Heat Spreaders

Application Note AN0032

CONTENTS

INTRODUCTION

Heat spreaders are intended to quickly and efficiently remove heat generated by passive and active chip components. The heat spreader does so by spreading the heat from the smaller "hot spots" of the component to a larger heat sink spreading the heat flux over a much wider area.

Typical applications include:

- Laser diode arrays
- LEDs
- RF power transistors
- High power passive components and other high power electronics

Device reliability and performance is often dependent upon junction or film temperatures on the chip. The lower and more stable the temperature, the better the performance and longer the lifetime. Figure 1 below represents a very basic stack showing how the heat spreader spreads the heat from a high power chip over a larger surface area.

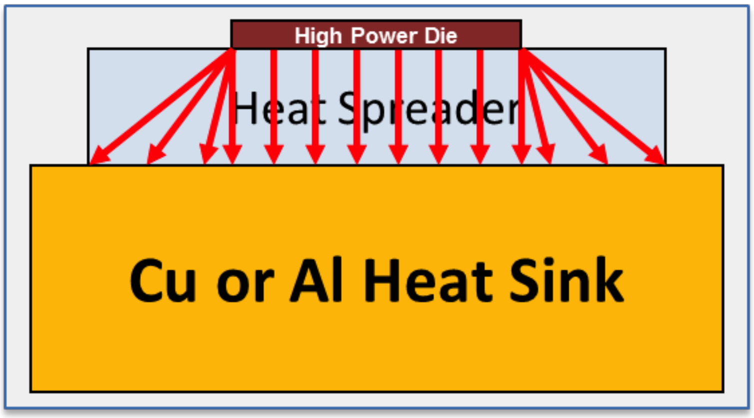


Figure 1: Basic Thermal Stack

Choosing a Material

Every material exhibits thermal characteristics. Some are good at conducting heat while others are better at insulating. Some expand significantly as they are heated while others expand very little. Knowing these characteristics is helpful to determine how well heat will be transferred away from the source. Table 1 on the next page lists some common materials used in electronic circuits and gives a comparison of their thermal conductivities and expansion coefficients.

Material	**Thermal Conductivity**$[\mathrm{W}/\mathrm{m}^\circ\mathrm{K}]$	**CTE**$[\mathrm{ppm}/^\circ\mathrm{K}]$
CVD Diamond	1000 - 1800	1.5
Copper	401	17.0
Beryllium Oxide	250	8.25
Silicon Carbide	250	2.4
Aluminum	237	24.0
Copper Tungsten	228	8.1
Molybdenum Copper	175	8.0
Aluminum Nitride	170	4.3
Gold Tin Solder	57	16.0
Gold Germanium Solder	44	13.0
Alumina	30	7.3
Thermally Conductive Epoxy (Silver)	1.5	70.0

Table 1: Material Comparisions

Thermal Conductivity (k)

The measure of how well a material conducts thermal energy specified in watts per meter-kelvin $[\mathrm{W}/\mathrm{m}^\circ\mathrm{K}]$. Using materials with high thermal conductivity will improve the flow of heat away from the source.

Thermal Resistance (R_θ)

The reciprocal of thermal conductivity specified in degrees kelvin per watt $[\mathrm{K}/\mathrm{W}]$. Materials will always exhibit some thermal resistance. A stack of multiple materials can be viewed as thermal resistors connected in series along the desired path of heat flow. Keeping the sum of thermal resistance low will ensure optimal thermal management of the heat source.

Factors that affect thermal resistance, besides thermal conductivity, are thickness (z) and surface area (A);

The equation for thermal resistance:

$$R_\theta = \frac{z}{A \times k} \tag{1}$$

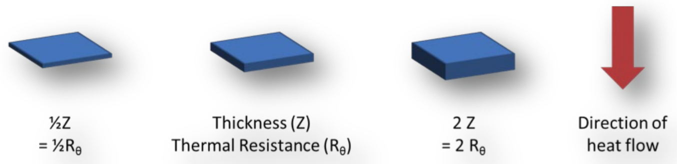
where:

z is thickness parallel to heat flow

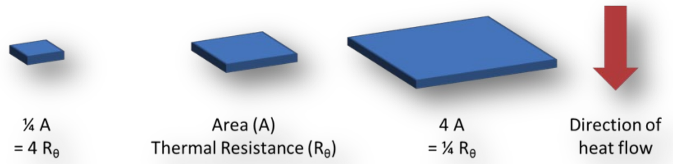
A is surface area perpendicular to heat flow

k is thermal conductivity of material

From the equation it can be seen that;



