Thermal Issues with GLAST Silicon Detectors in Space

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Abstract
We evaluate the self-heating of the GLAST silicon detectors in flight due to the leakage current caused by ionizing and displacing radiation. We establish the existing safety margins and specifications for the thermal contact of the detectors to the trays.

BACKGROUND

Self-heating of radiation damaged silicon detectors has been a concern for the large experiments at the Hadron Colliders [1,2]. The design of the ATLAS ladders has been driven by this concern [3]. The problem arises from the exponential dependence of the leakage current I on the temperature T [4]

$$I(T) = I(T_o) * (T/ T_o)^2 * \exp\{-E_b/2(1/(kT)-1/(kT_o))\}, \qquad (1)$$

with E_b = 1.2eV the silicon band gap. Close to zero degree C, for small temperature excursions ΔT (in degree C) this can be simplified to

$$I(\Delta T) = I_o * \exp\{\alpha * \Delta T\} \quad , \qquad (2)$$

with $\alpha = 1 / 11$. Assuming one end of the detector is held at temperature T_o, any location at the temperature $T_o + \Delta T$ will generate heat with a heat flux

$$q(\Delta T) = q_o * \exp\{\alpha * \Delta T\} \quad , \qquad (3)$$

where $q_o = I_o * V / A$ is the heat flux generated at the cooled end, V is the biasing voltage and A is the area of the detector. For example, for GLAST at end-of-mission, 5x design margin of the radiation dose and 25 ^oC, the expected leakage current is 11.2µA per detector [5], i.e. with a bias voltage of 100V:

$$q_o = 1.4*10^{-7}\ [W/mm^2] \quad . \qquad (4)$$

The increased heat will increase the temperature, followed by increased generation of leakage current, which increases the heat and thus temperature and so on. As shown in Ref [2], if the heat is not removed efficiently, for example because it has to be conducted for a long distance in thin silicon detectors, this can lead to thermal run-away. It turns out that thermal run-away occurs for a critical heat flux q_c and at a critical temperature T_c, where

$$T_c = T_o + 9 / (8\alpha) = T_o + 12^oC \quad . \qquad (5)$$

The critical heat flux q_c is evaluated at T_o and depends on the heat conductivity (K = 0.15 [W/(mm-^{o}K)] for Si), the thickness of the detector t =0.4 [mm], and the square of the length L of the conduction path (e = 2.72):

$$q_c = 2 * K * t / (e*L^2) * 9/ (8\alpha) \quad . \qquad (6)$$

GLAST CASE

To evaluate the potential of the GLAST detectors for run-away, we will evaluate the critical heat flux under the unrealistic assumption that the thermal contact is done only at the cooled end, i.e. L = 360mm,

$$q_c = 4.2*10^{-6} \ [W/mm^2], \ L = 360mm \quad . \qquad (7)$$

A more realistic assumption is that the detectors are connected to the cooling at every detector, i.e. that the heat flows only half the detector length at the maximum (L = 89.5/2mm) :

$$q_c = 2.7*10^{-4} \ [W/mm^2], \ L = 45mm \quad . \qquad (8)$$

Comparing Eq. (8) with Eq. (4), shows that if the GLAST detectors have good thermal contact to the tray at the every detector, the safety margin in detector current is about 2,000.

The maximum temperature increase expected is given by

$$T_{max} = q_o* L^2 / (2Kt) = 0.002\ ^oC \quad , L = 45mm. \qquad (9)$$

On the other hand, if the detectors would be run at 60 ^{o}C, and cooled only at the end of the ladders (L = 360mm), the expected heat flux of $1.7*10^{-6}$ [W/mm ^{2}] would be only a factor 2 from the critical heat flux and the temperature would rise by almost 2degrees across the detector.

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HEAT CONTACT between DETECTORS and TRAYS

The heat generated in one detector is Q=1.1mW at end-of-mission, 5x design margin of the radiation dose and 25 ^{o}C. Assuming one heat contact per detector, this heat must be conducted to the tray with only small temperature increase of the silicon (say <0.1 ^{o}K to include same safety). If we assume 25% areal coverage with glue, the combined heat conductivity K_T of the epoxy + Kapton + Face sheet+ closeout is determined from

$$Q = K_T * (0.25*A / d) * 0.1 \quad , \qquad (10)$$

where d is the length of the conduction path, and:

$$K_T > Q * (d / 0.25*A) / 0.1 \quad . \qquad (11)$$

Assuming that the tray structure is well conducting, and a conduction path of d = 0.5mm, the requirement for the heat conductivity of the sensor contact is not stringent:

$$K_T > 3*10^{-6} \ [W/(mm-{}^oK)] \quad . \qquad (12)$$

CONCLUSIONS

The GLAST silicon detectors have a large safety margins against thermal run-away, and the requirement for the thermal contact between detectors and the tray structure is not very stringent.

REFERENCES

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