Thermal Management Materials for PCBs used in Power Electronics

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Materials solutions for efficient cooling of electronic devices

- Possible heat dissipation pathways
- Thermal management solutions
- Thermal interface materials
- Mechanism of thermal conduction in interface materials
- Examples

Why Thermal Management?

Performance Reliability and Life Expectancy of electronic equipment are inversely related to the component temperature of the equipment

For Silicon based devices

Reliability / Life Time = <u>inverse exponential function of the operating temperature</u>

Need to effectively control the device operating temperature within the limits set by the device design engineers

Thermal management issues

Solid-air interface represents the greatest barrier in thermal management. Solid surfaces are never really flat or smooth enough to permit intimate contact

All surfaces have a certain roughness due to microscopic hills and valleys and poor surface flatness

Between two typical electronic components, as much as 99% of the surfaces are separated by a layer of interstitial air ***(Dr. Miksa de Sorgo, Electronics Cooling, 2000)***

Allowed junction temperatures

Allowable *Tj* (the maximum junction temperature) values range from:

- 115°C in typical microelectronics applications
- 180°C for some electronic control devices
- 65°C to 80°C for special and military applications

(S. Lee, Electronics Cooling, 1995)

Some basics

Q = Time rate of heat generated in Watts

$R = \Delta T/Q$, ΔT is the temperature difference between the two locations

(Similar to Ohm’s law: $R_e = \Delta V/I$)

