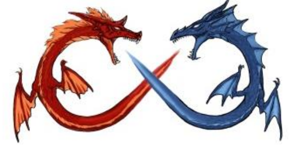

功率模組散熱技術

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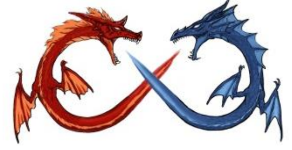
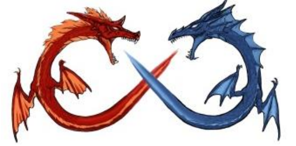


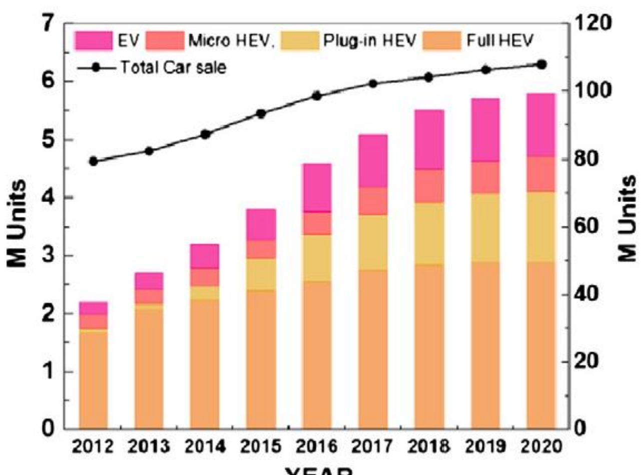
Outline

- ***General background for cooling of power electronics***
- ***Air cooling vs. liquid cooling***
- ***Fundamentals – Heat Transfer for Cold***
- ***Some designs***
- ***Short Summary & Outlook***

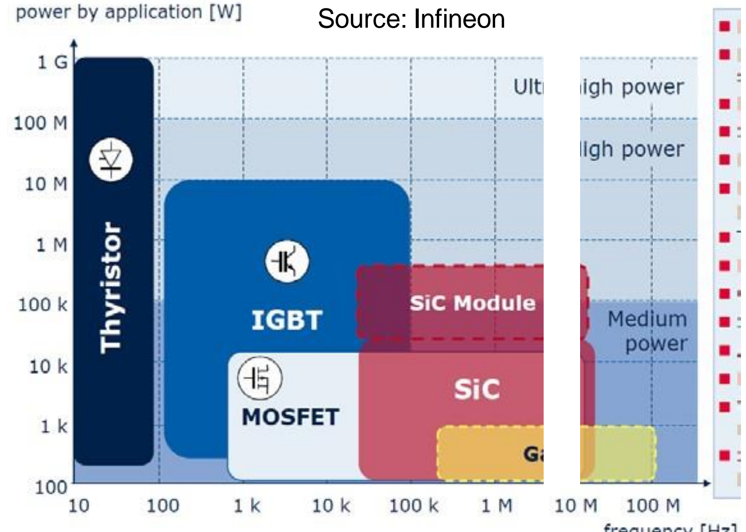


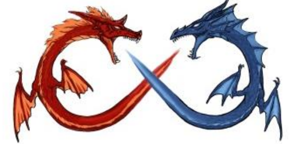
Background

- **Increased requirements of high power semiconductor device module for future automotive, aerospace and green & renewable energy industry**



Microelectronics Reliability 64 (2016) 474–478



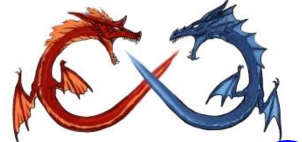


Technology Trends

- **Technology trends for high power module and discrete :**
  - ✓ **High temperature endurable materials >220°C (silver sintering, encapsulations)**
  - ✓ **High reliable and low stress interconnections (foil interconnects, ultrasonic bonding)**
  - ✓ **Thermal cooling solution (Dual-side cooling / micro-channel cooling)**

Source: Yole

	Current solutions Widely used by all players	*Emerging technos* At mass production and growing in market shares	*Potential breakthrough* At R&D stage. Still too expensive	
Interconnection	Al wire bonding	Al ribbon bonding Copper wire bonding	Foil sintering Foil ultrasonic wedge bonding	
Die attach	Pb/Sn alloy Or SAC alloy	Silver micro powder sintering	Nano powder sintering (no heating and pressure for attach process)	DBC on both sides: flip chip + Sintering on both sides +Cooling on both sides
Baseplate Cooling	Baseplate + heatsink AlSiC for long lifetime Al2O3 for cost	Thermal exchange improvements: • Shower power • DBC to heatsink (no baseplate)	Micro-channel cooling	

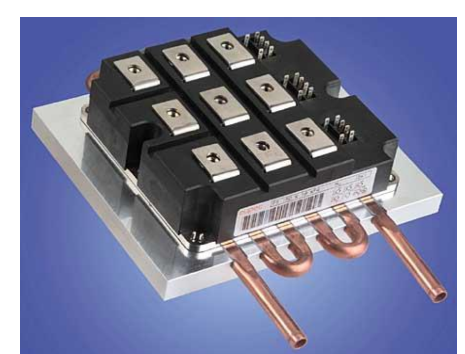


Cooling solutions - Summary

Air Cooled

•Low cost approach adequate, but limits capability of power devices
•Free & forced convection
•Jet impingement
•Augmentation via fin geometry

Air Cooled



Liquid Cooled

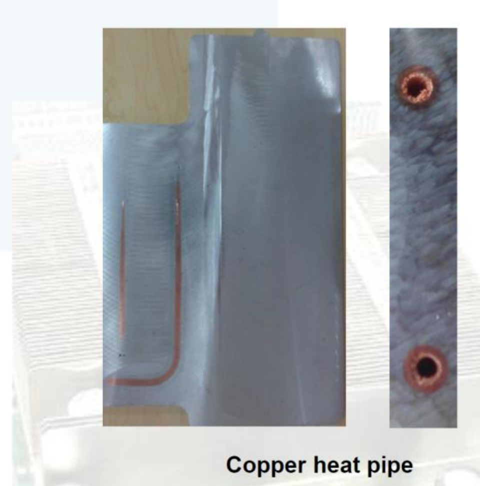
Liquid Cooled

- Pumped Water/dielectric fluid (Not an option in many applications)
- Heat pipe/thermosphion
- Microchannels
- Immersion cooling

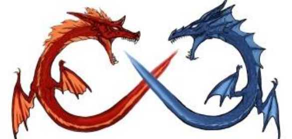
Conduction Augmentation

- Layer reduction
- Spread/contact resistance reduction

Copper heat spreader



Copper heat pipe



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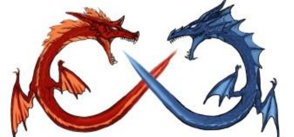
Chip power loss (W/cm²)
1000
300
100
30
10
Rated chip current density(A/cm²)
100
200
300
500
1000
Chip
Chip direct cooling
Chip
Integrated double side cooling module
Chip
Integrated single side cooling module
Heat sink
Bonding wire
Chip
Single side cooling module
Water cooled plate
Chip
Double side cooling module
Heat sink

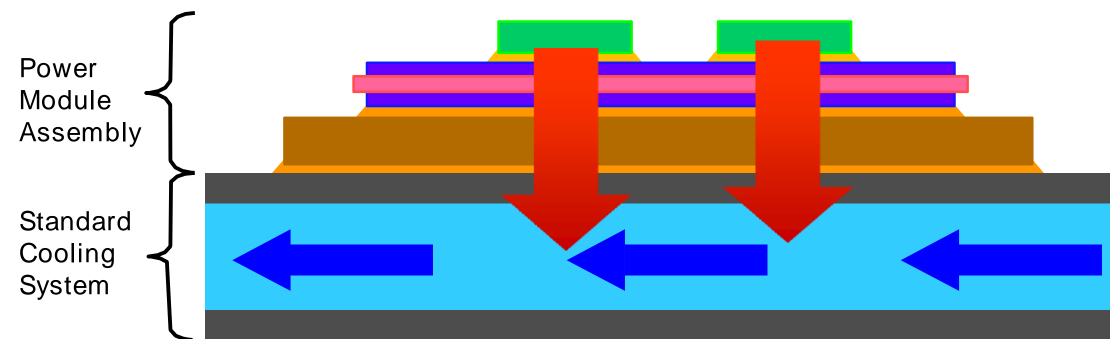
With increasing heat density, thermal interface resistance can become a bottleneck.

This calls for integrated electrical and thermal packaging so that the number of thermal interfaces from heat source to coolant are minimized.

- Z. John Chen and Ichiro Omura, Power Semiconductor Devices for Hybrid, Electric and Fuel Cell Vehicles, Proceedings of the IEEE, April 2007.

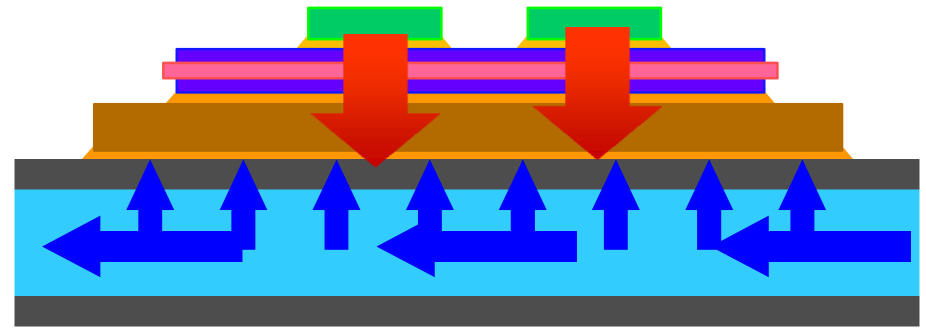


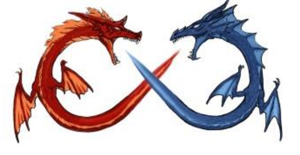
Reducing the number of thermal layers



1.Die
2.Solder
3.Direct Bonded Copper
4.Ceramic
5.Direct Bonded Copper
6.Solder
7.Heat spreader plate
8.Thermal Paste
9.Cooler

- Typical water cooled system
- 9 thermal layers and interfaces between electronic die and coolant fluid
- High package thermal resistance
- Low heat transfer coefficient generated by coldplate cooler



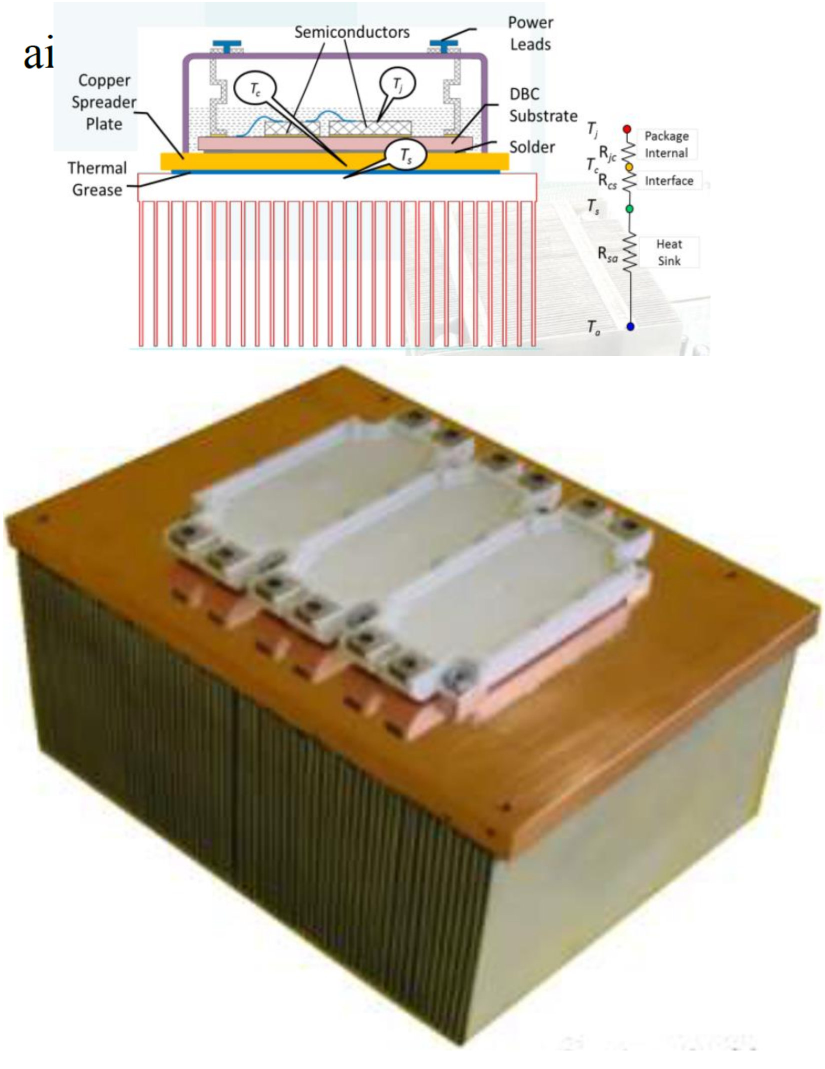


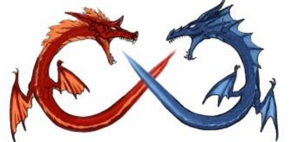
Advanced Cooling for Power Electronics

Sukhvinder S. Kang, Aavid Thermalloy LLC, Concord NH, USA

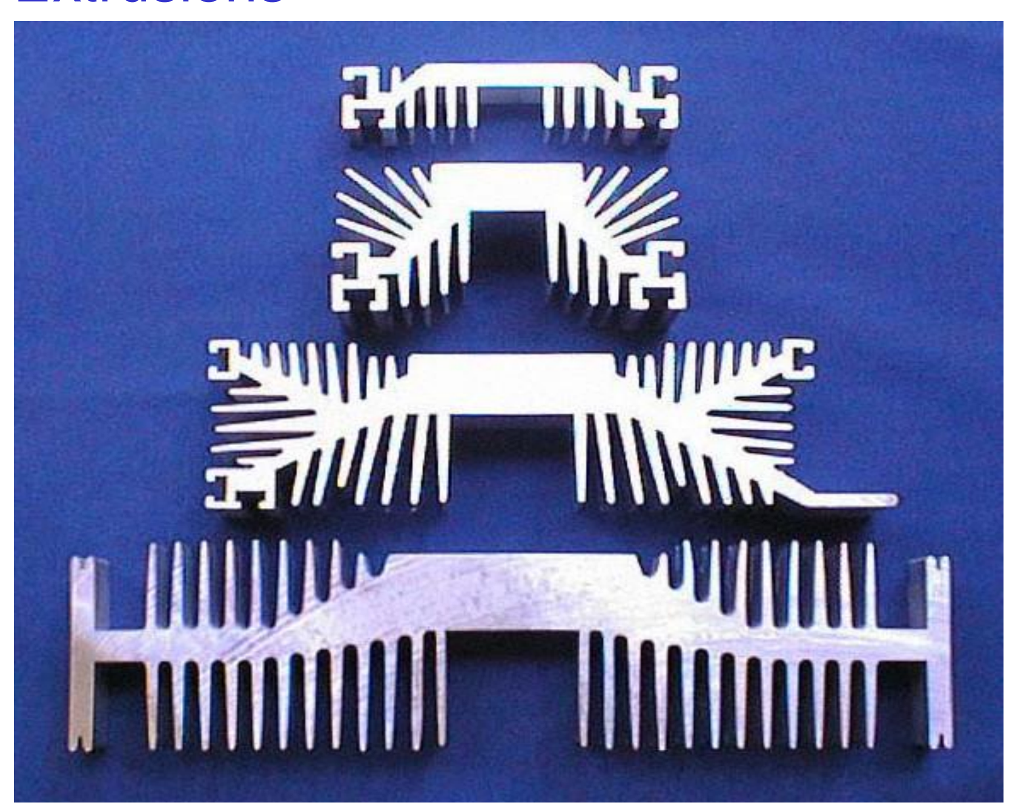
Table 1 Approximate thermal resistances in IGBT ai cooled assembly shown in Figure 5

