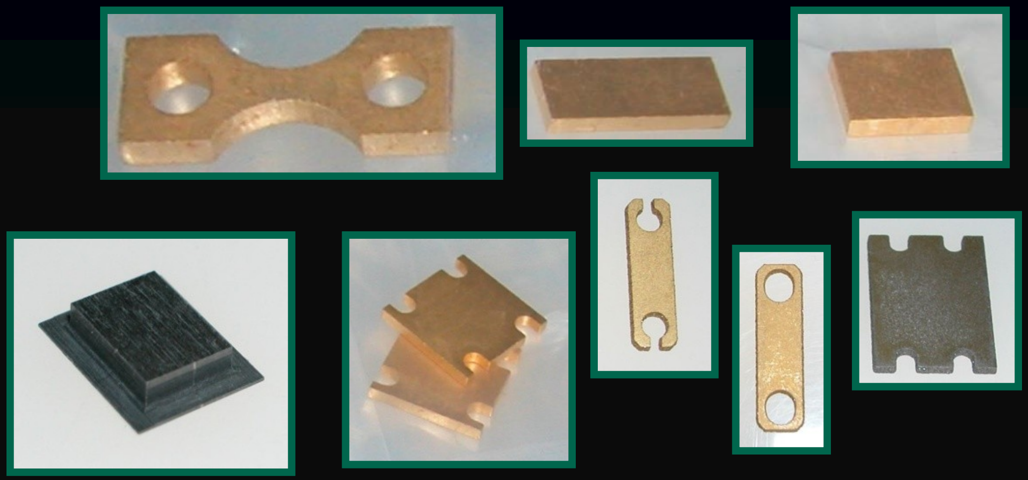
WAMICON 2011

Advanced Diamond based Metal Matrix Composites for Thermal Management of RF Devices



By

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INTERNATIONAL CORPORATION
Innovators of Nanomaterials and Nanocoatings

Agenda

- Thermal Management Packaging Flange Materials

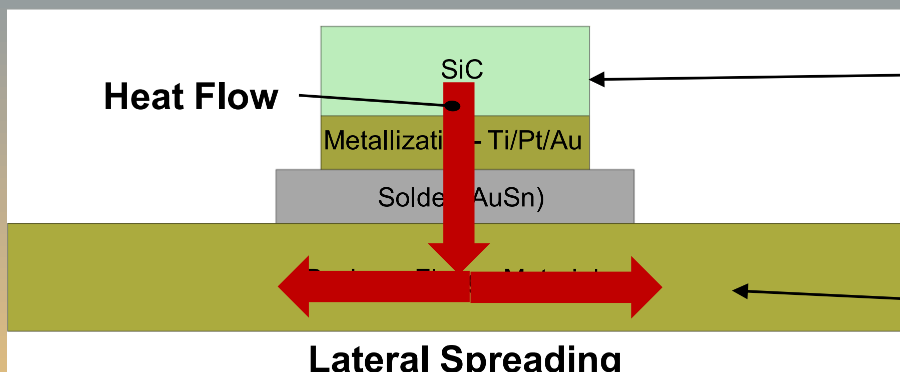
- GaN High Power Densities and the "New" RF Flange Material Requirements

- Aluminum Diamond Technology
    - Conversion Technology
    - Infiltration Technology
    - Surface Control Technology
    - Cutting Technology

- Thermal and Mechanical Properties

Thermal Management Packaging Materials

- RF Package Flange materials must have high thermal conductivity and a coefficient of thermal expansion close to that of the die material (e.g. Silicon Carbide)



TC=430W/mK, CTE=4

Current Materials:

W90Cu: 225 W/mK, CTE=6.5

CuMoCu: 220 W/mK, CTE=6.0

Thermal Management Packaging Material Properties

- RF Package Flange materials are typically a blend of copper for high thermal conductivity and Molybdenum or Tungsten to reduce the CTE

Material	Structure	Thermal Conductivity (W/mK)	CTE (ppm/K)
Cu	Pure	393	17
Diamond		1500	1.4
Silicon		136	4.1
SiC	4H-Si	430	4
AlSiC	63% SiC	>175	7.9
W90Cu	90% W	185	6.5
W75Cu	75% W	225	9
Mo70Cu	70% Mo	185	9.1
Mo50Cu	50% Mo	250	11.5
CuMoCu	1:4:1	220	6
CuMoCu	1:1:1	310	8.8
Cu/Mo70Cu/Cu	1:4:1 laminate	340	8

