Metal Coated Particles and Defense Applications

Technical Briefing

Presented to:

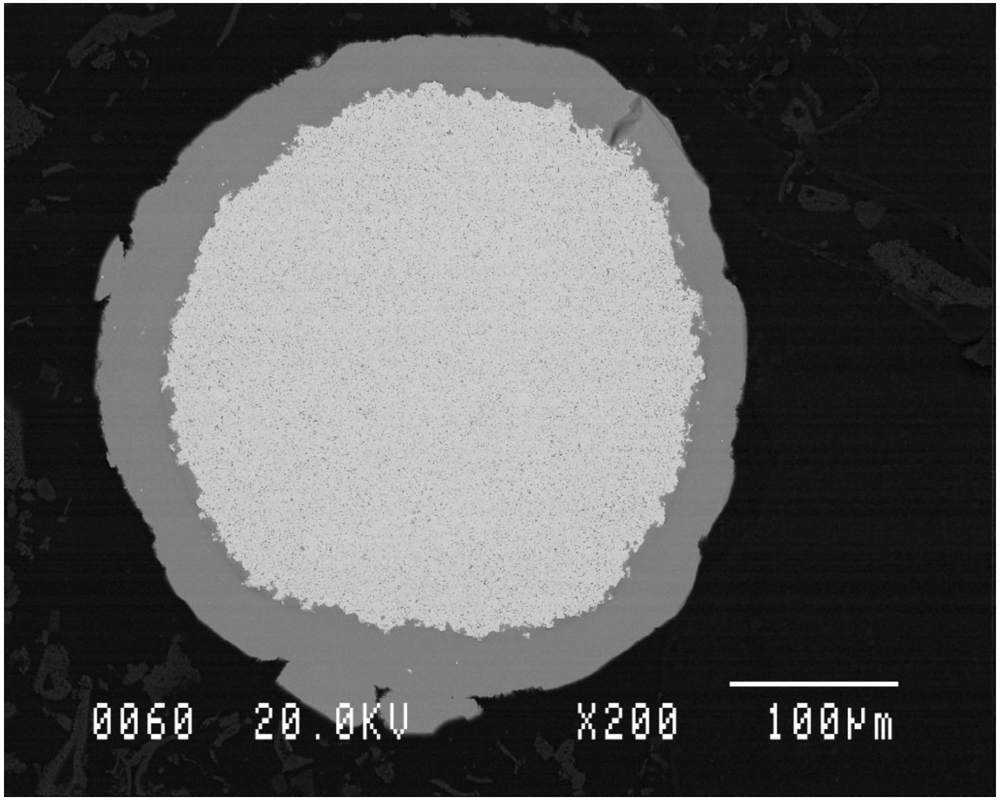
2013 Cold Spray Action Team

Worcester, MA

June 17, 2013

How MCPs Work

- Water-based solution-coating technology (including electroplating, electroless plating and others)
- Uniformly encapsulates each individual substrate particulate
- Nanocrystalline interface
- Single metal or multiple layers of metal coatings
- Uniformity of the coatings can be engineered down to the micron level
- Coating thickness can vary between 0.1 wt.% to higher than 95 wt.%
- Particle size, dependent on density, can range from several microns to several thousand microns
- MCP products avoid separation of light phase (Cu, Sn) and heavy phase (W) caused by vibrating or process handling
- During consolidation, the Metal Coated Particles behave like pure metal powder
- Ability to coat low melting point substrate materials (e.g. polymers)



Substrates & Coatings

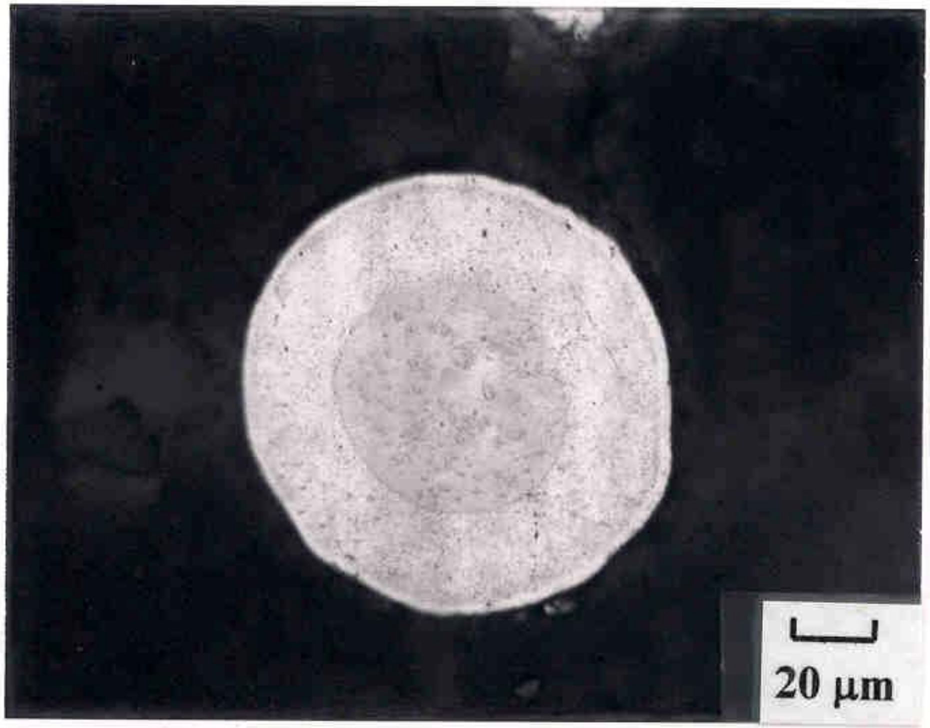
- Substrates:
  - Acrylic
  - Alumina
  - Aluminum
  - Aromatic polyester
  - Boron carbide/ nitride
  - Calcined bentonite
  - Chopped carbon fibers
  - Chromium
  - Copper
  - Diamond
  - Glass
  - Graphite (synthetic, natural flake, and whiskers)
  - Iron (iron base alloy)
  - Manganese/zinc/ferrite
  - Molybdenum
  - Neodymium/iron/boron
  - Nickel base alloy
  - Samarium Cobalt
  - Silicon/carbide (grains and whiskers)
  - Silver
  - Stainless steel
  - Titanium carbide/diboride
  - Titanium/nickel/alloy
  - TPG plates
  - Tungsten
  - Tungsten carbide
  - Yttria stabilized Zirconia
  - Zirconia/tungstate

- The metal coatings successfully applied on substrate particles include:
  - Cobalt
  - Copper
  - Iron
  - Nickel
  - Tin
  - Zinc
  - Gold
  - Silver
  - Or combinations of the metals listed
- MCP particles can range from less than 10 microns to more than 5 mm (depending on particle density and shape.)
- The coatings can be as thick as 80% or more by volume, or as thin as 0.5% by volume.
- Coverage of each particle is uniform and complete.
- Virtually any particle that can be wetted, does not react with water, and has a specific gravity greater than 1.0 is a candidate for coating.


Cu Coated Chopped Carbon Fiber (83.8 wt% 56.0 vol% Cu)

Advantages of our MCPs

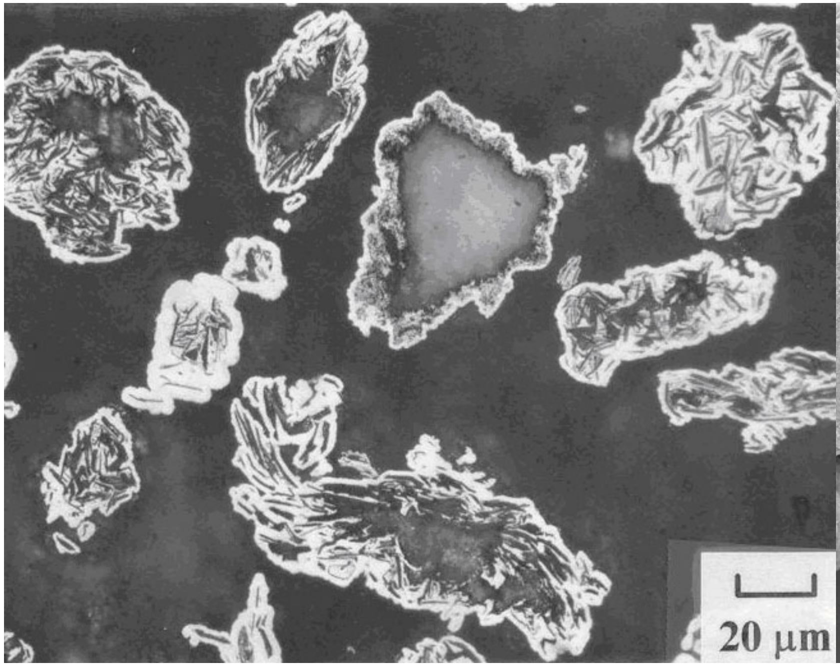
- Coverage of each particle uniform and complete
- Uniform coverage
- Thick or thin coatings
- Short production cycles
- Low cost
- Mass production
- Multiple metals on single particle

