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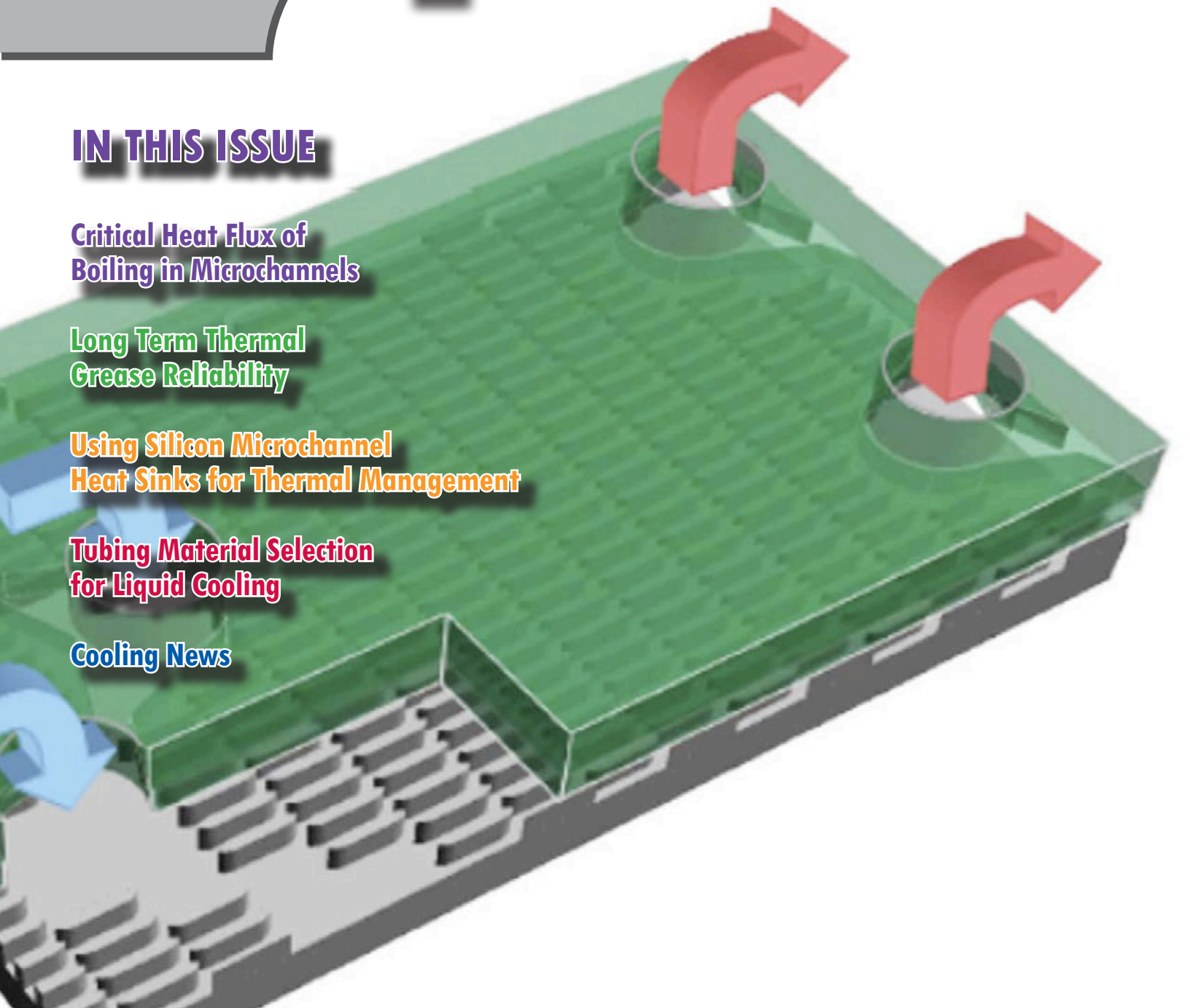

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EDITOR
KAVEH AZAR, Ph.D.
President & CEO,
Advanced Thermal Solutions, Inc.

MANAGING EDITOR
BAHMAN TAVASSOLI, Ph.D.
Chief Technology Officer,
Advanced Thermal Solutions, Inc.

NORTH AMERICA
ADVANCED THERMAL SOLUTIONS, INC.
89-27 Access Road Norwood, MA 02062 USA
T: 781.769.2800 | F: 781.769.9979 | www.qats.com

EUROPE
ADVANCED THERMAL SOLUTIONS, B.V.
De Nieuwe Vaart 50 | 1401 GS Bussum
The Netherlands
T: +31 (0) 3569 84715 | F: +31 (0) 3569 21294
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18 **Using Silicon Microchannel Heat Sinks for Thermal Management**

If high pressures with relatively low flow are allowable in a design, the microchannel heat sink is a very attractive option that can perform better than most coldplate designs. Reliability concerns about fittings or connections are heightened because of the increase in fluid pressure at the outlet of the pump and inlet of the cold plate.

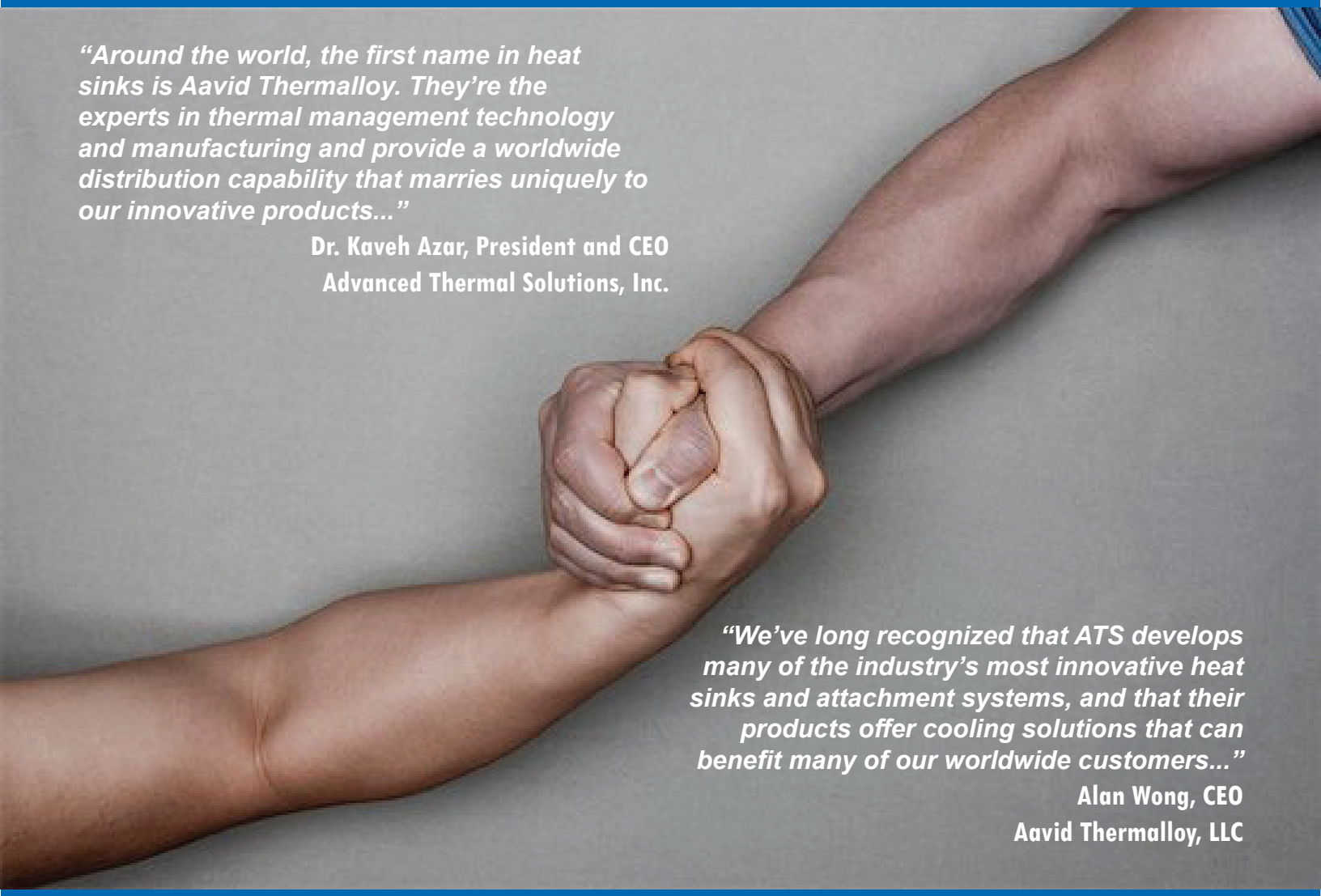
24 **Tubing Material Selection for Liquid Cooling**

Tubing can play a large role in the long term reliability of the solution. It is important to fully understand tubing characteristics, how they relate to evaporation, and how the loss of liquid affects the operation of the system (including pump cavitation and air blockage in a cold plate).

28 **Cooling News**

New products, services and events from around the industry.

TWO THERMAL MANAGEMENT POWERHOUSES JOIN FORCES



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Critical Heat Flux

of Boiling in Microchannels

The non-stop pursuit of faster computing speed and smaller package sizes is leading to more innovative chip cooling techniques. The ultimate goal is to reduce the thermal resistance from the chip junction to ambient, thus keeping the chip's junction temperature as low as possible. For high performance CPUs, graphics cards, power amplifiers and other devices, the simple air-cooling method has proven ineffective at dissipating high heat fluxes. Heat transfer methods such as heat pipes, vapor chambers, nano-materials, liquid cooling and miniature refrigeration systems have been attracting more interest.

A liquid-cooled microchannel heat sink has been shown to be a very effective way to remove high heat load. The single-phase liquid cooled microchannel has been used in many performance-critical applications such as laser diodes, RF power amplifiers and CPU cooling systems. Two-phase flow and boiling inside microchannels has an extremely high heat transfer coefficient. Its heat transfer ability is limited only by its critical heat flux (CHF). The CHF of boiling at a surface refers to the certain heat flux at which the surface heat transfer coefficient suddenly drops. Exceeding the CHF will lead to a sudden jump in surface temperature which will result in the failure of an electronic component.

Researchers realized that the critical heat flux correlation for a conventional size tube is not suitable for boiling inside microchannels due to geometry limits, flow pattern differences and surface tension effectiveness. The paper discusses recent studies on critical heat flux for small size channels.

