White Paper

Performance Alloys and Composites

System Performance of a Lightweight Beryllium Composite Heat Sink For Advanced Electronic Packaging

+1.800.375.4205 | materion.com/PAC

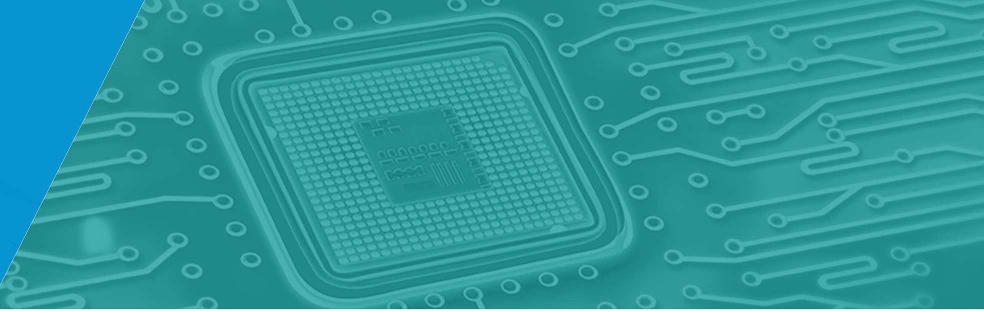
ABSTRACT

Recent advances in commercial and military electronics have created a need for electronic packaging materials that have thermal cycle reliability over a temperature range of -45°C to +85°C for increased operational lifetime, plus vibration reliability, while reducing the weight and size of the avionics packaging. This paper will present the development of a family of beryllium-based metal matrix composite materials, which offers the electronic packaging designers an attractive combination of properties to address the increasingly demanding needs of the electronic packaging engineer. The paper will focus on the system performance improvement using these new materials in applications such as the IRIDIUM® MCM-L package and various SEM-E electronic modules for aircraft avionics, like the F16 and F22.

INTRODUCTION

Recent advances in electronic packaging designs for multichip modules (MCMs) used in spacecraft electronics and standard electronic modules for aircraft avionics (SEM-E) have created a need for substrate materials that must have improved fundamental characteristics such as: high thermal conductivity (TC), low weight, high stiffness, improved thermal cycle reliability over broad temperature ranges, and a coefficient of thermal expansion (CTE) that ideally matches the components installed in the package or helps in constraint of the total package in order to minimize the thermal mismatch of the printed wiring board (PWB) materials and the packages. These advanced packaging designs also need materials to accommodate increased power demands while enduring the harsh environments of military applications.

To address those needs, Materion has developed a family of lightweight beryllium-based metal matrix composites. This family of materials, called E-Materials (grades E-20, E-40, E-60), offers a range of tailorable properties and a significant improvement over other electronic packaging materials such as copper-moly-copper (CMC), AlSiC, CuW, Kovar, and aluminum. E-Materials meet the thermal performance needs of applications ranging from MCMs, SEM-Es to R/F and digital microwave packages.



MATERIAL DESCRIPTION

The beryllium metal matrix composites consist of a fine single crystal beryllium oxide (BeO) platelet surrounded by a continuous beryllium (Be) matrix. The volume fraction of the BeO in the matrix is altered between 20-60% to tailor the thermal and mechanical properties as well as the density of the composite (Table I). Unlike many of the new advanced thermal performance materials, the properties of E-Materials are isotropic and thermally stable.[1] The resulting composites exhibit a high modulus, good thermal conductivity, low density and a lower CTE. Table I summarizes the various properties of selected materials that may be used for these types of applications.

