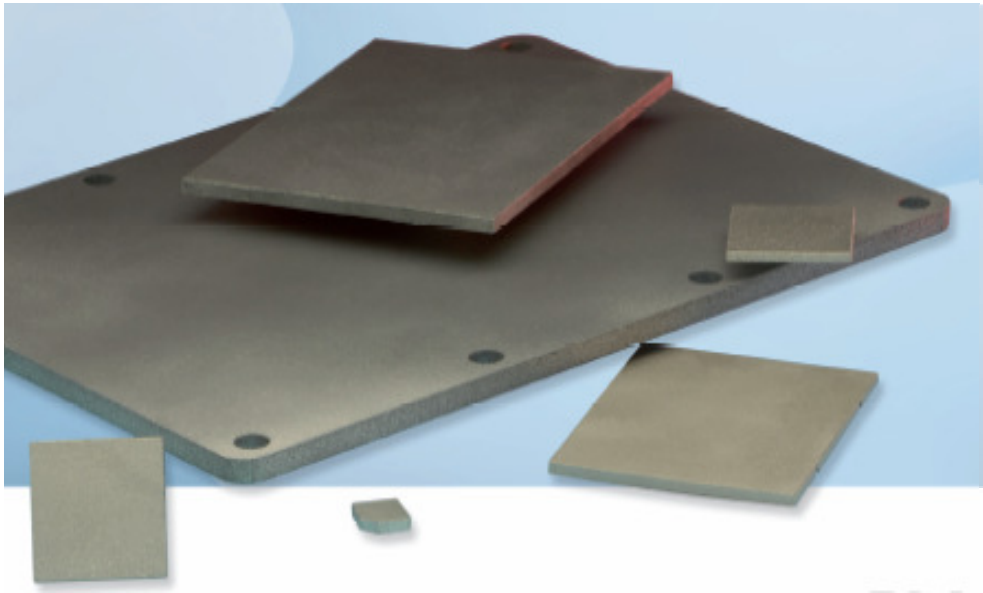
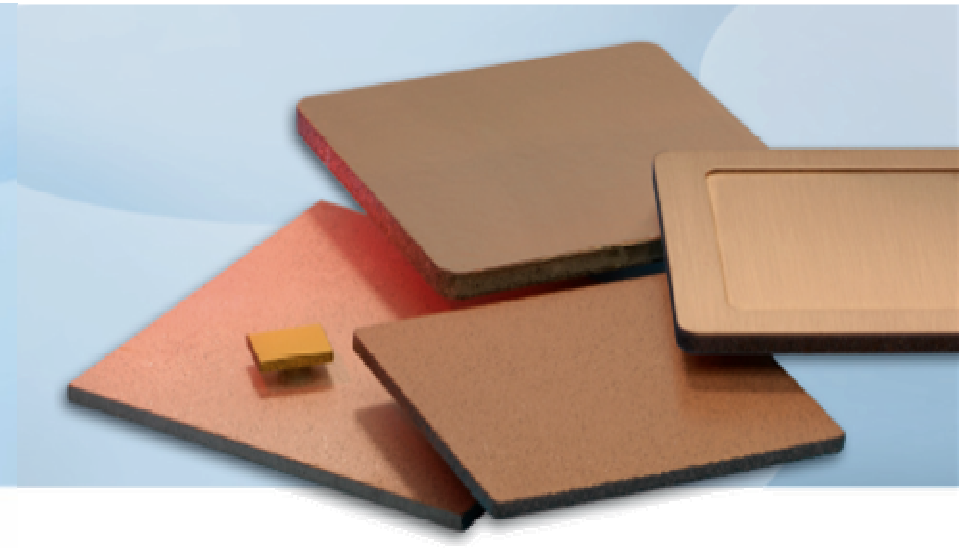
Sven Knippscheer, Ravi Bollina, Tobias Mrotzek, Janet Landgraf

Workshop on Materials for Collimators and Beam Absorbers
CERN, 4. September 2007

Development and Manufacturing Status of Diamond-based Composites





A Step ahead in Technology.

PLANSEE

Outline

- Introduction
  Markets, Applications, Thermal Materials
- Production Process of Diamond Composites
- Constitution and Microstructure
- Thermal Properties
- Thermal Cycling Tests
- Product Development

Markets and Applications | Main Markets

Microelectronics

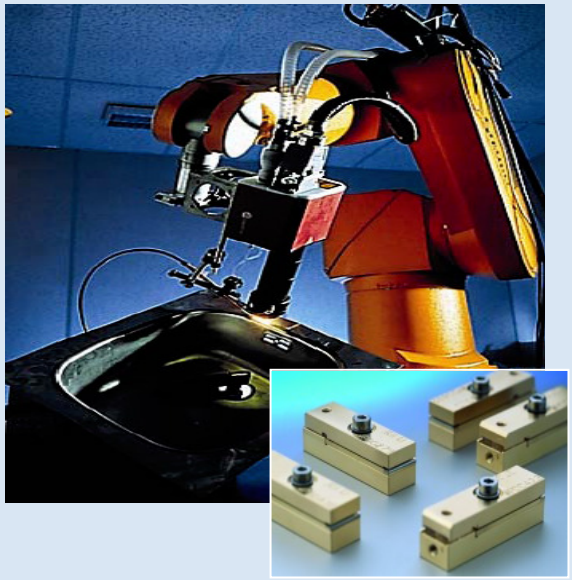
Server for large scale data processing

Higher clock rates and miniaturization of transistors lead to higher power density in micro-processors

Optoelectronics

Diode laser for manufacturing, laser pumping and medical application

Higher power density and stability of laser beam is limited by efficient heat transfer

