Introduction

It is well documented that rising die junction temperature creates a number of reliability and performance issues for power semiconductors. As an example, a Freescale White Paper on thermal management lists the following power semiconductor issues associated with high junction temperatures:[1]

- Increase in leakage currents
- Gate oxides degrade more quickly
- Ionic impurities move more readily
- Mechanical stresses increase
- Diode forward voltage fails
- MOSFET on-resistance increases
  MOSFET threshold voltage falls
- Bipolar transistor switching speeds slows
- Bipolar transistor gains tend to fall
- Breakdown voltages tend to increase
- Transistor Safe Operating Areas decrease

Consequently, one of the major roles of packaging in power semiconductor applications is to effectively remove heat from the semiconductor device. This is also one of the key reasons that the highest power devices utilize higher cost ceramic packaging options such as Direct Bond Copper (DBC) and Direct Plated Copper (DPC)[2]. For this type of packaging technology, thick Cu (either plated or from Cu foil) is bonded to ceramic substrates fabricated from alumina (96%), aluminum nitride (AlN), zirconia toughened alumina (ZTA) or Si_3N_4. The thermal conductivity of these different ceramic materials are listed in Table 1 below, along with the relative ceramic costs[3].

Ceramic	Thermal Conductivity (W/m-K)	Packaging Technology	Ceramic Cost Factor
Al_2O_3 (96%)	20 W/m-K	DBC or DPC	1
ZTA	25 W/m-K	DBC or DPC	>1
AlN (95%)	170 W/m-K minimum	Direct Plated Copper (DPC)	>8
Zirconia	140 W/m-K	Active metal braze	>8

[1] Freescale White Paper: Thermal Analysis of Semiconductor Systems

[2] DPC is a product line from Tong Hsing Electronic Industries, Taiwan and is used primarily for power semiconductors and for HBLED applications. It consists of patterned, plated Cu on ceramic boards.

[3] This is the relative cost of ceramic component alone, not including the cost to fabricate the package

As is clear from this table, which uses 96% alumina as the relative cost basis, higher thermal performance comes at a substantial increased material cost.

This paper will describe a new ceramic solution, based on aluminum nitride, that will provide a solution that falls in between 96% alumina and traditional AlN from both a cost and thermal performance standpoint.

Aluminum Nitride- Right Technical Solution But Too Expensive

Aluminum Nitride (AlN) is an ideal choice for high thermal demand applications because of its combination of high thermal conductivity and mid range CTE of 4.5 ppm/C; but AlN's >8 times cost factor relative to aluminum oxide limits its application significantly. AlN is currently used in power semiconductor packaging, but only in situations where there is no other feasible alternatives. The high cost pressure in the power semiconductor market and the significant portion of total device cost that packaging entails, increases the pressure to minimize high cost AlN usage.

AlN's high cost comes from a number of factors. Some of the most significant are listed in the table below:

Cost Factor	Comparison to Alumina	Comments
AlN ceramics are fabricated from AlN powder, and AlN powder cost for typical electronic grade material is extremely high	AlN powder is 15 to 25 times more expensive then alumina powder	Electronic applications almost exclusively utilize high cost "carbo-thermally reduced" AlN powder
AlN ceramics are processed at very high temperatures. High temperature furnaces increase capital costs and decrease furnace throughput	Alumina is processed at 1450C to 1620C, AlN is processed at 1825C.	For alumina, continuous furnaces are available. For AlN, only batch graphite or refractory metal furnaces are available.
High powder processing costs due to reaction with H_2O.	During early processing stages, ceramics are shaped by forming a ceramic, binder and solvent slurry. AlN reacts with water so the slurry must be non-aqueous, compared to aqueous processing for alumina.	Non-aqueous processing requires higher equipment costs due to explosion hazards and environmental concerns, and also require solvent recovery systems.

New AlN Based Ceramic Material for High Thermal Demand Applications

A new material has been developed which fits in the cost/performance "gap" between Al_2O_3 and conventional AlN. The main features of this new material, which is labeled "HBLED Grade AlN[4]" (due to its fit in the High Brightness LED market) are much lower powder and process costs, a thermal conductivity between alumina and conventional AlN and a white color which is highly reflective in the visible. This new material is an ideal material for power semiconductor applications where cost and thermal performance are also critical.