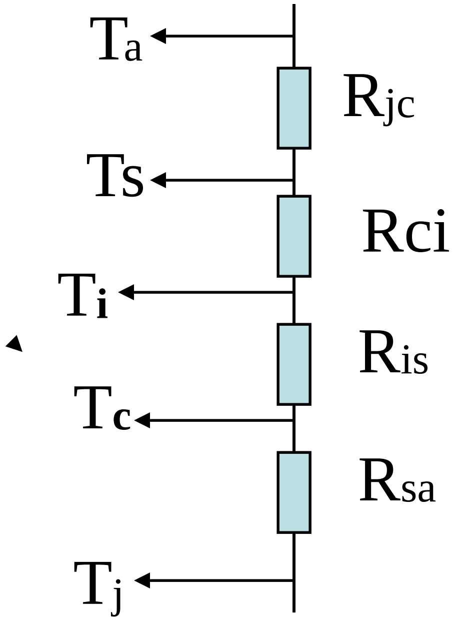
Example,

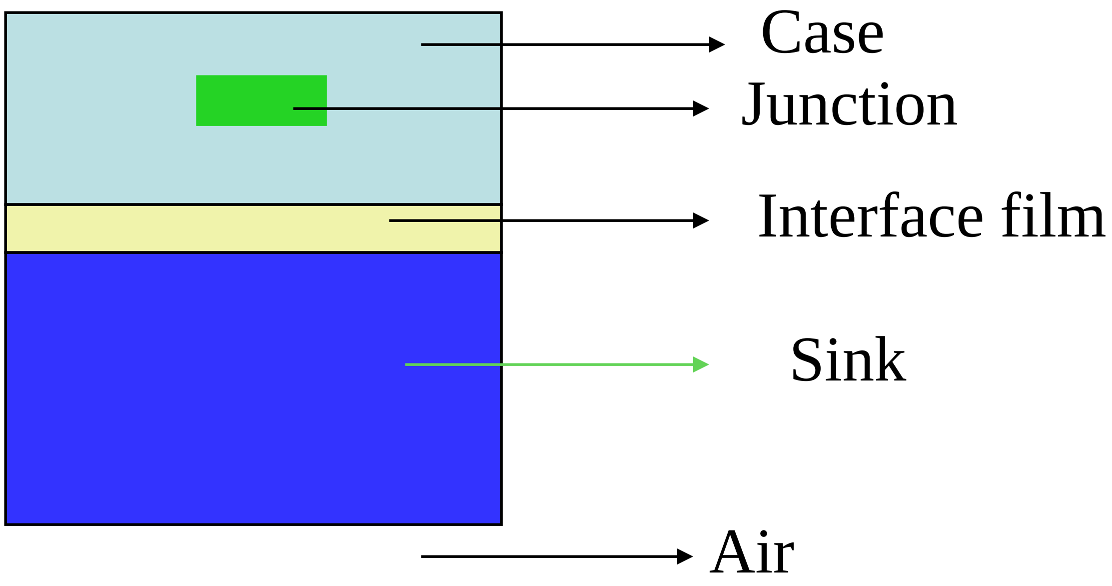
$R_{sa} = (T_{sa})/Q = (T_s - T_a)/Q$

R_{sa} is resistance of heat sink(s) - air(a) interface

Total Thermal Resistance is given by

$$R_{ja} = R_{jc} + R_{ci} + R_{is} + R_{sa} = (T_j - T_a)/Q$$





R_{ci} and R_{is} can be decreased significantly by surface finish and type of interface material

How much cooling is required?

The required Heat Sink Thermal Resistance is the heat sink resistance between sink and air:

$R_{sa} = ((T_s - T_a)/Q) - R_{jc} – R_{ci} - R_{is}$

Therefore, the thermal resistance value of chosen heat sink and interface material for the application has to be ***equal to or less than*** $\boldsymbol{R_{sa}}$ value for the junction temperature to be maintained at or below the specified T_j

Applications

- Microprocessors
- Power semiconductor modules
- High power laser diodes
- High power RF modules
- High brightness LEDs
- High power laser and RF weapons

Types of thermally conductive materials

- Greases
- Reactive compounds
- Elastomers
- Pressure sensitive adhesive films.

All are designed to conform to surface irregularities, thereby eliminating air voids and improving heat flow

Thermal Greases

(THERMALLY & ELECTRICALLY CONDUCTING)

Dispersed thermally conductive ceramic fillers in silicone or hydrocarbon oils to form a paste

Sufficient grease is applied to one of the mating surfaces

Grease flows into all voids during pressing to eliminate the interstitial air. Excess grease flows out

Joint integrity maintained with spring clips or mounting hardware

No electrical insulation provided

Thermally Conductive Compounds

(THERMALLY & ELECTRICALLY CONDUCTING)

Are compounds converted to a cured rubber film after heating at the thermal interface

Before curing, flows freely as grease to eliminate the air voids and reduce the thermal resistance of the interface

Does not require mechanical fasteners to maintain the integrity of the joint

No migration or bleeding issues like in grease

Thermally Conductive Elastomers

(THERMALLY AND/OR ELECTRICALLY CONDUCTING)

Silicone elastomer pads filled with thermally conductive ceramic particles

Available in thickness from about 3 mil upward

If required, elastomers pads can provide electrical insulation and can be used between surfaces that are at different electrical potential

Used under discrete power devices where electrical isolation is required

Thermally Conductive Adhesive Tapes

(THERMALLY AND/OR ELECTRICALLY CONDUCTING)

- Double-sided PSA films filled with sufficient ceramic powder to balance their thermal and adhesive properties
- Supported either with an aluminum foil or a polyimide film
- Adhesive tapes perform much like the elastomeric films, in that they also require some initial bonding pressure
- Require no mechanical support to maintain the mechanical or thermal integrity of the interface

Thermasil^{R} Bonding film

- Thermasil^{R} is a patented elastomeric thermal interface dielectric adhesive material
- Excellent thermal performance

  applications for the cooling of:

  Power Supplies, Under-the-hood and other automotive PCBs, Power Semiconductors and Motor Controls

Thermasil^{R} Thermally Conductive Silicone

Cure Condition	Sp. Gr.	Durometer Shore A	Tensile Strength PSI	% Elongation
330 F	1.4	80-90	1220	400
Tear Strength PPI	Resistivity, Ohm	Thermal Conductivity, W/mK	Flame test	Shelf life months
190	10^{12}	0.6	Pass	6