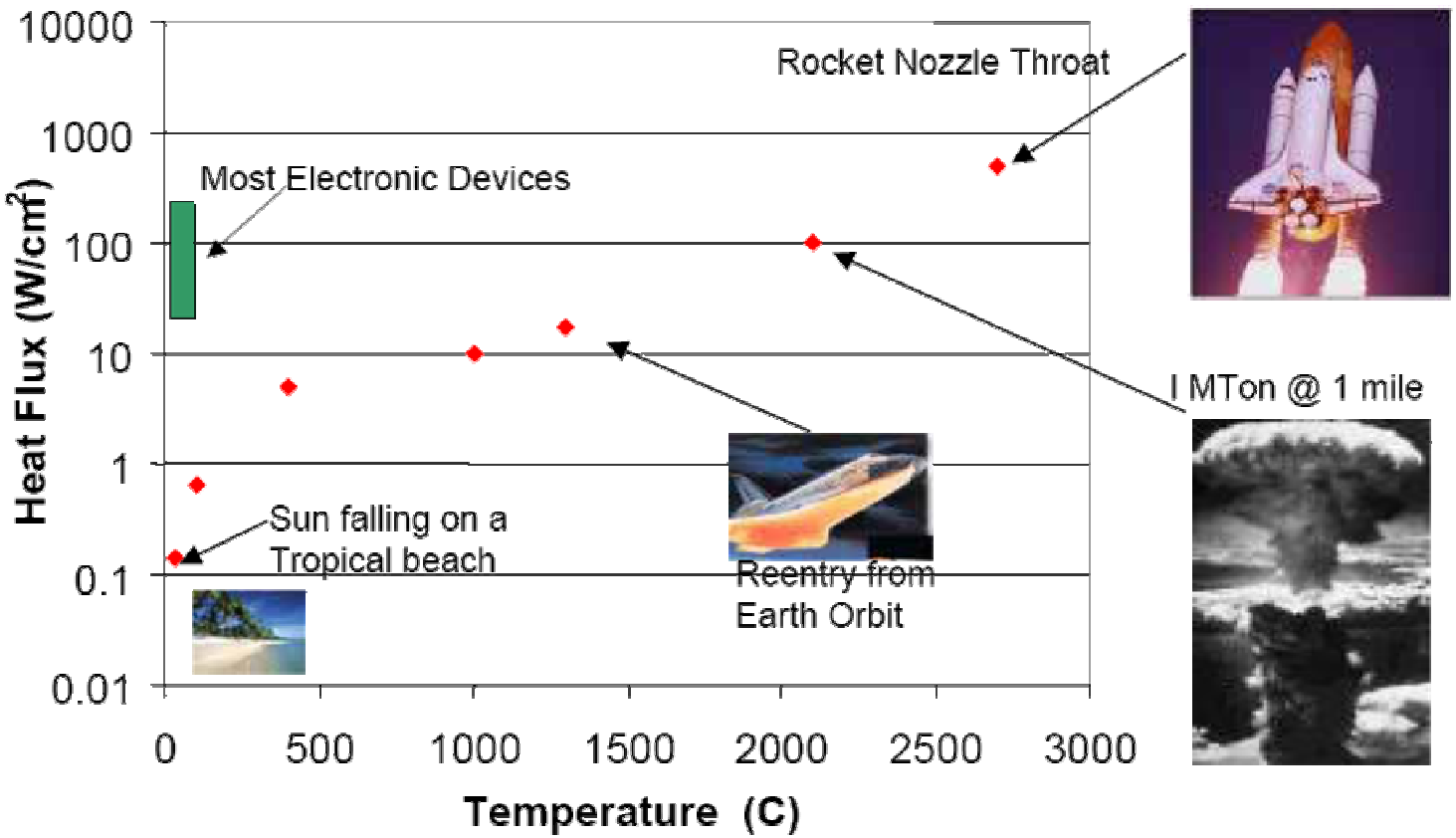


Power-electronics

Power converters (IGBT) for energy conversion

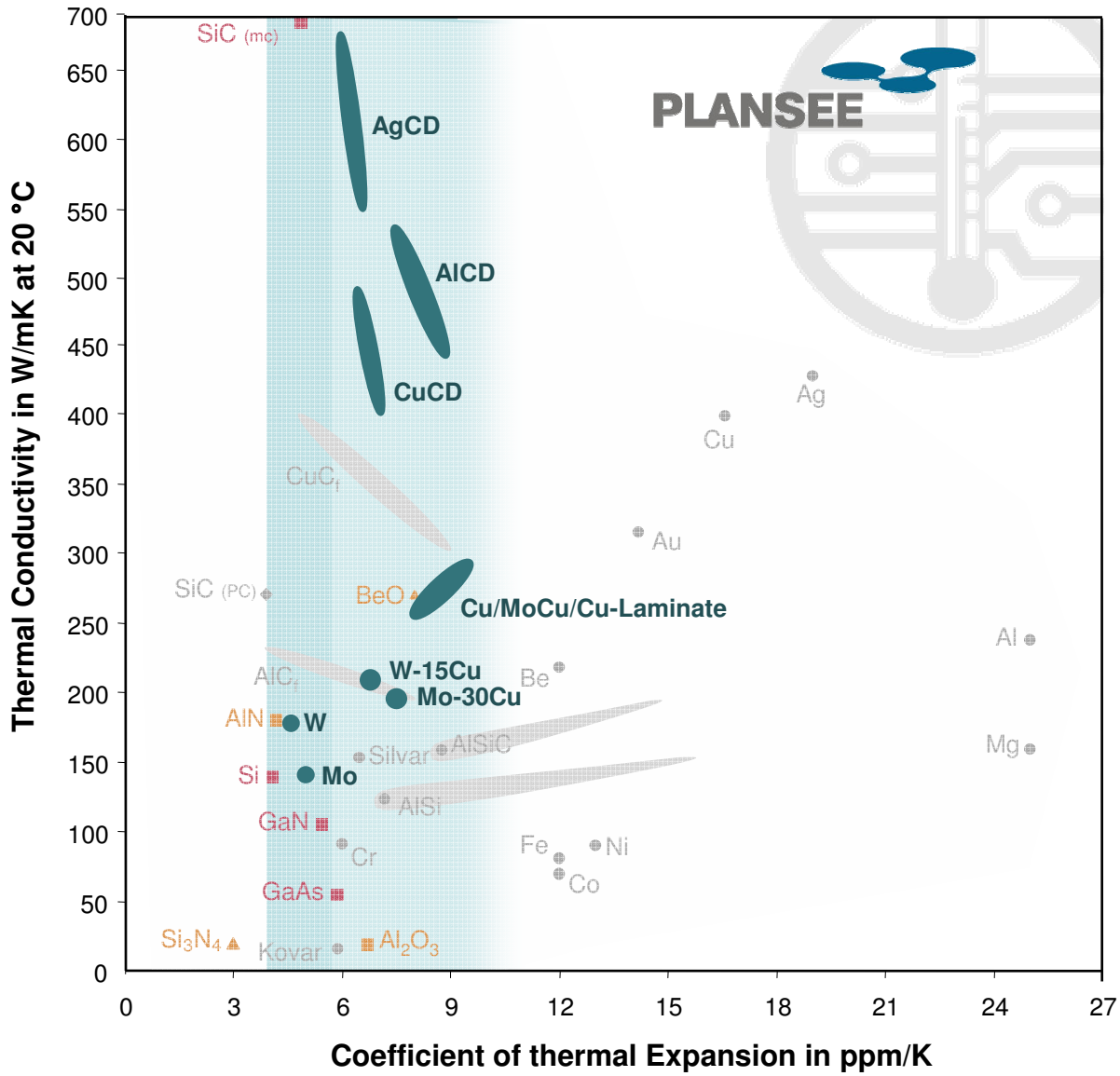
Size reduction and higher currents in power converters drive thermal conductivity of base plates

