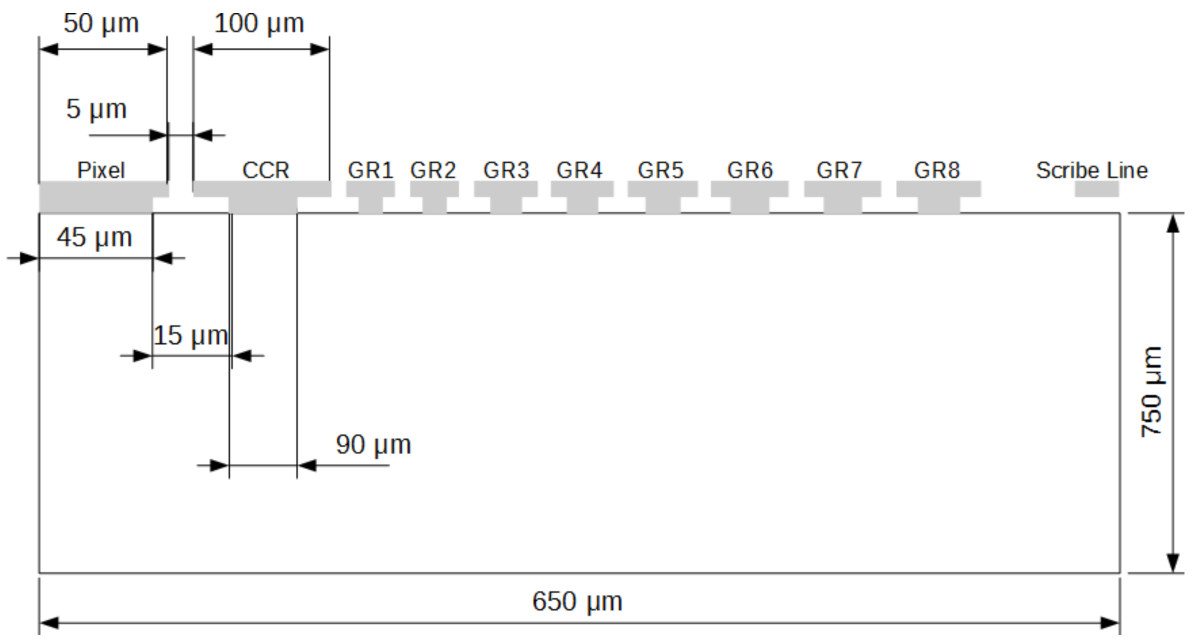
Report on Guard Ring Breakdown on ANL D7 with 6 μm p-stop

Simulation Model



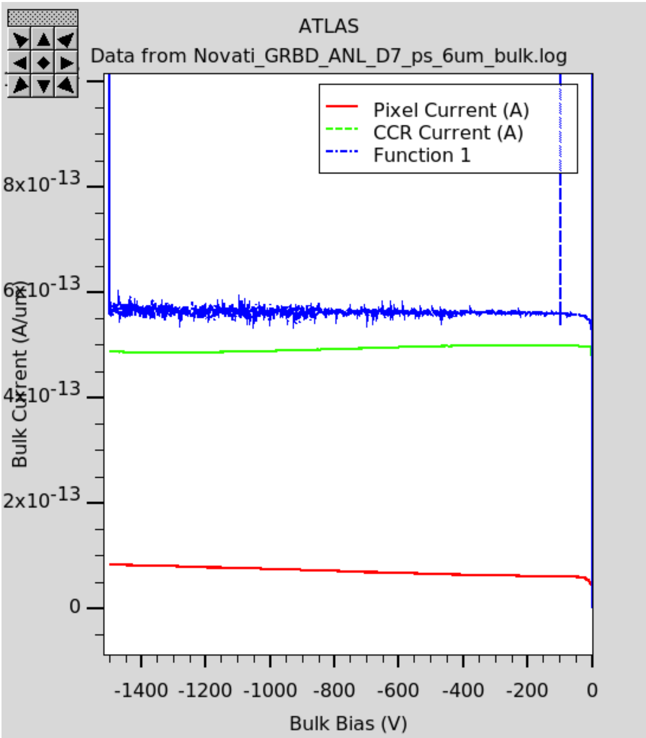
- 8 Guard Ring structure with 50 μm pixel (actually, half-width) pitch.
- 100-μm-wide Current Collection Ring: also grounded.
- P-stop implant width was reduced to 6 μm in an effort to avoid low bias breakdown.
- Guard ring size: 23.5 + 1.5 * N μm (N is the # of guard ring)
- Guard ring left overhang size: 1 + N μm
- Guard ring right overhang size: fixed 5 μm
- Space between Guard ring: 13.5 + 1.5 * N μm

