National Aeronautics and Space Administration

NASA Electronic Parts and Packaging Program
Electronic Technology Workshop

Introduction to Panel Discussion on Copper Bondwires

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Acronyms

Acronym	Description
BoK	Body of Knowledge
COTS	Commercial Off The Shelf
CTE	Coefficient of Thermal Expansion
EEE	Electrical, Electronic and Electromechanical
FAB	Free Air Ball
IMC	Intermetallic Compounds
MIL	Military
NASA	National Aeronautics and Space Administration
NEPP	NASA Electronic Parts and Packaging
pH	Measure of acid or alkalinity
QML	Qualified Manu
Tg	Glass transition temperature

Overview

- Description of NEPP BoKs
- Topics from NEPP BoK (White Paper) #1 (2015):
  - Comparison of Physical Properties for Gold, Silver and Copper Bondwires
  - Cost Comparison of Different Thickness Copper and Gold Bondwires
  - Basic Pros and Cons of Using Copper for Bondwires
  - Suggested Future Work
- Topics from BoK #2 (2018)

Cu Bond Wire Panel

- **Michael J. Sampson**; Co-Manager, NASA Electronic Parts and Packaging (NEPP) Program
- **Sultan Lilani**; Director; Technical Support; Integra Technologies
- **Dr. Mukul Saran**; Senior Member of Technical Staff; TI
- **Jeff Jarvis**; Engineering, D CIV USARMY AMRDEC
- **Dr. Aaron E. Pedigo**; Materials Engineer; Naval Surface Warfare Center , Crane Division, (NSWC Crane)
- **Robert Varner**; Quality and Safety, Parts, Materials, and Processes (QSP); Missile Defense Agency

What is a NEPP BoK?

- BoK means Body of Knowledge
- It is a report documenting all relevant, available details NEPP can capture on a particular EEE parts technology that NASA has an interest in.
- Its purpose is to identify what is already known so NEPP can focus resources on closing gaps, avoiding duplication and zero-in on key technical factors to evaluate for effectiveness, practicality, reliability and value before dedicating funds to an evaluation.
- There is no strict format but typical BoKs are 20 to 30 pages; images encouraged.
- NEPP released its first BoK on copper wirebonds in 2015
- Another BoK, documenting new information is awaiting official release

Selected Highlights from NEPP BoK for Copper Wire Bonding Number 1

Copper Versus Gold, Physicals

Property	Copper (Cu) Annealed	Gold (Au)	Au Delta to Cu	Silver (Ag)[1]	Ag Delta to Cu
Hardness, Vickers	50	25	-50%	25	-50%
Tensile Strength, Utimate (psi)	30,500	17,400	-43%	20,300	-33%
Modulus of Elasticity (ksi)	16,000	11,200	-30%	11,000	-31%
Electrical Resistivity (ohm-cm)	1.70×10^{-6}	2.20×10^{-6}	29%	1.55×10^{-6}	-9%
Thermal Conductivity (BTU-in/hr-ft^2-°F)	2670	2090	-22%	2910	9%
CTE, linear (um/m-oC) @Temperature 20.0 – 100°C	16.4	14.4	-12%	10.9	-33%

Note 1: Elemental silver is not used in wire bonding semiconductors. Silver alloy is used.
The Ag alloy electrical resistance is approximately twice that of copper and the CTE is higher than Cu.

Copper and Gold Financials

Property	Copper (Cu)	Gold (Au)	Au Delta to Cu
Cost of bulk material $/ounce	0.19	1200	+600%

Cost saving, copper compared to gold	
99.99% purity wire 0.7 mil	12%
99.99% purity wire 1.0 mil	66%
99.99% purity wire 2.0 mil	85%

Data From: Body of Knowledge (BOK) for Copper Wire Bonds, E. Rutkowski and M. J. Sampson (2015)

Pros

- Copper is an economic alternative to gold wire bonds in commercial device packages.
- Copper bonding wire has lower electrical resistance than gold bonding wire.
- Copper bonding wire has better thermal properties than gold bonding wire.
- Copper bonding wire has a higher current carrying capacity than gold bonding wire.
- Copper has a higher modulus of elasticity than gold resulting in stiffer wire bond loops which may lead to better wire sweep performance during the device molding process.
- Copper-Aluminum intermetallic formation rate is much slower than that of the gold to aluminum intermetallic formation rate which results in better reliability under ageing conditions