Technology | Heat flux challenge



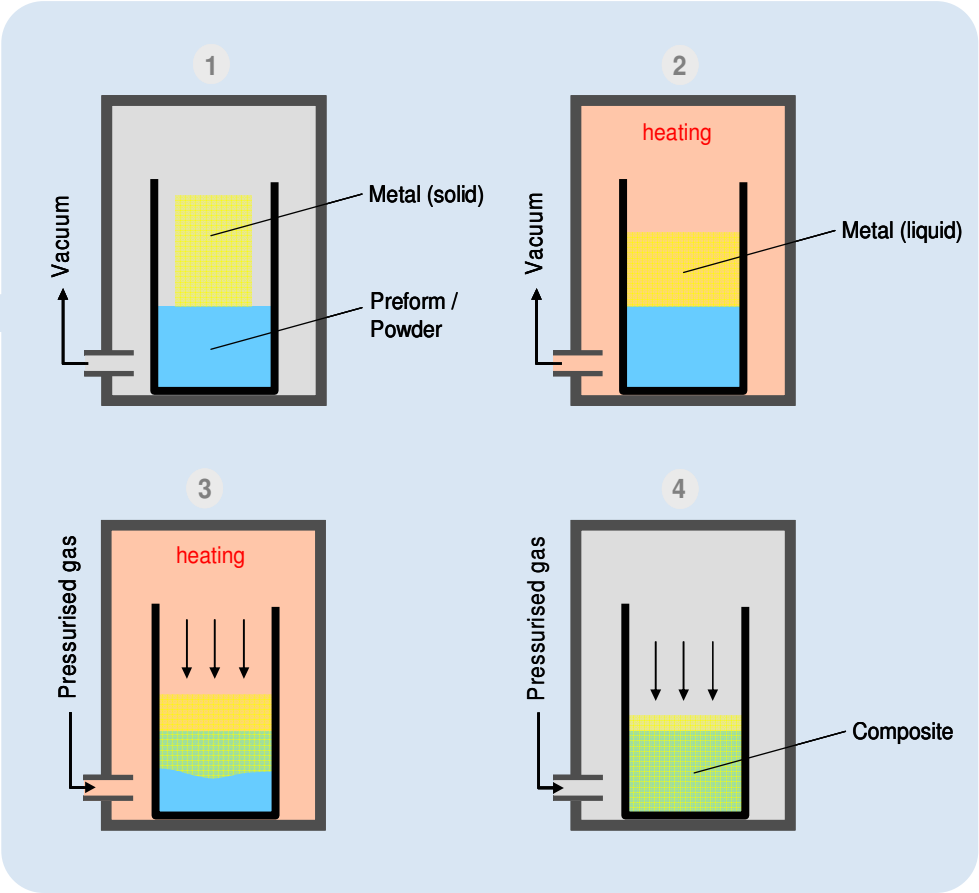
Source: Honeywell

Materials | TC and CTE of Thermal Management Materials

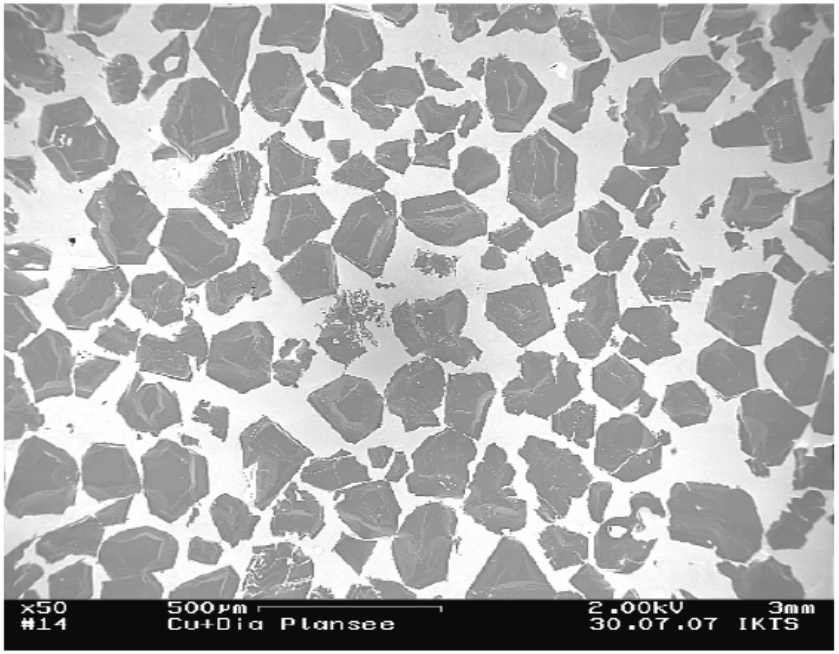


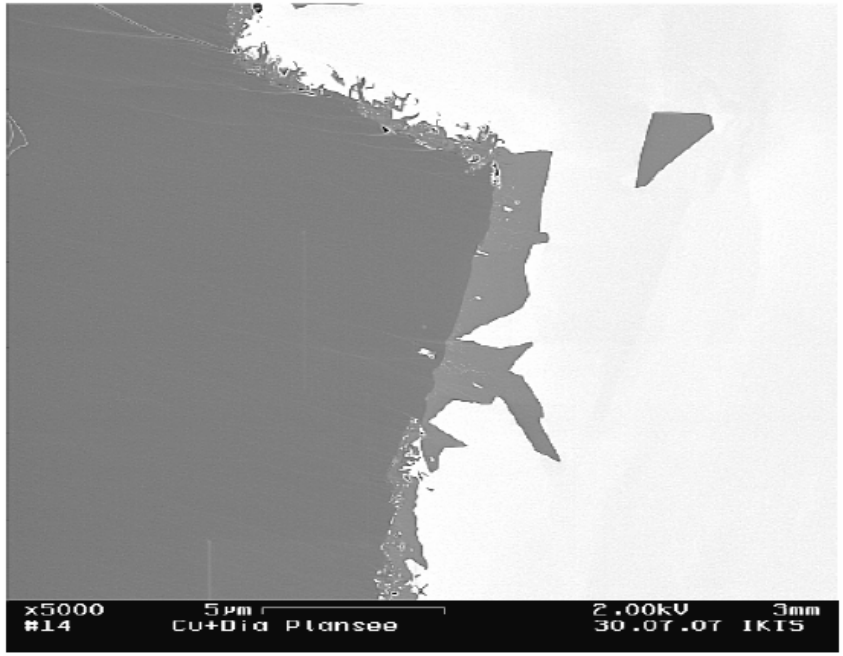
Diamond Composites | Gas Pressure Assisted Infiltration

- **Material income**
  - Inspection of diamond powder
  - Inspection of ingot material
- **Infiltration**
  - Assembly and filling of molds
  - Gas pressure infiltration
  - Inspection of infiltrated parts
- **Metallization (“thick film”)**
  - Cleaning / Surface preparation
  - Applying Ag or Cu layer
- **Machining**
  - Water jet cutting
  - Precision machining
- **Coating (thin film)**
  - Cleaning / Surface preparation
  - PVD Coating
- **Final inspection and shipping**



Diamond Composites | Microstructure





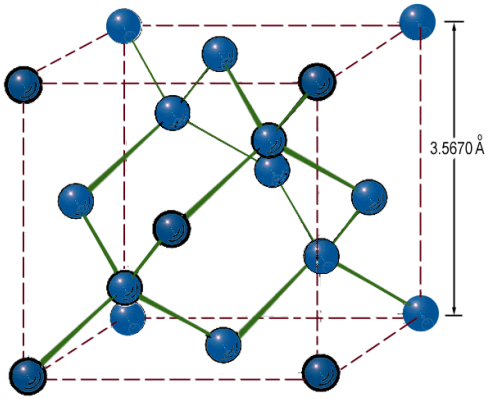
FESEM images of ion beam etched copper diamond composite samples