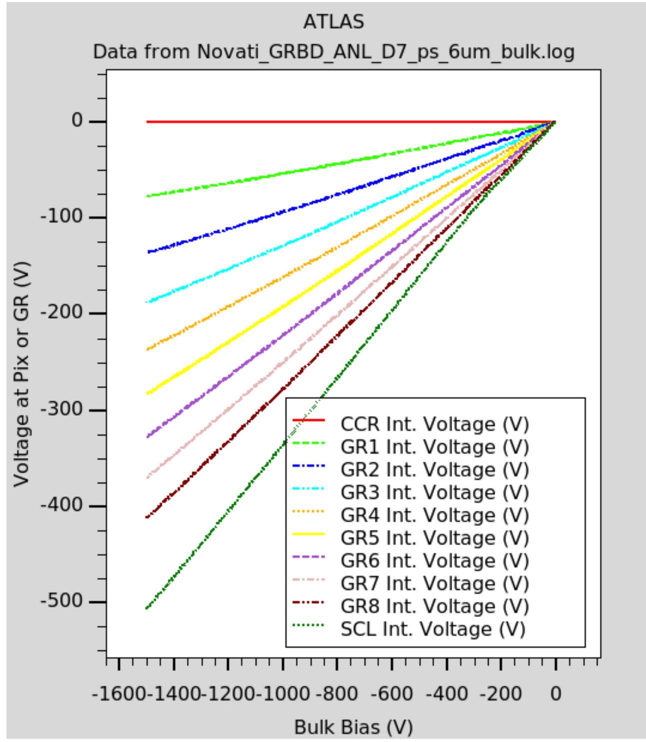
Simulation Setting

- Open circuit was implemented as a lumped resistance of 10^{20} Ω
- Substrate impurity: 10^{12} cm^3 of Boron
- Physical models(provided by Atlas): srh, fldmob, auger, bgn, btbt
- SRH constants:
  - Minority electron lifetime(taun0): 1 ms
  - Minority hole lifetime(taup0): 1 ms
- Impact ionization model: Shelburherr
- Interface trap density: 10^{10} cm^2
- The simulation was stopped at V_{bulk} = -1500 V.

