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Effect of accelerated annealing on p-type Si microstrip after very high doses (sLHC levels) of proton irradiation

Work done in the framework of the RD50 collaboration

G. Casse, P. Allport, University of Liverpool

A. Watson, University of Lancaster

G. Casse, 10th SDS, Wildbad-Kreuth, June 12-16 2005

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OUTLINE

- Accelerated annealing studies (@80^{o}C) have been performed in term of CCE of signal induced by mip-like electrons on p-type substrate miniature detectors after 1.1, 3.5 and 7.5 10^{15} pcm^{-2}.

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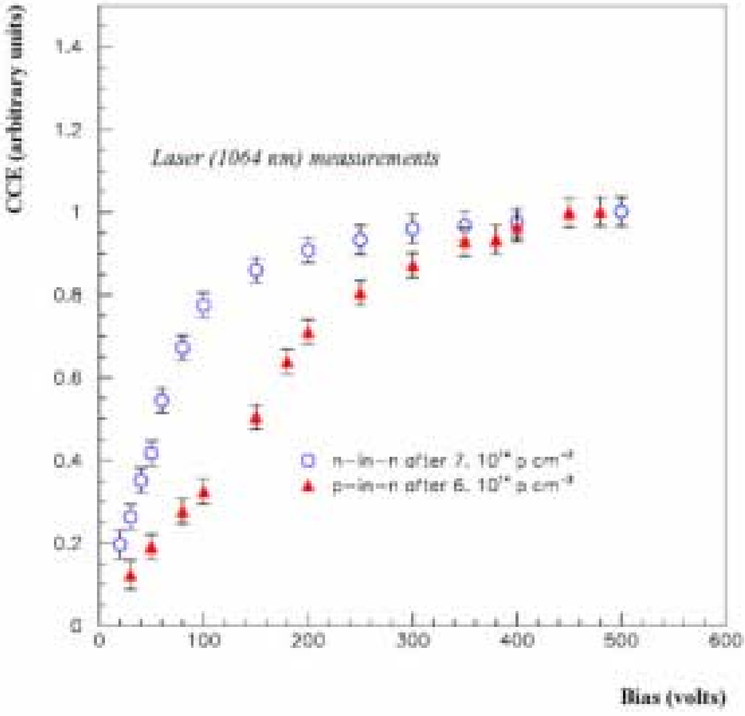
Material and set-up

A set of p-type substrate miniature detectors, AC coupled, 80 μm strip pitch with p-spray isolation, made by CNM (Barcelona) have been irradiated to three 24 GeV/c proton doses in the CERN-PS accelerator (thanks to M. Glaser and F. Ravotti) to doses exceeding 20 times the anticipated fluence for the innermost layer of microstrip detectors of the ATLAS tracker (namely 1.1, 3.5 and 7.5 10^{15} p cm^{-2}). These levels address well the final radiation fluences expected for the microstrip layers of the inner tracker of the upgraded LHC (sLHC). The detefctors have been characterised after irradiation in the most realistic working conditions, so by Charge Collection Efficiency (CCE) studies with signal induced by β particles (m.i.p.-like particles) from a ^{106}Ru source. They were read-out at LHC-speed with SCT128A analogue electronics while kept in a freezer at <-20°C.

Motivation for using n-side read out

It is now well accepted that the best results of segmented detector in term of mip detection performances after heavy irradiations are obtained by reading out the segmented n-side. This is due to the signal being formed mainly by electron carriers being collected on the high electric field side. The reduced charge collection time results in less trapping and higher signals. Example: comparison between a traditional p-in-n geometry (with high electric field on the backplane after type inversion) and n-in-n geometry (high electric field on the read-out side after type inversion) (LHCb detectors).

n-side read-out of a n-type (n^+-n) detector after 7.10^{14} p cm^{-2}, compared with a standard p^+-n after 6.10^{14} p cm^{-2} (LHCb VELO prototypes).



