Cost-Effective Manufacturing Of Aluminum Silicon Carbide (AlSiC) Electronic Packages

Mark A. Occhionero, Robert A. Hay,
Richard W. Adams, and Kevin P. Fennessy
Ceramics Process Systems Corp.
111 South Worcester Street
Chartley, MA 02712
Phone (508) 222-0617; Fax (508) 222-0220
http://www.alsic.com
marko@alsic.com, rhay@alsic.com,

Abstract

Today's microelectronics place ever increasing demands on the performance of electronic packaging materials and systems in terms of thermal management, weight, and functionality requirements. These requirements have pushed the development of new materials and processing technologies to provide high performance packaging solutions cost-effectively.

Aluminum Silicon Carbide (AlSiC) metal matrix composite (MMC) packages have a unique set of material properties that are ideally suited to the above requirements. The AlSiC coefficient of thermal expansion (CTE) value is compatible with direct IC device attachment allowing for the maximum thermal dissipation into the high thermal conductivity (170 – 200 W/mK) AlSiC package. Additionally, the low material density of AlSiC (3 g/cm^3) makes it ideal for weight sensitive applications.

The Ceramics Process Systems (CPS) AlSiC fabrication and processing technology provides both the material and the net-shape functional packaging geometry in one process step. This processing technology also allows the Concurrent Integration™ of feedthrus, seal rings and substrates, which eliminates the need for additional assembly operations. These manufacturing attributes allow AlSiC packaging to be cost competitive and offer performance advantages over competing packaging products/systems.

The AlSiC packaging design process and manufacturing process will be outlined through actual product example.

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

Introduction

The dilemma faced by 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 a packaging solutions with desired thermal management performance, improved and new functionalities,

at a competitive cost (often a lower cost) over traditional packages[4].

From a materials properties perspective, the combination of 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 in contrast to traditional packaging materials (Ni-Fe allows, CuMo, CuW).

From a manufacturing cost consideration 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 ability to fabricate both package geometry and material is termed "net-shape" fabrication. This net-shape fabrication processing technique allows for the assembly of functional components such as sealrings, feedthrus and substrate during processing fabrication. This assembly during fabrication, termed Concurrent Integration™, eliminates the need for subsequent brazing and soldering processing operations reducing the total packaging cost[5].

This paper will review the AlSiC material properties in contrast to traditional packaging materials. The CPS AlSiC QuickSet™/QuickCast™ process will also be examined to illustrate how design and functionality can be processed into electronic packaging cost-effectively. Product examples will be used for concept illustrations.

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.

Often marginally compatible stress

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**	**N/A**	**N/A**
AlSiC-8	**Packaging**	**3.0**	**7.63***	**180**	**N/A**	**207**
AlSiC-9	**Packaging**	**3.0**	**8.26***	**180**	**450**	**175**
AlSiC-10	**Packaging**	**3.00**	**9.89***	**165**	**N/A**	**N/A**
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

compensating layers are used to reduce these stresses between IC and heatsink material. For example Cu and Al have high thermal conductivity values making them ideal heatsinks. However Cu and Al also have high CTE values that require a thermal stress compensating material between the attached IC device. Alumina substrates with a marginally compatible CTE value are commonly used as this stress-compensating layer. Any thermal dissipation advantage from these Cu or Al heatsink materials is lost due to the thermally resistant alumina. Component reliability also becomes an issue as the consequence of the marginal CTE compensation in the form of delamination or cracking of the stress compensating substrates and/or the IC devices.

Traditional packaging materials such as Fe-Ni alloys like Kovar offer CTE values that are compatible with IC and substrate materials but offer no thermal dissipation advantage due to their low thermal conductivity. Materials like CuW and CuMo offer both CTE compatibility and high thermal conductivity values however the high material density makes them inappropriate choices for weight sensitive devices. Additionally production costs for CuMo and CuW packages are expensive for all but simple thin cross section geometrical shapes. This simple geometry limitation results in the requirement for additional processing steps and assembly operations to obtain functional packaging designs.

The Aluminum Silicon Carbide (AlSiC) material system offers the packaging designer a unique set of material properties that are suited to high performance advanced thermal management packaging designs. AlSiC is a composite material of Al-metal and SiC particulate. Thermal conductivity values for AlSiC materials are similar to Al-metal and the AlSiC CTE value(s) are compatible with direct device attachment.