Results

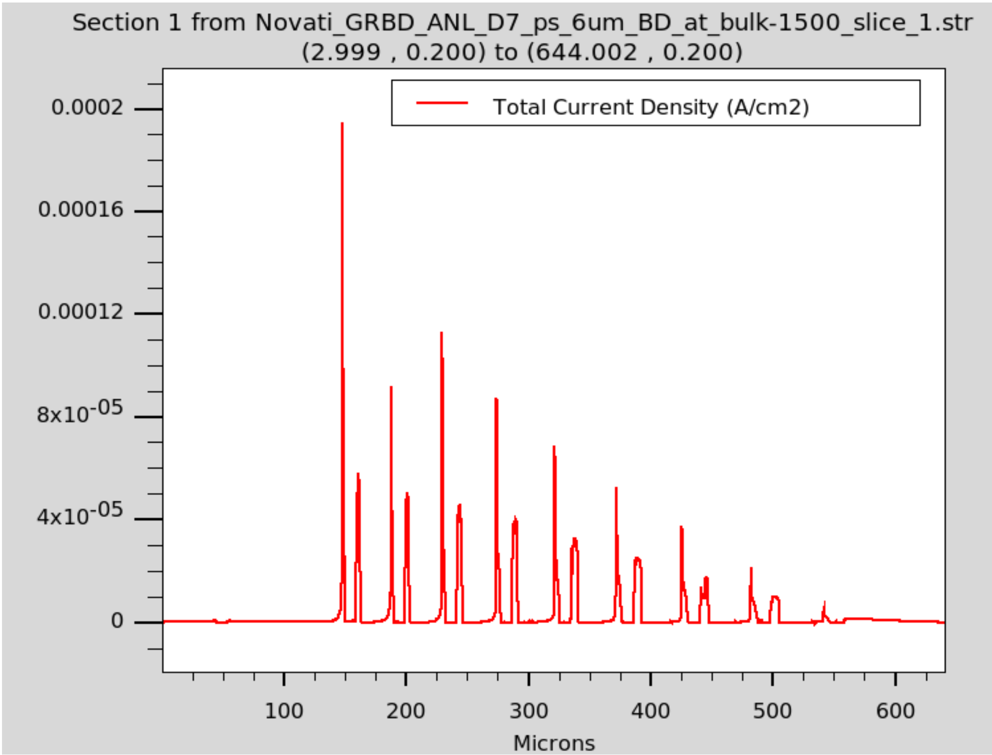
Bulk Current Leakage and GR Internal Bias





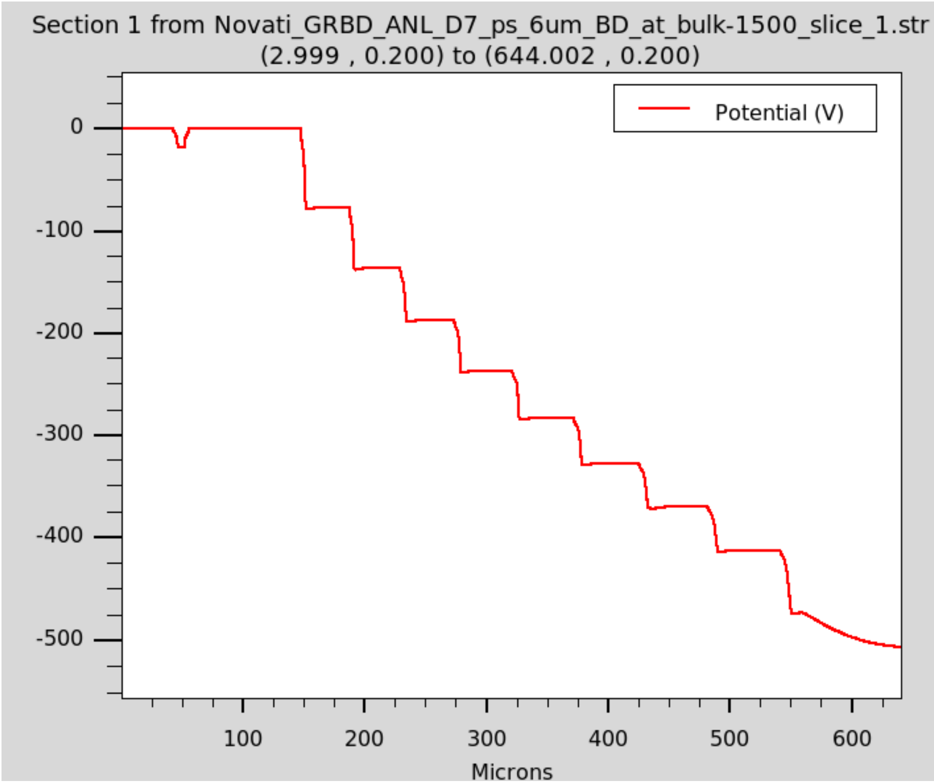
- Simulation was failed to converge at V_{bulk} ~ -1500 V.
- Outermost guard ring potential stays at ~ -430 V
- Scribe Line (floating on Oxide) potential at ~ -510 V
- Potential difference between pixel and the innermost guard ring (GR1) stays at ~ -80 V.