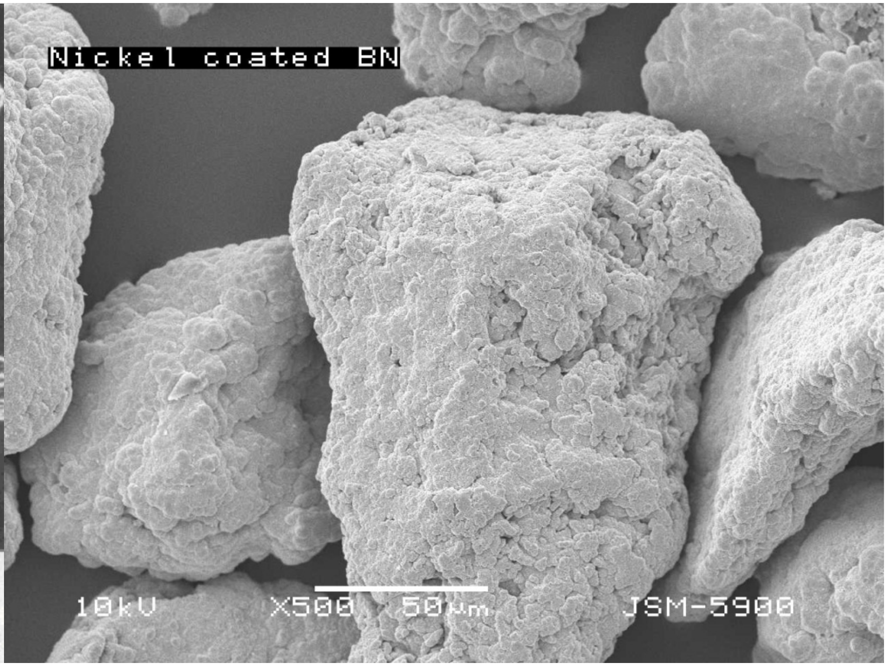


Ni/Cu Coated Anval B60C
(80 wt. % Cu, 1.5 wt.% Ni)

MCP – Nickel Coated BN

- Nickel-Coated Boron Nitride (BN) TECO 20040413
- Raw BN Particle Cost Range: $72.50 - $81.80 per pound
- BN suitable for MCP coatings range in size from -100mesh to +325 mesh



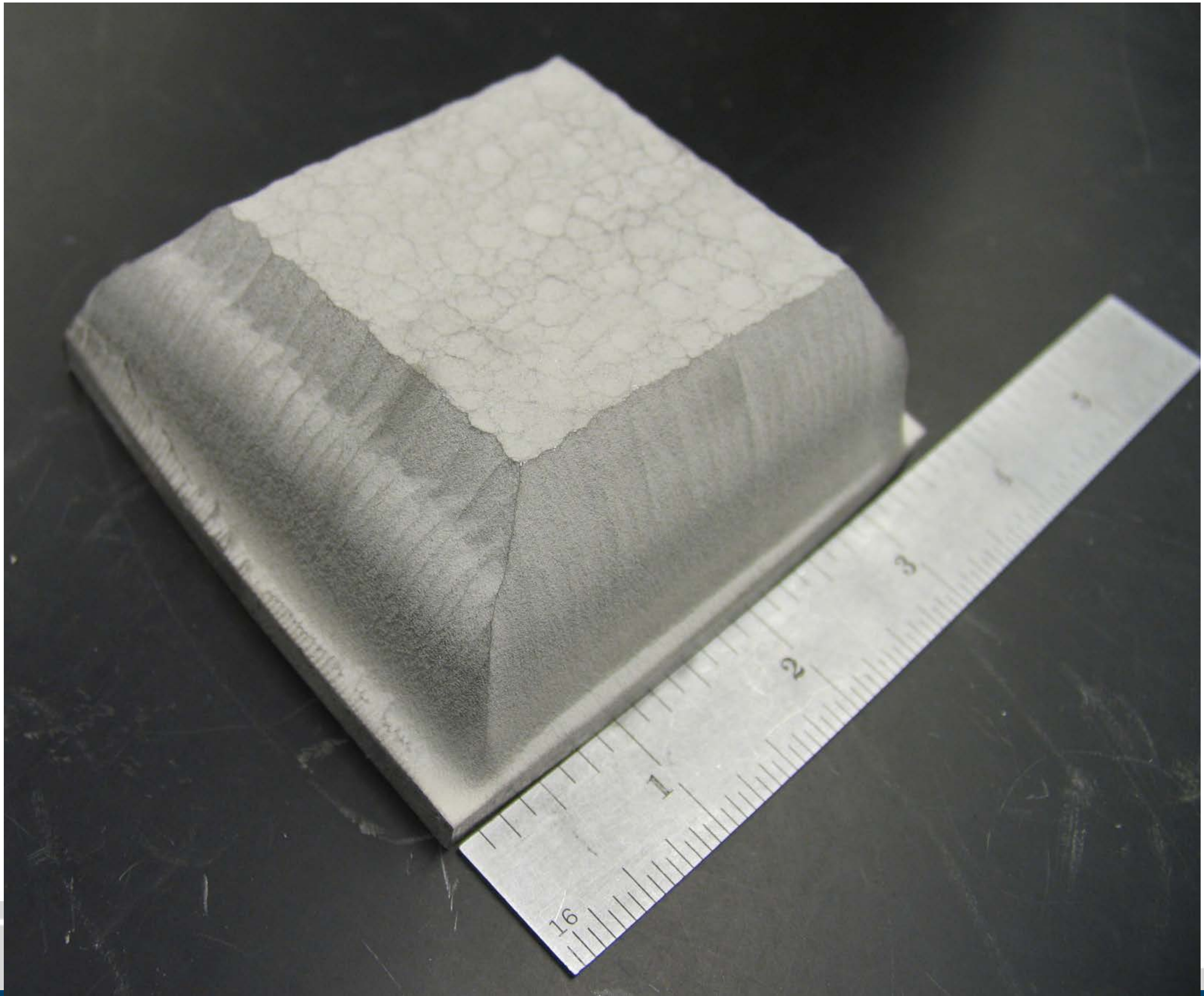


Typical behavior

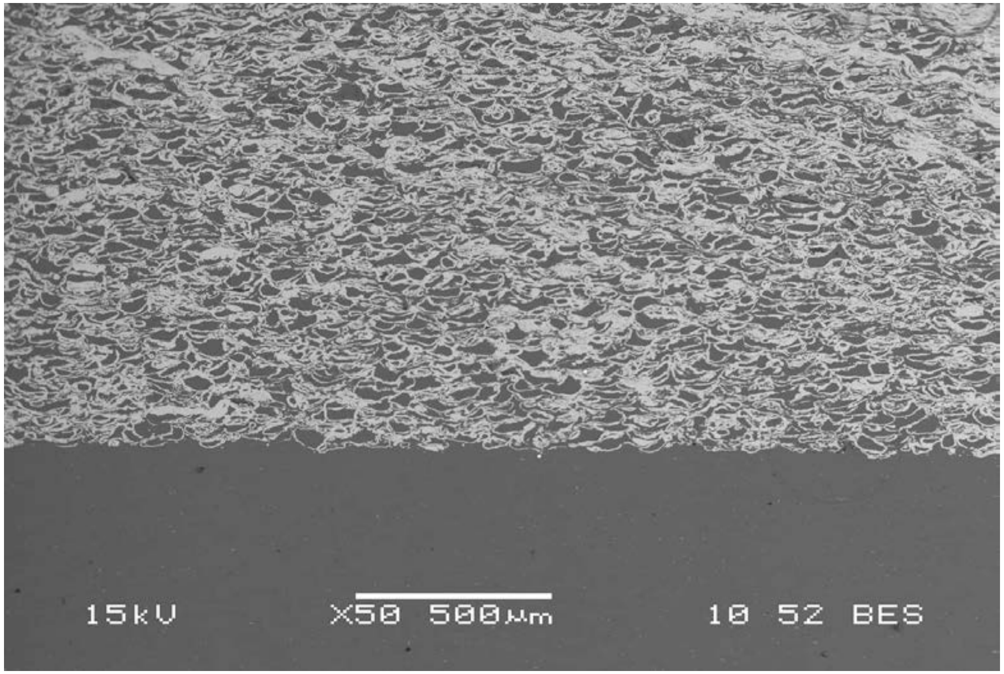
Cold-pressing of powders, and Thermal Spray and Cold Spray applications of completely and uniformly coated powders, typically exhibit the following:

- Low consolidation temperatures
- Fully dense coatings with no particle agglomeration
- High volume fraction loadings of ceramic and other particles
- Increased mechanical strength
- Less porosity and more ductility
- Superior wear and corrosion resistance
- Significantly higher deposition efficiency rates
- Less down time
- Substantially lower setup time and costs
- Less tool and nozzle wear
- Cost-effectiveness

Cold Spray Bulk Ni-Al

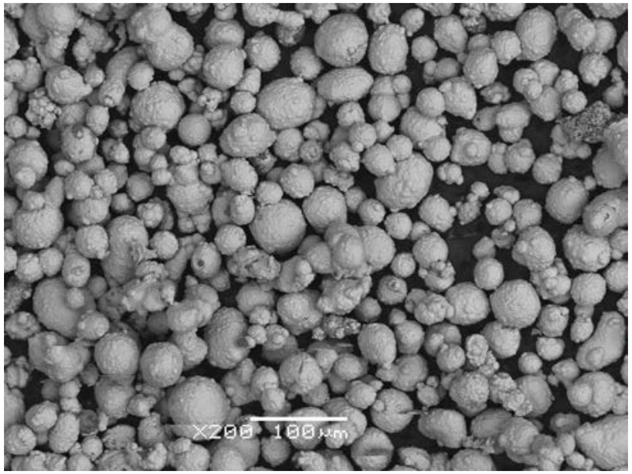


ARL Ni-Al shaped charges



Micron width ribbons of nickel around aluminum.