Qu and Mudawar [1] measured the critical heat flux for a water-cooled microchannel heat sink containing 21 parallel channels. The channel's cross section is 215 × 821 μm and its length is 4.48 cm. The microchannel array was tested in a module as shown in Figure 1. Four thermocouples were installed along the channel to monitor temperature.

Deionized water was used as the working fluid. In the test, its mass flow velocity varied from 86 to 368 kg/m^{2}s. The test conditions are shown in Table 1.

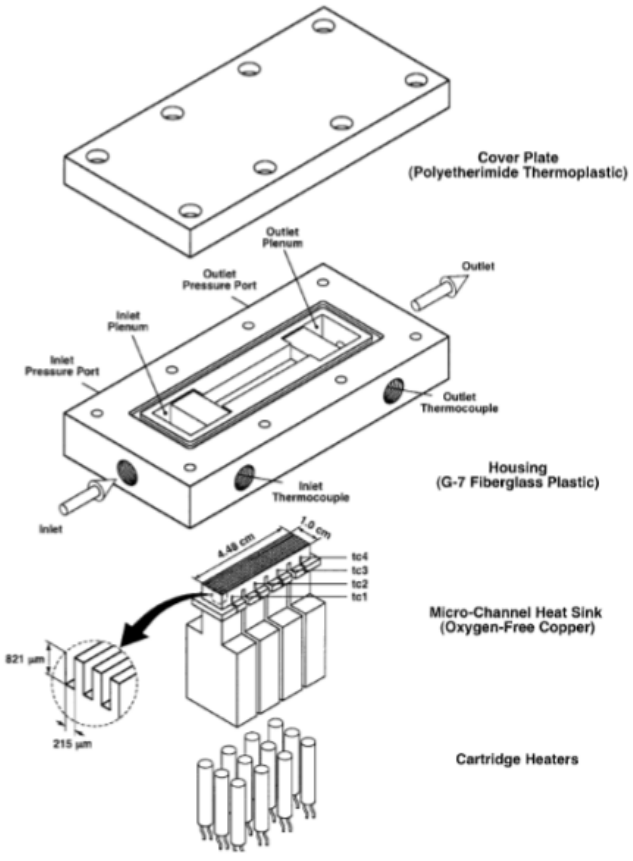

Figure 1. Microchannel Heat Sink Test Module [1].

Coolant	Inlet Temperature T_{in} (°C)	Mass Flow Velocity G (kg/m²S)	Outlet Pressure P_{out} (bar)	Pump Exit Pressure $P_{p,out}$ (bar)
Deionized Water	30.0	86–368	1.13	2.0
	60.0	86–368	1.13	2.0

Table 1. Operating Conditions for the CHF Study [1].

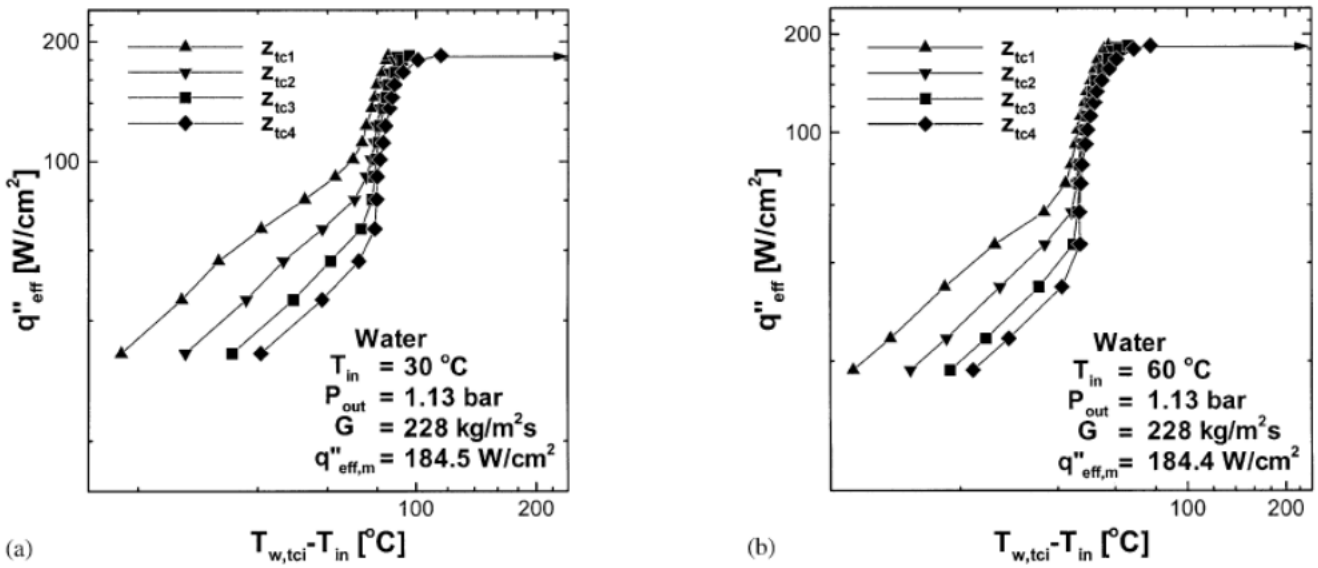

Figure 2. Boiling Curves Measured at z_{tc1} to z_{tc4} for: (a) G = 228 kg/m²s and T_{in} = 30˚C, and (b) G = 228 kg/m²s and T_{in} = 60˚C [1].

Figures 2(a) and 2(b) show typical boiling curves obtained at the four thermocouple locations for a mass flow velocity of 228 kg/m²s and inlet temperatures of 30 and 60 ˚C, respectively. Clearly the heat flux increases rapidly with small wall temperature increments after the boiling starts.

When the wall heat flux reached the CHF, the wall temperature began to jump. The measured CHF at different inlet temperature and mass flow velocity is shown in Table 2. In Table 2, $x_{e;out}$ is the thermodynamic equilibrium quality, $q''_{eff;m}$ is the CHF based on heat sink's top platform area, and $q''_{p;m}$ is the CHF based on the heated area inside the channel.

T_{in} (°C)	G (kg/m²s)	P_{in} (bar)	P_{out} (bar)	$x_{e;out}$	$q''_{eff;m}$ (W/cm²)	$q''_{p;m}$ (W/cm²)
32.16	85.9	1.213	1.131	0.524	107.64	26.91
30.66	124.2	1.231	1.127	0.398	126.48	31.62
31.66	159.2	1.271	1.133	0.376	154.94	38.74
31.46	194.5	1.285	1.129	0.310	164.93	41.24
30.65	228.0	1.310	1.135	0.288	184.48	46.13
30.60	263.2	1.331	1.130	0.250	193.64	48.42
30.54	299.5	1.309	1.123	0.214	200.00	50.01
30.65	336.1	1.331	1.132	0.178	201.66	50.42
30.63	368.4	1.324	1.139	0.172	216.76	54.20
59.00	85.9	1.223	1.131	0.562	105.66	26.42
60.69	124.2	1.249	1.135	0.434	121.69	30.43
60.50	159.2	1.310	1.141	0.424	153.21	38.31
58.96	194.5	1.314	1.131	0.361	164.60	41.16
60.69	228.0	1.366	1.140	0.344	184.43	46.12
59.34	263.2	1.375	1.132	0.295	189.59	47.41
60.88	299.5	1.398	1.135	0.283	207.33	51.84
59.94	336.1	1.393	1.143	0.233	201.59	50.41
59.63	368.4	1.375	1.133	0.214	207.85	51.97

Table 2. CHF Data for Water in a Rectangular Micro-channel Heat Sink [1].

Figure 3 shows the relation between CHF and mass flow velocity at different water inlet temperatures. The CHF increases with increasing mass flow velocity and has little dependence on inlet temperature.

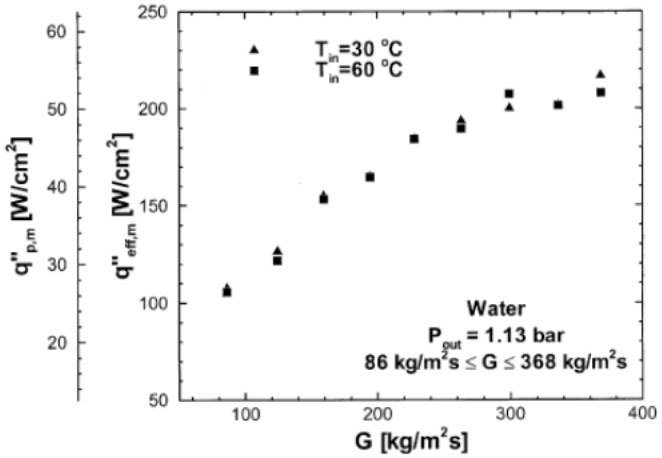

Figure 3. CHF vs. Mass Flow Velocity for Different Inlet Temperatures [1].

Wojtan et al. [2] conducted research on the CHF in single, uniformly heated microchannels. Experiments were performed to measure the CHF for R-134a and R- 245fa refrigerant flow boiling in rectangular microchannels. The microchannels' diameters were 0.5 and 0.8 mm, respectively. The test bench used is illustrated in Figure 4. The test section consisted of an 80 mm long stainless steel tube, used as a pre- heater, a 20 mm long glass tube for electrical insulation, a 110 mm long stainless steel tube with a heated section known as the microevaporator, and a 100 mm long glass tube for flow pattern visualization and optical measurements.

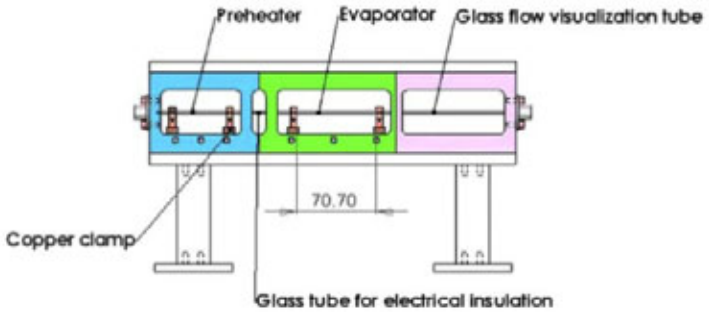

Figure 4. CHF Test Bench [2].

