



NanoCopper-Based Materials Solutions

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Press Release – April 5, 2017

Kuprion Inc. to Bring Copper-based Nanotechnology to the Global Market

Silicon Valley-based company targets more reliable electronics with versatile nanocopper materials invention

- **PALO ALTO, Calif., Apr. 5, 2017 –** Imagine electronics using less power, running cooler, lasting longer and withstanding higher operating temperatures. This could be the future through a novel nanocopper-based assembly material developed by scientists at Lockheed Martin’s Advanced Technology Center in Palo Alto, California. Under license from Lockheed Martin [NYSE: LMT], this material is now available through a recently created, independent start-up company, Kuprion Inc., who aims to commercialize this promising technology platform for multiple large markets.



INITIAL NANO COPPER PRODUCT READY TO COMPLETELY DISRUPT \$25B SOLDER MARKET

Press Release – April 5, 2017 - continued

- **“The future of electronics beyond soldering has begun. We are entering the age of solder-free electronics,” says Dr. Alfred Zinn, nanocopper inventor and Kuprion chief executive officer. “With this product, the industry will take a significant step toward more reliable systems that can overcome typical solder creep and fatigue issues as well as wicking problems during reflow. Nanocopper’s unique properties and ease of processing can benefit every device that has a circuit, its packaging and manufacture throughout the world.”**
- **Bulk copper is a better conductor versus solder and is more reliable, but its high melting temperature prevents its use as solder. Nanocopper bridges this gap by fusing rapidly into bulk copper at processing temperatures as low as 200 °C without pressure, and the resulting bonds can operate at much higher temperatures. Additionally, nanocopper enables all-copper-systems that can eliminate tin-whisker growth, brittle intermetallic compound formation and gold embrittlement. The completely flux-free nanocopper material does not liquify during “reflow”, which eliminates the two key causes of void formation. Together with the low processing temperature, it directly benefits production yield and assembly cost. For the first time, an assembly material is available whose operating temperature is not limited by its processing temperature.**

Press Release – April 5, 2017 - continued

- **About Kuprion Inc.:**
- **Founded in 2016 in Silicon Valley, Kuprion Inc. provides premier nanocopper-materials, assembly and packaging solutions for a wide range of global markets such as electronics and thermal management to meet customer needs. Kuprion is one of the few manufacturers in the world offering substantially oxide-free nanocopper that can be safely handled in air. Kuprion also makes custom formulations available to match its customers' needs and requirements.**

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<https://www.kuprioninc.com/>

Improved Heat Dissipation for High-Power LED Systems via Nanocopper-Based Metal SMT

IMAPS ATW on Thermal Management
Los Gatos, CA – Oct 2016

NextGenLM

Dr. Alfred A. Zinn
LM Fellow

The Core Team: Dr. Randall Stoltenberg, Jerome Chang, Yenling Tseng, Shannon Clark

NanoCopper Materials Platform

Flowable, nanoCopper “metal-adhesive” fusing to solid metal at as little as 200°C with high electrical and thermal conductivity.

- Large-scale manufacture
- Product formulation
- System application & assembly
- Many products / markets

