Characterization of a Novel Fluxless Surface Preparation Process for Die Interconnect Bonding

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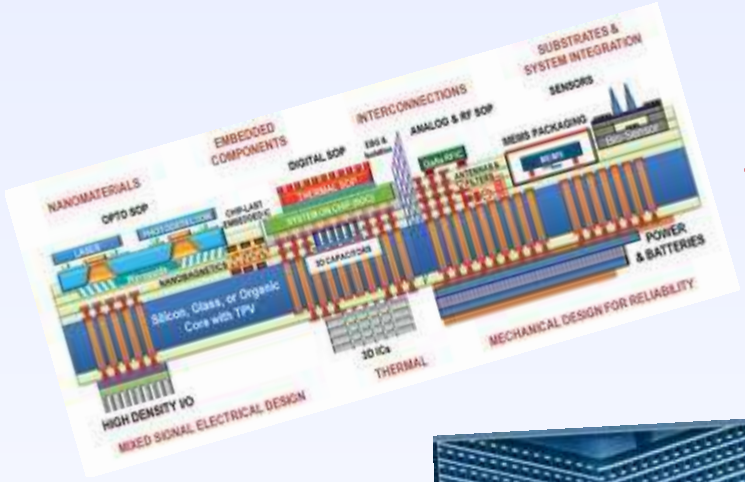
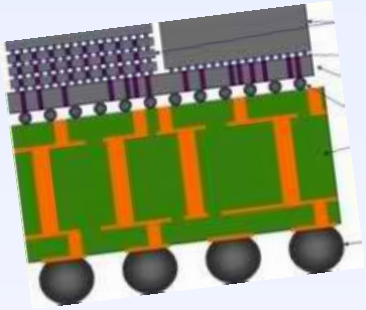
Agenda / Outline / Overview

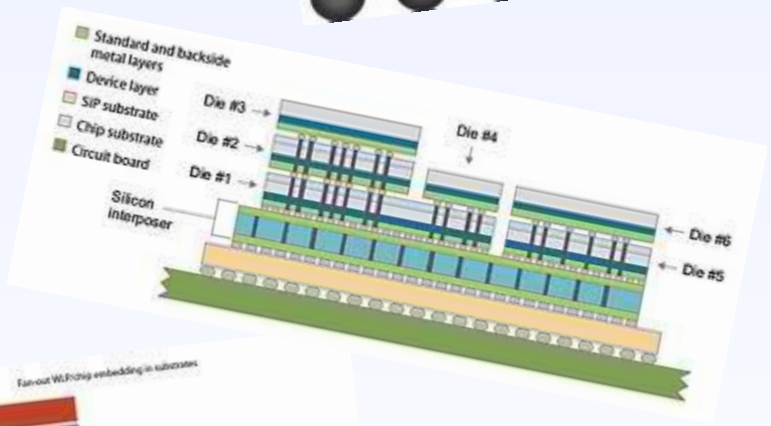
- Introduction
- Surface Preparation Metrics
- Experimental Results
- Summary
- Future Work
- Acknowledgements

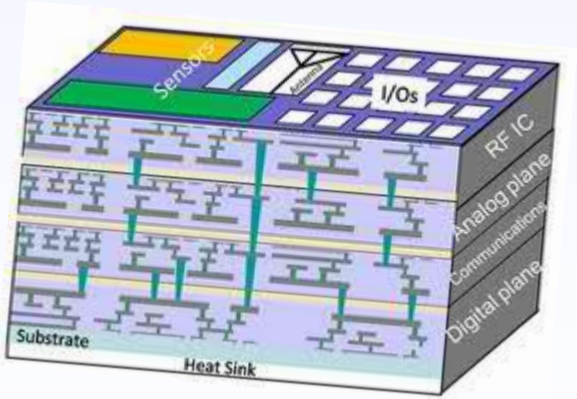
Cool 3D Structures

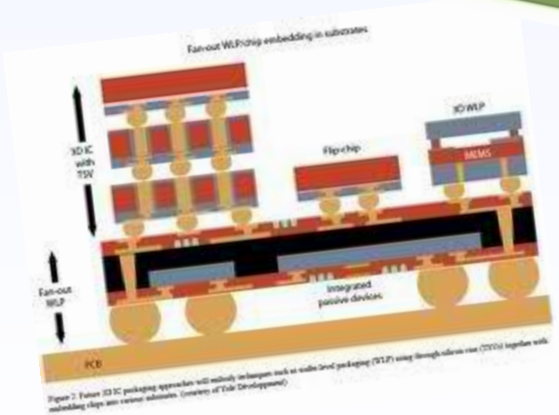


How are we going to actually assemble these???