(a) Increasing the thickness (or length parallel to the direction of heat flow) increases the thermal resistance



(b) Increasing the surface area perpendicular to the direction of heat flow decreases the thermal resistance

Figure 2: Thermal Resistance

To further illustrate the effect of increasing the surface area, below are images of thermal simulations from 45 x 25 mil to 130 x 105 mil. A 75-watt heat source was placed on top of a 12 mil thick CVD diamond heat spreader which was placed on top of a 25 mil thick, 175 mil square copper heat sink.

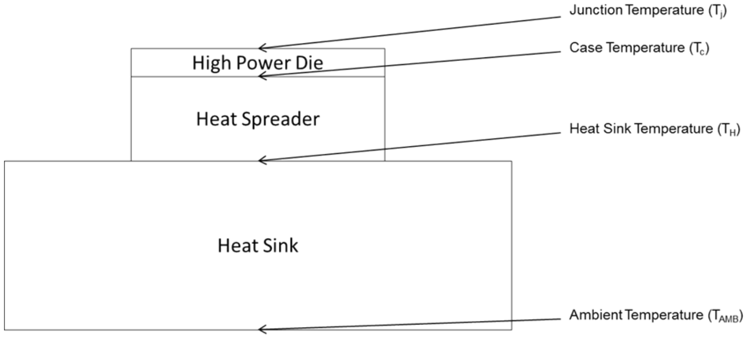
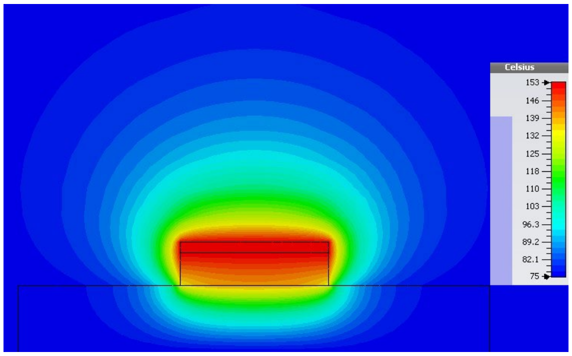
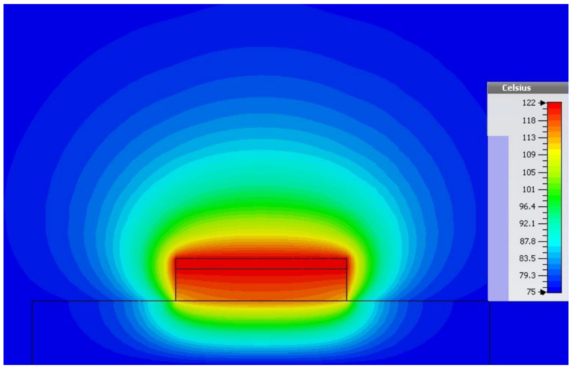


Figure 3: Thermal Stack



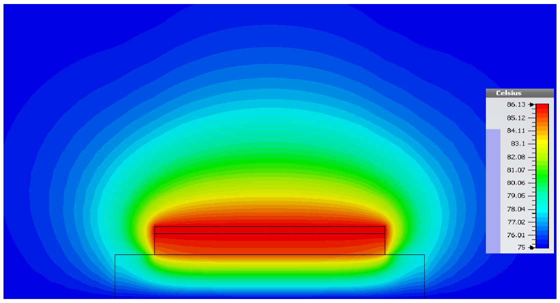
(a) 0402 heat spreader thermal simulation.

