Tailoring Circuit Materials for Power Electronic Applications

As electronic devices continue to shrink in size as they grow in power, demand grows for power electronic circuits with increased power density. Increased operating temperatures are one of the trade-offs of increased circuit power density, with an increase in thermal stress for the circuit materials that serve as substrates for modern power electronic circuits. This article provides an overview of a family of processes that can help take advantage of the many benefit available from ceramic circuit materials.

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The requirements for PCB materials capable of supporting high-density power electronics circuits are quite challenging, since they include both mechanical and electrical stability at high temperatures. To meet these demands, curamik® ADVANTAGE provides a ceramic-materials-based solution for the smaller, higher-power-density circuits of PCBs for modern power electronic applications. These materials feature ceramic substrates with low dielectric loss and low-loss copper conductors that support high voltages and currents in power-grid, energy, and industrial power applications. By design, ADVANTAGE is a family of features to optimize the performance of those materials.

A substrates family

The high-temperature, high-voltage circuit materials include four different ceramic-based substrates, each formulated to provide strengths and benefits in different applications. The materials are available with thick copper cladding for high-power circuits, with a direct-bonded copper (DBC) or active metal brazing (AMB) attachment of copper to substrate depending upon the substrate material. DBC materials employ a high-temperature melting and diffusion process in which pure copper is bonded to the ceramic substrate. AMB materials use high-temperature brazing to create a strong bond between the copper and the ceramic substrate material.

The four ceramic substrate materials provide different levels of power-handling and thermal-management capabilities (Figure 1). For example, curamik Power is based on Al_2O_3 ceramic substrates and is a good fit for cost-effective power electronic circuits. It has thermal conductivity of 24 W/m-K at 20°C. For slightly higher-power circuits, curamik Power Plus adds zirconium (ZrO_2) doping to the Al_2O_3 substrates to achieve thermal conductivity of 26 W/m-K and higher robustness. For a significant jump in operational lifetime and and thermal capabilities, curamik Performance uses silicon nitride (Si_3N_4) ceramic material to provide thermal conductivity of 90 W/m-K. Finally, for truly high-density power electronic circuits, curamik Thermal features aluminum nitride (AlN) substrates with outstanding thermal conductivity of 170 W/m-K. The materials can be supplied as master cards or formed into single parts as small as 15 mm × 15 mm.

Gaining an ADVANTAGE

These materials provide low loss with thermal properties well suited to a wide range of power electronic applications. For optimum performance, however, ADVANTAGE is a series of features meant to improve the performance and usability of these materials. This includes a choice of plating materials, addition of solder stop to control solder coverage, treatments for surface roughness, and a state-of-the-art silver sintering process that provides an attachment option to solder for critical high-temperature applications.

ADVANTAGE includes a wide selection of plating options for surface finishing of the copper patterns of the four mentioned above circuit materials, including nickel (Ni), nickel-gold (NiAu), and silver (Ag) plating. These different plating processes help to enhance solder wettability and improve the efficiency and effectiveness of a solder process used with the ceramic materials and improve wire bonding and ultrasonic welding. The in-house processes are performed by wet-chemical deposition and include a selective silver-plating capability so that sections of copper can remain bare as needed.

These ceramic circuit materials are manufactured by means of tightly controlled processes, resulting in consistent electrical and mechanical behavior from lot to lot and across the

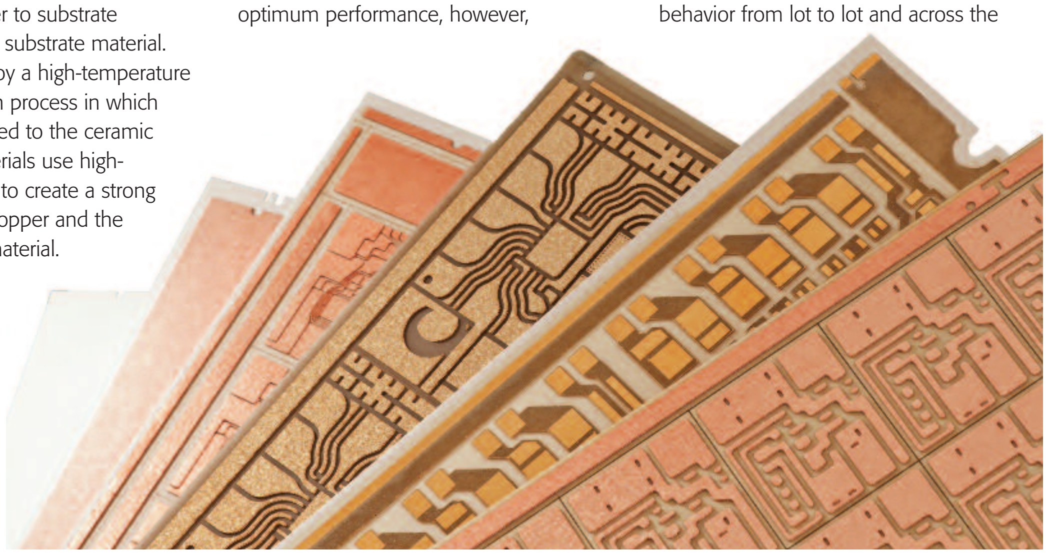

Figure 1: The four curamik ceramic circuit materials provide different levels of thermal dissipation