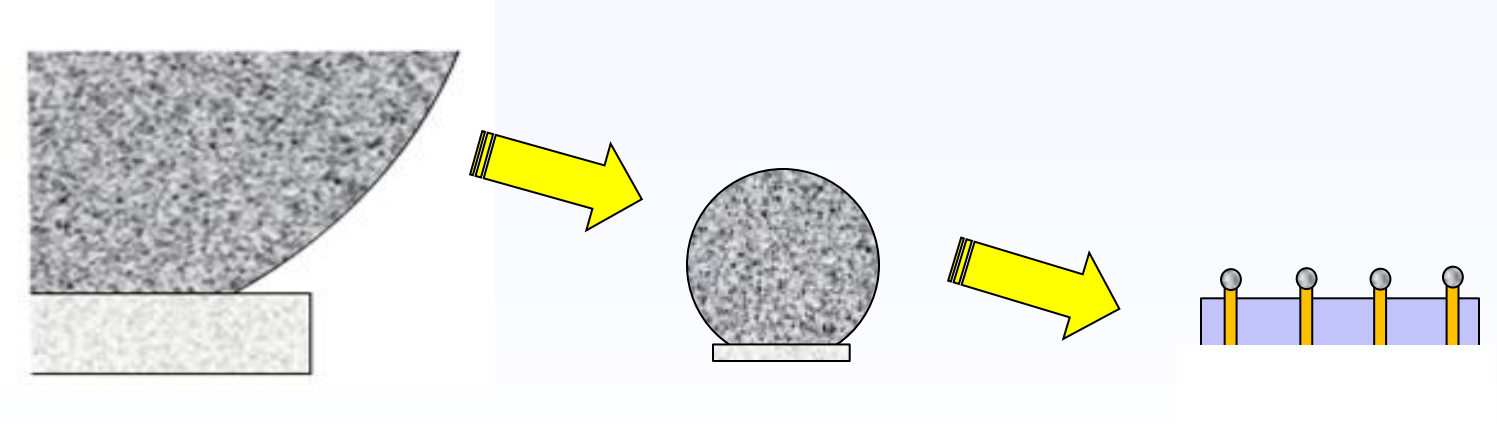






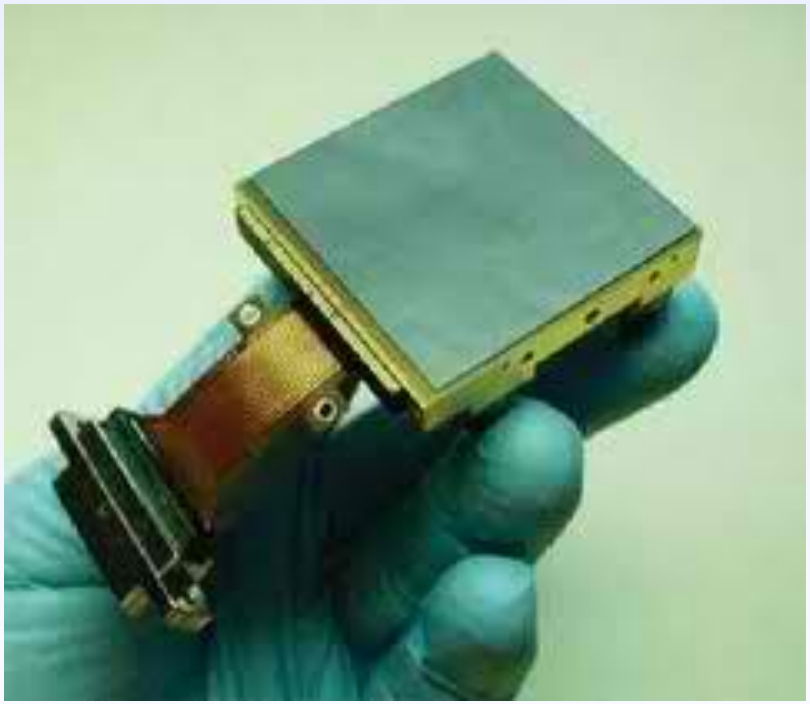
Introduction – Steady Demand for Finer Pitch Interconnects

- BGA
  - Ball-Grid arrays: 400-100u centers
- “Fine pitch” Flip Chip
  - C-4 - like processes: approaching sub-100u centers
- 3DIC chip stacking
  - Paradigm shift to TSVs, copper posts, SnAg caps: as low as 10u centers! True Microbumps as small as 3 microns.



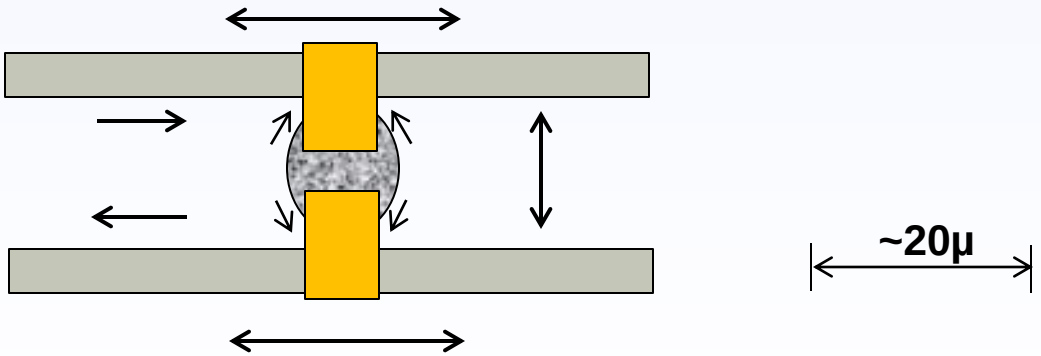
Some Clues From The Infrared Focal Plane Industry

2048 X 2048 IRFPA
4 Megapixel 3D Hybrid



Introduction – 3D Bonding is a Whole New Ballgame

- Micro-fine pitch and new bonding metallurgy require tighter restrictions on process control:
  - Bond alignment accuracy in X, Y, Theta, parallelism.
  - Maintaining alignment during initial (and subsequent) reflow.
  - Squeeze-out control.
  - Thermal expansion/flexibility/reliability issues.
  - Surface preparation to control oxides and contamination.



Why not Prep. with Flux, Acid, or RIE?

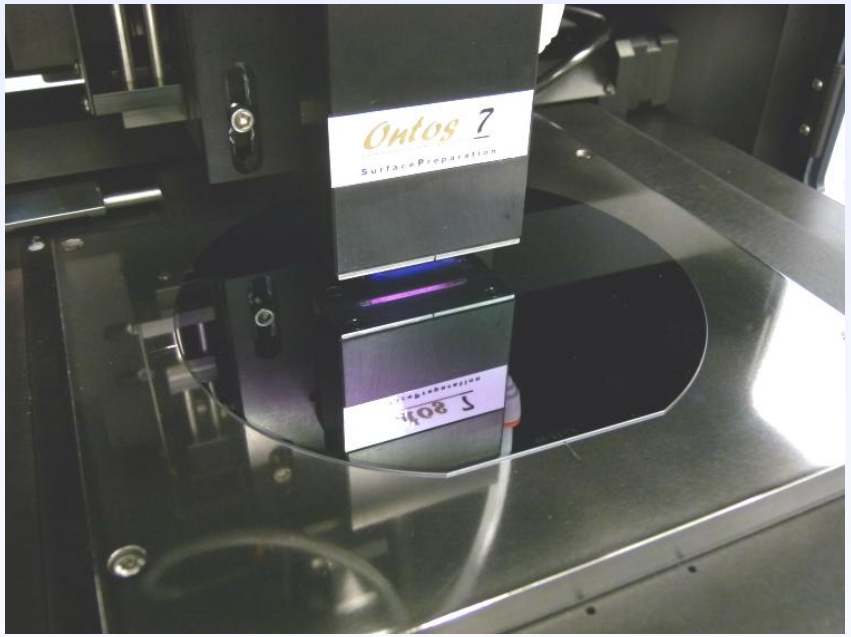
- Photoresist residue inhibits fluxes and acids - Non-uniformity.
- Narrow gaps – Flux cannot be removed. – Reliability.
- Acid dips difficult to control. Microbumps etch away in seconds. Electrolytic etch enhancement. Non-uniformity.
- Acid dips require rinse before bonding – re-oxidation is time-sensitive.
- Oxygen ashing – OK for organics, but grows hard Oxide!
- RIE is slow, expensive, and potentially damaging to sensitive chips - Re-oxidation is time-sensitive.

We Propose A "Radical" New Approach To Surface Prep:
Atmospheric Downstream Plasma Treatment

- Advantages:
  - Simple apparatus – no vacuum chamber.
  - Plasma is contained entirely within the process head, never contacting the chip/wafer.
  - Downstream radical chemistry only.
  - No exposure to: arc discharges, ions, bombardment, re-deposition.
  - CMOS safe.
  - Fast process - completes in seconds – continuous thruput capable.
  - Non-toxic, dry process. OSHA- and EPA-friendly.
  - Very effective at removing organic contamination films and loose particles.
  - Reduces native oxides on metallic surfaces.
  - Can add surface passivation against re-oxidation - removal not required.

