Physics 2980 Research in Physics Report

Andrew Thomas Kent

Department of Physics

Brown University

Professor Ulrich Heintz

May 2022

Chapter 1

Analysis

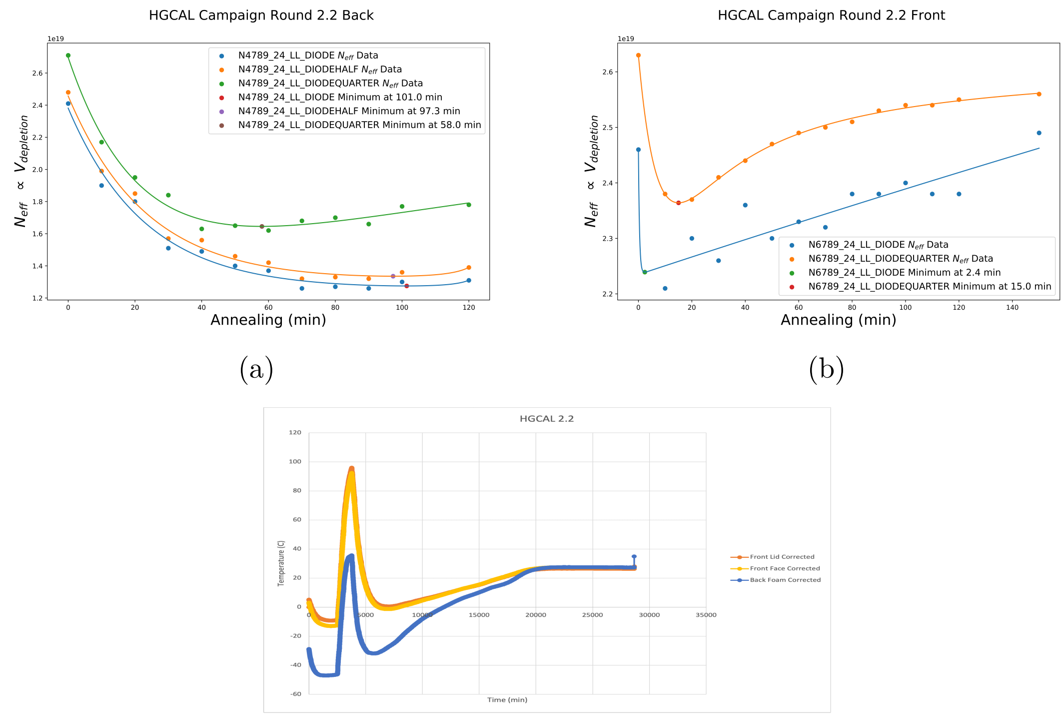
The following report involves using the Hamburg model to infer concurrent annealing and irradiation effects during use of the beamport at The Rhode Island Nuclear Science Center (RINSC) using HGCAL cutout silicon sensors.

1.1 Hamburg Model Analysis

This particular irradiation location experiences high temperatures throughout irradiation even when precautions are made (like filling the tube with dry ice), so better understanding how these effects are combined is critical to continued use of the beamport at RINSC and which may further lead to improvements on how those sensors are irradiated or greater understanding on the play between concurrent irradiation and annealing.

Within the different irradiation runs were also some D0 diodes (largely ineffective at giving reliable fluence estimates for irradiation times greater than 25 minutes due to the depletion voltage being greater than the 1100V limit), iron foils and full scale HGCAL hexagonal silicon diodes. The objective of this analysis was to try and shine a light on the interplay between annealing and irradiation during irradiation. The following grouping of plots constitute four of the seven different irradiation runs that I analyzed.

For the following analysis I will think of N_{eff} as a function of annealing time $N_{eff}(t)$, where $t_{min}^{60^oC}$ is the cumulative annealing at 60^oC which resulted in a minimum in $N_{eff}(t)$. Also, $\Phi_{eq}(t_{min}^{60^oC})$ is the fluence value which is extracted when using the data from the minimum of the $N_{eff}(t)$ curve. Finally, I will define A_{60^oC} as the cumulative equivalent annealing at 60^oC.