Stack-up layer	Thickness (mm)	Resistance (°C/kW)	Resistance Percentage of total
Silicon	0.2	0.6	1.3%
Silver	0.1	0.2	0.4%
Copper	0.3	0.2	0.5%
Al-Oxide	0.38	4.0	9.7%
Copper	0.3	0.2	0.4%
Solder	0.1	0.6	1.3%
Copper base plate	3	0.7	1.6%
Thermal Paste	0.05	4.2	10.0%
HS-Base spreading	20	12	28.9%
HS-Fins convective	110	19	45.8%
Total		41.5	100%





Common Stud & Disc Device Air Cooled Aluminum Extrusions



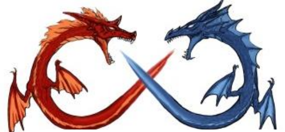
2”

23mm Stud/Disc

Up to 50mm Disc

Up to 67mm Disc

Up to 77mm Disc



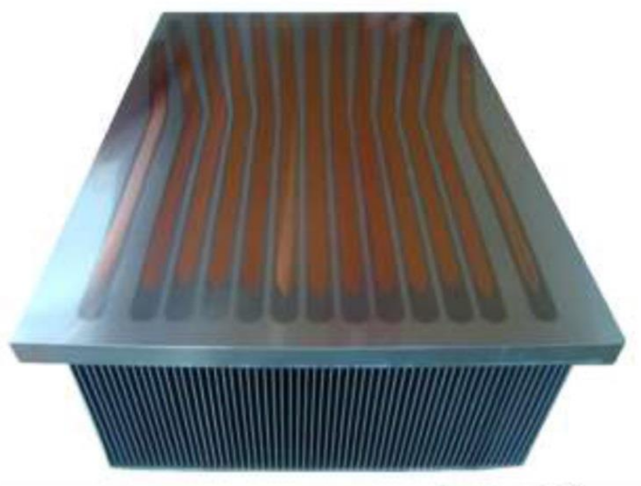


Figure 7 Air cooled heat sink with heat pipes embedded in an aluminum base

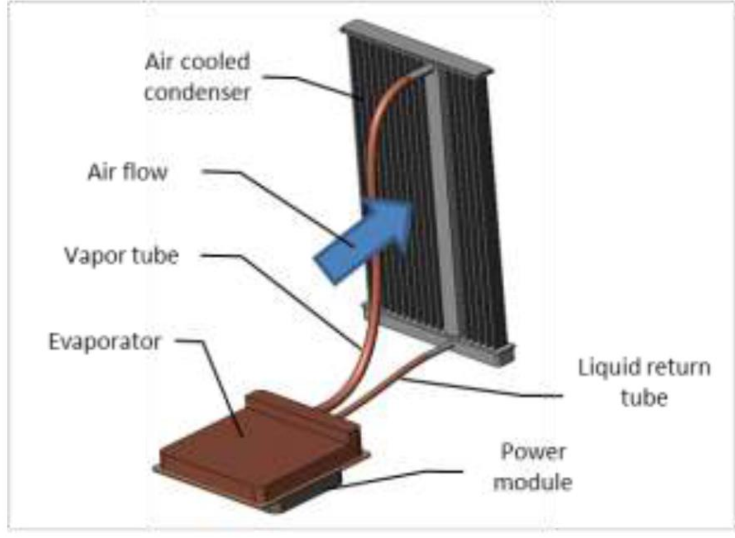


Figure 9 Air cooled heat sink using loop thermosiphon

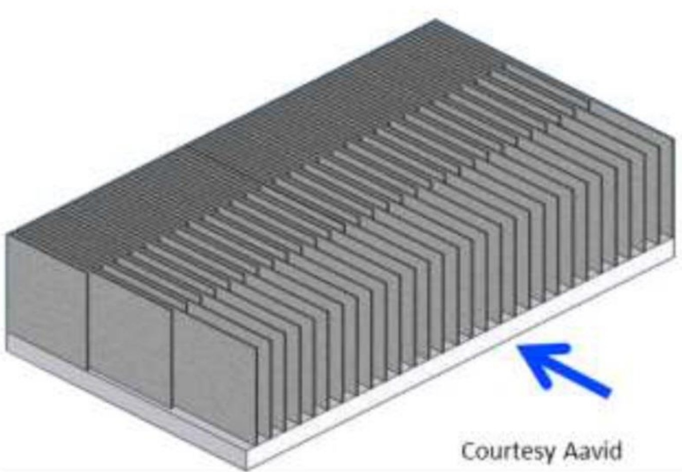
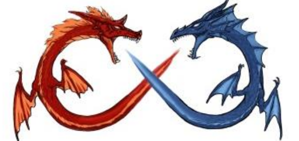


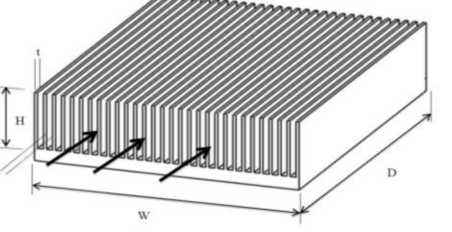
Figure 8 Advanced heat sink with increasing fin density along air flow direction

Figure 11 Thermosiphon air cooled system with power electronics immersed in dielectric fluid. IGBT is clamped between enhanced boiling plates.

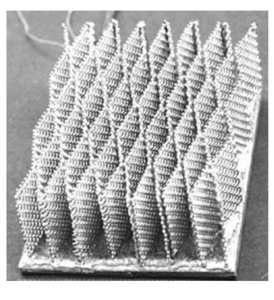


Novel Heat Sink

Wang, C.C., (2017), **"A Quick Overview of Compact Air-cooled Heat Sinks Applicable for Electronic Cooling – Recent Progress,"** ***Inventions***, Vol. 2, issue 1, article no. 5. Abstract: http://www.mdpi.com/2411-5134/2/1/5/. doi:10.3390/inventions2010005.



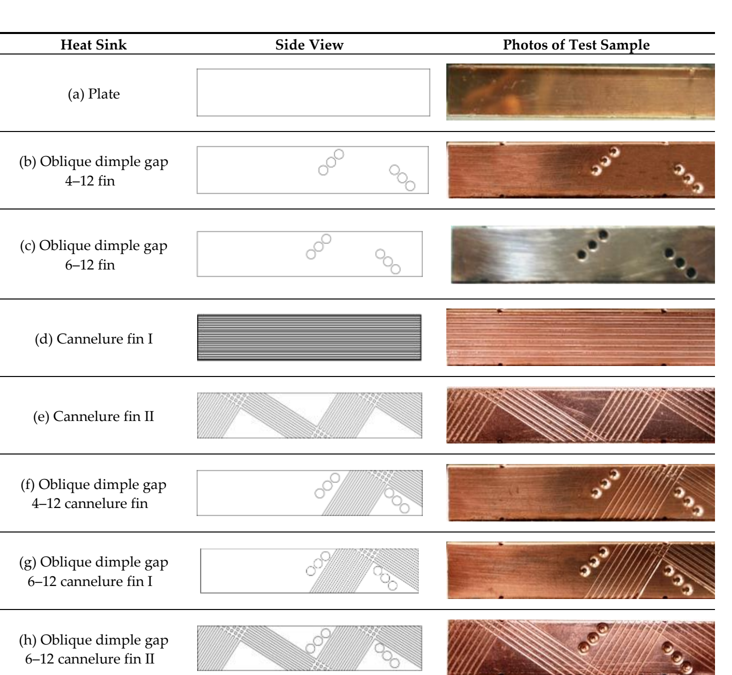
- Porous fins



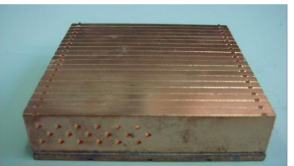
(**a**) (**b**) (**c**)

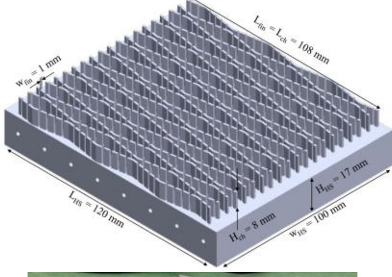
Figure 5. Fin structure tested by Krishnan et al. Reprinted with permission from [24].. (**a**) Fin metal foam heat sink; (**b**) slotted hexagon heat sink; (**c**) Schwartz type heat sink.

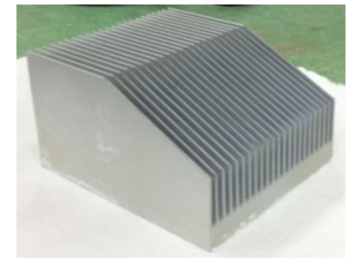
- VG, cannelure, Louver, partial bypass, slit, … Design

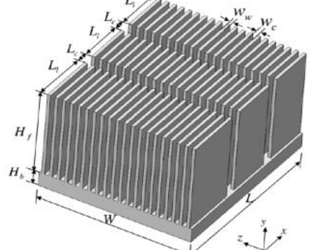


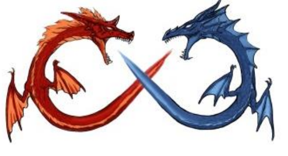
Heat Sink	Side View	Photos of Test Sample
(a) Plate		
(b) Oblique dimple gap 4–12 fin		
(c) Oblique dimple gap 6–12 fin		
(d) Cannelure fin I		
(e) Cannelure fin II		
(f) Oblique dimple gap 4–12 cannelure fin		
(g) Oblique dimple gap 6–12 cannelure fin I		
(h) Oblique dimple gap 6–12 cannelure fin II		











Historical studies related to fin design

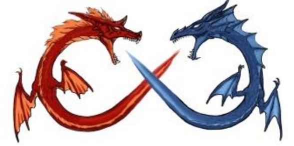
Authors	Year	Geometry	Orientation	Experimental/numerical
Bar-Cohen et al. [1]	2003	Rectangular fins	Vertical	Numerically
Mokheimer [2]	2003	Straight and pin fin with rectangular, convex parabolic, triangular and concave parabolic, and radial fins	Horizontal	Experimentally
Khan et al. [3]	2006	Circular, elliptical, square and rectangular fins	Horizontal	Numerically
Huang et al. [4]	2008	Flat and square pin fin heat sinks	Upward, sideward and downward	Experimentally
Goshayeshi and Ampofo [5]	2009	Rectangular fins	Vertical & horizontal	Numerically
Suryawanshi and Sane [6]	2009	Rectangular fins	Horizontal	Experimentally & numerically
Zhang and Liu [7]	2010	Rectangular fins	Vertical	Numerically & analytically
Fahiminia et al. [8]	2011	Rectangular fins	Vertical	Numerically
Goshayeshi et al. [9]	2011	Rectangular fins	Vertical	Experimentally
Torabi et al. [10]	2013	Rectangular, trapezoidal and concave parabolic	Horizontal	Numerically & analytically
Tari and mehrtash [11]	2013	Rectangular fins	Inclined $\pm 4^\circ \le \theta \le \pm 90^\circ$	Numerically & experimentally
Mehrtash and Tari [12]	2013	Rectangular fins	Inclined $\pm 4^\circ \le \theta \le \pm 90^\circ$	Numerically & experimentally
Tari and Mehrtash [13]	2013	Rectangular fins	Slightly inclined: $\theta = \pm 60^\circ$ to $\pm 90^\circ$	Experimentally & numerically
Kim et al. [14]	2013	Cylindrical heat sink	Horizontal	Experimentally

(a) Rectangular fin (b) Trapezoidal fin (c) Inverted trapezoidal fin

Approach I & II

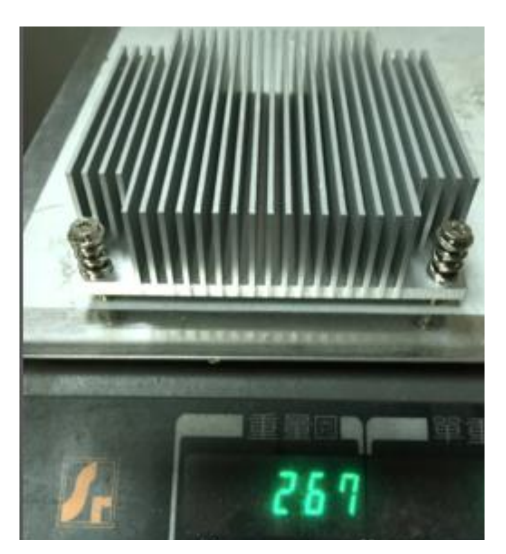
Approach III

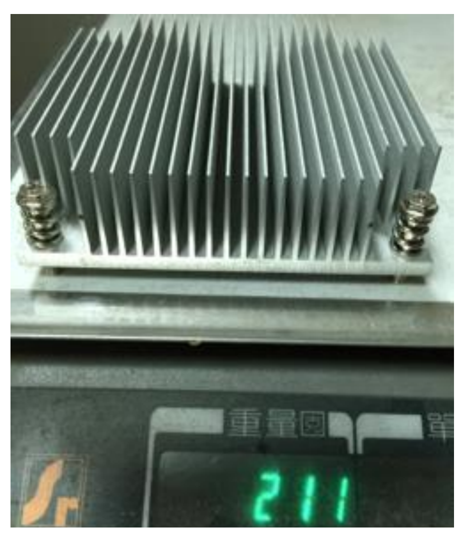
Chen, H.L., and Wang, C.C., (2016), "Analytical Analysis and Experimental Verification of Trapezoidal Fin for Assessment of Heat Sink Performance and Material Saving," *Applied Thermal Engineering*, Vol. 98, pp. 203-212.



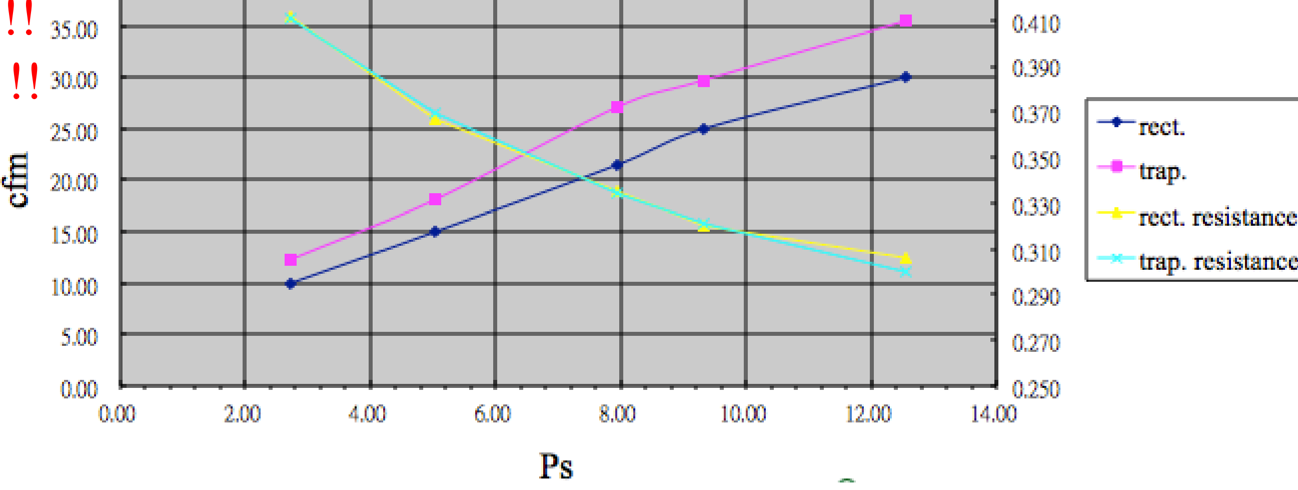
APPLICATION CASE

r_t =0.5, weight 25%↓↓ , performance 2.7%↓



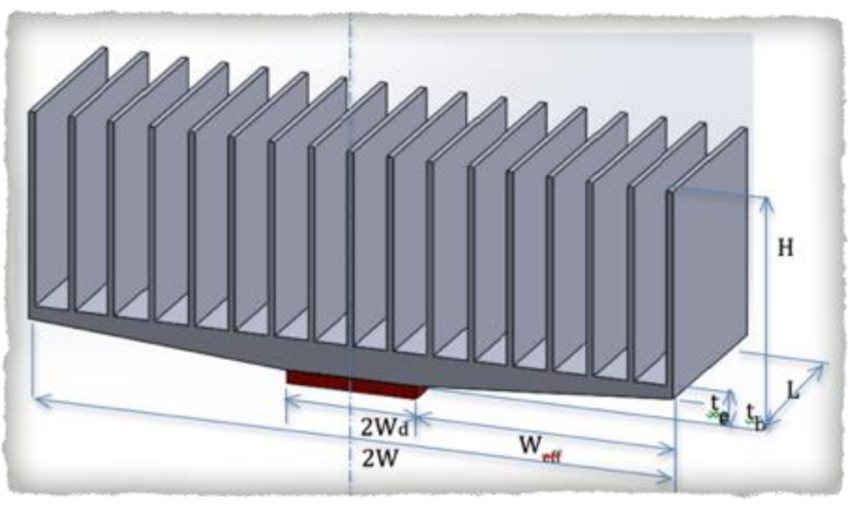


- Weight down 22%↓ !!
- Performance down 0% !!
- CFM gains 18-20%!!