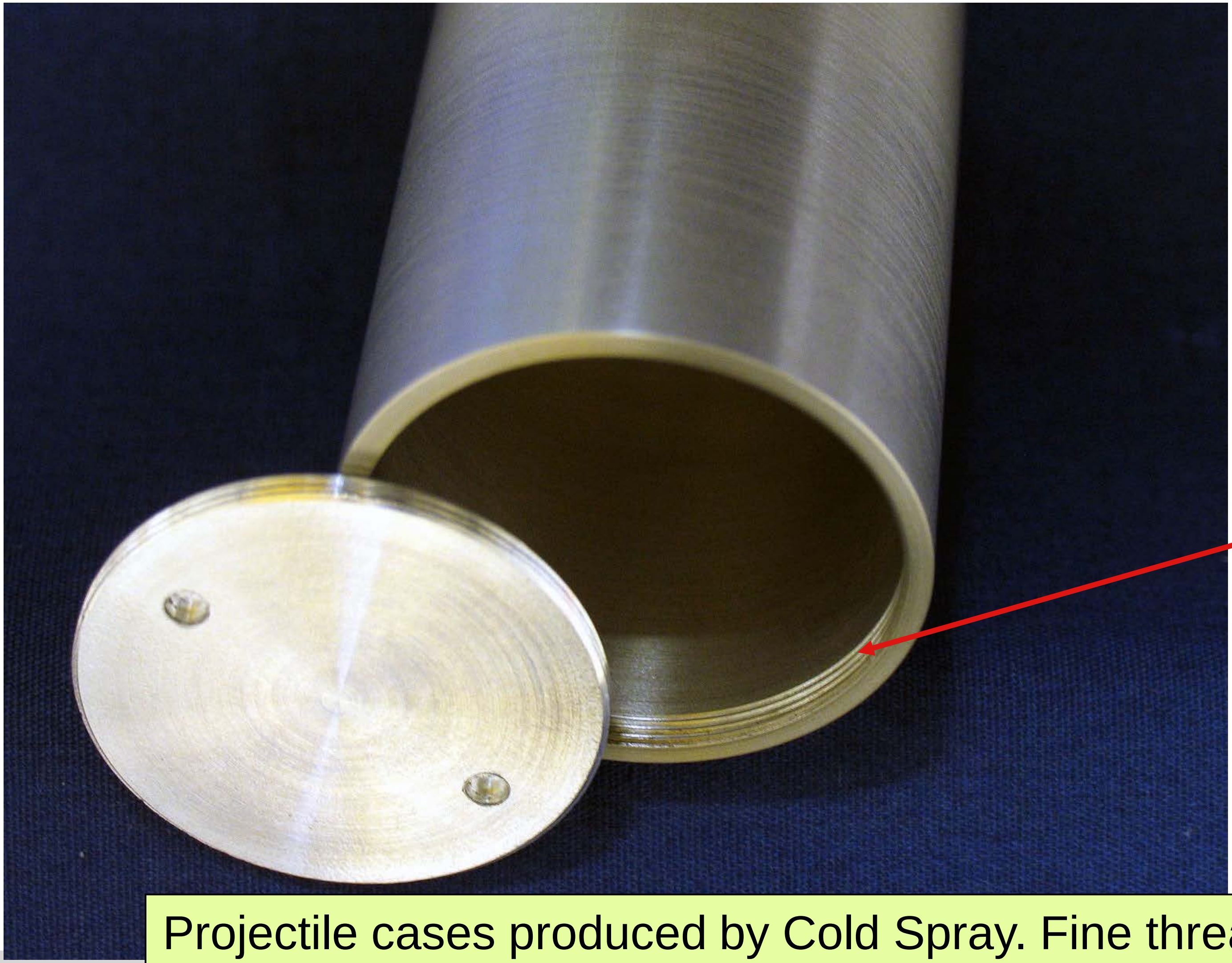
ARL fabricated Ni-Al shaped charge



FTG Ni-coated Al Powder

Complete Reaction of Ni-Al

Projectile Cases via Cold Spray

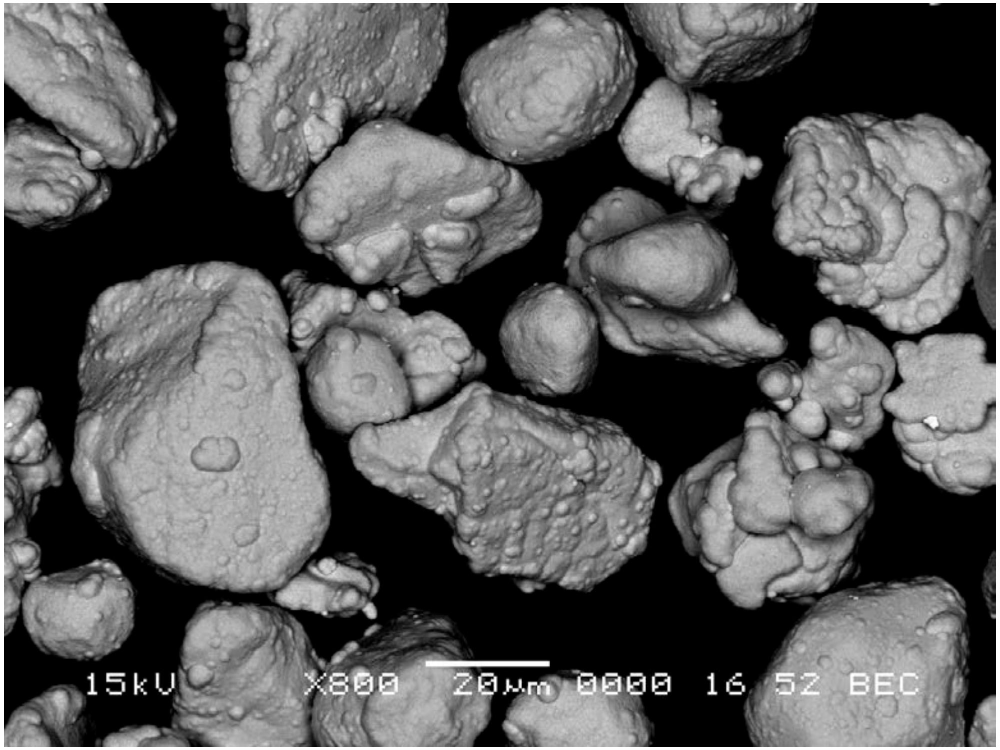


Fine threads

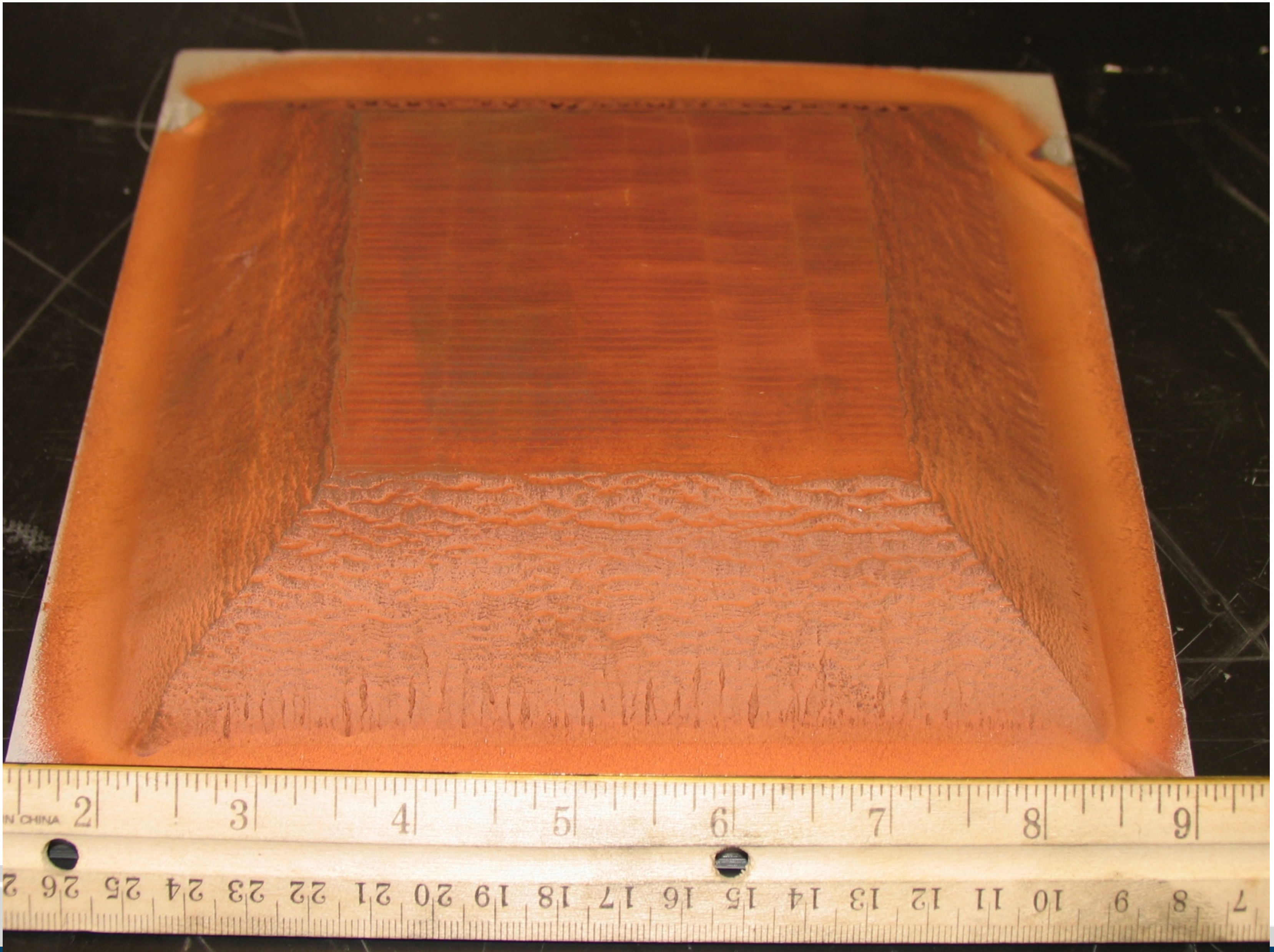
Projectile cases produced by Cold Spray. Fine threads were machined into the material with no difficulty.

