

AISiC for Optoelectronic Thermal Management and Packaging Designs

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Abstract

Aluminum silicon carbide (AISiC) metal matrix composite materials have gained acceptance in electronics packaging since 1992, providing reliable thermal management solutions for microwave, microelectronics, and power electronic applications. Attributes of high thermal conductivity (180 W/mK), thermal expansion matching capability, lightweight material density and the ability to fabricate packages to near net-shape make AISiC an ideal material to provide cost-effective thermal management solutions while improving reliability, as compared to other packaging materials.

Recently, AISiC components have been designed for the optoelectronics industry. Much like the microelectronics industry, the material attributes described above make AISiC an ideal material for improving optoelectronics module reliability.

This paper will discuss AISiC material and design attributes in terms of optoelectronic packaging thermal management and geometrical design needs. A product example for a thermoelectric cooler (TEC) with advanced heat spreading solution will be discussed.

Introduction

A major trend in optoelectronics packaging is for smaller, more efficient, and cost-effective packaging designs that improve device manufacturability and reliability. For improved reliability, the packaging designer must consider the mechanical and thermal behavior of the package materials set under two separate temperature regimes: module assembly and in service. Additionally, the designer must understand the packaging design tradeoffs that are required to meet customer cost and reliability needs. The designer must design a product that can be successfully manufactured while meeting customers' reliability requirements at a reasonable cost^[1].

Mechanical Design of Optoelectronic Packages

Mechanical design will determine the performance and reliability of a package during testing and also during exposure to its service environment. It is important to consider thermally-induced mechanical stresses from

For systems that are require to thermal cycle, the package material needs to have a high thermal conductivity value for effective heat

materials with different thermal expansion behaviors during the assembly operations such as brazing, soldering, welding, and epoxy joining. These thermally-induced mechanical stresses increase the failure probability of the device as well as failure probability of the package assembly that provides environmental protection for the module. By choosing materials that have compatible coefficients of thermal expansion (CTE), mechanical stresses are reduced and overall module reliability is improved^[2-4].

Thermal Design of Optoelectronic Packages

One must consider the application and operation of the optoelectronic module when designing the device package. Two types of optical module operating modes can be identified: 1) systems that are require to be reliable over multiple thermal cycles (on/off); and 2) module systems that require highly efficient thermal dissipation to maintain a constant uniform low temperature value (~-25-30°C).¹ dissipation¹ and a material CTE value that is compatible with the CTE value of the functional

¹ The authors recognize that the packaging heat dissipation for the module assembly is a function of: 1) Device power dissipation; 2) Physical size of the

device to reduce mechanical stresses during operation.

Copper has a high thermal conductivity for rapid heat dissipation, yet the CTE value (17ppm/°C) is not compatible with active device materials such as silicon (4 ppm/°C) and gallium arsenide (7 ppm/°C). Traditional solutions to the combination of a requirement for high thermal conductivity and compatible material CTE properties have included the application of thermal stress compensation layers between the active component and the package material; an example very typically is the use of an alumina substrate. However, these stress compensation layers have low thermal conductivity values and contribute to increase the thermal resistance of the assembly, decreasing heat dissipation capability for the module. Using high thermal conductivity copper may not therefore provide the thermal dissipation performance required meeting overall design objectives, because of the necessary stress compensation layers introduced. When the package and device CTE values are compatible, stress compensation layers can be reduced in number or eliminated, thereby decreasing the assembly thermal resistance and improving module heat dissipation capability and improving assembly and operation reliability.

In the case for laser diode substrates and packages the consideration is for a high thermal conductivity value and exceptional heat dissipation to maintain a fixed temperature of the die and improve the efficiency of the thermoelectric cooler (TEC). The function of the TEC is to maintain a fixed temperature of the die over a given operational ambient temperature range; the selection of the substrate and package material sets is intended to maximize the efficiency of the thermoelectric cooler and the ejection of heat from the module. These laser diodes are maintained at a fixed temperature, typically around 25°C; deviations from the fixed temperature result in signal losses and sub-optimal optical performance. CTE

active device; 3) Uniformity or non-uniformity of power distribution across the active device footprint; 4) Thermal conductivity values of each package material utilized; and, 5) Thermal resistance across the all interfaces including joining materials (solders, epoxies, etc.).

compatibility is not as important during normal device operation; it is a mechanical design consideration for reducing the thermally induced stresses that occur during module joining and assembly operations.