T_j	153°C
T_c	153°C
T_H	137°C
T_{AMB}	75°C



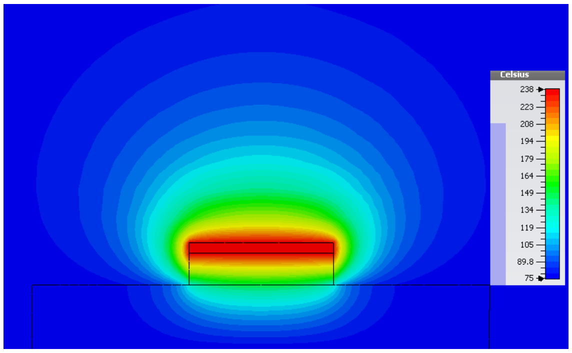
(b) 0603 heat spreader thermal simulation

T_j	122°C
T_c	122°C
T_H	115°C
T_{AMB}	75°C



(c) 1310 heat spreader thermal simulation

T_j	88°C
T_c	88°C
T_H	87°C
T_{AMB}	75°C



(d) 0402 BeO thermal simulation

T_j	238°C
T_c	238°C
T_H	157°C
T_{AMB}	75°C

Figure 4: Thermal Simulations

At 45 x 25 mil, the resultant *"film"* temperature from 75 watt is 153°C, Figure 4a. Increasing the size to 65 x 35 mil, the temperature decreases 31°C to 122°C while maintaining the 75 watt source, Figure 4b. And again increasing the size this time to 130 x 105 mil, the temperature drops to 86°C, Figure 4c. To illustrate how another material performs, the below image represents substituting the diamond with BeO. As can be seen, the heat does not flow uniformly through the material resulting in a high temperature delta from the top to the bottom of the BeO chip, Figure **??**. The *film* temp in this case is 238°C compared to 153°C with the 0402 diamond.

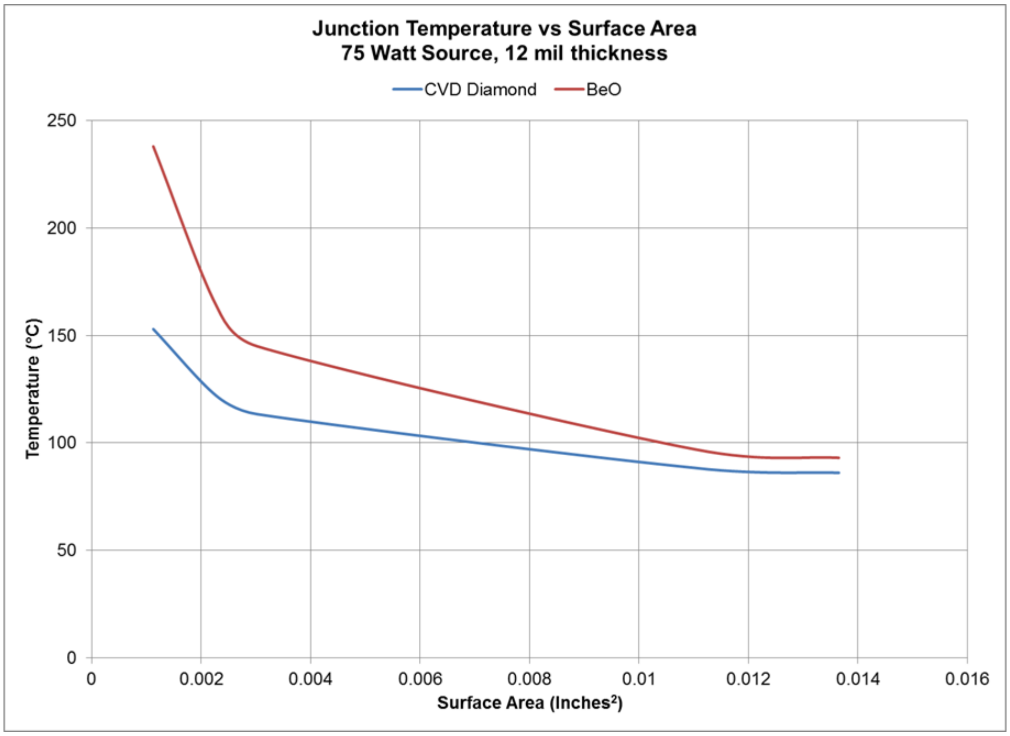


Figure 5: Junction Temperature vs Surface Area

COEFFICIENT OF THERMAL EXPANSION (CTE, A)

The tendency of matter to change in volume as a response to a change in temperature specified in [ppm/°K]. In circuit design, the linear CTE is used as it is the primary cause of tensile forces between different bonded materials. The longest length is used as this will exhibit the largest expansion. This is typically the diagonal.

