Aluminum Silicon Carbide (AlSiC) For Cost-Effective Thermal Management And Functional Microelectronic Packaging Design Solutions

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Abstract

Aluminum Silicon Carbide (AlSiC) metal matrix composite (MMC) materials have a unique set of material properties that are ideally suited for electronic packaging applications requiring thermal management solutions. The AlSiC coefficient of thermal expansion (CTE) value is compatible with direct IC device attachment for the maximum thermal dissipation (AlSiC thermal conductivity 170 – 200 W/mK).

The low material density of AlSiC (3 g/cm^3*) makes it ideal for weight sensitive applications such as portable devices over traditional thermal management materials such as CuMo (10 g/cm*^{3}*) and CuW (16 g/cm*^{3}*). Structural packaging requirements are satisfied by the material strength and stiffness that are both approximately three times greater than Al-metal. Additionally, AlSiC is a hermetic material that can be used to give protection to environmentally sensitive electronic components. Also, this composite material is electronically conductive providing EMI/RFI shielding.*

The AlSiC material and functional electronic packaging geometries are produced using Ceramics Process Systems Corporation's QuickSet™/QuickCast™ net-shape fabrication process. This net-shape packaging fabrication process is capable of producing complex geometrical packaging features without the need for costly machining. Additionally, functional packaging features such as feedthrus, sealrings and dielectric substrates are incorporated in AlSiC during fabrication using the CPS Concurrent Integration™ technique eliminating the need for the traditional assembly and brazing or soldering operations.

The ideal AlSiC material properties coupled with net-shape fabrication and Concurrent Integration™ processes cost-effectively provide high-performance thermal management solutions in functional packaging designs. This paper will review the AlSiC material properties contrasted to traditional heat-sinking materials. AlSiC fabrication processing flow will also be reviewed and discussed. Functional packaging designs and application solutions will be illustrated through CPS AlSiC product examples.

Key words: Electronic Packaging Material, Thermal Management, CTE, Lightweight

Introduction

The dilemma faced by the electronics packaging designer today is how to increase component density and provide the necessary thermal dissipation for improved component reliability, and performance. Compounding these design considerations are issues of increased packaging functionality at a reduced cost[1-3].

For the packaging manufacturer the designers' demands correspond to providing a package fabricated from a material which has the desired thermal management properties. Traditionally, the material fabrication and the packaging fabrication were two separate processing steps: 1) the fabrication of the material in a billet or sheet, followed by 2) machining of the billet to the desired shape.

For all but the simplest shapes the cost associated with packages fabricated in this manner are associated with the machining to the desired geometry and the expensive billet stock, much of which is lost to machining. Often these packages require additional assembly operations to add functional components such as sealrings, feedthrus and substrates which add to the total packaging cost.

Within the past ten years Aluminum Silicon Carbide (AlSiC) material(s) and components have provided packaging solutions with required thermal management performance, improved and new functionalities and at a competitive cost compared to traditional packages[4].

From a materials properties perspective, the combination of a thermal conductivity value of 170 W/mK, with coefficient of thermal expansion (CTE) values that are compatible with direct IC attachment makes AlSiC ideal thermal management material. Furthermore, AlSiC is more appropriate for weight sensitive applications because of a low material density compared with traditional packaging materials (Ni-Fe allows, CuMo, CuW).

The Ceramics Process Systems Corp. QuickSet™/QuickCast™ process provides both the material and the product shape in one process step without the need for expensive machining operations. The AlSiC raw materials are provided from inexpensive Al metal ingots and inexpensive SiC powder. The ability to fabricate the package geometry and material without finish machining is termed "net-shape" fabrication. This net-shape fabrication processing technique allows for the assembly of functional components such as sealrings, feedthrus and dielectric substrate during fabrication. This assembly during fabrication, termed Concurrent Integration™, eliminates the need for subsequent brazing and soldering, which reduces the total packaging cost[5].

Thermal Management Materials

To achieve the maximum thermal dissipation requires direct attachment of the heat generating device to a thermal substrate or package[6]. This requires that the thermal substrate/package having a high thermal conductivity for efficient heat dissipation. More importantly is the requirement that the coefficient of thermal expansion (CTE) of the substrate/package material be compatible with the CTE of the IC device. Wide CTE differences can result in thermally induced stresses that can cause the IC device to fail either by cracking or delaminating from the heat-sinking material[7].