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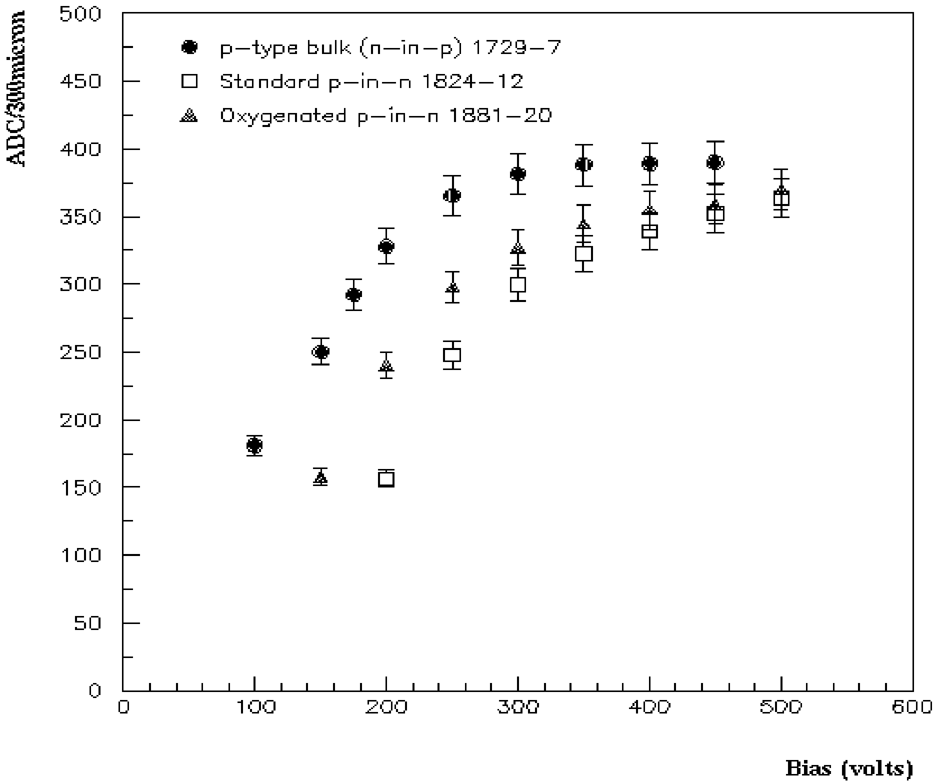
Motivation for using p-type silicon

The n-side read-out can be equally well implemented on a p-type substrate and keep the same advantages for CCE after irradiation and exhibiting two additional advantages compared to the n-type bulk.

- The p-type bulk doesn’t invert, so the junction side will always be on the same side before and after irradiation

- The p-type substrate devices don’t required backplane processing, which turns out being cheaper than the n-type. This argument can be of capital importance for large area coverage (sLHC trackers).



N-in-p full size segmented (microstrip) detectors have been made and successfully tested on standard p-type substrate

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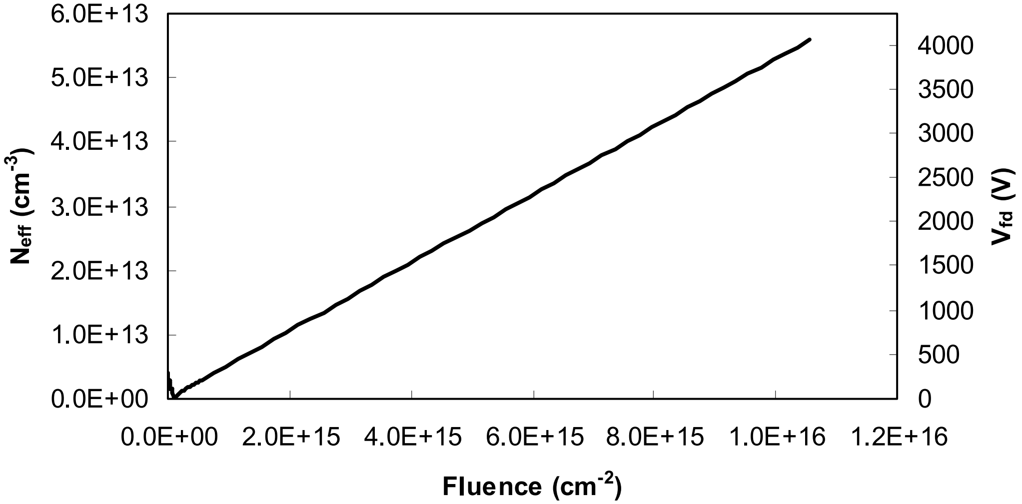
Performances of p-type substrate detectors after irradiation

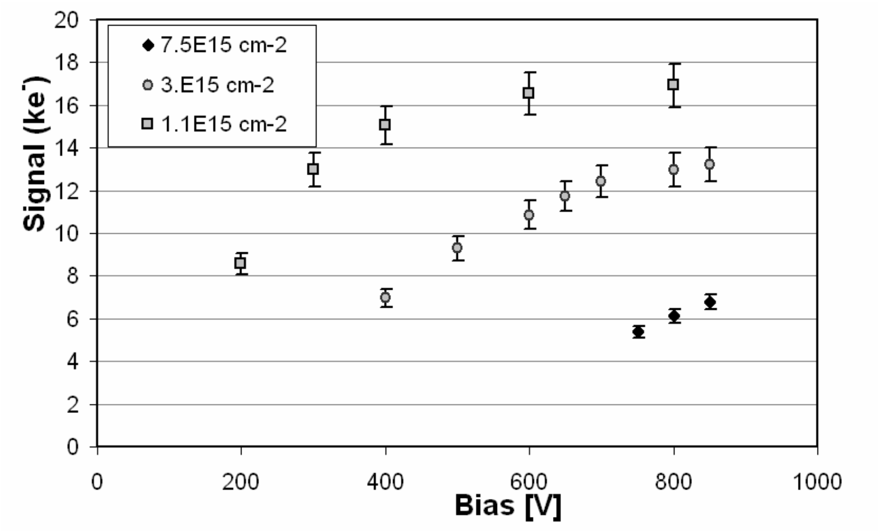
V_{FD} as a function of the proton fluence (at minimum after beneficial annealing) for oxygenated n-type FZ silicon. P-type FZ silicon **is not** expected to show lesser degradation as a function of fluence.