TABLE I

Materials and Their Properties for Microelectronic Packages

Material	Density g/cm³ (lb./in³)	Elastic Modulus GPa (msi)	Thermal Conductivity W/m/K (Btu/hr/ft/°F)	CTE PPM/ °C (ppm/ °fF) 25°-100°C
E-20	2.05 (.074)	289 (42)	200 (115)	9.5 (5.3)
E-40	2.28 (.082)	303 (44)	205 (118)	8.0 (4.4)
E-60	2.51 (.091)	316 (46)	210 (121)	6.5 (3.6)
AlSiC-70%	3.01 (.111)	220 (32)	~170 (98)	6.7 (3.7)
Al-SiC-45/55%	2.95 (.109)	195 (28)	160 (93)	8.5 (4.7)
Kovar	8.1 (.300)	140 (20)	14 (8)	5.9 (3.3)
CuMoCu 13/74/13%	9.9 (.360)	269 (39)	181 (105)	5.8 (3.2)
CuW-25/75%	14.8 (.538)	228 (34)	190 (110)	8.3 (4.6)
Aluminum 6061T6	2.75 (.100)	70 (10)	170 (98)	23.6 (13.1)

MATERIAL PROPERTIES

The properties of principal interest to the electronic packaging engineer designing MCM-L, SEM-E, and RF/Microwave base plates used in the package to dissipate heat and provide a good CTE match to the ceramic package are: a tailorable CTE, high thermal conductivity, high elastic modulus to reduce transmissibility, low weight, ease of fabrication using either net shape technologies or conventional machining practices, and reduced cost.

1.1 COEFFICIENT OF THERMAL EXPANSION

The CTE of the three (3) grades of Be-BeO metal matrix composites, E-20, E-40, E-60, have been measured by using a linear dilatometer per ASTM E 228- 85. The E-Material data presented in Table I represents the maximum CTE values defined by Materion's specifications.

CTE MEASUREMENTS

The material's dimensional stability over a wide range of temperatures (Figure I) is important in electronic packaging applications, especially military avionics, because of the temperatures during component assembly from processes like gold germanium brazing cycles, plus the duty cycle of the electronic module assemblies. Failure of the substrate material to maintain flatness over temperature, either from a CTE mismatch or dimensional instability during thermal cycling, can lead to premature failure of the solder joint connection of the components to the PWB material.

CHANGE IN FLATNESS OF E-60 AFTER CRYO-CYCLING

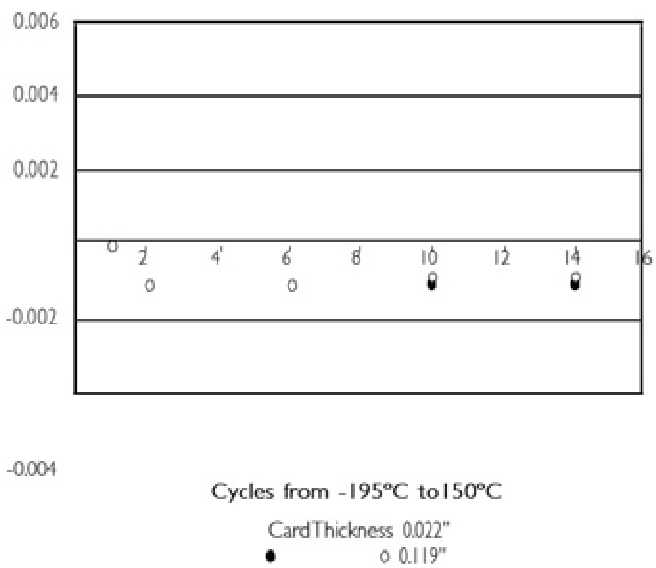
1.2 CRYO-CYCLING STIFFNESS AND VIBRATION RESISTANCE ANALYSIS

One potential failure mode of electronic packages is the dynamic stress exerted on the solder joints by random and sinusoidal vibration experienced in an actual flight environment of military aircraft or in launching of a telecommunications satellite. One way to reduce the effects of this vibration on component life is to have a core material that has a high elastic modulus, thereby increasing the first mode natural frequency to isolate module from the frequency of its mating hardware and reducing the transmissibility. The benefits of the high specific stiffness of the family of E-Materials (E-20, E-40, E-60) can be seen in the testing that was done at Naval Air Warfare Center.[4]