Atmospheric Downstream Plasma Apparatus

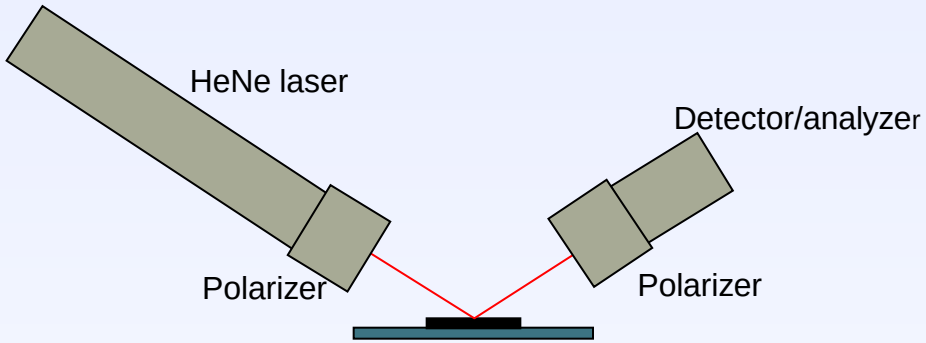
- Chip/wafer is scanned under compact process head.
- 25mm wide process zone.
- Typical scan rate: 1-5 mm/sec.
- Process runs in room ambient.
- Programmable control of plasma and scan parameters.
- Vacuum chuck handles small chips to 8” wafers.
- Typical power to internal plasma source: 60-100 Watts.
- Made in U.S.A.

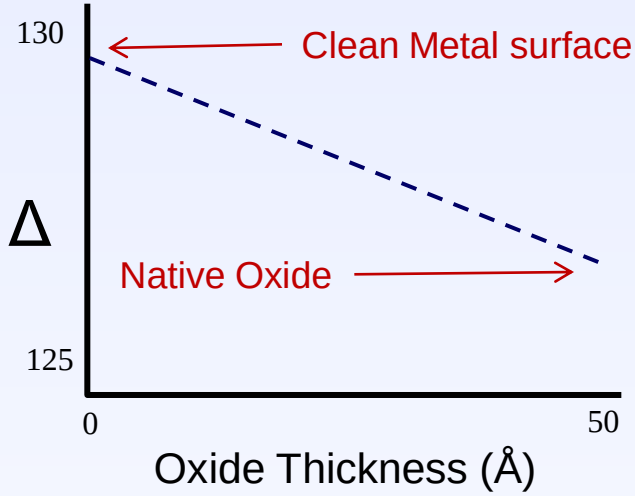


Surface Preparation Metrics
How Is The Process Monitored?

- Surface films only a few monolayers thick can compromise bonds, but are difficult to characterize.
  - XPS.
  - Empirical bonding tests.
  - Laser Ellipsometry provides fast, quantitative surface film data even at sub-monolayer coverages.

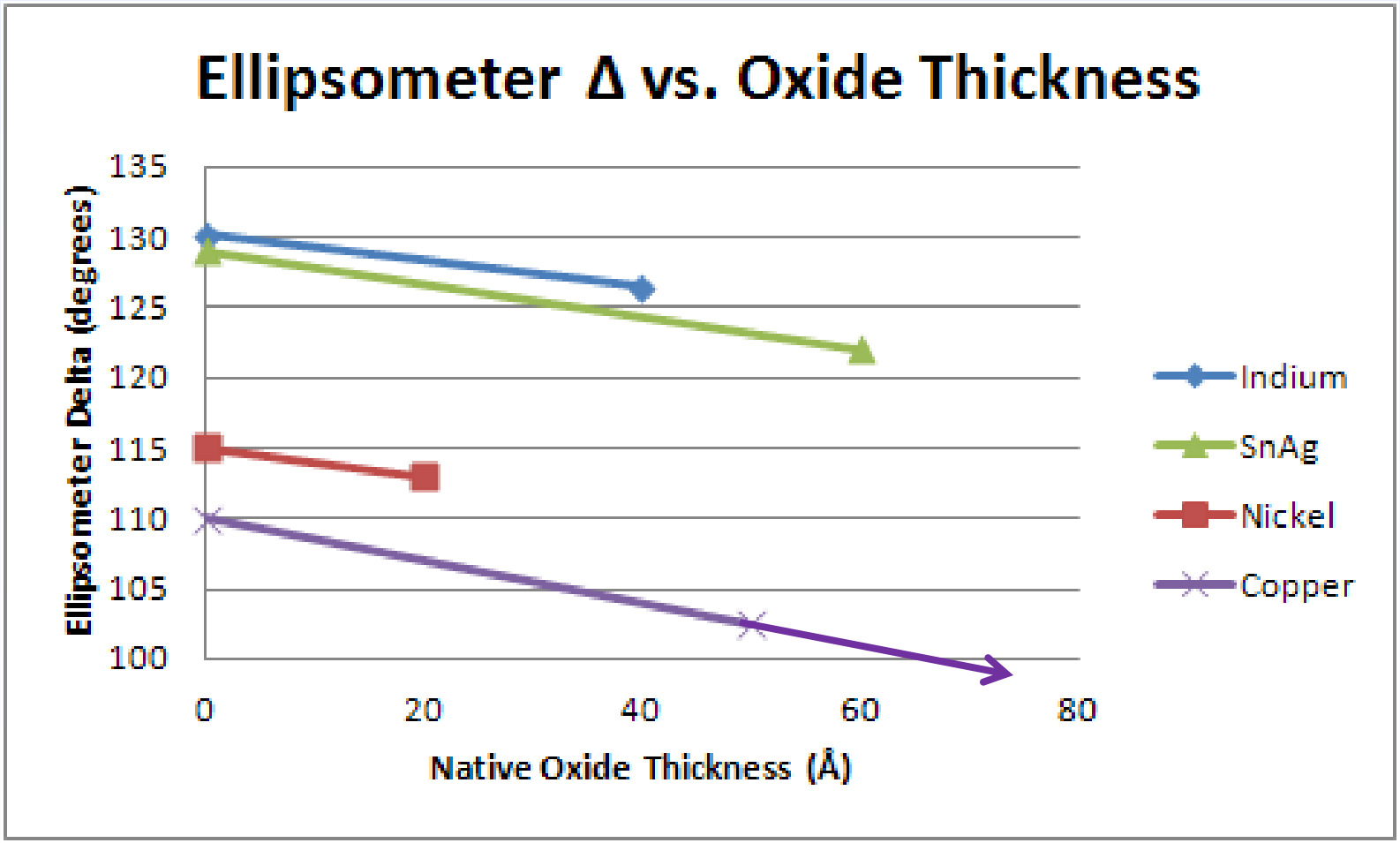
Laser Ellipsometry As A Surface Film Metric





- Polarized laser beam reflects from sample surface
- Change in polarization (Δ) depends on index and thickness of surface film (i.e. metal oxide)
- One degree change in Δ corresponds to ~2.5 monolayers of surface film (index dependant).