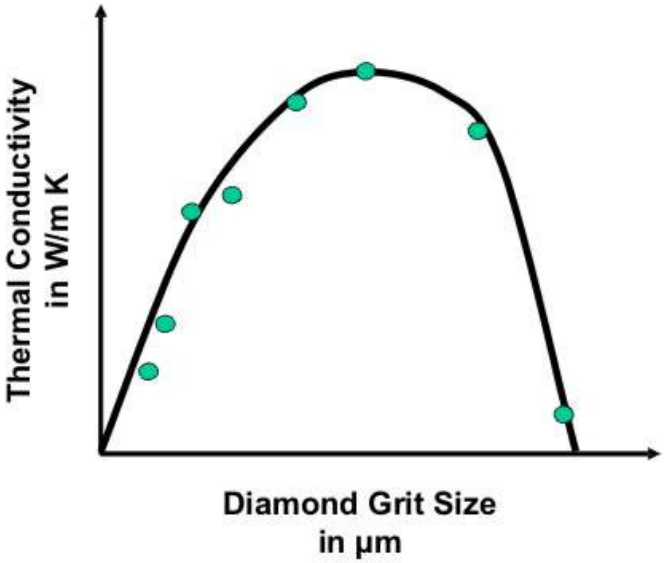
- Homogeneous distribution of diamond particles
- low microporosity
- Carbide phase between metal and non-metal facilitates mechanical and thermal bond

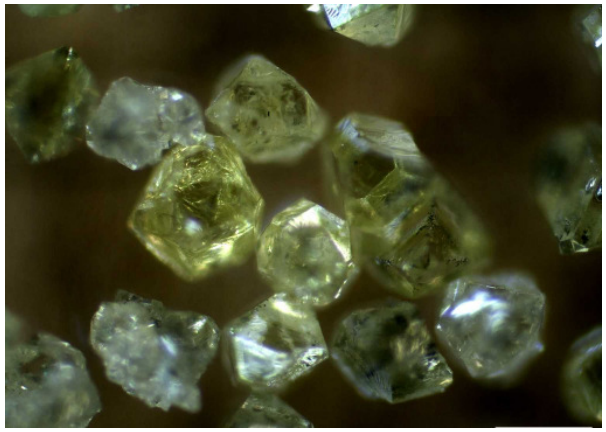
Diamond Composites | Thermal Conductivity vs Diamond Grade

The properties of the composite are affected by the type and size distribution of the diamond.

- Grade of diamond:
  - synthetic (type I) vs. natural (type II)
  - Content of Nitrogen and other impurities
  - amount of metallic inclusions
- Size distribution of the diamond particles
- Shape and surface of the diamond particles



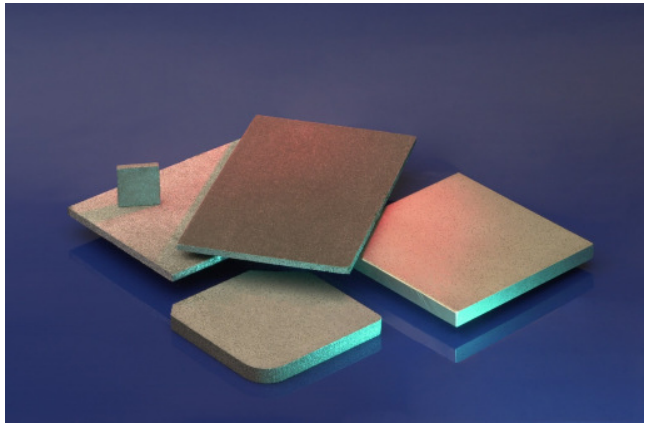


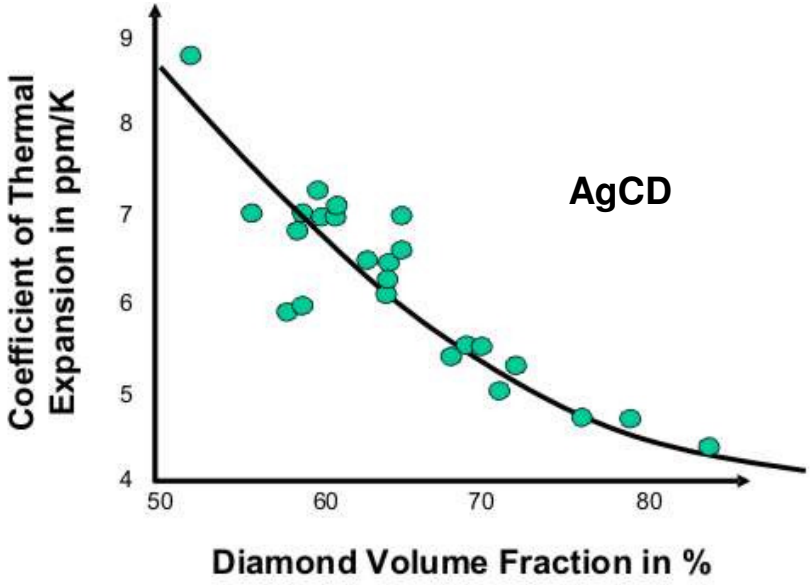


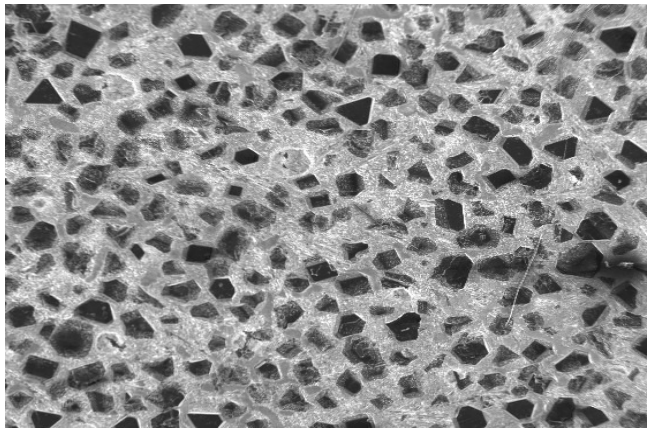
Diamond Composites | Thermal Expansion vs Diamond Content

Composite Material with high thermal conductivity (up to 700 W/mK) and tailored CTE (5 – 8 ppm / K)

