Coolant Tube Geometry Selection

Thermal solutions for the two cooling geometries of the 10-chip per module design were revised to include interface thermal resistances associated with the adhesives. The previous NASTRAN thermal solution for these two configurations resulted in -13.7ºC and -16.7 ºC module surface temperatures for the single U-Tube and Triple U-tube respectively. Referring to Figure 1 and Figure 2 we observe that the peak module surface temperatures are now -9.85ºC and -14.6ºC, respectively. The difference between the two types of solution, with respect to the effect on silicon surface temperature, is 3.85ºC and 2.1ºC respectively.

The peak chip temperatures for two solutions differ by 4.7ºC and 2.63ºC for the single U-Tube and Triple U-Tube respectively. Although, the differences are reasonably small, one will notice to maintain -25ºC at the module surface temperature would require approximately -32ºC and -37ºC coolant for the Triple U-Tube and the single U-tube coolant geometry respectively. This does not seem to be a big impact in either case, since for both solutions it was presumed that two-phase CO_2 coolant is used.

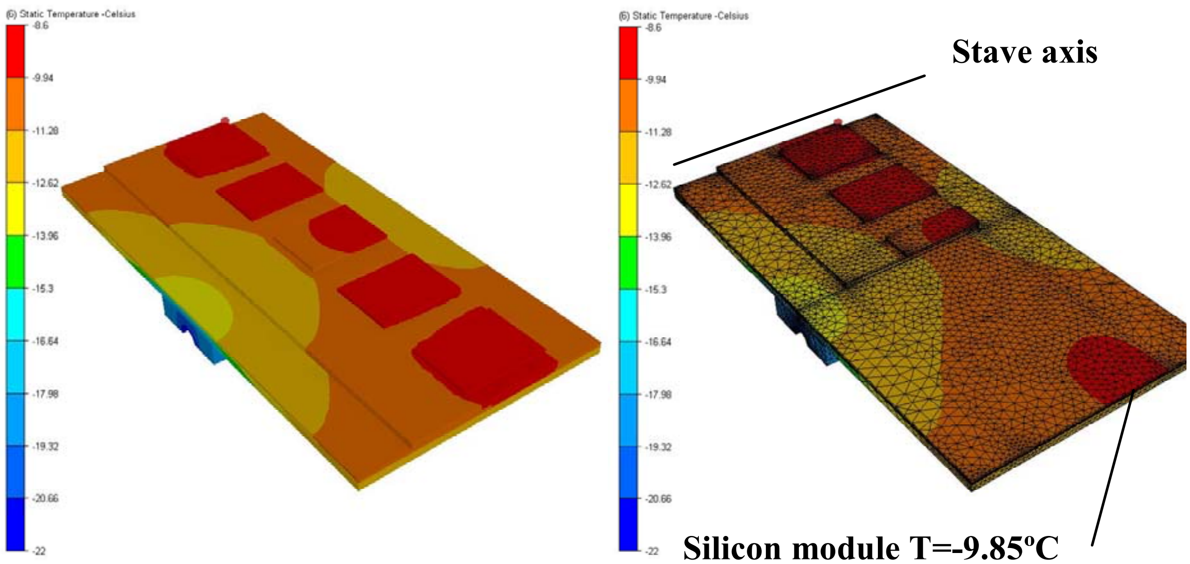

Figure 1: Thermal solution for single U-Tube with coolant wall at -22ºC. Peak chip surface temperature is -8.6 ºC.

There is an uncertainty in thermal conductivity chosen for the various interface materials. Table 1 lists the values used. For bonding chip to dielectric hybrid, Carl Haber uses silver adhesive with 1.55W/mK conductivity. I assumed the same material between the dielectric and BeO substrate. However, from the BeO to the module one might consider a filled adhesive (Al oxide or ALN). To keep the bond-line thickness at a minimum, there will be a limit the volume fraction of the additive. This material is assumed to be electrically non-conductive. This material might be used between the module, cable and cable to composite facing. An ALN CGL7018 or EG7658 like material is assumed for the joining of the POCO Foam to the composite and to the coolant tube. One will note for these materials I assumed a much lower thermal conductivity than quoted by the suppliers. One reason is unknown final thickness, and secondly, suppliers must achieve their results under very ideal situations, generally not duplicated by the users.