(1) GaN HEMT Technical Status: Transistors and MMICs for Military and Commercial Systems. Ray Pengelly, Cree RF, Research Triangle. Paper at IMS 2009 Boston

GaN High Power Densities

- GaN device power density is a function of operating voltage

- Increased operating voltage leads to increased RF power density

- Power densities in GaN devices can range from 4 to 11 watts per millimeter of gate periphery[(2)]

- High power densities lead to challenge for existing thermal management packaging materials which can lead to de-rating due to thermals

- This reduces the performance potential for the product

(2) GaN HEMT Technical Status: Transistors and MMICs for Military and Commercial Systems. Ray Pengelly, Cree RF, Research Triangle. Paper at IMS 2009 Boston

"New" RF Flange Material Requirements

- New flange materials are required that have higher thermal conductivity and a CTE matched to Silicon Carbide

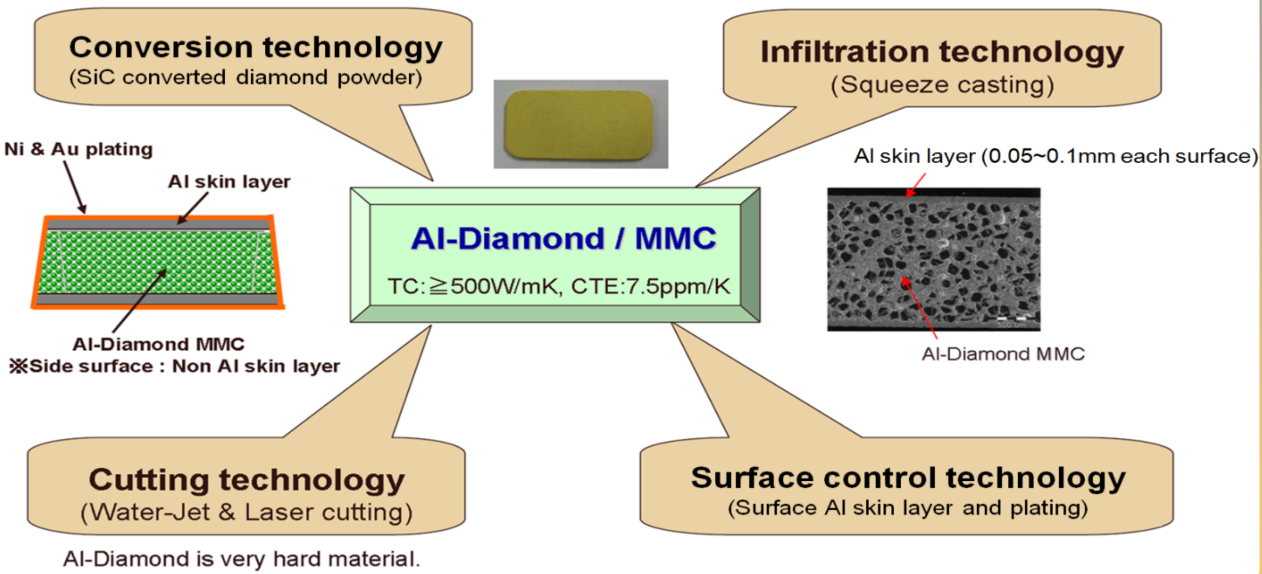
Requirements:

- ❑ Thermal Conductivity > 500 W/mK
- ❑ Low Coefficient of Thermal Expansion (4 to 8 ppm/K)
- ❑ Low Surface Roughness (< 1.0µm Ra, 40 µinch)
- ❑ Metallization that leads to successful die attach
- ❑ Good dimensional tolerances and material stability

Aluminum Diamond Technology

Aluminum Diamond is a Metal Matrix Composite (MMC) that consists of high conductivity diamond particles in combination with aluminum alloy metal that provides a high performance flange package material