Furthermore, AlSiC CTE can be designed to fit the behavior required for the specific application. Changing of the Al/SiC ratio and/or the Al-metal composition can modify the CTE. The range of CTE behaviors for CPS AlSiC materials is illustrated graphically in Figure 1 in terms of instantaneous CTE* as a function of temperature. CPS AlSiC CTE

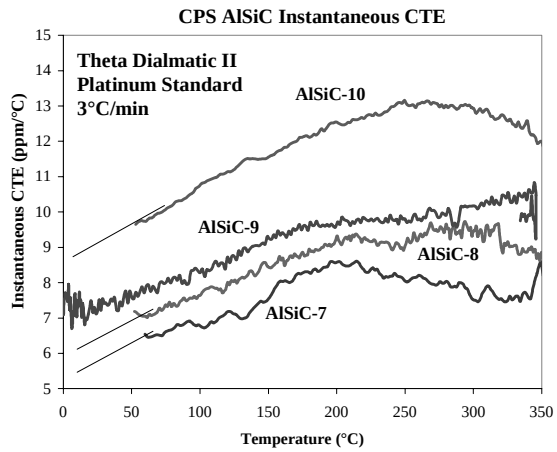

Figure 1. Ceramics Process Systems AlSiC Instantaneous CTE Behavior as a Function of Temperature and CTE Formulation.

formulations AlSiC–7 and –8 are ideal substrate choices for Si device attachment since these IC devices have a lower CTE value. AlSiC-9 is an ideal choice for 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 required to be attached to higher CTE materials such as printed circuit boards.

AlSiC Housing Fabrication: Cost-Effective Manufacturing Process

The CPS QuickSet™/QuickCast™ AlSiC fabrication process is outlined in Figure 2.

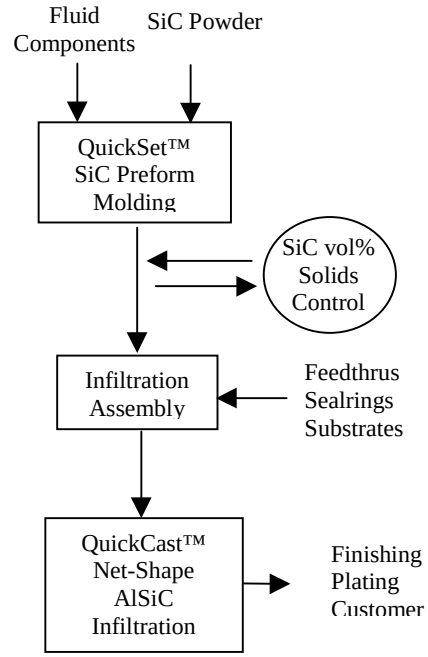

Figure 2 Ceramics Process Systems Corp. QuickSet™/QuickCast™ AlSiC Process Flow

* 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).

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. The SiC particulate 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[8].

SiC preforms are assembled into inexpensive and reusable infiltration mold tooling. Additionally, other functional components can be assembled into the infiltration tooling with the SiC preform for Concurrent Integration™ [9]. 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.

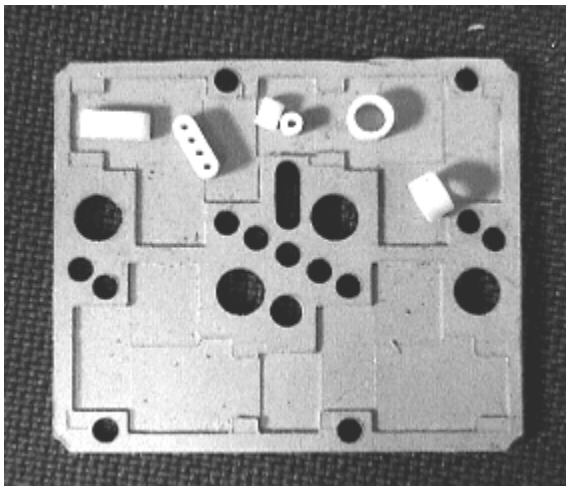

Figure 3 Porous QuickSet™ Injection Molded SiC HDI microwave MCM Preform with Ceramic Ferrules for Concurrent Integration™.

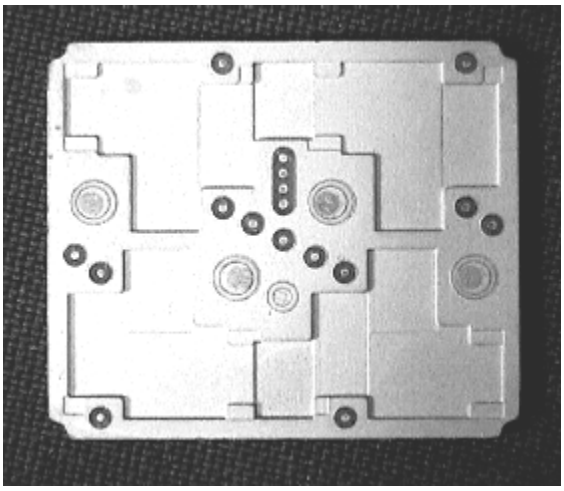

Figure 4 QuickCast™ Infiltrated and Concurrently Integrated™ HDI microwave MCM with Ni-Au plating.