Copper-coated tungsten

- **Program:**
  Cold Spray Process for program at the Army Research Lab
- **Material System:**
  Copper-coated tungsten
- **Benefits:**
  - Higher deposition efficiency
  - Material is easy to work with
  - Lower the consolidation process temperature to avoid harmful reactions between the matrix phase and the reinforcement phase at elevated temperatures
  - Avoids separation of light phase (Cu) and heavy phase (W) caused by vibrating or process handling
  - High-quality and uniform components with near-zero scrap rates.

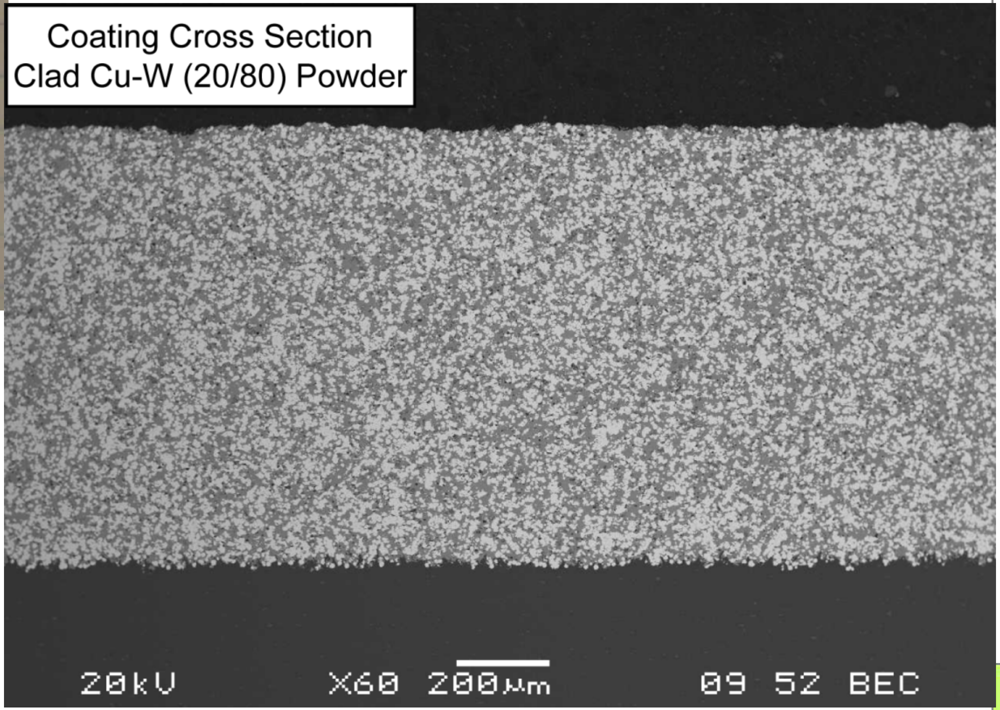


Cold Spray Cu-W



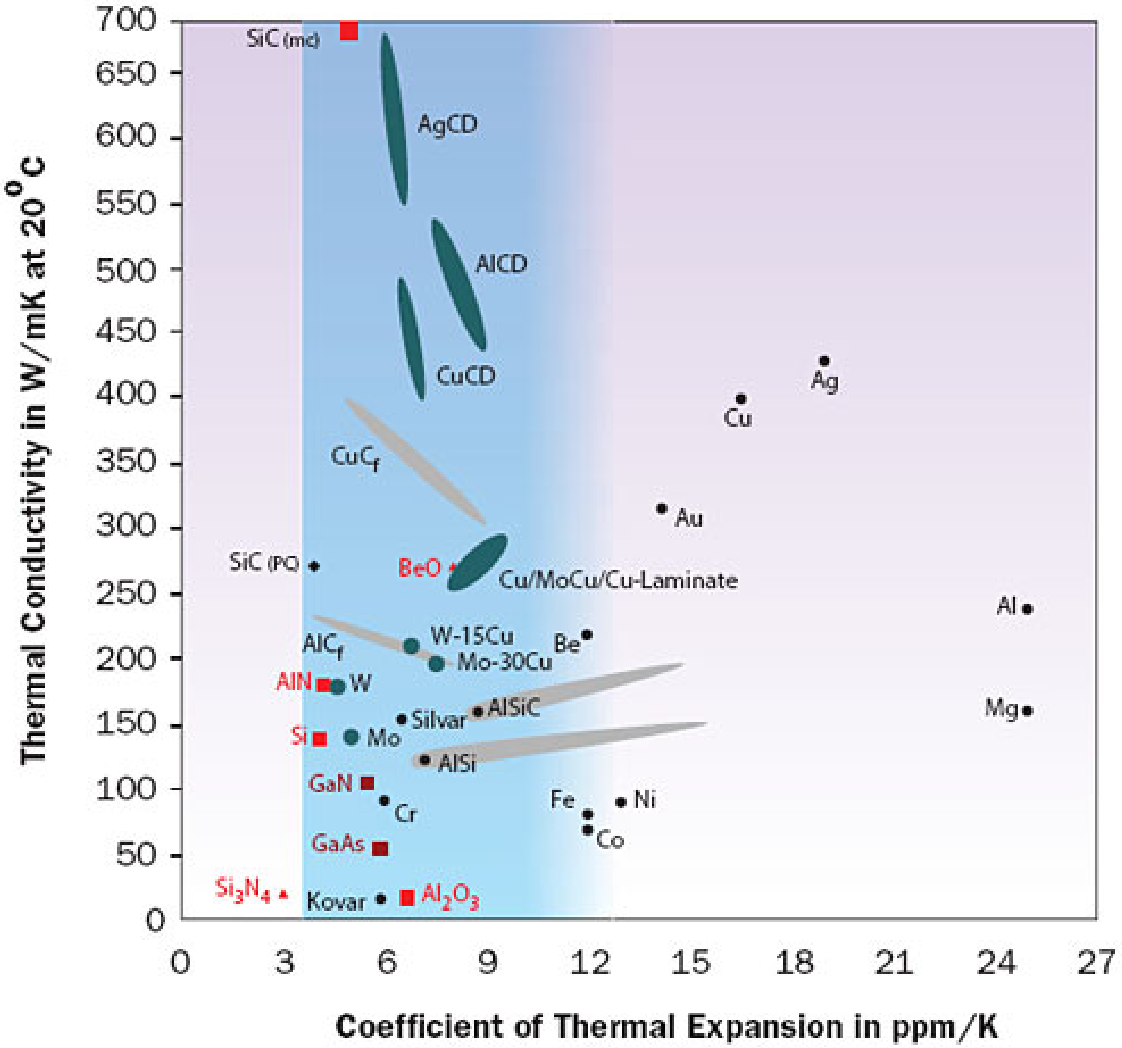
Cu-W shaped charges

Oil & gas Cu-W shaped charges consolidated via cold-pressing powders



ARL: Even particle distribution and homogeneity within cold-spray consolidation of Cu-W powder.

