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Location of bias voltage breakdown in n-in-p silicon segmented sensors with p-stop structure before and after irradiation

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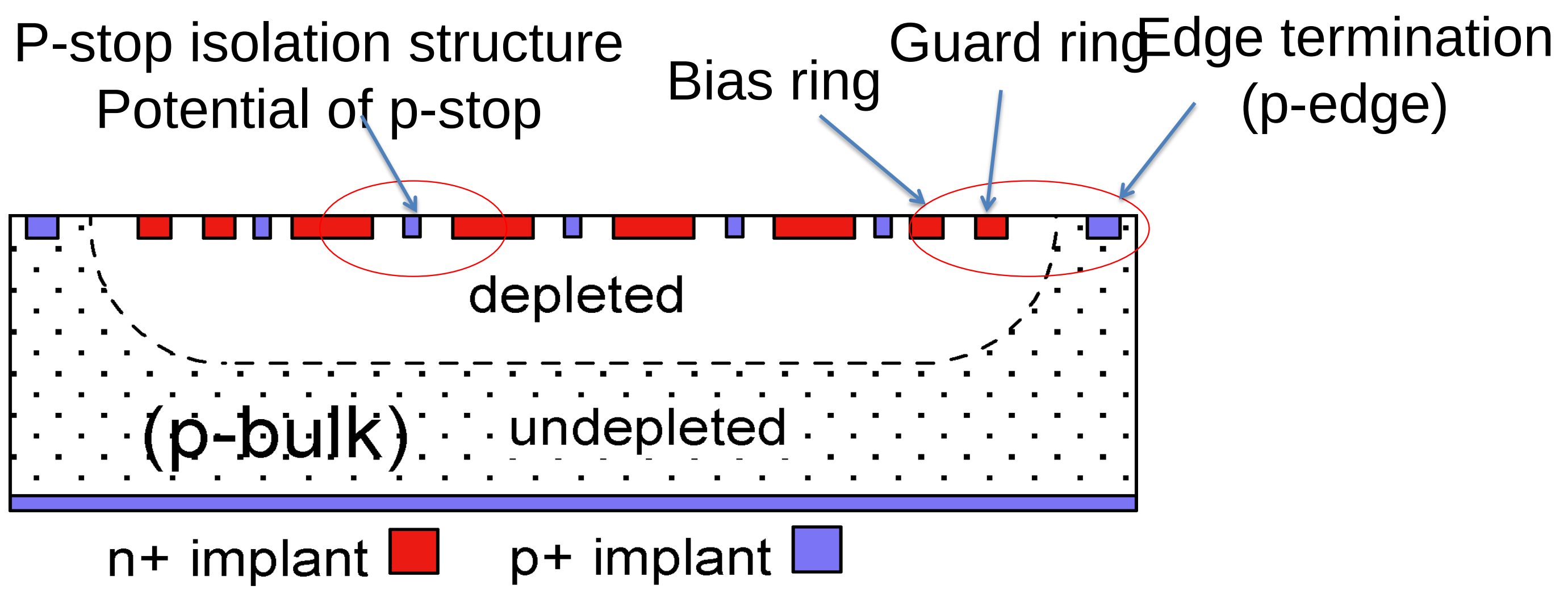
n-in-p Structures and Measurements



- Benefits of the n-in-p sensor
  - p-bulk: no type inversion after irradiation.
  - Mask process is required only in the top surface, thus more cost effective than double-side process.
  - n-side is the p-n junction side, always, and high electric field is anticipated.
- Issues
  - Positive charges are built-in and to build-up with radiation.
  - An isolation structure of n+ implants is required. We adopt the “p-stop” isolation, specifically “common p-stop” structure.
  - Electric field higher than the avalanche breakdown voltage (=electric field strength, ~300 kV/cm in Silicon) leads to the breakdown of bias voltage.
    - Such a breakdown at a local spot, we call “microdischarge (MD)” as the phenomenon appears as the rapid increase of leakage current.
- Location of microdischarge
  - We have identified the location experimentally by using a highly infra-red sensitive camera, so-called “hot-electron camera”.
  - We have analyzed the underlying physics with a technology cad (TCAD) program.

