Development of silicon nitride substrates with high thermal conductivity for heat sink applications based on economic technologies

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Abstract

Commercial applications for silicone nitrides include constructional elements in mechanical engineering/turbine manufacturing and cutting tools. These applications profit on characteristical properties like high strength at high temperatures, a low density, corrosion resistance against fused metals (especially non-ferrous metals), high hardness, low friction coefficient, wear resistance, a good thermal shock behaviour and spalling resistance.
Especially the thermal characteristics and mechanical strength makes Si_3N_4 suitable for applications in power electronics. However, silicon nitrides aren't yet competing with established materials in substrate technologies because of its comparable low thermal conductivity, which lays about 30 W/mK and its high manufacturing costs especially for the hot pressing process and the complex and expansive finishing by hard machining.
This study illustrates novel approaches to manufacture high thermal conductive Si_3N_4 substrates by near-net-shape and low cost tape casting techniques. The casted green tapes can easily be shaped by punching and can subsequent be sintered by gas pressure sintering, which is a quite cost efficient method. The low diffusion coefficient of nitrogen makes the sintering of Si_3N_4 a sophisticated issue as it inhibits solid-state sintering and thus requires a liquid phase. Therefore, it is important to systematically investigate the effect of sintering additives on the material properties, especially on thermal conductivity. Furthermore, the relationship between grain boundary, resulting phases and final properties are investigated by scanning electron microscopy and crystal phase analysis. To optimize material characteristics, a new developed microstructure-property-simulation using the finite element method of the Fraunhofer-Institut für Silicatforschung ISC was applied. A typical microstructure of sintered Si_3N_4 with β-crystallites and grain boundaries is shown in Figure 1. The simulation result of network structure generation is presented in Figure 2. The texture illustrates the sustained crystallite without preferred orientation.

High thermal conductive Si_3N_4 substrates have been soldered with copper using the active metal brazing (AMB). Screen-printing the brazing paste was done on ground surface. After the coating has dried, copper can be applicated. Brazing can be carried out either under protective atmosphere or in vacuum at temperatures between 900-1000 °C. If desired, an etch resist pattern may be printed to get a structured copper layer.

This investigation illustrates the possibility of assembling a Si_3N_4- AMB-substrate with a three times higher thermal conductivity as usual for heat-sink applications with the use of low cost shape forming and sintering methods and thus makes it possible to increase the life cycle of electronic assemblies.

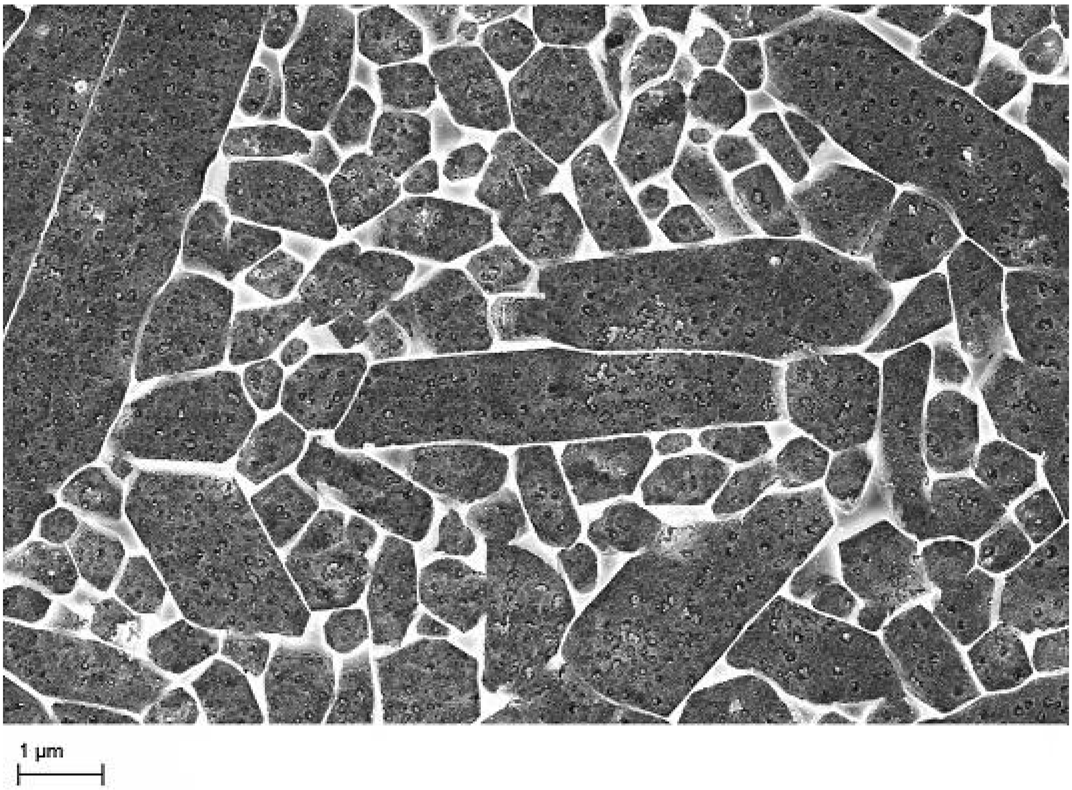

Fig. 1: Microstructure of sintered Si_3N_4 with sustained, hexagonal β-crystallites without preferred orientation and grain boundaries [1]

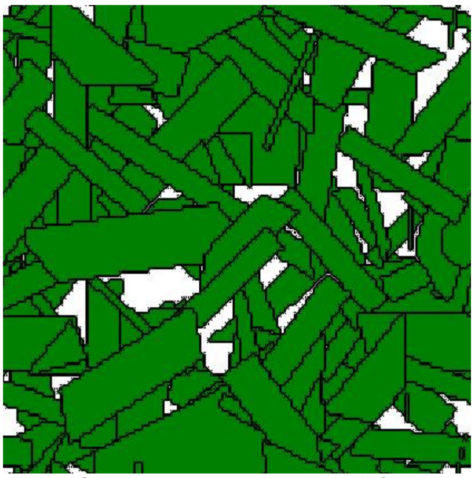

Fig. 2: Simulated microstructure of Si_3N_4 by microstructure-property-simulation using the finite element method of the Fraunhofer-Institut für Silicatforschung ISC with sustained, hexagonal β-crystallites without preferred orientation [1]

References

[1] courtesy of Fraunhofer-Institut für Silicatforschung ISC