Parameter	Range	Units
Fluid	R-134a, R-245fa	–
Channel diameter D	0.50, 0.80	mm
Heated length L_h	20–70	mm
Mass flow velocity G	400–1600	kg/m²s
Heat Flux q	3.2–600	kW/m²
Saturation Temperature T_{sat}	30, 35	°C
ΔT_{sub}	2–15	°C

Table 3. Operating Conditions for the CHF Study [2].

Figure 5 shows the measured wall heat flux vs. ΔT for 0.5 mm channels at a mass flow velocity of 1000 kg/m²s with refrigerant R-134a. In this test, the wall heat flux increases almost linearly with a small increase of the wall temperature in the boiling process. The CHF is obtained at q = 163 kW/m². At this point, vapor generated at the wall surface is preventing the liquid from continuously wetting the surface. The sudden drop of the heat transfer coefficient leads to the sudden jump of wall temperature as shown in the figure.

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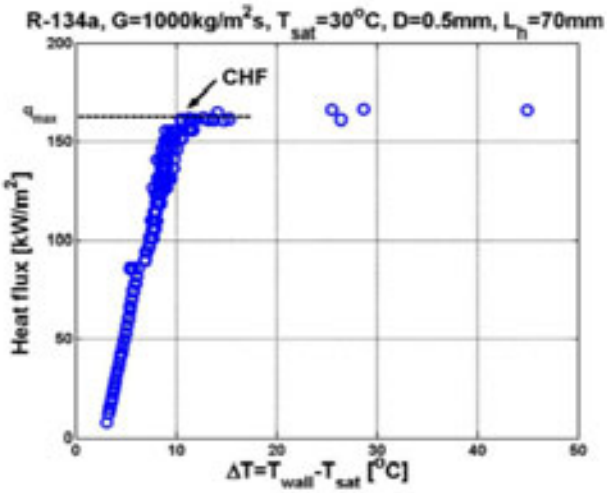

Figure 5. CHF of 0.5mm Channels at 1000 kg/m²s Mass Flow Velocity [2].

Figure 6 shows the relation between CHF and mass flow velocity for two different channels. The CHF increases with the increase of mass flow velocity. The 0.8 mm channel has a higher CHF than the 0.5 mm channel. Figure 7 shows the influence of the heated length on the CHF. The highest CHF was obtained by the shortest heated length.

The CHF curves for two different saturation temperatures are shown in Figure 8. It was found that at a mass flow velocity less than 1000 kg/m²s the CHF is almost independent of the saturation temperature. With the mass flow velocity larger than 1000 kg/m²s, tests with higher saturation temperature have a higher CHF.

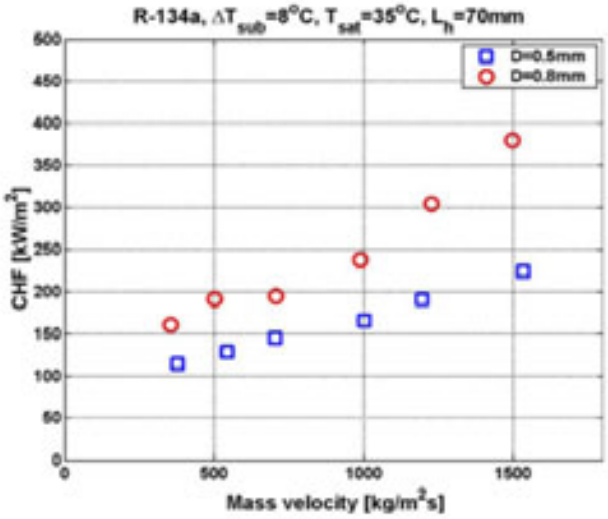

Figure 6. CHF vs. Mass Flow Velocity for Different Channels [2].

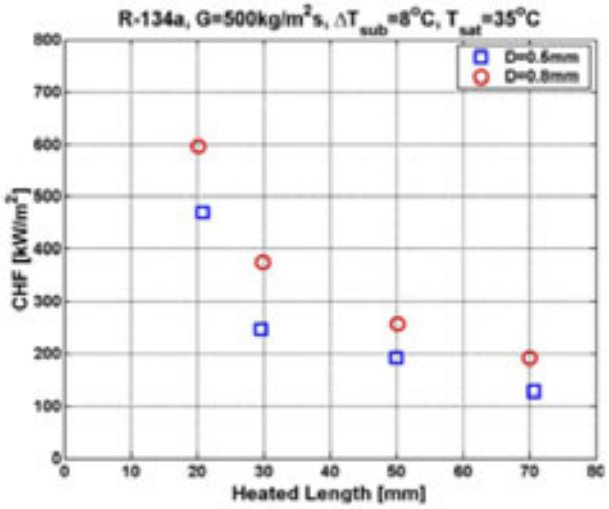

Figure 7. CHF vs. Heated Length for Different Channels [2].

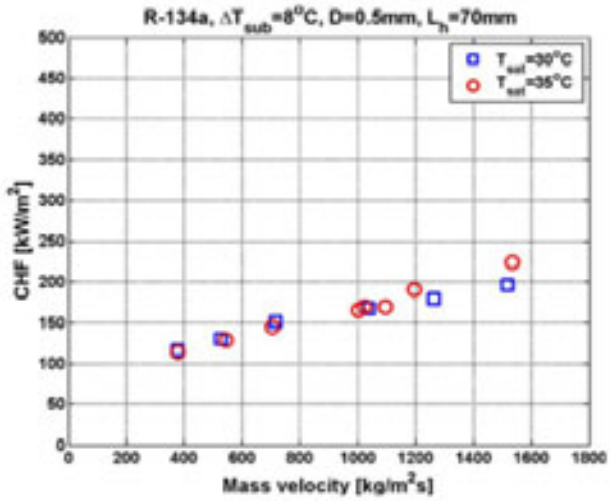

Figure 8. CHF vs. Mass Flow Rate for Different Saturation Temperatures [2].

From the studies of Qu and Mudawar, Wojtan et al, and other researchers, we can draw the following observation regarding critical heat flux in small and microchannels,

1. CHF directly links to channel geometry and diameter; larger diameter channel tend to have a larger CHF.

2. CHF increases with increasing mass flow velocity.

3. CHF is almost independent of the inlet temperature.

4. CHF has a certain dependency on saturation temperature, especially at high heat flux.

5. CHF has a strong dependence on heated length. Wojtan et al. found that CHF increases with decreasing heated length.

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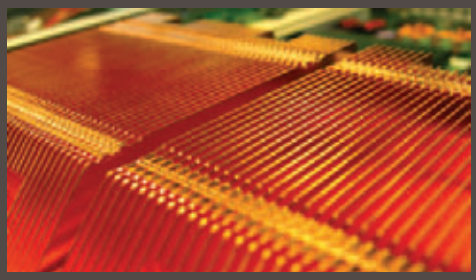

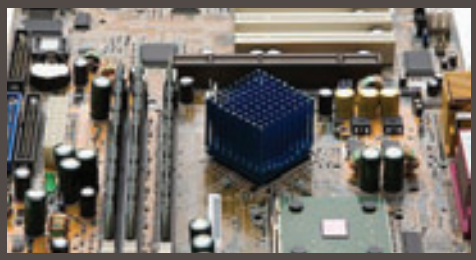

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Because the fluid mechanism and heat transfer process behind flow boiling in small channels are extremely complex, Both Qu and Wojtan found that CHF predictions rely heavily on empirical correlations that are derived from experiments. Because different researchers use different channel geometry, diameters, fluid, test methods, etc., there is no universal CHF correlation suitable for all conditions. Commonly used CHF correlations can easily have up to 50% error depending on application conditions. Better understanding of heat transfer mechanisms inside small channels will create more accurate CHF correlations in the future, which will lead to better design of microchannel heat sinks.

References:

1. Qu, W. and Mudawar, I., Measurement and Correlation of Critical Heat Flux in Two-phase Micro-channel Heat Sinks, Int. J. Heat and Mass Transfer 2004.

2. Wojtan, L., Revellin, R. and Thome, J., Investigation of Saturated Critical Heat Flux in a Single, Uniformly Heated Microchannel, J. Experimental Thermal and Fluid Science, 2006.

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Long Term

Thermal Grease Reliability

Introduction

Electronics cooling typically involves two or more objects in thermal contact with each other, such as a microprocessor and an attached heat sink. For such composite systems, the temperature drop across the interface between the objects may be appreciable [1]. This temperature change may be attributed to what is known as the thermal contact resistance [1]. Thermal contact resistance occurs due to the voids created by surface roughness effects, material defects and misalignment of the interface. The voids in the interface are filled with air. A properly applied thermal interface material (TIM) displaces the air inside the gaps between the two objects with a material that has a higher thermal conductivity [2]. Typical TIMs include thermal grease, epoxy, phase change materials, thermal tapes, silicone coated fabrics and gap fillers [2].

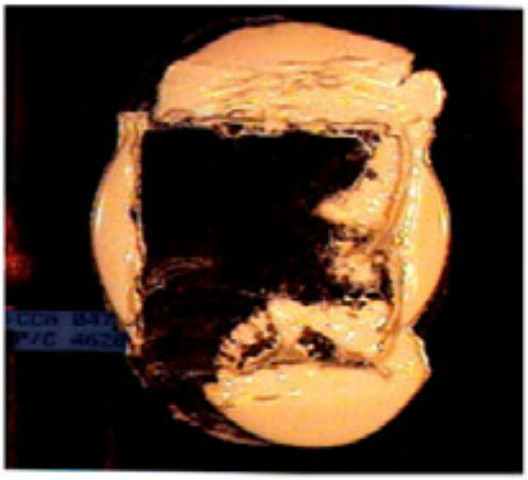
Among the different TIM options, thermal greases typically offer the best thermal performance and reduced manufacturing cycle times [3], though, depending on the application method, assembly can be messy [2]. Thermal greases have the ability to flow and conform to interfaces, do not require post-dispense processing such as curing, and have higher effective thermal conductivity compared to other classes of materials. Because thermal greases do not form any semi- or permanent bond between interfaces, rework for repair or upgrade can be achieved relatively easily. For these reasons, thermal greases are broadly employed in microelectronics and power module cooling applications.

When thermal greases are operated for an extended period, the thermal interface resistance can increase. The degradation mechanisms of greases are considerably different and more complicated to characterize than those of other common TIM solutions such as adhesives and pads [3]. This article discusses the failure mechanisms of grease interface layers as well as reliability testing methods and results.