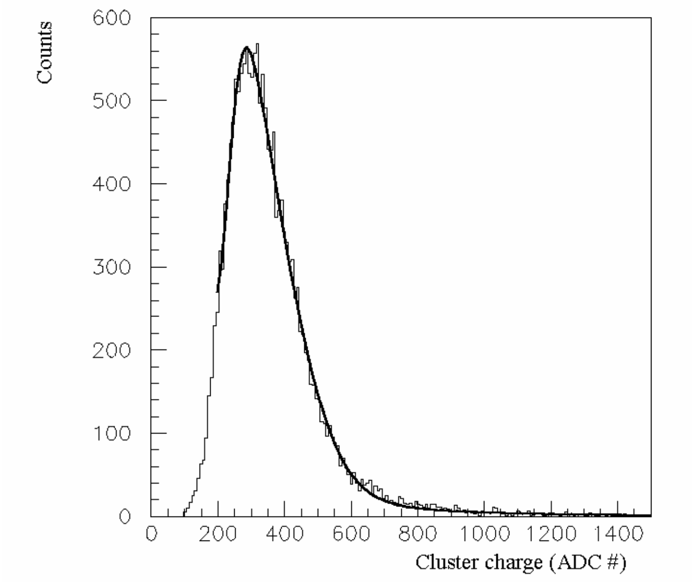
The irradiated devices have been studied in term of CCE after the different irradiation doses and at the end of the beneficial annealing period. The results have been previously presented. They were extremely encouraging in term of the collected charge, especially compared with the expectation derived by the extrapolation of the V_{FD} at those high doses.



Performances of p-type substrate detectors after irradiation

The V_{FD} after 7.5 10^{15} p cm^{-2} is expected at about 2800V for oxygen enriched n-type substrates. A bias voltage of 900V would give a “*depletion”* depth of about 160μm, that would yield a bit less than 12000 electrons in absence of trapping! The charge collected by the miniature p-type detectors is of ~7000 electrons, with a charge loss of 40%, which is remarkably good for that level of radiation.





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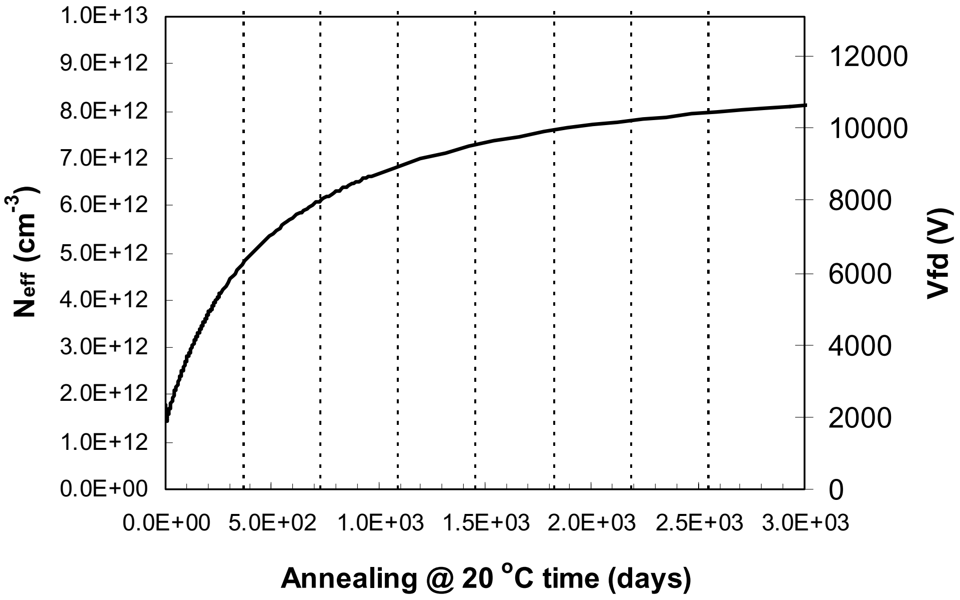
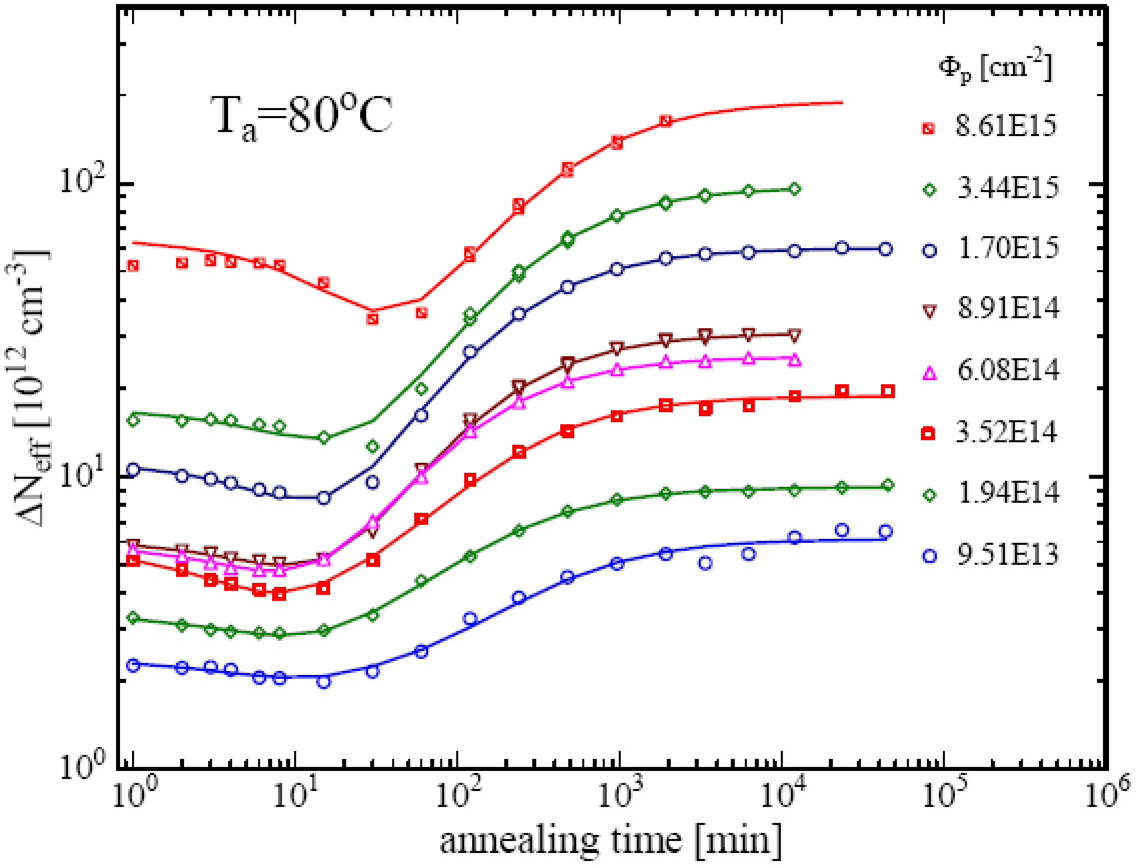
The V_{FD} becomes worse with time after irradiation, if the devices are kept at temperature close to R.T. (reverse annealing).

