Aluminum Silicon Carbide (AlSiC) Microprocessor Lids and Heat Sinks for Integrated Thermal Management Solutions

Mark A. Occhionero, Robert A. Hay,
Richard W. Adams, Kevin P. Fennessy, and Glenn Sundberg
Ceramics Process Systems Corp.
Chartley, MA 02712
http://www.alsic.com
marko@alsic.com

Abstract

The next generation microprocessor assemblies will require integrated thermal management design solutions as the device density and clock speeds increase. These solutions will include a heat spreader, or lid, that is in contact with the heat generating microprocessor in the total packaging assembly. The materials choice for these integrated heat spreader solutions must provide the following material property attributes.

- *High bulk thermal conductivity*
- *CTE compatibility with the Device and/or Microprocessor Assembly*
- *EMI/RFI Shielding*
- *Light weight*
- *Dimensional Stability/Flatness (minimize bond line length resulting in a decreased Q_C).*
- *Competitive Pricing*

AlSiC, Aluminum Silicon Carbide, metal matrix composite materials meet the material property, design and pricing demands for microprocessor assemblies that require integrated heat sink thermal management solutions. The CTE of AlSiC material and components can be tuned to be compatible with the specific heatsink application by controlling the SiC volume fraction in the AlSiC composite. AlSiC products with CTE values 7 – 9 ppm/°C (30 – 250°C) are suitable for direct attachment to GaAs and Si devices and ceramic substrate. Higher CTE materials 10 – 12 ppm/°C are used for attachment to printed circuit boards.

The AlSiC thermal conductivity value is 180 – 200 W/mK (compositional dependent) similar to CuMo and CuW materials. The material density of AlSiC is 1/3rd to 1/5th that of CuMo and CuW making AlSiC more suited to weight sensitive applications.

The Ceramics Process Systems AlSiC components are cost-effectively fabricated to net-shape attaining close dimensional tolerances with minimal machining. The AlSiC material composition (hence CTE) is controlled by monitoring the SiC volume fraction of a tightly toleranced SiC preform fabricated with the QuickSet™ injection molding process. The pore structure of the SiC preform is infiltrated with molten Al-metal (termed the QuickCast™ process) to form the AlSiC composite material to the exact product dimensions defined by the infiltration mold. The combined processes form a fully dense, hermetic material of discrete SiC particulate in a continuous Al-metal matrix phase. This process is currently used for high volume production for a number of product geometries and thermal management applications including MPU integrated heat spreading lid solutions.

The ideal material properties coupled with AlSiC fabrication process provide low-cost high-performance functional integrated thermal management heat spreading solutions for microprocessor applications. This paper will illustrate the AlSiC material/design capabilities through microprocessor heat spreader examples.

Key words: microprocessor integrated heat sink Electronic Packaging Material, Thermal Management, Thermal Conductivity, CTE, Lightweight

Introduction

Increased microprocessor speeds, power dissipation, footprint size reduction as well as reduction in total device size requires integrated thermal management solutions for the current and future generations of microprocessors. These solutions are usually provided in the form of a lid, or cap that is integrated in to the BGA flip chip or C4 assembly. AlSiC is a composite material of Al-metal and SiC particulate that is currently providing integrated thermal management solutions for microprocessors.

Since the late 1980's, AlSiC composite materials have been providing thermal management packaging solutions for high-power output microwave applications. AlSiC was an ideal material for these high end applications since it provided the necessary CTE compatibility with direct GaAs device attachment, as well as a high thermal conductivity (180 W/mK), and was lightweight in contrast to traditional thermal management materials like CuMo and CuW. Weight consideration was significant since most of these early microwave AlSiC packaging applications were airborne applications. AlSiC also provided the necessary hermeticity required for environmental protection of assembled devices as well as providing EMI/RFI shielding. The AlSiC packages also provided a high degree of component protection as a result of high strength and stiffness of AlSiC. Figure 1 shows an assembled AlSiC microwave package[1-3].

During the development of these AlSiC microwave packages the Ceramics Process Systems AlSiC process was refined to a net-fabrication process that formed both the composite and the final product shape to tight dimensional and geometrical requirements. The fabrication process was found to be cost-competitive to similar machined Cu, Al, CuMo, and CuW packages. Additionally the forming process also allowed the hermetic assembly of functional components such as feedthrus, seal ring, and dielectric substrates which eliminated the need for subsequent soldering or brazing assembly steps.