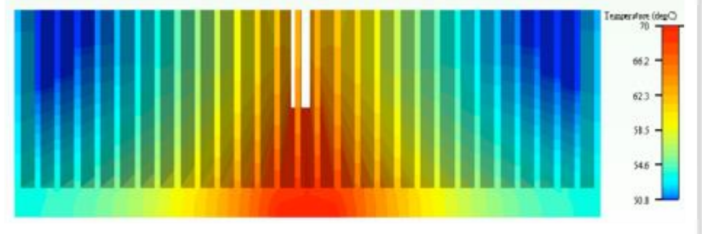


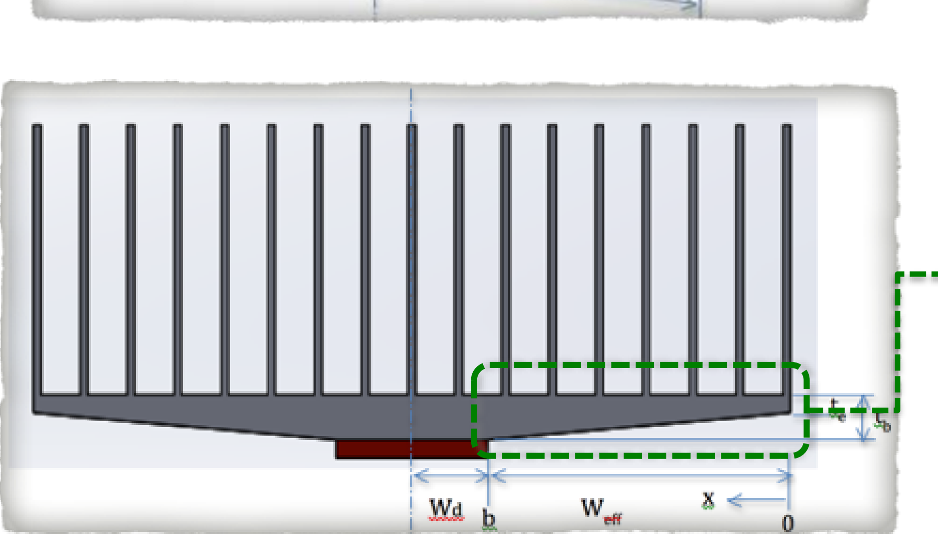
Chen, H.L., and Wang, C.C., (2016), "Analytical Analysis and Experimental Verification of Trapezoidal Fin for Assessment of Heat Sink Performance and Material Saving," *Applied Thermal Engineering*, Vol. 98, pp. 203-212.

Schematics of heat sink – saving of base area

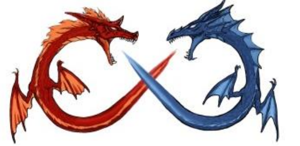


- Base edge is x=0 position
- Chip edge is x=b



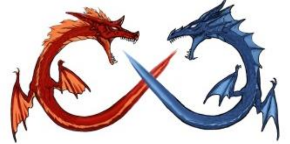


length for material saving study



Base weight reductions

Chen, H.L., and Wang, C.C., (2017), “Analytical analysis and experimental verification of weight saving with heat sink having trapezoidal base,” *Applied Thermal Engineering*, in reveiew.



Fundamentals:

Heat Transfer Augmentation of Cold-Plate

- Heat Transfer Augmentation ($Q = UA\Delta T_m$)

  Q : heat transfer rate,

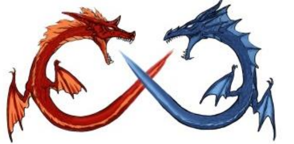
  U: overall heat transfer Coeff.

  A: Area

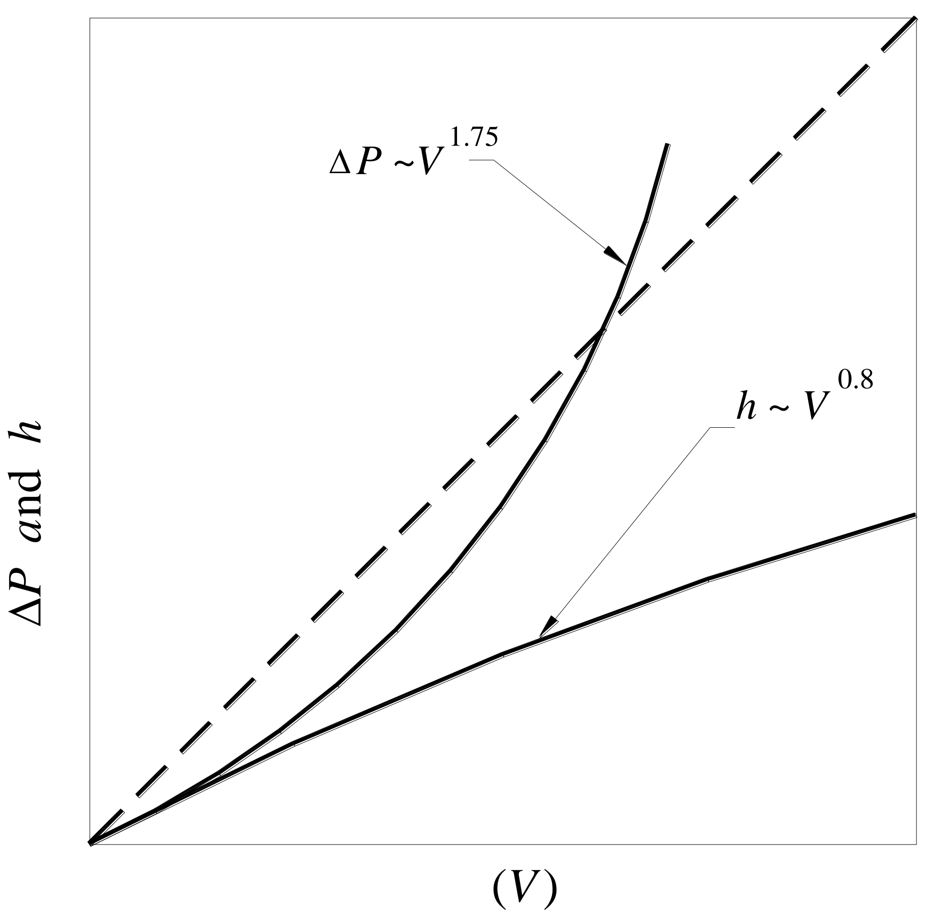
  ΔT_m: mean temperature difference

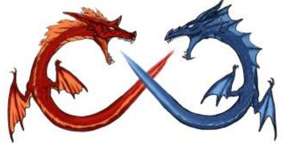
For electronic cooling $Q = \eta_o hA\Delta T_m$

- Do we really need enhancement?
- When do we need the enhancement?
- Where should we place enhancements?
- Is it cost-effective?



Taking into consideration about the influence of pressure drop (pumping power)





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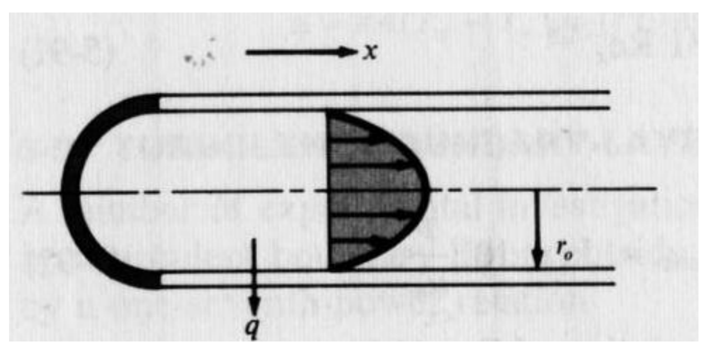
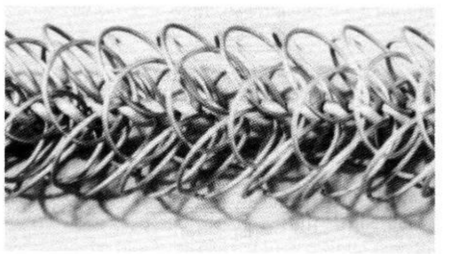
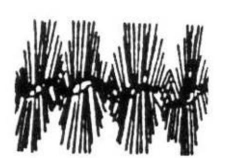
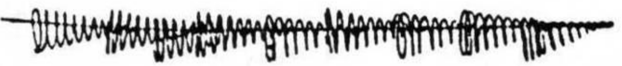
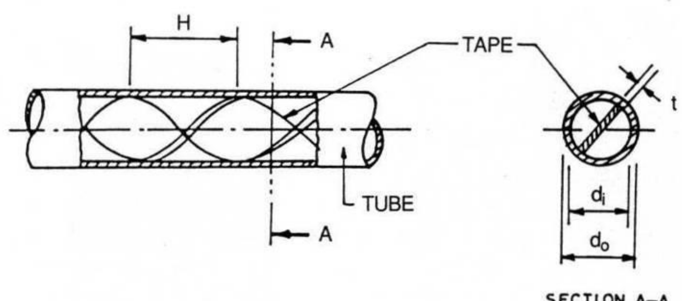
Augmentation of single-phase flow – Laminar Flow

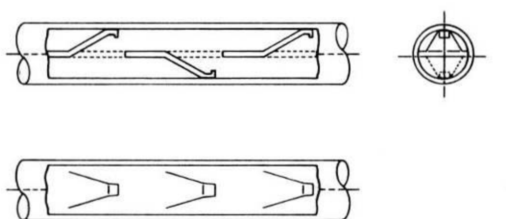


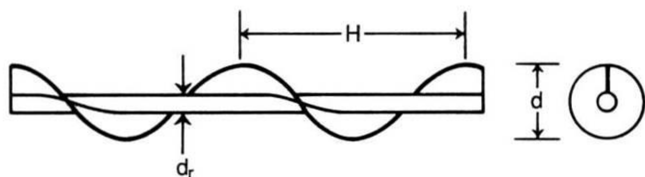


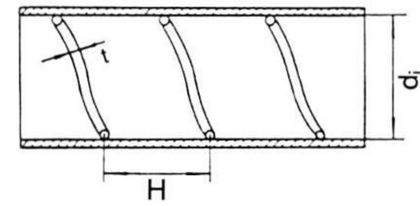


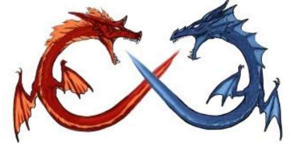












Augmentation in turbulent flow

Three-dimensional roughness ("uniform roughness")

Ridge-type two-dimensional roughness ("repeated ribs")

Groove-type two-dimensional roughness

α

p/e e/d_i $p/e = 2$ $p/e = 4$

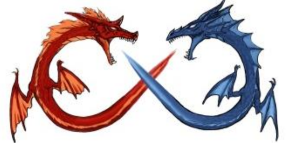
p/e e/d_i $p/e = 15$ $p/e = 5$ $p/e = 2$

p/e e/d_i $p/e = 5$ $p/e = 2$ $p/e = 1$

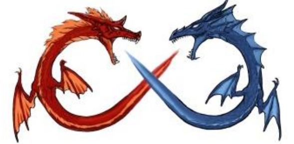
Laminar sublayer

u

Turbulent core



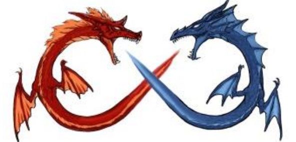
Cold Plate - Some designs



Augmentation based on plate HXs

dimension: 50 mm x 50 mm x 2 mm

U - type | Chevron (V) | (OSF)

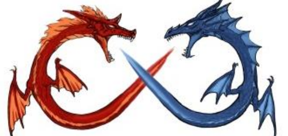


Temperature Distribution..

°C

28 30.5 33

	Power	Flowrate (mL/min)	Inlet Temp.
	20	230	30 °C



Advanced Cooling for Power Electronics

Sukhvinder S. Kang, Aavid Thermalloy LLC, Concord NH, USA

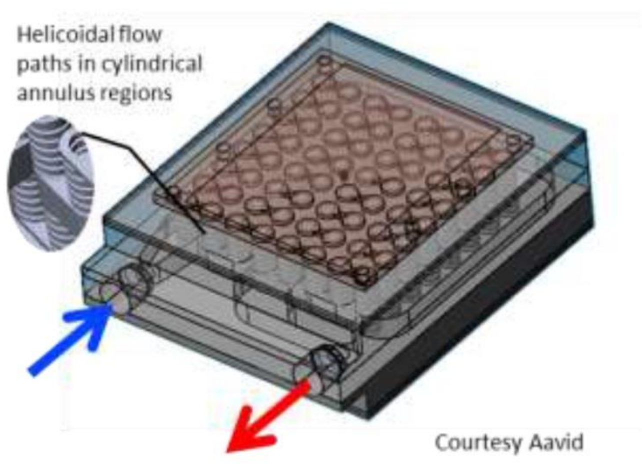


Figure 12 Vortex Liquid Cold Plate in a double sided cooling version.