The reverse annealing of the V_{FD} has been extensively studied and parameterised for n-type silicon detectors (as an example this is the prediction of the changes of V_{FD} for a device irradiated to 3.510^{15} p cm^{-2} according to the parameter accepted by RD48 – see e.g. RD48 3rd status report). An increase of V_{FD} larger than a factor of 4 after 6 y at room temperature is expected.



It is reasonable to assume that a similar annealing takes place for p-type silicon.

The only direct CV measurements available up to very high doses were performed on thin n-type devices (50 µm thick). The corresponding V_{FD} value after 7 years equivalent annealing time at 20°C for a device irradiated to 8.6 10^{15} p cm^{-2} is >12000V (the fit parameters to the various data points here agree with the RD48 predictions-Hamburg model).



Presented by E. Fretwurst at the 4th RD50 workshop, CERN 5th-7th May 2004.

Annealing studies of p-type substrates by measuring CCE

The reported annealing studies have generally been performed by evaluating the V_{FD} from the Capacitance-Voltage characteristic of irradiated simple pad diodes. In our annealing studies we measured the CCE of the 80m pitch miniature strip detectors with LHC-speed (40MHz) analogue electronics. We didn’t perform CV measurements on those devices. For comparison with the annealing of V_{FD}, the prediction from the model quoted above are used.