Irradiation

- γ irradiations
  - Y. Takahasi et al., Nucl. Instr. Meth. A699 (2013)107-111
  - 200 Gy/hr, accumulated to 600 Gy
- Proton irradiations
  - S. Mitsui et al., Nucl. Instr. Meth. A699 (2013) 36-40
  - CYRIC, Tohoku Univ.
  - 70 MeV protons from 930AVF Cyclotron
  - Irradiation setup in the 32 course
  - CYRIC exp. no. 9214, e.g.
  - Fluences:
    - 5.2×10^{12}, 1.1×10^{13}, 1.2×10^{14}, 1.2×10^{15} n_{eq}/cm^2

Measurements

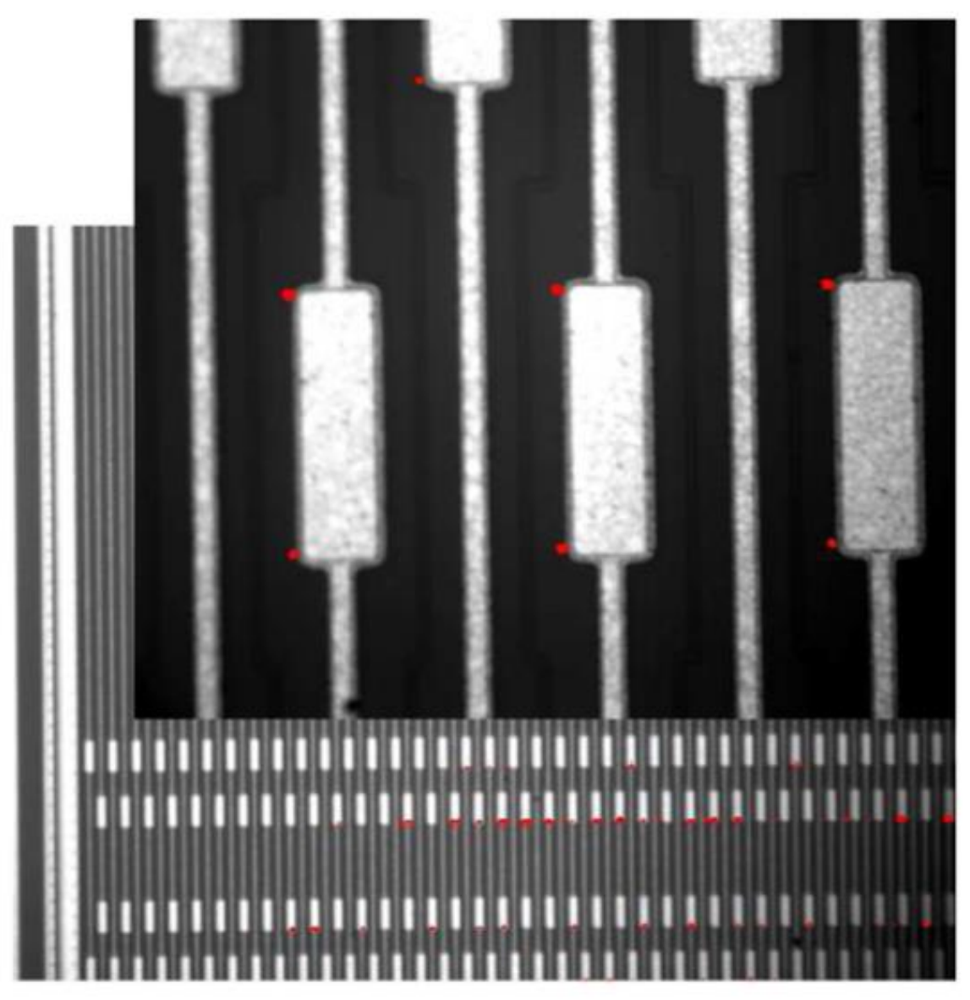


Fig. 9. Hot spots observed at AC pad corners. The AC pad is 60 μm wide and 200 μm long.