Current density (2D slice across the model)



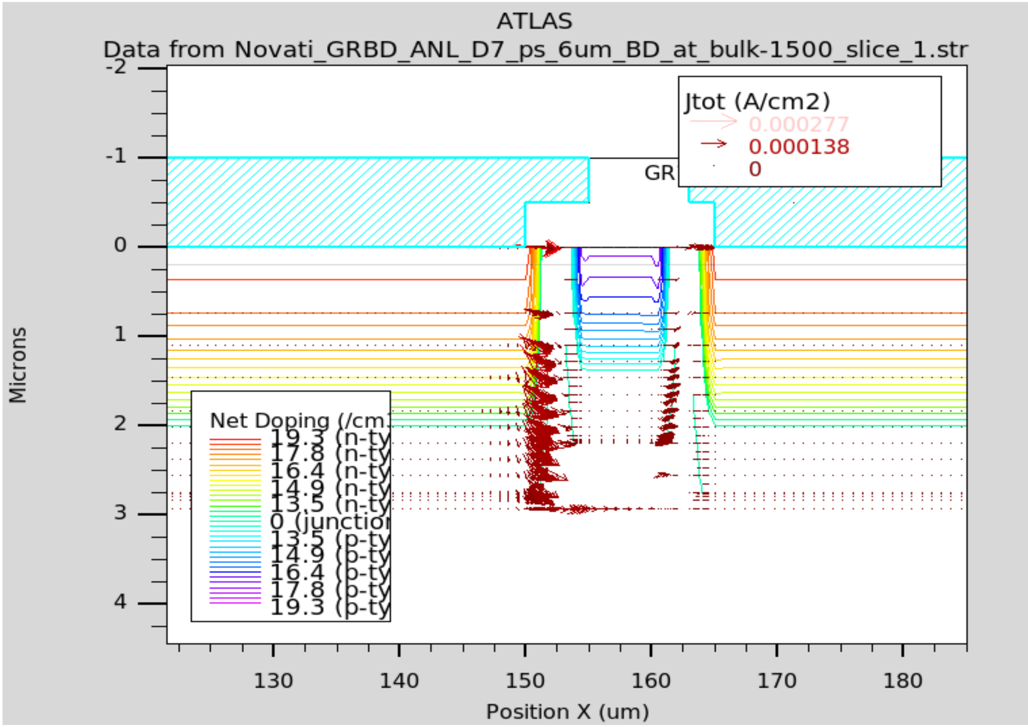
- The current flow is happening on each side of all p-stop implants.
- The device has not reached breakdown state yet: The current density stays lower than 1e-3 A/cm2 range.
- The N-P junctions show higher current density than P-N junctions: The lateral current was mainly stemmed from impact ionization.

Potential (1D Slice across the model)