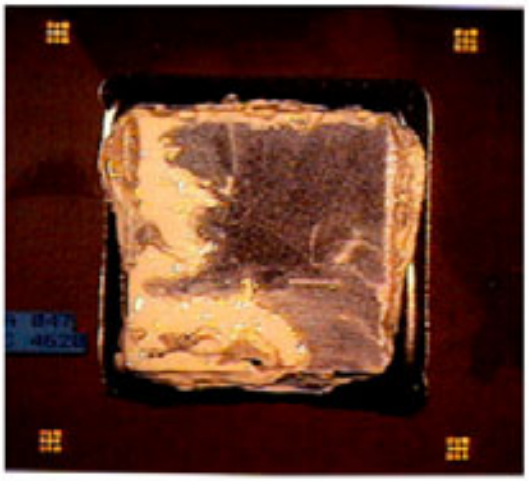
Failure Mechanisms of Thermal Grease TIMs

Thermal greases and pastes are typically made of silicone oils that are loaded with thermal conductive filler [4]. Because thermal greases do not cure they will not change into a gel or hard adhesive type material. The absence of curing allows the materials to provide a low interfacial thermal resistance. However, this also makes them susceptible to a variety of failure mechanisms during their service life, including some unlike those experienced by thermal gels, adhesives, and pads [4].

The two main causes for the increased thermal resistance of a grease layer are grease pump-out and grease dry-out [3]. The powering up or powering down of a device causes a relative motion between the die and the heat spreader (in-plane and out-of-plane), which tends to squeeze the thermal grease out of the interface gap. This phenomenon is referred to as pump-out and results in increased thermal resistance due to the loss of grease material from the interface [5] [6]. An example of thermal grease pump-out is shown in Figure 1.



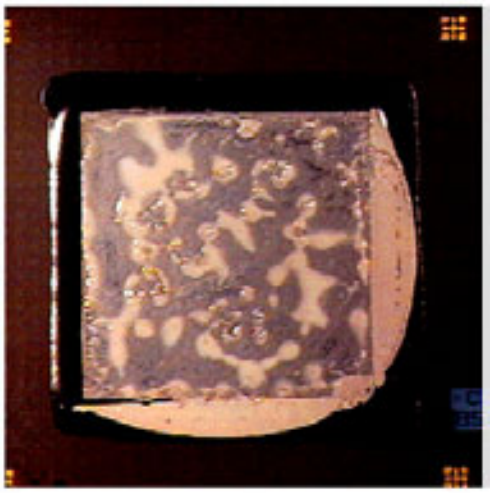
(a)



(b)

Figure 1. Typical Thermal Grease Pump-out, Showing the Heat Sink (a) and Die Back Sides (b) [5].

(a)



(b)

Figure 2. Typical Thermal Grease Dry Out, Showing the Heat Sink (a) and Die Back Sides (b) [5].

Grease dry-out occurs due to the separation of the filler from the polymer matrix at elevated temperatures. The polymer matrix tends to flow out of the interface preferentially, which dries out the thermal grease. This results in increased in-situ thermal resistance of the material [5]. An example of thermal grease dry-out is shown in Figure 2. This phenomenon is strongly dependent on the temperature of the material, with higher temperatures resulting in accelerated degradation [5].

Exposure to high humidity levels has also been shown to induce changes in the thermal resistance of a grease layer. This is primarily an effect of the filler and resin system employed and its response to high levels of moisture.

Reliability Testing Methods

Grease characteristics (e.g. filler material, rheology, resin system), process parameters (e.g. grease application method, clamping force and method), end-use environmental conditions, and geometries (e.g. cooling structure, dimensions of die and spreader/sink, surface roughness), all effect the thermal performance of a grease layer and its reliability [3]. It is not practical to accurately test various greases for all possible parameters. One method for evaluating a number of thermal greases is to subject them to a combination of accelerated stress tests using thermally (e.g. temperature range, heat flux), mechanically and geometrically similar tests to the application.

Four types of reliability tests are discussed in [3]: these are thermal cycling, high temperature storage, high temperature/ high humidity exposure and mechanically induced pump-out tests. The reliability tests are conducted in a combination of three test set-ups, namely the grease fixture, aluminium-grease-silicone structure and one set up specifically for the mechanically induced pump-out test.

Test	Sample Geometry	Measurement Parameter	Pressure Levels	Al Surface Roughness Levels
Thermal Cycling (-50 to 150°C; 20 Minute Cycle; 1000 Cycles)	Grease Fixture	Thermal (Resistance, Conductivity)	1 (0.1 MPa)	1 (420 nm)
	Al-grease-Si Layered Structure	Visual (% Voiding)	2 (0.1 MPa, 0.31 MPa)	2 (420 nm, 1000 nm)
High Temperature Storage (150°C; 200 Hours)	Grease Fixture	Thermal (Resistance, Conductivity)	1 (0.1 MPa)	1 (420 nm)
	Al-grease-Si Layered Structure	Visual (% Voiding)	2 (0.1 MPa, 0.31 MPa)	2 (420 nm, 1000 nm)
(85°C/85% R.H.; 1000 Hours)	Grease Fixture	Thermal (Resistance, Conductivity)	1 (0.2 MPa)	1 (420 nm)
Mechanical Cycling (0.1 Hz, 1500 Cycles, Between 100 and 150μm)	Cooling Chuck-grease-Thermal Die	Junction Temperature	At 100μm, 125μm, and 150μm	N/A

Table 1. Thermal Grease Accelerated Stress Tests Conducted by Gowda, et al. [3].

For the thermal cycling and high temperature storage tests, two sample geometries were used [3]. The first, shown in Figure 3, features a three-layered silicon-grease-aluminum sample in a grease fixture where different bolt pressures can be applied. This set-up was used to measure the thermal performance of the greases at time-zero and after reliability testing. The second, shown in Figure 4, is a three-layer structure of aluminum-grease- silicon. It was set up to monitor the degradation of the grease layers using acoustic microscopy. Different bolt pressures and surface roughnesses of the aluminum plates were used in the visual tests to determine if there was any effect of these parameters on the degradation of a grease interface.

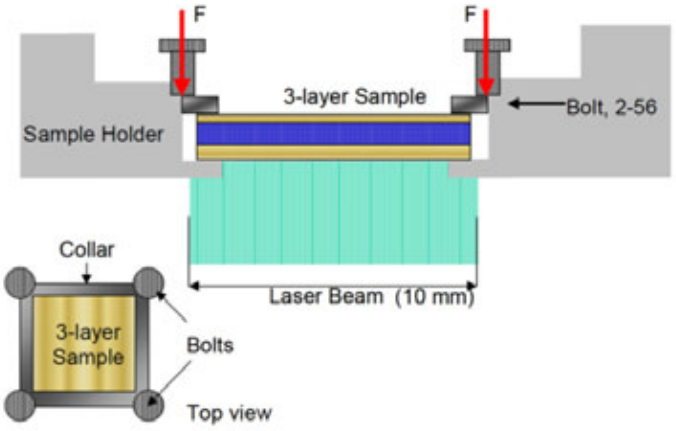


Figure 3. Thermal Grease Measurement Fixtures [4].

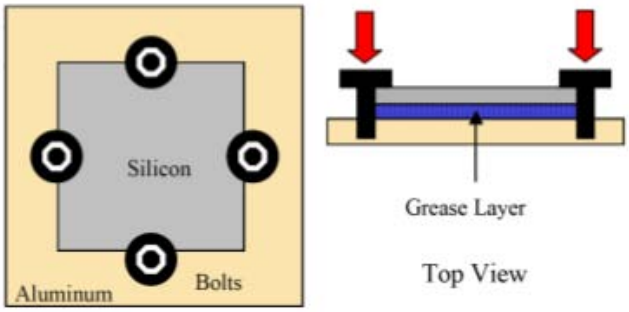


Figure 4. Aluminum-Grease-Silicone (Al-Grease-Si) Structure for Visual Monitoring [4.]

To simulate the pump-out effect of grease layers resulting from dimensional changes in the package, an accelerated mechanical cycling test was adopted. This mechanically induced pump-out test was reported by Chiu, et al. [6], where the TIM gap is cyclically varied between two gap limits that are representative of the dimensional changes in the module

under study. This test can simulate power cycling effects, but with much faster turn-around times, and has been validated in Chiu, et al. [6].

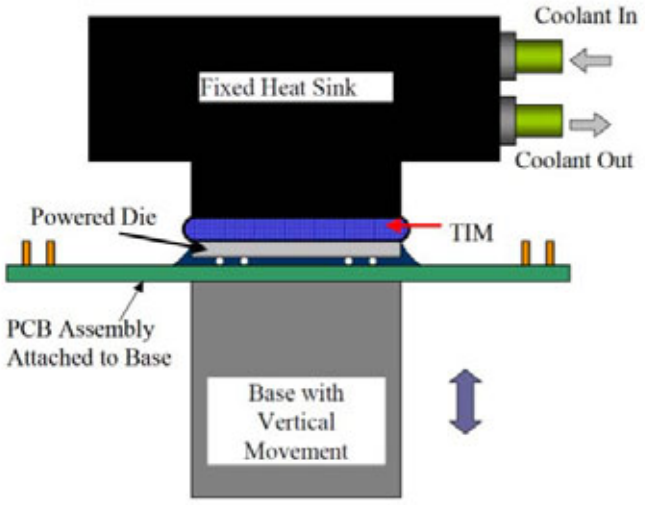


Figure 5. Mechanical Cycling Set-up to Simulate Grease Pump-out [4].

Reliability Test Results

Five thermal greases were tested by Gowda, et al. [3]. Their characteristics were studied and their thermal performance was measured using the laser flash thermal diffusivity method. The primary filler in theses greases was boron nitride (BN) spheres, with an average size of 60 µm. An increase in the thermal conductivity was observed with an increase in the filler loading for all five greases, as shown in Table 2. There was an increase in thermal conductivity and a decrease in thermal resistance with an increase in filler loading and pressure at which the measurements were made.