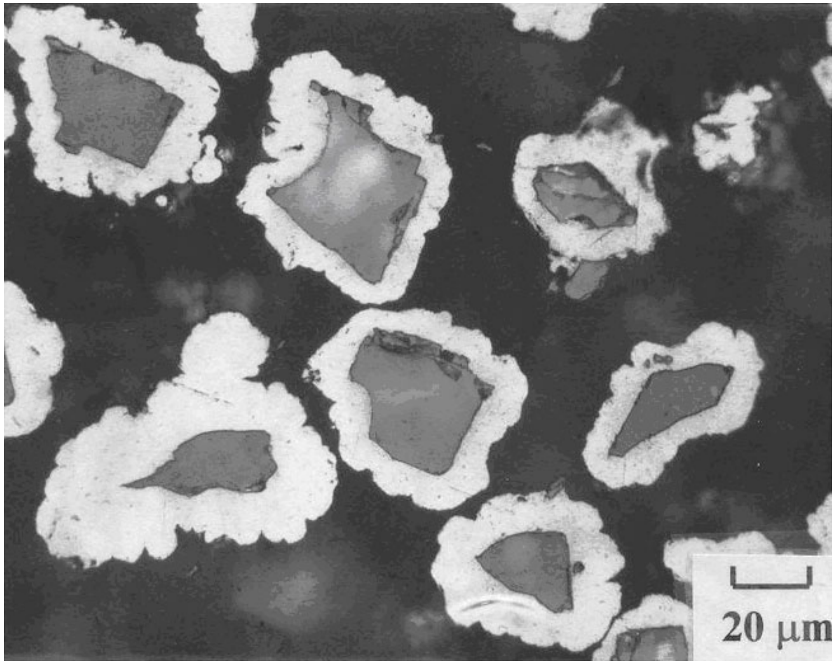
Advanced Metal Diamond Composites



Source: Electronics Cooling - November 1, 2008)

MCP Products // Copper Coated Particles

- Copper-coated Silicon Carbide (SiC)
  - Offers the superior hardness and thermal conductivity of molybdenum for electronic, tool, and wear part applications



Electronics (Cu-SiC)

Sample Vol% SiC	Average Density (g/cm^3)	Avg. Coefficient of Thermal Expansion (ppm/^{0}C)			Thermal Conductivity (W/mK)	
		X axis	Y axis	Z axis	In-plane	Through-plane
30%	7.18	11.2	11.5	11.8	300	
40%	6.56	11.2	11.2	11.0	274	
36%	7.02	9.6	9.8	10.5	255	
60%	5.51	9.3	8.7	10.0	275	260

The material properties were in line with expectations and should present an attractive alternative to AlSiC for applications in which density is not a critical factor. The lack of formability and difficulty of machining in this material, however, tends to show that components must be made to net shape, or very near net shape. The high surface finish and flatness/planarity requirements of a heat spreading application will need to be addressed in a net shape forming operation. Modeling should be done to determine the expected manufacturing cost of this approach.

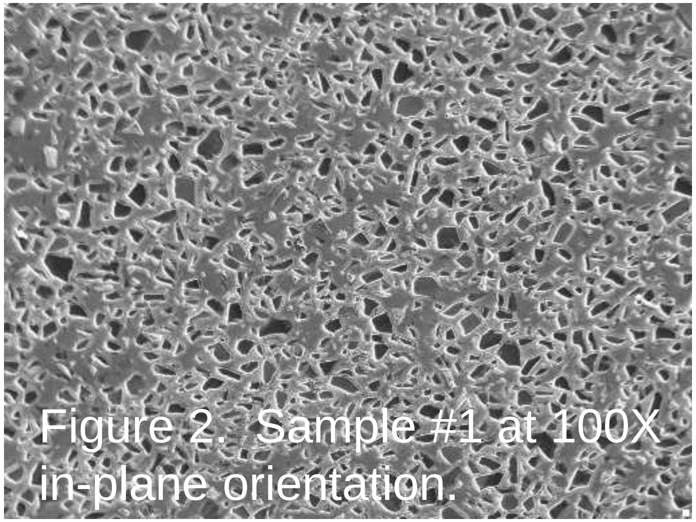


Figure 2. Sample #1 at 100X in-plane orientation.

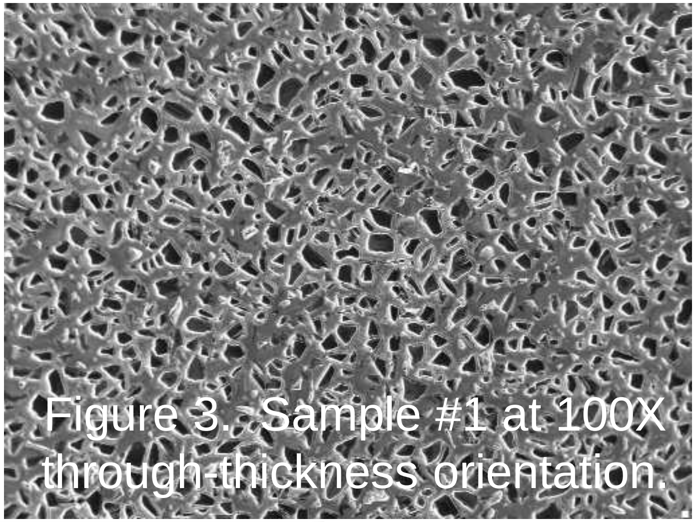
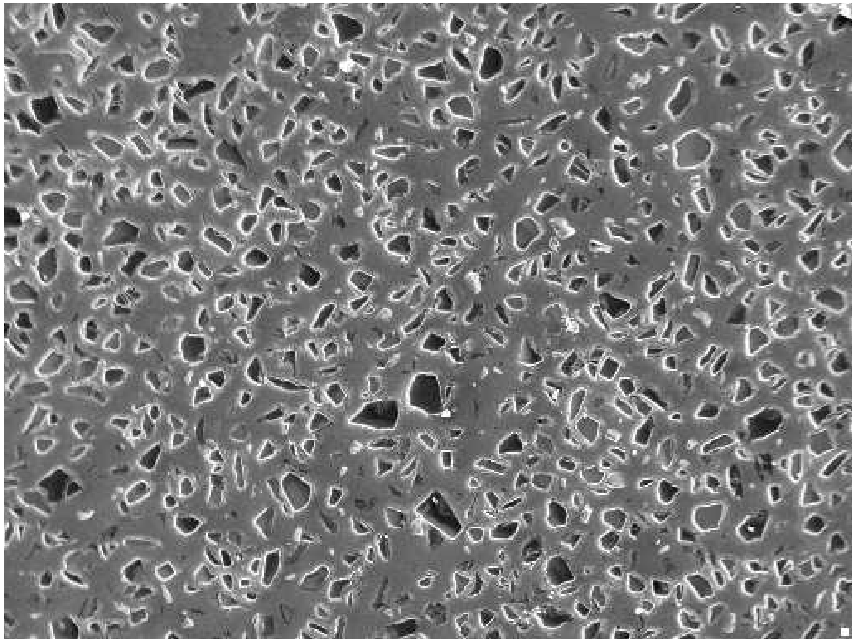


Figure 3. Sample #1 at 100X through-thickness orientation.