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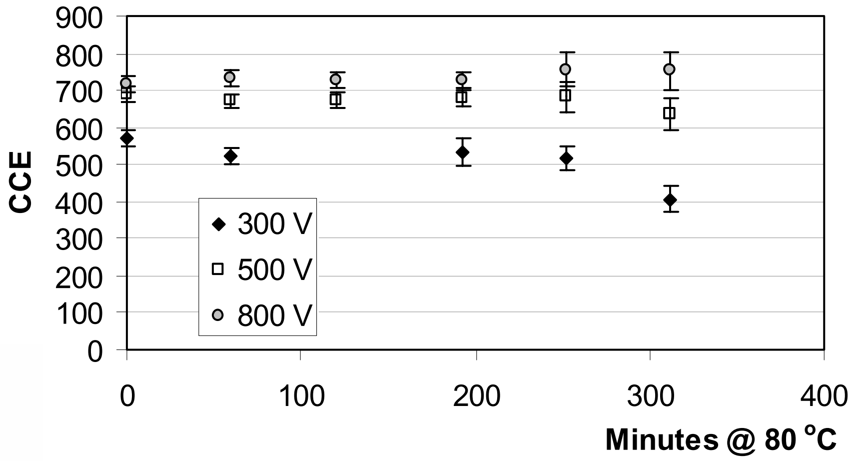
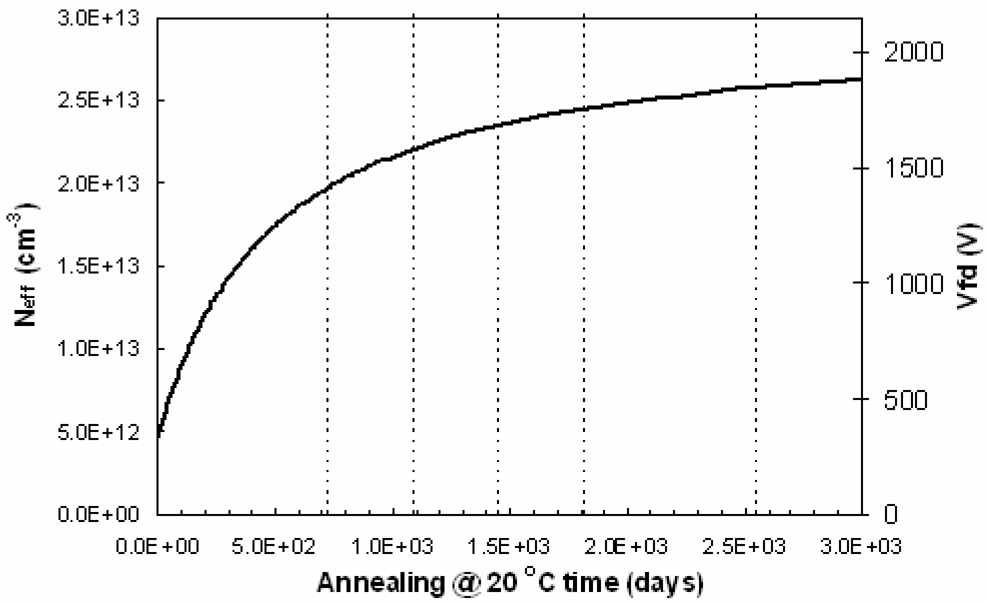
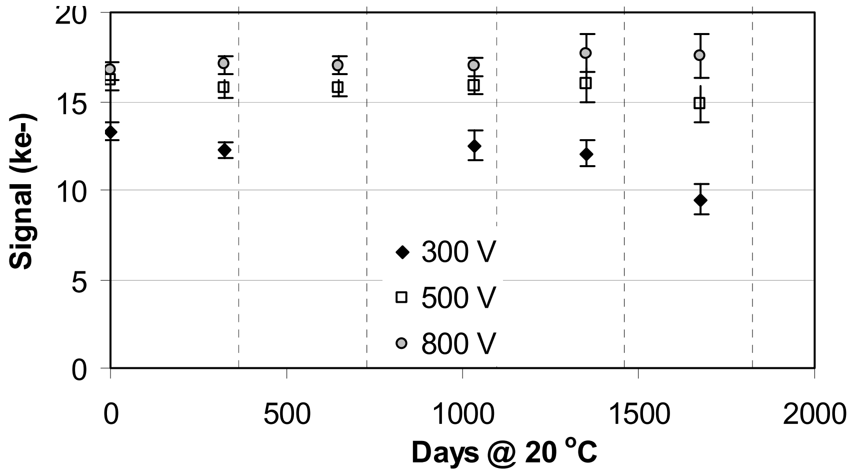
CCE annealing studies of p-type detector irradiated to 1.1 10^{15} p cm^{-2}