The new HBLED grade AlN has a thermal conductivity of 100 W/m-K which is 5 times higher than alumina, but 42% lower than conventional AlN. This is more than adequate for most power semiconductor applications. The mechanical, electrical and physical properties are very similar to conventional AlN.

One very critical factor is that this new AlN material utilizes a much lower cost AlN powder that is made by "direct nitridation" of aluminum metal. This powder is typically 60-75% less expensive than the traditional carbo-thermally reduced powder[5] used in electronics applications.

In addition, HBLED ALN is processed at 1700-1725C. In this temperature range, continuous furnaces are available which use alumina heat shields and Mo heating elements. Though more expensive than lower temperature alumina sintering furnaces, from a cost and throughput standpoint this is a significant improvement compared to conventional AlN processing in high temperature refractory metal or graphite batch furnaces.

Figure 1 below has a picture of HBLED grade AlN, which is white. The tile dimensions are 4.5" square. It is shown with a traditional AlN substrate (which in this case is 2" square).

What is Next?

This article focusses on a new AlN ceramic technology that results in a material that from a cost/performance standpoint bridges the current wide gap between high thermal conductivity, high cost AlN; and lower thermal performance, lower cost aluminum oxide.

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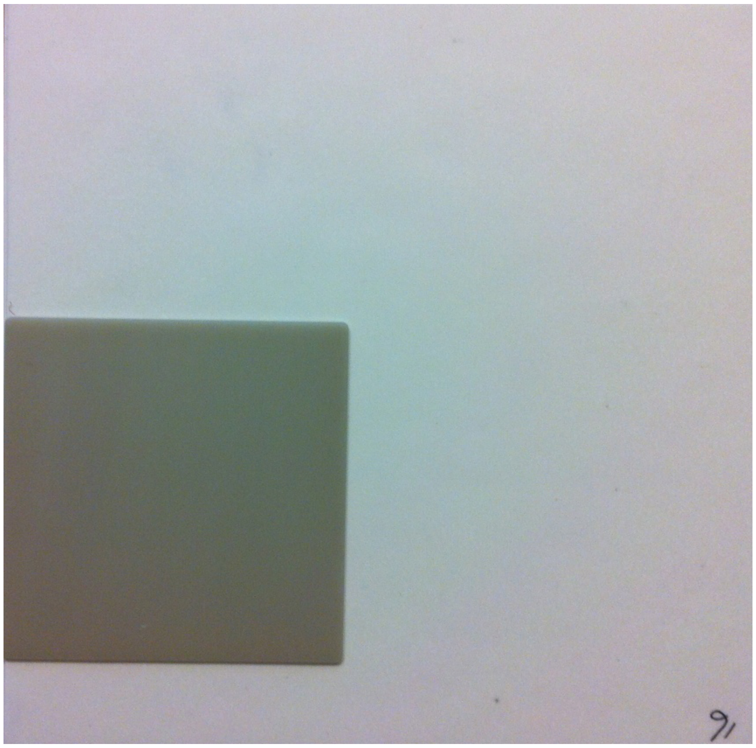
[4] Because of the high thermal demand in the high brightness LED market, this material was originally designed for this application and that is the origin of the name.

[5] Fabricated using the carbo-thermal reduction of aluminum oxide



For the focus applications of this technology, which includes power semiconductor and HBLED packaging, the 100W/m-K thermal performance is more than adequate. Due to the highly cost competitive nature of these applications, and the current high packaging costs for power devices, there is a strong fit for a new material with significantly lower cost structure. As this material is adapted more widely, it is expected that it will compete favorably for many applications that are now served exclusively by aluminum oxide.

About CMC

CMC Laboratories, Inc. (www.cmclaboratories.com) is an advanced materials development firm located in Tempe, Arizona. CMC specializes in developing new materials for electronic interconnect and packaging applications. CMC has applied for a patent to cover the technology described in this article and is now actively licensing this technology to interested manufacturers.