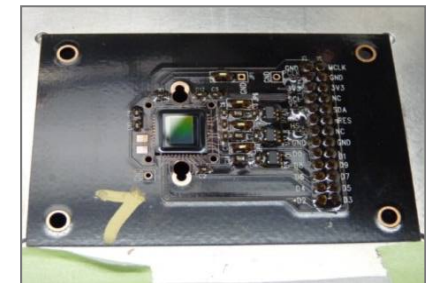


nanoCu paste



100 L pilot plant

LED Emitters



Solder-free circuit board

**HIGH PERFORMANCE, HIGH RELIABILITY SOLDER-FREE
ELECTRONICS**

QuantumFuse™ Materials Platform Addresses Multiple Applications & Markets



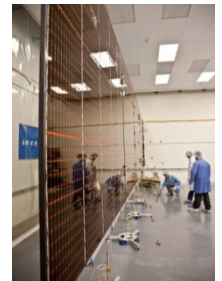
Electronic Solder-like Pastes

3D Printable Inks

Emulsions/Coatings



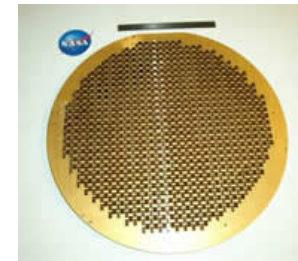
High-Reliability Electronics



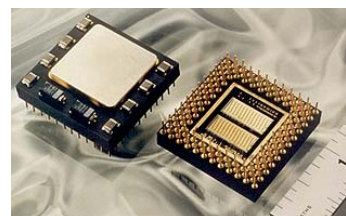
Photovoltaics



Flat Panel Displays
Touchscreens



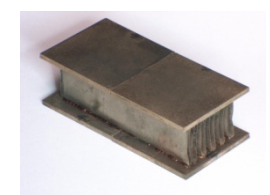
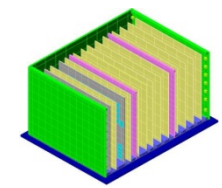
Flexible/Printed Electronics (e.g. phased array antennas)



3D Electronics Packaging



Thermal Applications



Low Temp. Cu/Al Brazing

QUANTUMFUSE™ COMBINES THE BENEFITS OF COPPER (PERFORMANCE, COST) WITH INDUSTRY-COMPATIBLE LOW-TEMPERATURE PROCESSING

Challenge: Scaleability to Drive Down Cost



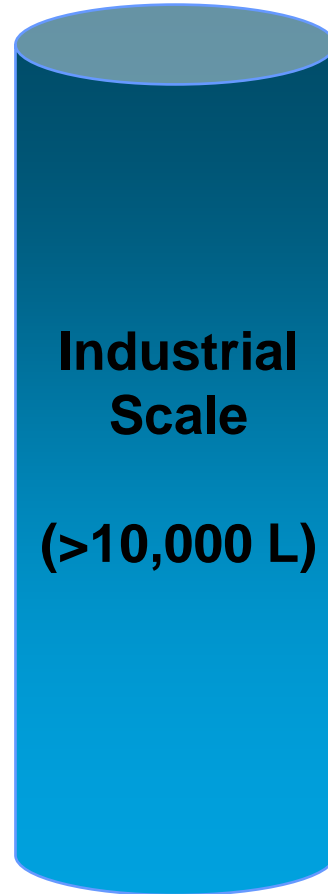
- Need industrial scale production to minimize cost
 - Commodity material → requires competitive pricing
- Enabled by single “pot” process:
 - Mix precursor and surfactants
 - Add reducing agent
 - Isolate powder
- Setting up & qualifying supply chain
 - Yield now over 1 kg per batch