AlSiC processing capability offers advantages in providing cost-effective and functional package designs for optoelectronic modules. The CPS forming process casts the AlSiC composite to a final functional package shape to tight dimensional tolerances. These net-shape cast AlSiC components can typically be manufactured at lower cost than the traditional materials used for such modules: machined aluminum, copper, copper-molybdenum, copper-tungsten, or iron alloy 15 (Kovar).

Figure 1 illustrates as-cast features in very current optoelectronic package components. In general these packages have more complex geometries than processor and ASIC package lids, having pedestals for diode mounts and port features for optical inputs and outputs. It is key to note that all the features on this product are provided as cast, without machining. If machined, these features would make the product more expensive and constrain manufacturability at high volume.

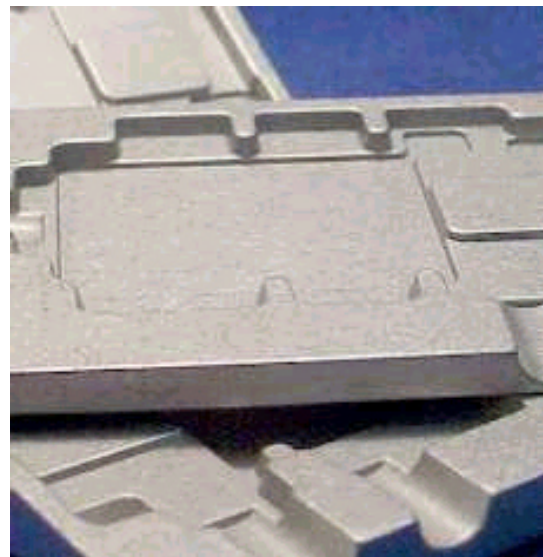


Figure 1: AlSiC Optoelectronic Package Examples. All features provided as cast.

AlSiC Packaging Solutions for Optoelectronics
AlSiC materials and AlSiC/Composite systems can be used to provide packaging

solutions for optoelectronic devices. The properties that make AISiC ideal for electronics and optoelectronics packaging are: high thermal conductivity value (180 W/mK), and CTE values that are compatible with materials used in device assemblies; lower density; and lower net-shape casting costs. AISiC metal matrix composites offer a CTE value that is determined by the composition of silicon carbide particulate in a continuous aluminum alloy matrix. AISiC composites with higher silicon carbide content have lower composite CTE values (silicon carbide having a low CTE, and aluminum alloys having a high CTE). Figure 2 shows a polished section micrograph of AISiC-9 that has a dense (hermetic) microstructure of silicon carbide particulate in the aluminum alloy matrix^[2-4].

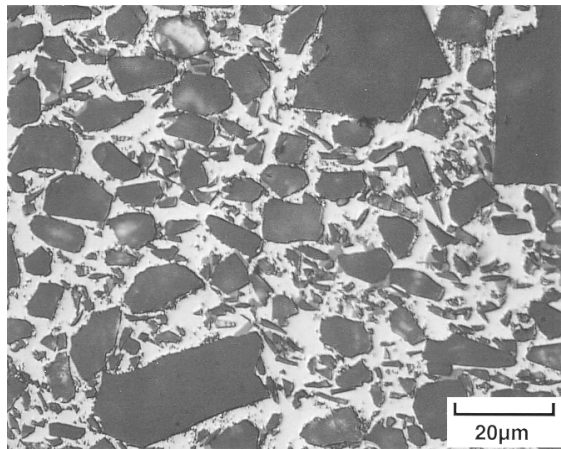


Figure 2: AISiC-9 microstructure showing the SiC particulate in a continuous aluminum alloy (A356.2) matrix.