In the early 1990's AlSiC materials were introduced as power substrates for the commercial communication applications for cellular base stations (an example is shown in Figure 2). Here the AlSiC cost-competitively replaced Cu substrates because of the close CTE match of assembled components. The CTE match ultimately resulted in increased component reliability, and a dramatic drop in the cost of ownership of the assembled base station units[4]. The added benefit was the size reduction the overall component and the consolidation of attached ceramic components as a result of the close CTE match of the AlSiC power-substrate[1]. These AlSiC power substrate

Figure 1: Ni-Au Plated Assembled AlSiC Microwave Package.

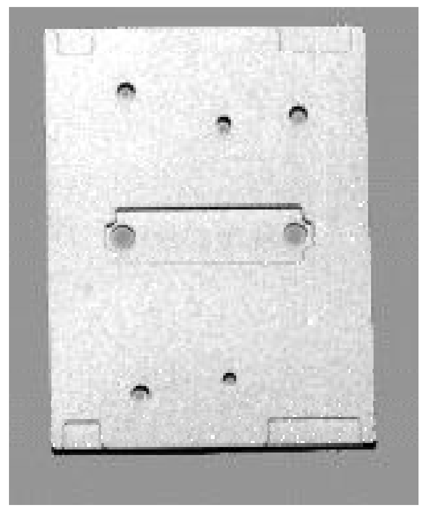

Figure 2: AlSiC power substrate for cellular communications industry.

has evolved into providing solutions for larger format products such as IGBT's and other high power applications [5,6].

Similar thermal management requirements initially identified by the microwave electronics packaging industry are being addressed by the microprocessor industry today. Figure 3 shows examples of AlSiC microprocessor lids.

There are some significant differences however in terms of the desired target material properties and design considerations for AlSiC

[1] For Cu substrates the assembly required multiple discreet devices mounted on small stress compensating alumina substrates that had multiple external interconnections. In the AlSiC solution all devices were mounted on a single substrate, reducing the component size and reducing the need for external interconnections.

microprocessor lids. The most significant difference is that the integrated microprocessor lid applications is the material and the design must provide a thermal management CTE solution for the total microprocessor assembly (chip, BGA, interposer, board). A CTE balance of the microprocessor assembly reduces device or interconnections cracking by reducing the magnitude of thermally induced stresses thus increasing the microprocessor reliability. Since different microprocessor manufactures have different assemblies and designs the CTE requirement for the AlSiC integrated lid must change and be tailored to the specific application.

Fortunately the CPS AlSiC CTE can be easily tailored to the specific application as a result of the composites nature (AlSiC is a combination of the higher CTE valued Al-metal and lower CTE valued SiC particulate). AlSiC Microprocessor material and lid design concepts will be discussed [3].

AlSiC Material Properties

Figure 4 shows a polished micrograph of the CPS AlSiC composite material that is characterized by discrete SiC particles in a continuous Al-metal matrix phase. AlSiC composite thermal management properties are a result of the combination ratio of the SiC and Aluminum material properties. This is especially true for the composite CTE -value that is intermediate to high CTE value of Al-metal at 23 ppm/°C and the low CTE value of SiC at 4 ppm/°C. The AlSiC composite CTE behavior can be tailored to match the CTE values of an attached component or components by changing ratio of SiC and Al-metal. Furthermore the CTE value can be tuned for an integrated lid that will moderate the overall CTE of an assembly system.

AlSiC composite produced for lid applications are AlSiC-9, -10, and -12 that have average CTE values of 9, 10 and 12 ppm/°C respectively, over the temperature range of 25° - 150°C. Table 1 contrasts the CPS AlSiC composites to traditional heat sink/heat spreader materials, IC materials, and alumina, a common substrate material. Figure 5 graphically shows the instantaneous CTE behavior for CPS AlSiC-9, -10 and –12 between 30 and 200°C.

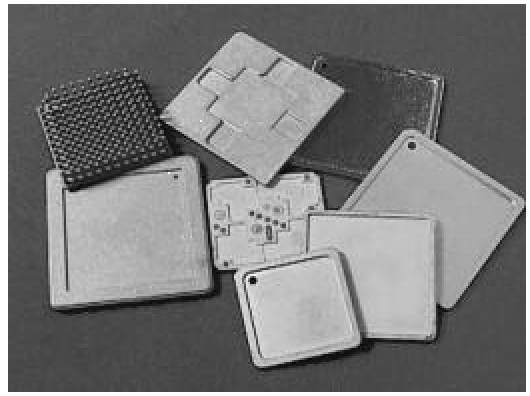

Figure 3: CPS AlSiC Lids demonstrating design capability.