The equation for the change in length over temperature:

$$dl = l_0 \times a \times (t_1 - t_0) \tag{2}$$

where:

l_0 is starting length

a is CTE

t_0 is starting temperature

t_1 is ending temperature

From the equation it can be seen that;

The starting length is a major factor in the amount of expansion.

For Example:

Diamond has a CTE of 1.5 ppm/°K. A 50 mil long by 25 mil wide diamond chip (diagonal of 56 mils) is heated from 25°C to 125°C. Using the equation, we can calculate the linear expansion in the length and width:

Diamond: Change in length = 56 x [1.5 X 10-6] x (125 – 25) = 0.0084 mil or 0.0000084 inches

Let's swap out diamond for copper, which has a CTE of 17 ppm/°K, using the same dimensions:

Copper: Change in length = 56 x [17 X 10-6] x (125 – 25) = 0.0952 mil or 0.0000952 inches

Let's do the same but with a 250 x 125 mil chip (diagonal of 280 mils)

Diamond: Change in length = 280 x [1.5 X 10-6] x (125 – 25) = 0.042 mil or 0.000042 inches

Copper: Change in length = 280 x [17 X 10-6] x (125 – 25) = 0.476 mil or 0.000476 inches

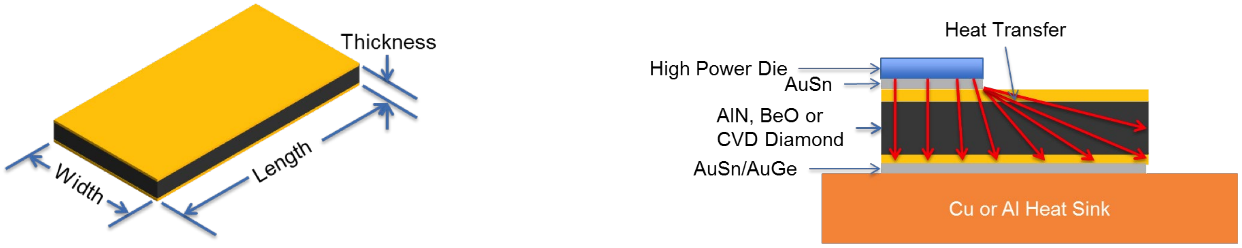
In summary, besides the CTE of the material, the size of component plays a major role in the actual amount of thermal expansion. The risk of mechanical stress failures due to thermal mismatch of materials increases significantly as the component sizes increase.

CHOOSING A CONFIGURATION

EMC Technology offers three standard heat spreader configurations. One is metallized on the top and bottom only to provide electrical isolation from the heat sink. The second is completely metallized to provide electrical conductivity to the heat sink. The third has metallized mounting pads to be used as an electrically isolated thermal bridge to simply move heat from one location to another horizontally.

ELECTRICALLY ISOLATED

- Electrical isolation from heat sink
- Low capacitance
- DC blocking



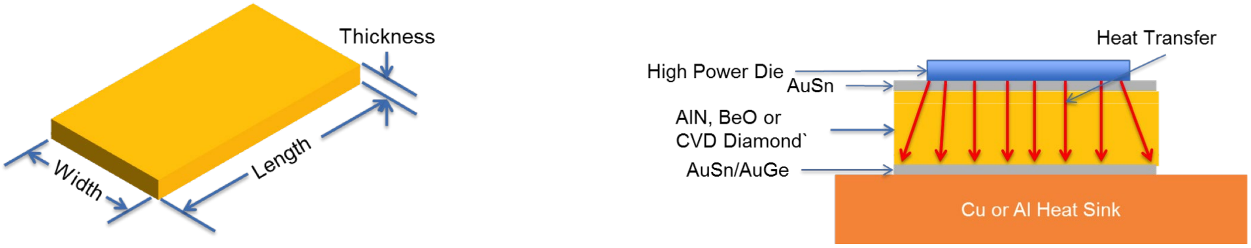
(a) Configuration

(b) Device Stack

Figure 6: Electrically Isolated

ELECTRICALLY CONDUCTIVE

- Low loss conductor



(a) Configuration

(b) Device Stack

Figure 7: Electrically Conductive

THERMAL BRIDGING

- Horizontal heat transfer
- DC blocking

(a) Configuration

(b) Device Stack

Figure 8: Thermal Bridging

HEAT SPREADER ATTACHMENT

METALLIZATION OPTIONS

There are two main metallization options;

