



Bias effects in highly irradiated n⁺-p silicon strip detectors after long term annealing



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Outline

- Motivation
- Samples
- First observations
- Alibava measurements/results
- Edge-TCT measurements/results
- Conclusions
- Outlook

Motivation



N.Pacifico (PhD thesis, 2012) – 300 μm, 1x10¹⁶

MPI HLL 150 μm, 5x10¹⁵ n/cm²

- Bistable behavior (CM quenching) noticed after long-term annealing and current injection in FZ n⁺-p devices.
- Significant drop in (expected) collected charge and leakage current in MPI-HLL 150 μm thin detector, after keeping it at V_{bias} for long period of time.
- Hamburg and JSI reports of bistable defect/bias voltage effects on space charge in irradiated silicon detectors [Nuc.Physics B 44 (1995) 468-474, NIM A: 450 (2000) 288-296, 466 (2001) 345-353, 476 (2002) 565-568]

Samples

Sample	Fluence	Annealing
 2xMPI-HLL (produced by Soitec)* 1x1.2 cm², 150 μm and 75 μm thick, bonded on low resistivity handle wafer Material/type: FZ, p-type initial V_{fd}~82 V and 18 V respectively 	Φ _{eq} =5·10 ¹⁵ cm ⁻² Thanks to: Philipp We	Sequential steps at 60ºC up to a cumulative time of 40960 min.
2) 2xHPK (ATLAS-07 run) 1x1 cm ² , 300 μm thick, 75-100 μm pitch Material/type: FZ, p-type isolation: p-stop, narrow common initial V _{fd} ~190 V	$\Phi_{eq} = 5 \cdot 10^{15} \text{ cm}^{-2}$ $\Phi_{eq} = 1 \cdot 10^{16} \text{ cm}^{-2}$ (Fluence history: 1,2,5 \cdot 10^{15} \text{ cm}^{-2} with annealing up to 80 min)	Sequential steps at 60°C up to a cumulative time of 10240 min.

Irradiation performed with 1MeV reactor neutrons at TRIGA (JSI, Ljubljana).

- After each annealing step (up to 10240 min), CC measurements were performed in range of bias voltages from -500 V to 1000 V, which lasted for only a couple of hours not enough for experiencing any significant bias effects.
- After mounting each sample inside the Edge-TCT setup, the focus (min. FWHM below the bonded strip) had to be established.

Experimental setups



- Signal generation: 1064 nm laser, 200 Hz rate
- The amount of injected e-h pairs can be controlled by tuning the laser power
- Position of e-h generation controlled by 3 submicron moving tables (x,y,z)
- Relative charge collection measurements
- Possibility to extract induced signals, charge collection profiles, velocity/el.field profiles, etc.



- 3.6MBq ⁹⁰Sr fast beta source, rate: ~330 Hz
- Triggered by a scintillator/PMT
- Seed cut: SNR>5, neighbor cut: SNR>3
- System gain ~400e/ADC
- ALIBAVA software gives real time readout from the test board (temperature, event display, noise, signal etc.)
- Both setups provide detector temperature control by means of a Peltier element within range from -20°C to +60°C, enabling annealing to be performed with the sample mounted inside. Dry air environment: dew point <-50°C.</p>

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CCE/leakage current drop under bias?





- After 40960 min of annealing at 60°C, the leakage current of the MPI-HLL thin 150 μm detector experienced a noticeable drop while searching for focus at 500V.
- Several repeated measurements (without switching off the cooling or bias, takes 1-3) show quite different detector behavior with time under bias – CC and I_{leak} went down significantly!
- After leaving the detector overnight (~12h), the original detector behavior was mostly restored (takes 4-9)

Confirmed observations – bistable damage?



- The 75 μm sample annealed for 20480 min at 60°C showed a very large increase (nearly ten-fold!) in charge collection, owing to charge multiplication.
- However, after keeping the detector for more than 24 h at V_{bias} = 500 V, a nearly six-fold decrease in collected charge is observed.
- For bias voltages below 500 V it was even lower than immediately after irradiation (due to increased space charge with annealing and increased full depletion voltage)



- ALIBAVA readout system was used for study because it was possible to perform direct noise measurements.
- After 10240 min at 60°C, the CC climbs to even ~30k electrons of MPV (~42k mean) at V_{bias}=1000V, comparing to ~11k after only 80 min at same temperature.
- Beneficial effect on the leakage current is also noticeable before higher CM.
- However, after keeping the detector at V_{bias}=800 V for ~240h, it results in a nearly twofold decrease in both collected charge and correspondingly the leakage current.
- The exact time progression of this CC and current drop at 800 V follows:



- Both CC and I_{leak} seem to fully stabilize after ~10000 min (first kink at ~2000 min!). After this time, obviously only the stable damage has influence on the N_{eff}, which apparently is still sufficient for CM, but at a much lower scale.
- However, while CC and I_{leak} experience more than a twofold decrease (>56%) at this voltage, the SNR drop is less (~41%). With the noise drop even smaller (~31%)!
- This means that the SNR remains mostly due to larger contribution of CM to the signal, instead of the noise, supporting previous assumptions.