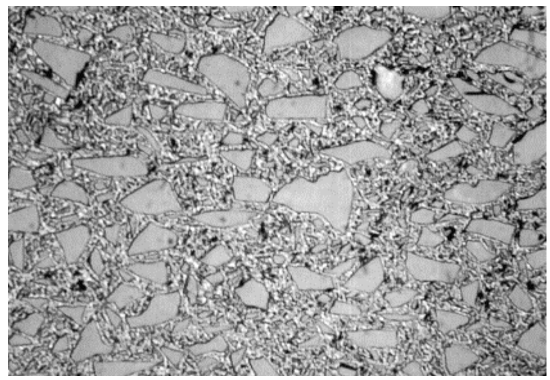

Figure 4 AlSiC microstructure with the discrete SiC particles in dark contrast and the continuous Al-metal phase in bright contrast.

Table 1: Material Property Comparison

Material	Common Material Use	Density (g/cm^3)	CTE ppm/° (25-150°C)	Thermal Conductivity (W/mK)	Bend Strength (Mpa)	Young's Modulus (GPa)
Si	IC	2.3	4.2	151		112
GaAs	IC	5.23	6.5	54		
AlSiC-9	**Lids & Heat Sinks**	**3.01**	**8.26***	**180**	**450**	**175**
AlSiC-10		**2.97**	**9.89***	**185**	**450**	**167**
AlSiC-12		**2.87**	**12.42**	**180**	**--**	**--**
Cu	Heat Sink	8.96	17.8	398	330	131
Al	Heat Sink	2.7	23.6	238	137-200	68
Alumina	Substrate	3.98	6.5*	20 - 30	300	350

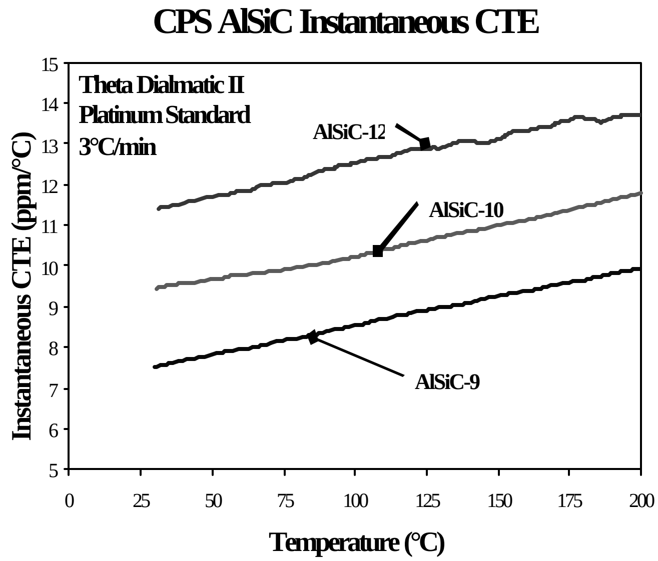

Figure 5: Instantaneous CTE Behaviors for CPS AlSiC-9, AlSiC-10 and AlSiC-12 Composites for Integrated Microprocessor Lids.

Microprocessor Assembly and Integrated AlSiC Lid for CTE Compensation

Figure 6 shows a cross section of the microprocessor assembly. As illustrated there are many material systems that contribute to the flip chip overall thermal performance and the overall thermally induced stresses associated with differential CTE values.

The device material, Si or GaAs, have low CTE values 4.2 and 6.5 ppm/°C, respectively. These devices are attached (bumped or soldered) to higher CTE value metallic (High temp solder, Cu and Au) I/O BGA which are then attached to a ceramic substrate (Alumina with CTE value of 6.7 ppm/°C) or a PCB that have CTE values between 12 and 15 ppm/°C. Often times a filled epoxy underfill material is added to compensate for differential CTE thermally induced stresses between the device and ceramic substrate or PCB. These assemblies often times require a lid for heat spreading and to provide protection to the device in subsequent end user assembly operations (heat sink application or fanned heat sink attachment). Traditional lid materials like Cu and Al have high CTE values of 17 and 23 ppm/°C. These lid materials are thermally interfaced to the device through thermal grease to avoid introducing a large thermally induced stress associated with direct attachment. The lids do add to the thermal stress equation of the total microprocessor assembly since they are attached to the PCB or substrate by epoxies or solder. The thermal stress equation for microprocessor assemblies is complex depending on the assembly geometry and the CTE behaviors of many different materials and requires complex thermal modeling evaluation. In general, component materials that have CTE values more closely matched to the device CTE value, like the AlSiC lid materials, can minimize the thermally induced stresses of the overall assembly. However, if the lid is to be attached to the substrate of the PCB, a close CTE match to these materials is important. AlSiC-12 with a CTE value of 12.4 ppm/°C is appropriate for PCB board attachment; AlSiC-9 with a CTE value of 8.3 ppm/°C is suitable for mounting to ceramic substrates.