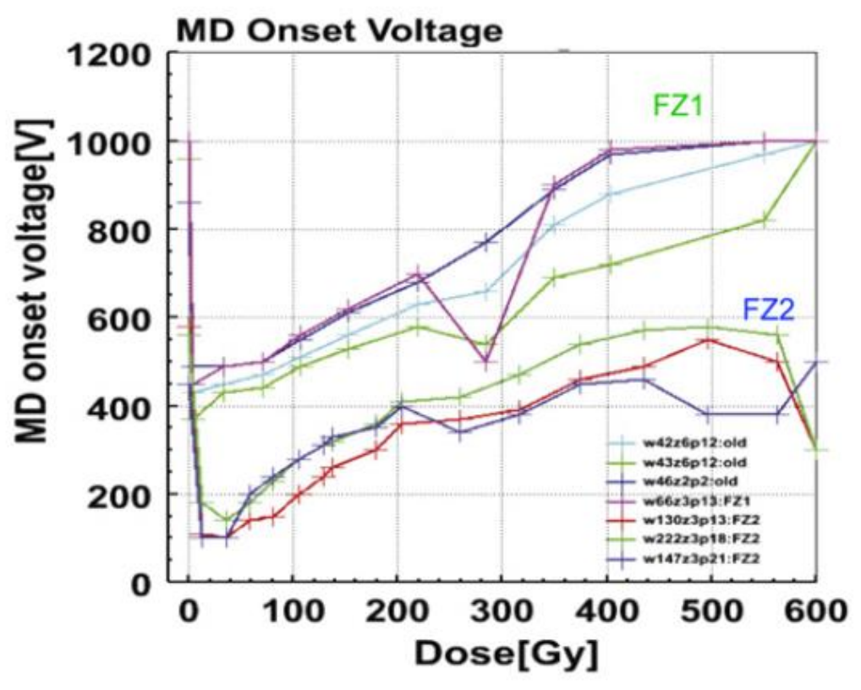
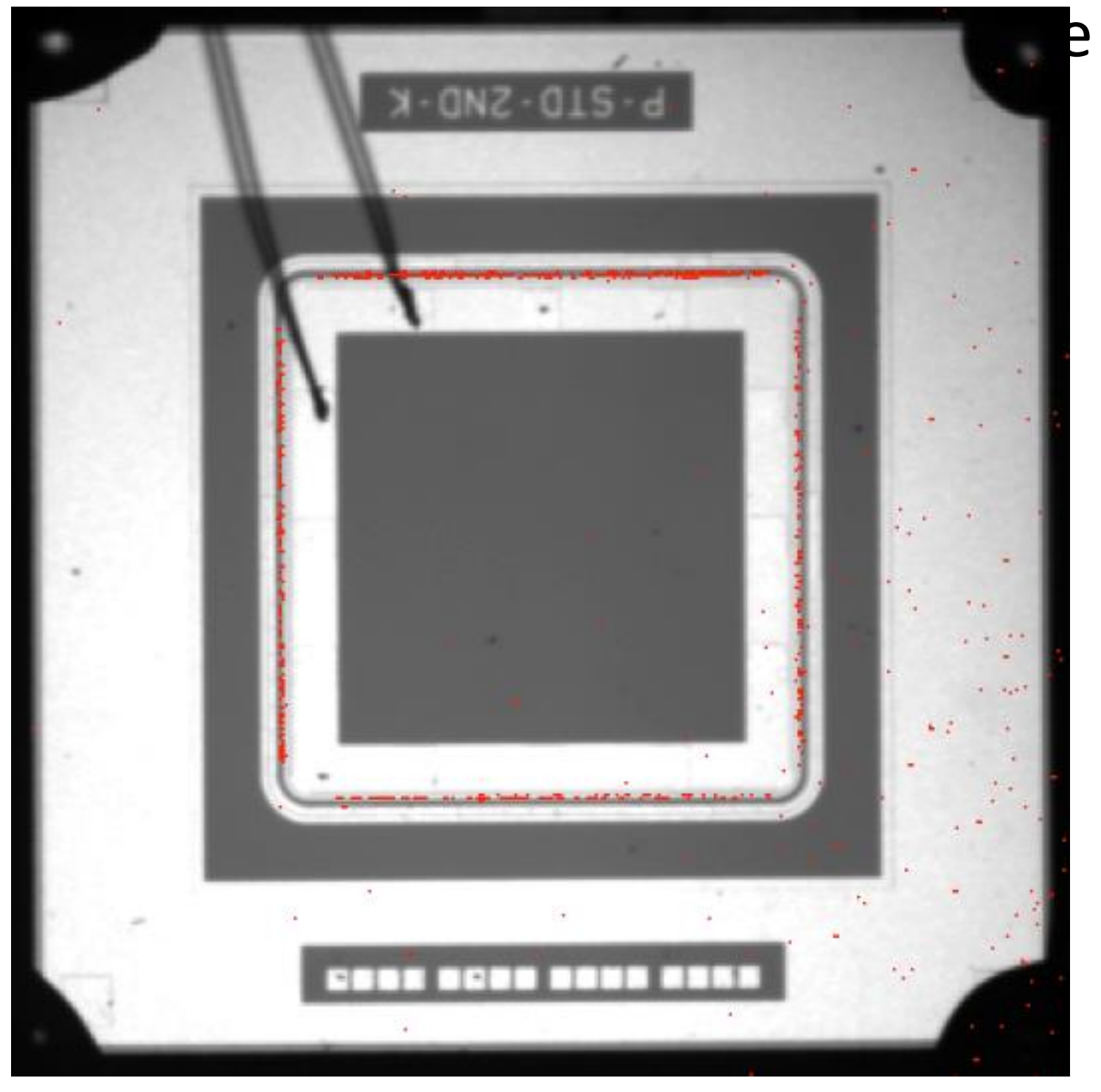