Initial V_{FD} ~ 420V

Final V_{FD} ~ 1900V





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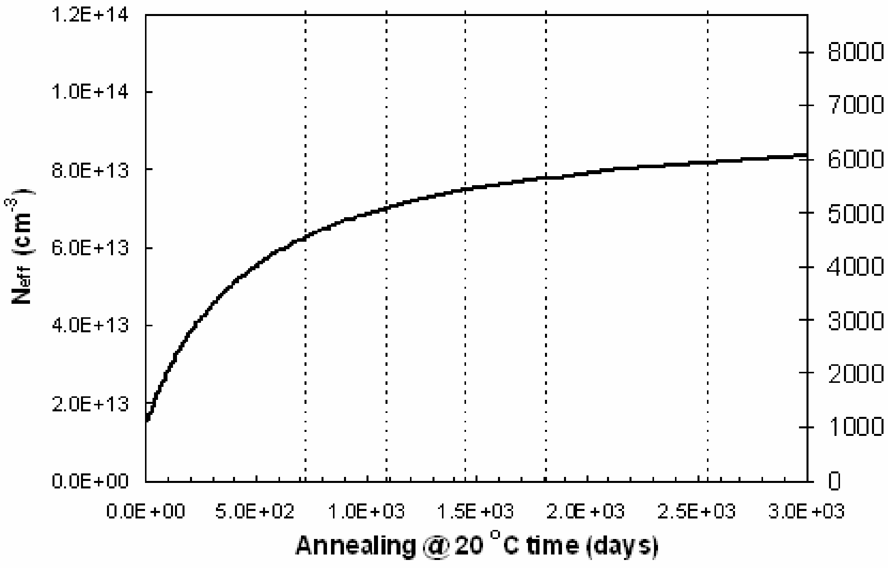
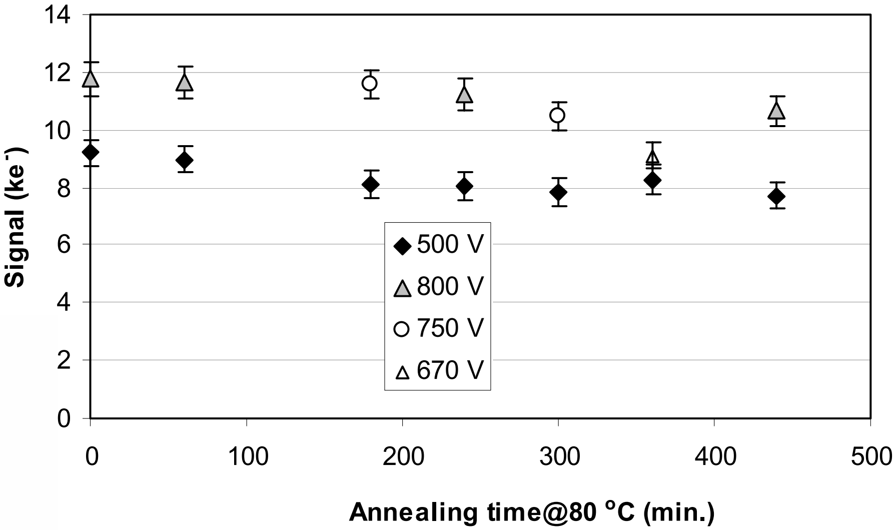
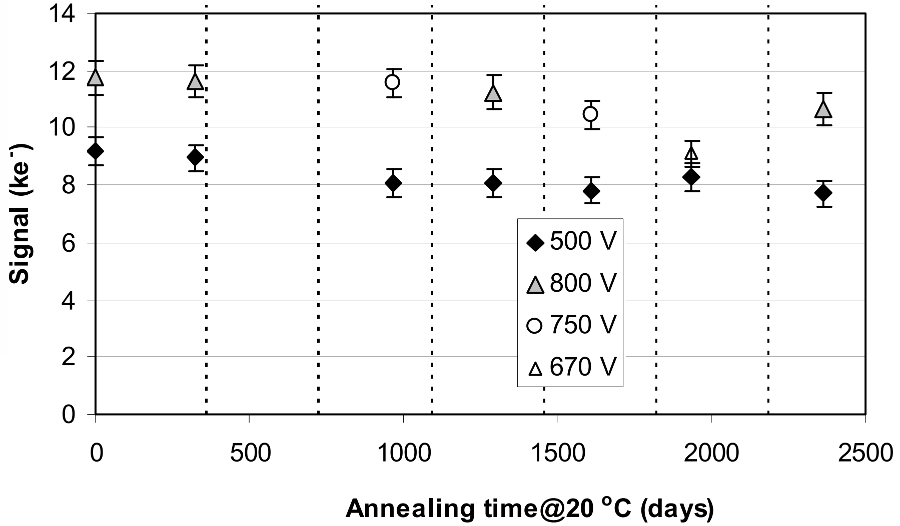
P-type detector irradiated to 3.5 10^{15} p cm^{-2}