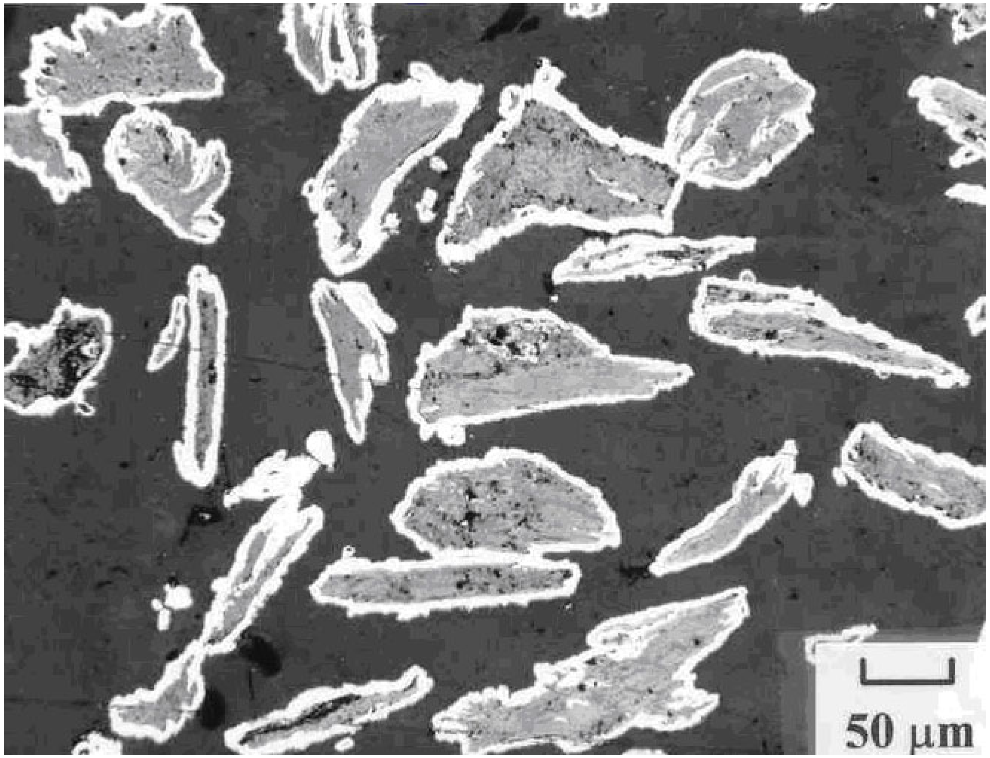
Consolidated Particles



100X through-thickness orientation

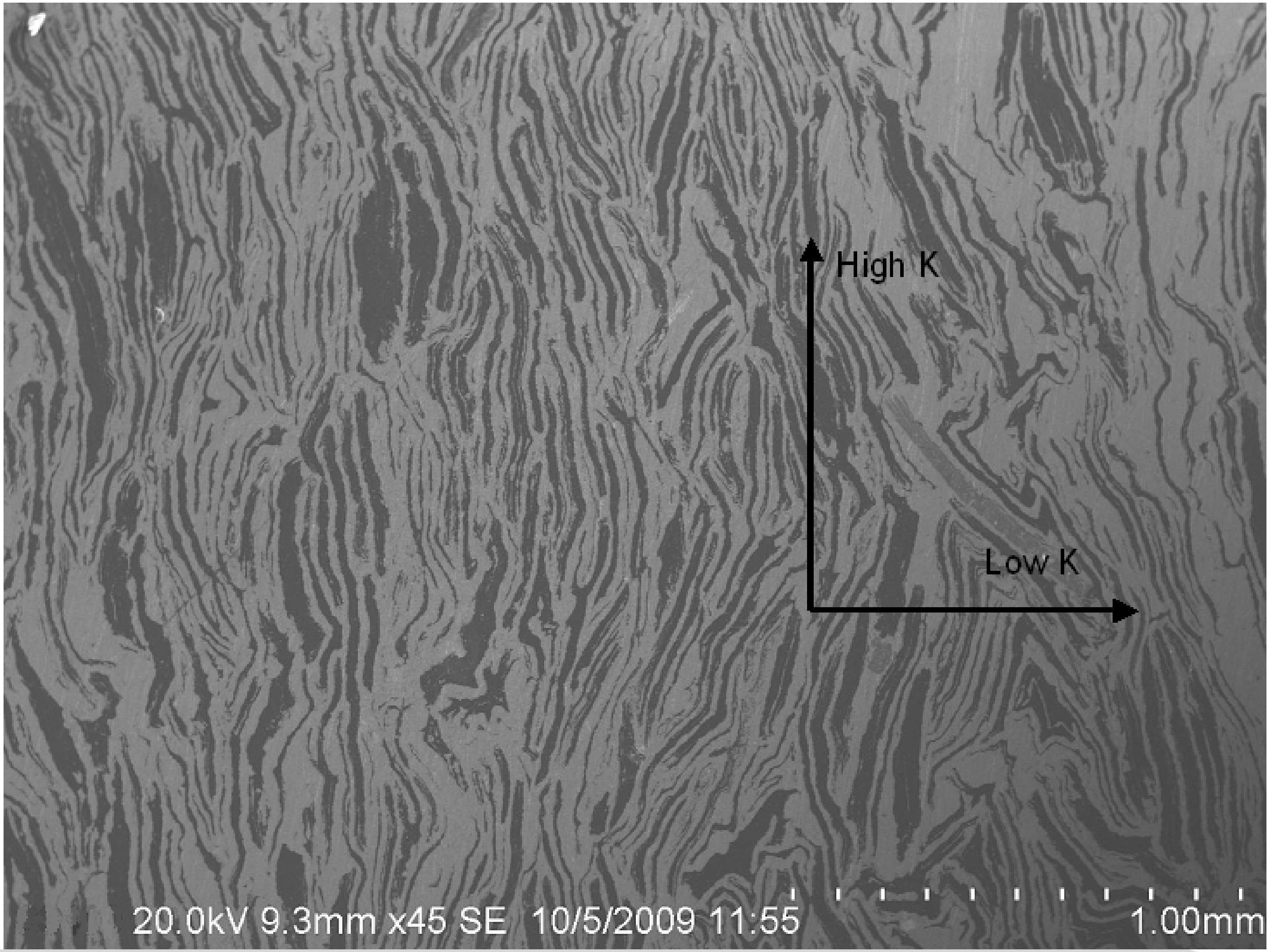
- Bonding is only between the metal coatings
- In consolidation, MCPs behave as pure metal powders
- Avoids direct contact between reinforcement particulates
- Result: MMCs without particle agglomeration
- 30 to 100 percent improvements observed in mechanical strength and ductility

- Copper Coated Graphite (Synthetic)
  - Thermal Management, Electrode applications



Cu-Graphite Flake Microstructure

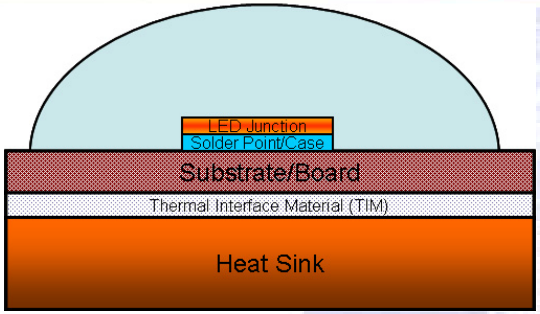
Copper-Graphite Flake microstructure

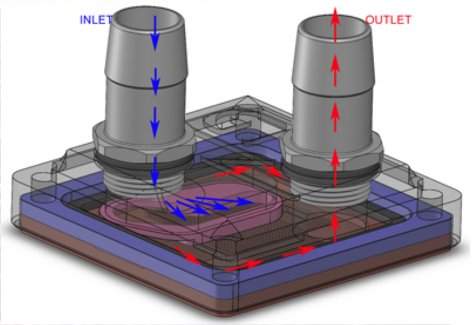


High Conductivity Graphite Flake/Cu Properties

- Vf loading of 55-70% by volume of graphite flake in Cu matrix
- Density of 4.14 - 5.16 g/cm3
- Easily machined
- Thermal conductivity ranging from 700-850 W/mK in X-Y plane, CTE = 6-7.5 ppm
- Z-axis conductivity is 110 W/mK
- Can be improved to 275 W/mK using an addition of diamond particles to the graphite flake
- Composite Can be Ni/Au plated
- Currently Available in sizes up to 1”x1” x0.5” and smaller, scale up to produce 8”x8”x1” under way

Latest Defense Applications



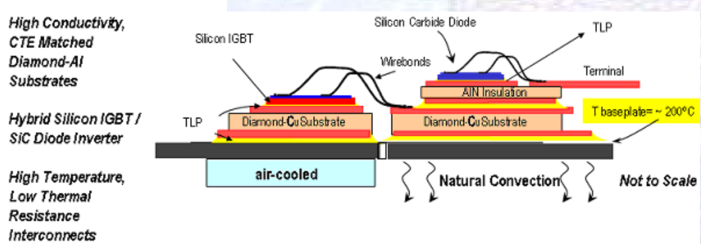


Markets For High Thermal Conductivity/Matched CTE Materials

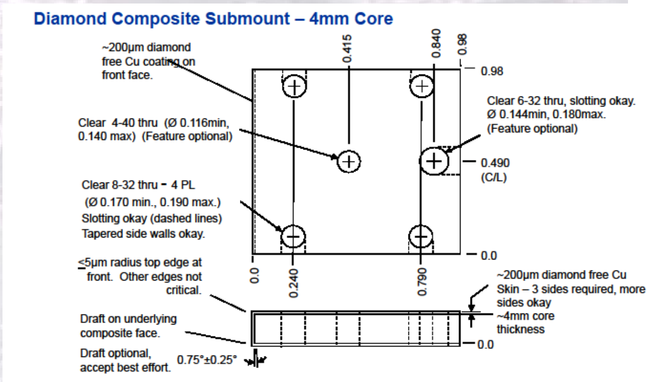
Substrates for IGBT boards and inverters