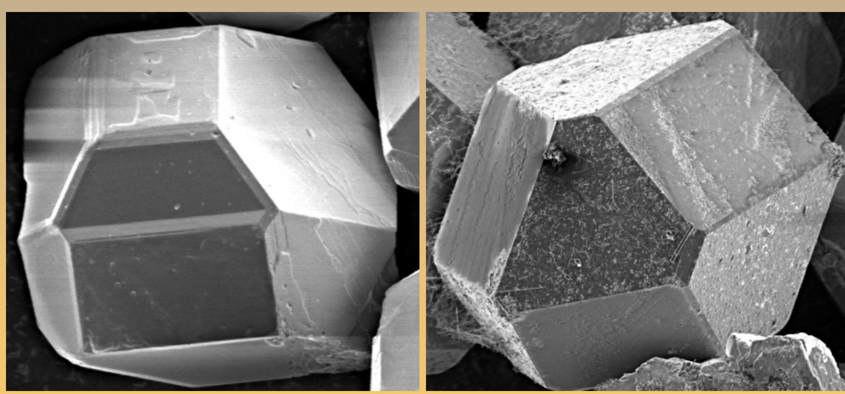
1) Diamond Conversion
2) Metal Infiltration
3) Surface Control
4) Cutting



Key technological features of Aluminum Diamond material

Diamond Conversion Technology

- Diamond particles are low cost synthetic diamond (typically used by the polishing industry). They have thermal conductivity ranging from 1000-1500 W/mK
- Diamond particles are surface converted with SiC layer
- This SiC surface conversion is critical in providing interface between diamond and aluminum alloy and provides high thermal conductivity and thermal stability for the MMC



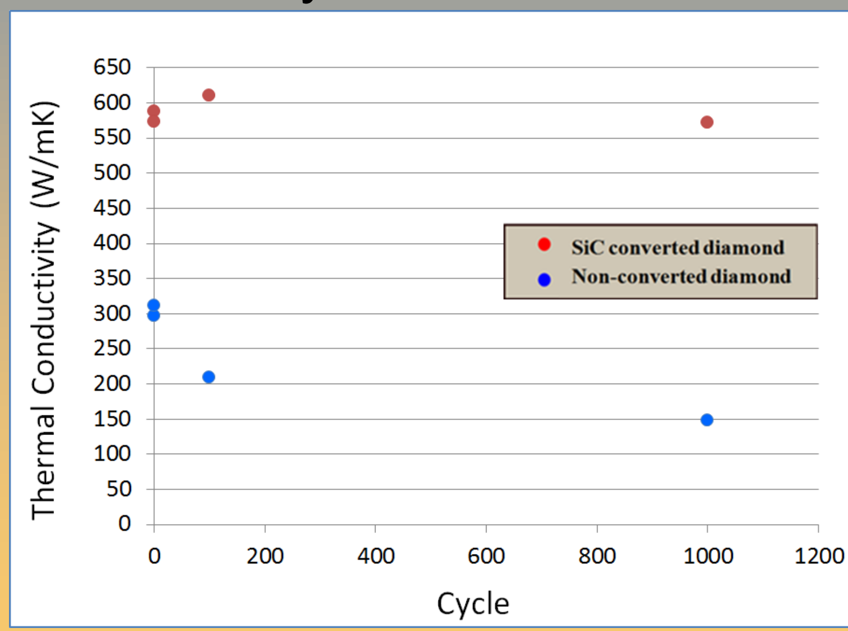
Non-converted and Converted Diamond Particle

Non-converted and Converted Diamond Powder

Diamond Conversion Technology

- Comparison of MMCs made with and without SiC converted diamond powder show rapid decrease in thermal conductivity for MMC made with non-converted diamond after several high temperature cycles

