Proceedings of the Forth Annual Portable by Design Conference,
Electronics Design, March 24-27, pp 398-403

A NEW SUBSTATE FOR ELECTRONICS PACKAGING: ALUMINUM-SILICON CARBIDE (AlSiC) COMPOSITES

Mark Occhionero, Richard Adams, and Kevin Fennessy

Ceramics Process Systems, Corp.

Chartley, MA 02712

Abstract

AlSiC is an ideal packaging material for today's high power density Si and GaAs chips. AlSiC's unique set of material properties includes a high thermal conductivity and IC device compatible coefficient of thermal expansion (CTE) that permits direct device attachment for maximum thermal dissipation. The low material density of AlSiC is ideal for weight sensitive applications such as portable devices. This paper reviews the AlSiC material properties contrasted with the material properties of traditional electronic heat sinking materials.

Introduction

Maximum heat dissipation is a requirement for today's higher power GaAs and Si integrated circuit devices. The maximum heat dissipation is achieved by mounting active devices directly to high thermal conductivity heat sinking substrates or packages. Direct attachment requires a compatible coefficient of thermal expansion (CTE) value of the heat sink material to avoid stress failure of the IC device.

Traditional thermal dissipation materials like copper and aluminum have CTE values that are much greater than IC devices. To compensate, the IC device is mounted on a stress reducing interface material with a marginally compatible CTE to the heat-sinking device. Interface materials, such as highly thermally resistive alumina substrates, result in a thermal dissipation penalty.

The Fe-Ni alloy packaging materials like Kovar have compatible CTE values but offer no thermal dissipation advantage due to low thermal conductivity values. Although CuMo and CuW packaging materials have high thermal conductivity and compatible CTE values, these materials have high densities that make them inappropriate for weight sensitive applications such as portable devices[1,2].

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 light weight, making it appropriate for portable designs and other weight sensitive applications.

Additionally, the AlSiC material and process system have two significant advantages over traditional packaging materials. The first is that packages can be fabricated to net-shape during material processing. Net-shape fabrication offers the designer flexibility to develop complex tight tolerance package geometries without the need to machine these features. Secondly, 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 thermal conductivity, compatible CTE , and low material density are technology enabling attributes of AlSiC that create improvements in design opportunities for the packaging engineer[5].

AlSiC Composite Material System

The AlSiC material is fabricated by pressure infiltration of molten aluminum metal into a SiC particulate preform. The SiC preform and the infiltration tooling incorporate all the features of the final product allowing for the net-shape package fabrication[5,6,7]. Figure 1 displays a SiC lid preform with the corresponding Ni-Au plated AlSiC lid and ceramic feedthrus. The ceramic feedthrus were integrated in this lid during the infiltration process using the Concurrent Integration™ technique that is discussed later in this text.

The AlSiC microstructure is composed of a continuous Al-metal phase with discrete SiC particulate phase, as shown in Figure 2. The AlSiC composite microstructure is fully dense with no void space creating a hermetic material; He leak rates are better than 10-9 atm cc/s measured on 0.010 inch material cross sections. This hermeticity level allows fabricated AlSiC packages to provide environmental protection of functional components.

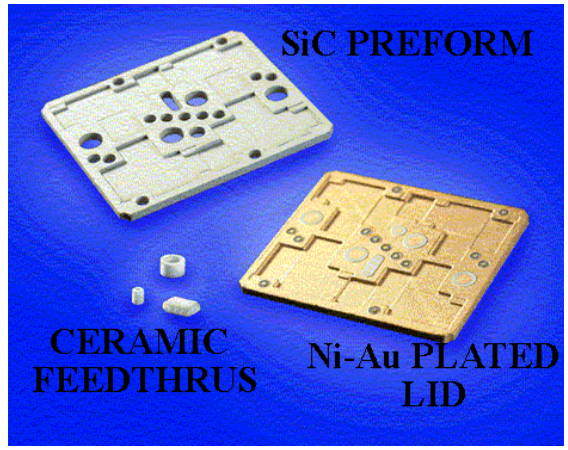


Figure 1. SiC Preform and Ni-Au Plated AlSiC Lid and Ceramic Feedthrus.