(a) (b) (c)

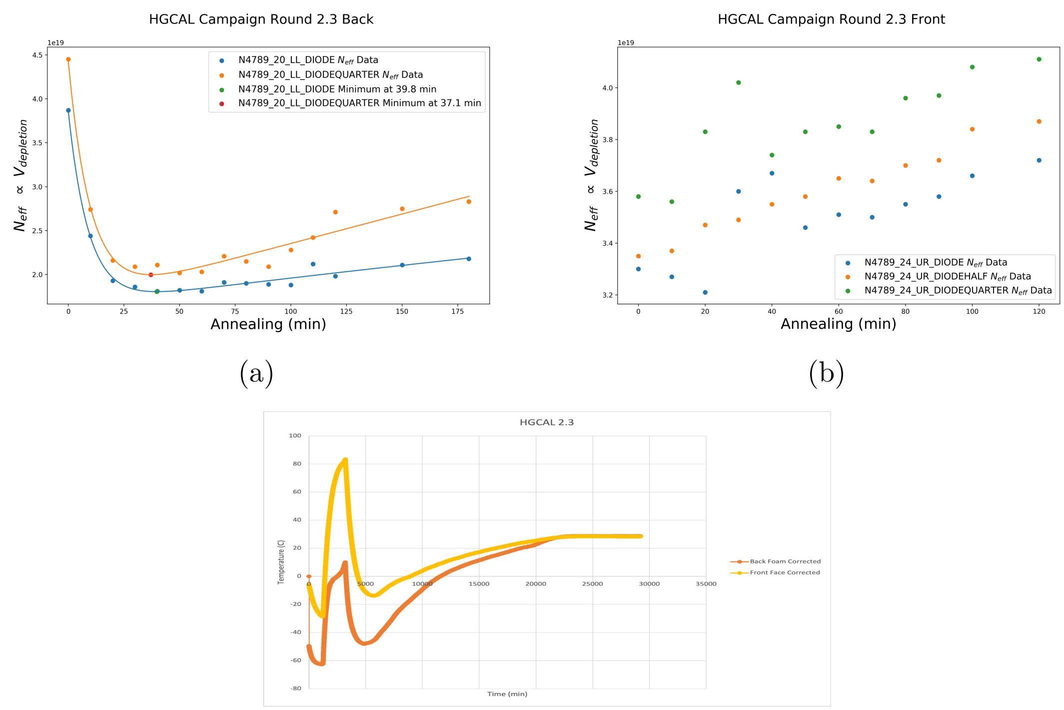
Figure 1.1: Hamburg analysis of HGCAL diodes irradiated at RINSC for 43 minutes. (a) HGCAL diode at back of beamport, (b) HGCAL diode at front of beamport, (c) temperature profile from start of irradiation to them being pulled out.

In HGCAL round 2.2 (figure 1.1) we can notice that the front diode experienced a higher temperature with a cumulative equivalent annealing at 60^oC of 504 minutes whereas the back diode experienced approximately 6.01 minutes of cumulative equivalent annealing at 60^oC.

Diode	Location	$t_{min}^{60^oC}$	$\Phi_{eq}(t_{min}^{60^oC})$	A_{60^oC}
DIODE	BP Front	15.0	9.54E+14	504
DIODEQUARTER	BP Front	2.4	1.08E+15	504
DIODE	BP Back	101.0	1.35E+15	6.01
DIODEHALF	BP Back	97.3	1.28E+15	6.01
DIODEQUARTER	BP Back	58.0	1.61E+15	6.01

Table 1.1: HGCAL Round 2.2 Extracted Hamburg Values

Therefore we expect the minimum of N_{eff} to occur at a lower cumulative annealing for the front diodes, this is in-fact the case and we can see that the DIODE for the front HGCAL cutout saw a minimum occur at 15.0 minutes where DIODE on the back HGCAL cutout had a minimum at 101.0. Although we expect a higher measured fluence for the cutout on the front of the beamport, the opposite is the case. From table 1.1 we can see that the fluence estimate is nearly 30% higher for the back DIODE than for the front.