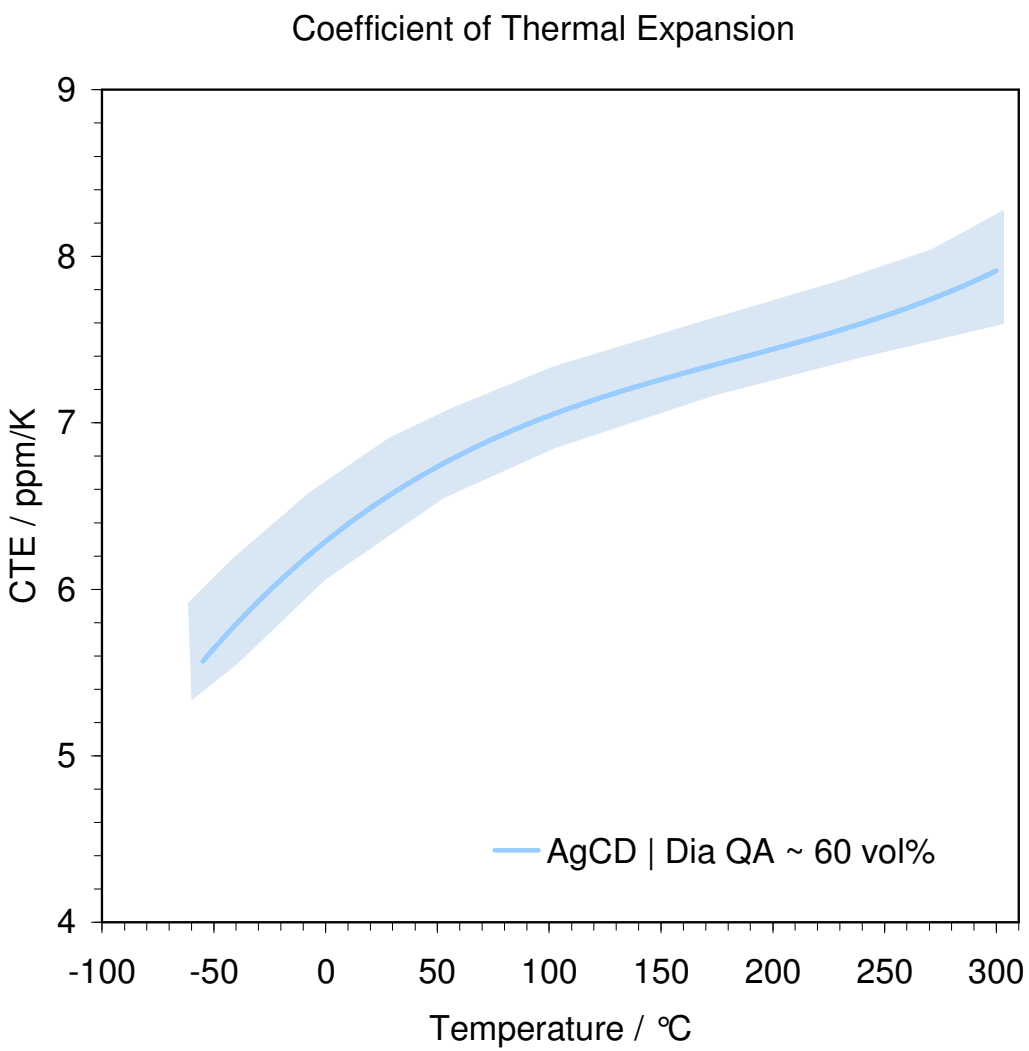
- Diamond particles are implemented in a highly thermal conductive metallic matrix (Ag, Cu, Al).
- The CTE can be tailored by the volume content of diamond.
- An estimation for the achievable thermal conductivity and CTE can be given by the Hashin-Strikman bounds.



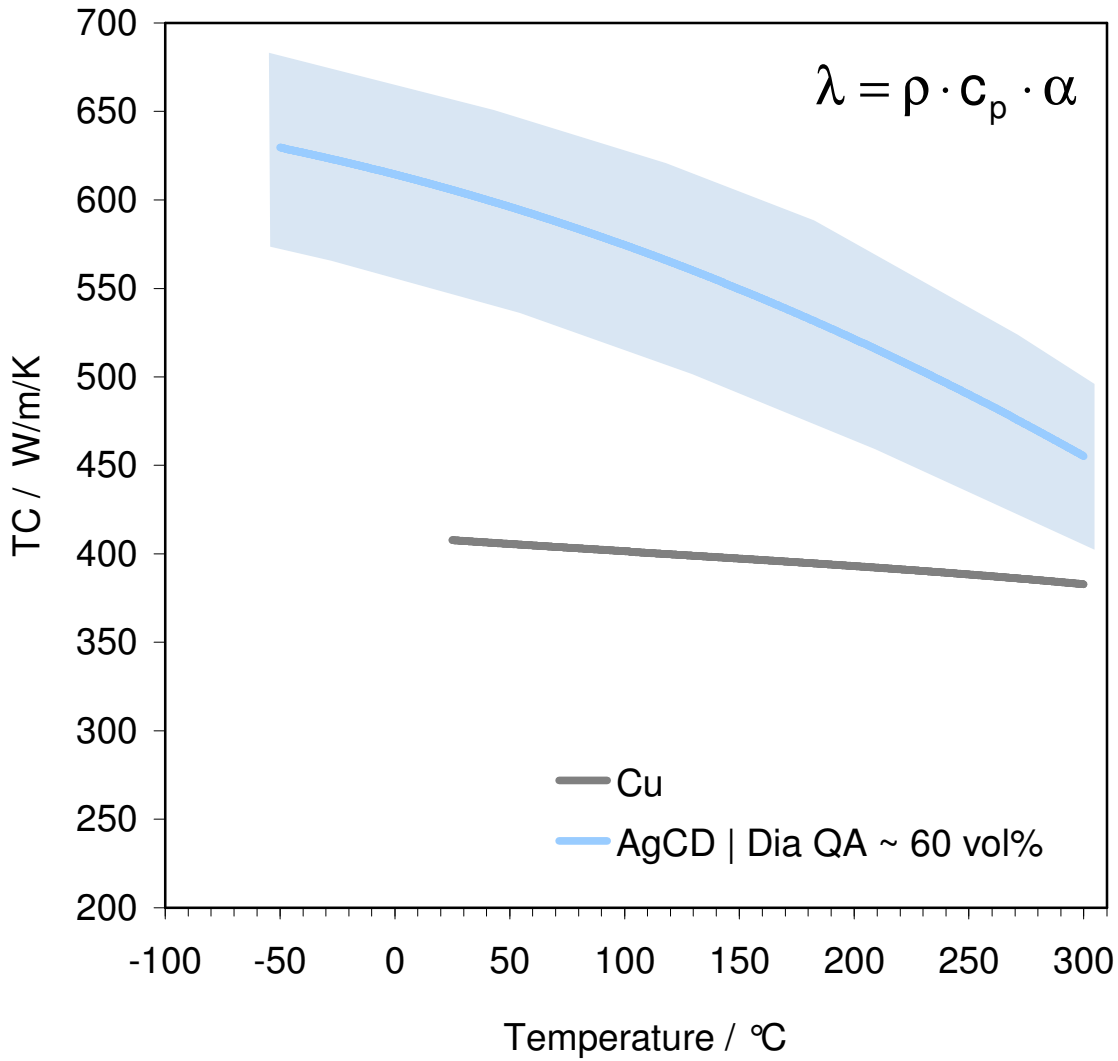




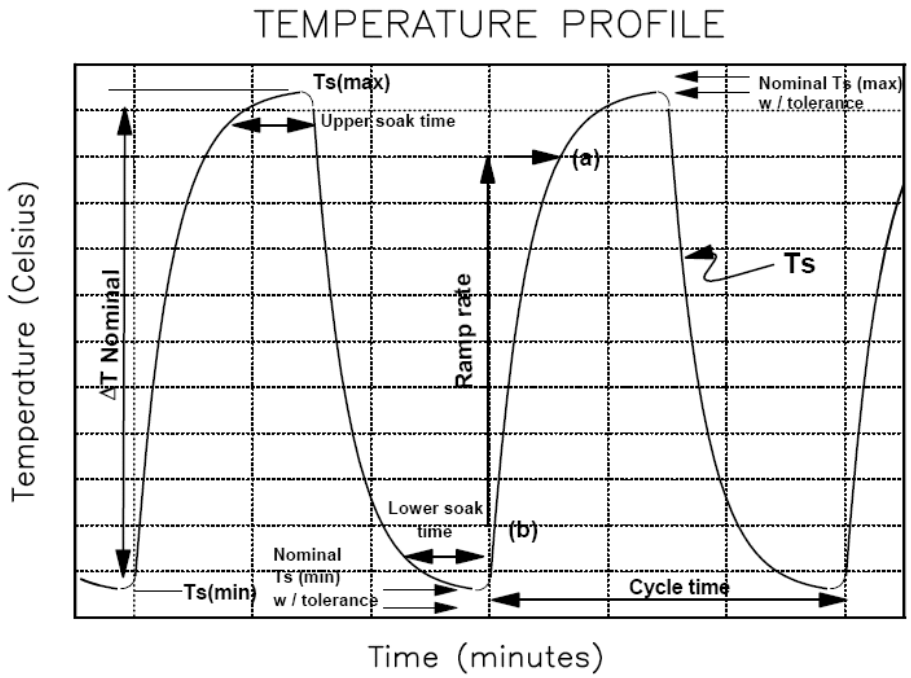
Diamond Composites | Coefficient of Thermal Expansion