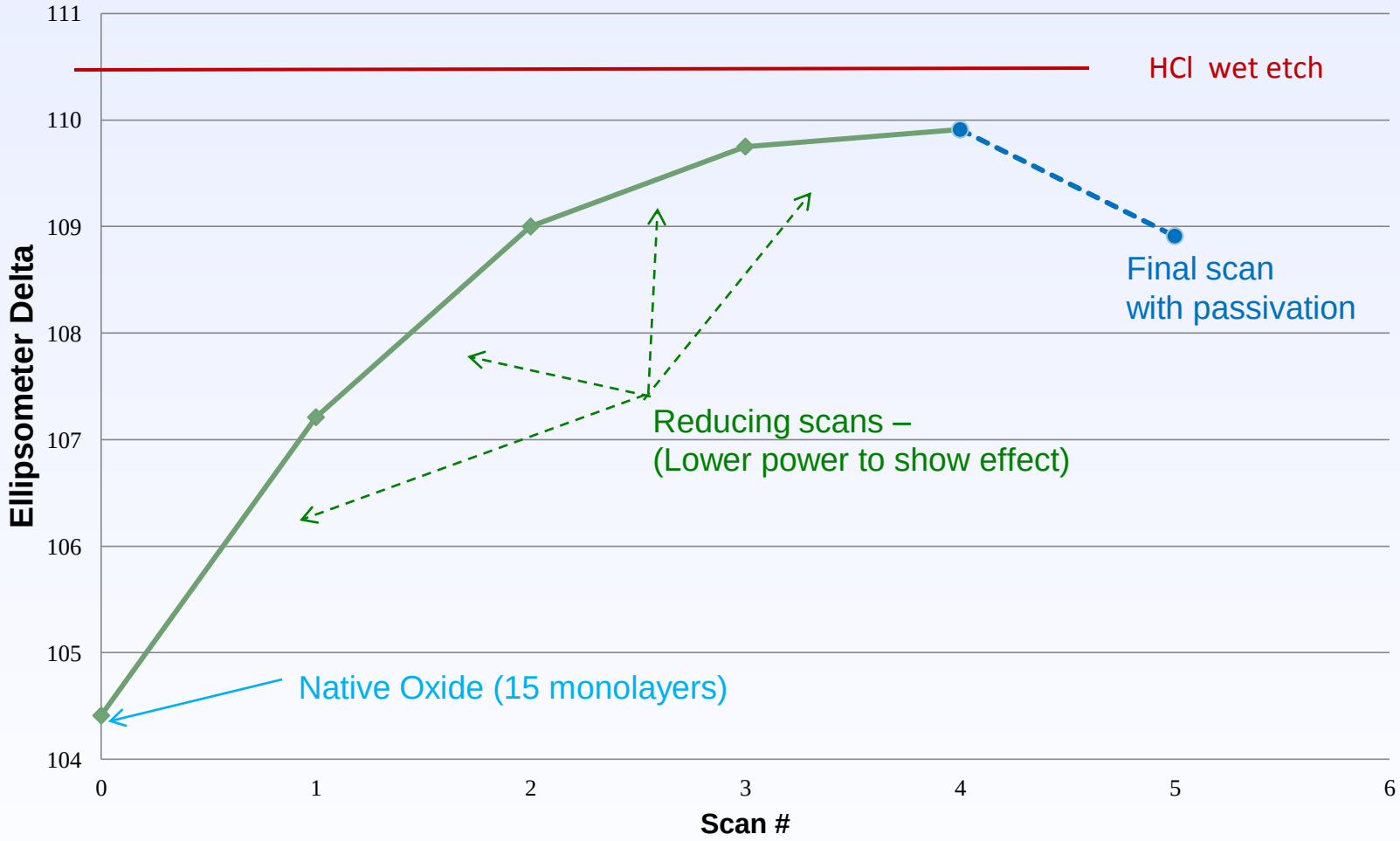
Examples Of Ellipsometer Response



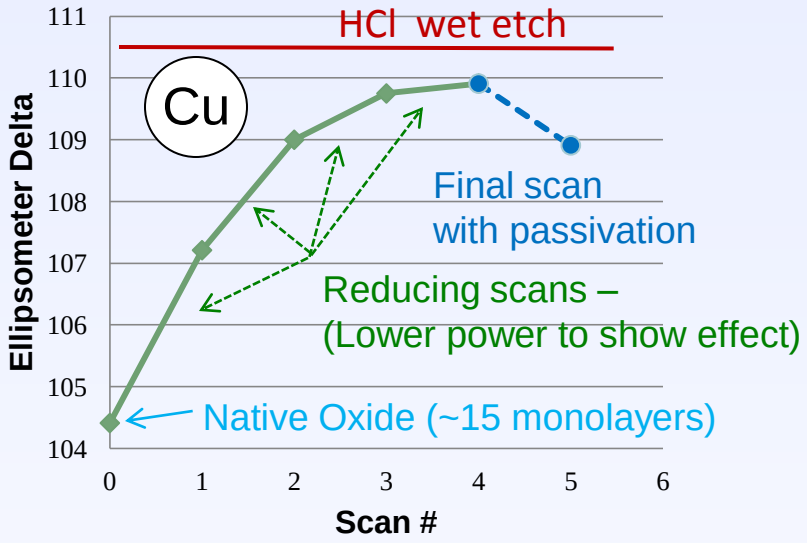
Process-Induced Ellipsometer Response:

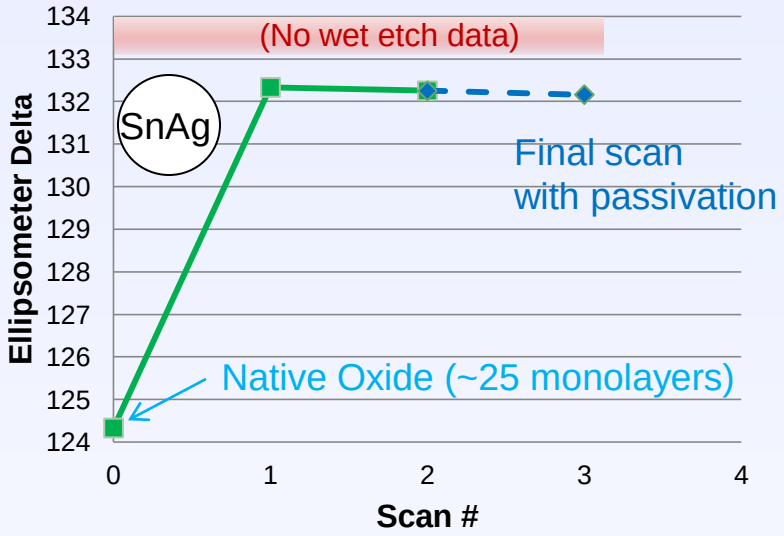
- Copper
- SnAg
- Nickel
- Indium

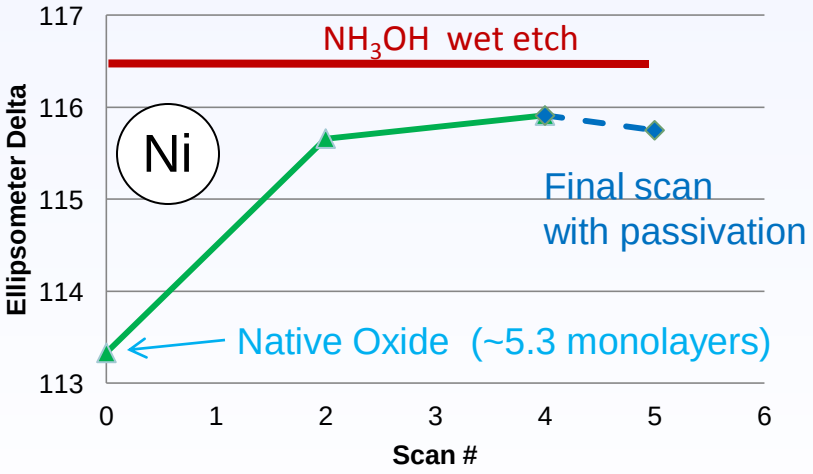
Copper Response To Atmospheric Plasma Treatment