(a) (b) (c)

Figure 1.2: Hamburg analysis of HGCAL diodes irradiated at RINSC for 86 minutes

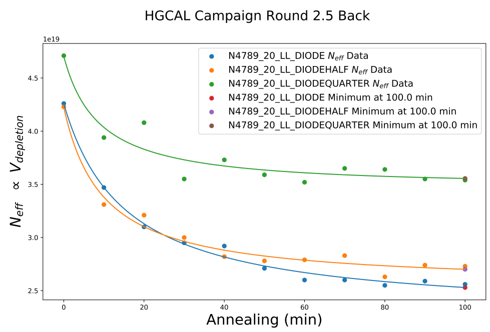
In HGCAL round 2.3 (seen in figure 1.2) we can see a very close agreement between the two diodes on the BP_Back HGCAL cutout while the BP_Front diodes seem to have experienced so much annealing during irradiation that they past the minimum ($N_{eff}(t_{min}^{60^oC})$) prior to being brought back from RINSC.

Diode	Location	$t_{min}^{60^oC}$	$\Phi_{eq}(t_{min}^{60^oC})$	A_{60^oC}
DIODE	BP Front	0	2.08E+15	374
DIODEHALF	BP Front	0	2.15E+15	374
DIODEQUARTER	BP Front	0	2.35E+15	374
DIODE	BP Back	39.8	2.78E+15	5.62
DIODEQUARTER	BP Back	37.1	3.09E+15	5.62

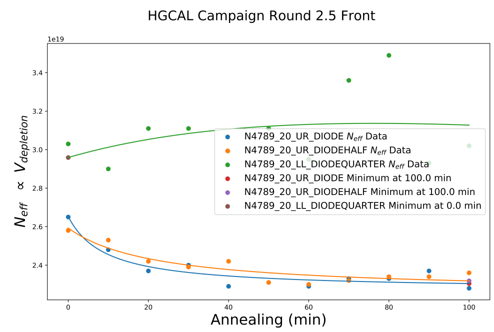
Table 1.2: HGCAL Round 2.3 Extracted Hamburg Values

This is confirmed by the data in table 1.2 which indicates the front diodes experienced 374 minutes of cumulative annealing at 60^oC to the back diodes 5.62 minutes. Although the cumulative annealing analysis would seem to indicate that $N_{eff}(t_{min}^{60^oC})$ should occur at ~ 70 minutes, we instead find that it occurs at ~ 40

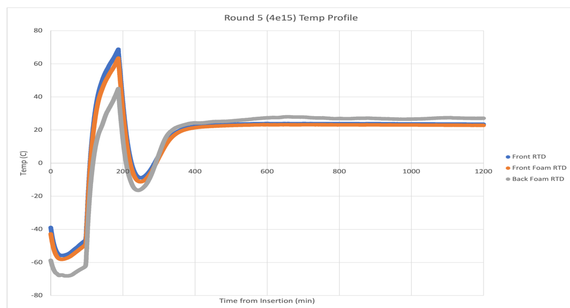
minutes. The fluence estimates for this round were again flipped from what we would have expected them to be, with the front DIODE measuring $2.08 \cdot 10^{15}$ n/cm^{-2} to the back DIODE's $2.78 \cdot 10^{15}$ n/cm^{-2}, a 33% difference between the two.



