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Product Brief

High Thermal Conductivity Silicon Nitride Substrates May Help Accelerate Development of Compact, High-Power Power Control Units

Highlights

- Toshiba Silicon Nitride (SIN) substrates provide both excellent mechanical properties and high thermal conductivity.
- Toshiba has succeeded in developing high thermal conductivity Silicon Nitride substrates that offer benefits over both Alumina and Aluminum Nitride substrates.
- Toshiba Silicon Nitride substrates have higher mechanical strength even though it is thinner than both Alumina substrates and Aluminum Nitride substrates.

Description

In automotive shows around the world, the next-generation electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) attract a great deal of attention. The wide range of choices from high-power concept cars to high-efficiency sub-compacts to sport utility vehicles are all based on the compact, lightweight, high-power capabilities of the power control unit (PCU).

A key component of the PCU is the ceramic substrate, which transfers heat generated by the power semiconductor devices away from the semiconductor, as well as providing electrical insulation between these devices.

This article introduces Toshiba Silicon Nitride (SIN) substrates, which provide both excellent mechanical properties and high thermal conductivity.

Development Utilizing the Base Technologies Used for Space Shuttles

Silicon Nitride, used in hybrid ceramic bearings, both ball and roller bearings, was initially developed via a joint venture between Toshiba Materials and JTEKT Corporation (KOYO Bearings). Due to Silicon Nitride's excellent mechanical properties, such as high strength and toughness, it has been utilized in highly demanding applications including the space shuttle and wind power generators. Conventional substrate solutions for inverters, power semiconductors and power modules have included Alumina and Aluminum Nitride (AIN). Based on technologies of functional materials that have been acquired over the years along with an internally developed additive[1], Toshiba succeeded in developing high thermal conductivity Silicon Nitride substrates that offer benefits over both Alumina and Aluminum Nitride substrates. Toshiba Silicon Nitride substrates are available with either plain, unmetalized surfaces or with copper, either full face or patterned attached to both surfaces.

Silicon Nitride has Excellent Mechanical Properties and High Thermal Conductivity

Although resin and Alumina substrates are inexpensive, they have inferior heat dissipation properties compared to Nitride ceramic substrates. For this reason, resin and Alumina substrates are most often used in low power applications where less heat needs to be dissipated. Aluminum Nitride (ALN) and Silicon Nitride (SIN) substrates on the other hand, have superior heat dissipation properties and are better suited for use with high-power discrete semiconductors and high-power PCU modules.

On the surface, one might conclude that Silicon Nitride substrates with only 90W/mK thermal conductivity are inferior at dissipating heat compared to Aluminum Nitride substrates with 170W/mK thermal conductivity. However, because the mechanical strength of the SIN substrate is more than twice that of an ALN substrate, the thermal resistance of a thinner SIN substrate, that is 0.32 mm thick, is almost equivalent to that of a thicker ALN substrate, that is 0.635 mm thick. Additionally, the higher bend strength of the SIN increases the maximum deflection of the substrate to more than 1.5 times that of the other ceramic substrates, meaning that they have high resistance to compression and impact[2].

Comparison of Properties of Electrically Insulating Substrates

PCUs, including inverters, DC/DC converters, junction boxes and vehicle mounted chargers, are required to be small and lightweight to facilitate mounting in an engine compartment, and to deliver high power for enabling excellent engine performance. To achieve these goals, improved insulation and heat dissipation properties are indispensable.

The insulated substrates used in power modules are classified mainly into 4 types: resin substrates and ceramic substrates of Alumina, Aluminum Nitride and Silicon Nitride. Figure 1 shows a comparison of the properties of each substrate type.

Figure 1. Comparison of properties for electrical insulating substrates.
(Superior ⭘ > ● > ▲ inferior)

Substrate	Heat Dissipation	Mechanical Properties	Insulation Reliability	Cost
Resin	▲	●	▲	⭘
Alumina (Al_2O_2)	●	▲	●	●
Aluminum Nitride (AN)	⭘	▲	●	●
Silicon Nitride (Si_3N_4)	⭘	⭘	⭘	▲

Double-sided heat dissipation structures are placed on both sides of a device.

Contact Information

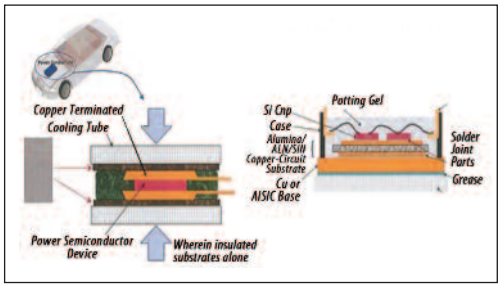
Toshiba America
Electronic Components, Inc.
Advanced Materials Division
290 Donald Lynch Blvd.
Marlborough, MA 01752
amd@taec.toshiba.com
Tel: 508-303-5041
Fax: 508-481-8890

Enhanced Flexibility in Design Enables Various Module Structures

In recent years, semiconductor power modules tend to consist of thinner ceramic substrates with thicker copper layers in order to decrease thermal resistance. In addition to higher mechanical strength, the Silicon Nitride substrates have more than twice the fracture toughness than both Alumina and Aluminum Nitride substrates. As a result, even in cases where the thickness of a Silicon Nitride substrate is reduced to 0.32 mm and the copper plate is increased from 0.3 mm to 0.6 mm, the thinner SIN substrate can easily survive as many or more than 3,000 cycles of thermal cycle testing[3] not only as a result of its superior strength but also its superior fracture toughness.

Silicon Nitride substrates with these properties can be utilized in double-sided heat dissipation structures where substrates are layered on both sides of the semiconductor device to allow heat to be dissipated from both sides of the device (figure 2.)

Figure 2. Conventional structure and "double-sided heat dissipation structure" of a semiconductor power module



In an increasing number of cases, ultrasonic bonding of electrode terminals directly to copper circuit plates is conducted in order to enhance productivity of power modules and joint reliability.

It is a concern that ultrasonic bonding can cause cracks when using Alumina or Aluminum Nitride substrates. The fracture toughness of Silicon Nitride substrates eliminates that concern and provides improved mechanical reliability.

Silicon Nitride substrates can thus offer high flexibility in design by providing a combination of excellent mechanical properties and reliability. This enables a wider variety of module designs than would be possible using Alumina or Aluminum Nitride substrates.

Silicon Nitride Substrates Benefit Wide Bandgap Semiconductors

Currently, while Si (Silicon) devices are mainly used as power semiconductor devices, the use of SiC devices is becoming more popular in order to achieve compact semiconductor modules.

SiC semiconductor devices can be operated at temperatures of 200 degrees C or higher, typical for their higher operating voltages. Since Silicon Nitride substrates can survive the higher operating temperatures of these SiC devices, they contribute to the development of compact. high-power PCUs. Thermal test data and the SIN Standard Specification are available from the Advanced Materials Division of Toshiba America Electronic Components, Inc.

1 Based on Toshiba research
2 The ALN-AMC and SIN-AMC Specifications are available from the Advanced Materials Division.
3 Thermal Cycle Test data are available from the Advanced Materials Division.

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