Submounts for laser diodes and MMIC devices/LED Lighting

Cold plates for CPU cooling



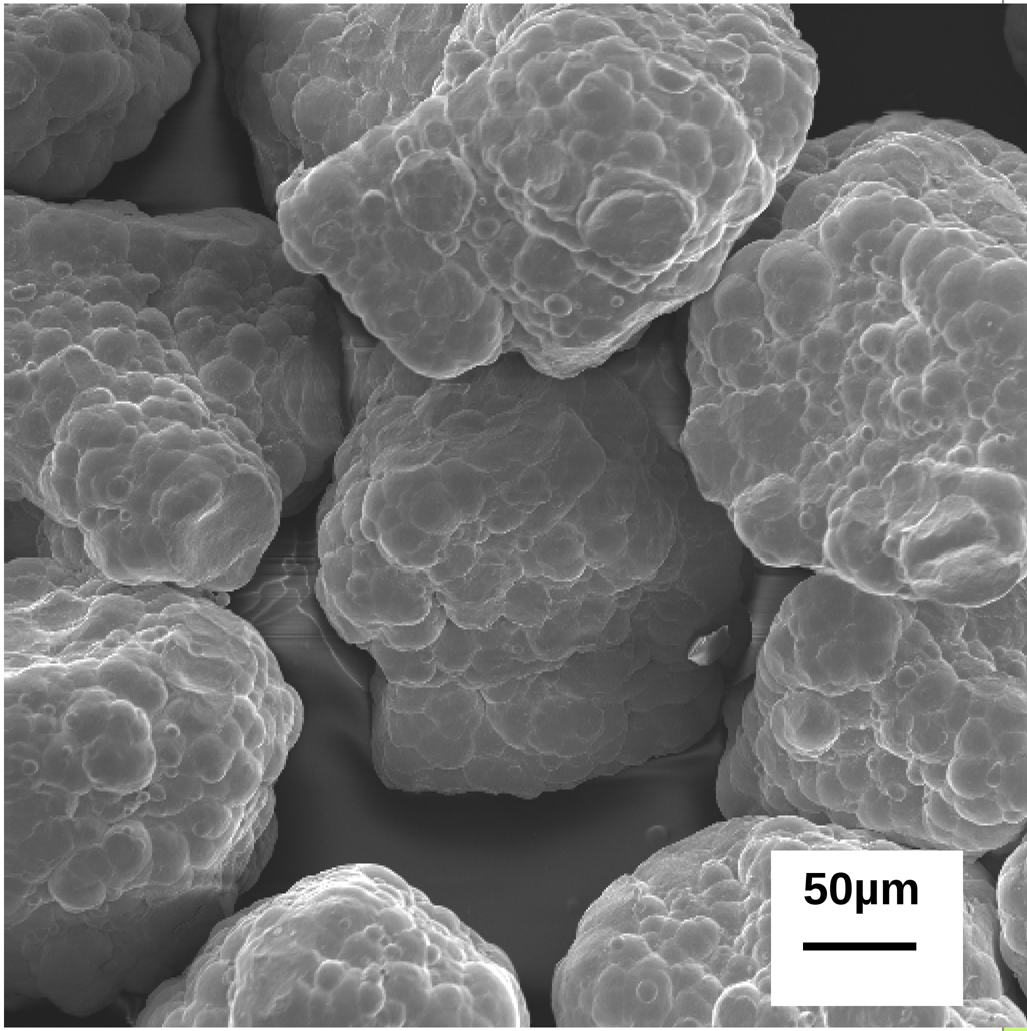
Power Electronics



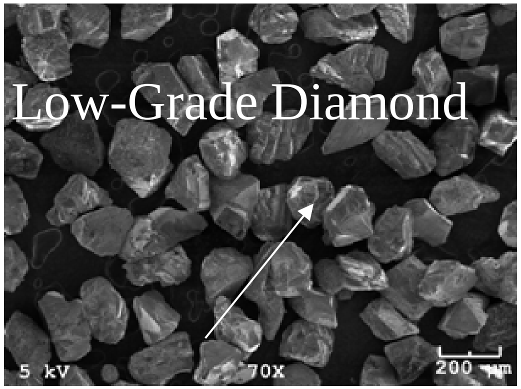
Optoelectronics

Copper Diamond

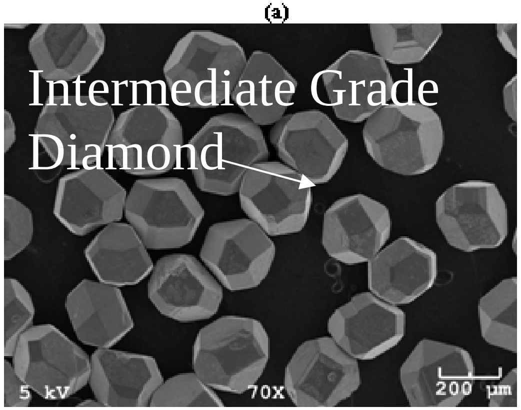
- Greater than 550 W/mK using a standard metal-bond grade diamond with a thermal conductivity of 1200 W/mK.
- It is possible that these numbers could reach 850-900 W/mK by using a higher grade of diamond and 40 volume % loading.
- The coefficient of thermal expansion (CTE) of diamond is only a fraction of that of monolithic metals.
- Cost competitive in production-level quantities.



Cu-coated Diamond

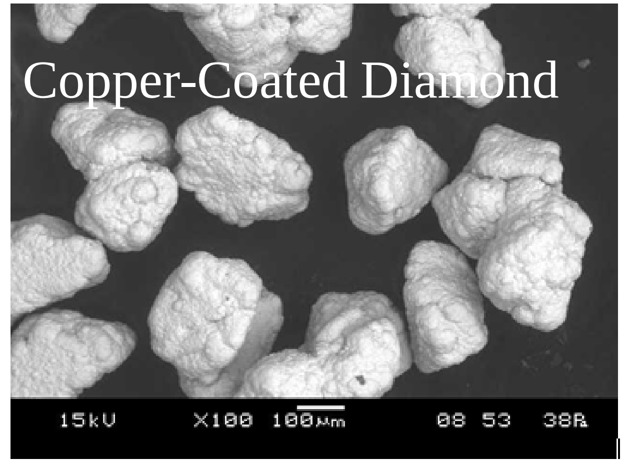


(a)

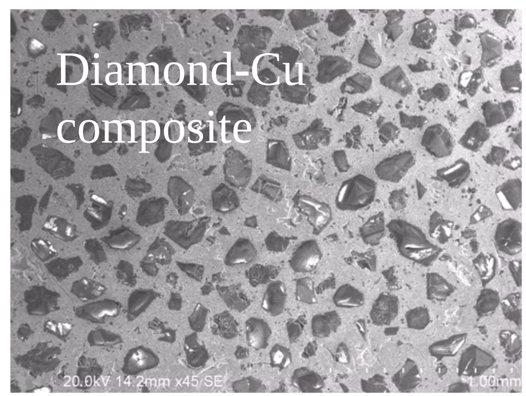


(b)

Starting Diamond Powder
(a) Low-grade Diamond (6 cents/ct)
(b) Intermediate-grade Diamond powder (22 cents/ct)



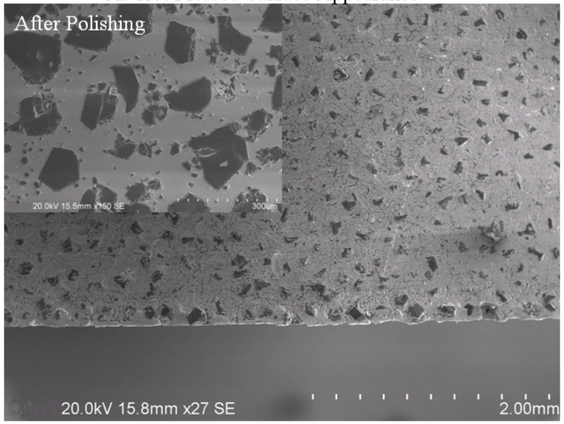
Pure Cu Coated diamond Powder

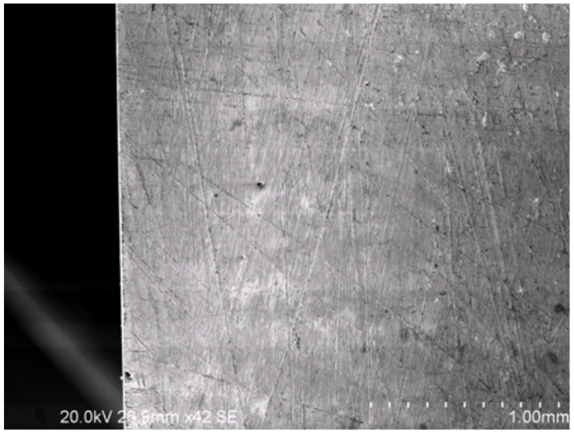


Advantage of using Cu-coated diamond powder
Approach is very uniform diamond distribution
In the composite, no Powder Mixing/Blending is required

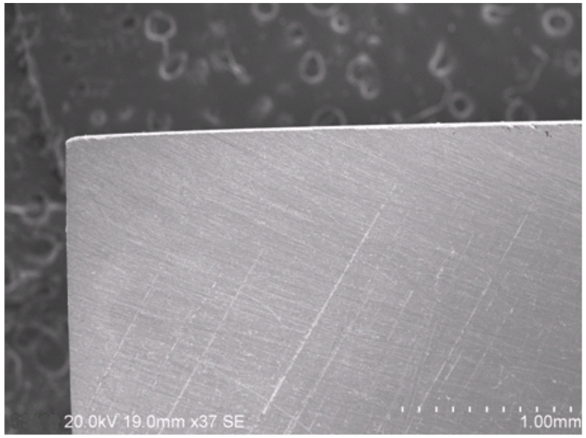
Surface appearance after various Plating steps