FIGURE 1

Changing in Flatness of E-60 After Cryo-Cycling

TABLE 2



Vibration Testing Results

MATERIAL	ELASTIC MODULUS GPa (msi)	NATURAL FREQUENCY (Hz)	G	TRANSMISSIBILITY (OUTPUT G/INPUT G)	THICKNESS cm (in)	DENSITY g/cm³ (lb./in³)
Al 6061 T6	68 (10)	530	265	8.8	0.250 (0.098)	2.7 (0.098)
AlSiC-70%	255 (37)	498	120	4.0	0.245 (0.096)	3.0 (0.108)
BeBeO-E-60	316 (46)	720	66	1.9	0.241 (0.095)	2.5 (0.090)
BMI/P130 (60%)	280 x axis (41)	630	78	2.6	0.244 (0.096)	1.9 (0.069)
Copper	120 (17)	230	525	17.5	0.250 (0.098)	8.2 (0.296)

Another way to look at vibration damage is to look at the cumulative damage ratio (RN) on the solder joints of a typical line replaceable module (LRM). According to analysis done by Harris for the F22, solder joints with lead geometries of .0085" wide and .005" high, with a lead stiffness KD (lb./in) up to 6.82, had 0.01% failure ratio using a BeBeO core bonded to a 0.05" thick polyimide PWB.[3] This is in comparison to using the same components and PWB with an equal thickness 6061T6 aluminum core with 308.0 RN ratio. This also assumed a rack transmissibility of 0.3 with the weapons bay open. Texas Instruments also recently tested an E-60 core with an 8-layer polyimide board bonded on both sides of a 0.100" (2.5 mm) thick E-60 core with 250 vibratory cycles, 3 axes sequential for 10 minutes per axis, at 6.00 Gs 'RMS for an F16 module on the Modular Mission Computer (MMC) without a solder joint failure on Leadless Ceramic Chip Carriers (LCCCs) up to 4410s with a 0.050 lead pitch.[6]

1.3 ENVIRONMENTAL TESTING

With the increasing demands from the package designers, materials not only need to have higher thermal conductivity, tailorable CTE and a high natural vibration frequency, but they must also survive today's harsh service environments for them to truly provide total benefit to the end user.

1.3.1 SALT FOG TESTING

E-Materials have been tested for salt fog from 48 hours to up to 500 hours per MILSTD-810C Method 509-1, both cyclic and static immersion in a 5% NaCl solution at 95°F.7 These tests were run on bare E-Materials, a duplex nickel plating, cadmium over nickel, an epoxy primer over chem film and a conversion coat. All coatings passed 500-hour salt fog testing, except the conversion coat, which survived 96 hours. One testing agency, National Technical Systems, found that if the plating/coating demarcation line is not controlled well in the process, there can be a potential for corrosion to attack the base metal at that point.[8] Therefore, if there is a duplex coating, one of the coatings should overlap the other by 0.005" to prevent preferential attack. They also found that with metal matrix composite materials, the faying surface should have either duplex plating or be anodized to prevent a galvanic cell reaction. This was true for both E-Materials and the AlSiC materials that were tested.

TABLE 3

Corrosion Test Results Base Material (5% Salt @ 95°F)

MATERIAL	COATING	RESULTS	COATING	RESULTS	COATING	RESULTS
6061 T6	Chem Film	Passed 96 hours	Duplex nickel	Passed 500 hours	Epoxy Primer over Chem Film	Passed 500 hours
E-20 Be-BeO-E-60	Chem Film	Passed 96 hours	Duplex nickel	Minor damage after 500 hours	Epoxy Primer over Chem Film	Passed 500 hours
E-40 Be-BeO-E-60	Chem Film	Passed 96 hours	Duplex nickel	Minor damage after 500 hours	Epoxy Primer over Chem Film	Passed 500 hours
AlBeMet	Chem Film	Passed 96 hours	Duplex nickel	Minor damage after 500 hours	Epoxy Primer over Chem Film	Passed 500 hours
AlSiC-65%	Chem Film	Passed 96 hours	Duplex nickel	Passed 500 hours	Epoxy Primer over Chem Film	Passed 500 hours

CASE HISTORIES

Motorola Satellite Communications Division developed IRIDIUM®, an MCM-L packaging design that serves as a transmit/receive module. A large number of packaging design drivers were addressed in the design.[9] One of those was the chassis design and material selection. There were four material factors that were evaluated in choosing the right material.