Diamond Composites | Thermal Conductivity



Diamond Composites | Thermal Cycling Tests



Thermal cycling chamber

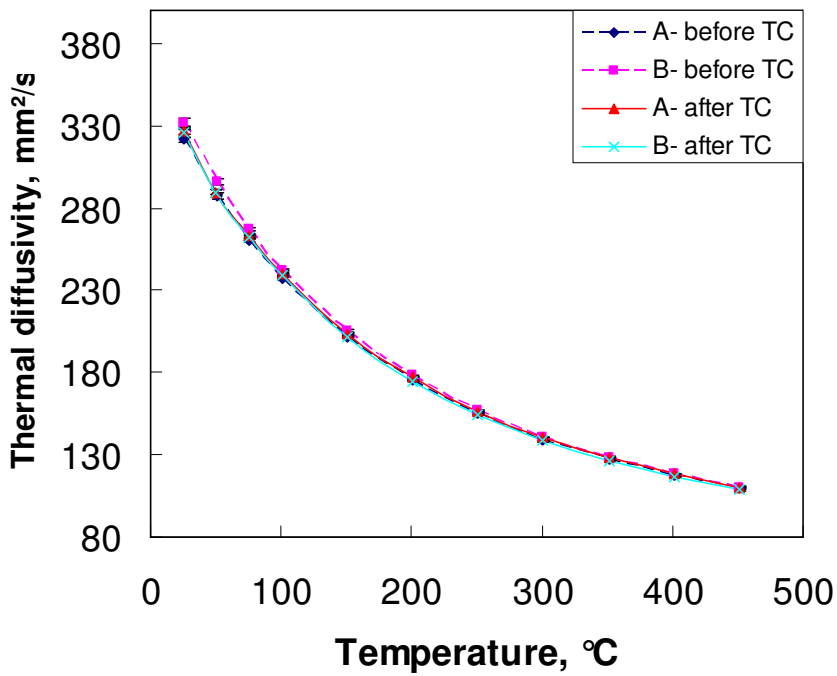
Thermal cycling tests were performed in a two chamber cycling oven according to JESD-A104-C (temperature cycle H and a soak mode 3):

Temperature: -55° C / +150° C,
1000 thermal cycles
20 min storage time in each chamber

