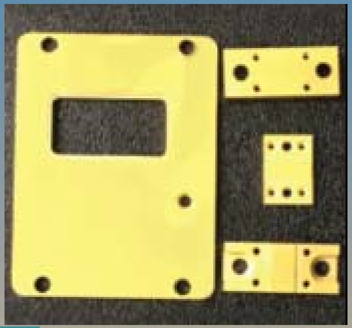
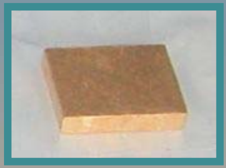
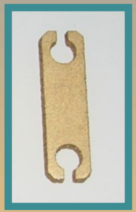
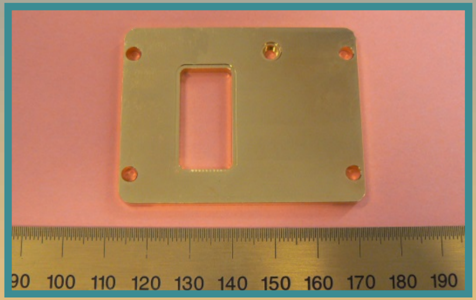
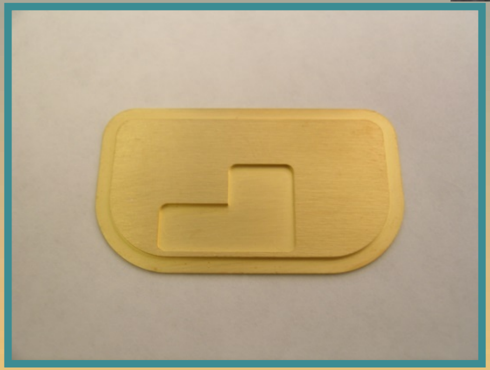
A Novel Thermal Management Approach for Packaging of High Power GaN Devices

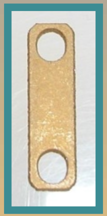












April 6th, 2016

NANO MATERIALS INTERNATIONAL CORPORATION
Innovators of Nanomaterials and Nanocoatings

saes group SMI Spectra-Mat, Inc.
a SAES Group company

Agenda

- Thermal Management Flange and Package Materials
- GaN High Power Densities and the “New” RF Flange and Package Material Requirements
- Hybrid Thermal Solution Concept & Benefits
- Joining Methods
- Joint Validation
- Conclusions

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Company Introduction

Nano Materials International Corporation (NMIC)

NMIC is a design, manufacturing, and sales organization located in Tucson, Arizona that supplies the highest performing material, called Aluminum Diamond, for the RF amplifier, Laser Diode, and Cutting Tool markets.

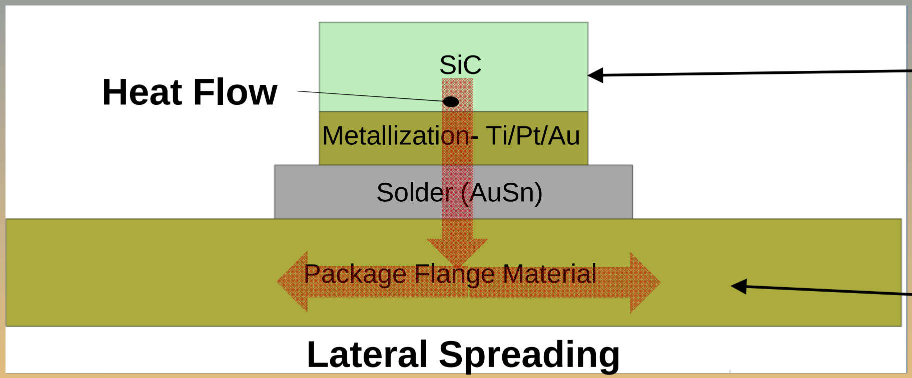
Spectra-Mat

Spectra-Mat leverages over 50 years of engineering and manufacturing experience in serving the high power semiconductor laser, RF and MW industries with tungsten copper and moly copper parts.

Spectra-Mat controls every single production steps in USA of tungsten copper parts from powder purity to dedicated plating line.

