

Aluminum Silicon Carbide (AlSiC) for Thermal Management Solutions and Functional Packaging Designs

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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. 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). Additionally, the low material density of AlSiC makes it ideal for weight sensitive applications such as portable devices.

The AlSiC material and functional electronic packaging geometries are produced using Ceramics Process Systems Corporation's QuickSet™/QuickCast™ net-shape (without machining) fabrication process. Additionally, functional packaging features such as feedthrus, sealrings and 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 AlSiC fabrication process provides low-cost high performance functional thermal management packaging solutions. This paper will review the material properties of AlSiC 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

Heat dissipation is an ever-increasing requirement for packaging today's microelectronic systems. Maximum heat dissipation is achieved by the direct attachment of the heat-generating device to the heat-sinking material. Direct device attachment requires that the coefficient of thermal expansion (hereafter CTE) of the heat-sinking material be compatible with the heat-generating device(s). A compatible CTE value will allow the device and heat-sinking material to expand at similar rates thus avoiding thermally induced stress that can result in device fracture and failure or thermal interface fracture and subsequent device failure.

Traditional thermal dissipation materials like Cu- and Al-metal have CTE values that are much higher than IC devices and do not allow reliable direct device attachment. To compensate for the CTE difference IC devices are mounted on marginally compatible stress-compensating interface materials that reduce stress between the heat-generating device and the heat-sinking material. Traditionally these stress-compensating layers give

rise to a thermal resistance barrier between the IC and heat sink. Any thermal management advantage provided by the high thermal conductivity of these materials is lost as a consequence.

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 performance. 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^{1,2}. 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 has a high thermal conductivity and compatible CTE permitting direct IC device attachment. AlSiC is also lightweight, making it appropriate for portable designs and other weight sensitive applications.

The AlSiC material/fabrication process provides two significant advantages over traditional packaging materials. The first advantage is that packages are fabricated to net-shape during material processing using the Ceramics Process Systems Corp. (CPS) QuickSet™/QuickCast™ approach. Net-shape fabrication offers the designer flexibility to develop complex tight tolerance package geometries eliminating the need for costly machining. The second advantage is that functional components such as feedthrus, sealrings, and substrates can be hermetically integrated in packages during AlSiC processing^{3,4}. This single step process, termed Concurrent Integration™, eliminates the need for subsequent integration operations such as brazing and soldering which can be yield limiting. Net-shape fabrication and Concurrent Integration™, coupled with high thermal conductivity, compatible CTE, and low material density are technology enabling attributes of AlSiC that offer low-cost design opportunities for the packaging engineer⁵.

This paper will describe the AlSiC composite material fabrication process. The AlSiC composite material properties will be compared to traditional electronic packaging materials. Component development case studies will illustrate how the unique set of AlSiC composite material properties and the CPS AlSiC fabrication process offer a performance advantage as well as low-cost packaging solutions over traditional packaging materials.

Processing Description

The Ceramics Process Systems AlSiC fabrication process consists of fabricating a preform with a controlled SiC particulate content using the QuickSet™ injection molding process. The resulting preforms are fabricated with the same features and the same dimensional tolerance of the final product. The SiC preform is inserted into precisely fabricated low-cost tooling and is infiltrated with molten Al-metal using pressure. Figure 1 shows a SiC preform and the infiltrated product for a microwave electronic package (detailed product description in following section). The molten metal infiltrates the porous SiC preform completely to form a dense composite of discrete SiC particulate in a continuous Al-metal matrix shown in Figure 2. This dense microstructure yields a hermetic material which has He leak rates that are better than 10^{-9} atm cc/s as measured on 0.010-inch material cross sections. This hermeticity



Figure 1 SiC preform (L) and AlSiC infiltrated (R) product for microwave electronic package.