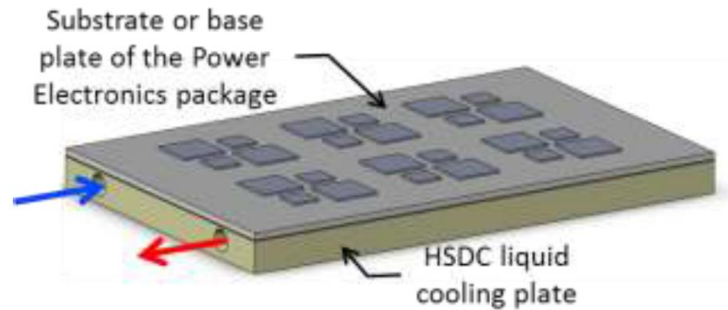


Figure 14 Liquid cooling of Power Electronics package using High Shear Direct Contact concept

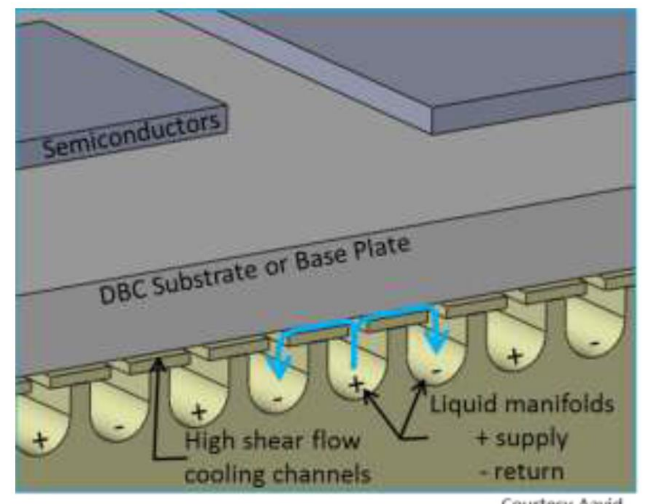
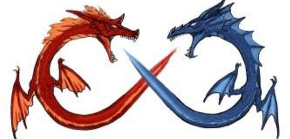


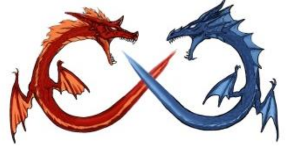
Figure 15 High shear flow cooling channels and flow pattern in the HSDC liquid cooling plate



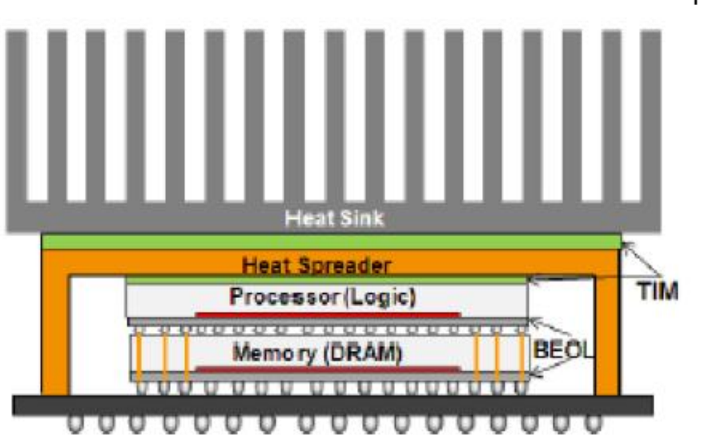
Microelectronics Reliability
Volume 55, Issues 9–10, August–September 2015, Pages 1938-1944

Bondwire
Chip
Solder Pad
Copper
Ceramic Isolator
Copper
Solder Layer
Copper Baseplate

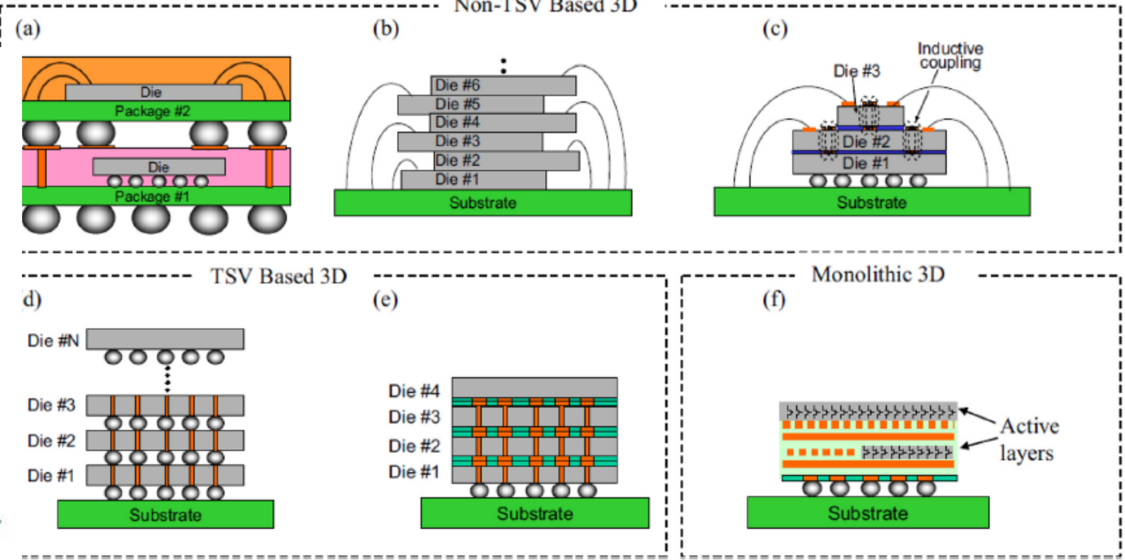
Fig. 1. Hybridpack2 power module from Infineon.



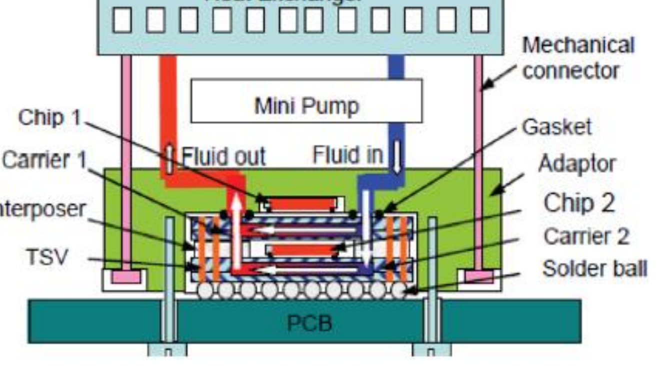
Advanced Designs..



ig. 12 Thermal management in 3D chip stacks using conven-
ional air cooling [55]



.g. 2 Existing packaging and 3D integration technologies: (*a*) stacking of fully packaged die (*b*) die stacking based on wire
onding, (*c*) die stacking using wireless interconnection, (*d*) die stacking using controlled collapse chip connection (C4)
umps and TSVs, (*e*) die stacking based on thin-film bonding, and (*f*) monolithic 3I



g. 14 Schematic of integrated liquid cooling system for 3I
ystem using microfluidic channel [56]

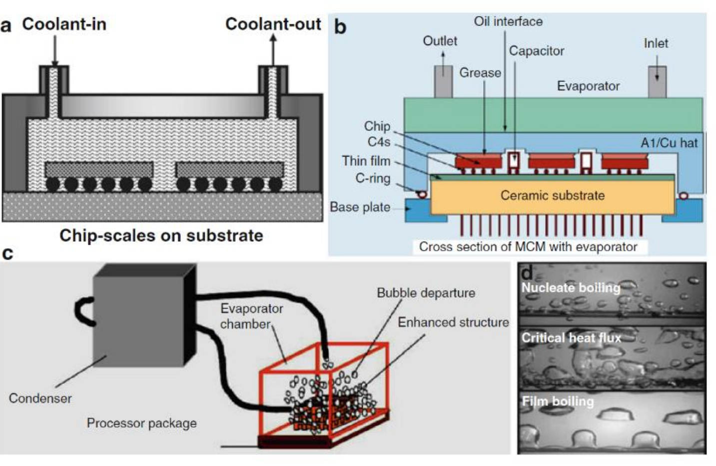
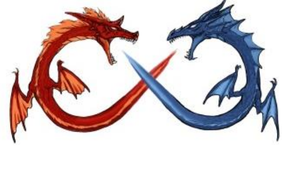


Fig. 15 Assembly of 3D prototype of integrated microfluidic channel cooling solution [58]

3D IC, A Review of Recent Advances in Thermal Management in Three Dimensional Chip Stacks in Electronic Systems. Journal of Electronic Packaging, ASME, 2011, Vol. 133 / 041011-1



Advanced Thermal Management Solutions in Planar 2D Circuits

- Compact Thermosyphon

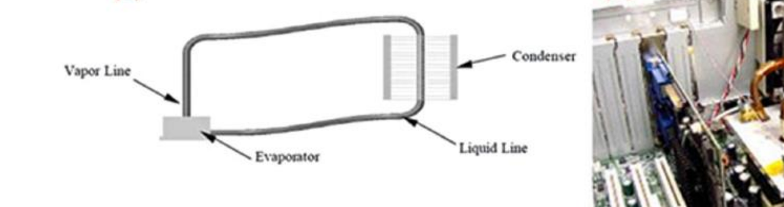


Fig. 6 (*a*) Loop thermosyphon and (*b*) HP Vectra PC with the thermosyphon assembly [26]

- Mirco CPL (capillary pump Loops)
- Miniature Loop Heat Pipe

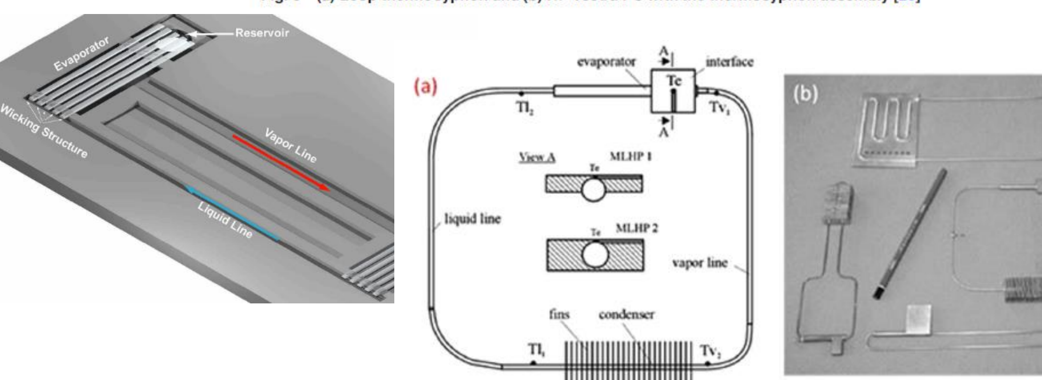


Fig. 7 (*a*) Miniature loop heat pipe principle and (*b*) general view of miniature loop heat pipe [27

- Electro-Osmotic Pump
- Stacked Micro-Channel

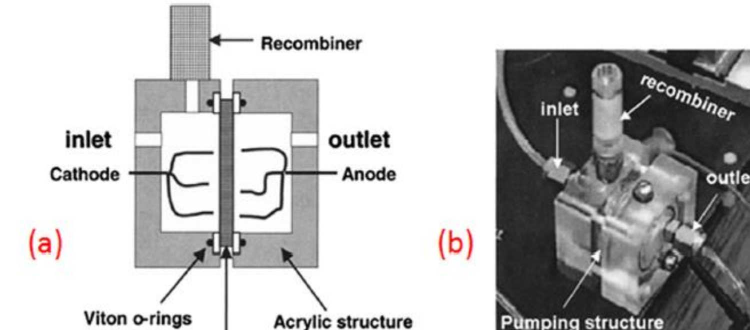


Fig. 8 (*a*) Schematic and (*b*) image of an electro-osmotic pump [28]

DESIGN AND FABRICATION OF A MICRO-CPL FOR CHIP-LEVEL COOLING, Dorian Liepmann, 2001

3D IC, A Review of Recent Advances in Thermal Management in Three Dimensional Chip Stacks in Electronic Systems. Journal of Electronic Packaging, ASME, 2011, Vol. 133 / 041011-1

Advanced Thermal Management Solutions

- Impinging Jet
- Thermoelectric Micro-Cooler
- Miniature Vapor Compression Heat Pump
- Miniature Absorption Heat Pump

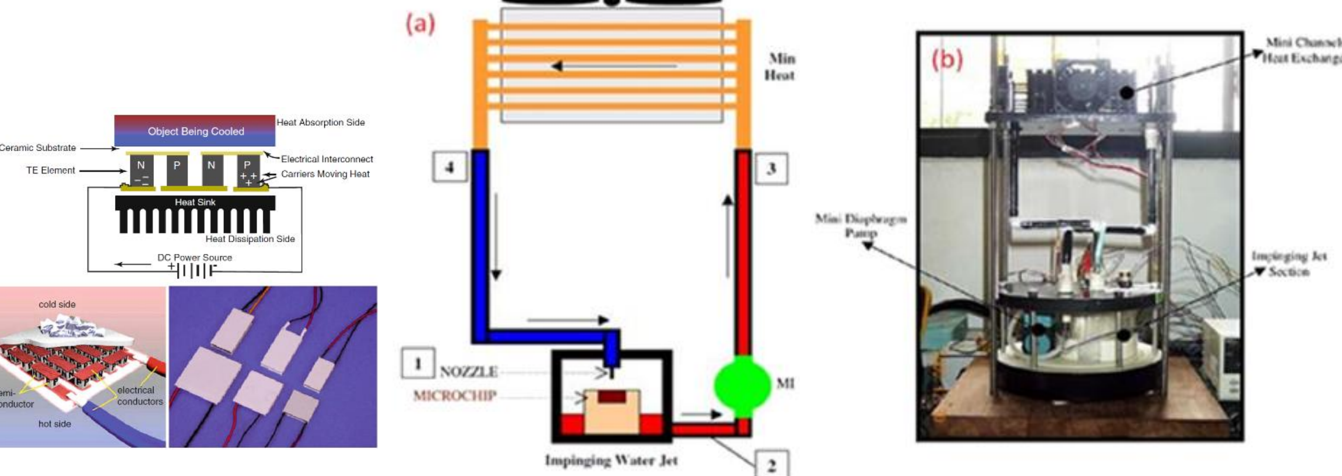


Fig. 9 (*a*) Schematic and (*b*) close-up picture of the impinging jet cooling system [30]

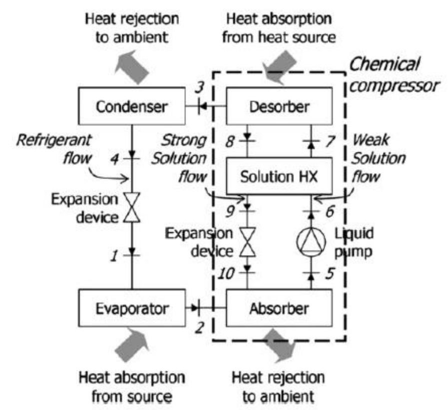
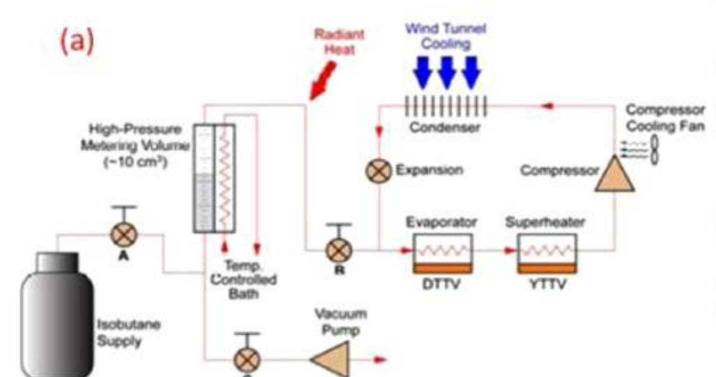


Fig. 11 Schematic of miniature absorption heat pump micro-electronics cooling solution [34]



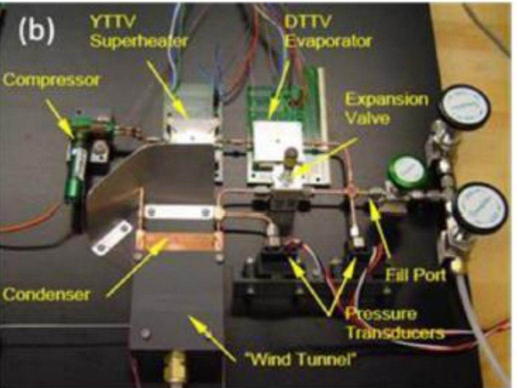


Fig. 10 (*a*) Schematic and (*b*) actual setup of a miniature vapor compression heat pump microelectronics cooling solution [33]

DESIGN AND FABRICATION OF A MICRO-CPL FOR CHIP-LEVEL COOLING, Dorian Liepmann, 2001

3D IC, A Review of Recent Advances in Thermal Management in Three Dimensional Chip Stacks in Electronic Systems. Journal of Electronic Packaging, ASME, 2011, Vol. 133 / 041011-1