- Since the collisions at LHC experiments run for around 17h, then pause for 2h before repeating the cycle without lowering the bias or increasing the temperature, it was interesting to observe what would happen if the detector would be left at -20°C in this state, with no bias applied.
- After 2h and again after 12h at -20°C with no bias applied, no improvement was found. It seems as though this temperature 'freezes' the bistable damage effect.
- This means that the bistable defects need certain amount of thermal energy in order to activate again. The exposure time is presumed to be dependent on the temperature.



- Attempt to calculate activation energy too unstable (current fall at very high rate).
- Attempt to restore previous state (bistable damage 'deactivated') failed*.
- Again, the temperature T=-20°C was tested for 'freezing' the effect confirmed.
- Activation of bistable damage by leaving the detector for a day at RT optimal >48h.

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- The detector was kept for more than 48h at RT with no bias applied to activate all the bistable defects again and measurements repeated up to 5120 min at 800 V the same pattern was found.
- This behavior was tested at higher bias voltage, V_{bias}=1000 V, and the results again show very similar pattern, but with the SNR remaining very high (the drop was less than 9%!), while the CC and I_{leak} drop is somewhat smaller than at 800 V (CC: ~42% and I_{leak}: ~30%). The noise drop was thus greater (~36%), again confirming the beneficial effect of the CM.
- Space charge concentration in the stable state invokes a sufficient amount of CM at higher bias voltages, enough to greatly overpower the induced noise increase!



- CC/IV measurements for the whole bias range after 5120 min at 1000 V were compared with the previous at 800 V and show remarkable (non-expected) resemblance.
- The values at 800 V after 5120 min regardless of the voltage at which the detector was being kept (both 800 and 1000 V), show agreement to less than 5%!
- This means that the amount of applied bias voltage/current through time does not influence neither the time constants, nor the magnitude of the values at any given stage.
- Bias effect evolution under V_{bias}=600 V was also examined and cross-checked with the previous results a match of less than 3% in values was found^{*}. However, the voltage is too low for any significant CM and therefore the SNR drops to even less than 10.

Edge-TCT measurements (HPK - 1x10¹⁶ n/cm², t_{ann}=10240 min@60°C*)



- The detector was biased to 600 V (higher voltages produced unstable leakage current) and CC/IV was performed at successive time intervals up to 5120 min. The results again revealed a very similar pattern.
- As before, there is a significant drop in charge collection until the first kink at ~2000 min and afterwards seem to slowly stabilize (up to 5120 min). From the charge collection profiles, greatest lost of charge can be seen in the active/depleted bulk, as expected.
- The signals however reveal exactly how bistable defects influence charge collection and what actually happens during this process:

Edge-TCT measurements (HPK - $1x10^{16}$ n/cm², t_{ann}=10240 min@60°C)



Bistable damage affects CM only! –The first peak remains the same!

Thermally induced space charge is bistable?

Edge-TCT measurements (HPK - 1x10¹⁶ n/cm², t_{ann}=10240 min@60°C)



- This is also confirmed if the total charge collection before the bias effect is compared to the results afterwards.
- Before multiplication kicks in (V_{bias}<300V), there is virtually no difference in collected charge. However, above this point, even though there is some CM (as seen in previous slide), the total charge collected drops for more than 67% at 600 V! (almost twice as much than seen in Alibava at 5·10¹⁵n/cm²)
- This means that the amount of bistable damage developed by thermal annealing is also radiation fluence dependant. This in agreement with expectations, because neither CM, nor bistability were so clearly experienced at lower fluences (<1.10¹⁵ n/cm²).

Conclusions

- Bistable damage occurs in irradiated and long term annealed silicon detectors giving contribution to manifold increase in CC through CM mechanism (due to increase in N_{eff}), and decrease if the detector is kept under bias for long periods of time.
- Most of the bistable defects get deactivated after ~2000 min under bias, regardless of its magnitude.
- The amount of applied bias in time does not influence neither the time constants, nor the magnitude of the values at any given point/voltage. The pattern is fully repeatable.
- Bistable damage need certain amount of thermal energy/annealing in order to fully reactivate (>48h at RT). It was not possible to deactivate it with high leakage current. Temperature T=-20°C has a 'freezing' effect.
- CM is shown to have more beneficial effect to CC than to the increase of noise.
- Higher voltage causes CM even in the 'stable' state, therefore less impact on CCE, noise and SNR.
- Bistable defects affect CM only (no change in signal peak from primary generated charge).

Outlook

- How does this effect develop with isochronal and isothermal annealing at different radiation fluences?..
- What is the effect without annealing at different radiation fluences?
- Irradiation flavor/particle dependence?
- How does the STFZ behave in comparison with DOFZ?
- Detector thickness dependence?..





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Thank you for your attention.

Backup (HPK - 1x10¹⁶ n/cm², t_{ann}=10240 min@60°C)