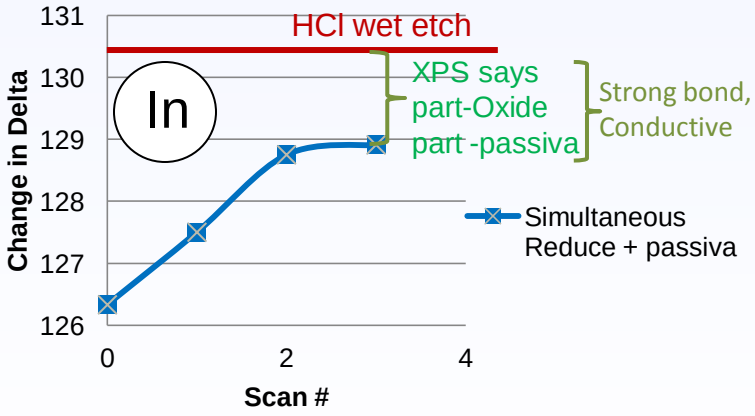


Cu Similar response from SnAg, Ni, and In



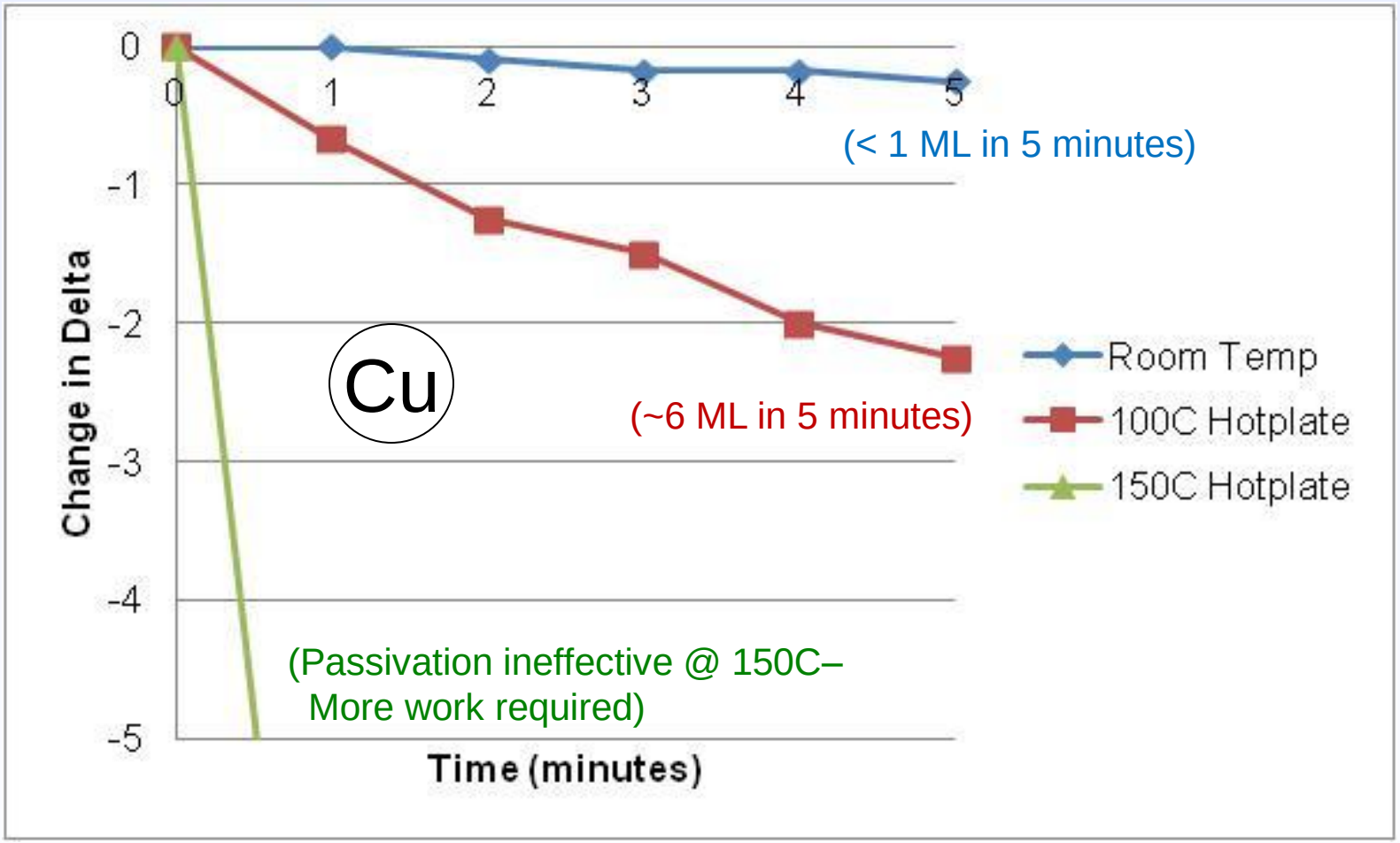




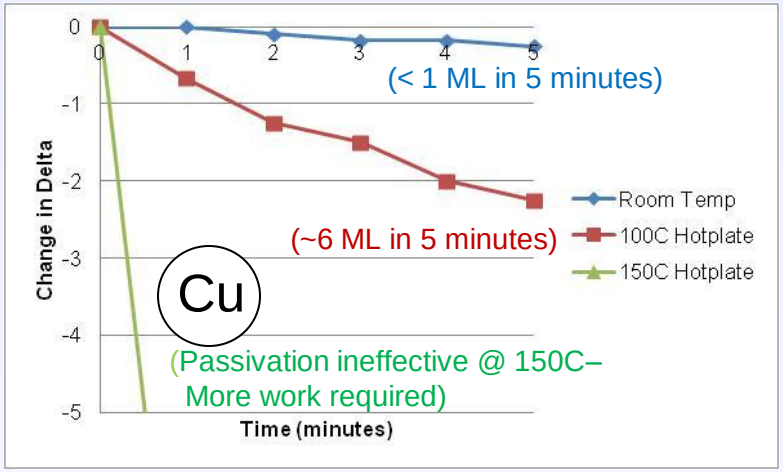


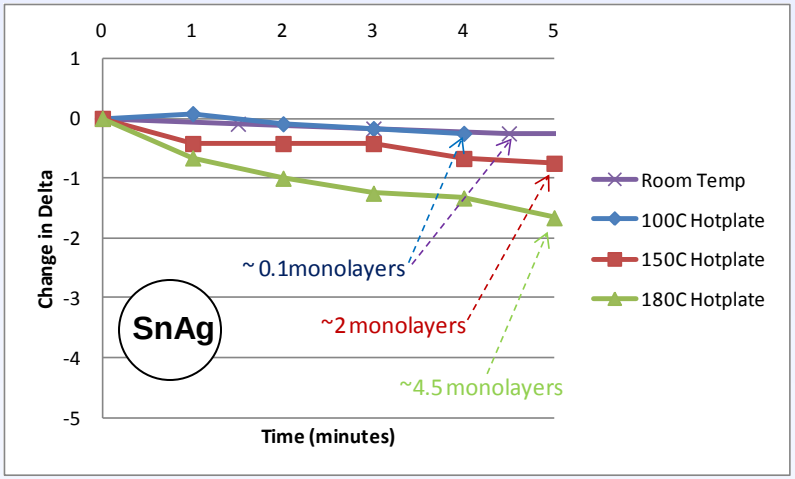
Passivation Stability

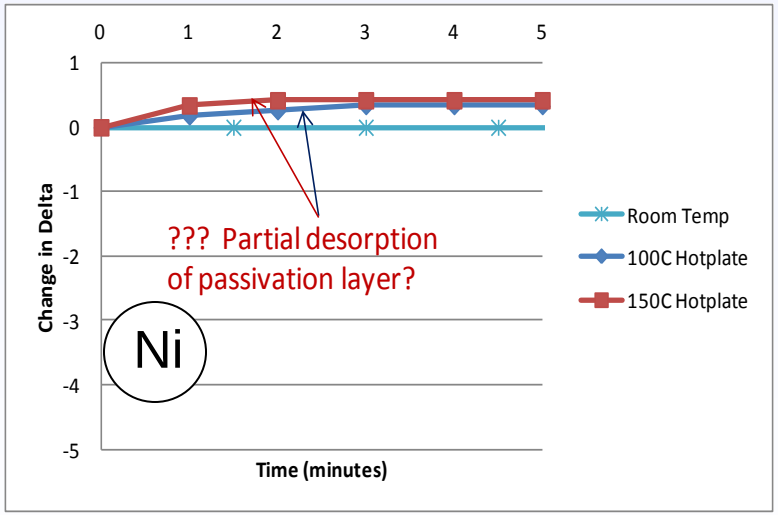
Copper Passivation Effectiveness Vs Temperature (in air)

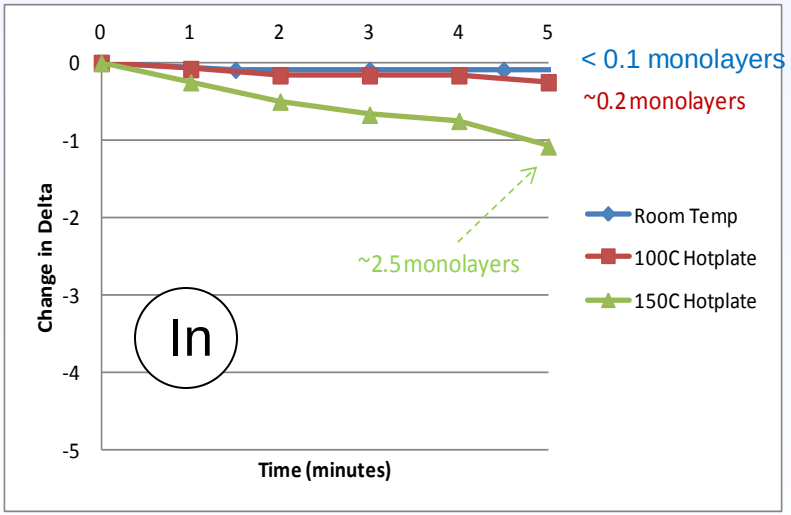


Passivation Is More Effective On SnAg, Ni, And In



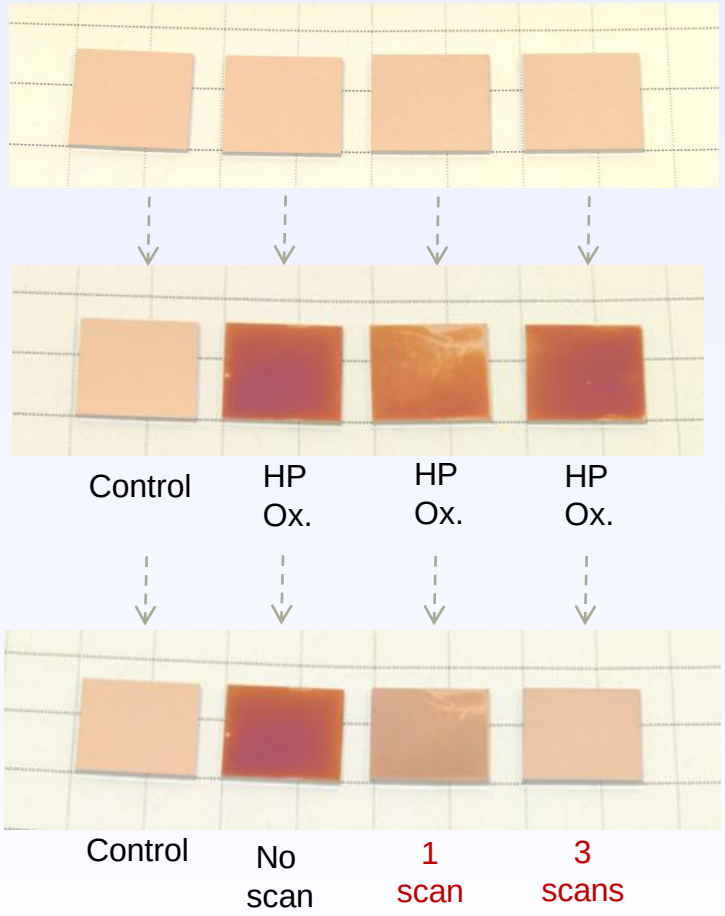






Physical Results

Graphic Demonstration: Removing Heavy Copper Oxide at R.T.