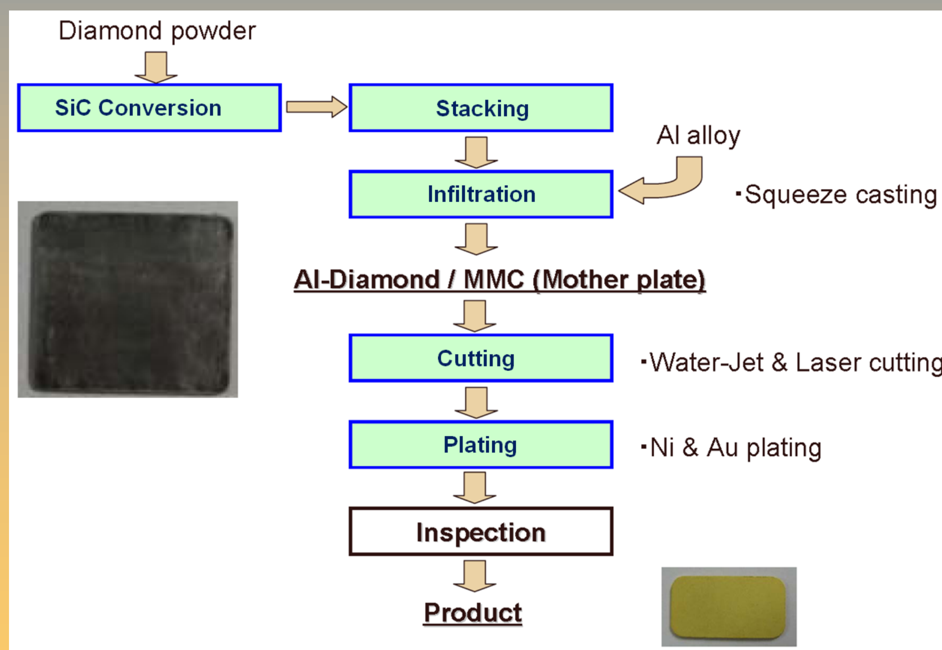
- This shows breakdown of thermal interface between diamond particles and aluminum alloy matrix



Comparison of Thermal Conductivity after cycling (-40 C x 30min/120 C x 30min, Air)

Metal Infiltration Technology

- Aluminum Diamond MMC fabrication involves “squeeze casting” process for forcing molten aluminum alloy into tooling that contains surface converted diamond powder
- Pressures are between 50-150MPa. Mother plate (e.g. 40mm x 40mm) that is used to produce RF flanges is obtained from this process

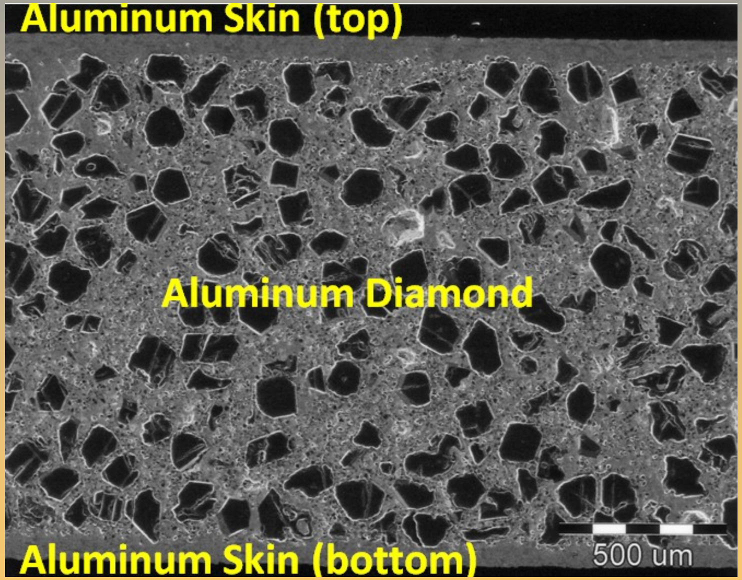


Metal Infiltration Technology

- High pressures are achieved by mechanical compression of the molten aluminum alloy into a sealed die that contains tooling holding the diamond powder
- The tooling is stacked and the molten aluminum alloy infiltrates through the tooling and into the diamond powder and solidifies
- Several hundred mother plates are produced per infiltration "shot" and are produced to the customer requested thickness
- Depending on RF Flange size, this produces several thousand parts per shot
- Squeeze casting is a proven high volume production method and is used to produce Aluminum Silicon Carbide thermal management materials

Surface Control Technology

- For successful die attach, flanges require smooth surface and quality plating. Die voiding can cause rapid device failure
- An in-situ produced aluminum alloy skin (0.05-0.010mm) is applied to the top and bottom surfaces of the flanges to provide surface roughness < 1.0µm Ra



