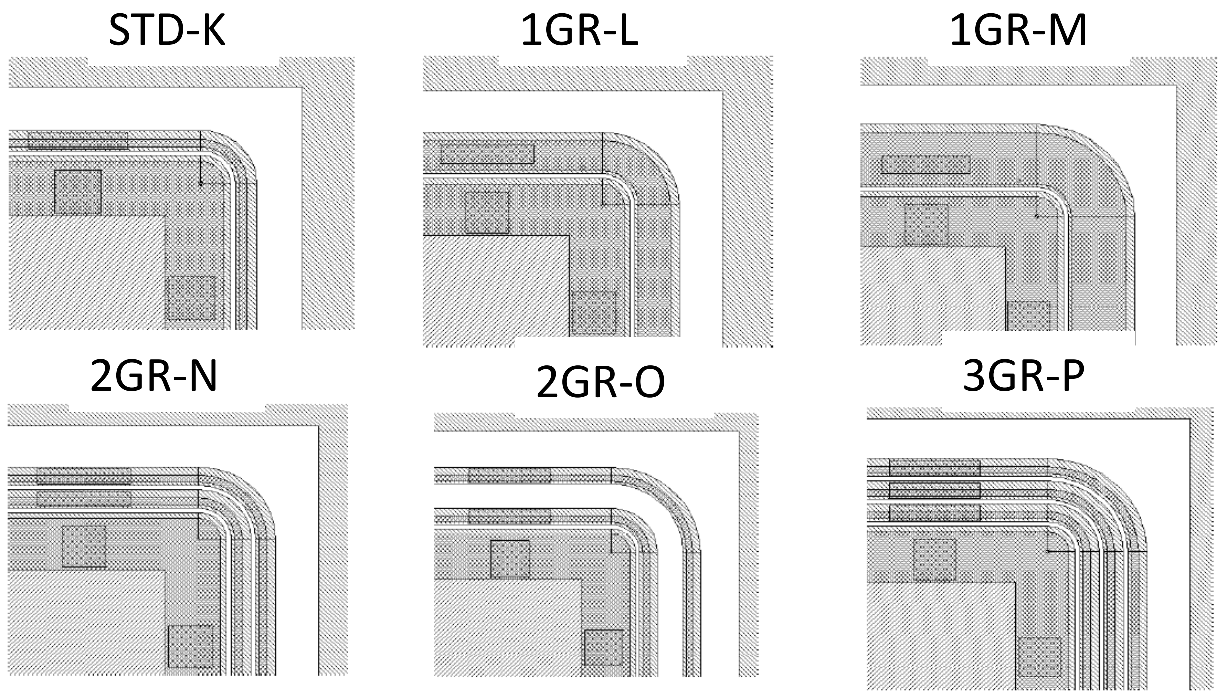




- The substrate type changes to p-type by irradiation over 10^{14} n/cm^2
  - Surface is still N-type
  - p-n junction at the edge
- Onset voltages were ~600 V or lower
  - then, extrapolate to 1000 V
- The field width holding 1000 V (?)
  => ~400 μm