First, due to the high MMIC wattages, a direct physical attachment of the die to a metallic chassis is desired. The chassis' material thermal properties play an important role in maintaining junction temperatures at or below 70°C; thermal conductivity greater than 180 W/m/K is needed to provide sufficient thermal conduction.

Secondly, the chassis' materials CTE should be slightly higher than that of the GaAs, (5.5-5.7 ppm/°C) but within several ppm/°C. This is important due to both the low fracture toughness of the GaAs and the fragility of a 0.004" finished die thickness. The higher CTE will preferably put the GaAs into a slight compression upon cooling. Also, the chassis must partially constrain the circuit board material in order to reduce the stress on the copper transmission lines over the temperature cycles. Therefore, a CTE of 8-9 ppm/°C was the targeted range.

The third factor was the chassis' weight, especially on a satellite system where it is not unusual for a launch cost on a per pound basis to be in excess of $10,000 per pound. Therefore, the chassis materials weight target was not to exceed 3.1g/cc (0.12 lb./in^3).

The fourth factor was the manufacturability/cost of the chassis. The chassis had to be plateable with gold and electroless nickel for wire bonding for ground connections. Further, the chassis material had to have good machinability due to the tight dimensional control required for the part dimensions. Also, because the design was somewhat immature, there is great benefit to having the flexibility to change dimensions and hole locations, or in general modify the design without having to change expensive net shape tooling. Lastly, the material had to be available in the size needed, 0.550" x 5.5" x 7.5", and in the production timeframe.

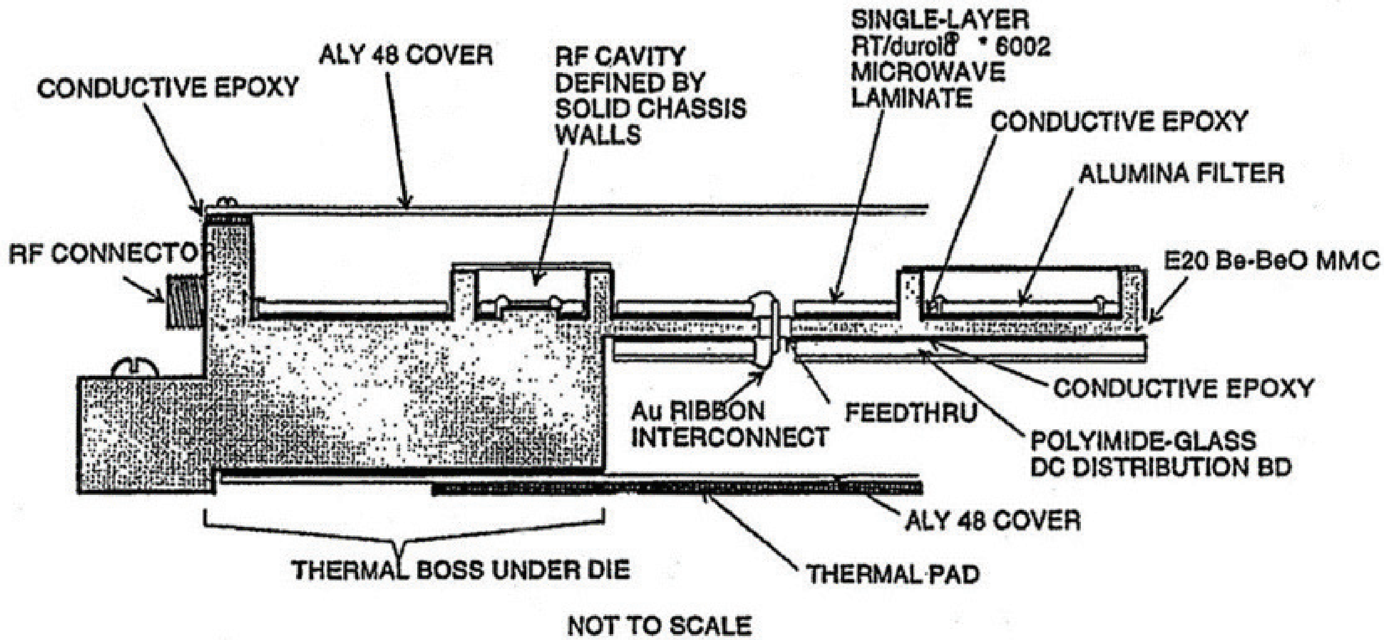
All of these factors led to Motorola evaluating four materials: AlSiC (50% Vol.), a CuW (75-25%), Sumitomo's A40 (Al-40%Si) material and the Be/BeO composite E-20 (see Table 4).