Cross Section of Aluminum Diamond MMC

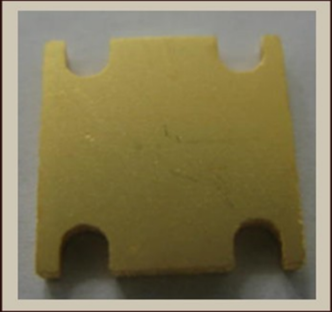
Surface Control Technology

- Ni/Au plating is applied to the Aluminum Diamond MMC to support die attach
- Electroless nickel followed by electric nickel plating with a combined thickness of 7.0µm is utilized as the initial plating layer
- Electric gold plating of 2.0um is then applied
- Chemical resistance test and bake test performed to validate plating
- No weight loss or blisters observed after tests

1) Application of NMIC standard plating: Ni (7µm) + Au (2µm)
2) Test conditions (chemical resistance):
    a. $H_2SO_4/H_2O_2/H_2O$ = 5/1/1, 85°C x 2 minutes
    b. HCl (18%), 25°C x 2 minutes
    c. KOH (12N), 85°C x 2 minutes
3) Heating test: 450°C x 10 minutes

Sample	Plating		Weight loss (mg/cm^2)		
	Ni	Au	H_2SO_4	HCl	KOH
STD. Type	7µm	2µm	0	0	0

450℃×10min.

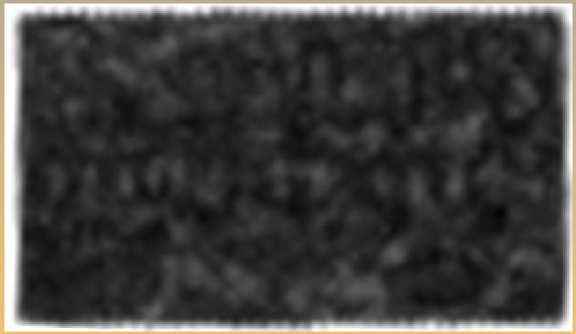


Surface Control Technology

- Die attach testing performed by end user with AuSn solder

- Validation testing successfully performed consisting of yield evaluation, RF testing, thermal cycling, and RF thermal testing

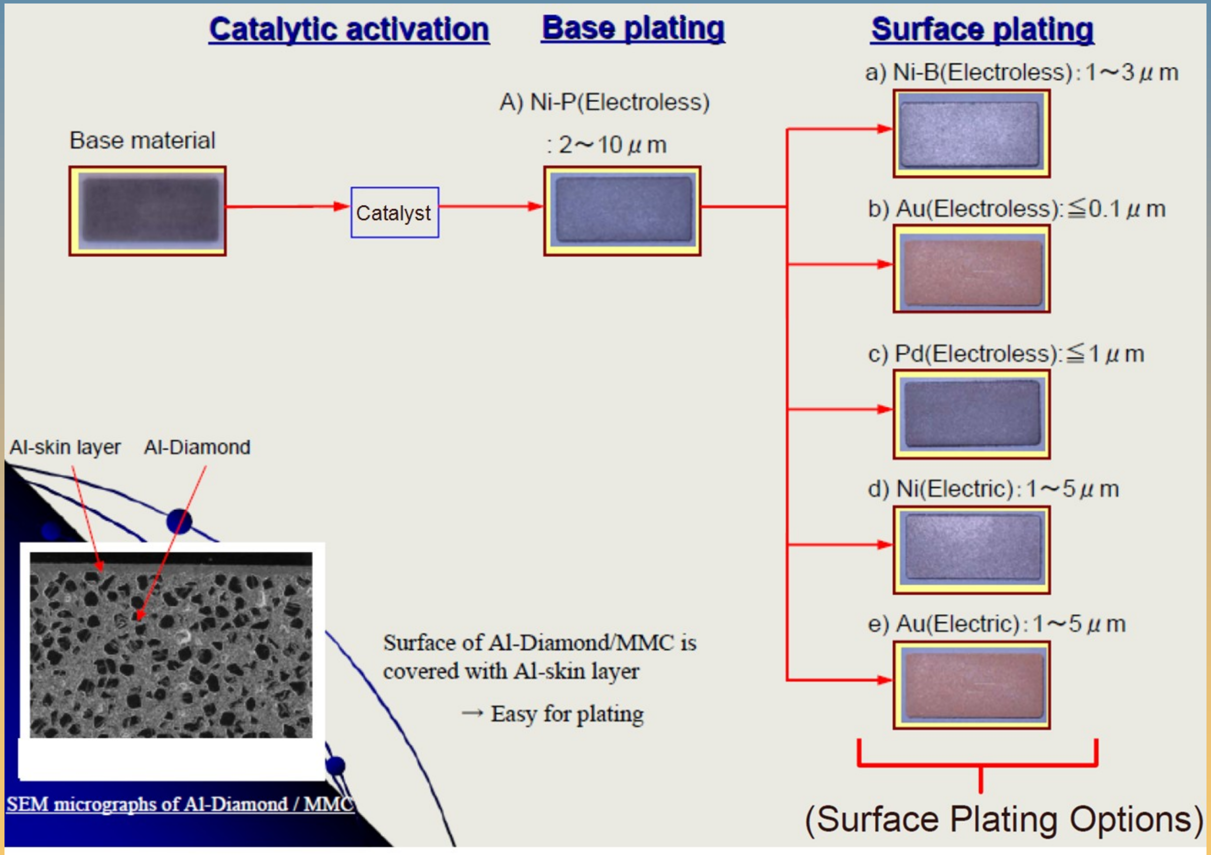
- SAM (Scanning Acoustic Microscopy) imaging performed on parts that illustrates no voiding under the die



