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Thermal simulation of ATLAS barrel SCT modules - I

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Abstract

A finite element thermal analysis is performed for the various configurations of the ATLAS barrel SCT module. The design of the module are based on the recent proposal by RAL to reduce the overall radiation thickness of the module. Its several variations are also evaluated. The main goal of the present calculation is to estimate the safety margin for the thermal runaway.

1. Module models

Eight different module geometries as listed in Table 1 are evaluated. Figure 1 shows the mod-

Table 1 Module models

model	description
model-RAL	Original model given by RAL in mid March, 1997
model-1	BeO picture-frame baseboard
model-2	model-1 but with a longer PG basebaord
model-3	model-1 but the baseboard is all made of PG
model-4	model-3 with no thermal connection on the other bridge side
model-5	model-3 added by BeO stiffeners on both sides of PG tongues.
model-6	suggested by Y. Unno
model-8	model-6 but PG extended to the cooling-side edge

el-RAL proposed by RAL in mid-March 1997. This design is a new attempt in order to reduce the effective material thickness of the ATLAS barrel SCT module.

Triggered by this attempt, variations of the design are proposed at KEK from models 1 to 8. Essential change is the shape and configuration of the baseboard on which both silicon microstrip detectors are attached. The baseboard provides not only the mechanical stiffness for support but also the thermal path from the detector to the cooling channel.

Figure 2 shows the configuration of the baseboard.

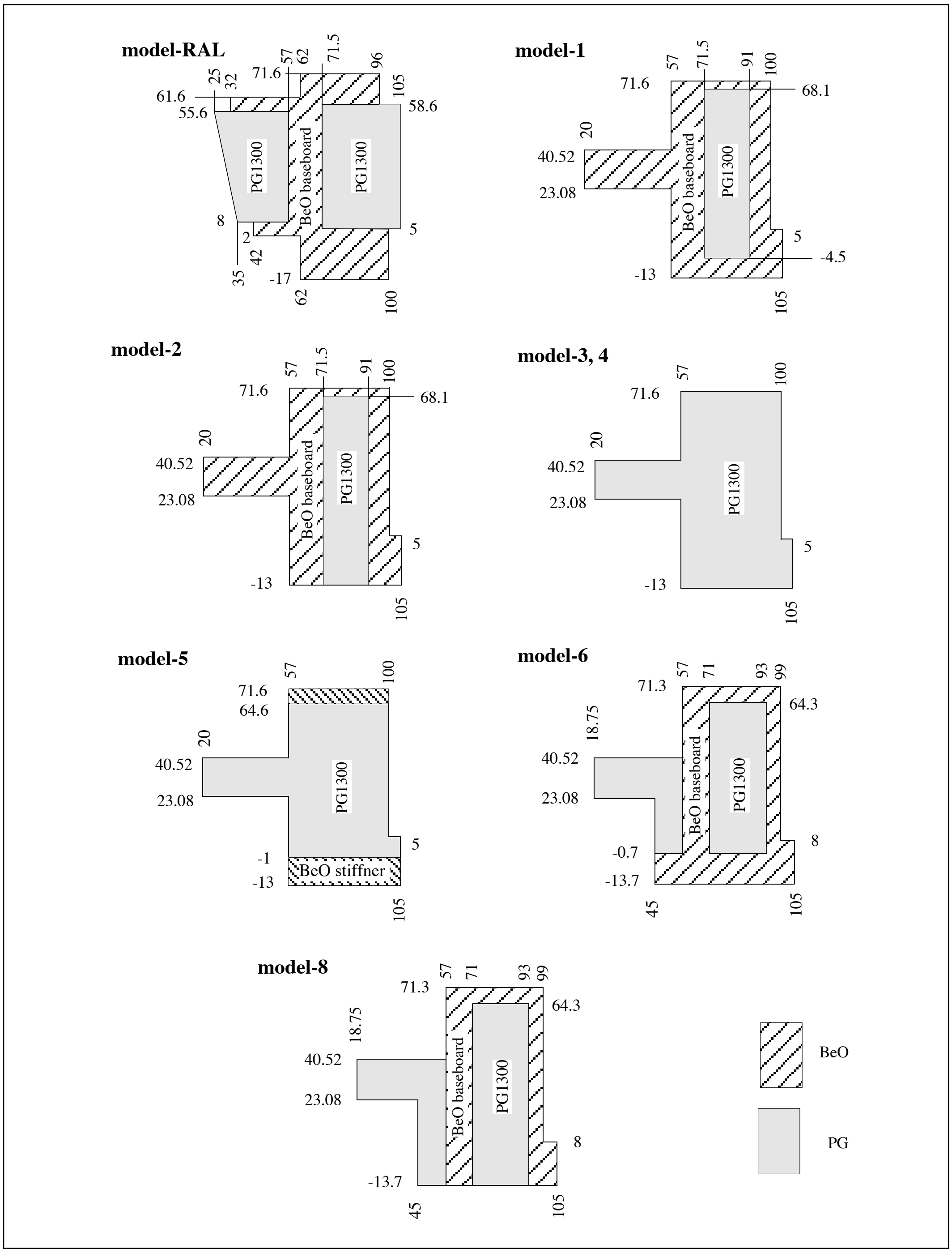


Figure 2 Design on the baseboard.