1. Sputtered 1000Å Titanium, 1200Å Min. Platinum, 5000Å Min. Gold
    - Compatible with all solders and conductive epoxies
    - Forms the strongest bond with CVD Diamond
    - Can withstand the highest temperature without oxidizing
    - Can withstand multiple re-flows
2. Sputtered 500Å TiW, 50 micro inches Min. NiV, 50 micro inches Min.Gold (or Silver)
    - Lower Cost
    - Patternable
    - Solderable
    - Wire bondable with increased gold thickness

ATTACHMENT MATERIALS

The attachment materials typically contribute the most to the overall thermal resistance of the assembly. The metallization options allow for all common solder materials to be used and if need be, the gold finish can be increased to allow for wire bonding. Lower thermal resistance is achieved by using a material with as high of a thermal conductivity as possible and as thin as possible. This is easier to achieve with a metallic solder rather than an epoxy.

High temperature attachment solders of AuSn and AuGe (280°C and 356°C eutectic) have proven to be the best in offering an extremely strong bond that without sacrificing major thermal performance. The stiffness of these hard solders helps minimize transfer of tensile load to the chip that results from major CTE mismatch.

For best performance, any solder or epoxy that is used should be re-flowed or cured following conventional methods and according to the process and profile suggested by the material vendor.

OPTIMAL HEAT SPREADER DIMENSIONS

Heat spreader size and thickness may be optimized for each application using thermo- mechanical FEM modeling of the assembly. Keeping surface areas as large as possible and thicknesses to a minimum will help to minimize the system thermal resistance.

SUMMARY

Heat spreaders are intended to spread heat out over a larger surface area than the source to more efficiently remove heat generated by active and passive components. Heat spreaders can be used in many different configurations and are optimized by;

- Choosing materials with high thermal conductivity
- Keeping thicknesses to a minimum
- Keeping surface areas to a maximum

AuSn and AuGe solders provide the best attachment while maintaining reasonable thermal conductivity. Using thermo-mechanical modeling is the best way to determine the optimal size.