Grease	Filler	Filler Loading (%)	Viscosity @ 0.1/sec (Pa-s)	Density (g/cc)	BLT (µm)	k (W/mK)	R (mm²K/W)	BLT (µm)	k (W/mK)	R (mm²K/W)	BLT (µm)	k (W/mK)	R (mm²K/W)
					at 0.1 MPa	at 0.1 MPa	at 0.1 MPa	at 0.2 MPa	at 0.2 MPa	at 0.2 MPa	at 0.3 MPa	at 0.3 MPa	at 0.3 MPa
A-1	60µm Spherical BN	35.8	575	1.2	56.4	4.2	13.7	51.3	4.3	11.9	48.3	4.4	10.9
A-2	60µm Spherical BN	41.6	980	1.3	71.1	5.2	14.0	67.3	5.4	12.6	59.2	5.2	11.4
A-3	60µm Spherical BN	46.4	1910	1.4	92.7	5.7	16.5	74.9	7.9	9.5	69.9	8.3	8.4
B-1	60µm Spherical BN + Secondary Filler	71.7	3300	2.2	50.0	6.5	7.8	47.0	7.9	6.0	43.9	8.4	5.2
B-2	60µm Spherical BN + Secondary Filler	80.1	6900	2.4	57.2	7.9	7.4	51.3	9.8	5.3	51.8	10.3	5.1

Table 2. Characteristics of Greases Studied by Gowda, et al. and Their Thermal Performance [3].

When the reliability tests were conducted, the only one which resulted in an increase in the thermal resistance was mechanically induced pumping, as shown in Figure 6. In the Al-grease-Si fixture-based thermal cycle tests, the thermal resistance dropped for all greases [3].

It is important to note that in the case of the fixture-based test, the pressure on the grease layers was applied consistently across the five greases. This allowed the viscosity and filler characteristics to dictate the resulting bondline or grease thickness. For the mechanical cycling test, similar bondlines were maintained for all the greases [3].

In addition, the Al-grease-Si structures allow a reduction in bondline (BLT) or grease thickness when the viscosities of the greases reduce at elevated temperatures, but do not impose a cyclic change in TIM bondline during temperature cycling. In the mechanical cycling test, the grease thickness is maintained between the same two set limits but varied cyclically between these limits. This explains the difference in the results between the thermal cycling and mechanical cycling tests.

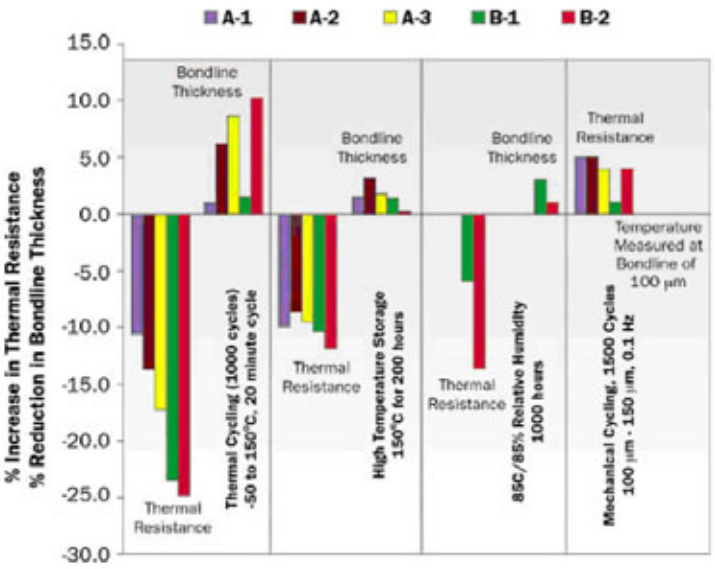


Figure 6. Results of Grease Reliability Testing. Adapted from [3] and [4].

Summary

Determining the long term thermal resistance of thermal greases is complex. This article has discussed four tests used by Gowda, et al. to evaluate the reliability of five different types of greases. These tests do not cover the full range of stress conditions that grease can be subjected to in a microprocessor environment [3]. They do, however, provide a means for screening thermal greases for dry-out, voiding and in-plane grease movement during the grease selection process.

The test results show an overestimate of reliability because the pump-out mechanism was not accurately simulated. Tests conducted with mechanical pump-out were the only ones that showed an increase in the thermal resistance of the interface.

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T: 781.769.2800 | F: 769.769.9979 | www.qats.com

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NEW HEAT SINK CLIP SYSTEM IMPROVES THERMAL PERFORMANCE, REQUIRES MINIMAL SPACE AROUND BGA COMPONENTS

Norwood, MA, April 27, 2009 – Advanced Thermal Solutions, Inc. announced today the introduction of superGRIP™, a new two-component, attachment system which quickly and securely mounts heat sinks to a wide range of hot running Ball Grid Array (BGA) components, while using a minimal amount of space on the PCB and eliminating the need to drill holes.

The two-part superGRIP system features a plastic frame clip, that fastens securely around the perimeter of a component, and a metal spring clip, which slips through the heat sink's fin field and locks securely to both ends to the plastic frame. The resulting superGRIP assembly applies steady, even pressure to the component throughout the product lifecycle, improving thermal performance and long-term reliability.

"The superGRIP system is a great addition to ATS' family of mechanical attachments for heat sinks," said Joseph Mennucci, engineering manager for ATS. "With this latest edition, ATS now offers two tiers of heat sink clip attachment: maxiGRIP™, for general purpose and high performance applications; and superGRIP, for high performance applications with densely populated PCBs and little space around the component for mechanical attachment."

Like its cousin maxiGRIP, ATS' superGRIP heat sink attachment system permits the use of high performance phase changing thermal interface materials that improve heat transfer by as much as 20 times over typical double-sided adhesive thermal tapes. Both superGRIP and maxiGRIP™ allow for the heat sink to be detached and reattached without damaging the component or the PCB, an important feature for applications where PCB rework and ease of assembly and disassembly are important.

The superGRIP system is available with ATS' maxiFLOW™ family of heat sinks, which feature a low profile, spread fin architecture to maximize surface area for more effective convection (air) cooling. Testing at an air flow rate of just 0.5 m/s (100 ft/m) shows that device junction temperatures (Tj) can be reduced by more than 20 percent below the temperatures achieved using heat sinks with traditional fin styles.

ATS will initially be offering 51 superGRIP/maxiFLOW heat sink and attachment assemblies, available from ATS for 17 component sizes, from 15 mm x 15 mm to 45 mm x 45 mm, and heat sink heights of 7.5 mm, 12.5 mm and 17.5 mm. The superGRIP system will also be available with ATS' straight fin and cross cut heat sinks, as well as additional sizes, as custom options.

For more information about ATS' high performance heat sink products with superGRIP or maxiGRIP clip attachment, lead times and pricing, please visit www.qats.com or call 781-769-2800.

About Advanced Thermal Solutions
Advanced Thermal Solutions is a leading engineering and manufacturing company supplying complete thermal and mechanical packaging solutions from analysis and testing to final production. ATS provides a wide range of air and liquid cooling solutions, laboratory-quality thermal instrumentation, along with thermal design consulting services and training. For more information about Advanced Thermal Solutions, Inc., please visit www.qats.com or call 781-769- 2800.

Using

Silicon Microchannel Heat Sinks for Thermal Management

As liquid cooling technology is more readily adopted in electronics thermal management, particularly where very high heat fluxes are involved, there is a push to develop more efficient and cost effective cold plates to transfer device heat into the liquid cooling loop. More than twenty years ago, Tuckerman and Pease [1] pioneered the notion of microchannels for high capacity cooling. They noted that one particularly effective design would be to carve micro-scale channels into a piece of material. The local heat transfer coefficient increases with the decrease of channel size, and heat transfer would increase as more surface area is generated.

Even today, manufacturing microchannels through any material presents challenges. But, the concept is valid – if a fluid is forced through many small channels, as opposed to fewer large channels, heat transfer can be increased. Heat transfer is a function of surface area and the convection coefficient, and for a smaller channel both of these parameters are increased. When the hydraulic diameter of the channel decreases the heat transfer coefficient increases for a relative constant fluid velocity. This increase in thermal performance per unit flow rate generally comes with a larger pressure drop through the cold plate. If high pressures with relatively low flow are allowable in a design, the microchannel heat sink is a very attractive option that can perform better than most other coldplate designs. Reliability concerns about fittings or connections are heightened because of the increase in fluid pressure at the outlet of the pump and inlet of the cold plate.

Figure 1 highlights the stack of thermal resistances from the junction to the ambient. The heat sink dominates most of the thermal resistance in applications like those seen on the left of Figure 1. In some cases some of the other resistances (e.g. internal solder) can be ignored or neglected in design. As seen on the right, because of the very low thermal resistance of many microchannel heat sinks the stack of thermal resistances becomes more important and the material interface resistances become much more significant in design.

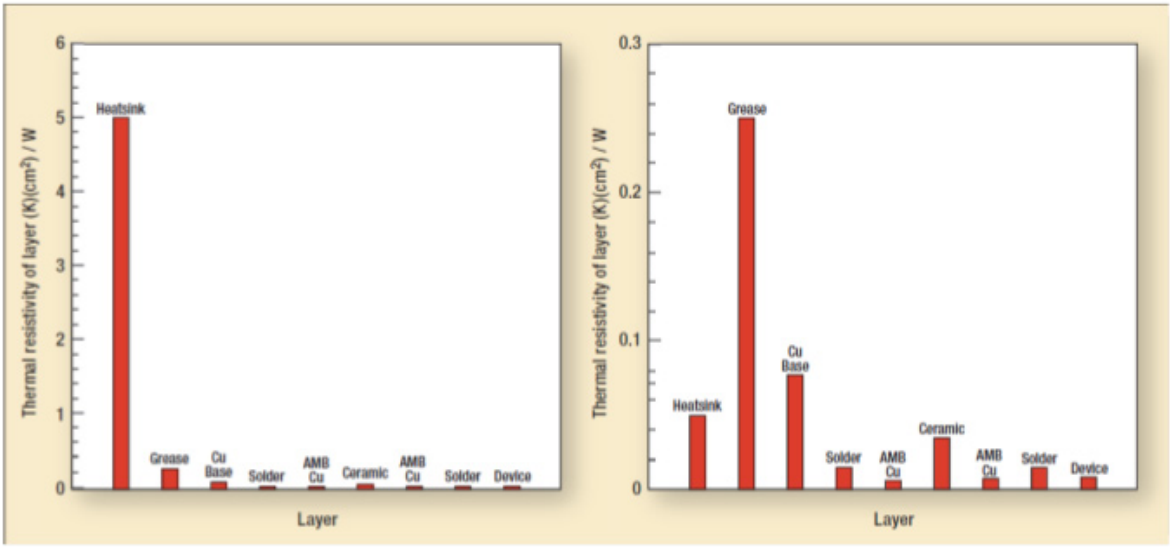

Figure 1. Stack of Thermal Resistances with a Conventional Air-Cooled Heat Sink (left) as Compared to a Microchannel Heat Sink (right) [1].

