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Charge trapping in oxygenated and control irradiated silicon detectors

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Outline:

- Irradiation details
- Questions left open in previous works
- Parameterisation of CCE curves
- Comparison of CCE between oxygenated and control detectors

Four miniature microstrip detectors (1x1 cm^2, 128 strips) produced by SINTEF were irradiated at room temperature and unbiased in the CERN-PS beam with 24 GeV/c protons. Two pairs of non-oxygenated and oxygenated devices were irradiated to $3 \cdot 10^{14}$ cm^{-2} and $4 \cdot 10^{14}$ cm^{-2}. A non irradiated non-oxygenated detector with identical characteristics have been used for reference.

Detector conventional name:	**Oxygenation**	**Irradiation dose [p cm^{-2}]**
S1	No	Non irradiated
S2	No	$3 \cdot 10^{14}$
S3	Yes	$3 \cdot 10^{14}$
S4	No	$4 \cdot 10^{14}$
S5	Yes	$4 \cdot 10^{14}$

Their 128 strips were bonded to a wide bandwidth current amplifier for the CCE studies. The CCE was obtained by the integral of the averaged signal (from a ^{106}Ru source) on the oscilloscope.

A comparison between the CCE of oxygenated and control diodes was carried out using light spot from a 1060 nm laser. The results gave a figure of ~50V shift of the CCE curve to lower biases whit oxygenated substrates.
The normalisation of the CCE curve of irradiated devices was obtained using the maximum charge collected with strong over-depletion (~2 V_{FD}) biases. Is this normalisation reliable enough?
Using this normalisation would imply no relevant difference between the different substrates in term of *permanent trapping*.
An absolute normalisation can be obtained using m.i.p.'s.

We analysed the CCE curves using a parameterisation that allows the extraction of the V_{FD} and of the trapping. The fraction Δq of the charge Δq_0 released in an arbitrary position x_0 in the active volume that survives to the trapping after a distance dx in the detector can be expressed by:

$$\Delta q = \Delta q_0 \exp\left\{-dx \middle/ \lambda(E_0)\right\} \qquad (1)$$

The trapping is inversely proportional to the velocity of the charge carriers. The velocity of the charge carriers is proportional to the electric field E until saturation and it is usually parameterised as:

$$v(E) = \mu_{e,h} E \Big/ \left[1 + (\mu_{e,h} E / v_S)^{\gamma}\right]^{1/\gamma}$$

We can define a mean free path, λ, proportional to the velocity and finally to the electric field as follows:

$$\lambda(E) = \lambda_0 + \Lambda E$$

where λ_0 is the mean free path with no electric field and Λ is expressed in $\mu m^2 V^{-1}$.

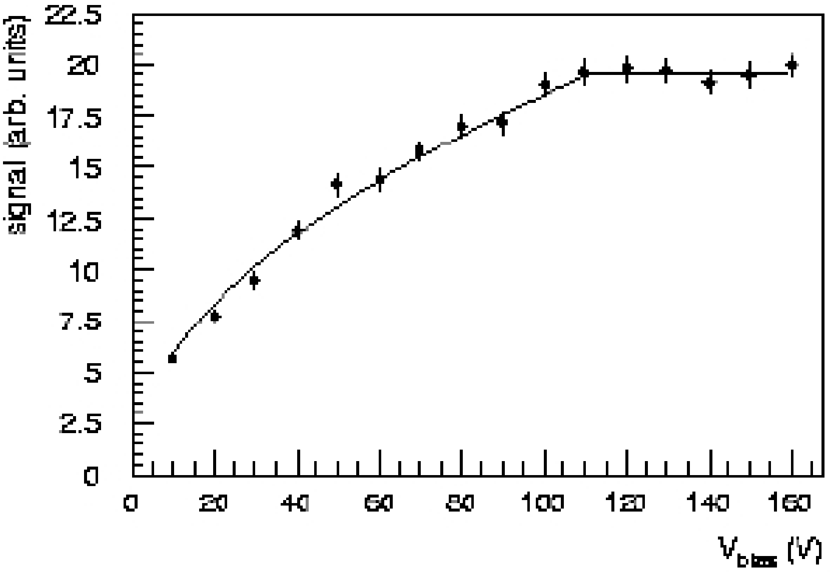
The saturation velocity is practically never reached at the voltages we biased the detectors, so no correction have been introduced to the linear dependence of Λ on the electric field. The electric field distribution through the detector depth is assumed to be linear, like in non irradiated devices.