AlSiC material properties compared to traditional package materials, dielectric substrates, and IC materials (GaAs and Si) are given in Table 1.

TABLE 1: AlSiC Material Properties Compared with Common Packaging, Substrate and IC Materials.

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-7	**Packaging**	**3.0**	**6.90**[*]	**150**		**206**
AlSiC-8	**Packaging**	**3.0**	**7.63**[*]	**180**		**206**
AlSiC-9	**Packaging**	**3.0**	**8.26**[*]	**180**	**450**	**192**
AlSiC-10	**Packaging**	**3.0**	**9.89**[*]	**165**		**167**
Kovar (Ni-Fe)	Packaging	8.1	5.2	11 - 17		131
CuW (10-20% Cu)	Packaging	15.7 - 17.0	6.5 - 8.3	180 - 200	1172	367
CuMo (15-20%Mo)	Packaging	10	7 - 8	160 - 170		313
Cu	Packaging	8.96	17.8	398	330	131
Al	Packaging	2.7	23.6	238	137-200	68
SiC	Substrate	3.2	2.7	200 - 270	450	415
AlN[**]	Substrate	3.3	4.0[*]	170 - 200	300	310
Alumina	Substrate	3.98	6.5[*]	20 - 30	300	350
Beryllia	Substrate	3.9	7.6	250	250	345

[*] CTE data measured on Theta Dilamatic II Dilatometer to platinum reference at 3°C/m heating and cooling.
[**] CPS AlN

Figure 1 shows the AlSiC instantaneous thermal expansion behavior[*] as a function of temperature. The differences in AlSiC CTE behaviors are controlled by changing Al/SiC ratio and/or the Al-metal composition. From these CTE behaviors it is possible to choose an AlSiC material best suited to given packaging application. In general, the AlSiC CTE value is chosen to be 1 – 2 ppm/°C greater than the attached components to insure slight compressive stress after solder or braze attachment for increased reliability.

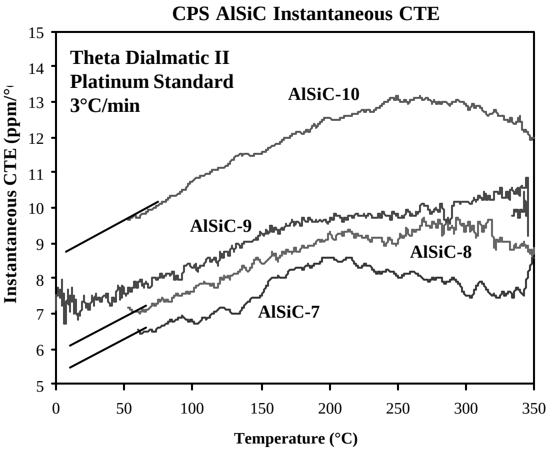

Figure 1. Ceramics Process Systems AlSiC Instantaneous CTE Behavior as a Function of Temperature and CTE Formulation.

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[*] The instantaneous CTE represents the thermal expansion behavior at a given temperature over a small temperature change (the small temperature change is defined as 3°C for the above plots).

AlSiC CTE Compatibility

CPS AlSiC–7 and –8 materials are ideal choices for direct Si device attachment since the Si IC devices have a lower CTE value. AlSiC-9 is an ideal choice for direct GaAs devices. AlSiC-9 is also compatible with alumina substrate attachment for ancillary component circuitry. AlSiC-10 is designed for heat sink lids that are attached to higher CTE materials such as printed circuit boards.