Thermal Management Flange and Package Materials

- RF flange and package 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

Traditional Material:

W90Cu: 225 W/mK, CTE = 6.5

HTC Material:

Aluminum Diamond: 500W/mK, CTE = 7.0

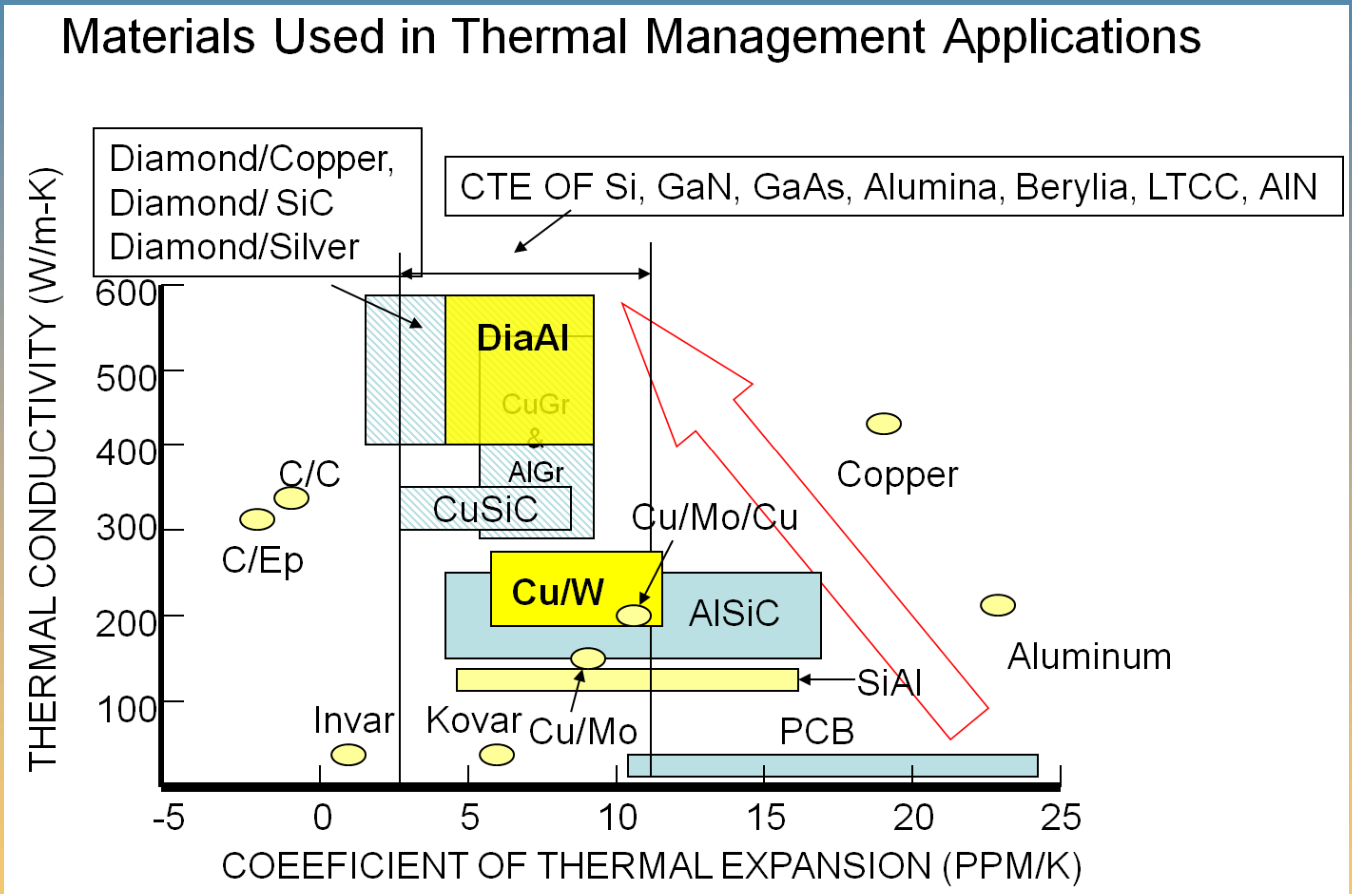
Thermal Management Flange and Package Material Properties

- RF flange and package 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

Thermal Management Flange and Package Materials



(2) HTM Source

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[(3)]

- 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

(3) 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 and Package Material Requirements