The total charge collected by the detector is given by the integral over the whole detector thickness of the first expression and the maximum collected charge by an irradiated detector is the total injected charge decreased by the fraction of charge trapped when the velocity is saturated in the detector, namely

$$q_M = q_0 \frac{(\lambda_o+\lambda_E)}{w}\left\{1-\exp\left[-w/(\lambda_0+\lambda_E)\right]\right\}$$

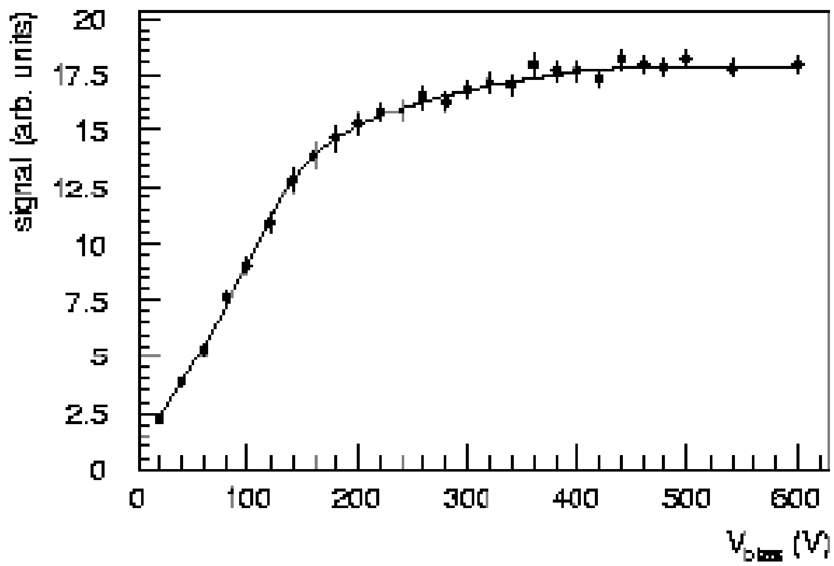
We fit the CCE data with the function (1) computed on 300 points (with dx = 1μm).

CCE of non-irradiated device (fitting using the linear dependence of the CCE on the square root of the applied bias)

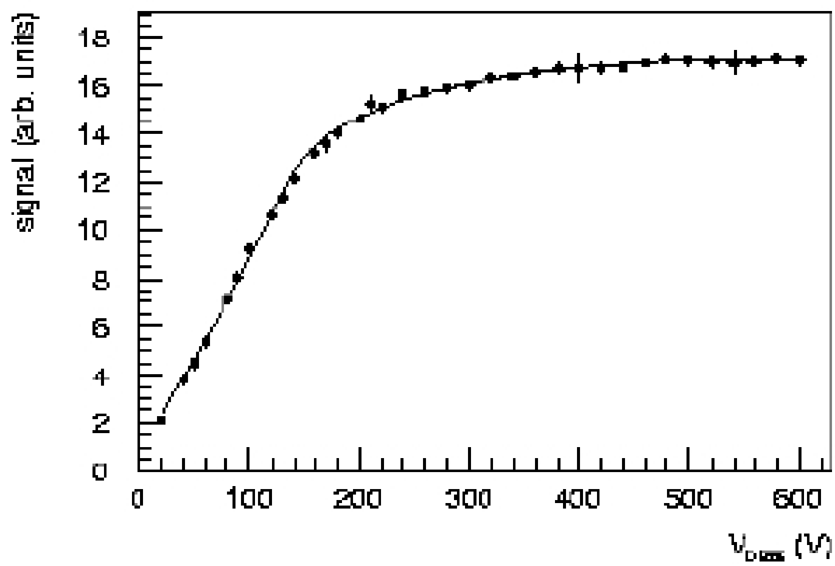


CCE of standard and oxygenated detectors irradiated to $3*10^{14}$ p cm^{-2}.