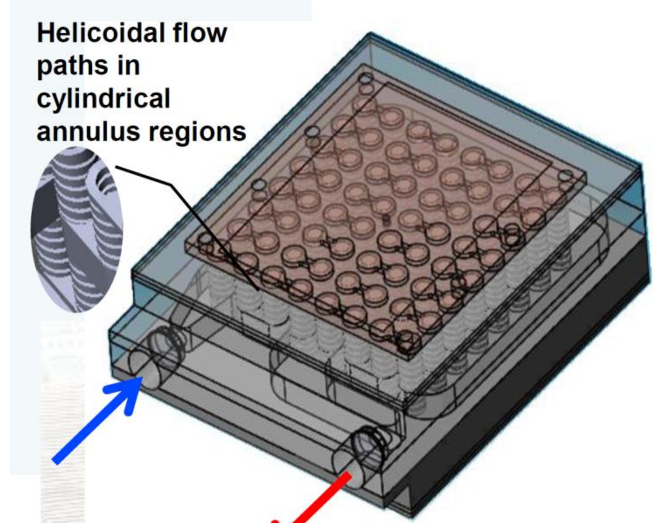
Liquid Cooling Solution Indirect & Direct

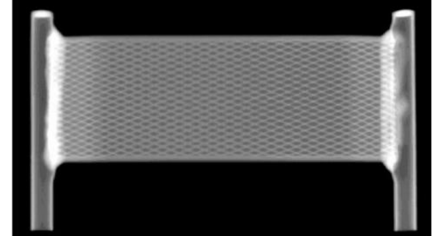
Single Tube type

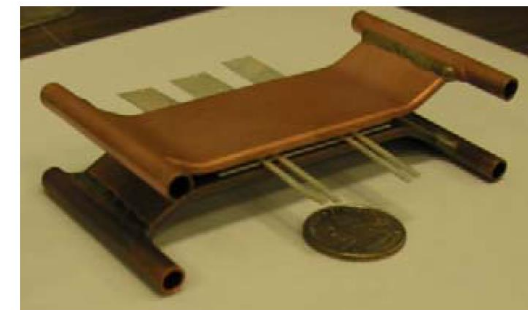
Parallel-Tube type

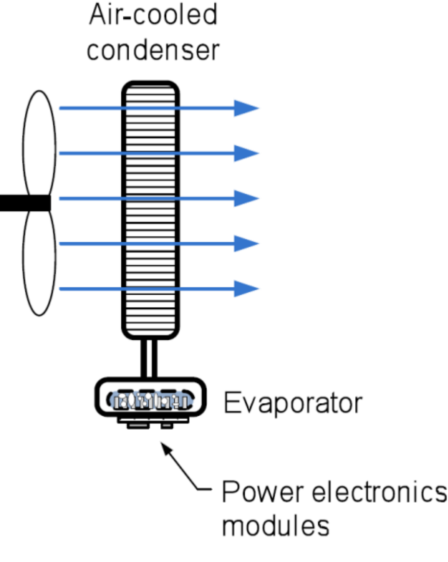
Channel or offset fin Type

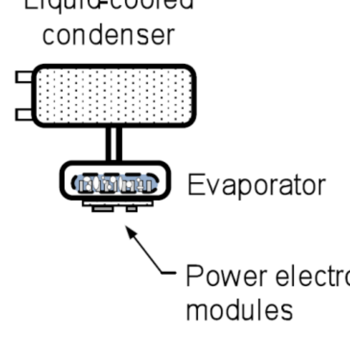
Hi-Shear Channel Type

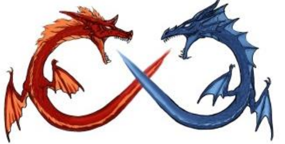






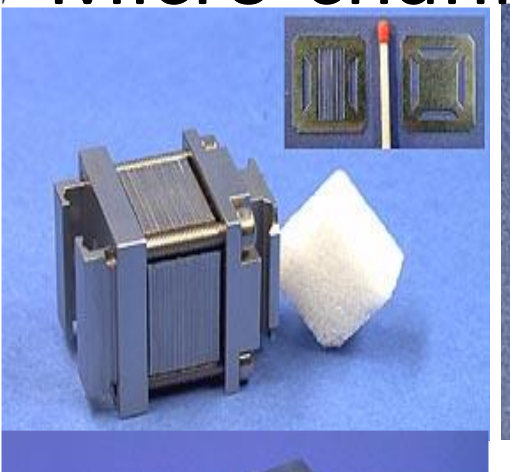


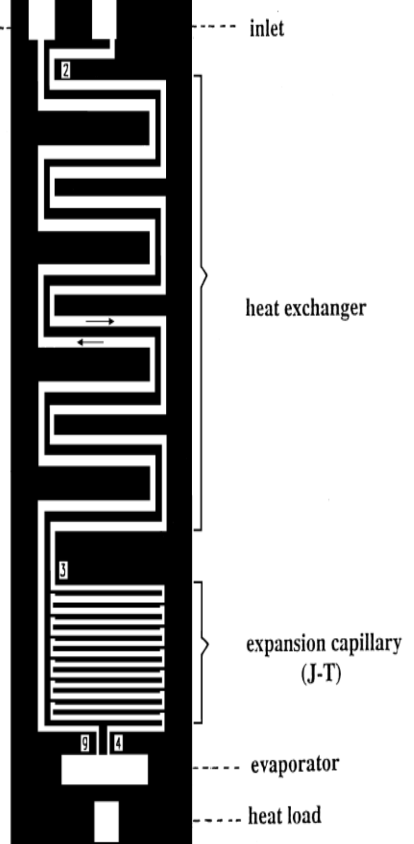


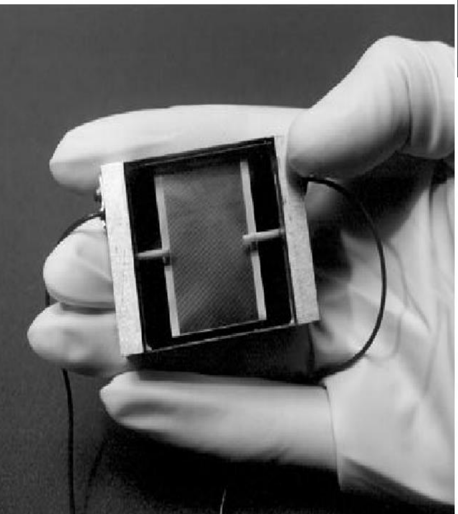


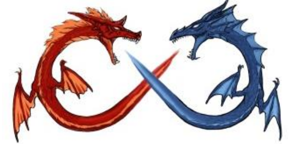
國立交通大學 National Chiao Tung University

Micro-channel HXs - Example









Why Use smaller Channel?

Consider a reduction of D_h with a factor of 10

- In this case, 10 times increase of heat transfer coefficient ($Nu = hD_h/k$)
- In this case, 10 times increase of heat surface area at the same volume)
- For the same thermal resistance, flow rate, and pressure drop constraints, the microchannel design offers 1/100 Less volume!

$$\Delta P = \frac{4L}{D_h} f \frac{1}{2}\rho u^2 = \frac{4L}{D_h} f \frac{\rho u D_h}{\mu} \frac{\mu}{D_h} \frac{1}{2} u$$

$$= \frac{2\mu u L}{D_h^2} f \,\mathrm{Re}$$

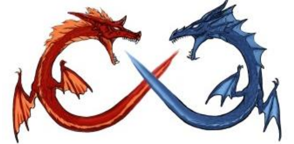
$$\Delta P \propto \frac{L}{D_h^2} \quad \rightarrow L \text{ must reduce to } \frac{1}{100} \text{ to}$$

maintain a constant ΔP, while the thermal

resistance $\frac{1}{hA}$ stays the same! This implies a reduction of volume to its original $\frac{1}{100}$

(a)

(b)



Journal of Electronic Packaging, 2011, Vol. 133 / 041011-1

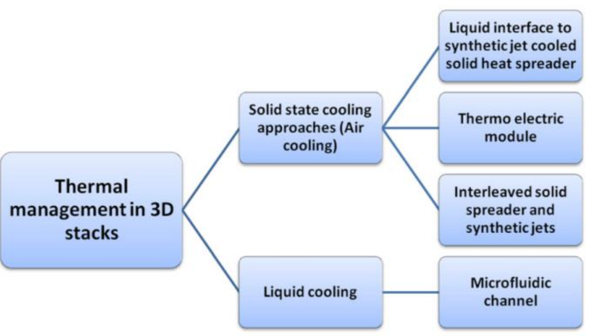
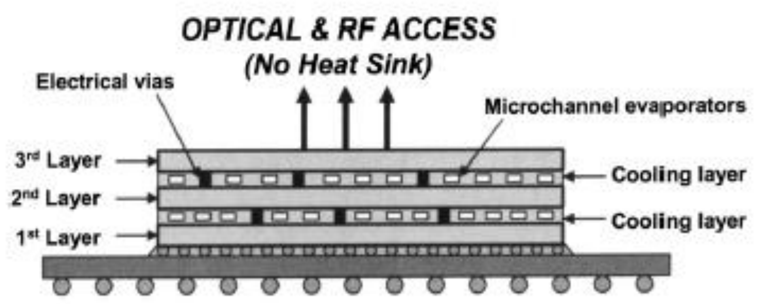
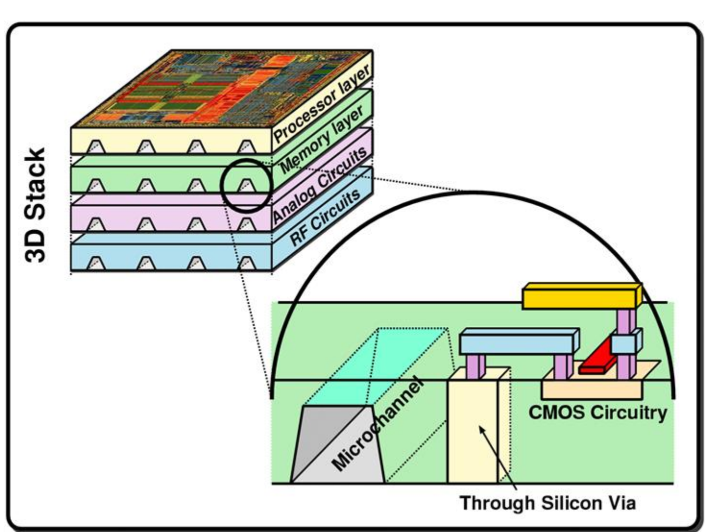


Fig. 13 Thermal management strategies in 3D stacks



(a) 3D circuit with a microchannel cooling system

3D IC with Microchannel



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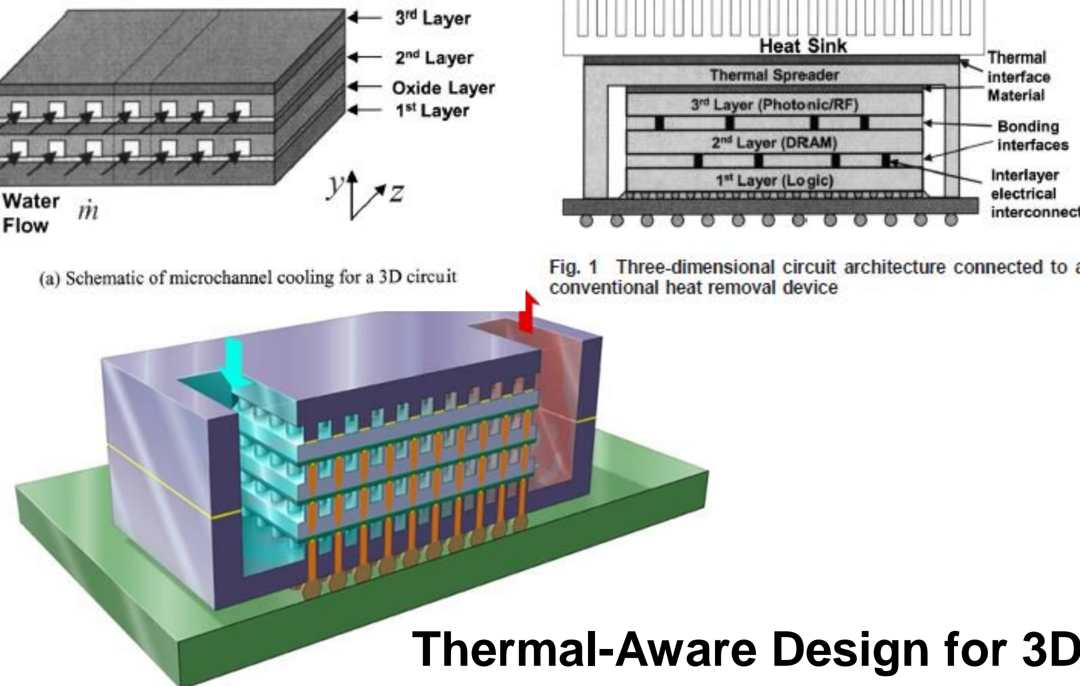
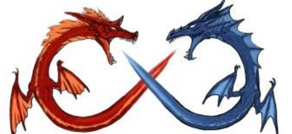


(a) Schematic of microchannel cooling for a 3D circuit

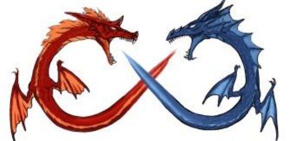
Fig. 1 Three-dimensional circuit architecture connected to a conventional heat removal device

Thermal-Aware Design for 3D Multi-Processor



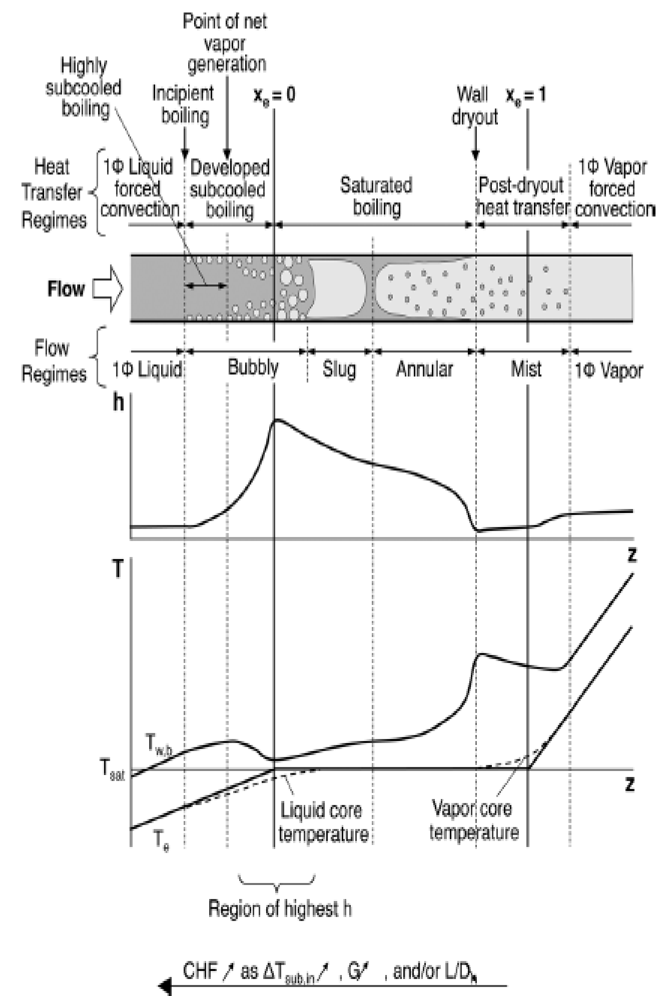
Two-Phase Boiling in Microchannels

- Fluid entering microchannels is heated to the point where it boils
- Flow in microchannels is highly unpredictable and can produce large voids and multiple flow regimes inside of tubes
- No accurate analytical models currently exist; many analytical models have errors ranging from 10% to well over 100%



Two-phase Flow in Microchannels

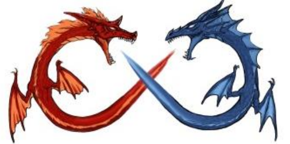
- Fact: For single phase flow, thermalfluids characteristics virtually no change either in Microchannel or conventional macrochannel.
- How about two-phase flow?