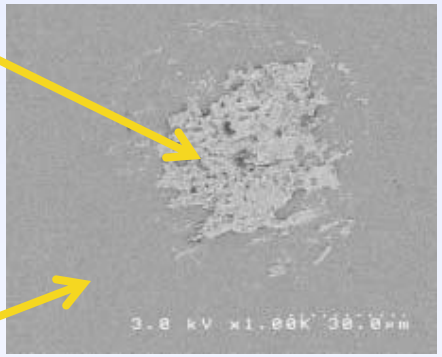
4 Cu/Si coupons out of the box

3 coupons hotplate oxidized - 150C, 12 minutes (Approximately 400 Angstroms)

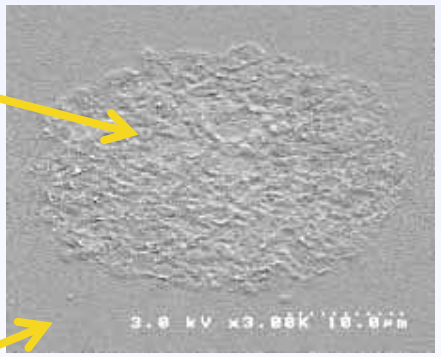
Atmospheric Plasma reduces Cu Oxide at R.T.
3 scans returns Cu to native state.

Bonding to Treated Copper

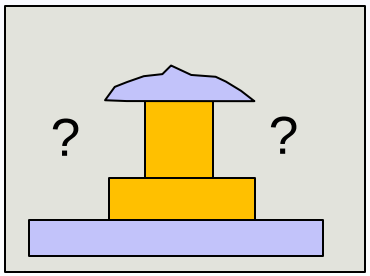
- Indium to Copper
  - Both surfaces treated.
  - Room temperature compression.
  - No reflow.
  - Shear test shows In bonded to Cu.



- SnAg to Copper
  - Both surfaces treated.
  - 185C compression in air.
  - NO reflow
  - Shear test shows SnAg bonded to Cu.

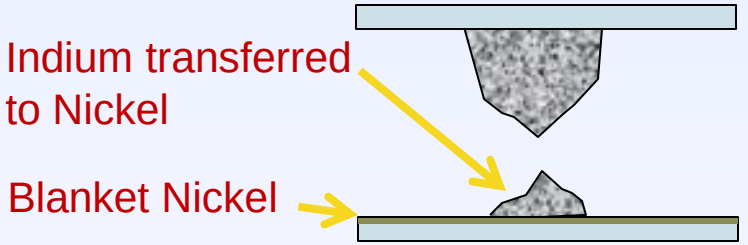


- Copper to Copper
  - Want to try.
  - Need samples.

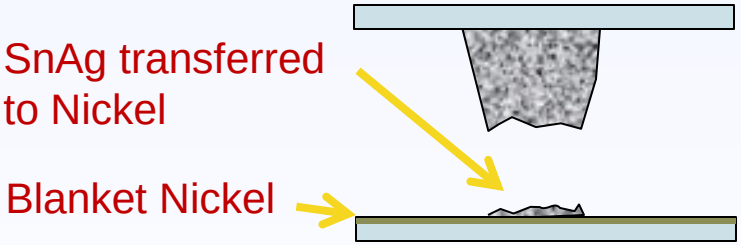


Excellent Bonding to Treated Nickel

- Indium to Nickel
  - Both surfaces treated.
  - Room temperature compression.
  - No reflow.
  - Pull test showed Indium transferred to blanket Nickel. (no photo available)
  - Tensile rupture of Indium within bump



- SnAg to Nickel
  - Both surfaces treated.
  - 180C compression.
  - No reflow.
  - Pull test showed SnAg transferred to blanket Nickel. (no photo available)
  - Tensile rupture of SnAg within bump



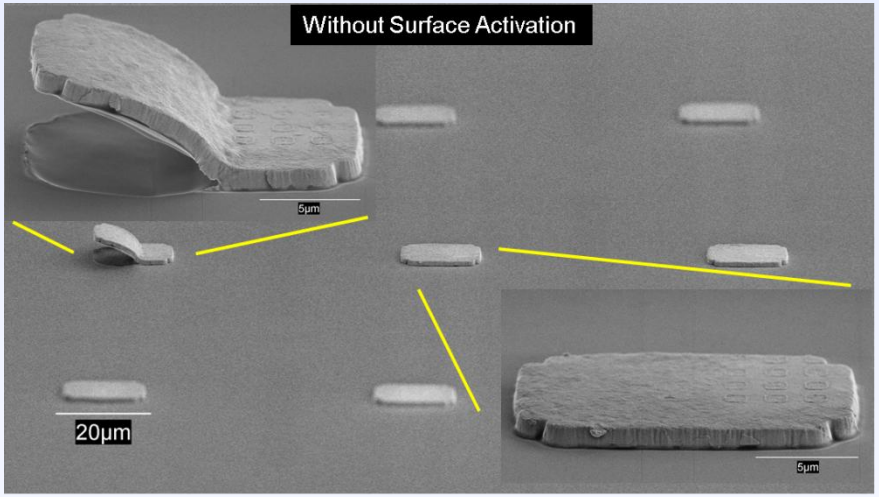
Benefit of Ni over Cu: No fragile intermetallics!

Special Case: Gold

Thermocompression at 200C

Bonding Gold Pad to Gold Pad

- Gold pad to Gold pad
  - No surface treatment.
  - Compression @ 200 C
  - No reflow.
  - Pull test showed Gold pad compression but low adhesion