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Cons

- Copper bonding wire is significantly more prone to corrosion issues than gold bonding wire
  - The molding compound pH and molding compound halide concentrations need to be controlled.
  - In addition, delamination of the package needs to be avoided.
- Copper is harder than gold resulting in a smaller manufacturing process window and the need for stronger bond pads
  - Copper bond wires would be difficult to implement on legacy semiconductor devices due to the potential need to redesign bond pads to accommodate the extra copper hardness.
- Copper bonding requires additional manufacturing process expense:
  - Nitrogen is required for a Free Air Ball (FAB) for palladium coated copper bonding wire
  - Forming gas (such as 95% Nitrogen, 5% Helium) is required for pure copper bonding wires
  - In order to create a reliable FAB.
- Gold wire bonds have a well-established reliability history over many decades
  - Copper wire bonds in COTS parts have been only recently seen usage on a large scale.
- Copper bonding wire has a limited manufacturing shelf life
  - Can be mitigated by using a more expensive palladium coated copper bonding wire.
- Copper has a greater CTE than gold
  - Part designs should ensure the copper to molding compound CTE mismatch is minimized

Principle Challenges of Wire Bonding With Copper

- Hardness:
  - Copper has 2X the Vickers hardness of gold
  - Also, copper rapidly work hardens, including during bonding which increases risk of cratered bond pads, aluminum splash from the bond pads
- Oxidation:
  - Copper oxidizes readily, impairing formation of intermetallics (IMCs)
  - Impairs Electric Flame-off ball formation

Suggested Future Work

- Attempts to find technical literature on copper wire bonding inside hermetic packages were unsuccessful.
  - NASA should monitor for any proposed adoption of copper wire bonds in hermetic packages, especially for MIL (military) QML (Qualified Manufacturer List) devices.
- Specification needed to define appropriate qualification of copper wire bonded semiconductors for spaceflight hardware.
  - In addition to the electrical and environmental testing requirements in this specification, a mechanical section could be included to define the appropriate visual inspection criteria for copper wire bonds and suitable wire bond pull and bond shear strength requirements.
- A study is needed on one or more automotive grade semiconductors manufactured with copper bond wire interconnects in an epoxy molded package to examine:
  - DPAs to learn about bond pad construction
  - Workmanship assessment of ball bond and stitch bond quality characteristics
  - Materials identification study of the bonding wire elemental constituents
  - Molding compound properties such as CTE and T_g
  - Identification of any contaminants (such as halogens), moisture and pH

Selected Highlights from NEPP BoK for Copper Wire Bonding Number 2

Topics from latest NEPP BoK

- Two recent U.S.A. patents on mitigating wire bond corrosion; crevice corrosion; aluminum bond pad corrosion;
- Two papers regarding degradation of palladium coated copper wire bonds; palladium congregation in first bond of palladium coated copper wire;
- Six new reports on the development of <u>palladium coated copper wire with gold flash</u>;
- Importance of aluminum bond pad thickness
- Copper wedge bonds on silver and nickel-palladium-gold-silver metallization;
- Wire bond shear test method revision;
- Copper ball bond shear test threshold values in a U.S.A. patent;
- Copper stitch bond cracks
- Copper wire bond failure due to corrosion/delamination resulted in device failures;
- Copper bond pads;
- Sulfur compounds in epoxy packages;

Suggested Future Work

- Potential research studies in the following areas may be considered:
  - Researching the feasibility of implementing a stringent destructive bond pull test specification for copper wire bonds to assure a higher safety factor.
  - Investigating copper ball bond shear test statements that were reported in an U.S.A. patent for potential applicability in a shear test.
  - Investigating the appropriateness of a potential IMC thickness and /or IMC coverage specification in a qualification document.

Body of Knowledge (BOK) for Copper Wire Bonds

E. Rutkowski[1] and M. J. Sampson[2]

1. ARES Technical Services Corporation, 2. NASA Goddard Space Flight Center

(January 1, 2015)

Executive Summary

Copper wire bonds have replaced gold wire bonds in the majority of commercial semiconductor devices for the latest technology nodes. Although economics has been the driving mechanism to lower semiconductor packaging costs for a savings of about 20% by replacing gold wire bonds with copper

Update - Body of Knowledge (BOK) for Copper Wire Bonds (June 6, 2018)

E. Rutkowski[1] and M. J. Sampson[2]

1. ARES Technical Services Corporation, 2. NASA Goddard Space Flight Center

Executive Summary

Copper wire bond technology developments continue to be a subject of technical interest to the NASA (National Aeronautics and Space Administration) NEPP (NASA Electronic Parts and Packaging Program) which funded this update. Based on this new research, additional copper bond wire