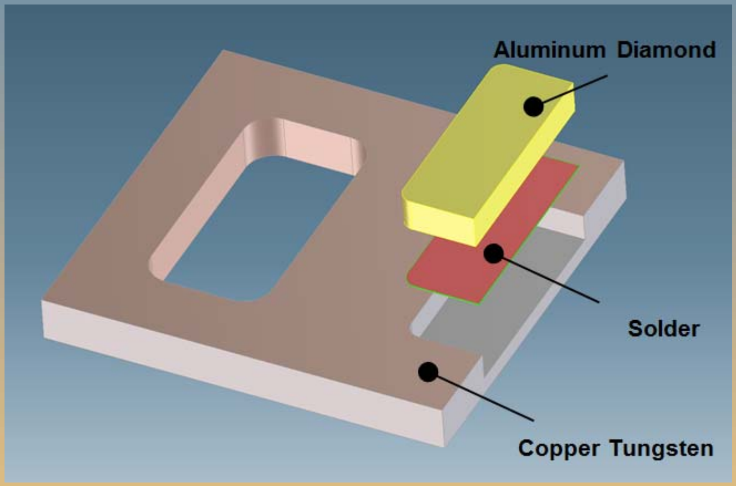
- New flange and package materials are required that have higher thermal conductivity and a CTE matched to Silicon Carbide

Requirements:

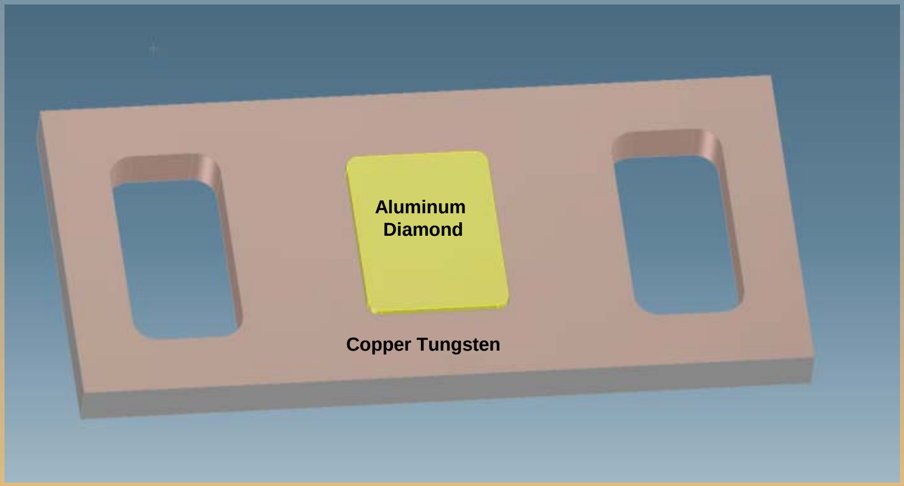
- ❑ Thermal Conductivity > 500 W/mK
- ❑ Low Coefficient of Thermal Expansion (4 to 8 ppm/K)
- ❑ Low Surface Roughness (< 0.84 µm Ra, 32 µinch achieved)
- ❑ Metallization that leads to successful die attach
- ❑ Good dimensional tolerances and material stability
- ❑ Machinable
- ❑ Ability to support complex 2d and 3d shapes
- ❑ Ability to support larger sizes (> 2" x 2")

Hybrid Thermal Solution Concept & Benefits

It is proposed to combine Copper Tungsten with Aluminum Diamond for a thermal solution that achieves the best properties of both materials.



Cross Section of Aluminum Diamond Joined to Copper Tungsten base



Examples of Aluminum Diamond flange joined to Copper Tungsten base

Hybrid Thermal Solution Concept & Benefits

It is proposed to combine Copper Tungsten with Aluminum Diamond for a thermal solution that achieves the following benefits utilizing the best properties of both materials.

1. Selective location of HTC (high thermal conductivity) material (Aluminum Diamond) for thermal and weight challenged devices.

2. CTE matched Copper Tungsten provides a machinable material for fabrication of complex 2D and 3D shapes and support of large package size.