Flow regimes, heat transfer regimes, and variations of wall temperature and convective heat transfer coefficient along microchannel flow

Requirements for a Liquid Coolant for Electronics

- **Good thermo-physical properties** (high thermal conductivity and specific heat; low viscosity; high latent heat of evaporation for two-phase application)
- **Low freezing point and burst point** (sometimes burst protection at -40°C or lower is required for shipping and/or storage purposes)
- **High atmospheric boiling point** (or low vapor pressure at the operating temperature) for single phase system; a narrow desired boiling point for a two-phase system
- **Good chemical and thermal stability** for the life of the electronics system
- **High flash point and auto-ignition temperature** (sometimes non-combustibility is a requirement)
- **Non-corrosive to materials of construction** (metals as well as polymers and other non-metals)
- **No or minimal regulatory constraints** (environmentally friendly, nontoxic, and possibly biodegradable)
- **Economical**

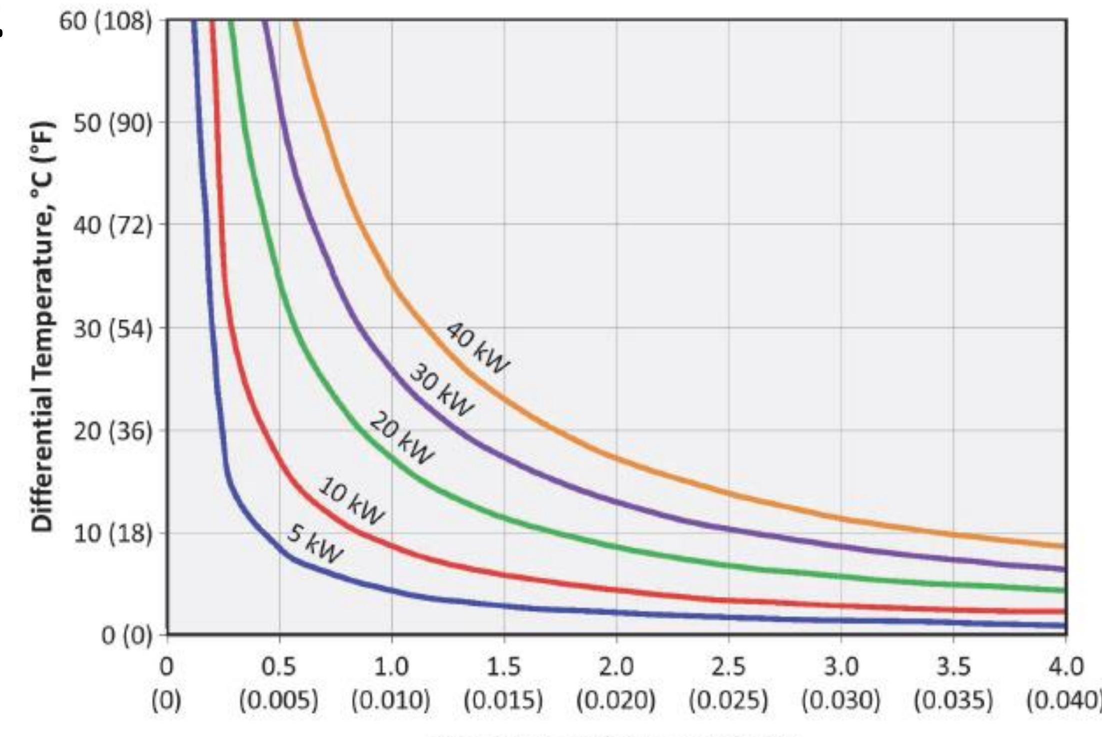


Fluid Selection

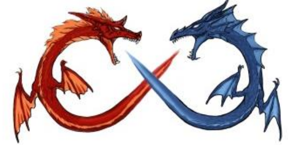
- Is the fluid in direct contact with the electronics?
  - No. Water will normally be used due to the fact that it is cheap and has superior thermal properties.
  - Yes. A dielectric must be used. Consideration must be given to the thermal properties of different dielectric fluids.

Water Flow Rates/Pressures

- Water flow rates are shown in Figure for given heat loads and given temperature differences. **Temperature differences typically fall between 5°C to 10°C** (9°F to 18°F).
- Minimum facility pressure differential (drop) should not be lower than 0.4 bar.



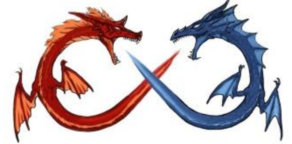
Typical water flow rates for constant heat load



Velocity Limits

- Too high velocities lead to **erosion, sound/vibration, water hammer, and air entrainment**.
- **Particulate-free water will cause less water velocity damage** to the tubes and associated hardware.
- Guidance on maximum water piping velocities for systems that operate over 8000 hours per year. **Water velocities in flexible tubing should be maintained below 1.5 m/s** (5 ft/s).

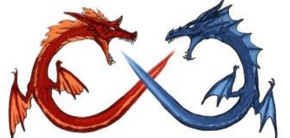
Pipe Size, mm (in.)	Maximum Velocity (ft/s)	Maximum Velocity (m/s)
>75 (>3)	7.0	2.1
38 to 75 (1.5 to 3)	6.0	1.8
25 (<1)	5.0	1.5
All flexible tubing	5.0	1.5



Water Quality

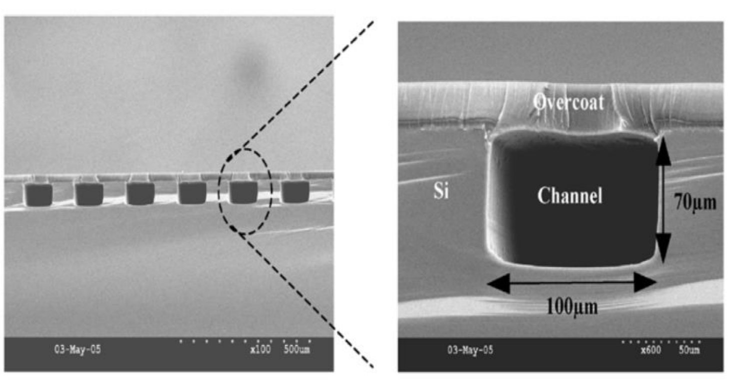
- Water Quality Specifications Supplied to ITE
- Chapter 49, "Water Treatment," of the *ASHRAE Handbook— HVAC Applications* (ASHRAE 2011).

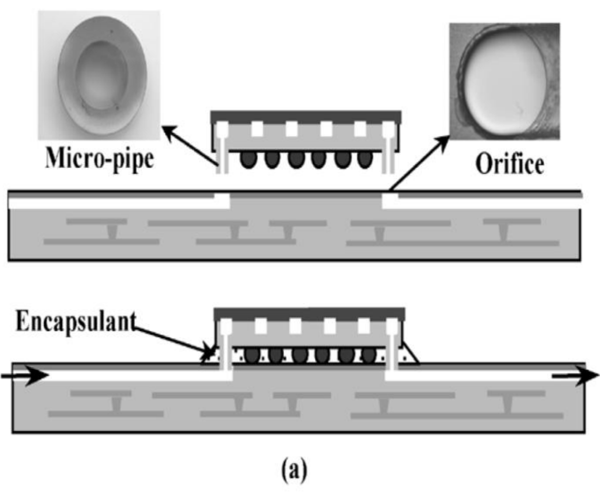
Parameter	Recommended Limits
pH	7 to 9
Corrosion	Inhibitor(s) required
Sulfides	<10 ppm
Sulfate	<100 ppm
Chloride	<50 ppm
Bacteria	<1000 CFUs/mL
Total hardness (as $CaCO_3$)	<200 ppm
Residue after evaporation	<500 ppm
Turbidity	<20 NTU (nephelometric)



IEEE ELECTRON DEVICE LETTERS

VOL. 27, 2006, pp.117-119





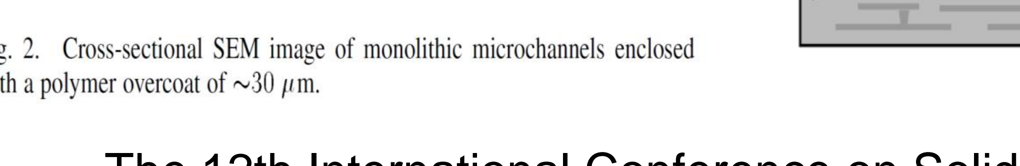
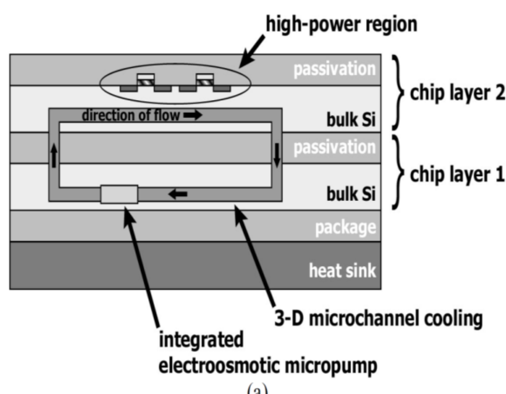
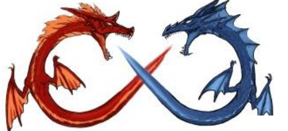


Fig. 2. Cross-sectional SEM image of monolithic microchannels enclosed with a polymer overcoat of ~30 μm.

The 12th International Conference on Solid State Sensors, Actuators and Microsystems, 2003



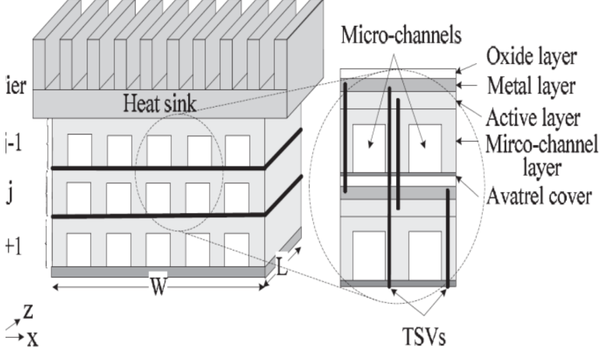
(a)



Hybrid 3D-IC Cooling System Using Micro-Fluidic Cooling and Thermal TSVs (through-silicon-vias)

2012 IEEE Computer Society Annual Symposium on VLSI

IEEE TRANSACTIONS ON COMPONENTS, PACKAGING AND MANUFACTURING TECHNOLOGY, VOL. 3, NO. 11, NOVEMBER 2013, pp. 1842-1850.



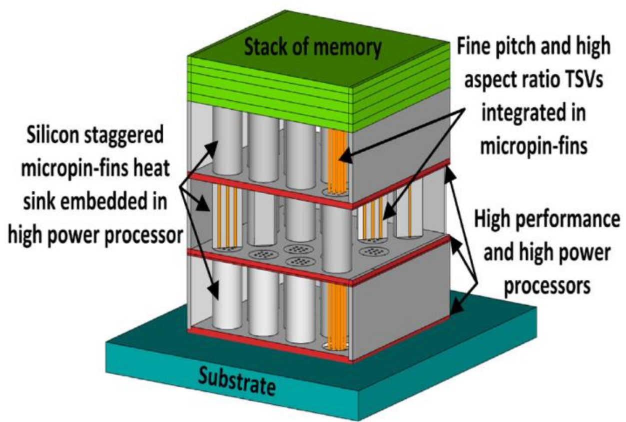


Fig. 1. Schematic of a three-microprocessor chip stack each with interlayer microfluidic cooling. A 3-D stack of memory chips resides above the microprocessors. High aspect ratio TSVs are integrated in the micropin-fin heat sink.

Silicon μPin-fins
3x3 array of Cu TSVs with SiO_2 sidewall liner

Fig. 13. SEM (left) and optical images (right) of high aspect ratio TSVs integrated in micropin-fins (10 μm diameter, 35 μm pitch, and 178 μm tall).

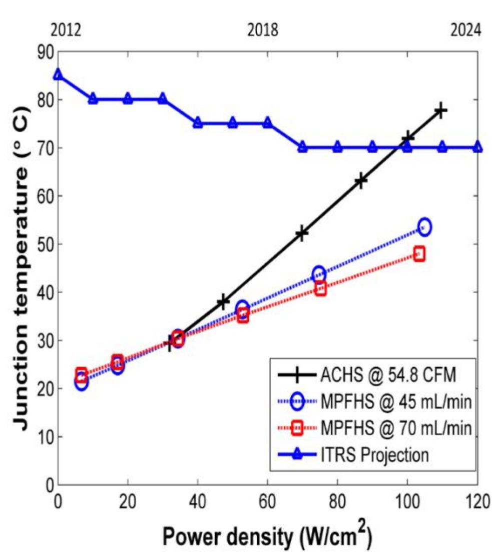
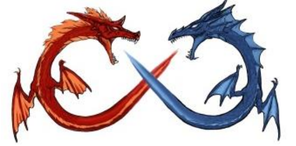
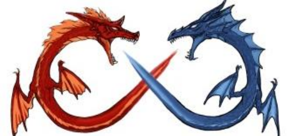


Fig. 17. Average junction temperature under air cooling and microfluidic cooling compared with ITRS projections.