ASC Products

Hi Rigidity Thermally Conductive Silicone

Cure Condition	Sp. Gr.	Durometer Shore A	Tensile Strength PSI	% Elongation
330 F	1.6	85-95	1020	150
Tear Strength PPI	Resistivity, Ohm	Thermal Conductivity, W/mK	Flame test	Shelf life months
50	10^{12}	0.7	Pass	6

Conformal Thermally Conductive Silicone Pad

Cure Condition	Sp. Gr.	Durometer Shore A	Tensile Strength PSI	% Elongation
200 F or less	1.3	50-60	625	315
Tear Strength PPI	Resistivity, Ohm	Thermal Conductivity, W/mK	Flame test	Shelf life months
62	10^{12}	0.54	Pass	6

ASC Products

Electrically & Thermally Conductive Silver/Aluminum Silicone

Cure Condition	Sp. Gr.	Durometer Shore A	Tensile Strength PSI	% Elongation
330 F	2.1	68-82	200	200
Tear Strength PPI	Resistivity, Ohm	Thermal Conductivity, W/mK	Flame test	Shelf life months
50	0.002	1.6	Pass	6

Electrically & Thermally Conductive Silver Silicone

Cure Condition	Sp. Gr.	Durometer Shore A	Tensile Strength PSI	% Elongation
330 F	1.4	80-90	1220	400
Tear Strength PPI	Resistivity, Ohm	Thermal Conductivity, W/mK	Flame test	Shelf life months
190	0.0007	1.8	Pass	6

Thermal Data of Electrically Conductive Adhesives

	Fused solder	Epoxy film	Ag-silicone	Thermo plastic paste	Polyester /pressure sensitive resin	Thermo plastic (anisotr-opic)
Conductive medium	Sn/Pb: 50/50	Ag	Ag	Ag	Cu/Ni	Sn/Pb:63/37
Operating temp F	340	260	500	320	NA	302
Thermal Cond, W/mC	83	3.5	1.2	3.0	1.5	NA

Temperature dependence of resistivity of silver-silicone film

Temp C	22	40	60	80	100	130
Resistivity milliohm /cm	4.0	3.2	3.4	3.2	3.5	1.2

Accelerated life test, 85% RH/85C (after reflow at 446 F)

Material	Initial peel strength (PS), ppi	Final PS after 1000 h ALT	Initial resistivity, milliohm /cm	Resistivity after 1000 h ALT
Silicone	12	10	0.10	0.25
Epoxy	14	0	0.20	0.20
Sn/Pb solder	21	20	<0.05	0.10