SAM image showing no voiding
(courtesy of Cree)

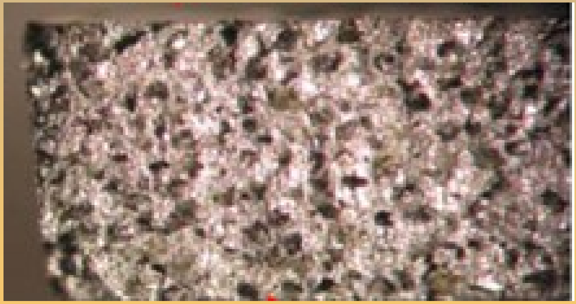
Surface Control Technology

- Plating thickness and type configurable to customer requirements

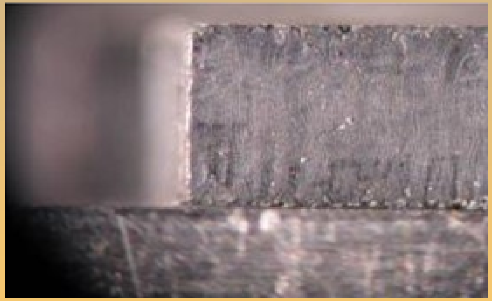


Cutting Technology

- The diamond particles in the MMC make aluminum diamond very difficult to cut by conventional methods (e.g. milling or grinding)
- Aluminum Diamond flanges are cut from the mother plate to specific dimensions by waterjet or laser cutting
- Waterjet cutting is faster than laser cutting but at the expense of edge sharpness.
- For the waterjet, the diamond particles are cleaved whereas the laser sees the diamond as carbon and vaporizes the diamond



Edge view of Waterjet cut part



Edge view of Laser cut part

Cutting Technology

- The dimesional design rules for Aluminum Diamond are presented
- Size, hole size, distance from side to hole, and taper tolerances dictated by cutting method
- Thickness, flatness, surface roughness, and plating tolerance governed by processing steps

Item	Standard	Special	Notes
Size Tolerance (mm)	±0.1*1	±0.05*2	*1 Waterjet *2 Laser cut
Thickness tolerance (mm)	±0.1	±0.05	
Max. thickness (mm)	3.0		
Thickness tolerance (mm)	±0.1	±0.05	
Side taper/thickness (μm/mm)	40*1 to 50*1	10*2	*1 Waterjet *2 Laser cut
Min. hole size (mm)	Ø0.5*1	Ø 0.3*2	*1 Waterjet *2 Laser cut
Min. distance from side surface to hole	0.7*1	0.5*2	*1 Waterjet *2 Laser cut
Tolerance of Plating thickness (μm)	±1.0	±0.5	
Flatness (μm/inch)	≤ 50	≤ 40	
Surface roughness Ra (μm)	≤ 1.5	≤ 0.6	