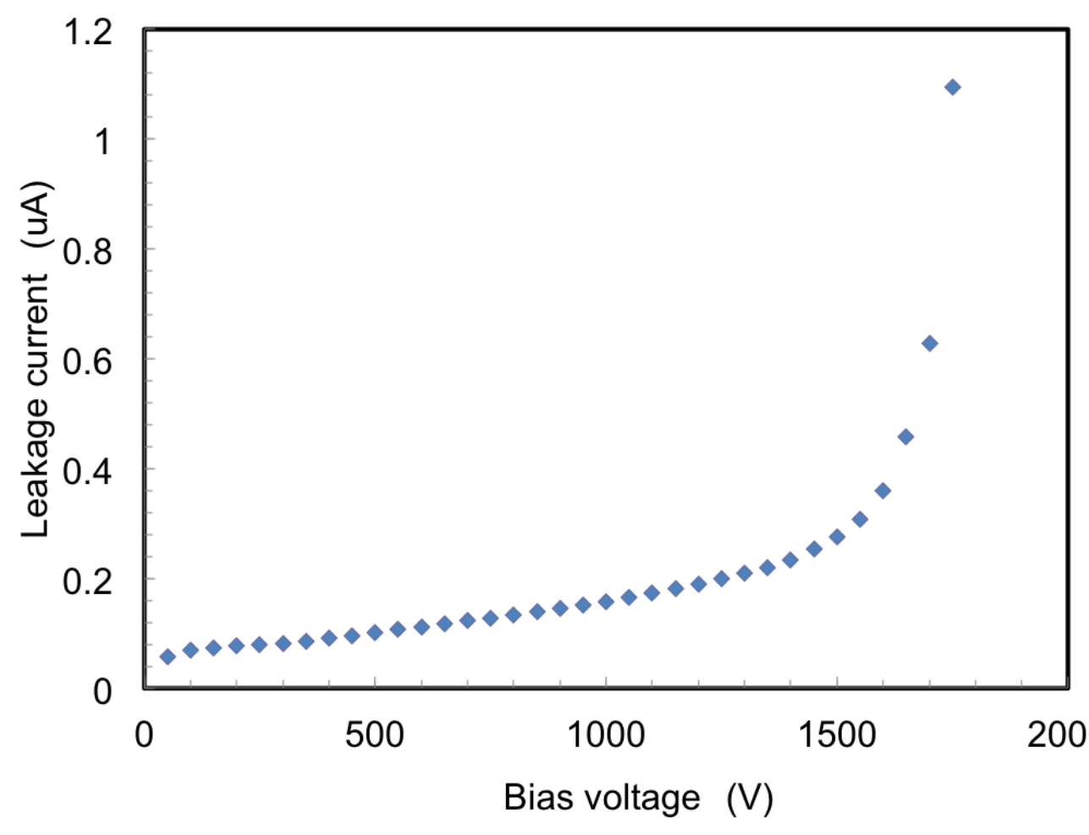