AlSiC Housing Fabrication: Cost-Effective Manufacturing Process

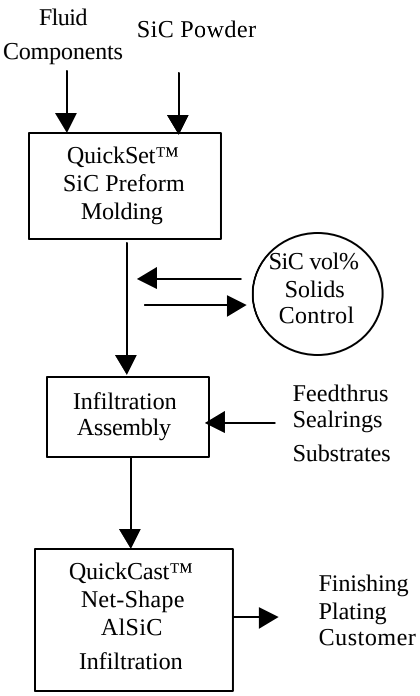

Figure 2 Ceramics Process Systems Corp. QuickSet™/QuickCast™ AlSiC Process Flow

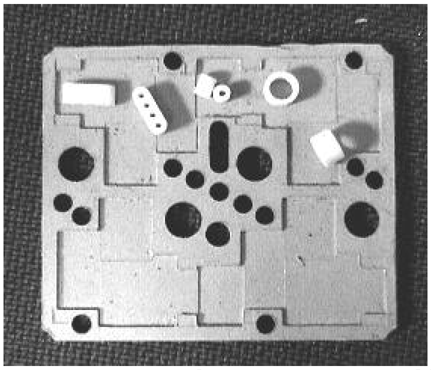

Figure 3 Porous QuickSet™ Injection Molded SiC HDI microwave MCM Preform with Ceramic Ferrules for Concurrent Integration™.

The CPS QuickSet™/QuickCast™ AlSiC fabrication process is outlined in Figure 2. The process consists of first fabricating a porous SiC particulate preform using the QuickSet™ Injection molding process. The preform has the exact geometrical features of the final housing with dimensional tolerances held typically to +/- 0.001 inches [0.025 mm]. The SiC particulates are uniformly distributed in the preform which when infiltrated, results in a uniform composite microstructure. The SiC particulate concentration is also controlled by the injection molding process, and is held to +/- 0.5-vol%. By controlling the preform solids concentration the Al/SiC ratio of the final housing is controlled to maintain a reproducible CTE behavior^{7}.

SiC preforms are assembled into inexpensive and reusable infiltration mold tooling. Functional components can also be assembled in this tooling with the SiC preform for Concurrent Integration™ ^{5}. Figure 3 shows a SiC preform with ceramic ferrules for coaxial feedthru integration into a High-Density Interconnect (HDI) microwave MCM package. The infiltration tooling has the exact dimensions and tolerances of the final product. Using pressure assistance, molten Al-metal (typical casting alloys) are forced into the pore structure of the SiC preform to form a dense hermetic composite material in the desired product shape geometry. Figure 4 shows the finished Ni-Au metallized HDI microwave MCM with Concurrently Integrated™ feedthrus. Figure 5 shows an optical micrograph of a polished AlSiC-9 cross-section.

The combination of inexpensive raw materials (SiC and Al-metal) and a simple robust

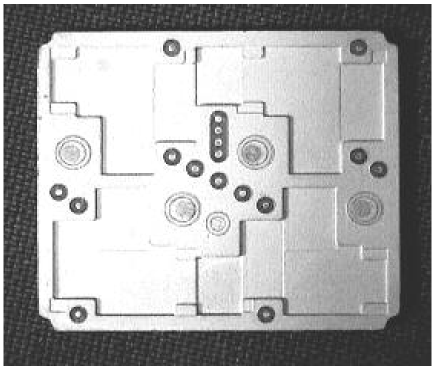

Figure 4 QuickCast™ Infiltrated and Concurrently Integrated™ HDI microwave MCM with Ni-Au plating.

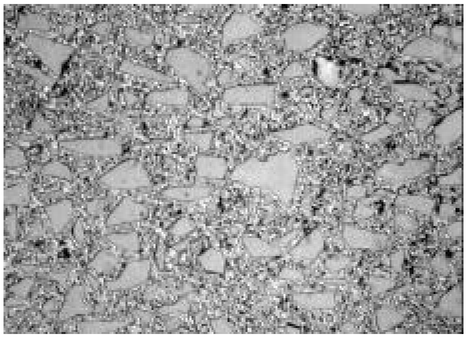

Figure 5 AlSiC microstructure with the discrete SiC particles in dark contrast and the continuous Al-metal phase in bright contrast.

net-shape fabrication processing technology yield thermal management packages that are cost competitive with traditional machined housings. Additionally, the added functionality and value of Concurrently Integrated™ components eliminates the need for subsequent assembly processes. The CPS AlSiC fabrication process is rapid. The typical processing cycle from the point of SiC preform fabrication to final infiltrated and finished part is two days.