ATC pilot plant



100 L reactor
>1 kg / batch

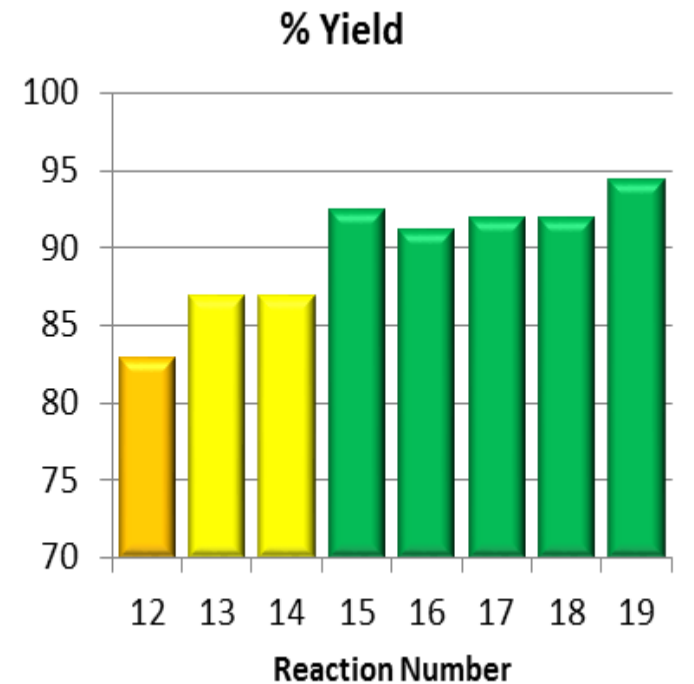


100 L PILOT PROCESS → >1 KG NANOCOPPER

2015-2016 Process Improvements

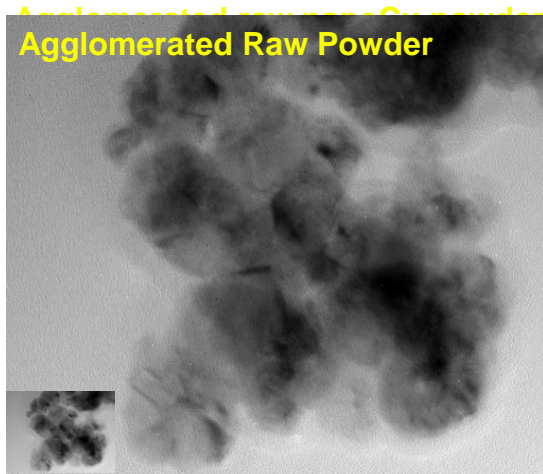


- **Raw nanoCopper Cost Reduction**
 - Yield over >90%
- **Process Chemistry**
 - Had to replace original glyme solvent due to unavailability (REACH)