(a)



(b)



(c)

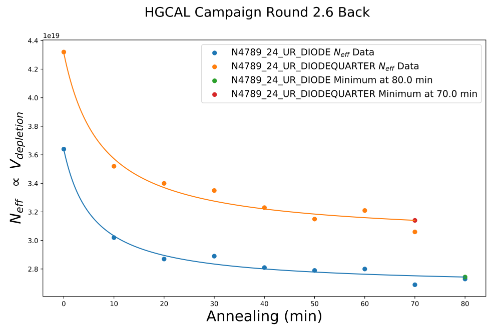
Figure 1.3: Hamburg analysis of HGCAL diodes irradiated at RINSC for 86 minutes

HGCAL round 2.5 was irradiated for 86 minutes, and although the diodes on the front and back experienced very different cumulative equivalent annealing (69.17 minutes for the front and 11 minutes for the back) their N_{eff} vs. Annealing graphs showed very similar results.

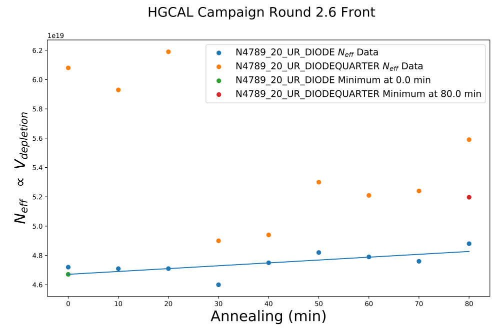
Diode	Location	$t^{60^oC}_{min}$	$\Phi_{eq}(t^{60^oC}_{min})$	A_{60^oC}
DIODE	BP Front	100.0	2.81E+15	69.17
DIODEHALF	BP Front	100.0	2.90E+15	69.17
DIODEQUARTER	BP Front	NA	3.31E+15	69.17
DIODE	BP Back	100.0	2.35E+15	11
DIODEHALF	BP Back	100.0	2.93E+15	11
DIODEQUARTER	BP Back	100.0	3.35E+15	11

Table 1.3: HGCAL Round 2.5 Extracted Hamburg Values

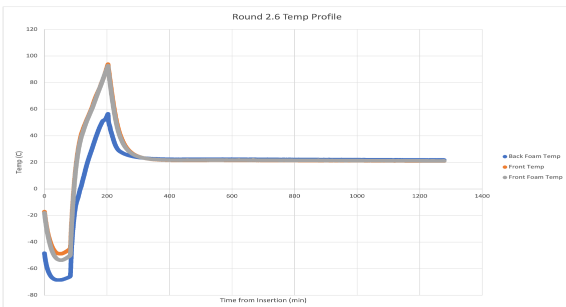
In table 1.3 we can see that the fluence value for the front DIODE was in fact higher than the back, which is what we expect should happen. Its not quite clear what happened in BP_Front DIODEQUARTER, though since this is the smallest diode it is not cause for concern and should be dismissed.



(a)



(b)



(c)

Figure 1.4: Hamburg analysis of HGCAL diodes irradiated at RINSC for 118 minutes

HGCAL round 2.6 was another one of the longer irradiation runs at 118 minutes, and we can see the effects of the longer irradiation in the front HGCAL cutout.

Diode	Location	$t_{min}^{60^oC}$	$\Phi_{eq}(t_{min}^{60^oC})$	A_{60^oC}
DIODE	BP Front	0	2.86E+15	739.3
DIODEQUARTER	BP Front	0	3.35E+15	739.3
DIODE	BP Back	80.0	3.68E+15	20.6
DIODEQUARTER	BP Back	70.0	4.16E+15	20.6

Table 1.4: HGCAL Round 2.6 Extracted Hamburg Values

In table 1.4 we can see what is partially reflected in figure 1.4, that a cumulative equivalent annealing of 739.3 minutes was more than significant enough to push N_{eff} into the region where each successive annealing step resulted in a higher N_{eff}. Looking at the diodes in the back of the beamport we register a cumulative equivalent annealing of 20.6 minutes and so suspect a minimum to occur at around 60 minutes. Further measurements need to be taken in order to better understand the overall curve.