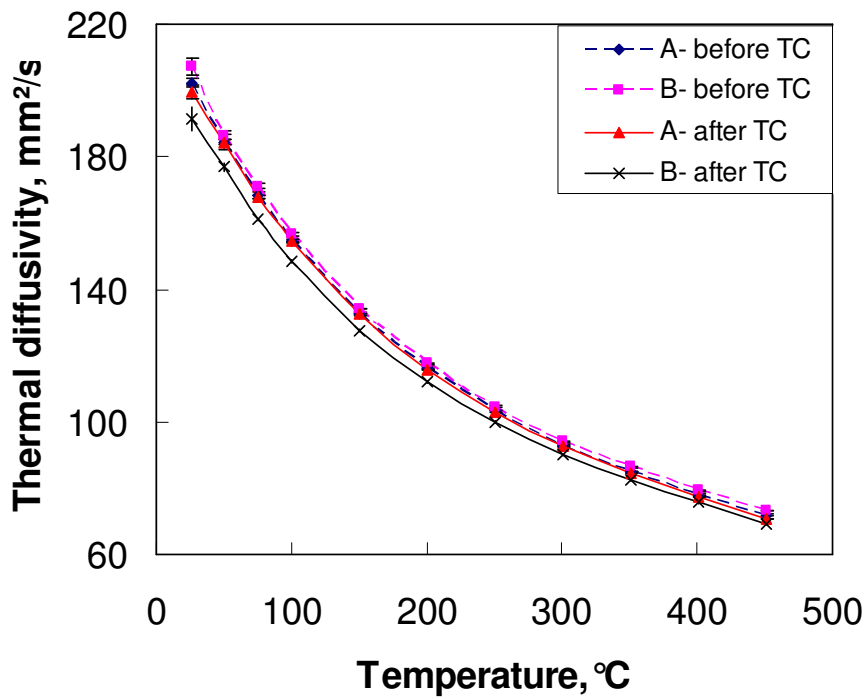
Courtesy: Siemens AG

Thermal Diffusivity | Before and after thermal cycling

Silver-diamond composite

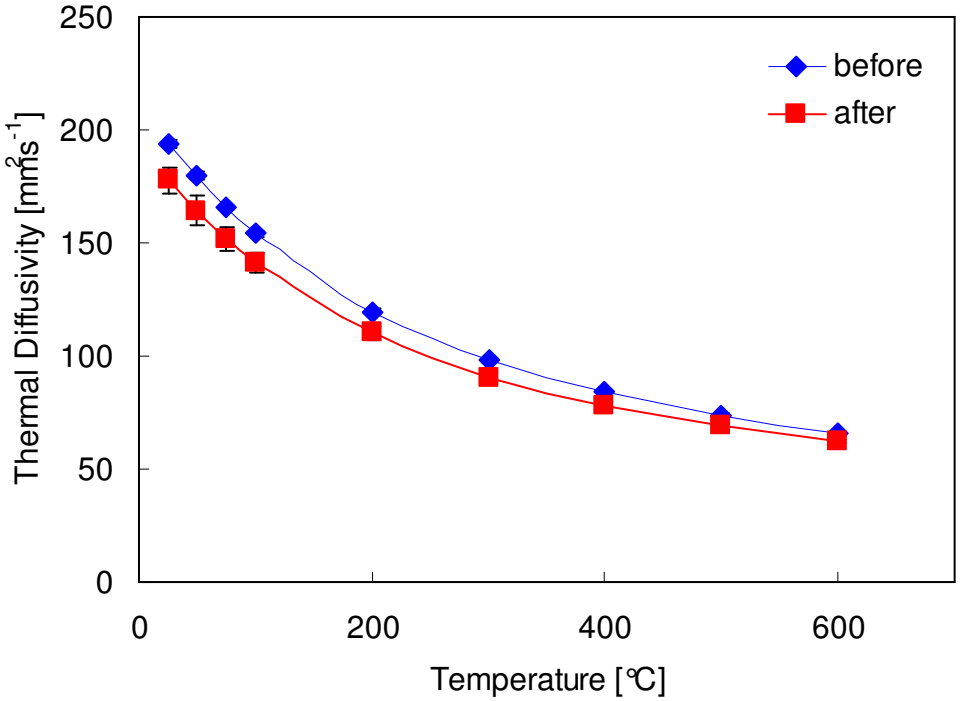


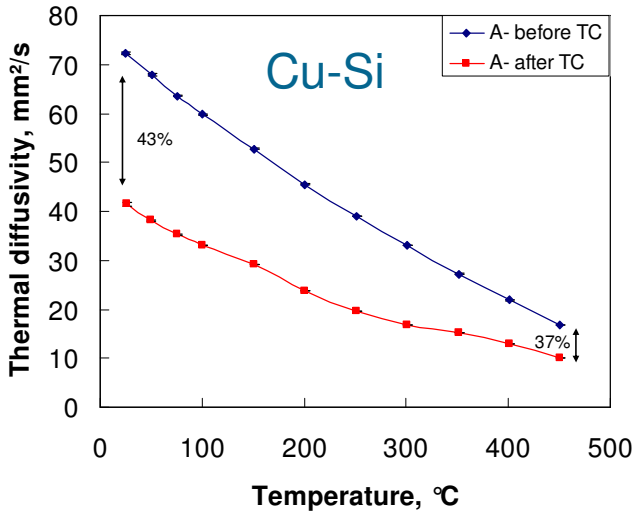
Aluminum-diamond composite

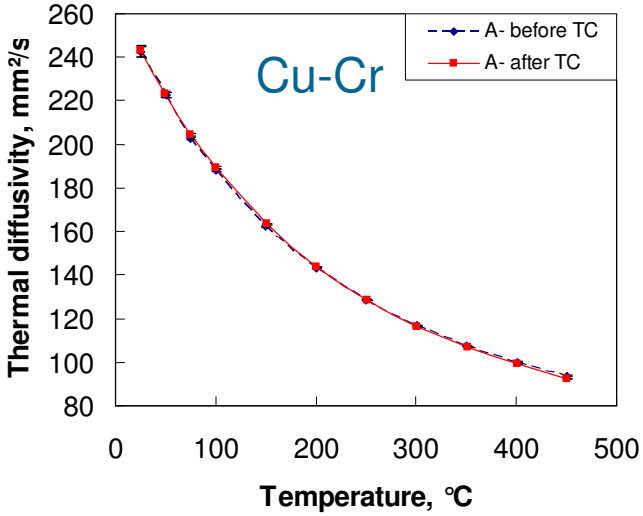


Thermal Properties | Before and after thermal cycling (CuCD)

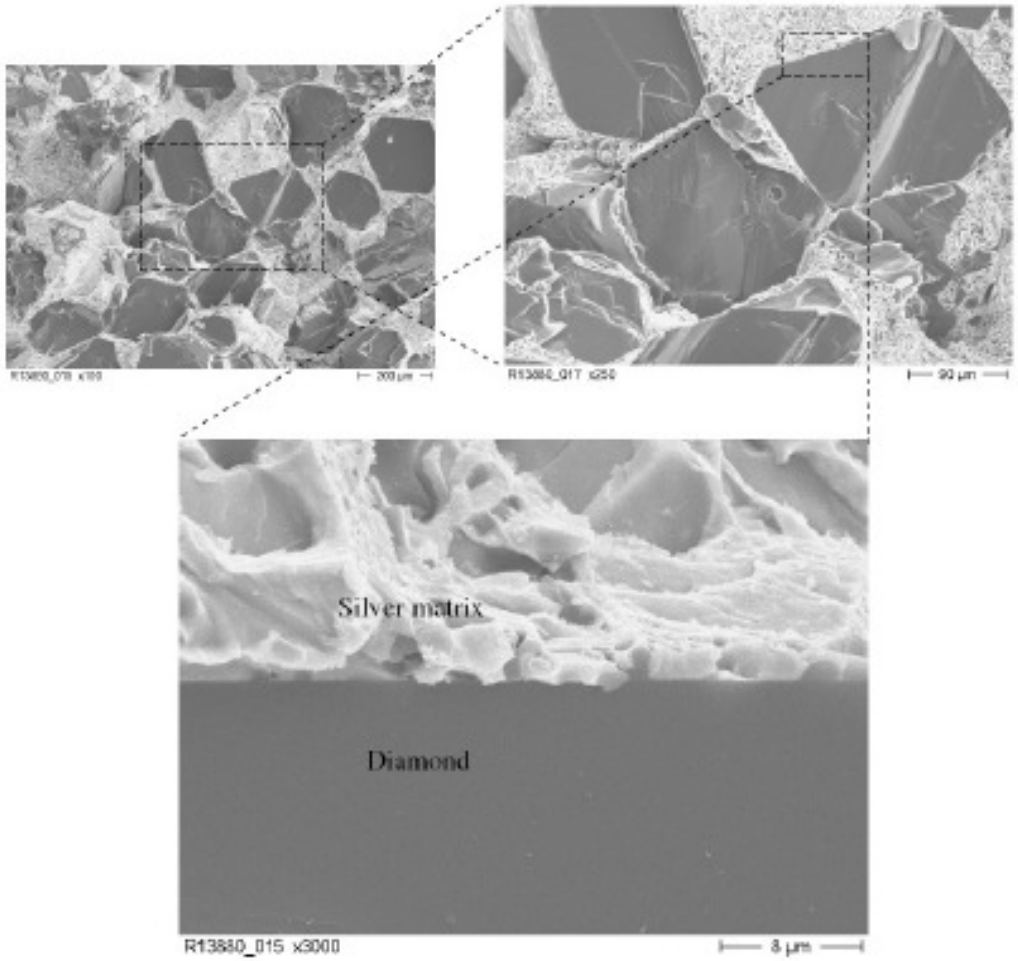
Copper-diamond composites





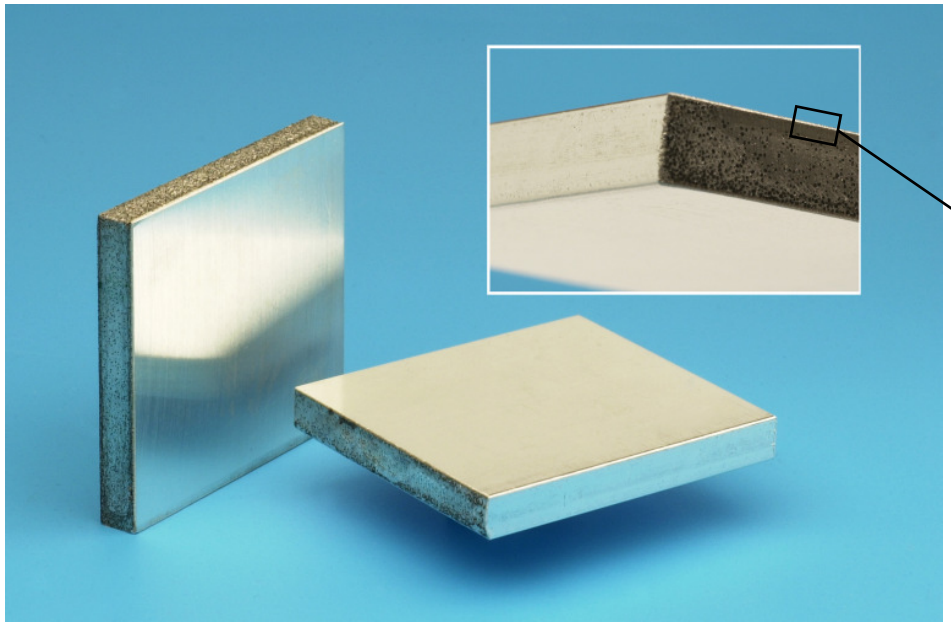


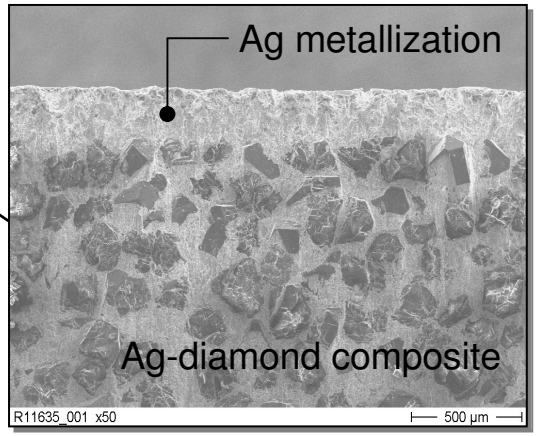
Fracture surface | After thermal cycling-AgCD



Intact Interfaces!