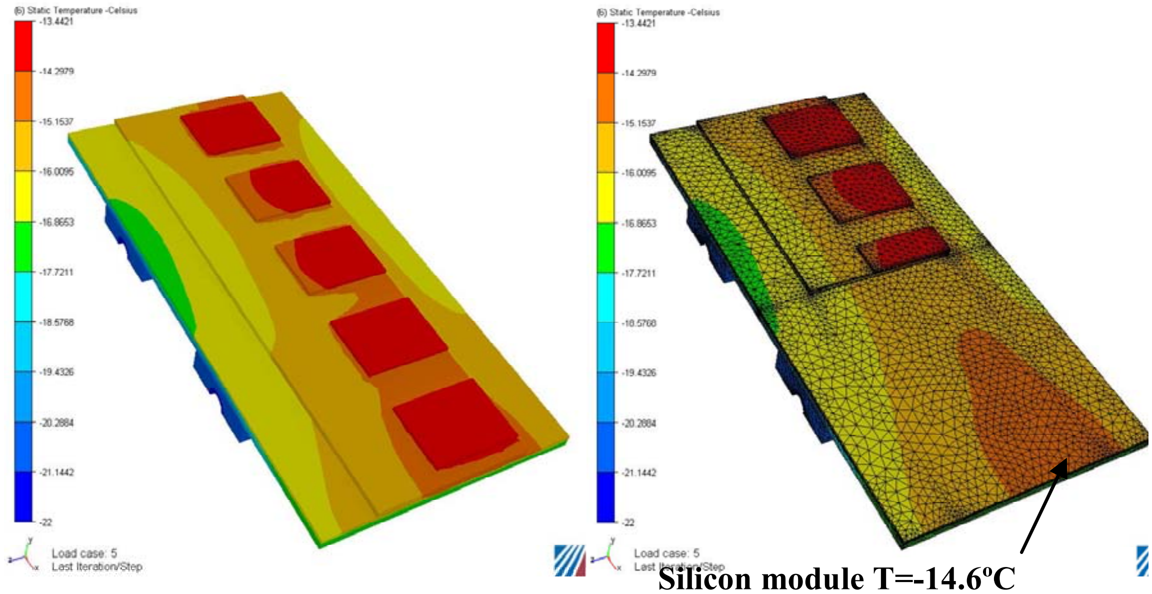

Figure 2: Thermal solution for Triple U-Tube with coolant wall at -22 ºC. Peak chip temperature is -13.44 ºC.

Table 1: Interface Material Conductivities Used in Thermal FEA.

Interface	Interface Thickness (inches)	Thermal Conductivity (W/mK)
Chip to Dielectric Hybrid	0.002	1.55
Dielectric to BeO Substrate	0.002	1.55
BeO to Silicon Module	0.002	0.8
Module to Cable	0.002	0.8
Cable to Composite Facing	0.002	0.8
Composite Facing to POCO	0.004	1.0
POCO to Coolant Tube Wall	0.004	1.0

Composite Facing Fiber Orientation

For a stave supported at the extreme ends, the fiber orientation choice favored concentration along the stave axis. This led to a 4:1 fiber orientation. However, when faced with the potential option for a few additional supports along the stave length, i.e., involving a cylindrical structure, one should consider changing the fiber orientation to favor thermal aspects. In this connection, comparative solutions were made for a balanced 2D lay-up. K1100 fiber was included in this comparison, since this fiber has a noticeably higher conductivity than K13D2U; both have the same axial modulus.

The question might arise as to the benefit of increasing the thermal conductivity of the composite facing, *through its thickness*. A solution with an arbitrary value of 50W/mK was used in this comparison. From Table 2, we see that the difference is not great, an improvement of 1.65ºC in module temperature for the single U-Tube design. The underlying reason is that heat flux along the POCO Foam tube interface is reasonably low. The heat spreading in the entire structure from the chips on down was shown in the previous NASTRAN was shown to be extremely beneficial in this regard.

Upgrading the fiber to K1100 would reduce the chip and module temperatures by 2.37ºC and 2.55ºC respectively. This was illustrated for the single U-Tube geometry, since the effect would be less for the Triple U-Tube design.

Table 2: Thermal Stave Solutions Using CFD Design. Interface Materials listed in Table 1 for Coolant Tube Wall Temperature of -22ºC.

Fiber	Lay-up	Cable K (W/mK)	Chip Peak Temp. (ºC)	Module Peak Temp. (ºC)	Cooling Tube
K13D2U(386/97/1.44)	4:1	0.12	-8.6	-9.85	Single U-Tube
K13D2U(240.8/240.8/1.44)	1:1	0.12	-10.6	-11.9	Single U-Tube
K13D2U(386/97/1.44)	4:1	0.12	-13.44	-14.6	Triple U-Tube
K13D2U(240.8/240.8/1.44)	1:1	0.12	-15.2	-14.1	Triple U-Tube
K1100(301/301/1.44)	1:1	0.12	-10.97	-12.4	Single U-Tube
K13D2U(386/97/*50*)	4:1	0.12	-10.37	-11.5	Single U-Tube
K13D2U(386/97/1.44)	4:1	*0.35*	-10.14	-11.3	Single U-Tube

Comment on Heat Fluxes

As a matter of checking the temperature drop at several faces were hand calculated and compared to the CFDesign solution. For the assumed adhesive thicknesses and values of conductivities, one can see that the temperature drops are not particularly great, even in the high flux region of the coolant tube outer surface.

Table 3: Estimated Temperature Gradients through Specific Flux Regions for the Single U-Tube Geometry compared to CFDesign (CFD)

Region	Flux-(W/cm^2)	Heat-(W)	ΔT-(ºC)	CFD-(ºC)
Chip to Hybrid	0.896	0.5	0.293	0.295
Facing to POCO Foam Saddle	1.136	2.5	1.15	1.14 to 1.16
POCO Foam to Tube	2.285	2.5	2.32	2.34

Good contact between the cooling tube and the POCO foam is important. Accidentally doubling of the adhesive thickness from 0.004in to 0.008in will produce another two degrees of gradient.

The overall gradient from the chip surface to the inner of the cooling tube for the single U-Tube is 13.4ºC. This gradient decreased to 8.56ºC by changing to Triple U-Tube geometry, almost a 5ºC drop or a 57% improvement. No other change produced as significant drop.