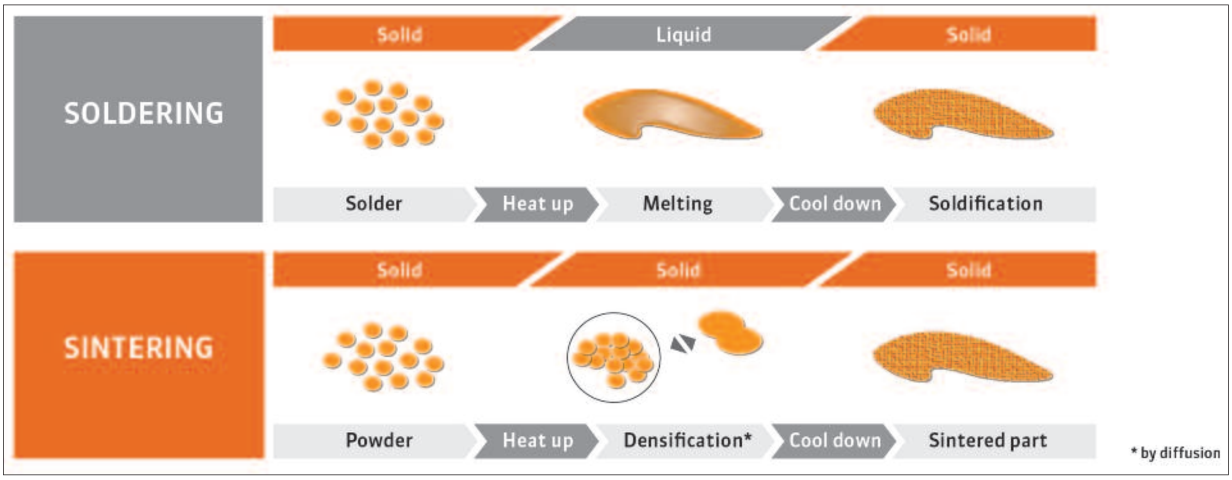

Figure 2: Silver sintering is a process in which heat is applied to a silver paste, resulting in densification (Soldering-Sintering graphic from curamik Substrates for Silver Sintering tech note)

surface of each master card. For most circuit wire-bonding and soldering processes, the normal surface roughness of curamik materials (with $R_{max} = 50\ \mu m$ and $R_z = 16\ \mu m$) suitable for thick wire bonding and standard soldering process. But when thin wire bonds are required, the surface roughness should be minimized as much as possible. As part of the ADVANTAGE process, chemical or mechanical treatments are available to reduce the surface roughness of the materials to less than 50 % of the standard z-axis surface roughness: R_z less than 6 µm for mechanical treatment and R_z less than 7 µm for chemical treatment.

Formation of solder bridges during circuit fabrication is often difficult to avoid. The "overflow" of solder can not only jeopardize performance and reliability, but can decrease production yields. Fortunately, curamik circuit materials can be treated with solder stop to help streamline and stabilize the soldering process. The solder stop materials, which can be precisely positioned on a PCB, separate areas requiring solder from those that do not, such as wire-bonded connections. Solder stop for these circuit materials is available in standard and high-temperature versions, both in minimum width of 0.4 mm that can be positioned with a tolerance of ±0.2 mm. Standard solder stop is designed to withstand temperatures as high as 288°C for 10 s while high-temperature solder stop can handle temperatures as high as 400°C for as long as 5 min.

Handling the heat

As an alternative to soldering in high-power/high-temperature applications, silver sintering is available for all of the curamik ceramic materials as part of the ADVANTAGE family. Compared to a soldering process in which heat is applied until a solid reaches its melting point and is then allowed to cool down and solidify to form a bond, silver sintering is a process in which heat is applied to a silver paste, resulting in densification (Figure 2). During silver sintering, several actions occur simultaneously, including grain growth, pore growth, and densification.

Silver has a melting point of 961°C and excellent thermal conductivity of 240 W/m-K. The size of the silver particles in the sintering paste can be controlled for different degrees of thermal dissipation, with better dissipation coming from smaller particles. The use of smaller particles also allows application of the sintering paste by conventional printing methods to achieve fine-resolution features on the circuit materials. Sintering takes place in conventional ovens (Figure 3) in an air/nitrogen atmosphere and can be used for form silver sintered joints with thicknesses ranging from 50 to 100 µm, although thinner silver-sintered joints are becoming more popular. (For more information on silver sintering for the curamik ceramic materials, visit the Design Support Hub **(https://www.rogerscorp.com/pes/design/index.aspx)** and download a copy of the tech note "curamik® SUBSTRATES for Silver Sintering.")

ADVANTAGE processes also include treatment of DBC ceramic materials to achieve partial-discharge-free performance, essentially for high-power circuits at blocking voltages to 1.7 kV. DBC master cards are treated to close voids so that even at voltages to 3.8 kV, partial discharge is less than 10 pC. This elimination of voids in the ceramic material results in higher reliability and longer operating lifetimes for high-power circuit designs, including converters and inverters. Additional ceramic processes include laser drilling of holes with 1mm minimum diameter and tolerance of +0.05/-0.02 mm; engraving of text or numeric data matrix code onto a ceramic substrate for full traceability; etching of integrated copper steps and cavities; and organic surface treatment to help improve wire-bonding and soldering processes.

Process	Stencil Printing	Drying	Die Pick and Place	Sintering
Equipment	conventional printing equipment	conventional box oven	die placer with heated tooling	sinter press
Parameter	standard parameter	drying in air 10 min. at 100°C	die placement temperature 120°C	sinter pressure 5-30 Mpa sinter temperature 230°C sinter time 3 min. in air

Figure 3: Process flow for silver pastes with micro-particles