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Depletion Voltage after Proton Irradiation with a Fluence of 10^{14}p/cm^2

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ABSTRACT

The depletion voltage of radiation damaged silicon detectors is a function of the time elapsed since irradiation, normalized with anneal times which are temperature dependent .

TEMPERATURE CONTROL:

The reason for the strict temperature control in silicon detector irradiations is the fact that the observed depletion voltage is a function of both the applied fluence and the operating temperature during irradiation and annealing. For intense irradiation as performed for ATLAS, the initial depletion voltage right after beam shut-off is up to a factor 4 higher than at the minimum, which is reached after a short-term annealing governed by the short term anneal time τ_s. With increasing time, the depletion voltage increases again, the so-called anti-annealing, with a characteristic long-term anti-anneal time τ_l. The lowest depletion voltage is reached at a time long with respect to τ_s and short with respect to τ_l. For very large fluences of 10^{14}p/cm^2 and above, during irradiation with constant flux F, the depletion voltage V_D is given by the following approximation [1] :

$$V_D = vz*F*t+vs*F*\tau s*[1-\exp(-t/\tau s)]+va*F*\{t+\tau l*[-1+\exp(-t/\tau l)]\}$$

and after an instantaneous fluence ϕ, and elapsed time dt, the depletion voltage is approximately:

$$V_D\ (dt)= \phi*\{vz+vs*\exp(-dt/\tau s)+va*[1-\exp(-dt/\tau l)]\}$$

To first order, the constants v are independent of fluence and temperature and have been measured to be:

constant minimum :	$vz=1.06*10^{-12}$ V-cm^{-2}
short-term:	$vs=3*10^{-12}$ V-cm^{-2} [2]
long-term:	$va=3.8*10^{-12}$V-cm^{-2}

As pointed out before, the lowest depletion voltage is reached when: $\tau_s << t << \tau_l$. Both anneal times are independent of fluence and are a function of the operating temperature alone:

$$\tau_s= 70*\exp(-0.175T) \text{ days}$$
$$\tau_l= 9140*\exp(-0.152T) \text{ days} \quad , \quad T \text{ in } ^oC.$$

Table I shows the anneal times as a function of temperature. We find that $\tau_l \approx 200*\tau_s$. It should be noted, that for the LHC, where the duration of irradiation is several years, we plan to operate at -10^{o}C. Here where the times are of the order days, an elevated temperature gives the

[1] H.-J. Ziock e*t al*, Nucl. Instr. & Meth., **A342**, 96 (1994)
[2] the value of $1.34*10^{-12}$ in Ref.1 is an underestimate

minimum depletion. From Table I, we found an optimal operating temperature of 10^{o}C. If we ensure that the initial damage is annealed out, the uncertainty in the exact size of this part which anneals out short-term is irrelevant.

Table I

T[^{o}C]	t_s [days]	t_s [hrs]	t_l [days]
-10	403	9670	4.18e+04
-5	168	4030	1.95e+04
0	70	1680	9140
5	29.2	700	4270
10	12.2	292	1999
15	5.07	122	935
20	2.11	50.7	437
25	0.881	21.1	20
30	0.367	8.82	95.6
35	0.153	3.67	44.7
40	0.0638	1.53	20.9
50	0.0111	0.266	4.57

Fig 1 graphically describes the depletion voltage as a function of time assuming an instantaneous fluence of 10^{14}/cm^2 -which is correct for irradiation at -10^{o}C where the anneal time is very long . It is clear that in absence of a precise accounting of the anneal times, the depletion voltage can vary by a large factor. Note that the minimum depletion voltage is very well defined and a unique function of the fluence. Given several devices with the same fluence received, one can guess the fluence from the smallest depletion voltage measured.