 - Better process characteristics (no foaming)
 - Improved workup chemistry validated
- **Manufacturing Process**
 - Cost reduction through further scale-up
 - >1 kg batches

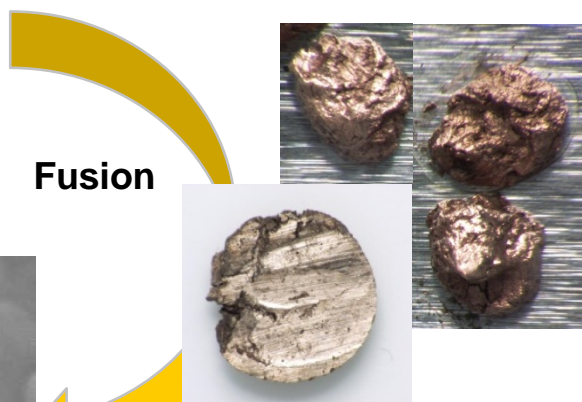


PROCESS IMPROVEMENTS → YIELD >90%

NanoCopper Morphology (TEM / SEM)

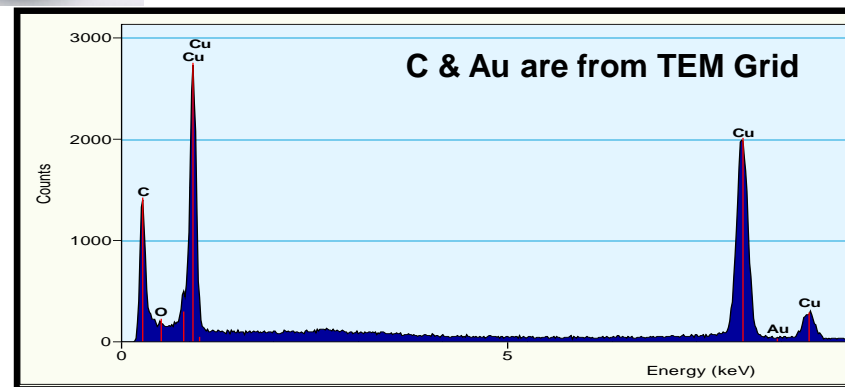
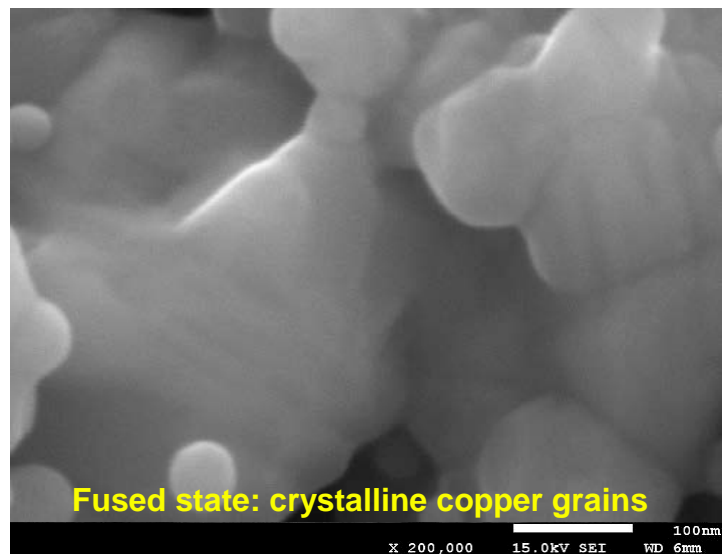