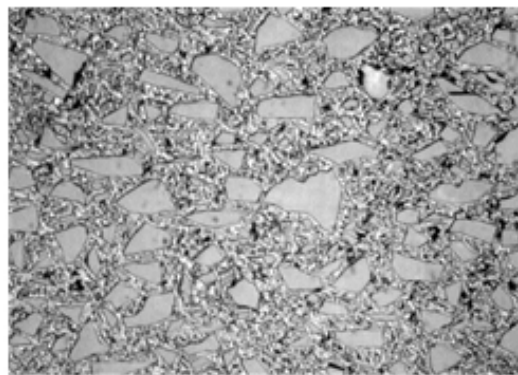


Figure 2 AlSiC microstructure with the discrete SiC particles in dark contrast and the continuous Al-metal phase in bright contrast.

level allows fabricated AlSiC packages to provide environmental protection of enclosed components.

The unique AlSiC material properties result from a combination of the constituent material properties; AlSiC properties are tailored by varying the ratio of these constituents. The IC CTE compatible AlSiC compositions have a SiC particulate content between 60 - 70 vol%. Table 1 compares the material properties of AlSiC to Si, GaAs and traditional packaging materials.

AlSiC composite materials have thermal conductivity values that are similar to aluminum metal, and CTE values that are similar to alumina. These attributes make AlSiC packages ideal for direct active device attachment to maximize thermal dissipation and improve product reliability.

AlSiC strength and stiffness compare favorably to traditional packaging materials. The ultimate bending strength of AlSiC is two to three times greater than Al-metal. The AlSiC Young's modulus - a measure of a material's stiffness - is

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

Material	Density (g/cm ³)	CTE ppm/° (25-150°C)	Thermal Conductivity (W/mK)	Bend Strength (MPa)	Young's Modulus (GPa)
Si	2.3	4.2	151		112
GaAs	5.23	6.5	54		
AlSiC (63v% SiC)	3.0	7.5	170 - 200	450	175
Kovar (Ni-Fe)	8.1	5.2	11 - 17		131
CuW (10-20% Cu)	15.7 - 17.0	6.5 - 8.3	180 - 200	1172	367
CuMo (15-20% Mo)	10	7 - 8	160 - 170		313
Cu	8.96	17.8	398	330	131
Al	2.7	23.6	238	137-200	68
SiC	3.2	2.7	200 - 270	450	415
AlN	3.3	4.5	170 - 200	300	310
Alumina	3.98	6.5	20 - 30	300	350
Beryllia	3.9	7.6	250	250	345

three times greater than Al-metal, and two times greater than Cu-metal. The high stiffness to low density ratio is structurally desirable for larger parts with thin cross sections. This attribute permits designs to incorporate feature like fins to maximize cooling surface area.

The close dimensional match between preform and infiltrated product, illustrated in Figure 1, result in a controlled Al-metal skin thickness. Figure 3 shows an AlSiC housing surface cross section illustrating the Al-metal skin thickness, and the Ni and Au plating thickness. The close tolerance and minimization of the Al-metal skin thickness results in a surface CTE value that is the same as the bulk material CTE value.

Case Study 1: AlSiC Carrier Plate

Figure 4 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.

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

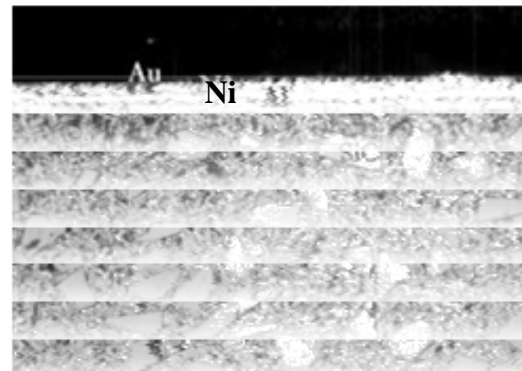


Figure 3 AlSiC surface cross section showing Al-metal surface layer and the Ni and Au metallization layers.