Advantages of elastomers

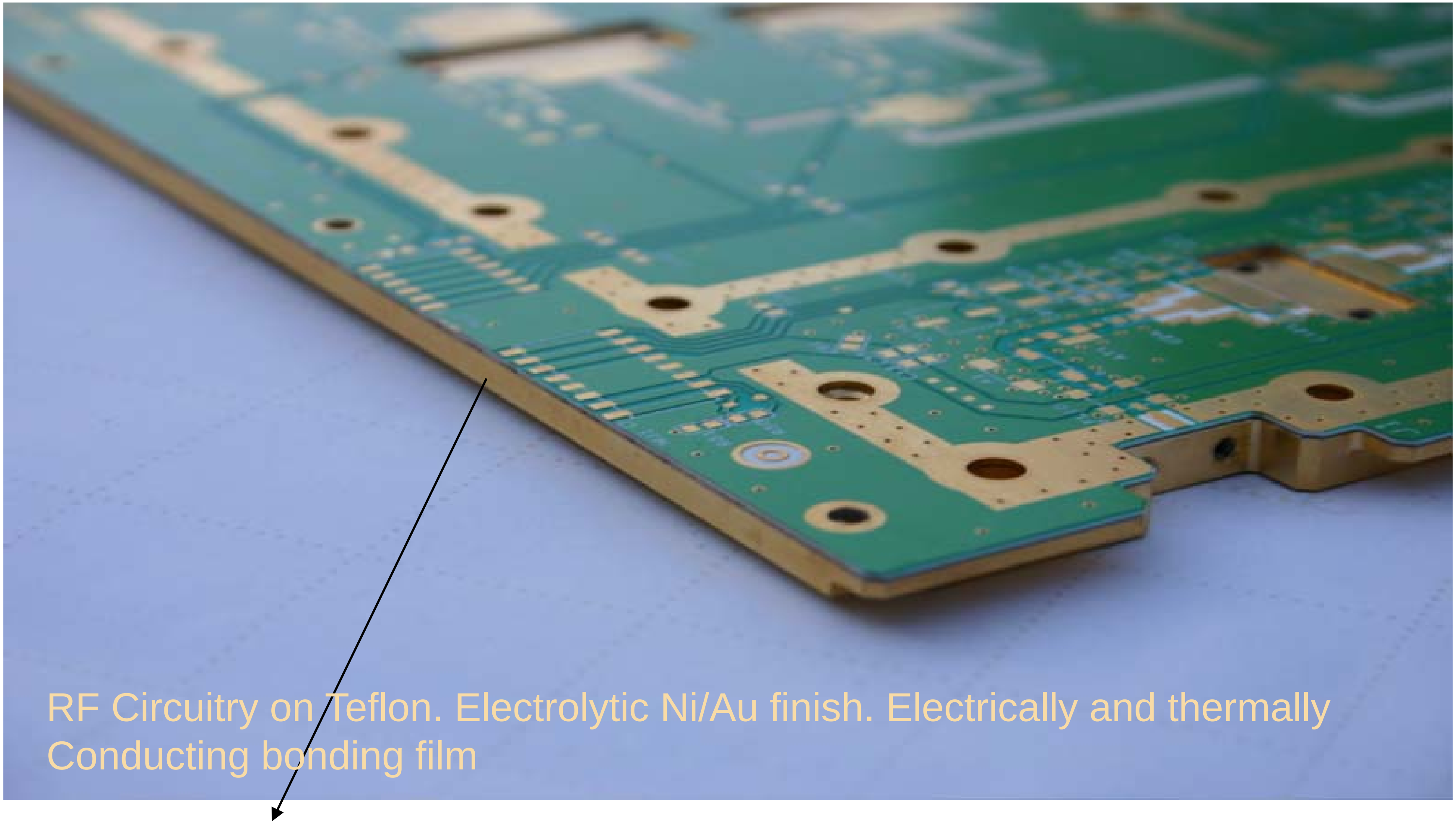
- Elastomers combine the advantages of not exhibiting melt or flow during solder flow, and remain flexible after curing to accommodate stress due to CTE differences
- Thermal conductivity: 1.2 W/M C
- Operating temp: 500 F (stability: -150 to +600 F)
- Si-O Bond Energy: 88-117 kcal/mol vs 83-85 kcal/mol for C-C
- Oxidative attack less for 1^0 H of CH_3 in silicone than 2^0 or 3^0 H found in epoxy

Silver Epoxy based adhesive

- Operating Temperature 260 F
- Thermal conductivity: 8.3 W/mC
- Silver flakes in epoxy resin
- Thermoset (rigid, does not melt or flow during solder reflow)
- Problem of CTE mismatch stress

ASC Products

RF Circuitry for base station antenna



RF Circuitry on Teflon. Electrolytic Ni/Au finish. Electrically and thermally Conducting bonding film

Ni/Au plated PTFE post bonded with Al heat-sink

ASC Products

Some Thermasil mounted samples

Automotive

LED

Automotive

Future Directions

The power required to drive a one billion transistor microprocessor <u>in 2010 will be 600 Watts …</u>

(*Patrick Gelsinger* from *Intel*, in an article written by A. Cataldo & P. Kallender in *Electronic Engineering Times*)

This will necessitate the use of solutions beyond the capabilities of current commercially available thermal interface systems…

….would probably require interface materials with <u>conductivities > 30 W/m^{o}C!</u>

Future Directions (contd.)