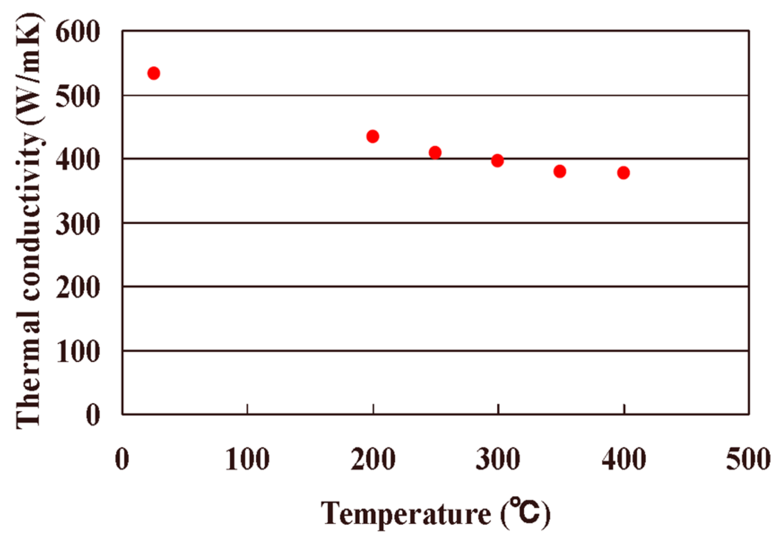
Thermal and Mechanical Properties

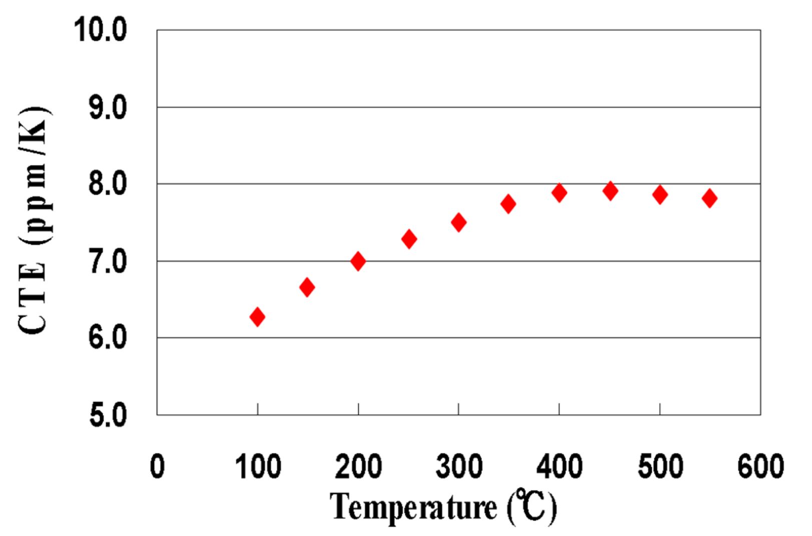
- General material properties for Aluminum Diamond are below
- Thermal Conductivity greater than 500W/mK
- CTE is 7.5ppm/K

Item	Typical Data
Diamond Content (Vol%)	57
Density (g/cm^3)	3.17
Thermal Conductivity (W/mK)	500
Specific Heat (J/gK)	0.62
Coefficient of Thermal Expansion (ppm/K)	7.5
Flexural Strength (MPa)	300
Young’s Modulus (GPa)	340
Electrical Resistivity (Ω-m)	3.7×10^{-7}
Surface Roughness (μm Ra)	< 1.0
Melting Point (°C)	570

Thermal and Mechanical Properties

- Aluminum Diamond's thermal conductivity and CTE with respect to temperature are presented





Thermal conductivity
Laser Flash : ULVAC TC 7000 (JIS R 1611)

CTE
Rigaku TMA 8310 (JIS R 2207)

Conclusions

- Aluminum Diamond is a replacement RF flange materials for CuW or CuMo materials
- Thermal conductivity >500W/mK, CTE = 7.5ppm/K
- Dimensional tolerances and surface roughness can meet existing RF flange requirements
- Ni/Au plating provides base for successful die attach using AuSn solders
- Testing shows 25% reduction in die junction temperature allowing devices to operate without de-rating

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