Raw nanoCopper paste



Fuses to form solid copper slugs

Hard, dense, metallic luster, behaves like Cu



EXTENSIVE FUSION PROMISES GOOD PERFORMANCE / RELIABILITY

Tensile Test Results

- Non-ASTM standard pull test
- Widespread cohesive ductile failure
 - Required for high strength = true metal bond
- Adhesive inter-granular failure still present
- Average range around 6000 psi
 - Fully formulated, readily dispensable paste
 - Highest values above 7500 psi



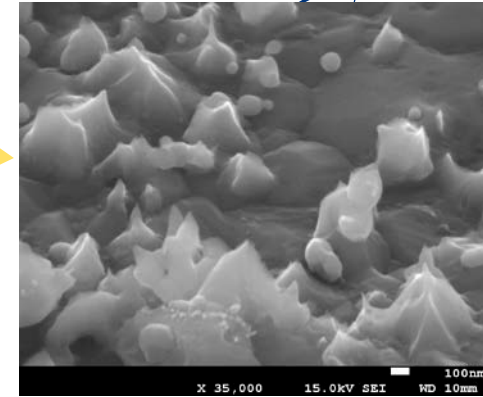
Assembly fixture



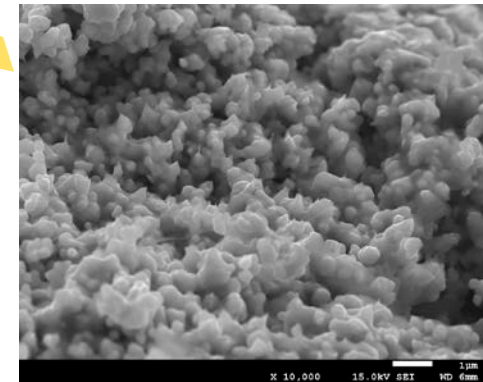
Test specimen



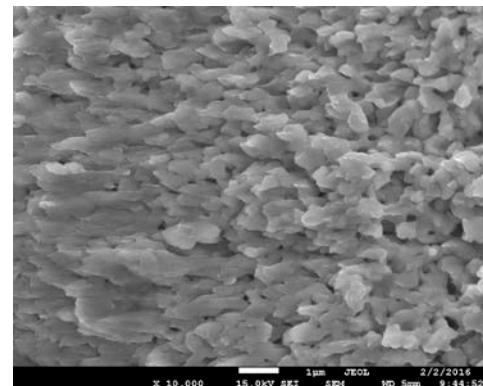
Fracture surface



Bonding to bulk Cu surface



Cohesive ductile failure

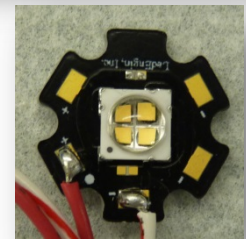
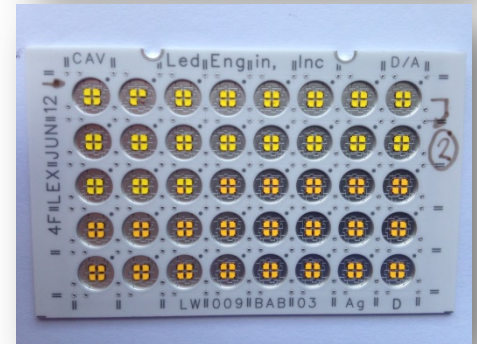
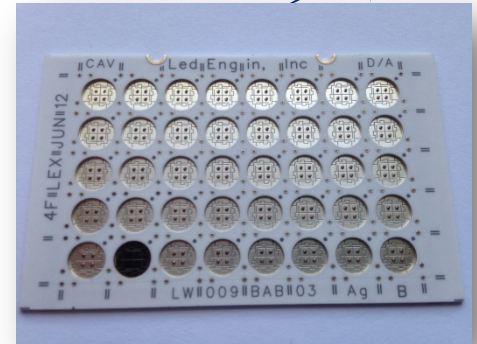