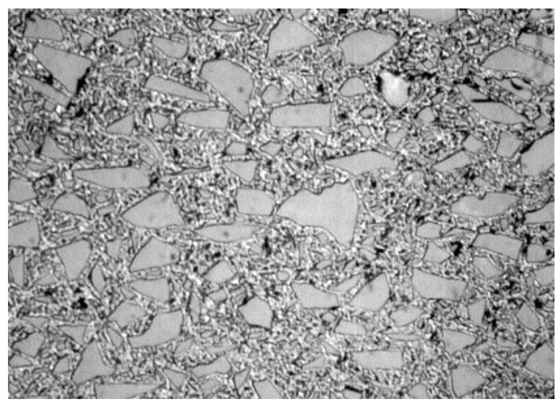


Figure 2. AlSiC Microstructure (SiC in dark contrast).

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 50-68 vol%. Table 1 compares the material properties of AlSiC to Si, GaAs and traditional packaging materials.

Proceedings of the Forth Annual Portable by Design Conference,
Electronics Design, March 24-27, pp 398-403

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

Material	Density g/cm^3	CTE ppm/° 25-150C	Thermal Conduct W/mK	Bend Strngth MPa	Young's Modulus GPa
Si	2.3	4.2	151		112
GaAs	5.23	6.5	54		
AlSiC (60v% SiC)	3.0	6.5 - 9	170 - 200	450	290
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

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.

Figure 3 displays graphically the AlSiC instantaneous CTE values between -50 and 350°C contrasted to alumina. The average CTE values for IC compatible AlSiC between room temperature and 150°C is 6.8 ppm/° which is marginally higher than 6.5 and 4.2 ppm/°, for GaAs and Si devices. This marginal CTE difference between AlSiC and the active devices is desirable and results in placing the IC chips in slight compression after attachment by brazing or soldering. These compressive forces reduce the risk of component cracking failure and increase product reliability.

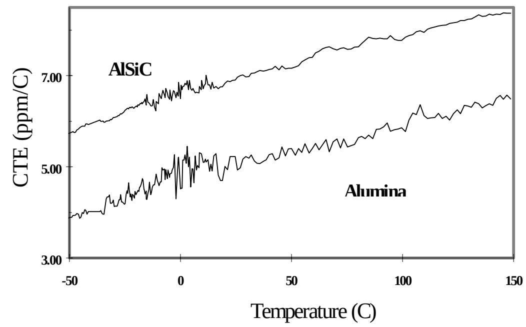
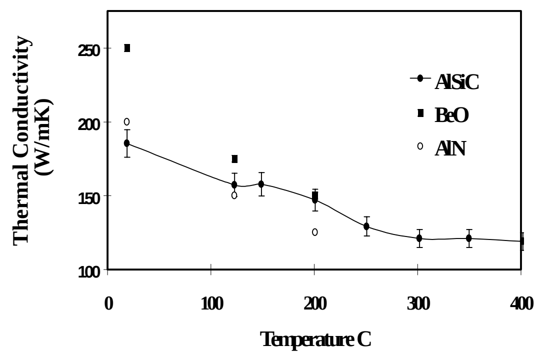


Figure 3. AlSiC Instantaneous CTE versus Temperature.

Thermal conductivity as a function of temperature from room temperature to 400°C for AlSiC is plotted in Figure 4. These data are compared with data for beryllia (BeO) and aluminum nitride (AlN) which are known high thermal conductivity substrate materials.



.

Figure 4. Thermal Conductivity Versus Temperature for AlSiC, AlN and BeO.

As shown in Figure 4 the thermal conductivity values of AlSiC and AlN are similar from room temperature to 150 °C. Above 150°C, AlSiC performs better than AlN for thermal dissipation with a slightly higher thermal conductivity value. At room temperature AlSiC thermal conductivity value is well below beryllia which has room temperature thermal conductivity values ranging from 215 to 300 W/mK. At elevated IC power chip operating temperatures BeO and AlSiC thermal conductivity values are comparable.