APPENDIX

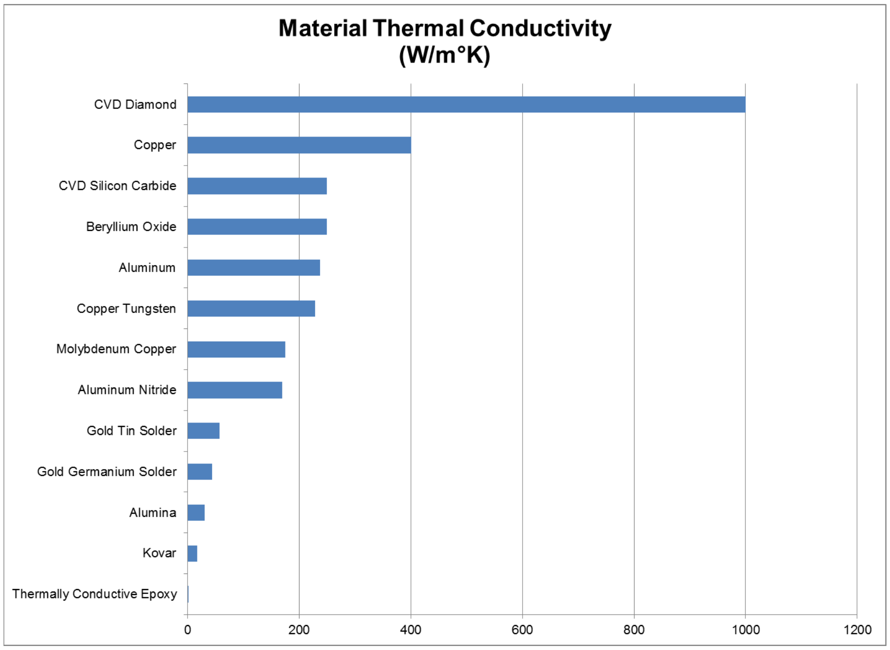


Figure 9: Thermal Conductivity Comparison

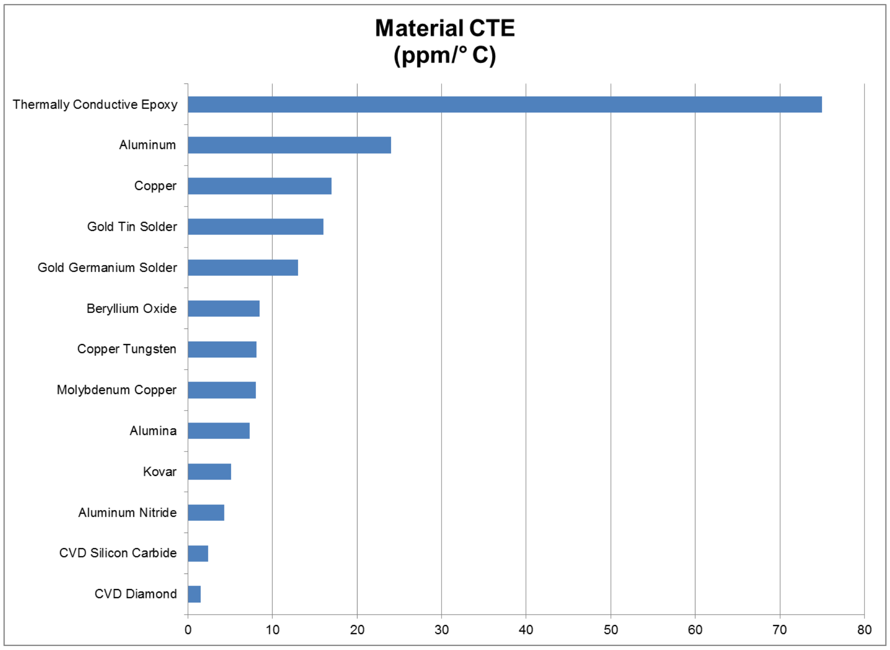