Material Composition	LMSSC Flight Use	Liquidus Temp (deg C)	Ultimate Tensile Strength (Psi)	Shear Strength (Psi)	Young's Modulus (Gpa)	Density (g/cm ³)	Elongation (%)
Sn 60 Pb 40	Yes	190.6	6400	5700		8.67	
Sn 63 Pb 37	Yes	183	4920	4400	35	8.42	35-176
Sn 96.5 Ag 3.5	Yes	221	7977	4400	56	7.5	35
Sn 10 Pb 90	Yes	302	4400	3780		10.94	

REACHED STRENGTH OF SPACE QUALIFIED SOLDER

LED Bonding Application

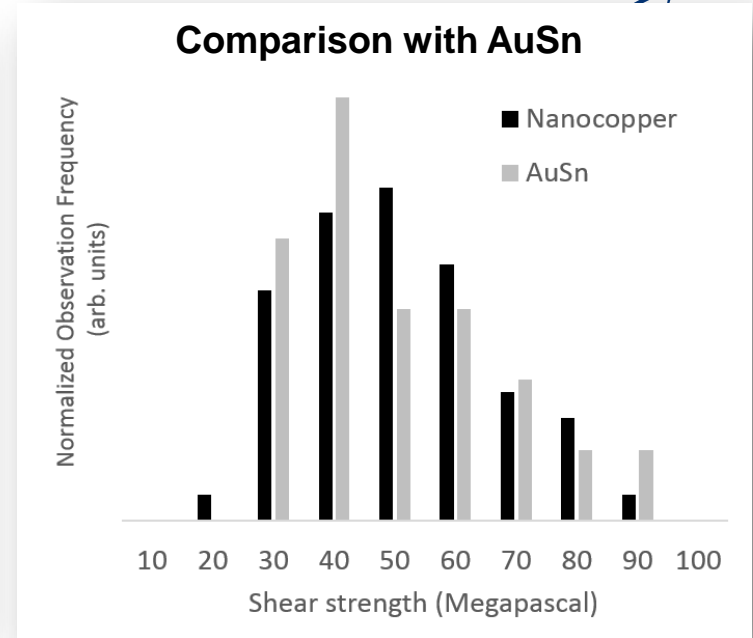
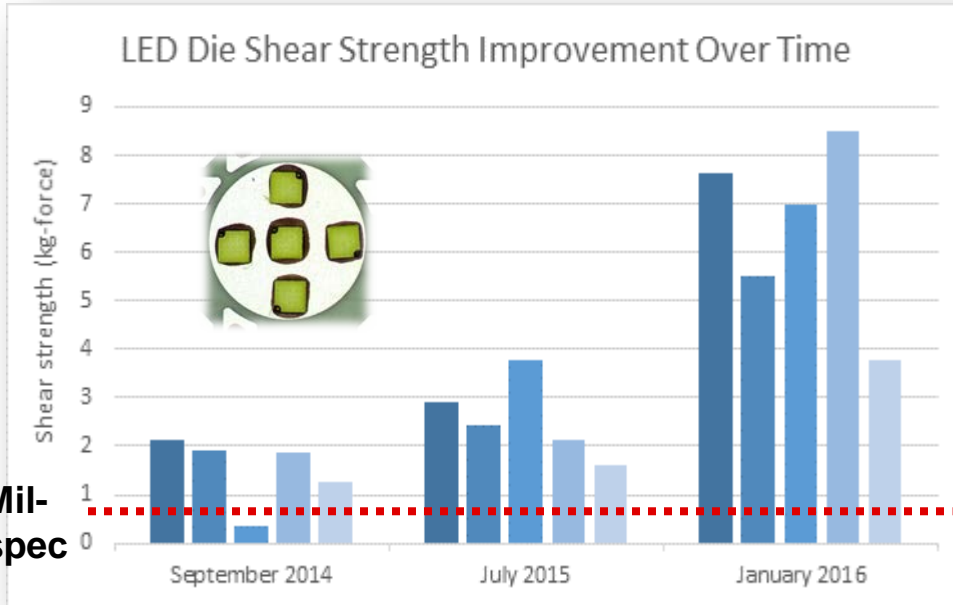
- Over 130 formulations evaluated
 - Repeatable dispensing of less than 0.1 mg
- Improved Rheology
 - Can readily dispense >4g/mL dense paste
 - using standard solder dispensing equipment
 - Paste is stable, does not “cream”
 - Over 6 month Shelf-life
- Paste density can now be controlled
 - Can dial-in to over 5 g/mL
 - Over 90% Cu by weight!