Initial V_{FD} ~ 1300V

Final V_{FD} ~ 6000V







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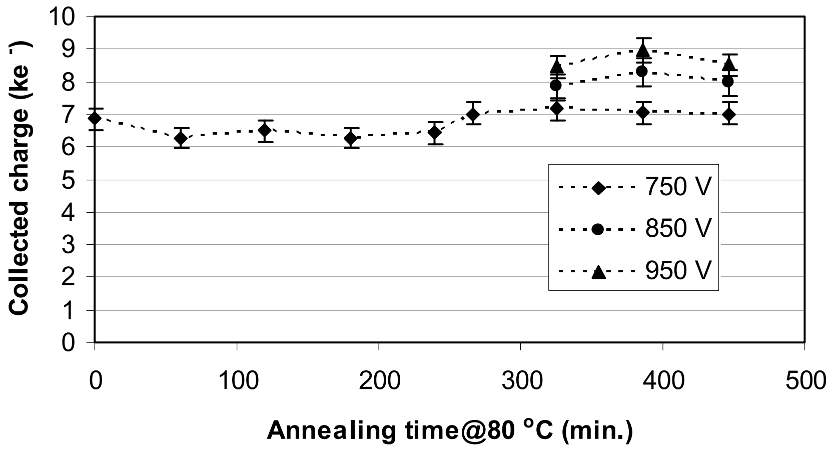
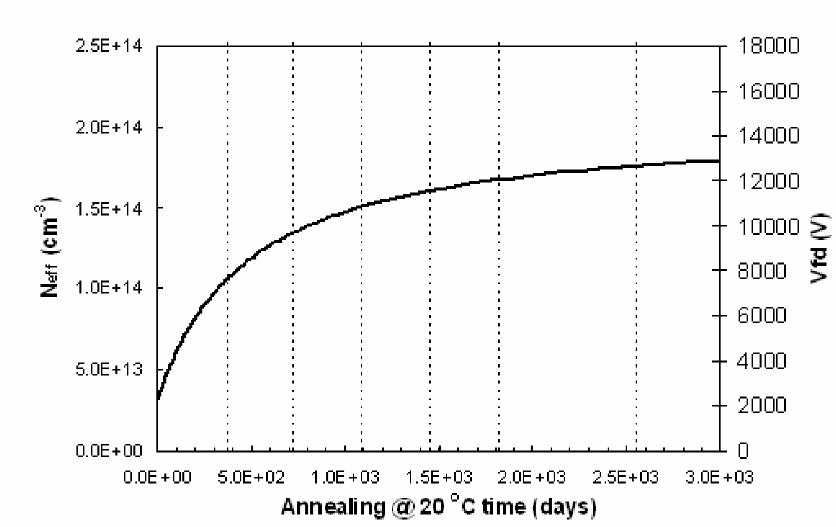
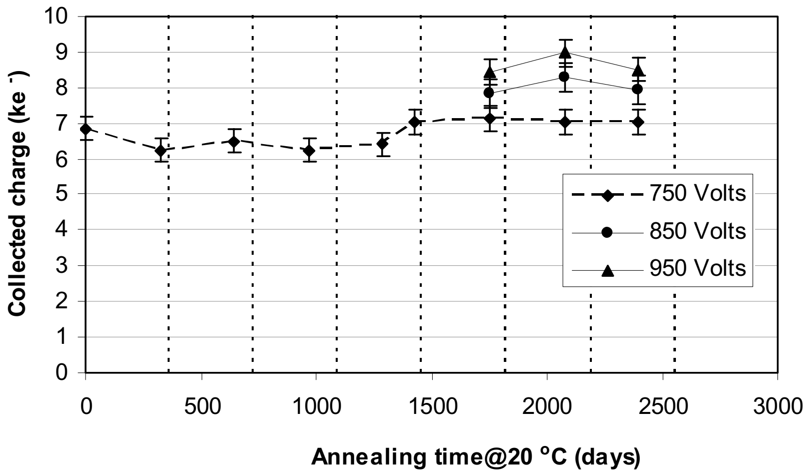
P-type detector irradiated to 7.5 10^{15} p cm^{-2}

Initial V_{FD} ~ 2800V

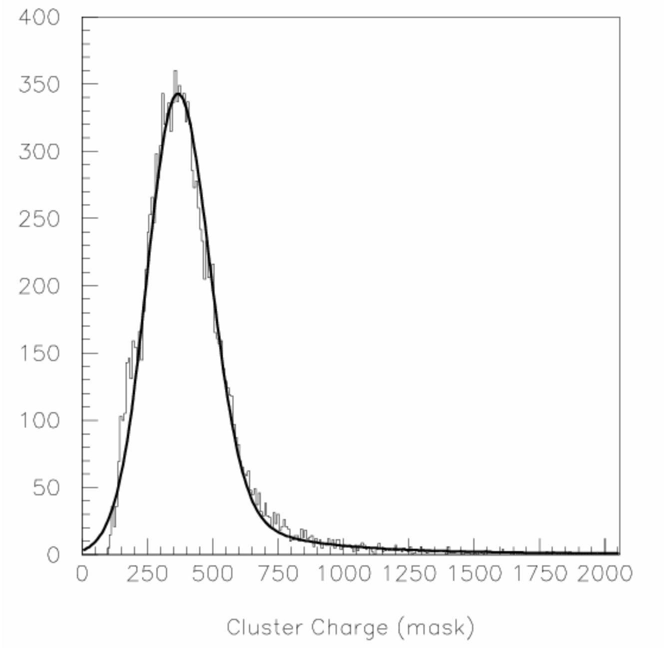
Final ~12000 V!







The measured signal loss after long term annealing doesn't correspond to the changes in the depletion voltage. Even after 6 equivalent y at 20 °C the measured signal (after a fluence of 7.5 10^{15}cm^{-2}) exceeds 8 times the noise (that remains unchanged with annealing, as expected), and in no case the degradation of the signal follows the changes of the V_{FD}.