Oxygenated

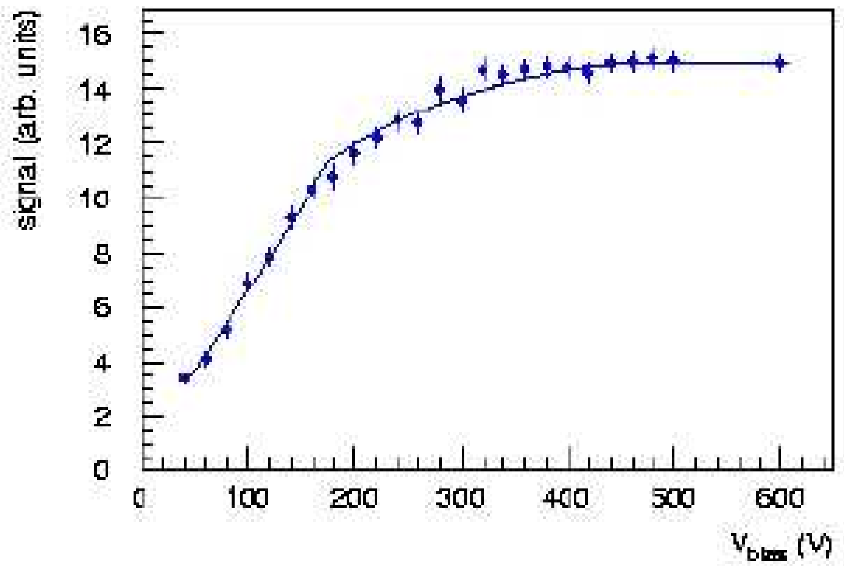


Standard

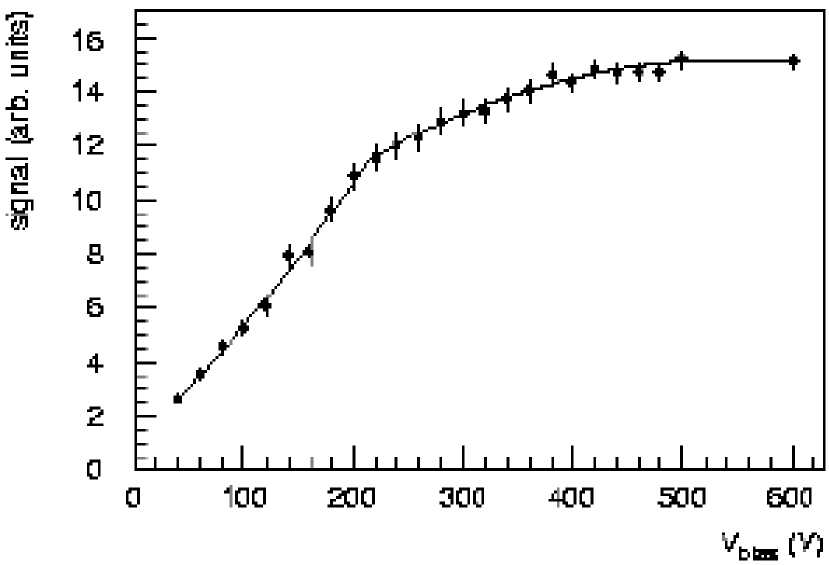


CCE of oxygenated and standard detectors irradiated to $4*10^{14}$ p cm^{-2}.

Oxygenated



Standard



Parameters from the fit:

Det. name	q_o (arb. units)	V_{FD} (V)	λ_0 (μm)	Λ (μm^2 V^{-1})	q_M/q_o (%)
S2	19.9 ± 0.9	136.2 ± 2	188 ± 6	1000 ± 250	91 ± 4
S3	18.5 ± 0.7	138 ± 5	206 ± 10	1250 ± 90	87 ± 5
S4	19.9 ± 0.8	213 ± 5	184 ± 10	320 ± 90	76 ± 3
S5	18.7 ± 0.4	175 ± 11	204 ± 15	440 ± 50	77 ± 4

Conclusions

The oxygen enriched material gives a certain improvement in term of bias required for complete charge collection of heavily irradiated silicon detectors (as we and other documented in previous works). For this run with this producer the improvement can be quoted in ~40 volts for the detectors irradiated to $4 \cdot 10^{14}$ 24 GeV/c protons cm^{-2}, while no difference has been observed for the detectors irradiated to $3 \cdot 10^{14}$ cm^{-2}. The level of the plateau of the charge collection is the same for the oxygenated and non-oxygenated detectors after the two different doses of irradiation, implying no relevant differences in the permanent charge trapping between these substrates. The improvement of the charge collection in heavily irradiated oxygenated detectors is probably mainly due to the reduction of the space charge concentration (and therefore of V_{FD}) in respect of non-oxygenated devices.
We could estimate the effect of the trapping by the ratio of the charge collection at V_{FD} to the maximum charge. We found that only ~72% of the charge is collected at full depletion in heavily irradiated detector.
The charge deficit after irradiation is evaluated for the two given doses by comparison to the pre-irradiation value and is ~10% after $3 \cdot 10^{14}$ cm^{-2} and ~23% after $4 \cdot 10^{14}$ cm^{-2}.