Assembled Emitter

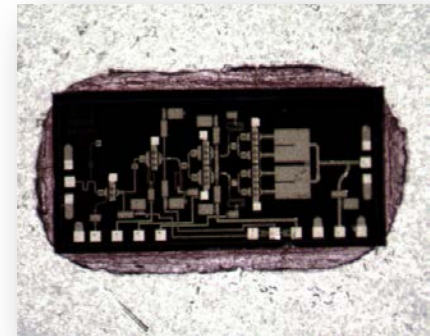
DENSITY > 3.7 g/mL, > 90% BY WEIGHT CU

LED Shear Test Results



- Used LEDs as test vehicle
- 5 LEDs per run
- Shear test over >5 kg
 - Mil-standard for 1 mm² is ~ 600g
- Now testing larger dies
 - 2 x 4 mm MMICs

MMIC on
ENiPG/Metgraf



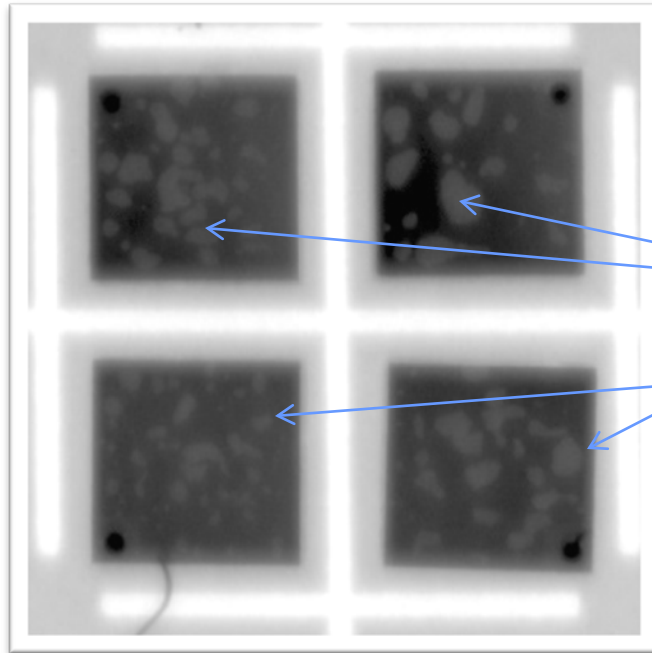
SIGNIFICANT IMPROVEMENTS IN SHEAR STRENGTH AND REPRODUCIBILITY

Comparison with AuSn Solder



- X-ray analysis
 - LEDs on ceramic substrate

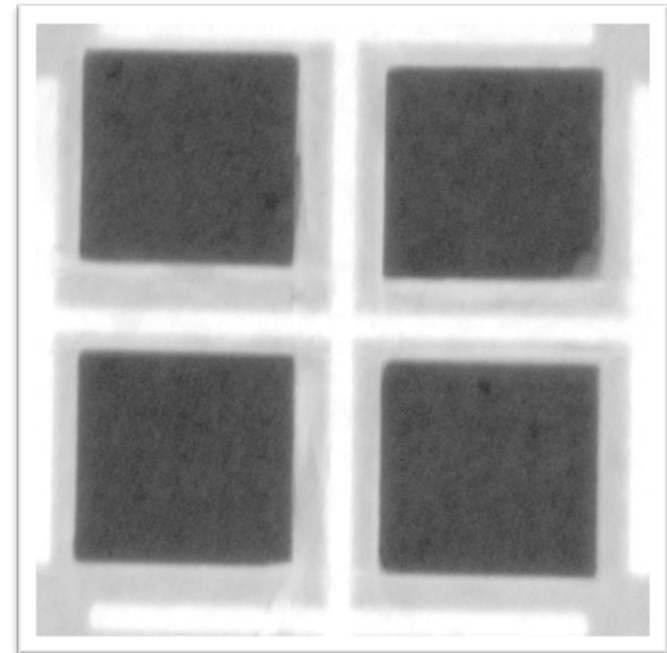
Commercial AuSn Solder



Voids

- **Multiple large voids**
 - Chance of early failure due to burn-out

Nanocopper Bondline



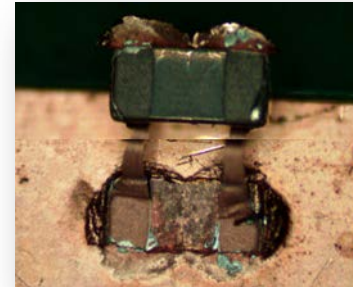
- **No voids**
 - Potential for very long life
 - High reliability

SIGNIFICANT IMPROVEMENTS IN SHEAR STRENGTH AND REPRODUCIBILITY

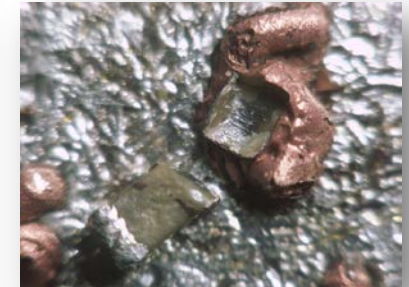
SMT Bonding



- Good bonding to Cu, Ag, Au, ENIG, Sn / SAC
 - In some cases over 80MPa
 - Average around 50 MPa
 - Voltage regulators
 - BGA and QFP packages
 - 26 pin through-hole connector