As manufacturing technologies evolved, it became more economical to design very high power electronics with microchannel heat sinks..There are now many applications which can viably use a microchannel-cooled design; these range from high power lasers to IGBTs in automotive applications. The heat sink is typically interfaced to either the device substrate or to the top encapsulating heat spreader as commonly seen on many package designs. A silicon microchannel heat sink can be effectively bonded to the rear of a silicon device's substrate using low thermal impedance materials such as silver-laced epoxy [2]. For many applications, it is not practical to form the microchannels in the rear of the device substrate, given the already high cost and complexity of electronic packages. A copper microchannel heat sink cannot be feasibly bonded to the rear of the device substrate, given the dissimilarities in the thermal expansion of copper and silicon.

A copper heat sink would require a forgiving thermal interface material, which for many very high power applications is unacceptable. When a heat sink is so efficient that the thermal resistance of the interface material, or thermal grease in the case of Figure 1, dominates relative to the other sources of thermal resistances, choosing a design that does not require the use of a thermal interface material, or allows the impact of the TIM to be minimized, is important for high thermal stress applications [3].

As mentioned, silicon microchannel heat sinks are usually manufactured by etching the channels directly into a starting block of material. The process of etching is well developed, and the technology is used often for circuit boards and device-level applications. Very fine features on the order of micrometers can be carefully and accurately produced, hence the term "microchannel" cold plates. Figure 2 is a sample computer aided design rendering of a microchannel consisting of a micro-grooved silicon plate [2] with an adapter block mounted on top to create the channels. Note that the design is constructed of many slot-like channels that create a staggered pin fin configuration. The use of staggered pin fins allows increased thermal performance by preventing the full growth of the boundary layer. Offset orientation of the inlet ports and outlet ports prevents parallel flow and ensures good mixing and turbulent flow.

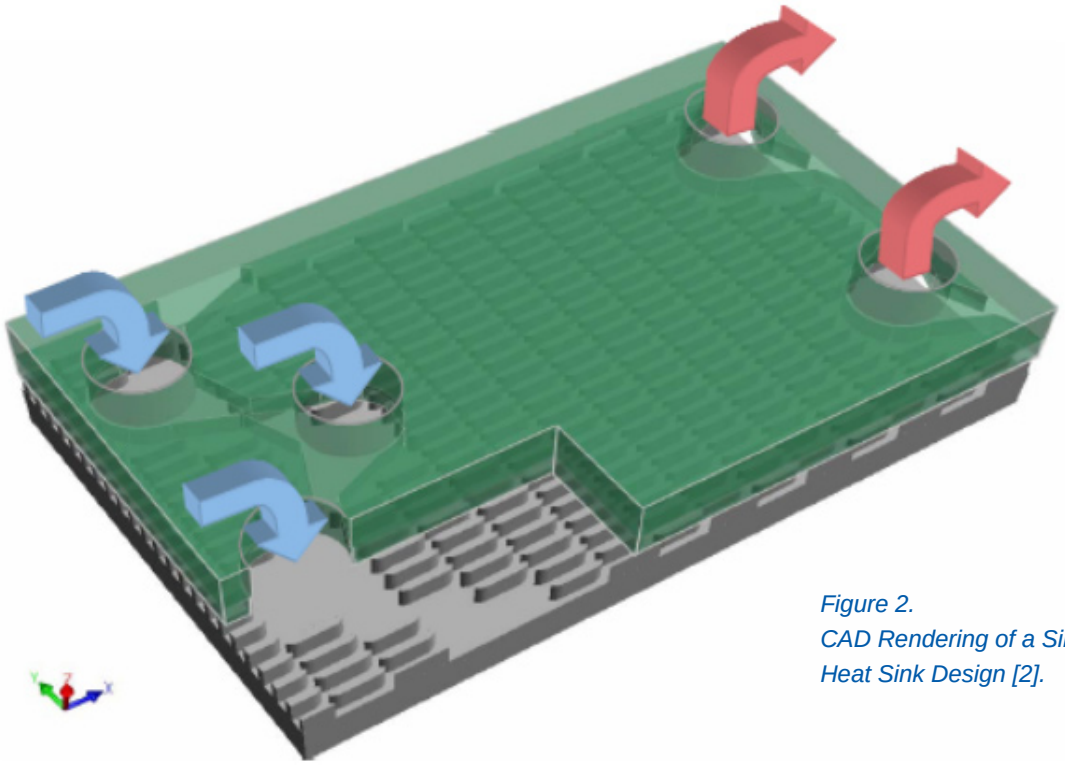

Figure 2.
CAD Rendering of a Silicon Microchannel Heat Sink Design [2].

The microchannel heat sink is particularly useful because its simplicity and low form factor allow it to be used as a device-level solution. In this case, the cooler can be integrated and packaged directly with the component itself, which lessens the need for mechanical fastening and thermal interface materials. Figure 3 shows a concept device- level adaptation involving a test setup with a microchannel heat sink. Here, a chip with an attached silicon microchannel cooler is affixed to a ceramic PGA substrate and a gasketed manifold block is directly coupled to the top of the microchannel cooler.

In summary, a silicon microchannel heat sink design may be useful for high thermal stress applications, given the high degree of performance that is possible within its conceptual design. The use of microchannels increases the convection coefficient from the channel's walls while increasing the amount of workable surface area. This leads to an aggregate increase in potential performance relative to basic and common heat sink designs, at the expense of pressure drop through the cold plate. A silicon microchannel allows direct bonding to the component substrate which can eliminate the need for a thermal interface material while also eliminating differences in material rates of thermal expansion. These microchannel heat sink designs are one of the prominent concepts at the forefront of high power dissipation techniques for high performance electronics.

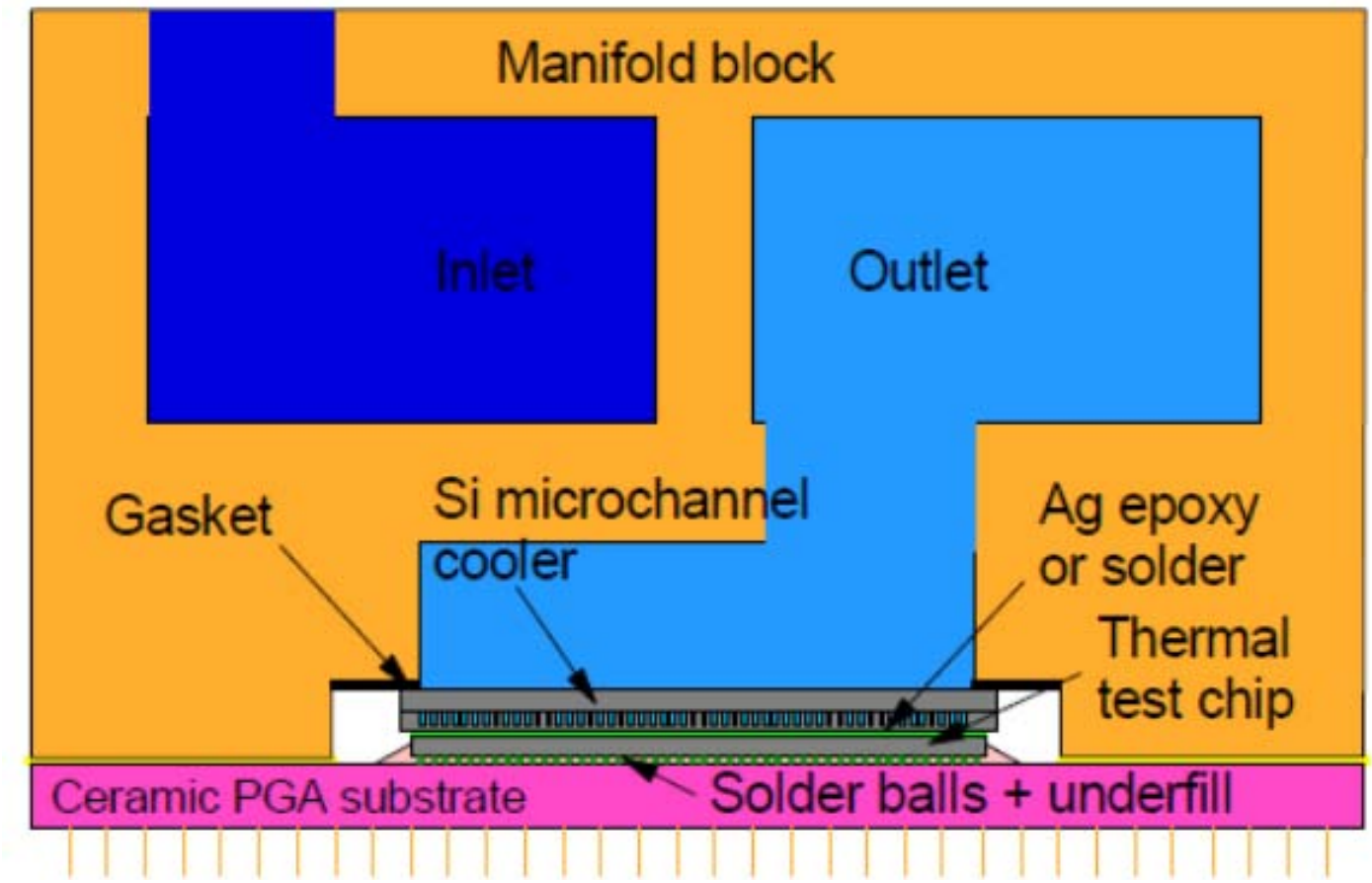

Figure 3. Concept of a PGA-Mounted Device with an Attached Microchannel Heat Sink [4].

Thermal Management Design Kit

ATS-TMDK-96

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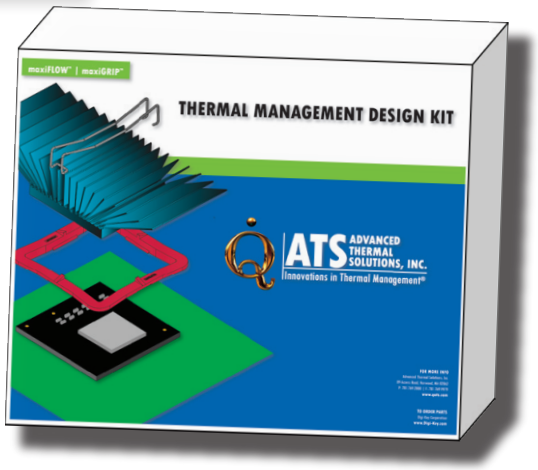
Advanced Thermal Solutions' Thermal Mangement Design Kit contains 96 of its best-selling maxiFLOW™ heat sinks and maxiGRIP™ sink attachment systems, to quickly provide optimum component cooling solutions during the prototyping, trouble shooting and final design stages.