TABLE 4

Materials Selection Chart

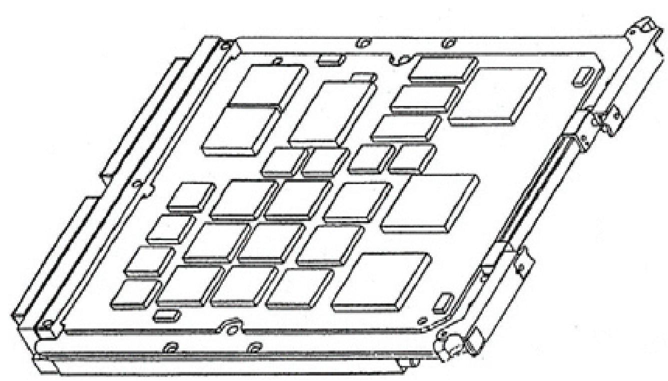
DENSITY g/cm^3 (lb/in^3)	MATERIAL	MODULUS GPa (msi)	THERMAL CONDUCTIVITY @ 25°C-W/m/K (Btu/hr/ft/°F)	CTE ppm/°C (ppm/ °F)	PLATEABILITY ELECTROLESS NICKEL/GOLD	MACHINABILITY	MANUFACTURING CAPABILITY SIZE
14.80 (0.53)	Thermkon 75%W-25%	228 (34)	190 (110)	8.3 (4.6)	Good	Good	
3.10 (0.11)	Sumitomo A40	70 (11)	125 (72)	13.5 (7.5)	Excellent	Fair	Module size exceeds current mfg capability
3.00 (0.11)	AlSiC 55% Volume SiC	168 (25)	180 (104)	9.0 (5.0)	Fair - results not always predictable	Poor - need diamond tools or EDM	.125" x 7.5" x 10"
2.05 (0.07)	E-20 Be/ BeO	303 (44)	215 (124)	8.7 (4.8)	Excellent	Good - can use carbide, EDM, laser	20" x 20" x 20"

The advantages of the E-20 material in meeting all of the design criteria, low weight, controlled CTE, high thermal conductivity, excellent manufacturability, and a cost that was acceptable within the guidelines and reduced the launch cost made E-20 the material of choice in building the IRIDIUM® chassis (see figure).



APPROACH #2 SOLID CHASSIS WALLS DEFINE RF CAVITIES

Recent advances in military electronics' Standard Electronic Modules Format E (SEM-E) have created a need for electronic packaging with increased performance and operational lifetimes, while decreasing size and weight. The need for improved thermal management in electronic packaging increased power densities and circuit speeds. Enhanced thermal management can improve reliability and, as a result, lower maintenance costs. The SEM-E Heatsinks, Figure 1, is used extensively for thermal management of surface mount designs of military electronics and avionics. In fact, on the F22 aircraft, there are reportable over 400 SEM-E modules per aircraft.