3. Hybrid solution is economically viable.

	Aluminum Diamond	**Copper Tungsten**	
Base Material	AS-D60	Wcu 94/6	W/Cu 90/10
Thermal Conductivity (W/mK)	500	176	201
CTE (x 10^{-6} /°C)	7	5.8	6.2
Specific Heat (J/g°C)	0.62	0.037	0.038
Density (g/cc)	3.2	17.6	17.2
Machinability	Difficult	Excellent	Excellent

Joining Methods

Requirements and Methods:

1. Aluminum Diamond and Copper Tungsten should be Ni/Au plated prior to joining. Side gap between materials should exist for maximum and minimum material tolerances.

2. AuSn or AuGe solder to be utilized to join the two materials.
   - Note melting point of gold will increase, allowing subsequent die attach using AuSn (controlled temperature range)
   - Some customer may request AuGe bond of Aluminum Diamond to Copper Tungsten to allow greater temperature window for AuSn die attach

3. Other materials could be used such as:
   - Silver epoxies
   - Silver pastes
   - Silver films

Joining Methods – Attach material Properties

General Properties of attach materials

Alloy Properties

Property	AuSn
Liquidus (oC)	280
Solidus (oC)	280
Processing Peak Temp (oC)	320-340
Density (g/cm3)	14.18
Electrical Resistance (microhms cm)	20.7
Electrical Conductivity (%IACS)	8.3
Thermal Conductivity (W/mK)	58
Tensile Strength (PSI)	40,000
Yield Strength (PSI)	36,500
Elongation (%)	2.1

AuSn 80/20 – Materion
Type = Au based solder
Peak temp = 320-340°C

	Argomax® 8020
Application	Film – Die Transfer Film
Sintering Temperature	200-300°C
Thermal Conductivity	200-300W/mK
Common substrates	DBC
Surface Finish Compatibility	Ag , Au

Argomax 8020 – Alpha
Type = Silver based die transfer film
Peak temp = 300°C

Item	Data	Appendix
Cure condition	200 deg. C 90 min.	no pressure, in air
Viscosity	140 Pa*s	E type viscometer 0.5 rpm
Elastic modulus	17.6 GPa	Tensile test
Coefficient of thermal expansion	19 ppm	TMA method
Thermal conductivity	> 200 W7m*K	Laser flash method
Volume resistance	6μ Ω	Four point probe method
Shear strength at 260 deg. C	> 30 MPa	Die backside Au/Ag plated CU LF
Applicable adhered	Ag, Au, Bare Cu	-

Pressureless Silver Sintering Paste – Kyocera
Type = Silver paste
Peak temp = 200°C

CURED PROPERTIES (after 110°C, 60 minute pre-bake and 200°C, 30 minute cure)					
Thermal conductivity	60	45	12	W/m°K	
Electrical resistivity	8	9	35	μΩ-cm	
Adhesion	3,200	2,200	4,000	PSI	250-mil silicon die shear, bare ceramic
Thermal expansion	26	26	35	ppm/°C	
Flexural modulus	600,000	500,000	800,000	PSI	
Ionic impurities	<30	<30	<30	ppm	Total of Cl-, F-, K+, and Na+
Silver content	93	93	85	%	By weight
Density	6.7	6.7	4.9	g/cc	

DM6030Hk – Diemat
Type = Silver Loaded Epoxy
Peak temp = 200°C

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Joint Validation

- It is important to validate that a void free bond exists between Aluminum Diamond and Copper Tungsten. Several methods can be utilized:

- Non-destructive
  - Sonoscan of interface to examine bond to look for homogenous properties
  - Laserflash of bond in several locations to look for consistency in thermal diffusivity across the bond

- Destructive
  - Cross section part and mechanically polish
    - Examine with SEM and EDAX
  - Cross section part and Argon ion beam polish
    - Examine with SEM and EDAX

Joint Validation - Sonoscan™

- Acoustic micro-imaging such as Sonoscan can be used to provide image of bond joint between Aluminum Diamond and Copper Tungsten

- Image analysis software from the Sonoscan system can be used to examine joint interfaces (solder-Copper Tungsten and solder-Aluminum Diamond) and solder joint itself.

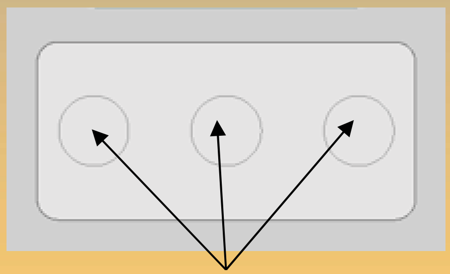
- Process is accurate, quick, and non-destructive. Can be used inline in production.