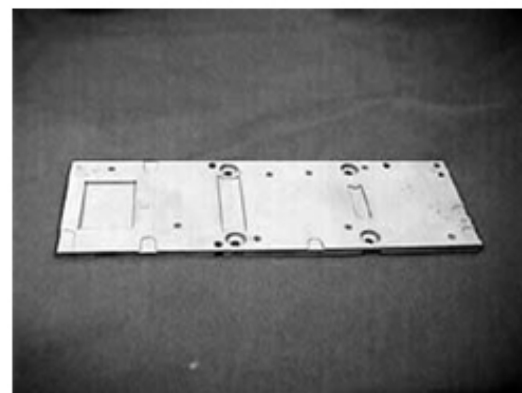


Figure 4 Net-Shape AlSiC Carrier Plate. Replaces machined Cu.

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 5 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.

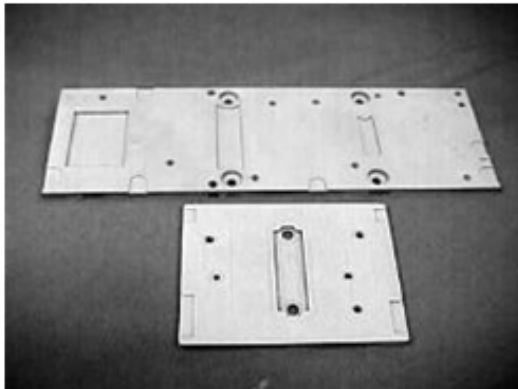


Figure 5 New AlSiC carrier plate in foreground contrasted to original design.

Packaging all supporting electronics on one alumina substrates 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.

Case Study 2: Microwave Housing

Figure 6 shows an AlSiC microwave electronic package and the AlSiC package that was plated, integrated and assembled and sealed using traditional processing operations. This package was also shown in Figure 1 illustrating the close dimensional similarity of the preform with respect to

the final infiltrated product and the net-shape forming capability of the CPS QuickSet™/QuickCast™ AlSiC fabrication process. The key requirement for this package besides thermal management was that this package be lightweight for its' airborne application.



Figure 6 Ni-Au Plated AlSiC microwave package (L), and integrated, assembled, and sealed package (R).

This package is roughly 2 inches long x 0.75 inches wide and approximately 0.250 inches high. The package base is approximately 0.050 inches thick with 0.020-inch steps. The internal walls are provided for EMI/RFI shielding between electronic components within the package; walls are approximately 0.200 inch high and 0.030 thick. An added feature to this product is a drilled and tapped hole for gas purging after assembly and sealing. This port shown in the closer detail in Figure 7 was drilled and tapped into the AlSiC package after infiltration. This machined region of the package was in pure Al-metal to make drilling and tapping simple and inexpensive. Infiltrating a hole in the SiC preform provided the pure Al-metal region for machining.



Figure 7 Microwave package close-up of drilled and tapped gas purge port (R). The left two ports are co-axial feedthrus.

The package was Ni-Au plated to allow for a Au-Ge braze assembly. Assembled components include a 30-pin header, co-axial feedthrus, and the brazing of a Ni-Fe alloy sealring. After integration, the lid was laser sealed to the Ni-Fe sealring.

This AlSiC product demonstrates the sophistication of net-shape AlSiC material/package fabrication technology today and the integration of this material into traditional microwave packaging assembly operations.

Case Study 3: IGBT Base

Figure 8 shows an AlSiC IGBT base that has a Concurrently Integrated™ and metallized high thermal conductivity AlN substrate.



Figure 8 AlN substrate (L) and AlSiC IGBT base with Concurrently Integrated™ and metallized AlN (R).

Functional components, such as feedthrus, sealrings^{8,9}, and substrates can be incorporated into AlSiC packages by processing these components with the SiC preforms during the Al-metal infiltration process. This technique, termed Concurrent Integration™, hermetically bonds functional components in one process step, and eliminates the need for potentially yield limiting brazing and soldering assembly operations.