Contact ripped off



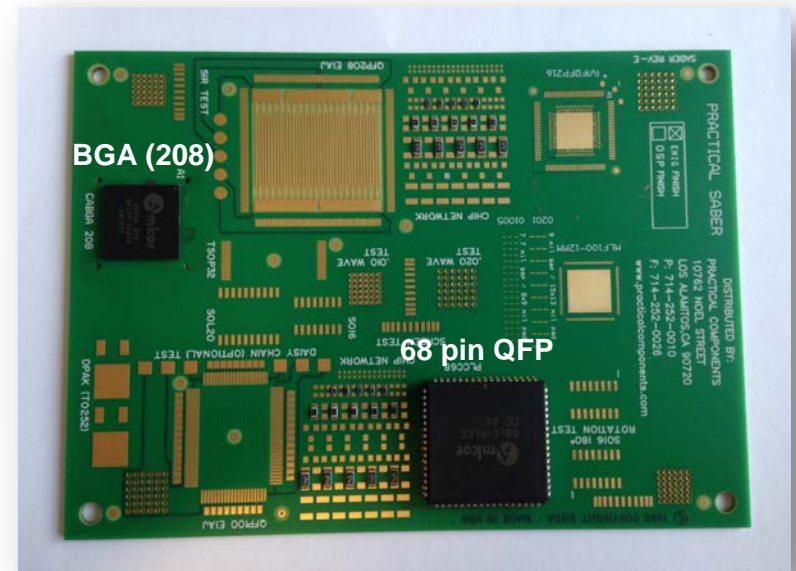
Broken Resistor



5-lead voltage regulators



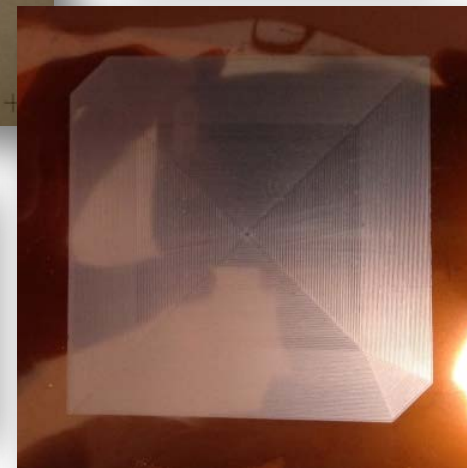
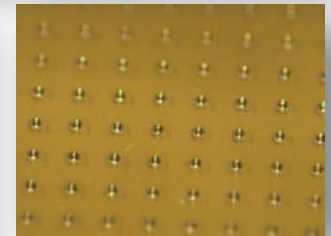
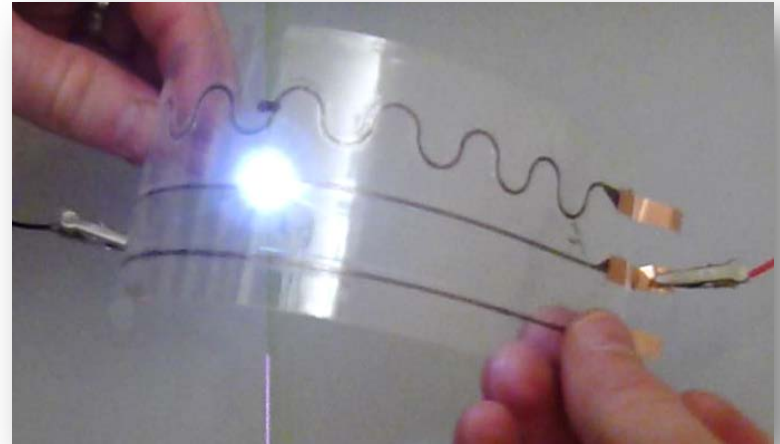
26-pin through-hole connector



Printing Applications



- **Initial demonstration of:**
 - Traces over 1 mm wide and
 - As narrow as 25 micron
 - 250 nm to 2 micron thick
 - Six passes on top of each other
 - Bumps / pillars >60 micron tall
(10 x 10 arrays)
 - Different substrates
- **Application in 3D printing & additive manufacturing**
 - Potential for injection molding



Overall Materials Advantages



- **Special features:**
 - Processing temperature as low as 200°C
 - Drop-in replacement for solder
 - Good adhesion to Cu, Ag, Sn*, SAC*, ENIG
- **Up to 10x higher thermal / electr. conductivity compared to solder once fully optimized**
- **Unique rework process**
 - Low temperature (<200°C) process enables multiple rework cycles
- **Tin-whisker-free**
- **No Cu dissolution or pad weakening / failure**
- **No brittle IMC formation / no gold embrittlement**



ENABLES RELIABLE ALL-COPPER SYSTEMS



Thank you
for your interest!