Multi guard study



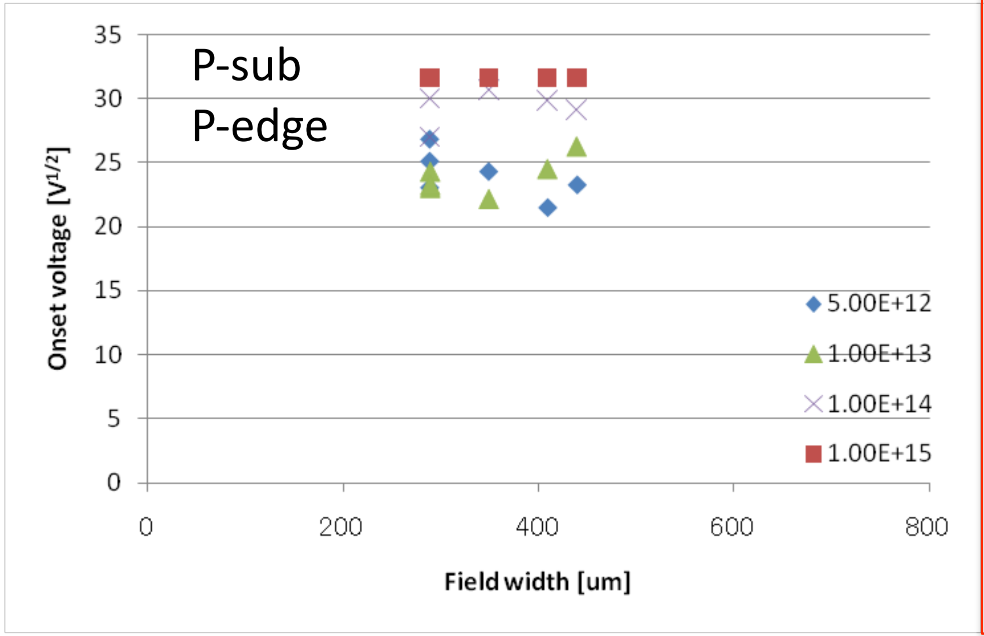


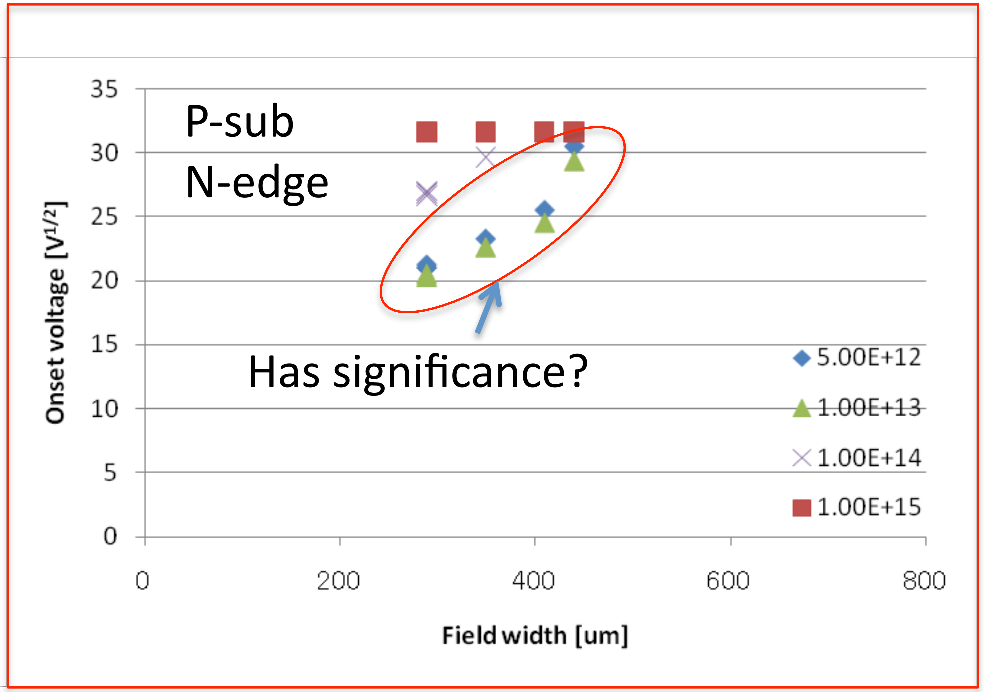
- In order to investigate whether the number of guard rings will help to reduce the edge distance

Samples

- Field width :
  - STD-K = 1GR-L = 1GR-M (289 μm), 2GR-N (349 μm), 3GR-P (409 μm), 2GR-O (439 μm)
  - Watch the number of guard rings in the sequence of “Field width”
- p-sub : 320 μm thickness, p-edge/n-edge
- n-sub : 320 and 200 μm thickness, p-edge/n-edge
- Fluence : 5.7e12, 1.1e13, 1.2e14, 1e15 n/cm^2, Annealed at 60deg.C for 80 min.