In the example given not only is the AlN (dielectric) substrate incorporated in the AlSiC housing, but also the substrate surface metallization (Al-metal) that allows for electrical interconnection is applied. The Al-metal surface metallization pattern on the AlN substrate is formed by a pattern in the infiltration tooling. Aluminum oxide, zirconia, alumina-zirconia, silicon carbide, diamond-coated silicon carbide and CVD diamond substrates can also be incorporated in AlSiC components.

This product replaces a machined Cu-housing with a direct bonded copper (DBC) and metallized alumina substrate assembly. The AlSiC product represents a significant performance and cost

advantage over the Cu-housing alternative since it provides a net-shape, completely assembled product in one fabrication step.

The AlSiC/AlN housing represents a significant performance and reliability advantage over the Cu-DBC substrate product as well. The AlSiC/AlN component passed thermal fatigue testing between -50° and 150°C for over 1000 cycles without catastrophic failure. The Cu-DBC alumina package failed typically in less than 100 cycles.

Conclusions

The AlSiC material properties are 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/package 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 three examples given in this paper.

References

- [1] R.W. Adams, B.E. Novich, D.Kane, K. Brantferger, R.Oberle and S.Chai, "A Lightweight High Thermal Conductivity Metal Matrix Composite Microwave Module Package For Airborne Applications," Proceedings of Government Microcircuit Applications Conference (GOMAC), Digest of Papers , Vol. 20, pp 454-456 November 1994.

[2] B.E. Novich and R.W. Adams, "Design and Fabrication of Metal Matrix Composites for Microwave and Millimeter Wave Integrated Circuit Packages," Proceedings of 1994 International Symposium on Microelectronics, ISHM Boston, MA November 15-17, 1994, pp 590-595.

[3] R.W. Adams, B.E. Novich and K.P. Fennessy, "Concurrent IntegrationTM of Al/SiC MMIC Packages," Proceedings of the 1995 International Symposium on Microelectronics, ISHM, Los Angeles CA, October 1995, pp 36-41.

[4] B.E. Novich, R.W. Adams, and M.A. Occhionero, "low Cost MCM-D Cavity Substrates for Packaging High Density Si and GaAs Devices," Proceedings of the 10th European Microelectronics Conference, ISHM, Copenhagen, Denmark, May 14-17, 1995, pp 475-481.

[5] R.W. Adams, M.A. Occhionero, and K.P. Fennessy, "CTE Compatible Thermal Packaging Solutions - Net-Shape Fabricated AlSiC and AlN," Proceedings of the Third Annual Portable by Design Conference, Electronic Design, March 25-29, 1996, pp 527-536.

[6] B.E. Novich and R.W. Adams, "Aluminum/Silicon Carbide (AlSiC) Metal Matrix Composites For Advanced Packaging Applications," Proceedings of the 1995 International Electronics Packaging Conference, IEPS, San Diego CA, September 24-27, 1995, pp 220-227.

[7] B.E. Novich, R.W. Adams, and K.P. Fennessy, "Metal Matrix Composites for Single Chip and Multichip Microprocessor Packaging," Proceedings of the 1995 International Electronics Packaging Conference, IEPS, San Diego CA, September 24-27, 1995.

[8] B.Dufour, M. McNulty, and S.Miller, "Microwave Multichip Module Utilizing Aluminum Silicon Carbide With In-Situ Cast Components and High Density Interconnect Technology," International Journal of Microcircuits and Electronics Packaging, Vol 20, [3], pp 303 - 308, IMAPS, (1997).

[9] J.A. Reddick III et al, "High Density Microwave Packaging Program - Phase 1 Texas Instruments/Martin-Marietta Team", Proceedings of the IEEE MTT-S 1995 International Microwave Symposium, IEEE., Orlando, FL, May 14-19, 1995, Vol 1, pp 173-176.