Varying the silicon carbide percentage of an AISiC composite allows the selection of a CTE value that is compatible to the optoelectronics module. Table 1 summarizes the AISiC material properties for Ceramics Process Systems' AISiC formulations 9, 10, and 12. AISiC-9, with an average CTE value of 8.75 ppm/°C (30 – 200°C), is appropriate for use in assemblies with ceramic substrates. The CTE of AISiC-9 being slightly higher than gallium arsenide and alumina (Al₂O₃), by 1 ppm/°C, puts these materials in slight compression due to elevated temperature assembly techniques (brazing, soldering, epoxy curing). This slight compressive state improves reliability of these brittle components that are strong in compression, making them more resistant to

cracking. Higher tensile stresses are required to crack the device or substrate^[2-4].

Table 1 AISiC Material Properties

Material	AISiC 9	AISiC 10	AISiC 12
SiC vol%	63	55	37
Al (A356.2) vol%	37	45	63
Thermal Conductivity (W/mK) @ 25°C	180	180	170
Specific Heat (J/gK) @ 25°C	0.74	0.78	0.80
CTE (30 - 200°C)	8.75	10.56	11.5
Density (g/cm ³)	3.01	2.96	2.89
Youngs Modulus (GPa)	188	167	167
Shear Modulus (GPa)	76	67	69
Strength (MPa)	488	450	471
Hermeticity (Atm-cm ³ /s He)	< 10 ⁻⁹	< 10 ⁻⁹	< 10 ⁻⁹
Electrical Resistance (μOhm-cm)	20.7	20.7	20.7

AISiC-12, which has an average CTE value of 11.7 ppm/°C (30 - 200°C), is more appropriate in assemblies that include printed circuit board materials. Printed circuit board materials such as the very common FR4, have higher CTE values, typically 14 – 17 ppm/°C. The AISiC-12 material can be used to moderate the thermal stress induced bowing and flexing of the assembly during thermal cycling in service. Moderating (eliminating) the amount of bow by utilizing AISiC-12 will improve the reliability of the device assembly.

Although general material uses are described above, the appropriate AISiC material composition selection will best be determined by evaluating the CTE values of all of the materials in the optoelectronics module. Thermally induced stresses during module assembly and during module operation can be mitigated by

selection of a compatible material set. Table 2 compares the AISiC material compositions 9, 10 and 12 to compatible material systems.

Table 2 AISiC Material Compatibility

Material	AISiC 9	AISiC 10	AISiC 12
Seal Ring Materials	Alloy 48 – 52	Alloy 52	SS 17-4PH
Substrate Materials	Al ₂ O ₃ , AlN, DBC AlN	PCB, FR4	PCB, FR4
LTCC Materials	Ferro A6M, A6S / Heraeus CT2000 / Kyocera GL560		Kyocera GL771
Plating	Electroless Ni, Au Flash, Ni-Au, Cu-flame spray babbitt		
Integration	Dielectric substrates (design specific), coaxial ceramic feedthrus, seal rings, HOPG, cooling tubes		
Compatible materials based upon comparison of CTE over 30° - 150°C to AISiC and current know designs and applications. Materials and systems are only suggested. LTCC material selection is not an endorsement of vendor's material.			

High Thermal Dissipation Systems

Improvements in heat spreading and thermal dissipation are often required for laser diode and thermal electric cooler systems that must be maintained at a constant temperature (around 25°C)^[1]. In these systems, materials with extremely high thermal conductivity such as Highly-Oriented Pyrolytic Graphite (HOPG) and CVD diamond, can be incorporated within the AISiC component during the casting process^[2].

Such materials with extremely high thermal conductivity values (> 1000 W/mK) are located within the AISiC component to provide zones of extremely rapid heat spreading and, if desired, through-plane conductivity for maximum dissipation. HOPG materials have thermal conductivity values in the X-Y plane ranging from 1350 – 1700 W/mK dependent upon processing. Typically this material can be processed most cost effectively² at 1350 W/mK.

² Inserts approximately 1-inch (25.4 mm) square and 0.015-inch (0.38 mm) thick add \$3 – 4 to the cost of the composite product, compared to

The thermal conductivity in the Z-dimension (thickness) is on the order of 10 – 30 W/mK. HOPG material offers exceptional heat spreading despite the low z-axis thermal conductivity value.