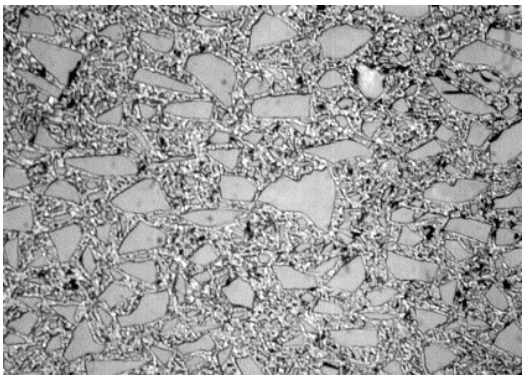

Figure 5 AlSiC microstructure with the discrete SiC particles in dark contrast and the continuous Al-metal phase in bright contrast.

The combination of inexpensive raw materials (SiC and Al-metal) and a simple robust 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 processing steps. 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 attached conventionally.

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 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 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 integrated (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. The substrate is Ni-Au plated for soldering and brazing operations[11].

AlSiC Carrier Plate Substrate

Figure 6 shows an AlSiC carrier substrate that replaced a machined Cu-carrier substrate. The substitution of the net-shaped AlSiC carrier plate was cost-competitive with the machined Cu-metal component and resulted in improvements in thermal dissipation, component reliability, weight savings and space economy.

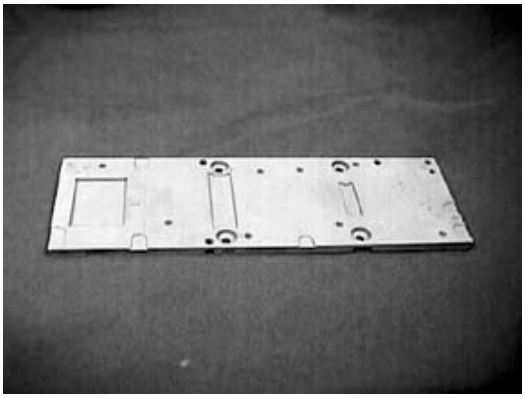

Figure 6 Net-Shape AlSiC Carrier Plate. Replaces machined Cu.

In the Cu-carrier plate, heat-generating devices were mounted on alumina substrates for stress compensation. These alumina substrates in this assembly often crack when in service, causing a failure of the component and device.

Additionally, for the Cu-carrier it was necessary to mount all supporting electronics on multiple small discrete alumina substrates. The substrate size was kept small to minimize the overall thermally induced stress and prevent substrate cracking and failure of supporting electronics.

Substituting AlSiC for the copper eliminates the need for the CTE compensating substrates between the IC device and carrier plate allowing for direct device attachment. Improved thermal dissipation was realized with AlSiC versus Cu-metal since the thermal resistant barrier was eliminated, the component/system reliability increased.

Additionally, since the alumina CTE is compatible with AlSiC, all supporting electronics could be packaged on one alumina substrate in comparison to the many small discrete substrates required with Cu-carriers. As a result the total component size was reduced by nearly a third. Figure 7 shows the reduced size carrier substrate contrasted to the original. Size reduction results in more economical use of space and an AlSiC component cost reduction.

Packaging all supporting electronics on one alumina substrate simplifies assembly and the component reliability resulting in the attachment of only one substrate versus multiple discrete substrates and the need for interconnections between components.

The resulting AlSiC component weight was reduced to one-ninth of the original component weight, which is a result of the one-third reduction in the component size, and the lower density of AlSiC[4].

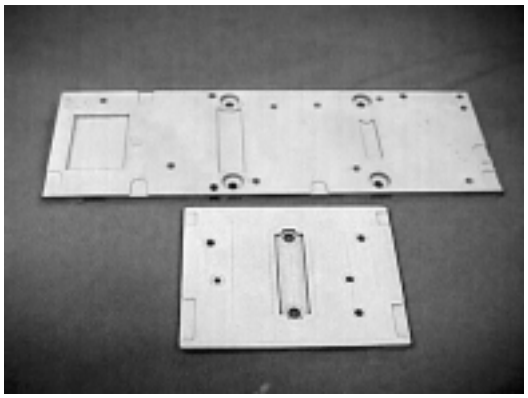

Figure 7 New AlSiC carrier plate in foreground contrasted to original design.

Summary

From a materials perspective 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 can be used to Concurrently Integrate™ 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 consequence, 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 examples given in this paper.

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