After packaging fabrication, AlSiC packages can be surface treated for component assembly with Ni, Ni-Au plating, Cu-flame spray coatings, and anodization processes. Typical Au-Ge, Au-Sn, Pb-Sn brazing and soldering assembly processing can be used for die and circuitry attachment. Aside from the Concurrent Integration™ process, sealrings including Alloy 46, 52, Titanium, Explosion Clad Materials, multi-pin headers and feedthrus may be conventionally attached.

Cost Effective Manufacturing with Enabling Functionality

The microwave MCM package shown in Figures 3 and 4 illustrates the functionality of the CPS AlSiC packaging fabrication process which enables new component assembly technologies such as HDI. HDI is a chips first MCM technology where the bare die are placed into package cavities that have precise depths such that the tops of the assembled devices are coplanar with the surrounding package. The package and die are laminated with a polyimide in which vias are drilled to the die pads and substrate. The laminate and vias are then sputtered, and patterned. Lamination, sputtering and patterning is repeated as necessary to build the desired multi-layer plated via circuitry[3].

This AlSiC packaging offers several advantages, aside from the thermal management properties, over traditional electronic packaging materials. The QuickSet™/QuickCast™ net-shape fabrication process allows for very precisely depth cavities. Tolerances of these cavity depths were held to +/- 0.001 inches [0.025 mm] enabling the repeatable coplanar assembly of devices with the surrounding substrate. The net-shape AlSiC packaging provides a much more cost-effective package over traditional packaging materials that required expensive machining to provide these same geometrical features.

Additionally, the AlSiC packages also provide a higher level of integration with feedthrus and sealrings as compared to traditional packaging schemes that require subsequent assembly of discrete components. The planarity of the feedthrus in this assembly allows for direct HDI interconnection to the circuit, eliminating the need for wire or ribbon bond connection and providing a more robust and cost-effective integration[3].

Dense ceramic ferrules (alumina, silicon carbide, silicon nitride, or zirconia) are assembled with SiC preform in the infiltration tooling. During infiltration these ferrules are Concurrently Integrated™ within the package to form coaxial feedthrus, like that shown in the HDI microwave MCM example. The dense ceramic provides dielectric isolation from the infiltrated inner diameter of the ferrule that provides the electrical conduction path. These integral feedthrus are hermetic to a He-leak rate of $< 10^{-9}$ cc/s following multiple liquid-to-liquid thermal cycles between –50 and 150°C. In this module the cavity depths are controlled to the top plane of the substrate to +/- 0.0005 inches [0.013 mm]. The substrate is Ni-Au plated for soldering and brazing operations.

AlSiC Products and Applications

Figure 6 shows AlSiC microwave package for an airborne application. This product illustrates AlSiC functionality with traditional Ni-Au plating process and the subsequent assembly to integrate a 30-pin header, coaxial feedthrus and Fe-Ni alloy sealring. The 0.030 inch [0.76 mm] wide internal walls provided EMI/RFI shielding between the transmit and receive circuitry. The sealring was used to attach a lid by laser sealing to provide a hermetic package. This AlSiC package represents a significant weight savings over the Kovar product that it replaced in addition to providing the high thermal conductivity for thermal management.

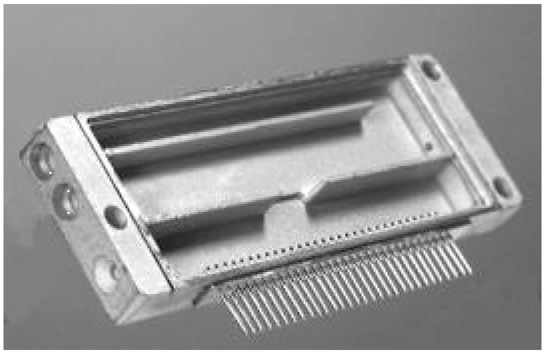

Figure 6 Ni-Au plated AlSiC microwave package assembled with coaxial feedthrus and 30-pin header and Fe-Ni Alloy sealring.