Fig. 4. Micro-discharge onset voltage vs. accumulated dose, measured at 200 V bias and 200 Gy/h. The two clusters of the curves correspond to FZ1 and FZ2 wafers.

- After γ irradiation, onset of microdischarge occurred at the n-implant, instead of p-stop edges, and “annealed” along the accumulation of dose.
- MD at n-implant edge could be a “corner” effect, but …
- Proton irradiations
  - Hot spots were observed first at the edge of the bias ring, and then at the inside of the edge metal.





CYRIC proton irradiated,
1x10^{14} n_{eq}/cm^2
10 uA at 2000 V, -15 ° C

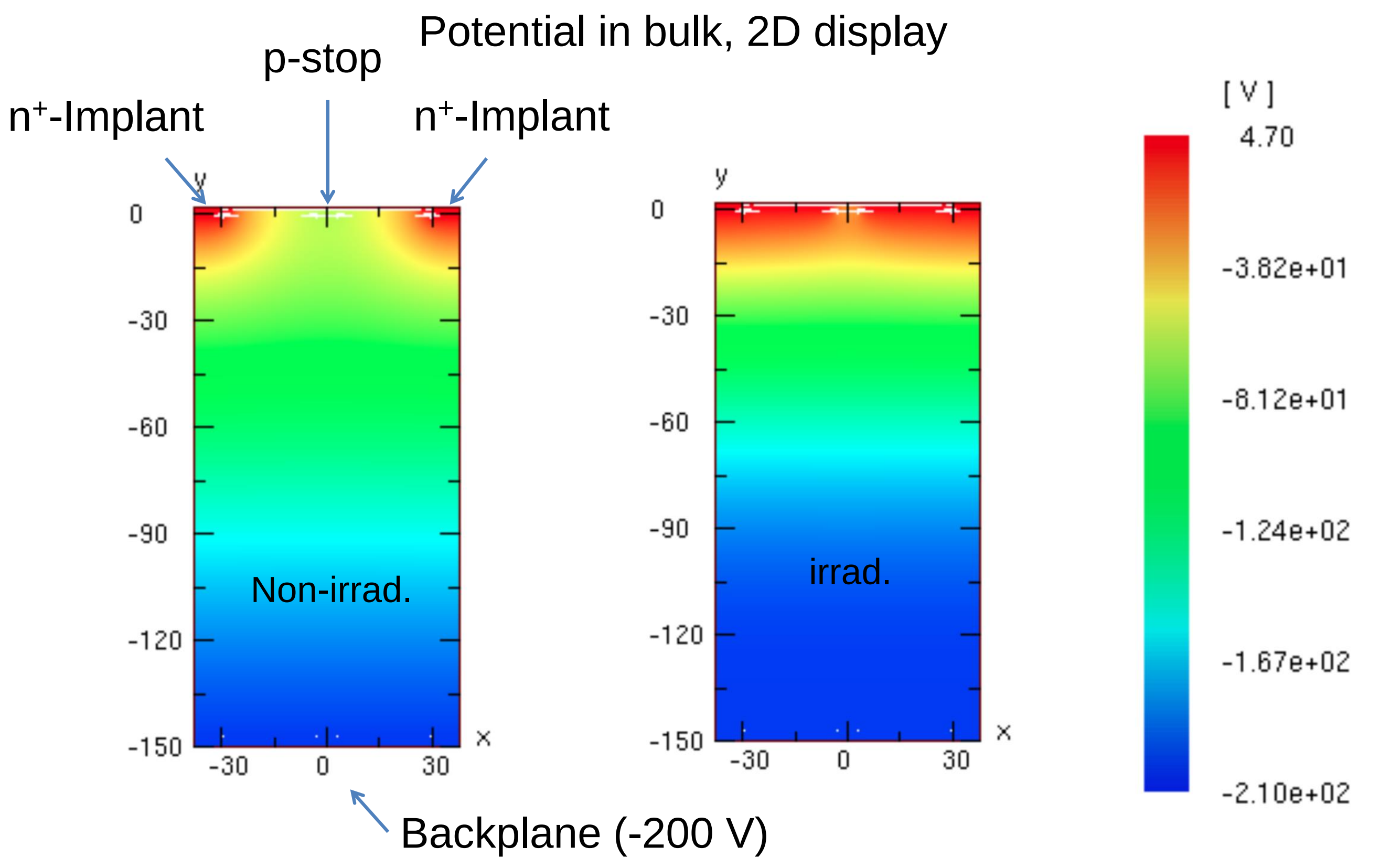
TCAD Simulation

- Semiconductor Technology Computer-Aided Design (TCAD) tool
  - ENEXSS 5.5, developed by SELETE in Japan
  - Device simulation part: HyDeLEOS
- N-in-p strip sensor
  - 75 µm pitch, p-stop 4x10^{12} cm^{-2}
  - 150 µm thickness
  - p-type bulk, Neff=4.7×10^{12} cm^{-3}, V_{FDV}=80 V at 150 µm
- Radiation damage approximation:
  - Increase of acceptor-like state ← Effective doping concentration
  - Increase of leakage current ← SRH model
  - Increase of interface charge ← Fixed oxide charge
- Non irrad. condition
  - Neff=4.7×10^{12} cm^{-3}
  - SRH An, Ap=1.0,
  - Fixed Oxide Charge =1×10^{10} cm^{-2}