Figure 10: CTE Comparison

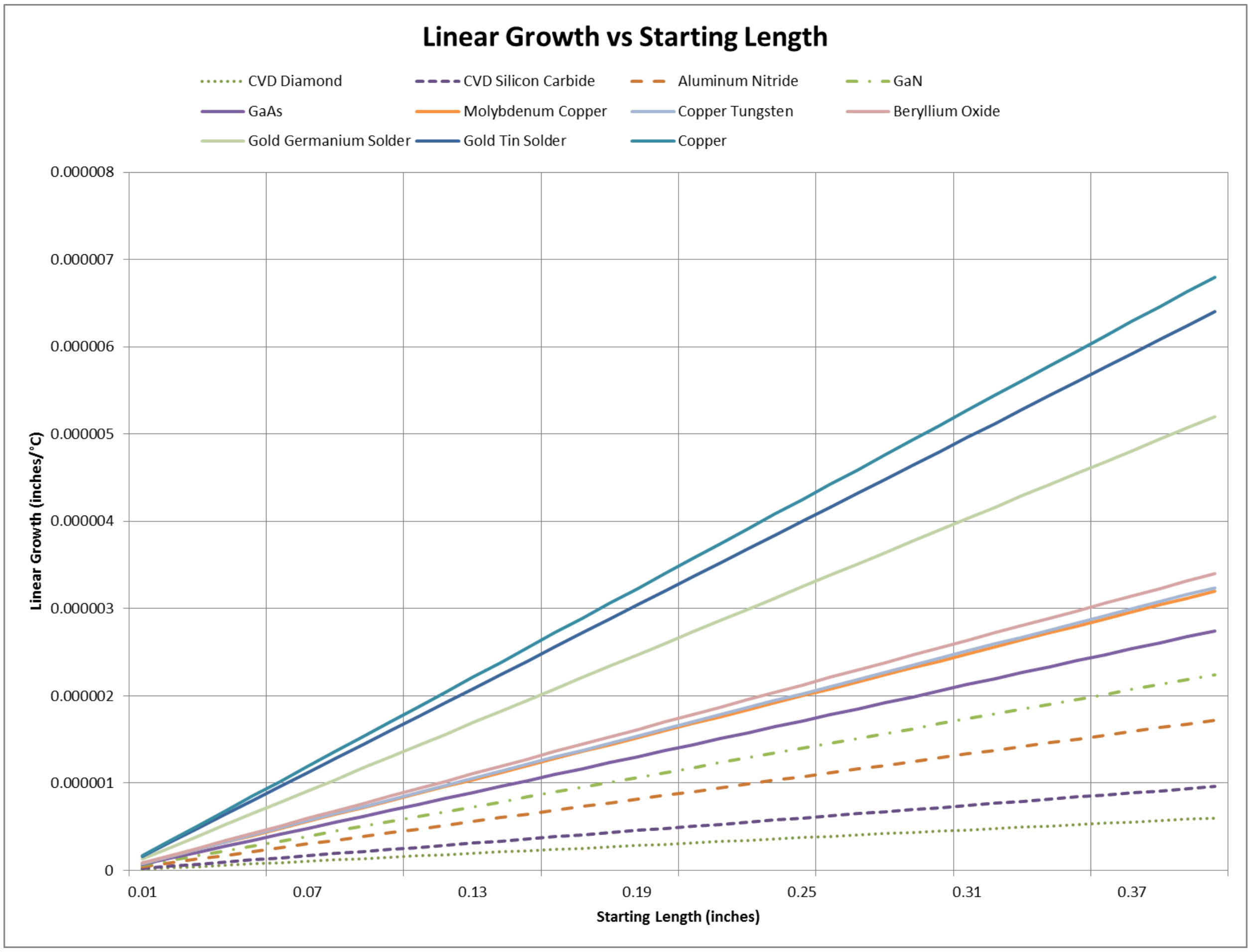
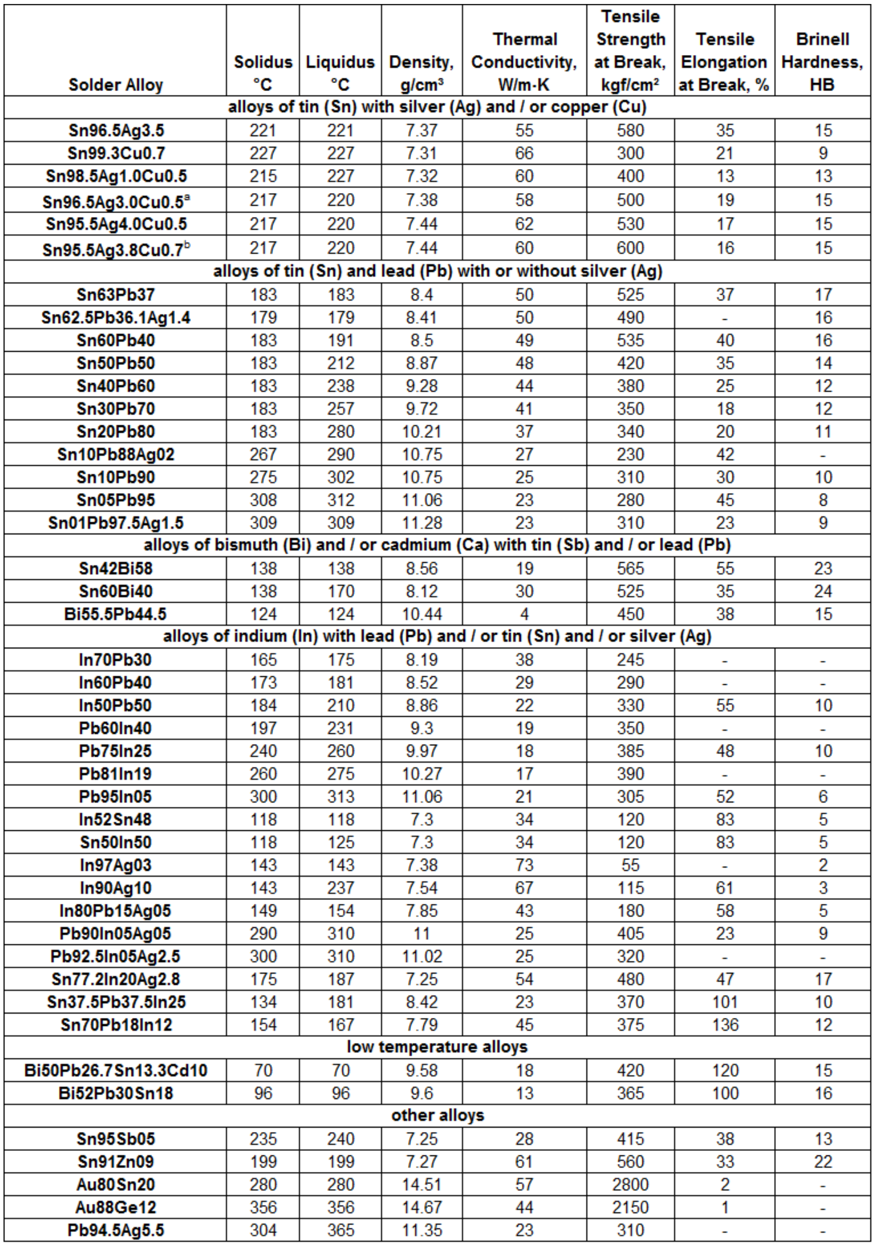