There are 288 parts in all, including heat sink, frame clip, spring clip and pre-applied thermal interface material for 16 of the most common component sizes available. This allows engineers to have the best cooling solution available for nearly every application.



ATS maxiFLOW heat sinks feature a low profile, spread fin array to maximize surface area for more effective air (convective) cooling. The maxiGRIP heat sink attachment system features a plastic frame clip and a stainless steel spring clip that runs through the heat sink's fin field, fastens securely to the plastic frame and applies steady, even pressure to the component throughout the product lifecycle.

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17 mm x 17 mm
19 mm x 19 mm
21 mm x 21 mm
23 mm x 23 mm
25 mm x 25 mm
27 mm x 27 mm
29 mm x 29 mm
30 mm x 30 mm
31 mm x 31 mm
32.5 mm x 32.5 mm
33 mm x 33 mm
35 mm x 35 mm
37.5 mm 37.5 mm
40 mm x 40 mm
42.5 mm x 42.5 mm
45 mm x 45 mm

COMPONENT HEIGHTS:

Standard - 3 mm to 4.5 mm
Low Profile - 1.5 mm to 2.99 mm

HEAT SINK HEIGHTS:

STD	LP Components
7.5 mm	9.5 mm
12.5 mm	14.5 mm
17.5 mm	19.5 mm

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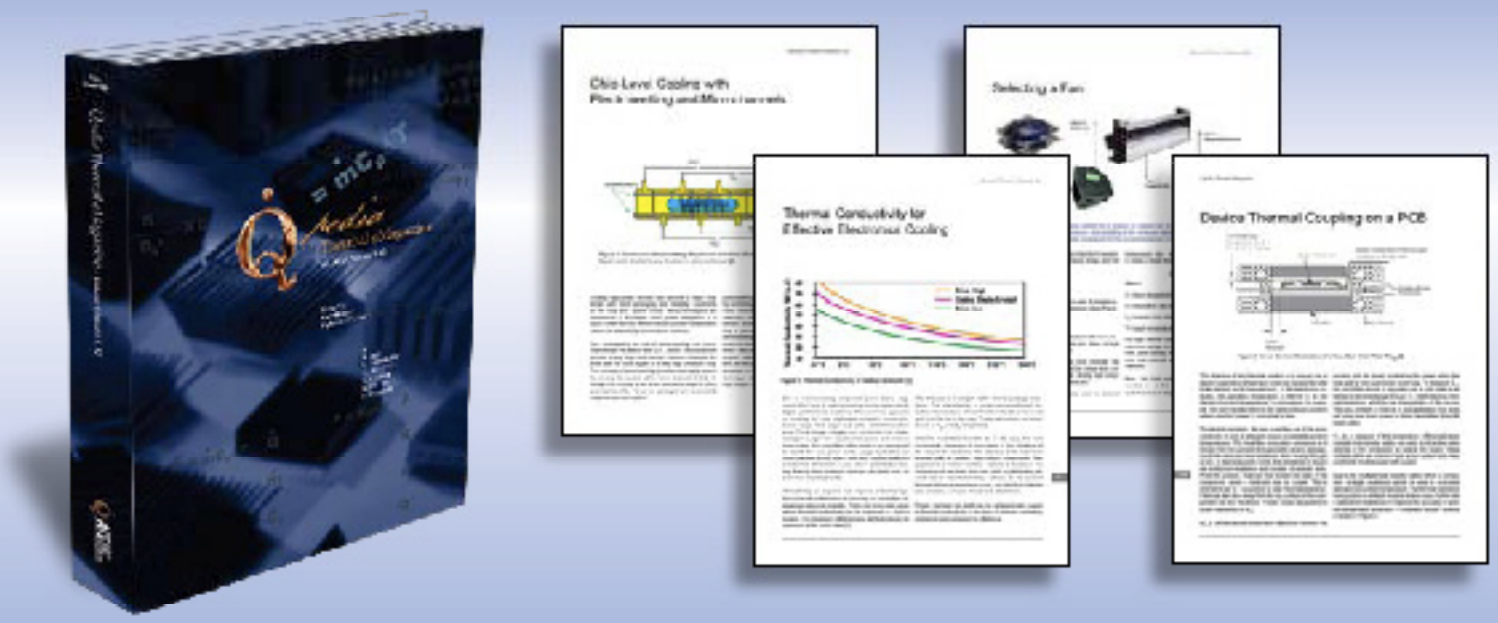

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All articles are written and edited at the engineer-level by the thermal and mechanical engineers from Advanced Thermal Solutions, including Kaveh Azar, Ph.D., the company's president and CEO; and Bahman Tavassoli, Ph.D., its chief technologist. Both Azar and Tavassoli are internationally recognized experts in the thermal management of electronics.

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The thermal solutions market is making a gradual transition into liquid cooling. But, at the same time, there is growing unease over the reliability of liquid cooling systems. The main concerns involve pump lifetime, radiator corrosion and cold plate leakage, and many hours of design and testing have gone into improving these cooling parts.
However, another critical component is often overlooked: the tubing used in a cooling loop. This tubing can play a large role in the long term reliability of the solution. It is important to fully understand tubing characteristics, how they relate to evaporation, and how the loss of liquid affects the operation of the system (including pump cavitation and air blockage in a cold plate).

Intel has developed a cooling solution for their Core 2 Extreme processors [1] and studied the effects of tubing material on the solution's performance. A summary of their findings is presented below.

The proper choice of tubing material requires balancing several different criteria. The parameters considered were cost, flexibility, flammability and vapor transmissibility.

Three different types of tubing materials were tested for liquid loss by connecting a known length of tubing to the ALCT (advanced liquid cooling technology) pump, and measuring the assembly weight prior to the start and then periodically during the test to quantify the loss [1]. The liquid evaporation and migration of vapor through the plastic walls to atmosphere is the mode of liquid loss that is affected by the internal structure of plastic and its wall thickness. The pumps were run at 1450 RPM and the temperature of the liquid was maintained at 50ºC. An extremely accurate scale is required to measure the weekly losses that allow for the calculation of a loss rate.

The results for the three different tubing materials are summarized in Table 1. The Norprene® tubing configuration had the lowest loss rate of 0.25 grams/week and was chosen as the tubing material for ALCT. Material parameters were 3/8 in. internal diameter and 5/8 in. outer diameter (1/8 in. wall thickness).

Tubing Material	Loss Rate (grams/week)
Polyurethene	5.0
PVC	1.2
Norprene®	0.25

Table 1. Weekly Loss Rate of Different Tubing Materials

Liquid loss through vapor migration through tubing walls and joints can be minimized, but not eliminated, as shown by the relatively impermeable material of Norprene rubber.

Metal tubing was not a good option, due to the flexibility needed for the solution assembly inside a chassis.

The effect of liquid loss can be mitigated, at least for a reasonable operational life of the solution, by providing a liquid reservoir. A continuous operation test at 50ºC and 1450 RPM was conducted with the assembly mass monitored every week to identify weekly mass loss rate. The mass loss data with three samples over seven weeks duration is shown in Figure 1. The data shows that the average loss rate was 0.25-0.30 grams/week and is reasonably consistent for three samples. The reservoir size of 38 mL (38 grams for water) was chosen to provide 152 weeks (approximately three years) of operational life. The pump is expected to have additional resilience to liquid loss before significantly impacting thermal performance.

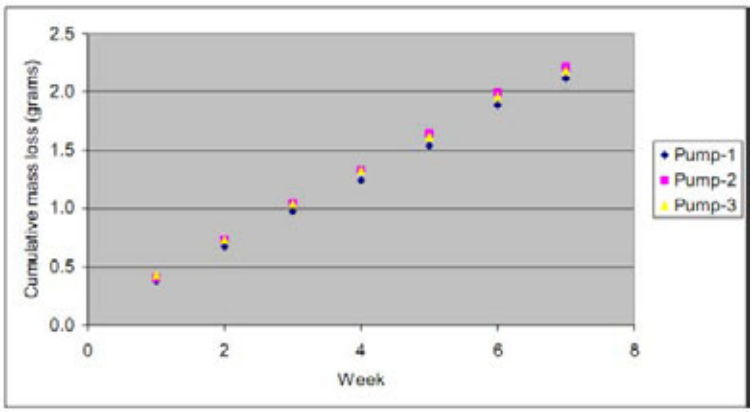

Figure 1. Assembly Cumulative Mass Loss Data in a Continuous Operation Test at 50ºC and 1450 RPM.

The reservoir presence in the assembly and its impact on thermal performance was also confirmed by drawing the liquid out in increments of 5 mL and measuring the thermal performance at each flow mass reduction. The thermal resistance data is shown in Figure 2. It can be seen that, when 65 mL or more liquid is drawn, the thermal resistance of the system goes up significantly.

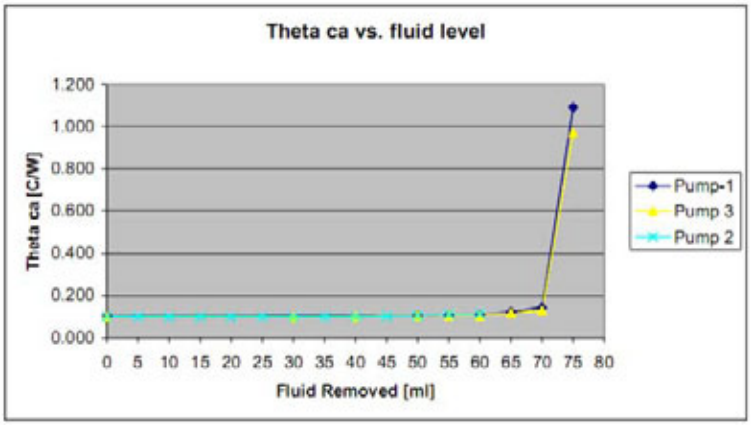

Figure 2. Thermal Resistance Curve for the Loss of Liquid in a System.