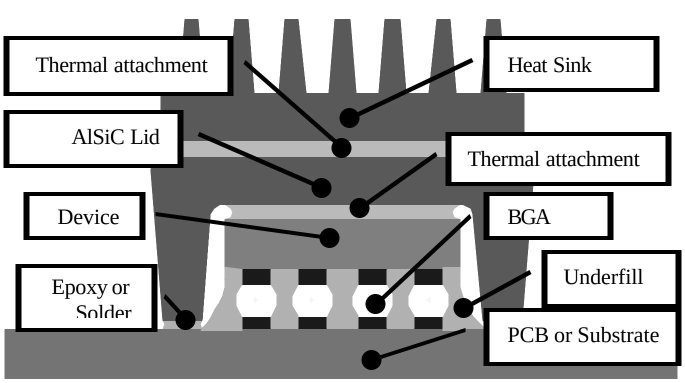

Figure 6 Schematic Cross Section of a Microprocessor Assembly

Integrated Microprocessor Lid Key Design Considerations

The primary design consideration of an integrated heat-spreading lid is to minimize the gap between the lid and top of the device and to decrease the bond line length to reduce device lid/interface thermal resistance. This is necessary since the thermal grease materials have low thermal conductivity values of 1 – 2 W/mK. To minimize this gap requires control of dimensions and tolerance between the lid cavity depth and the height of the lid walls. In addition, the lid flatness and parallelism are also necessary in minimizing the bond line length of this interface. Generally, the AlSiC lid forming process can provide cavity wall height dimensional tolerance of ± 0.002 inch [0.054 mm] and meets a flatness of 0.0015 inch/inch [0.04 mm/25.4 mm]. The gap between the device and lid interface, thus the bond-line length, can be reproducibly controlled with the AlSiC provided tolerance and flatness capability.

The lid must also provide mechanical protection of the device from the end user's heatsink attachment. Maintaining clearance between the cavity and device assembly can provide this protection. The clearance however increases the bond line length and thus thermal resistance as discussed above. The amount of clearance can be minimized by choosing a lid material with a higher stiffness value (reducing deflection of the lid during subsequent heat sink attachment). The CPS AlSiC materials have stiffness values that are comparable to Cu-metal lids and three times greater than Al-metal lids.

Flatness of the top of the lid is also critical to minimize the bond line length thus the thermal resistance between the lid and attached heat sink device.

General dimensional guidelines for AlSiC fabricated lids are illustrated in Figure 7.

Conclusions

AlSiC lids are currently being used for integrated heatsinks in microprocessor designs. AlSiC provides the necessary CTE compensation required for these assemblies increasing device reliability. Because of the composite nature of AlSiC, CTE values can be tuned for the specific applications, ranging from 8 to 12 ppm/°C, by changing the Al/SiC ratio. The 180 W/mK thermal conductivity of AlSiC material provides reliable thermal dissipation. The AlSiC fabrication process also provides lids with tight dimensional tolerance and good flatness minimizing the interfacial bond line length, to reduce thermal resistance throughout the assembly. Additionally, the AlSiC material also provides the necessary EMI/RFI shielding required for higher clock speed microprocessors. AlSiC material and fabrication process, originally developed for the microwave industry, is a mature process that allows for high volume manufacturing.

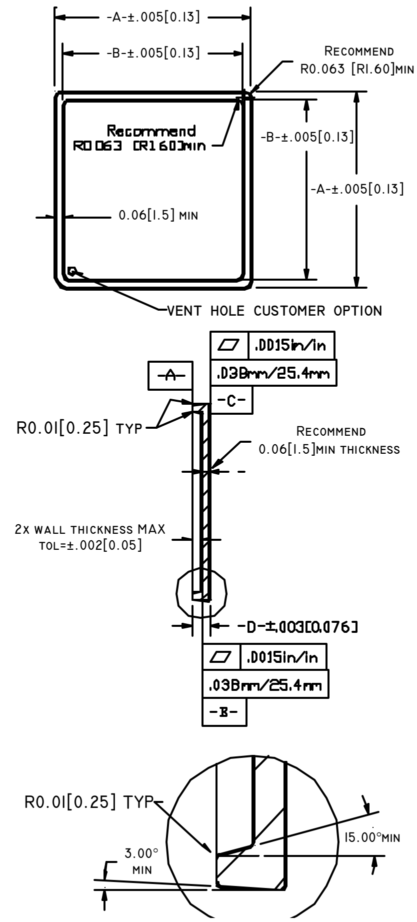

Figure 7 CPS AlSiC Lid Design Guidelines

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