Figure 11: Linear Growth vs Starting Length



Solder Alloy	Solidus °C	Liquidus °C	Density, g/cm³	Thermal Conductivity, W/m·K	Tensile Strength at Break, kgf/cm²	Tensile Elongation at Break, %	Brinell Hardness, HB
alloys of tin (Sn) with silver (Ag) and / or copper (Cu)							
Sn96.5Ag3.5	221	221	7.37	55	580	35	15
Sn99.3Cu0.7	227	227	7.31	66	300	21	9
Sn98.5Ag1.0Cu0.5	215	227	7.32	60	400	13	13
Sn96.5Ag3.0Cu0.5[a]	217	220	7.38	58	500	19	15
Sn95.5Ag4.0Cu0.5	217	220	7.44	62	530	17	15
Sn95.5Ag3.8Cu0.7[b]	217	220	7.44	60	600	16	15
alloys of tin (Sn) and lead (Pb) with or without silver (Ag)							
Sn63Pb37	183	183	8.4	50	525	37	17
Sn62.5Pb36.1Ag1.4	179	179	8.41	50	490	-	16
Sn60Pb40	183	191	8.5	49	535	40	16
Sn50Pb50	183	212	8.87	48	420	35	14
Sn40Pb60	183	238	9.28	44	380	25	12
Sn30Pb70	183	257	9.72	41	350	18	12
Sn20Pb80	183	280	10.21	37	340	20	11
Sn10Pb88Ag02	267	290	10.75	27	230	42	-
Sn10Pb90	275	302	10.75	25	310	30	10
Sn05Pb95	308	312	11.06	23	280	45	8
Sn01Pb97.5Ag1.5	309	309	11.28	23	310	23	9
alloys of bismuth (Bi) and / or cadmium (Ca) with tin (Sb) and / or lead (Pb)							
Sn42Bi58	138	138	8.56	19	565	55	23
Sn60Bi40	138	170	8.12	30	525	35	24
Bi55.5Pb44.5	124	124	10.44	4	450	38	15
alloys of indium (In) with lead (Pb) and / or tin (Sn) and / or silver (Ag)							
In70Pb30	165	175	8.19	38	245	-	-
In60Pb40	173	181	8.52	29	290	-	-
In50Pb50	184	210	8.86	22	330	55	10
Pb60In40	197	231	9.3	19	350	-	-
Pb75In25	240	260	9.97	18	385	48	10
Pb81In19	260	275	10.27	17	390	-	-
Pb95In05	300	313	11.06	21	305	52	6
In52Sn48	118	118	7.3	34	120	83	5
Sn50In50	118	125	7.3	34	120	83	5
In97Ag03	143	143	7.38	73	55	-	2
In90Ag10	143	237	7.54	67	115	61	3
In80Pb15Ag05	149	154	7.85	43	180	58	5
Pb90In05Ag05	290	310	11	25	405	23	9
Pb92.5In05Ag2.5	300	310	11.02	25	320	-	-
Sn77.2In20Ag2.8	175	187	7.25	54	480	47	17
Sn37.5Pb37.5In25	134	181	8.42	23	370	101	10
Sn70Pb18In12	154	167	7.79	45	375	136	12
low temperature alloys							
Bi50Pb26.7Sn13.3Cd10	70	70	9.58	18	420	120	15
Bi52Pb30Sn18	96	96	9.6	13	365	100	16
other alloys							
Sn95Sb05	235	240	7.25	28	415	38	13
Sn91Zn09	199	199	7.27	61	560	33	22
Au80Sn20	280	280	14.51	57	2800	2	-
Au88Ge12	356	356	14.67	44	2150	1	-
Pb94.5Ag5.5	304	365	11.35	23	310	-	-

Figure 12: Solder Alloy Comparison