Figure 7 shows a Ni-plated AlSiC power substrate for a commercial microwave communication application. This product has numerous through-hole features and threaded holes that were held to +/- 0.002 [+/- 0.05mm] positional tolerance.

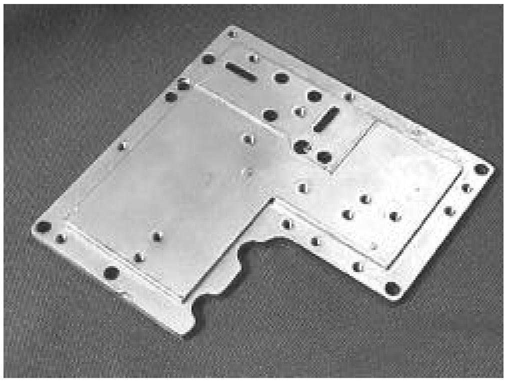

Figure 7: Ni-plated AlSiC Power Substrate for commercial communications application.

This AlSiC product replaced the machined Alloy-46 and/or stainless steel material that was initially specified. The primary reasons for this replacement were Alloy 46 material availability and the difficulty in machining stainless steel. Additionally, poor assembly yields and poor "in-service" reliability were realized as a result of the high stainless steel CTE value.

The introduction of AlSiC provided a lower cost material and a product solution. The AlSiC raw materials are inexpensive and readily available. The need for costly machining was eliminated by virtue of CPS net-shape forming process. Most importantly, the AlSiC material provided the desired CTE behavior to allow for high yield assembly and improvements the "in-service" product reliability. The AlSiC product replacement represented a significant cost savings to the customer.

Figure 8 illustrates the exceptional geometrical forming capability of the QuickSet™/QuickCast™ process. This product is approximately 4 inch [100 mm] wide and 7 inch [175 mm] long and has areas of thin 0.015 inch [0.38 mm] to thick 0.4 inch [10 mm] cross sectional thickness. The seven 1.5 inch [38 mm] long by 0.3 inch [7.6 mm] high walls in the center of the part are 0.032 inch [0.81 mm] wide and represent a feature that cannot be inexpensively fabricated in a machined housing. The wall features provide EMI/RFI shielding for the attached circuitry.

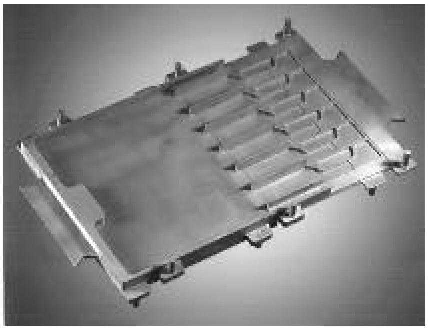

Figure 8: Large AlSiC housing with fine thin walls.

Summary

From a materials perspective CPS AlSiC is ideally suited to the requirements for today's microelectronics. AlSiC has IC compatible CTE value(s) and a high thermal conductivity value allowing for maximum thermal dissipation through direct device attachment. AlSiC is also a lightweight packaging material that makes it suitable for weight sensitive applications such as in portable and airborne devices.

Additionally, the unique AlSiC material/component fabrication is a low-cost process to fabricate functional electronic packaging to net-shape. Net-shape fabrication eliminates the need for expensive machining. Furthermore, the AlSiC material/packaging fabrication process allows additional utility with Concurrent Integration™ of functional components such as feedthrus, sealrings, and dielectric substrates. The Concurrent Integration™ of functional components eliminates the need for yield limiting assembly operations and adds increased performance and reliability to the electronics package.

The significant process and material advancements of AlSiC in past years has gained the acceptance of AlSiC heat sinks, packages and substrates in both military and commercial applications. The increased demand for AlSiC packages and materials have resulted in continual process improvements resulting in increased production rates. As a result, AlSiC electronic packaging has become a low-cost product as a function of this economy of scale. Product designs in AlSiC are cost competitive and offer significant performance value as is illustrated by the product examples given in this paper.

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