Irrad. condition
Neff=1.5×10^{13} cm^{-3},
SRH An, Ap=1×10^{-8} ,
Fixed Oxide Charge =1×10^{12} cm^{-2}

Electric potential of p-stop

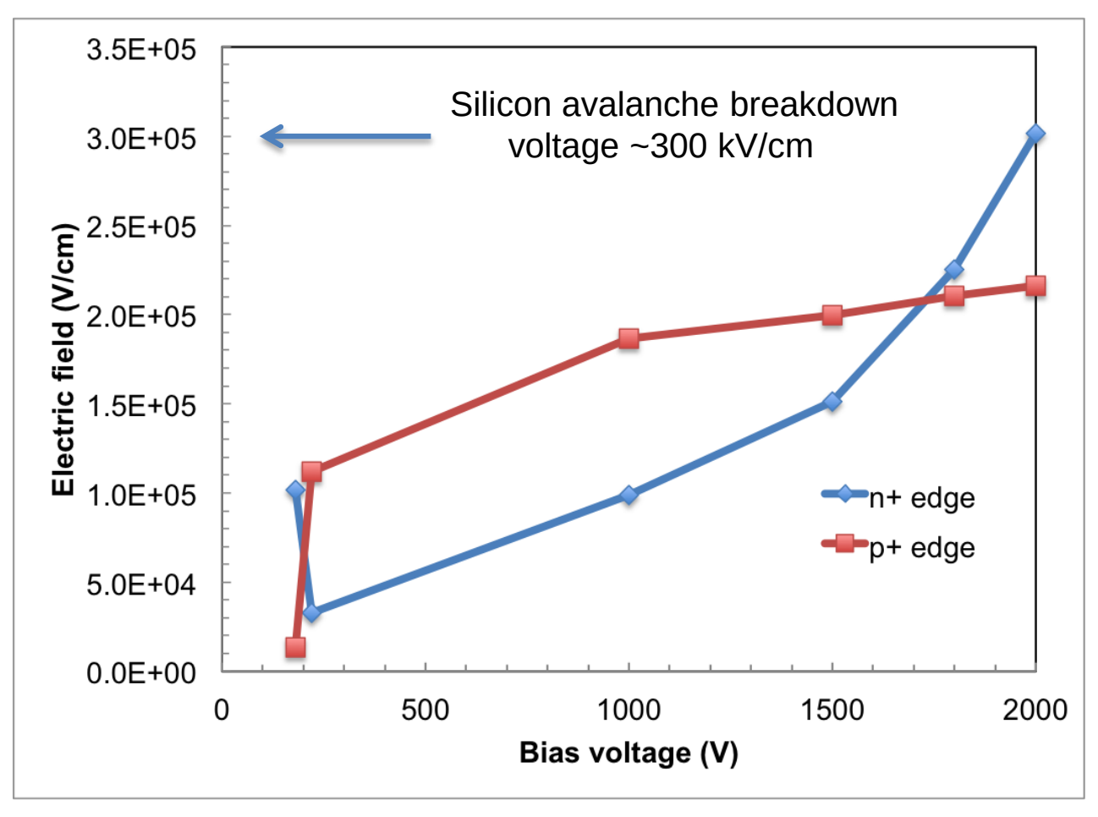
- Introduction of Si-SiO2 interface charge