- Nano ceramics dispersed in dielectrics for interface material
- Heat sink with high emmisivity and high surface area, e.g., thermally glazed coatings
- Thermal conductivity 1700 W/mK is being reported for new materials

Properties of Advanced Materials with Ultrahigh Thermal Conductivities

Matl.	Sp.Gr. (SG)	CTE	ITC	TTTC	SITC (ITC/SG)
CVD Diamond	3.52	1-2	1100-1800	1100-1800	310-510
HOPG	2.3	-1.0	1300-1700	10-25	565-740
Diamond-SiC	3.3	1.8	600	600	182

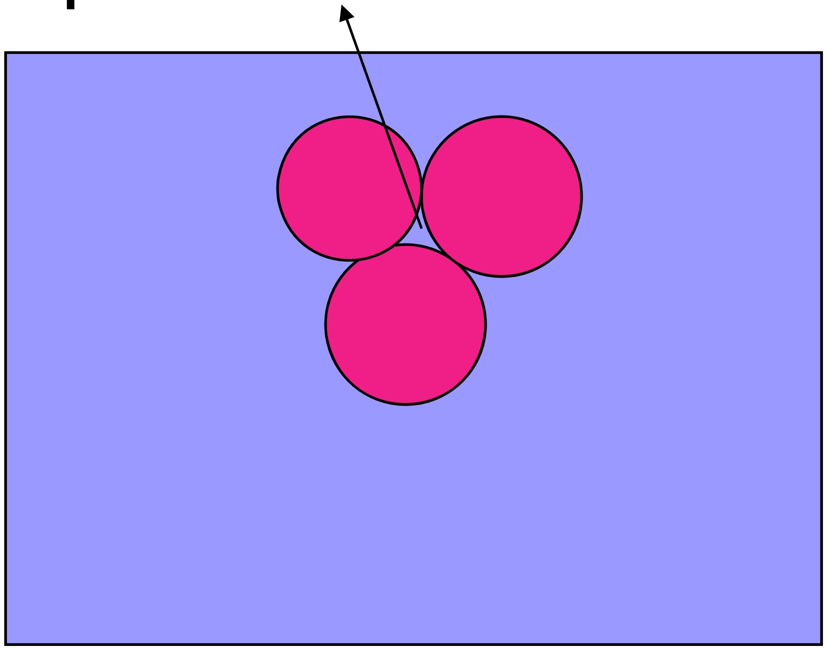
ITC: Inplane thermal conductivity, TTTC: Through thickness TC, SITC: Specific inplane TC in W/mK. HOTG: Highly oriented pyrolytic graphite

Advanced ceramics

- High thermal conductivity of 180 W/mK have been obtained in AlN by adding CaC_2, CaO, Y_2O_3 and C and hot pressing it (Y Kurokawa et al, J Am Cer Soc 71, 588 (1988))
- Diamond particle reinforced SiC heat spreader technology

Enhanced thermal conductivity mechanism in Y_2O_3: Si_3N_4

Y:Si Oxynitride crystalline or glassy phase (dissolves impurities of raw ceramic)



Thermal conductivity is 107 W/mK at 300 K (K. Watari et al, J Mater Sci Lett (1999))

Summary

Several thermal interface materials as adhesives and conformal pads are available

Thermal management of electronic packaging has reached a crucial stage calling for immediate cooling solutions

New materials technology advances hold greatly promise in creating novel thermal management solutions in tailoring interfaces and heat sinks