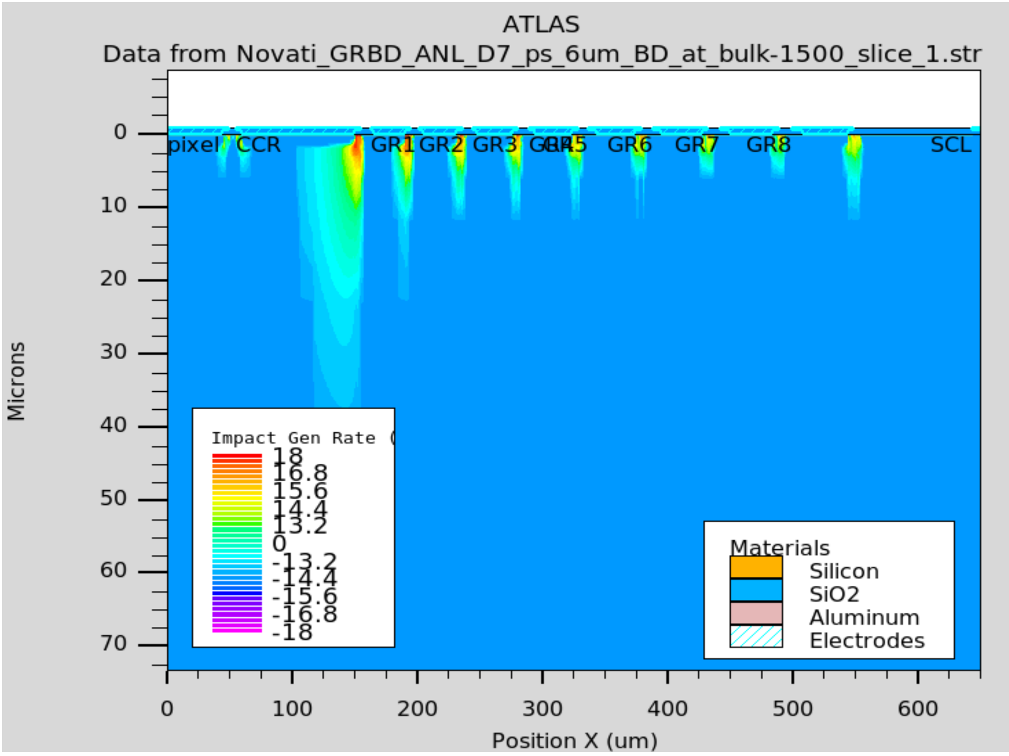
- The potential difference between the guard rings are slightly higher (10 ~ 20 V) than previous 8GR case.
- In other words, the reduced p-stop width, or increased p-stop distance from n+guard ring implants, improves breakdown characteristic.
- The scribe line also lowers the potential at the edge of the detector.
- The potential difference between CCR and GR1 is the most significant in this case as well.
- Also, GR to GR potential decreases by the distance from CCR. However, the decrease itself is not as severe as the previous 8 GR case due to variable (GR size.)
- It can be noted that the scribe line metal also plays role and the potential drop from the last GR to the SCR cannot be ignored.
  - We want to put it far away from the outermost GR: potential drop at the GR edge may cause another breakdown mayhem: a compromise is required.

Current Flow (2D Vector Plot)



- A zoomed in current density vector plot between CCR and GR1.
- The p-stop breakdown current is mostly hole current and flowing outwards from CCR.
- The CCR contact-p-stop-GR1 can be compared to a poor NPN bipolar transistor and punch-through current exists (the vector arrows at 3 µm-deep position) due to p-stop.
- We need the punch-through current to evacuate excessive electrons from the wafer edge, but they should be controlled to minimum (to ensure low noise) with p-stop implant. However, when the device fails, the impact ionization at the p-stop implant vicinity overwhelms.

Impact Generation 2D Contour Plot



- Severe impact ionization at the left side of p-stop implants is observed since the reverse bias has been applied at the N-P junctions.

Remarks and Conclusion

1. Although not reached the breakdown point, the reduced p-stop shows a great improvement from previous model which failed at V_{bulk} = -1038 V.
2. Moving the p-stop implants further away from n+ contact implants simply improved lateral breakdown characteristic (higher breakdown voltage) marginally.
3. Scribe line cannot be ignored. It can further reduce the top surface potential at the wafer edge but may cause another source of breakdown at the outermost guard ring p-stop implant.
4. Since the right side of p-stop, P-N junction, is forward biased, there is not much point to procure much space here. **So, we can place the p-stop implant towards the outer guard rings**.
5. Of course, we don't want a rectifying contact between guard rings. So, minimum distance from P-N implant needs to be maintained.
6. The GR width needs to be optimized to reduce the potential drop at CCR-GR1.