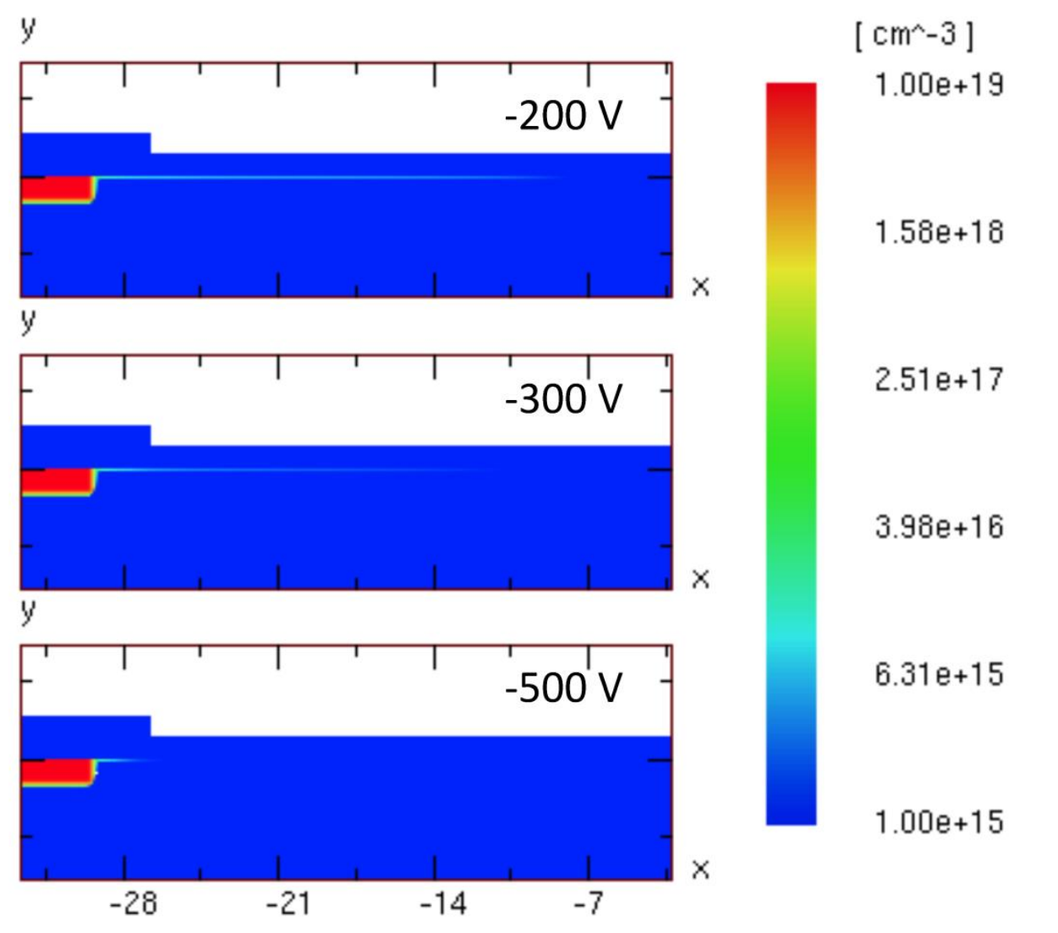


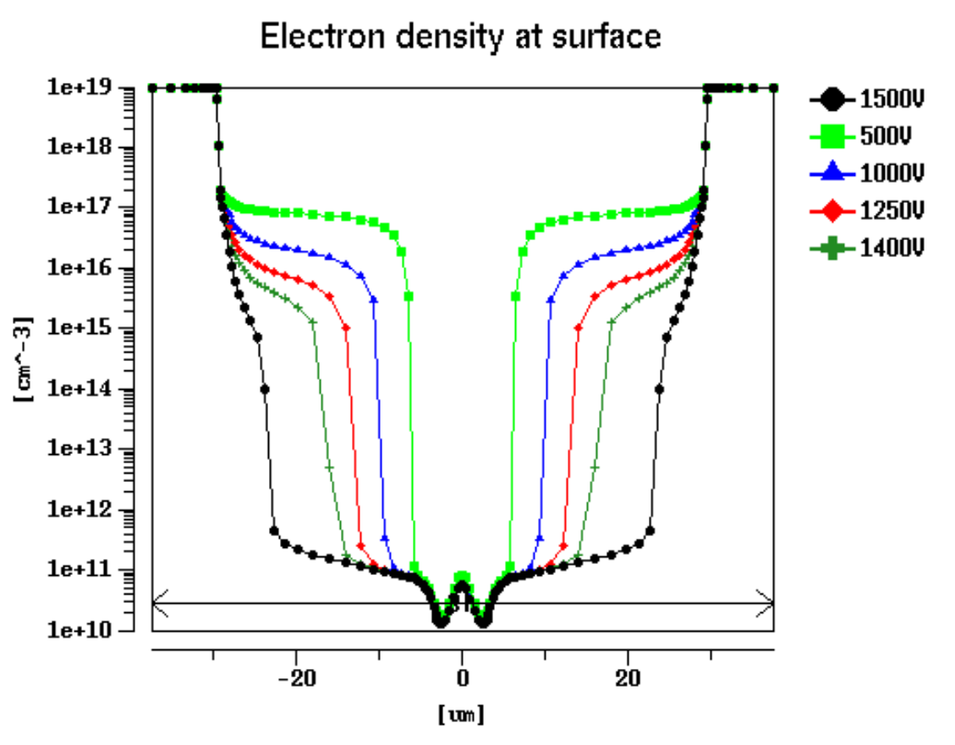
- Electric field becomes “flatter” due to the conductiveness of “electron” layer attracted to the positive interface charges.