CVD diamond substrates offer isotropic thermal conductivity values in the range of 1000 – 1500 W/mK, dependent on processing. These materials are somewhat limited in size and are more expensive than the HOPG materials.

These materials are inserted into the silicon carbide preform prior to the casting of the aluminum alloy to manufacture the AISiC composite. The AISiC composite completely envelops the heat-spreading material to provide a highly efficient thermal interface between the composite matrix and the insert. The AISiC component is designed to cost-effectively locate these materials in the area of thermal dissipation need. Additionally the AISiC package adds the geometrical and attachment functionality to these heat-spreading materials that enables a practical solution, as such extremely-high conductivity materials are thin, fragile, and typically found only in flat planar form factors.

The use of extremely high thermal conductivity inserts within an AISiC net-shape cast component also provides an efficient and cost-effective lid or uncooled module substrate, where no TEC is permissible for reliability or cost reasons. HOPG inserts can also be used to maximize heat transport through an AISiC substrate or other component, utilizing the excellent HOPG X-Y conductivity value in a through-plane configuration.

Optoelectronic TEC Substrate Example

Figure 3 shows the TEC mounting section of a laser diode packaging substrate with nickel-gold plating³. The HOPG insert is approximately 0.015 inches (0.38 mm) thick and is located in the center substrate within the silicon carbide preform matrix. After casting, the HOPG and composite material are in excellent thermal contact. A continuous aluminum alloy phase provides a permanent interface bond. It is also important to note that the substrate is cast to the final product dimensions and features

products without HOPG inserts, for production volumes in excess of 50K.

³ Electroless Ni low phosphorus (4 – 6%) 150 – 250 μ-inch thick, Au-Flash

without machining. The key design requirement in this product is to maintain uniform

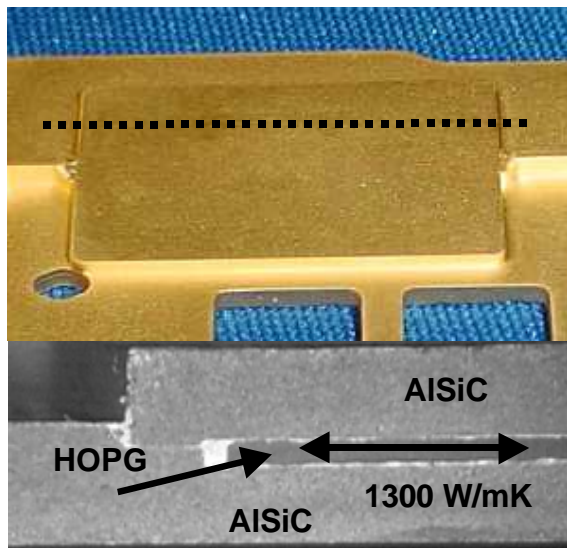


Figure 3: AISiC laser diode TEC substrate system showing TEC mount area (top) and the cross section showing the HOPG insert in the AISiC composite (bottom).

temperature across the TEC. This is accomplished by using the HOPG material to provide extremely rapid heat spreading to moderate the temperature across the TEC mount. AISiC-9 was chosen for this application since it was most compatible with the Al_2O_3 and direct-bond copper (DBC) substrate on the TEC.

Summary

AISiC packages have ideal material properties that lend themselves to optoelectronics applications. Much like the microelectronics industry, issues of thermal management, compatible thermal expansion, and reliability are concerns of the optoelectronics component designer. The designer must balance these concerns and provide a manufacturable packaging solution to his customer at a reasonable cost. AISiC processing lends itself to the fabrication of optoelectronic packages, incorporating required geometrical features using a cost-efficient net-shape casting process that is scaleable to high volume and reduces or eliminates machining cost. An AISiC substrate or package provides improved reliability as a result of high thermal conductivity value and reduced thermally-induced stress with proper selection of a CTE value compatible with the complete module material set. Additionally, the CPS AISiC net-shape casting process lends itself to the

incorporation of high heat spreading materials, such as highly-oriented pyrolytic graphite and CVD diamond. These hybrid composites have their application in cost-effectively providing temperature uniformity for laser diode thermoelectric cooler substrates; module lids; and uncooled substrates with extremely high thermal conductivity zones for maximum heat dissipation.

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