SEME-MODULE: SMT

One of the systems that is currently using SEM-E format module electronics is the F16 MMC currently built by Texas Instruments (TI) under contract from Lockheed Fort Worth. TI originally evaluated a number of core (heatsink) materials: CuMoCu, MoGrMO, AlSiC, and E-60, for this application. Their design criterion was a matched CTE of the core to the leadless/leaded components in order to provide constraint of the hard bonded PWB to drive the total sandwich CTE down to 8.5-9.5 ppm/°C. This required the core material to have a CTE of around 6-7 ppm/°C. They also wanted the core material to have a thermal conductivity of at least 180W/m/k in order to provide a good thermal conduction path for cooling the components in order to keep the junction temperatures below 75°C. The remaining design criteria was to reduce the weight of the total module as low as possible, because aircraft avionics as a percentage of the aircraft overall weight is now approaching almost 40% of the total aircraft weight. After a design trade study, TI selected the Be/BeO composite, E-60, for their baseline material.[10]

They then performed a number of qualifying tests on the E-60 cores. Among them were vibration testing, random flight and combined sinusoidal-random gunfire vibration. The vibration testing consisted of Environmental Stress Screen (ESS) of 3 axes sequential for 10 minutes per axis at 6.00 Gs RMS. They also did thermal cycle testing of the bonded ore, 10 temperature cycles from -54°C to +90°C, for approximately 5 hours per cycle. Each cycle also had a 30-minute dwell time for each temperature extreme. In an independent test apart from the qualification test for MMC, they also tested E-60 cores for 960 one-hour thermal cycles. After this test, there were no open circuits detected and visual inspection of the E-60 cores showed little fatigue of the solder joints.[11] The system is now in production on both the US and NATO F16 upgrades, 350 systems (8 modules per system), with a long range market potential of an additional 300-400 aircraft.

CONCLUSIONS

Beryllium based metal matrix composites, E-Materials, have been developed to meet the needs and enhance the performance of advanced electronic packaging applications. The materials have demonstrated in test and production, for both aircraft and satellite applications, that they can meet the avionic packaging designers' need for a high modulus, high thermal conductivity, low density and tailorable coefficient of thermal expansion material. At the same time, they can provide a cost effective solution to the systems' needs for improved reliability, lower life cycle costs, and reduced weight.

For more information or to speak with an engineer, visit www.materion.com/ematerials.

REFERENCES:

1. Grensing, F., Materion Beryllium & Composites, Inc. "Thermal and Mechanical Properties of Beryllium-Beryllium Oxide Composites", October 1991 TMS Meeting.
2. Parsonage, T., Materion Beryllium & Composites, Inc. "Thermal Performance of a Lightweight Heatsink", 7th International Sampe Electronics Materials Conference, June 22, 1994.
3. Private Correspondence, P. Heller, AIL Systems, 10/91.
4. Wagner, S., Naval Air Warfare Center, "Environmental Performance Evaluation of Advanced Composite Materials for use in Military Electronics", March, 1993.
5. Private Correspondence, B. Clark, Harris Corporation, 3/95.
6. Private Correspondence, Gary Hellums/Charles Barton,- Texas Instruments, DESG, March, 1996.
7. Grensing, F., Materion Beryllium & Composites, Inc., Internal Salt Fog Testing, 10/91.
8. National Technical Systems, Test Report Number 7446, March 21, 1995.
9. Torkington, R.S., Motorola Satellite Communications Division, "Microwave MCM-L Packaging for the IRIDIUM® Satellite Program", internal paper at Motorola, December 4, 1995.
10. Ozmat, B., Texas Instruments, " A New Composite Core Material For Surface Mount Technology Applications", internal TI document, October, 1991.
11. Private correspondence, D. Copple, Texas Instruments, 11/92.

HEALTH AND SAFETY

Processing Beryllium-containing products poses a health risk if safe practices are not followed. Inhalation of airborne beryllium can cause serious lung diseases in some individuals. Occupational safety and health regulatory agencies worldwide have set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Safety Data Sheet (SDS) before working with this material. The SDS and additional important beryllium health and safety information and guidance can be found at berylliumsafety.com, berylliumsafety.eu and Materion.com. For questions on safe practices for beryllium-containing products, contact the Materion Product Stewardship Group at +1.800.862.4118 or contact us by e mail at Materion-PS@Materion.com.