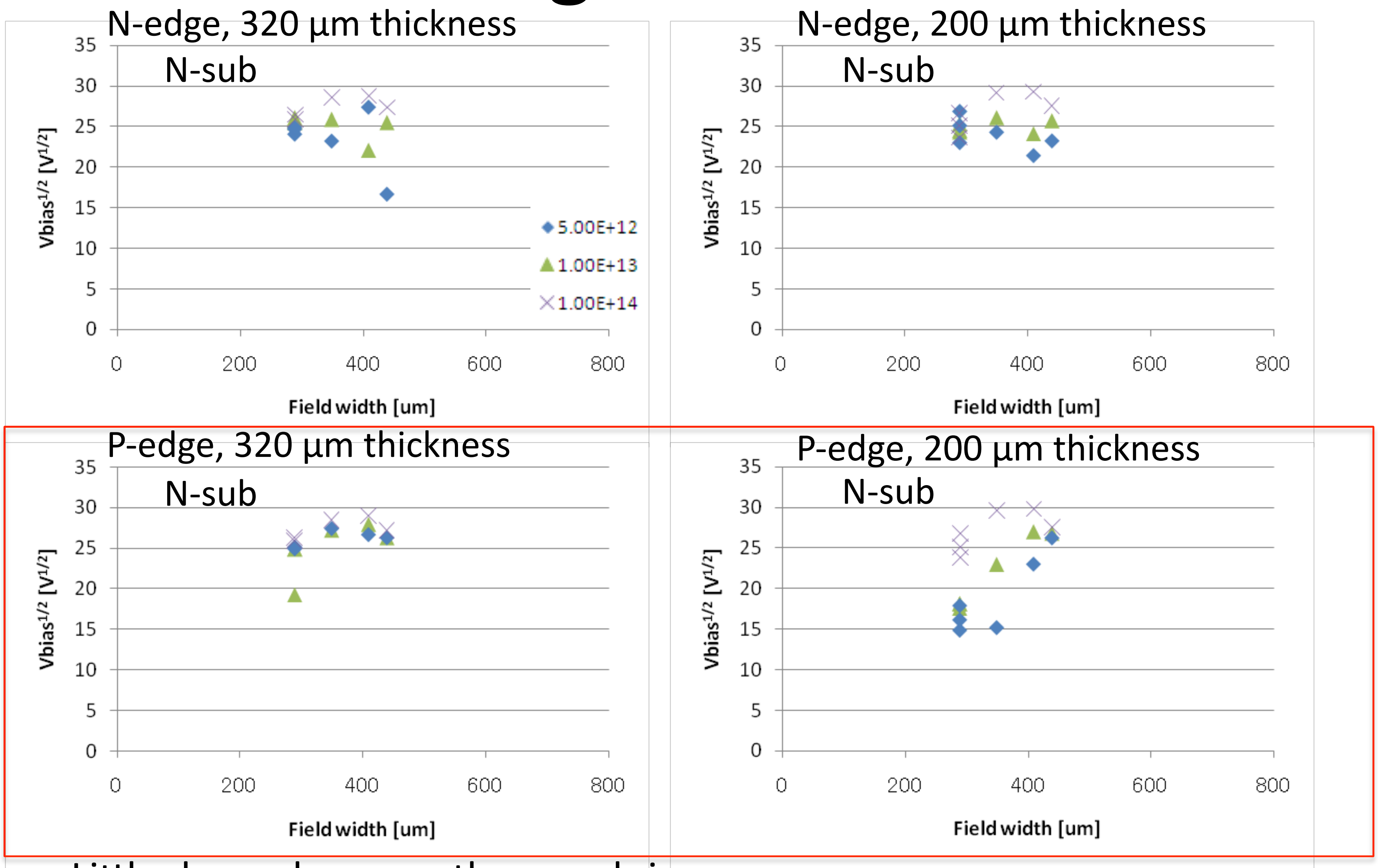
Multi guard P-sub 320µm thickness





- Evaluation of the onset voltages of microdischarge by IV measurement
- The onset voltage increases as the fluence increases
  - irrespectively of the variation of the guard rings
- P-sub/P-edge: insensitive, and the onset voltage of microdischarge is little different on the number of guard rings
- P-sub/N-edge: sensitive to the reach of the depletion to the edge
  - 3 guard rings is no better than 2 guard rings

Multi guard N-sub



- Little dependence on the guard rings
- Thinner may require wider field width

Summary

- PTP
  - BZ4D-5 (with full coverage) is the best among the samples, has potentiality to protect the AC coupling insulator, even after irradiation to 1×10^{15} n_{eq}/cm^2
- Slim edge
  - N-sub/N-edge is still insensitive to the reach of the depletion after 1×10^{14} n_{eq}/cm^2
  - N-sub or P-sub may require ≥ 400 µm field width to hold 1000 V
  - Thinner may require wider width
- Multi guard
  - Little fundamental difference on the number of guard rings in order to reduce the width of the edge, and the onset voltage of the microdischarge