The reservoir is located in the heat exchanger at its top as shown in Figure 3. An air spring or an accumulator is needed to prevent a high pressure situation due to operating or storage temperature changes. 8 mL air volume is provided on the top of the reservoir to develop an air spring that minimizes the sensitivity to temperature change on the pump's internal pressure. Figure 3 shows the cross sectional view of the reservoir and the radiator.

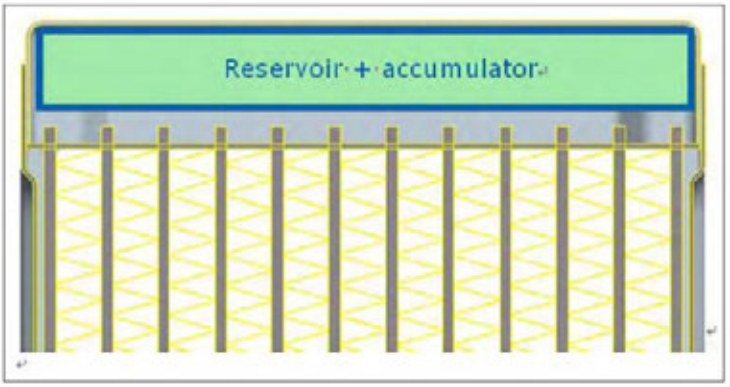

Figure 3. Cross Sectional View of Radiator and Reservoir.

Failure mechanisms that were considered in design reliability testing were:

1. Pump assembly cracking causing liquid loss;
2. Vapor loss through plastic walls and joints causing liquid loss;
3. Thermal performance degradation due to internal mechanisms affecting CPU TC (case) temperature; and
4. Pump motor and printed circuit board performance degradation affecting the pump RPM.

The reliability test results are summarized in Table 2.

Use Condition	Test Conditions	Failure mechanism	Results
Continuous Operation	T_{LIQUID} = 75 °C for 16 weeks	1	0/10 failure
	T_{LIQUID} = 50 °C	2	0.25-0.30 grams/week
	T_{LIQUID} = 50 °C	3	Insignificant change in Ψ_{ca} for 3 samples
	T_{LIQUID} = 50 °C	4	2% average RPM degradation after 8 weeks for 3 samples
On-off Cycles	T_{LIQUID} = 35-60 °C, 5500 cycles	1	0/3 failure
	T_{LIQUID} = 35-60 °C, 5500 cycles	2	3 grams loss after all cycles for 3 samples
	T_{LIQUID} = 35-60 °C, 7500 cycles	4	No RPM degradation for 0/3 samples

Table 2. Reliability Test Results.

A small sample size was used to evaluate design against reliability. Test results showed no assembly cracking failure in either continuous operation or on-off cycles. The liquid loss measured was very small compared to the reservoir capacity. Thermal resistance showed a change of -0.01 to +0.007ºC /W, which is insignificant compared to the measurement accuracy of approximately +/- 0.01ºC /W.

Neither the pump motor nor the PCB showed significant RPM degradation.

Reference:

1. Core 2 Extreme Thermal and Mechanical Design Guidelines, Document Number: 316854-002, Intel.com, March 2008.

Advanced Thermal Solutions, Inc.
89-27 Access Road Norwood, MA USA
T: 781.769.2800 F: 781.769.9979
www.qats.com

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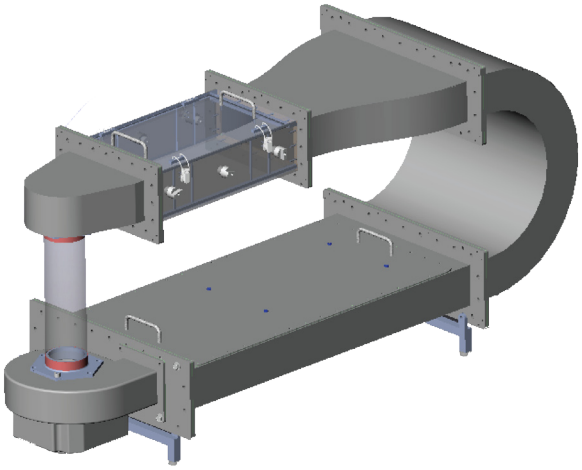
CLWT-067

BENCHTOP, CLOSED LOOP WIND TUNNEL FOR ELEVATED TEPERATURE TESTING OF BOARDS AND COMPONENTS



The CLWT-067 is a research-quality closed loop wind tunnel that provides a convenient, accurate system for thermally characterizing PCBs and individual components at controlled temperatures from ambient to 85°C.

The CLWT-067 wind tunnel produces air flows up to 7.5 m/s (1500 ft/min). With customization, it can generate flows up to 50 m/s (10,000 ft/min) using orifice plates (available optionally). The clear Lexan test section lets the user to view the test specimen and allows for flow visualization.

Unlike open loop wind tunnels, the CLWT-067 re-circulates internal air. This allows the system heater to quickly warm the air to a specific temperature. The testing of boards and components in hot air is a requirement in some NEBS and other standards. The precise controls and temperature range of the CLWT-067 wind tunnel allows its use for testing heat sink performance and for calibrating air and temperature sensors.

The complete wind tunnel fits on most lab benches and is powered from standard AC outlets. It has a smaller footprint than traditional, closed loop wind tunnels or environmental test chambers.

The wind tunnel's test section can be accessed from the top door for mounting and repositioning of boards, components and sensors. Internal rail guides provide an easy mechanism to install test specimens of different sizes (e.g., PCB, heat sink).

Instrument ports (6) are provided in the front and side walls of the test section for placing temperature and velocity sensors such as thermocouples, Pitot tubes and hot-wire anemometers.

OVERALL DIMENSIONS (L X W X H)
143.6 cm x 49.3 cm x 67.7 cm
(56.5" x 19.4" x 26.6")

TEST SECTION DIMENSIONS
41.8 cm x 22.5 cm x 9.5 cm
(16.4" x 8.9" x 3.7")

MATERIALS
ALUMINUM, PLEXIGLAS

FLOW RANGE
0 TO 7.5 m/s (1500 ft/min)

TEMPERATURE RANGE
Up to 85°C (185°F)

WEIGHT
70.7 kg (156 lbs.)

Custom options are also available. Contact ATS for details.

*RoHS Compliant

For further technical information, please contact Advanced Thermal Solutions, Inc. at 1-781-769-2800 or www.qats.com

FEATURES:

» **Quick Access**
Quickly change the test specimen through the front access test section

» **Sensor Ports**
Measure pressure, velocity and temperature through the sensor ports

» **Data Center**
View data and monitor events (with optional controller)

» **Flow Characteristics**
High quality flow with very low turbulence intensity

APPLICATIONS:

» **High Temperature Testing**
Evaluate the effects of elevated temperatures on component and PCB response and reliability

» **Heat Sink Characterization**
Characterize a variety of heat sink sizes for natural and forced convection cooling

» **Sensor Calibration**
Precision temperature and velocity controls allow accururate calibration of sensors

» **Component Testing**
Utilize for individual or multiple component testing

» **Multiple PCB Testing**
Test actual or simulated PCBs for thermal and flow distribution

Cooling News

New Products, Services and Events from around the Industry

First Thermostatically Controlled Fan Cord

The Gardtec Green Fan Cord allows AC fans to turn on/off as system ambient temperature calls for additional cooling. The fan cord will turn on cooling fans as ambient temperatures reach the upper 80's F, then turn off cooling fans as temperatures return to the lower 80's. The normal operation cost for a single AC cooling fan is $25-40 per year.

Typical applications call for cooling 55-60 hours per week, effectively allowing fans to be in the off position for 200 plus hours weekly. The return on investment cost is less than 6 months. Additionally, fan life is extended, noise levels are lowered and service needs are reduced. The Gardtec Green Fan Cord requires no additional wiring, PC boards or mounting of controls. Everything is built into a single fan cord assembly, ready to plug and go.

High Performance Heat Pipe Thermal Solution

The Intel DBX-B thermal solution offers the ability to ship pre-installed into a system while instilling confidence that the system will arrive undamaged and ready to deliver an extremely positive end user experience. This is made possible through careful materials selection and rigorous testing by Intel engineers committed to providing excellent thermal performance, low acoustic properties and unmatched reliability. This thermal solution is being provided as a benefit of boxed Intel® Core™ i7-980X processor Extreme Edition, along with a 3 year limited warranty.

Weather Resistant AC Fan Series

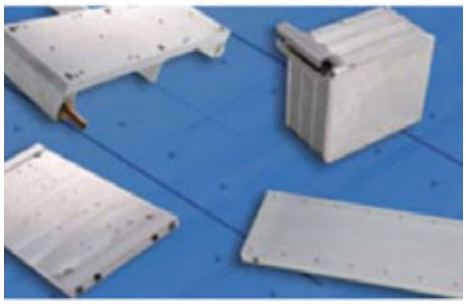
NMB Technologies Corporation is providing a series of high performance, weather resistant, oil proof and dustproof ac axial fans. The weather resistant (WR) ac fan series is currently available in three sizes, 80 mm X 25 mm, 119 mm X 38 mm, and 150 mm X 172 mm X 38 mm. They are designed and manufactured for harsh environment applications, such as industrial machines, inverters and chargers; as well as for outdoor applications where dust and water are present, such as solar power systems, security systems, marine products, electronic enclosures/control cabinets and telecommunications equipment.

Liquid Cooling for High-Power Thermal Management

A two-phase liquid cooling system for electronic thermal management and heat removal from high-power electronics is now available from Parker Hannifin. Parker's precision electronics cooling thermal management system technology can provide electronics cooling to power electronics designs of as much as twice the power density in half the space. Using a vaporizable dielectric fluid for electronics liquid cooling, the system boils this fluid across the base of the silicon chip, converting the fluid into a gas, and stabilizing the system's temperatures.

New Heat Sink Series for TO-220 Single Gauge Applications

Aavid Thermalloy has introduced a new line of heat sinks specifically for TO-220 Single Gauge applications. The new 5728 series is based on the best selling 5768 series that clamps onto the back plate. The dimensions have been modified to fit a thinner back plate.



Coolers for Converters

Webra water and air cooling solutions are available for various converters and inverters in wind power, traction and industry applications. Applications include water coolers for 62 mm IGBT modules, SKiiP, Primepack, 130 x 140 and 140 x 190 mm modules, each in different configurations, as well as universal coolers for mounting different module sizes. For medium voltage applications, water coolers are available for disc cell diameters up to 115 mm and clamping forces up to 150 kN. From AMS Technologies.

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