Location of Breakdown at High Voltages

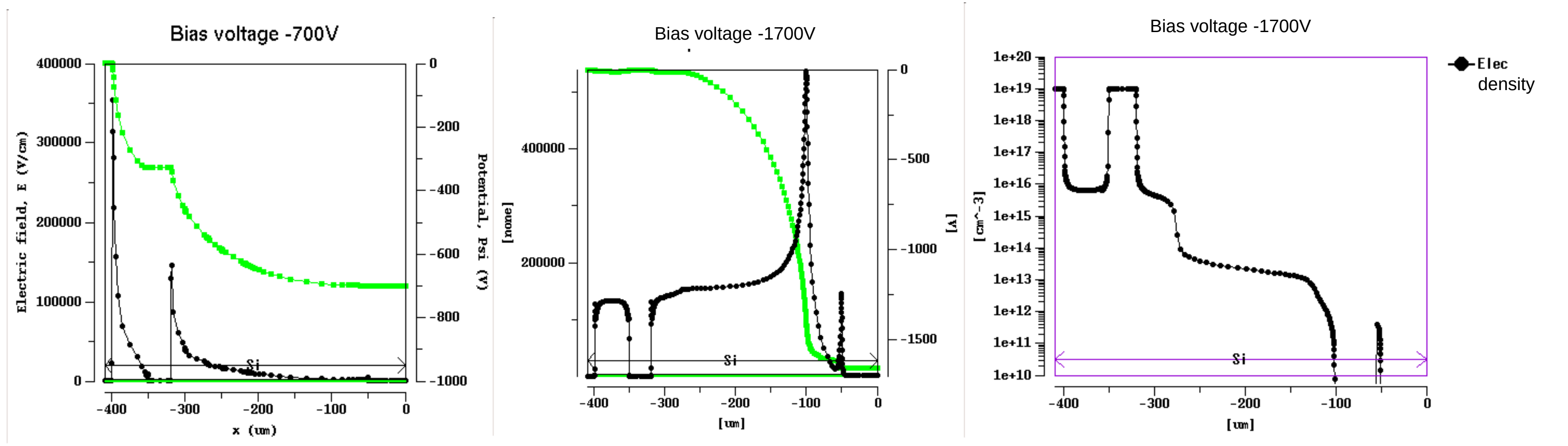
- Between n-implants and p-stops







- Non-irrad.
  - Highest electric field is at the n-implant edge
- Irrad.
  - Although the p-stop edge has the higher electric field at lower bias voltages,
  - the n-implant edge eventually takes over the highest electric field by the time of breakdown, ~300 kV/cm.
  - The rate to increase of the electric field at p-stop edge is saturating at higher voltage.
  - This is due to the diminishing electron layer attracted to the positive interface charges.
- Between the bias ring and the edge termination
  - Non-irrad.
    - Highest electric field is at the edge of the bias ring.
  - Irrad.
    - At low voltages, at the p-edge
    - The electron layer tends to diminish but not fast enough.
    - Still need to tune the TCAD simulations.



Summary

- Experimentally, we have been observing that the breakdown locations are at the n-implant edge before and after irradiation.
- This has been understood with TCAD simulation that the conductive electron layer attracted to the interface positive charges is diminishing as the bias voltage is increased.
- It is clearly demonstrated in the active sensor area.
- The similar trend is shown in the edge termination area, but not clear yet.