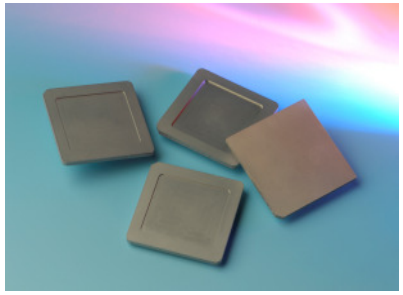
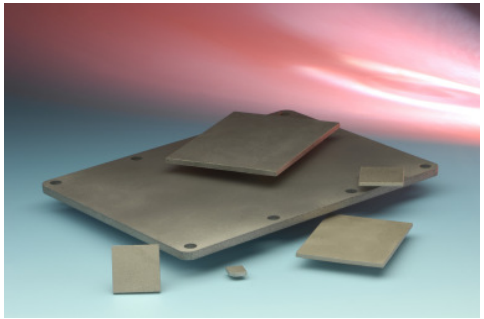
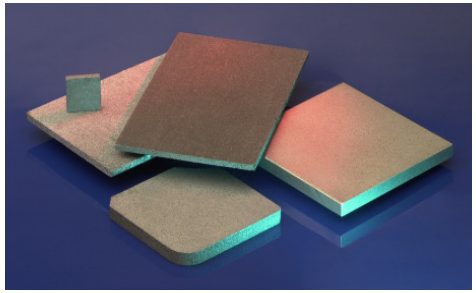
Diamond Composites | Surface Finish of AgCD Components

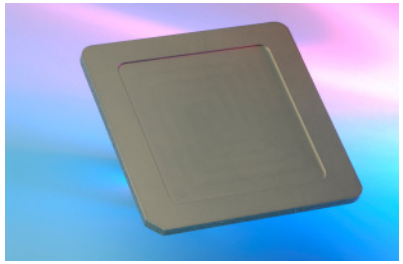
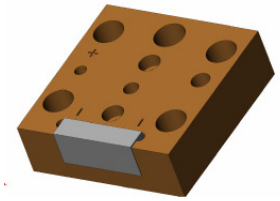
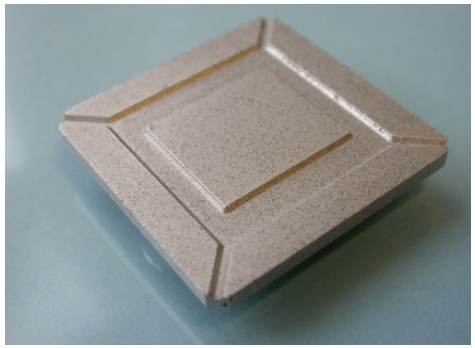


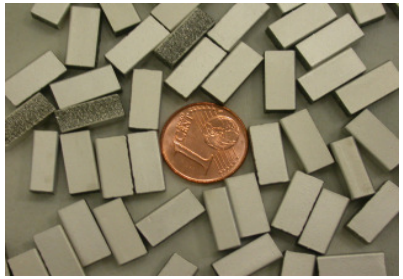


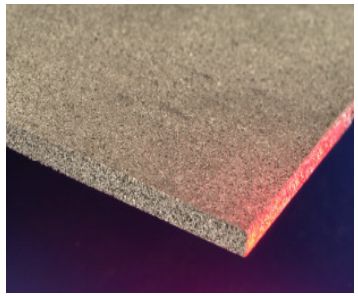
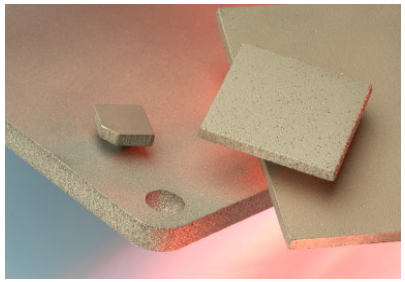
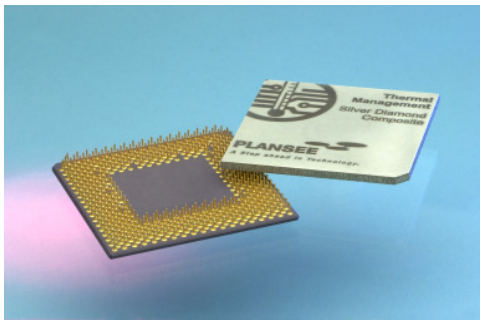
Silver diamond composite heat sinks can be provided with silver and copper metallization on top, bottom and lateral faces. Metallization allows conventional finishing processes, such as grinding, lapping, diamond milling, coating, etc..

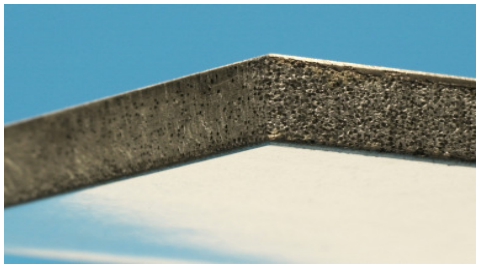
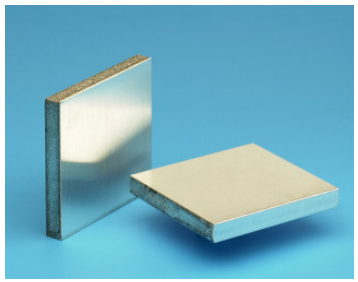
Diamond Composites | Product examples

Diamond Composites | Thermal and Physical Properties

		AgCD	AlCD	CuCD
Density [3]	20 °C [g/cm³]	6.0 – 6.2	2.9 – 3.1	5.5±0.04
Specific heat	20 °C [J/gK]	0.31	0.64	0.44
Thermal conductivity [2, 5]	20 °C / 100 °C [W/mK]	550 – 650 / 520 – 600	440 – 530 / 410 – 500	470 / 465
Coefficient of thermal expansion [1, 5]	20 °C / 200 °C [10^{-6}/K]	5.8 – 6.4 / 7.0 – 7.8	7.0 – 9.0 / 8.0 – 10.0	6.7 / 7.7
Specific electrical resistivity	20 °C [µΩcm]	8.5 – 9.0	10 – 20	9±0.8
Young's modulus (3-point-bending-test) [4]	20 °C [GPa]	250 – 300	220 – 250	255±10
Flexural strength (3-point-bending-test) [4]	20 °C [MPa]	320 – 380	100 – 120	230±10

[1] acc. to DIN 51045, [2] acc. to ASTM 1461-01, [3] acc. to DIN ISO 3325, [5] plated on both sides with 0,075 mm Ag

Stay cool!

- Questions??