As-Hot Pressed Surface Appearance



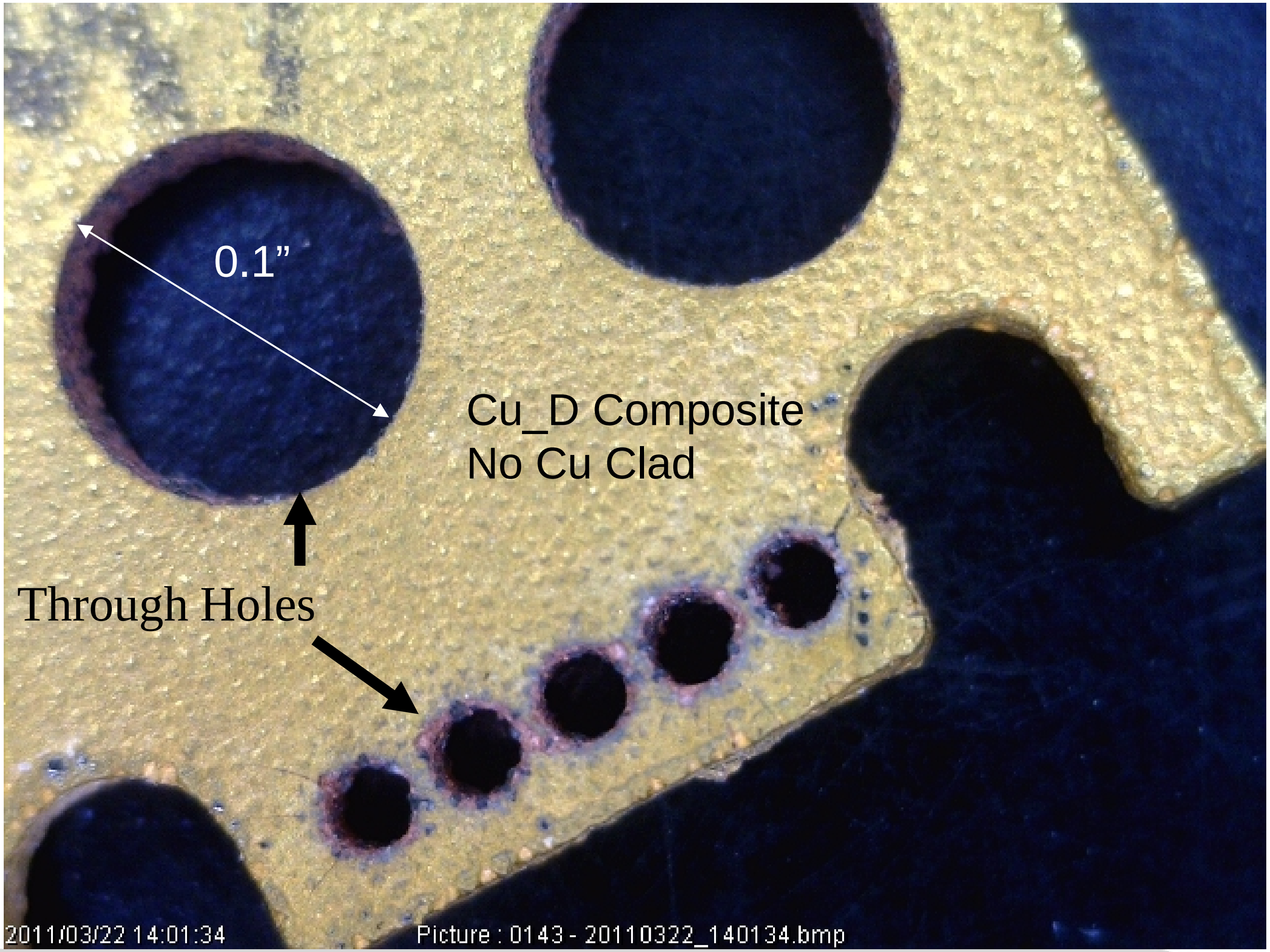


Cu-plated and polished/lapped.



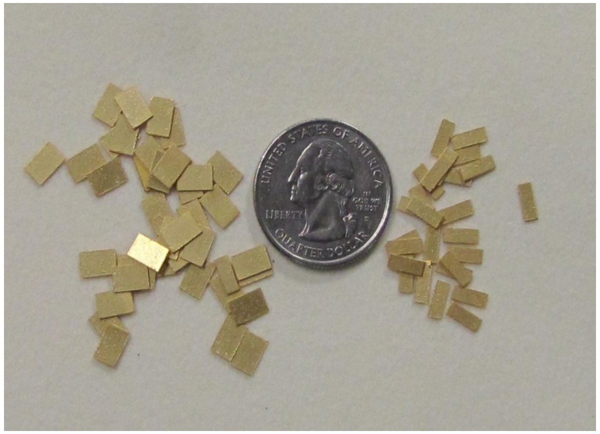
Cu surface layer on all sides.

Parts can have through holes

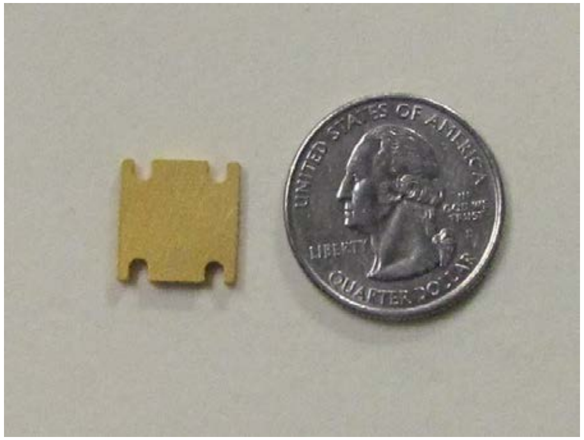


Various Cu-Diamond Product Forms

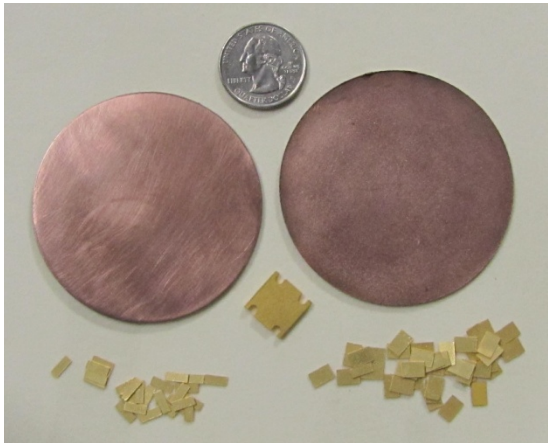
FTG uses metal-coated powder technology to manufacture precision Diamond/Cu components for electronic applications including submounts, carrier plates and lids for advanced packaging.



Miniture Ni/Au metallized Diamond/Cu carriers 0.015" thick



Ni/Au metallized 0.5 x x 0.5" x 0.06" Submount (Cu Clad)



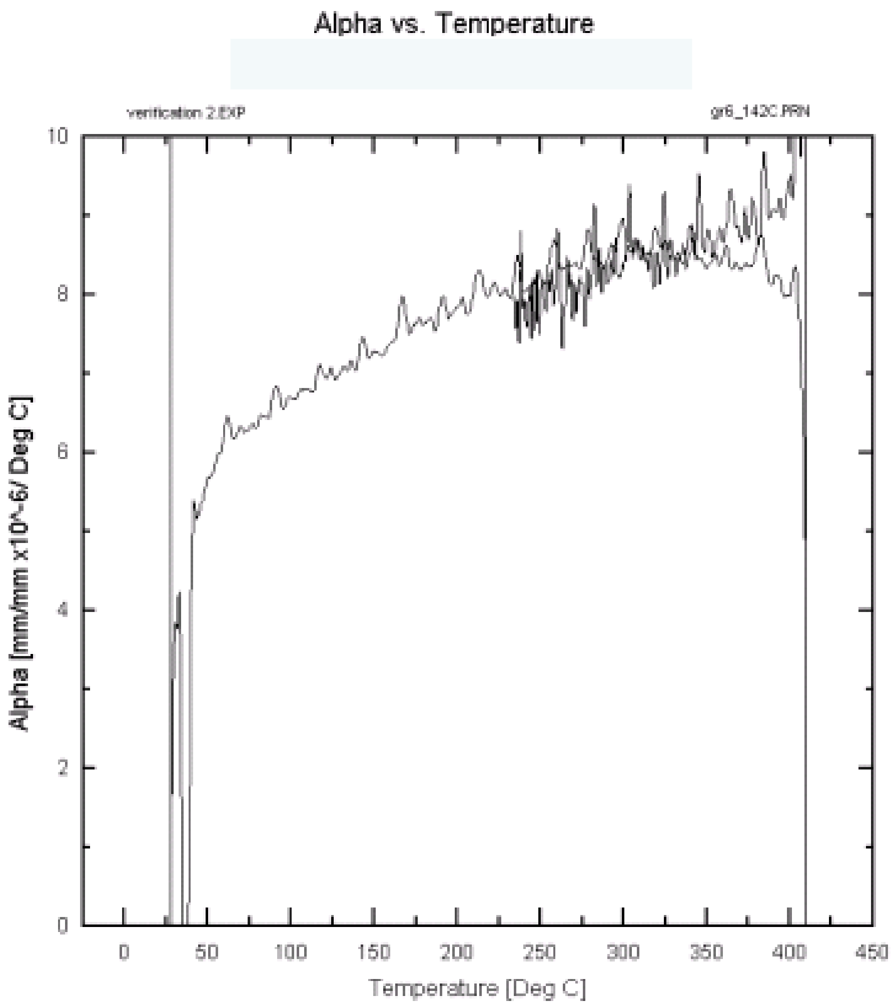
2.5" diameter x 0.06" Diamond/Cu rounds (unplated) Shown with other components

Comparison to Other Packing Materials

Description	Thermal conductivity (W/m.K)	CTE (ppm/k)	Density (grams/cm^3)
85W/15Cu wt%	180	7.2	16.2
Diamond/Cu (60% volume Diamond)	**450**	**6-8**	**5.70**
Al	190	24	2.78
Cu	395	18.5	8.96

Thermal conductivity measured via Laser Flash Diffusivity.

Coefficient of Thermal Expansion



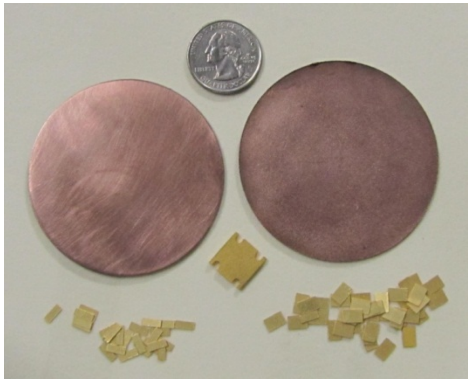
Treatment	CTE, ppm/C, mean from 50-300C
as received	7.9
re-run without taking from machine	7.3
after simulated AuSn reflow (22C/min heat, ~ 50C/min cool).	7.5

Parts Specifications

	Standard	Clad (4 mils Cu per side)
Surface Roughness	Ra=50-60 micro-inch	Ra<20 micro-inch
Flatness	4 mils	1mil
Coating	Ni/Au, Ni/Ag, others on request	Ni/Au, Ni/Ag, others on request

	Standard Nominal Size	Standard Tolerance	Clad Nominal Size	Clad Tolerance
Thickness (inch)	0.04-0.25	+/_0.004	0.04-0.25 (0.015)*	+/-0.002 (+/-10%)*
Length (inch)	0.05-1.5	+/-0.003	0.05-1.5	+/-0.003
Width (inch)	0.05-1.5	+/-0.003	0.05-1.5	+/-0.003

* Applies to thin shims/carriers made by specialized process



Thin shims >0.015" thick and standard Parts > 0.04" thick

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