Ratio of the signal measured after various annealing times at room temperature to the pre-annealed value

Bias	~1 y	~ 3 y	~ 4.5y
300 V	0.9	0.93	0.72
500 V	1.02	1.0	1.07
800 V	0.98	0.98	0.93

After 1.1 10^{15} p cm^{-2}

Bias	~1 y	~ 2.5 y	~ 6.5y
500 V	0.98	0.9	0.87
800 V	0.98	0.94	0.88

After 3.5 10^{15} p cm^{-2}

Bias	~1 y	~ 2.5 y	~ 6.7y
750 V	0.93	0.93	1.01

After 7.5 10^{15} p cm^{-2}

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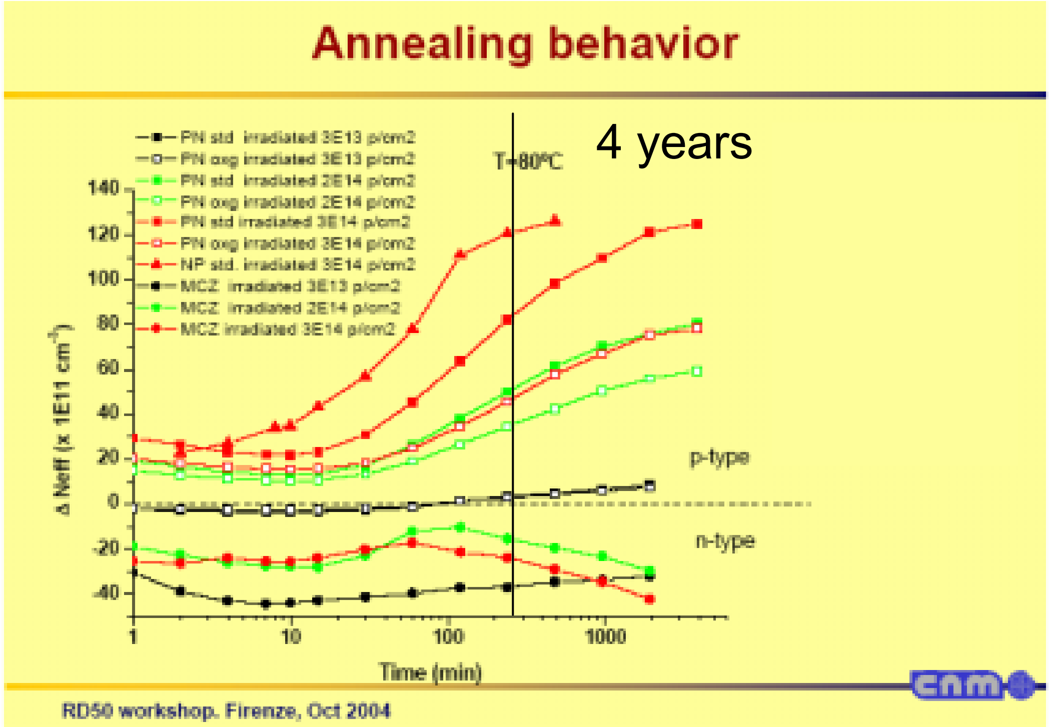
From the CCE measurements the reverse annealing seems suppressed (at least at very high voltages). Is it a real suppression of the reverse annealing in p-type silicon, or rather a feature of the measurement?

There are no available CV measurements of the p-type material annealing at those high doses. The only available measurements are on pad diodes made of same material as the miniature detectors. They were irradiated to 3 10^{14} p cm^{-2}, and show a six times increase of V_{fd}, after 4 years of annealing time @ 20°C.



Annealing behavior

RD50 workshop. Firenze, Oct 2004

The annealing of the p-type substrate shows the same (possibly worse) changes of the n-type substrate. The differences between the CCE and CV results must be related to the measurement.

G. Casse, 10th SDS, Wildbad-Kreuth, June 12-16 2005

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From the information available on CV-measurements of p-type detectors irradiated to lower doses, the reverse annealing seems to take place in a way similar to the n-type devices. If we assumed that the predictions on the V_{FD} changes of n-type silicon with time after irradiation are valid for the p-type, the CCE measurements are in a sharp disagreement with the CV measurements. It is noticeable that for the three different fluences, and at all voltages (even at the lowest voltage measured, namely 300 V after 1.1 10^{15} cm^{-2}, and 500 V after 3.5 and 7.5 10^{15} cm^{-2}), the collected charge doesn’t decrease sensitively up to 3 years at R.T. For the higher voltages the **CCE remains flat** after several year of equivalent R.T. annealing, while the V_{FD} changes by **more than a factor of 4!** This shows that the description of the relevant detector properties (CCE with mip signals) extrapolated from the measurements of the V_{FD} with CV methods is not complete and can lead to erroneous predictions. For very high level of irradiation, an accurate measurement of the electric field profile in the detector would be preferable (essential) for the description of the detector performances.

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Conclusions

We have shown that the annealing of the CCE after severe irradiation remains flat at very high voltages. Also the noise of the detector remains unchanged during the annealing, so it is actually the S/N that remains almost constant for several years at RT. After this results, the necessity of keeping the tracker detectors in the experiments (assuming they are n-side read-out) at room temperature for any length of time (e.g. for maintenance purposes) is not a problematic issue as it has always been assumed. We want to stress out that the cooling of the detectors during operation is not only related to the control of the reverse annealing, but it is essential to keep the reverse current below the limit of thermal run-away. The operation temperature of the detectors is therefore not affected by the results concerning the reverse annealing.