Immersion (Direct) Cooling

- In direct cooling electronics are immersed into a dielectric liquid
- Closed loop systems are normally used due to both the cost of the liquids used and the environmental issues associated with the liquids escaping into the atmosphere



Typical Liquids Used in Immersion

Natural convection:
- Air 1–3 atm
- Fluorochemical vapor
- Silicone oil
- Transformer oil
- Fluorochemical liquids

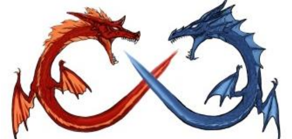
Forced convection:
- Air 1–3 atm
- Fluorochemical vapor
- Transformer oil
- Fluorochemical liquids

Boiling fluorochemical liquids

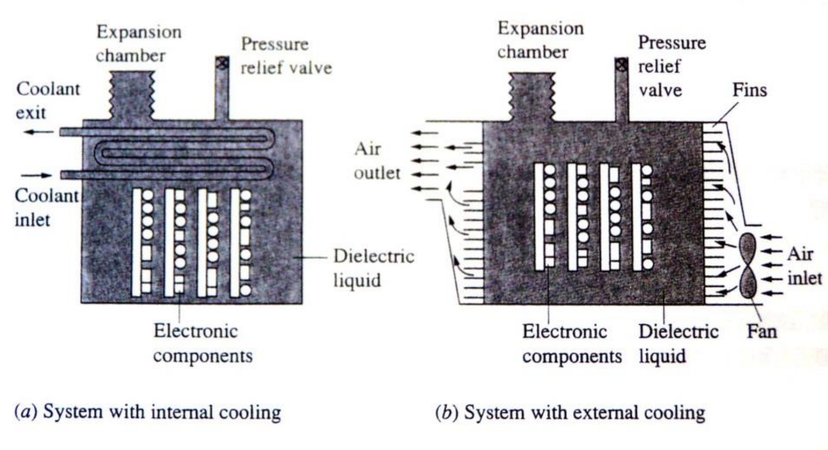
1 10 100 1000 10,000

W/m$^2\cdot$°C

Cengel, pg. 920



Boiling Used in Immersion

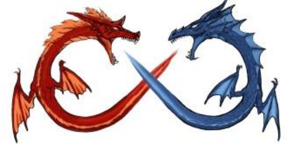


(*a*) System with internal cooling (*b*) System with external cooling

Cengel, pg. 919

- Electronics dissipate heat through the liquid
- Vapor bubbles are generated
- As vapor bubbles rise they come in contact with the cooler liquid produced by an immersed heat exchange and they implode

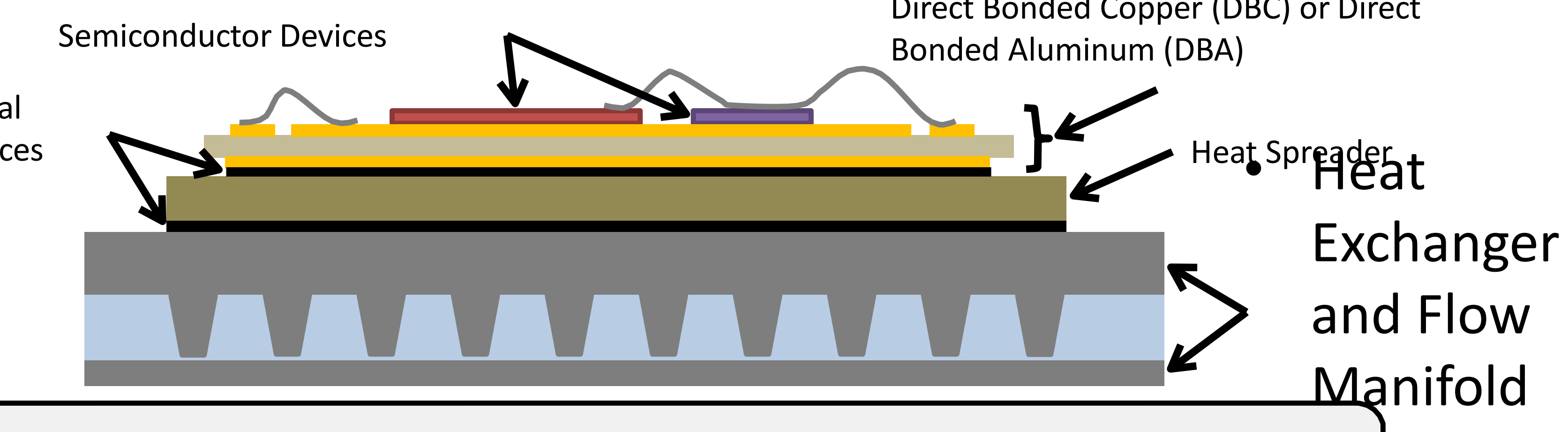
*The prior example is more efficient due to the heat transfer coefficient associated with condensation



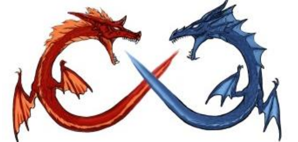
Concerns with Immersion

- Introduction of incompressible gasses into a vapor space
  - This will limit the amount of condensation that is allowed to occur and degrade heat transfer
- Leakage
  - Environmental Concerns
  - Reliability

Direct cooling & double sided cooling



- **Improved heat dissipation is needed to increase power for robust operation within cost and size constraints**



Impingement Cooling

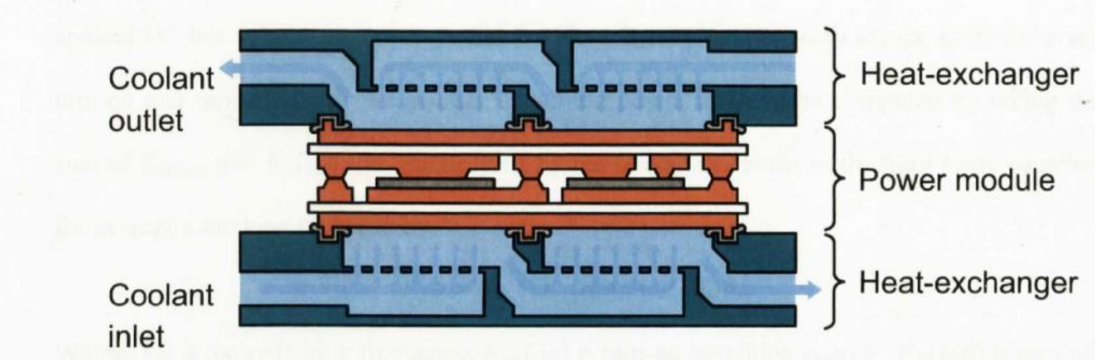


Figure 7 – A schematic diagram of a double side cooled sandwich module.

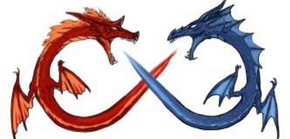
1. Jet Impingement
2. Heat transfer
3. Mixing of working fluid

2

Heat from Electronics

1

3



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National Chiao Tung University

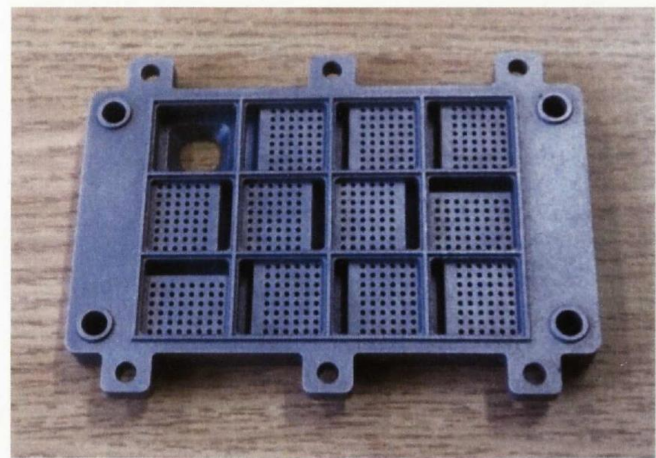


Figure 43 - Jet impingement cooler specifically designed to cool the baseplate of the power module pictured in Figure 39.

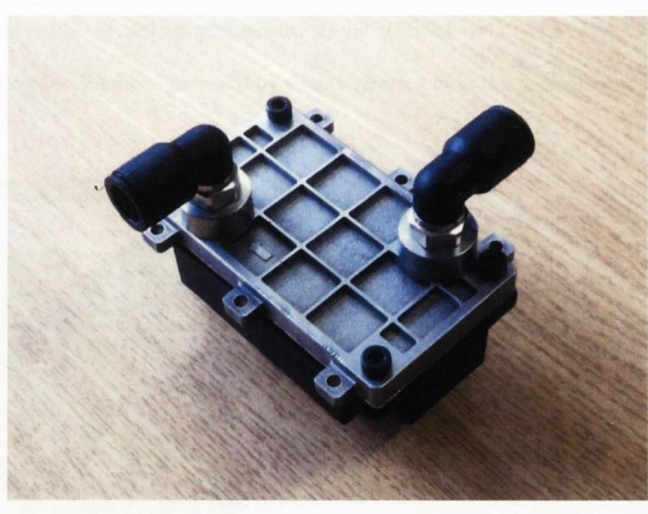


Figure 45 – The assembled direct baseplate impingement cooler showing inlet and outlet water connections.

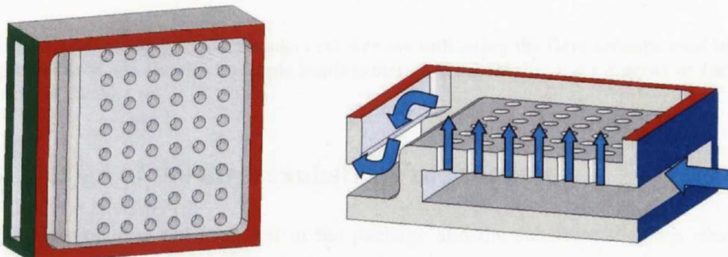
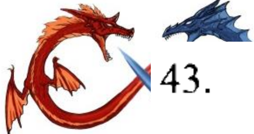
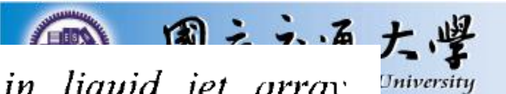


Figure 46 – Detail and cross section of a single jet impingement cell for the direct baseplate cooler containing a *6 x 8* array of *1mm* diameter jets spaced at *2mm*. The arrows indicate direction of water flow. The coolant enters the plenum through the slot in the blue plane, the red plane indicates the impingement surface, the coolant exits to the left through the slot in the green plane into the plenum of the adjacent cell.

Skuriat, Robert (2012) Direct jet impingement cooling of power electronics. PhD thesis, University of Nottingham.





43. Whelan, B.P. and A.J. Robinson, *Nozzle geometry effects in liquid jet array impingement*. Applied Thermal Engineering, 2009. **29**(11-12): p. 2211-2221.

Table 9 – Shapes and dimensions of nozzles used in the study [43].

Jet Shape		Area (mm²)	D_h (mm)
Round		0.785	1
Chevron		1.07	1
		0.785	*0.73*
Triangle		1.3	1
		0.785	*0.77*
Square		1	1
		0.785	*0.89*
Cross		1.8	1
		0.785	*0.66*
Medal		2.63	1
		0.785	*0.54*
Star		2.79	1
		0.785	*0.73*

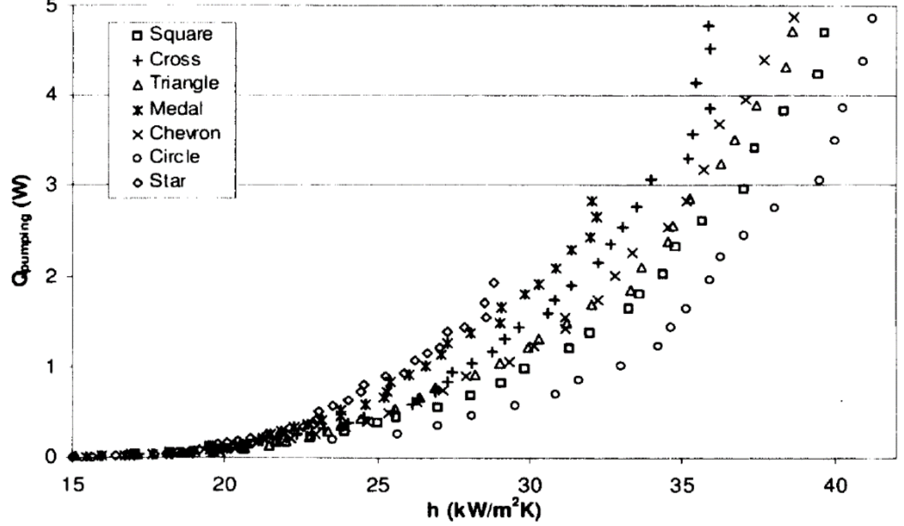
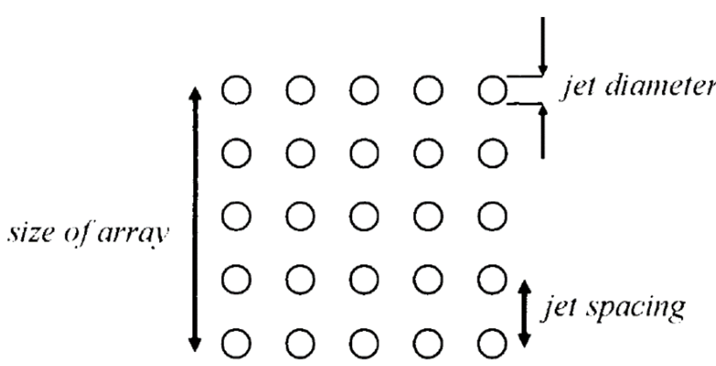


Figure 68 – Pumping power versus average heat transfer coefficient for different nozzle geometries of constant hydraulic diameter [43].



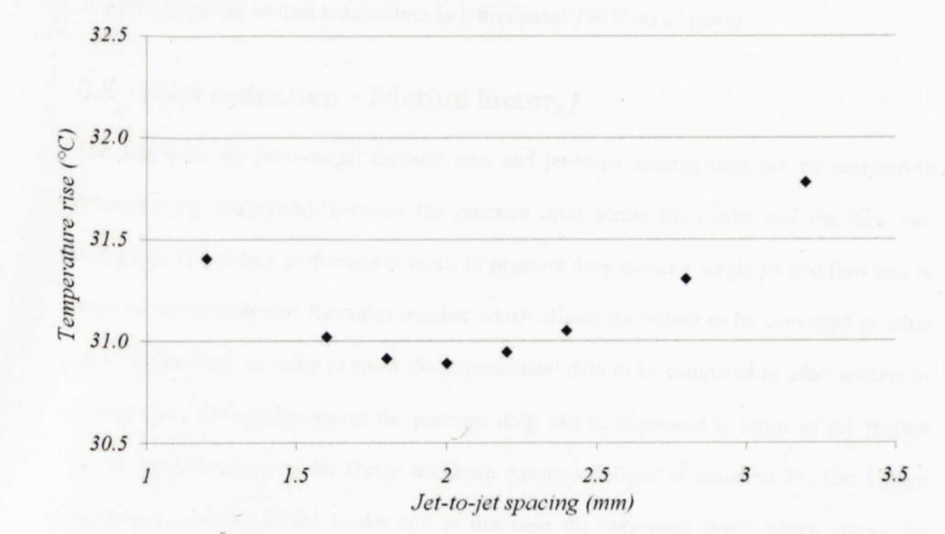
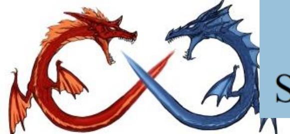
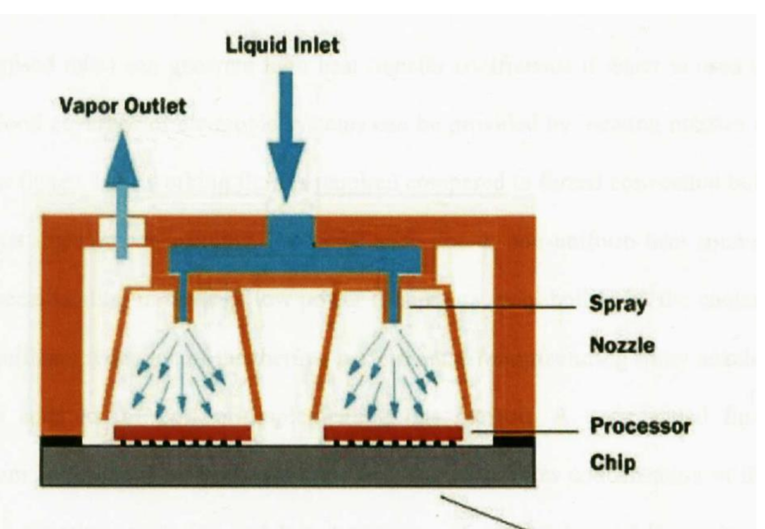
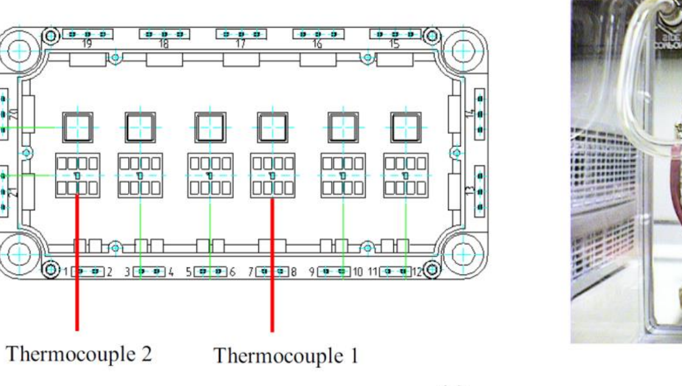


Figure 108 – Temperature rise versus jet-to-jet spacing at a pumping power of *5Watts*.