2. Thermal simulation

A finite-element thermal simulation is done using program ANSYS 5.1. A 3-D thermal and electrical solid elements is used. The thermal conductivity used in the program is listed in Table 2.

Table 2 Thermal conductivity of material used in the ANSYS simulation

material	conductivity (W/m·K)	material	conductivity (W/m·K)
silicon	130	BeO	280
PG1300	1300 (tangential) 3.5 (normal)	PG700	700 (tangential) 3.5 (normal)
thermal glue	0.5	Kapton hybrid	0.25
air	0.0245	BeO hybrid	280
quartz (fan-in)	0.15	bonding wire	150

For simplicity, the effects of surface convection and radiation emission are not included.

The cooling pipe is not included in the simulation. Instead, the temperature constraint is imposed at the contact of the cooling channel. The open triangle marks in the design figures show the location of this external constraint.

Heat generation in the electronics is simulated by usual bulk heat generation provided in ANSYS. The total heat generation in electronics is 3 or 4 Watts, corresponding to 1.5 or 2 W per side. 87% of the heat is assumed to be generated in the 1st chips (l x w x h = 7.2 x 4.0 x 0.35 mm^3) and the rest is generated in the 2nd chip (l x w x h = 7.2 x 5.5 x 0.35 mm^3).

The heat generation in the bulk of the radiation-damaged silicon detector is due to the bulk leakage current. The leakage current is known to have a strong temperature dependence:

$$I_{leak} \propto T^2 \cdot e^{-\frac{E_g}{2k_B T}}$$

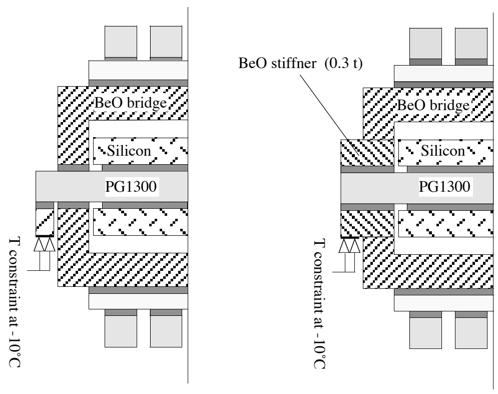
where E_g is the effective gap energy of about 1.23 eV and k_B is the Boltzmann constant. In ANSYS program, the electrical resistance of material can be made temperature dependent. An electro-thermal element is assigned for the bulk part of the silicon detector and it is assumed to carry an electrical conductance with the same temperature dependence as that of the leakage current. With this trick, one manages to simulate the temperature dependence of heat generation by the leakage current [1].

The thermal simulation has been demonstrated to work very well when it is compared with the thermal experiments using heater as well as actual radiation damaged detectors [1,2].

3. Results of thermal simulation

3-1. Thermal runaway point

Thermal simulation is performed for various models by varying the heat generation in the detector bulk. Since the heat generation strongly depends on temperature, it is decided to use the heat generation per mm^2 (of 300 μm thick silicon detector) at 0°C as a standard parameter. Actual heat generation is calculated using the T-dependence give above.



model-3 model-5

Table 3 Min and max of the $T_{silicon}$ at no bulk heat generation

model	T_{Si}min.(˚C)	T_{Si}max.(˚C)
model-RAL	-1.63	1.50
model-1	-3.37	0.53
model-2	-4.79	-1.03
model-3	-6.36	-3.47
model-4	-6.35	-3.91
model-5	-8.18	-5.42
model-6	-7.65	-4.45
model-8	-8.17	-4.91

including safety from the runaway point.

This view is noticed after all the calculation was finished. New series of simulation is of necessity in order to verify the present (tentative) conclusion as well as to find better module design.

References

[1] T. Kohriki et al., Cooling Test and Thermal Simulation of Silicon Microstrip Detectors for High Luminosity Operation, ATLAS Internal Note INDENT-NO-094.

[2] T. Kohriki et al., First Observation of Thermal Runaway in the Radiation Damaged Silicon Detector, IEEE Trans. Nucl. Sci. 43 (1996) 1200-1202