Joint Validation - Laserflash

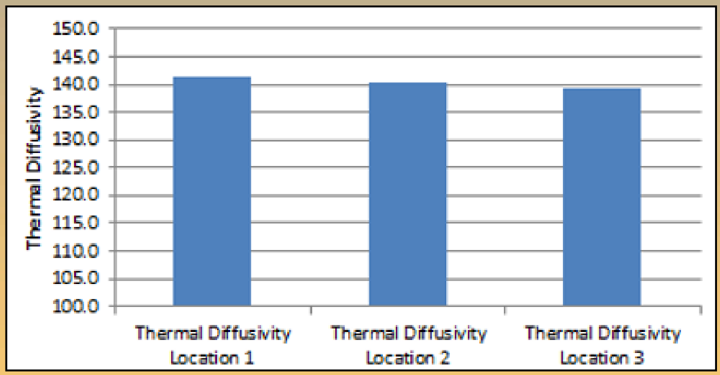
- Laserflash system can be used to measure effective thermal of hybrid structure.

- Netzch LFA447 system with matrix stage was utilized to examine thermal diffusivity of an Aluminum Diamond hybrid at different locations.

- Objective is to look for uniformity in results at different locations of the joined interfaces.



Region of Measurements
3.7mm Aperture Diameter shown



Thermal Diffusivity versus Location

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Joint Validation – Mechanical Polish

- Hybrid material can be cross sectioned with waterjet and the cross section mechanical polished.

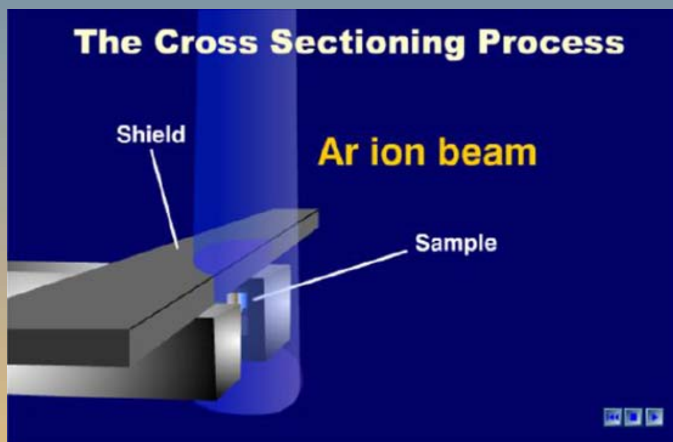
- Diamond wheels should be utilized to surface grind Aluminum Diamond and Copper Tungsten

- Stereo, SEM, and EDAX analysis can be utilized to examine joint

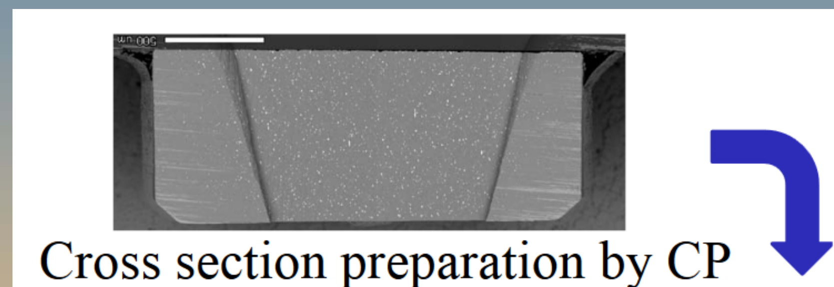
Joint Validation – Argon Ion Beam Polish

- Hybrid material can be cross sectioned with waterjet and cross section Argon Ion Beam polished. ~ 1mm x 1mm section case be polished

- Stereo, SEM, and EDAX analysis can be utilized to examine joint



JEOL CP Process



Reference: JEOL

- SEM, and EDAX analysis can be utilized to examine joint

Conclusions

- Hybrid solution offers superior thermal management especially for complex or large heatsinks.
  - Effective TC of 500 W/mk and CTE of 7 ppm/K
- Allows design schemes that would be otherwise uneconomical for that level of performance.
- Presently manufacturable at competitive cost in a variety of formats.
- Proven concept, and we have the capability to test the assemblies as required.