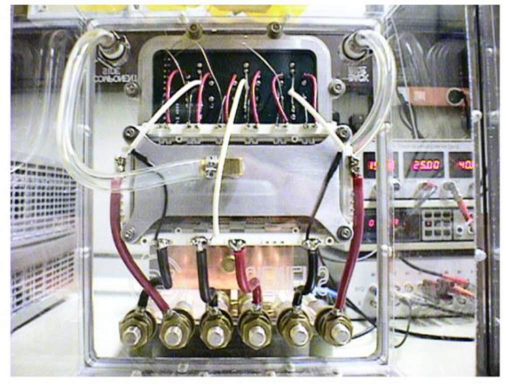


Spray Cooling





(a)

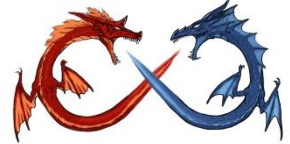


(b)

Figure 3. Spray cooling demonstration system (b) with BSM 150 GT 120 DN2 IGBT module (a)

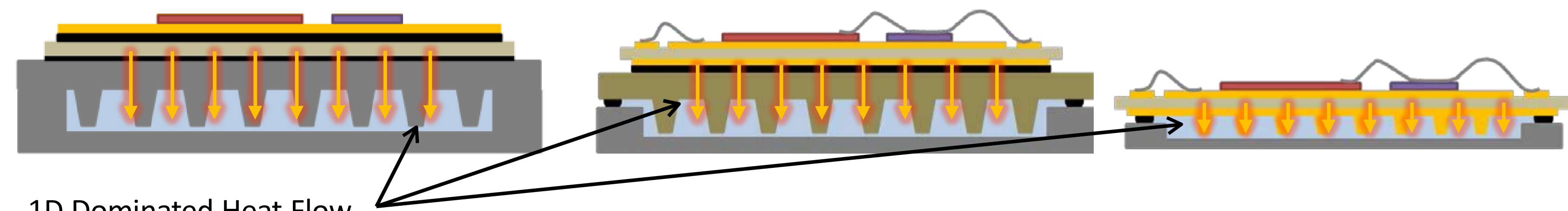
Table 2. Comparison of the temperatures and the thermal resistance of spray cooling and water-cooled plates at the IGBT module BSM 150 GT 120 DN2

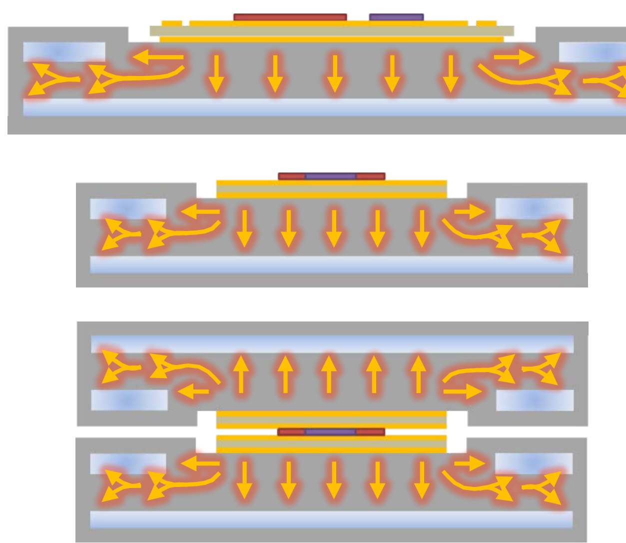
Type of cooling	Spray Cooling	Spray cooling without polyimide on chips	Direct liquid base-plate flow convection
Pressure [psi]	25	25	0.3
Power consumption [W]	108	108	
Flow rate Fluorinert / H_2O [l/min]	1.70	1.70	1.76
P_v power dissipation [W]	1371	1393	1198
T_c baseplate (thermocouple 1) [°C]	92.8	82.8	73.3
T_c baseplate (thermocouple 2) [°C]	94.0	82.2	70.8
T_a Fluorinert/H_2O (inlet) [°C]	38.8	40.2	16.4
T_j junction [°C]	127	111.2	106
$R_{th(j-c)}$ [K/W]	0.025	0.020	0.028
$R_{th(j-a)}$ [K/W]	0.064	0.051	0.075



Current State-of-Art:

- Reduce resistance by removing layers
- Require increasingly aggressive cooling techniques (potentially expensive)
- Rely on one-dimensional (1D) heat transfer through the stack

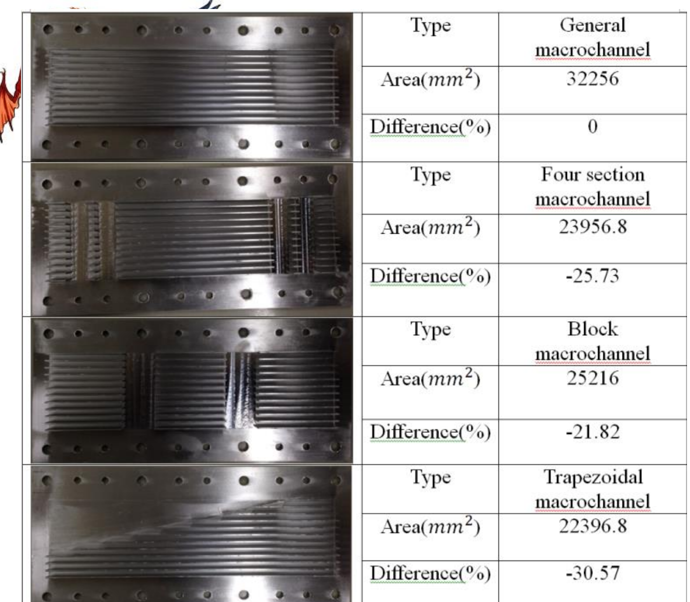




Conceptual Thermal Design:

- Enables multi-dimensional heat transfer
- Utilizes multiple cooling “zones”
- Compatible with multiple heat exchanger fabrication methods and area enhancements
    - Current design focuses on extrusion processes
        - Reduced heat exchanger cost
        - Increased flexibility
- Supports single and double-sided cooling
- Integrates channels (reduces seals)

國立交通大學
National Chiao Tung University
電熱管
水入口
熱電偶量測
水出口
nx25mm
53mmx8mm
置的地方，
通道擺放位置



Type	General macrochannel
Area(mm^2)	32256
Difference(%)	0
Type	Four section macrochannel
Area(mm^2)	23956.8
Difference(%)	-25.73
Type	Block macrochannel
Area(mm^2)	25216
Difference(%)	-21.82
Type	Trapezoidal macrochannel
Area(mm^2)	22396.8
Difference(%)	-30.57

Results -三片發泡銅實驗

單一片發泡銅實驗加熱瓦數為3300W

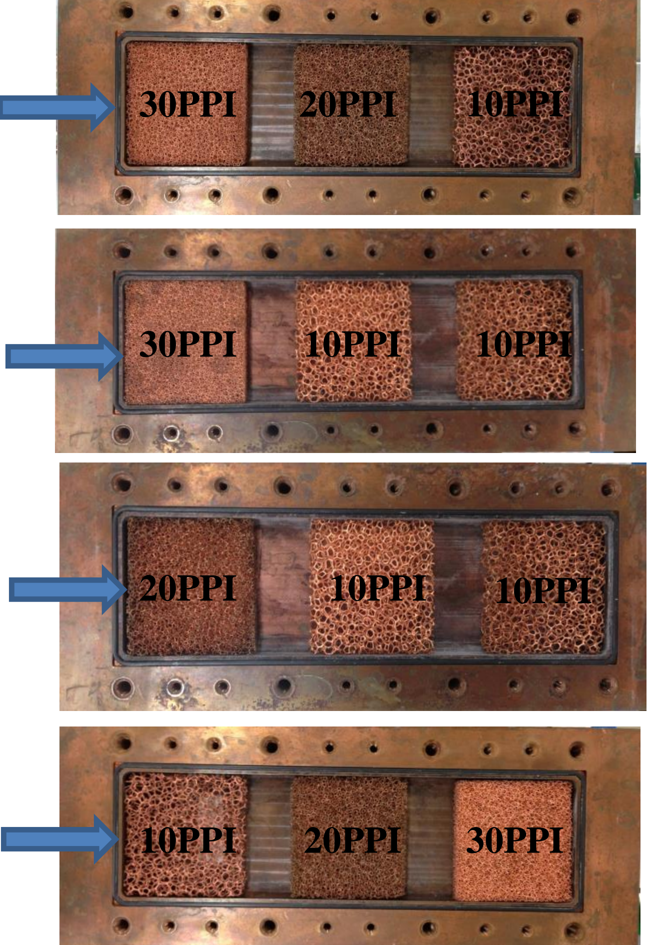
Thermal resistance (K/W)

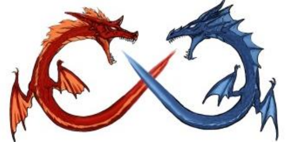
0.032
0.031
0.030
0.029
0.020
0.015
0.010

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8

Pumping power (W)

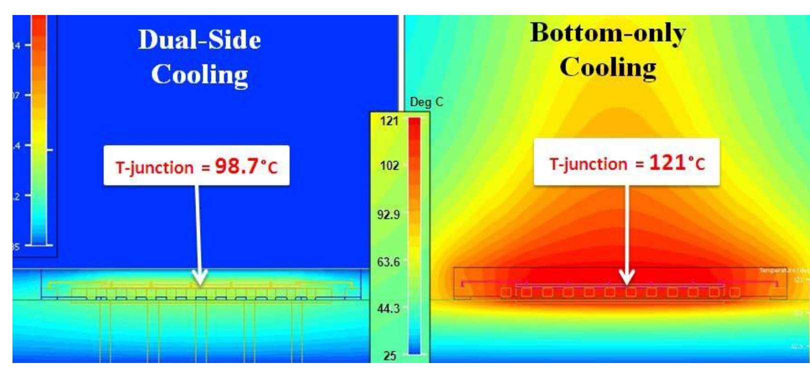
- General macrochannel
- Four section macrochannel
- Block macrochennel
- Trapezoidal macrochennel
- 10-20-30PPI(from inlet to outlet)
- 30-10-10PPI(from inlet to outlet)
- All of the20PPI
- 30-20-10PPI(from inlet to outlet)
- Plate





Summary & Outlook

- ✓ Dual side cooling structure package development and packaging process optimization
- ✓ High temperature endurable, high conductive TIM materials (Ag sintering)



Ref. Institute of Microelectronics
Dual side cooling effect T_{jmax} decreased compared with single side cooling

Conventional Power Module

Plastic case

Diode

IGBT

DBC substrate

Passive

Base plate

Conventional Power discrete *

Wire

IGBT

Lead frame

Heat spreader

Base plate (system board)

TV1* : Novel Dual side cooling Power Module

Heat spreader

Top RDL layer

Diode

IGBT

Heat spreader

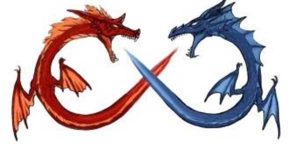
TV2* : Novel Dual side cooling Power Discrete

Heat spreader

IGBT

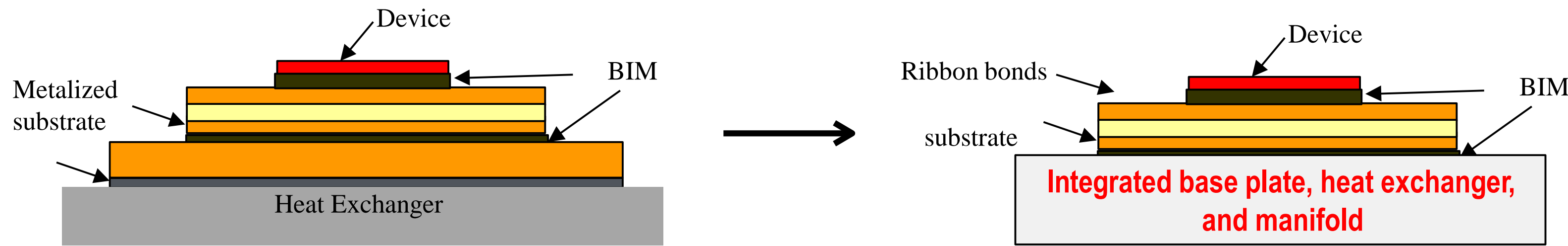
Heat spreader

* Conventional test vehicle with new material option can be considered as project test vehicle on the basis of members assembly support



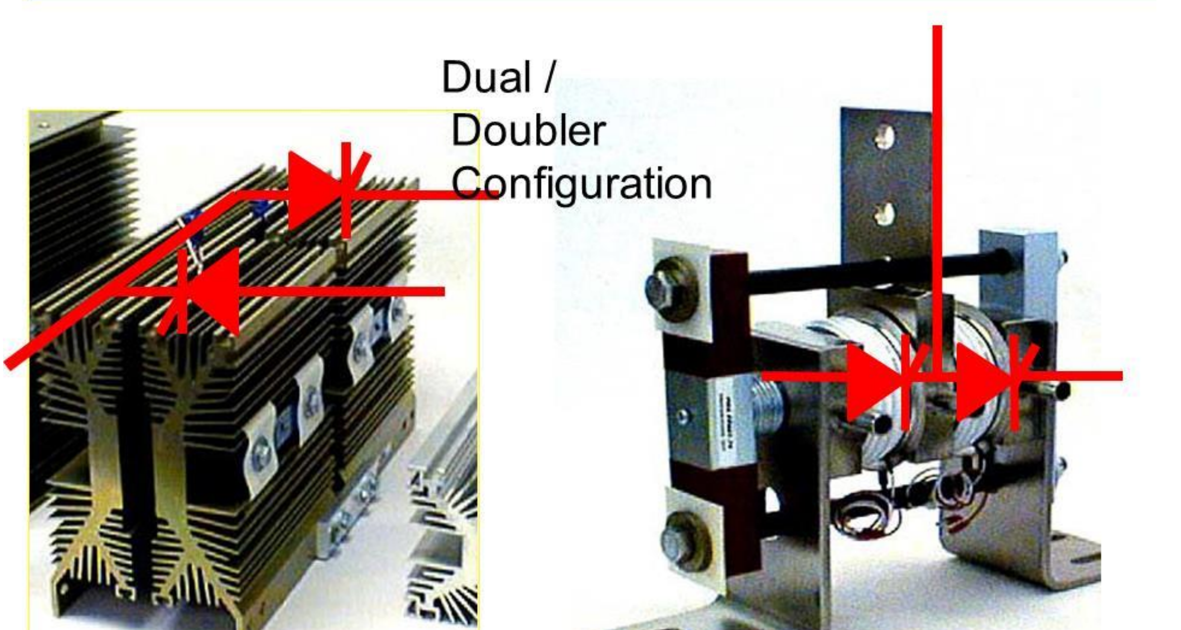
Summary & Outlook

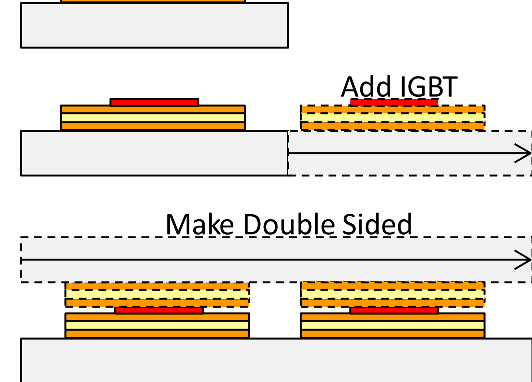
Heat exchanger, baseplate, and manifold are combined into a single part



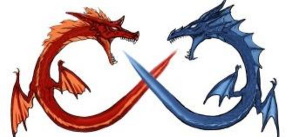
TIM: Thermal Interface Material
BIM: Bonded Interface Material

Designed to be extruded, easily scalable, and allow double sided cooling with no modification to design





Same design can be scaled to suit needs



Thank You