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

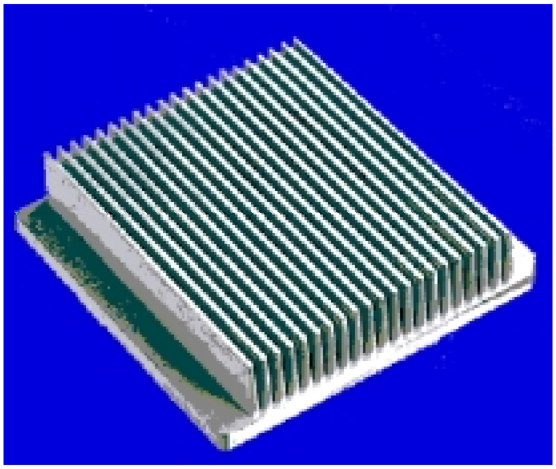


Figure 5. AlSiC BGA Lid with Integral Heat Sink Fins.

AlSiC Young's modulus - a measure of a material's stiffness - is three times greater than Al, and two times greater than Cu. 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. Figure 5 shows an AlSiC BGA lid with integral cooling fins.

AlSiC Plating and Integration

AlSiC packages and substrates can be plated using similar plating processes as traditional packaging materials including: Ni, Ni-Au, anodization and plasma flame spray coating. AlSiC packages can also be assembled with sealrings, feedthrus, and substrates using traditional low temperature eutectic brazing and soldering techniques. Figure 6 shows an Alloy-48 sealring and planar ceramic feedthrus that were brazed to an AlSiC housing.

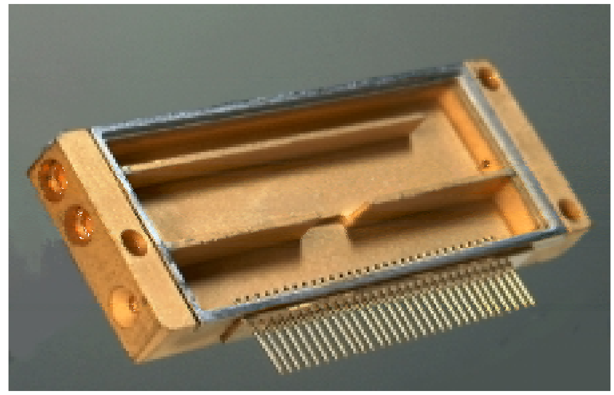


Figure 6. AlSiC housing with Brazed Seal Ring and 30 Pin Header Coaxial Feedthrus.

Sealrings, feedthrus, and substrates can be integrated in AlSiC packages during the fabrication process[3,4]. Concurrent Integration™ has the advantage of forming a hermetic seal between the functional component and AlSiC material in a single process step[6]. An example of Concurrent Integrated™ AlSiC housing is shown in Figure 7. In this housing a high thermal conductivity aluminum nitride substrate is captured in an AlSiC frame. In addition, electrical traces of aluminum metal were also incorporated on the AlN substrate surface during the infiltration process. The housing is Ni-plated to facilitate solder and wire bonding.

Figure 7. Concurrently Integrated™ AlSiC Housing with AlN substrate.

It is important to note that the great geometrical variety of AlSiC substrates, heat sinks and packages shown in the proceeding figures were fabricated to net-shape. Machined components from traditional packaging materials, which are usually provided in billet or sheet stock, would be costly[5].

Conclusions

AlSiC is an ideal packaging material for components and devices that require advanced thermal management performance. The low density of AlSiC makes it an appropriate choice for weight sensitive applications such as portable devices. Furthermore, net-shape fabrication, as well as Concurrent Integration™ processing offers significant design advantages over the traditional packaging materials. These attributes enable improvements in advanced packaging and thermal management designs that ultimately improve component reliability.

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. Product designs in AlSiC are cost competitive and offer significant performance value.

Acknowledgments:

The Authors would like to thank Professor D.P.H. Hasselman of Virginia Polytechnic Institute for Specific Heat and Thermal Diffusivity measurements. Additional thanks to Dr. James Forster of Texas Instruments for CTE measurements.

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.

Proceedings of the Forth Annual Portable by Design Conference, Electronics Design, March 24-27, pp 398-403

[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.