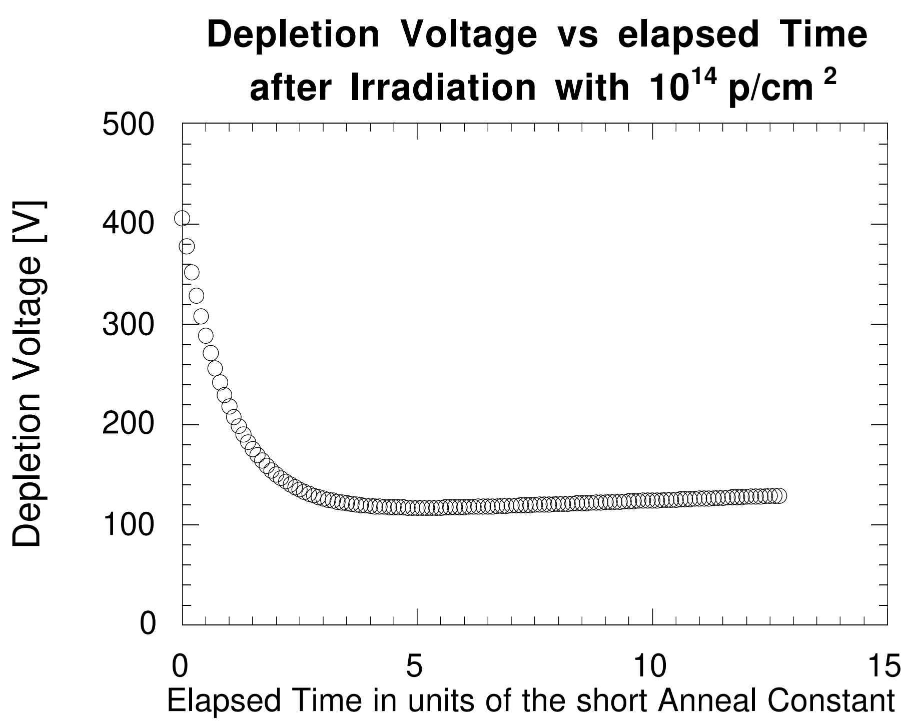

Fig 1 Predicted depletion voltage as a function of time after an instantaneous fluence of 10^{14}/cm^2. The elapsed time is in units of the short term annealing constant τ_s..

An additional constraint on the fluence can be derived from the observed leakage current. At room temperature, the longest anneal time is of the order 25days, being responsible for the last factor two in annealed current. Thus, for short anneal times and low temperature operation, the observed leakage current constant should be at least twice the long-term current constant, i.e. $\alpha \geq 5*10^{-17}$A/cm, when referred to 20^{o}C.

EXAMPLES

ATT7 measured in the 1996 H8 test was irradiated to 10^{14}/cm^2 and it's exposure to higher temperatures was strictly limited (<30min@<50^{o}C). We observe a depletion voltage of close to 300V, as one would expect from Fig.1. It's current was about 1mA @ -10^{o}C, which gives a leakage current constant $\alpha \approx 4.6*10^{-18}$@-10^{o}C and $\alpha \approx 4.4*10^{-17}$@20^{o}C, as required This means that both with respect to the depletion voltage and the leakage current, the operating conditions for ATT7 were those expected after a fluence of $2*10^{14}$/cm^2.

Data from several detectors from the ATLAS SCT proton irradiation program subjected to a fluence of $7.6*10^{13}$/cm^2 were presented during the September 1996 SCT week.

> The response, i.e. pulse height vs. bias voltage, of the SINTEF detector analyzed by Petra Riedler is compatible with a depletion voltage of 60-100V. The current at -10^{o}C is about 0.15mA, corresponding to a leakage current constant $\alpha \approx 1.7*10^{-17}$@20^{o}C. No C-V curve is available yet.
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> The response data of the double-sided MPI detector analyzed by Rainer Richter shows almost identical S/N for both sides to quite small bias voltages. The depletion voltage seems to be below 60V.- to quote A. Chilingarov: "it looks like intrinsic"-. The leakage current of less than 0.2mA corresponds to a leakage current constant $\alpha \approx 2.5*10^{-17}$@20^{o}C, assuming the detector to be 280µm thick.
>
> David Robinson's C-V data on the MICRON detector show a depletion voltage of 18V.

The data from all three detectors are consistent with a common fluence of about $3*10^{13}$/cm^2 and a differing temperature history: the SINTEF detector seems to have received little annealing, while the MPI and MICRON detectors seem to have annealed out quite a lot. This prediction can be checked easily by adding up the time at elevated temperature divided by the short term anneal time for this temperature. Note that for fluences much below 10^{14}/cm^{2,} the donor removal and inversion effects make the fluence dependence of the depletion voltage much more complicated than indicated above.

RECOMMENDATIONS

For every detector, an individual temperature history has to be kept,
starting during irradiations.
Before any measurement, I-V and C-V curves have to be taken
to understand the depletion voltage.
The time development of the depletion voltage should be checked against
the integral of the ratio of warm-up time over short time anneal time τ_S(T).
The leakage current constant α should be computed to cross-check the applied fluence.
The response of the damaged detector should be tested with a front-end with fast shaping,
as proposed for the ATLAS SCT.