Appendix: Input Deck

```
###############################################
#                                             #
# Simulation deck for Novati GR Breakdown     #
#                                             #
# September 17th 2015, Taylor Shin            #
#                                             #
###############################################
set dev_name = Novati_GRBD_ANL_D7_ps_6um
#
# Setting up mesh structure
#
go devedit3d
source ../str/${dev_name}.de
structure outf="../str/${dev_name}.str"
#
# Running device Simulation
#
go atlas simflags="-P 32"
# Setting up bias conditions
set bulkbias = -2500
#
# Setting up SiO2 interface traps (/cm2)
#
set fluence = 0
set qinterf_no_fluence = 8.8e11
#set qinterf_no_fluence = 1e11
#set qinterf_no_fluence = 1e10
#set qinterf_no_fluence = 0
#set qinterf_no_fluence = 2.5e12
set qinterf = (((2e12 - 5e10)/1e15)*$fluence) + $qinterf_no_fluence
#
# Reading in mesh from the devedit3d generated structure.
#
mesh infile="../str/${dev_name}.str"
interface qf=$qinterf
#
# Setting up physical models
#
# SRH constants, nsrh is only valid with consrh
#
set tau_fz = 1000 * 1e-6
```

```
set nsrh = 1e16
models consrh fldmob auger bgn cvt btbt fermi print
#models cvt srh fldmob fermi print
material region=1 \
    taun0=${tau_fz} taup0=${tau_fz} \
    NSRHN=${nsrh} NSRHP=${nsrh}
impact region=1 selb
#
## Electrode information:
# 1: bulk bias from backside (bulk)
# 2: Pixel (pixel)
# 3: Current Collection Ring (CCR)
# 4: Guard Ring 1 (GR1)
# 5: Guard Ring 2 (GR2)
# 6: Guard Ring 3 (GR3)
# 7: Guard Ring 4 (GR4)
# 8: Guard Ring 5 (GR5)
# 9: Guard Ring 6 (GR6)
# 10: Guard Ring 7 (GR7)
# 11: Guard Ring 8 (GR8)
# 12: Scribe Line (SCL) - floating on SiO~2
#
# Setting up floating electrodes
#
set init_float_current = 0
set init_float_charge = -1e-17
set open_ckt_res = 1e20
contact name=GR1 aluminum resist=${open_ckt_res}
contact name=GR2 aluminum resist=${open_ckt_res}
contact name=GR3 aluminum resist=${open_ckt_res}
contact name=GR4 aluminum resist=${open_ckt_res}
contact name=GR5 aluminum resist=${open_ckt_res}
contact name=GR6 aluminum resist=${open_ckt_res}
contact name=GR7 aluminum resist=${open_ckt_res}
contact name=GR8 aluminum resist=${open_ckt_res}
contact name=SCL aluminum floating
#
# Setting up calculation method
method direct \
    autonr maxtraps=200 atrap=1/1.61803398875 \
    climit=1e-4 dvmax=2.0 itlimit=50 \
    carr=2
#
```

```
# solving initial guess
#
solve init
solve v3 = 0 name=CCR
solve v2 = 0 name=pixel
solve v1 = 0 name=bulk
#
# saving initial guess results for opposite bias.
#
solve outfile="../Results/${dev_name}_init.str"
#
# biasing bulk down to breakdown
#
log outf="../Results/${dev_name}_bulk.log"
solve v1=0 vstep=-1 vfinal=-100 name=bulk cname=bulk compl=1.0e-4 master
solve vstep=-1 vfinal=${bulkbias} name=bulk cname=bulk compl=1.0e-4 master outfile="../tmp/$
{dev_name}_bulk${bulkbias}.str" onefileonly
#solve v1=-50 vstep=-5 vfinal=${bulkbias} name=bulk cname=bulk compl=1.0e-4 master
outfile="../tmp/${dev_name}_bulk${bulkbias}.00000"
#solve vstep=-1 vfinal=${bulkbias} name=bulk cname=bulk compl=1.0e-4 master
#solve v1=0 vstep=-1 vfinal=-10 name=bulk cname=bulk compl=1.0e-4 master
#curvetrace contr.name=bulk beg.val=-10 step.init=-1e-2 nextst.ratio=1.2 end.val=${bulkbias}
no.backtrace volt.cont
#solve curvetrace master outfile="../tmp/${dev_name}_bulk${bulkbias}.00000"
#
end
```