Credits: Brian Troelsen (SEM), Katlin Schroeder

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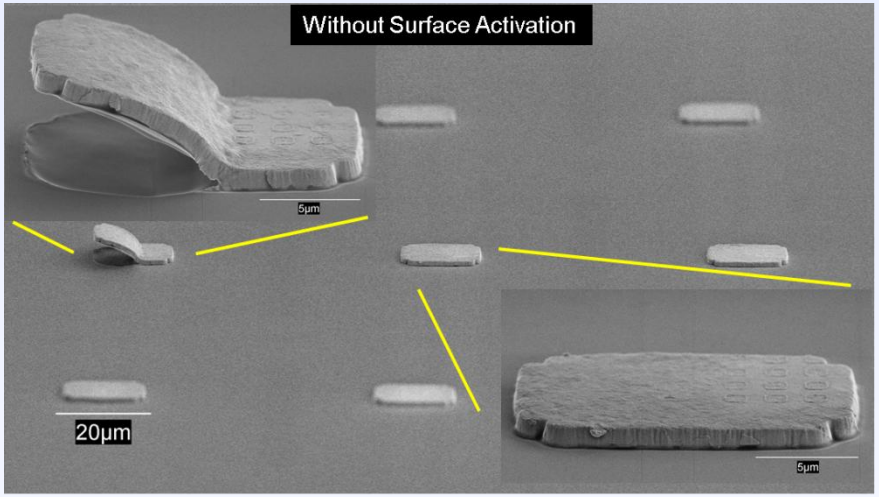
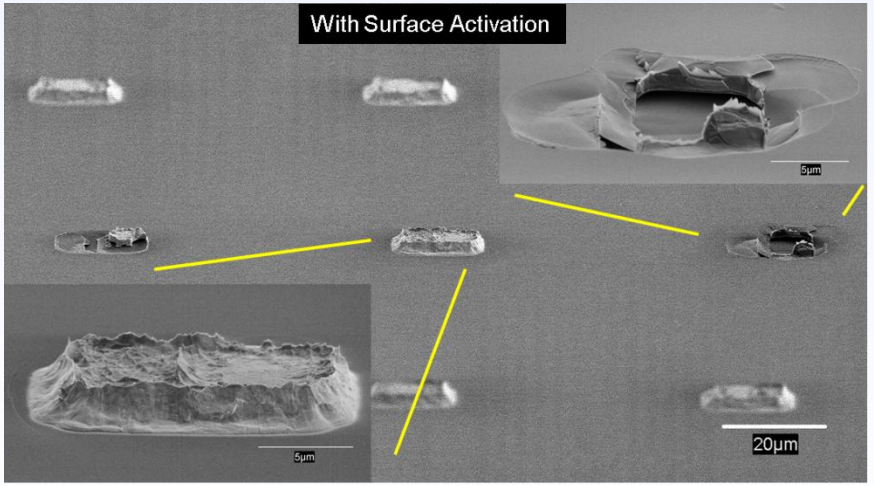


Credits: Brian Troelsen (SEM), Katlin Schroeder

- Gold pad to Gold pad
  - Both surfaces treated.
  - Compression @ 200 C
  - No reflow.
  - Pull test shows ideal tensile rupture of Gold
  - In many places, entire pad with underlying Silicon was pulled out.



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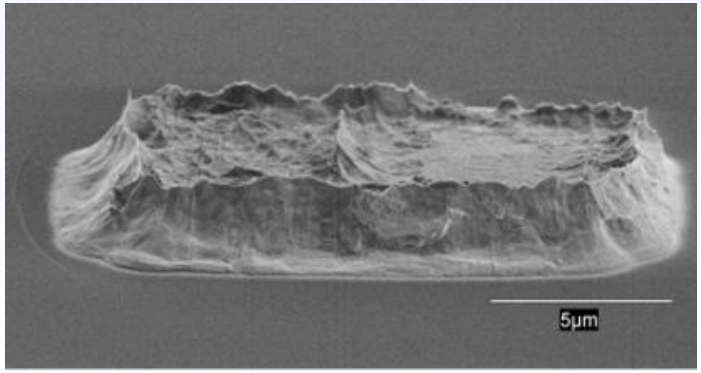
Gold Response To Atmospheric Plasma Treatment

Why Is Reducing Chemistry Having An Effect On Gold?

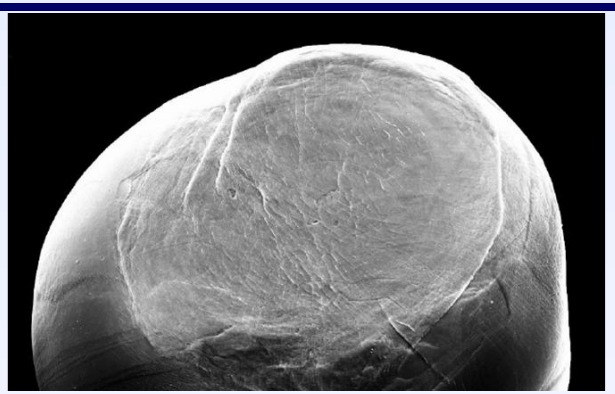
- Small 1 degree change in Delta corresponds to approximately 2.5 - 3 monolayers of…..What?
  - Au_2O_3?
  - Organic residue from previous photoresist liftoff?, dicing protect?
  - Perhaps a monolayer or two of adsorbed H_2O, OH, or general atmosphere organics?
  - A trace of Silicone from Gelpak container?
  - Need before/after XPS data.
- Whatever it is, the Atmospheric Surface Treatment does a very nice job of cleaning and activating the Gold surface for bonding.



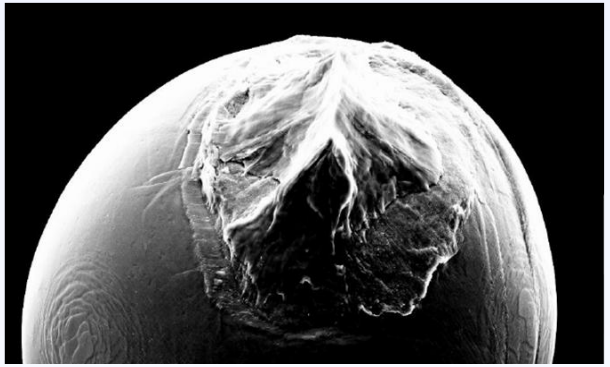
Special Case: Indium

Bonding With Indium

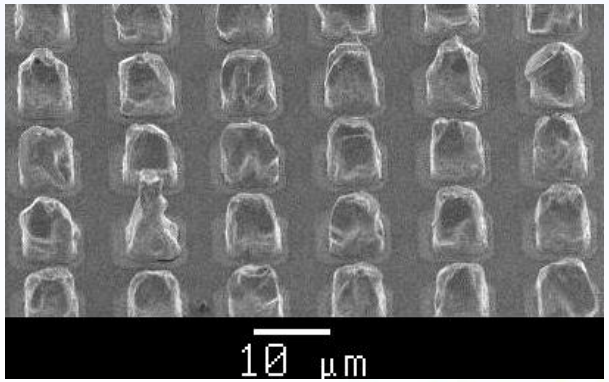
- Indium bump to Indium bump (70µ bumps)
  - No surface treatment.
  - Room temperature compression
    - 1 gram per bump.
  - No reflow.
  - Pull test shows Indium compression but zero adhesion



- Indium bump to Indium bump (70µ bumps)
  - Both surfaces treated.
  - Room temperature compression.
    - 1 gram per bump.
  - No reflow.
  - Pull test shows ideal tensile rupture of Indium.



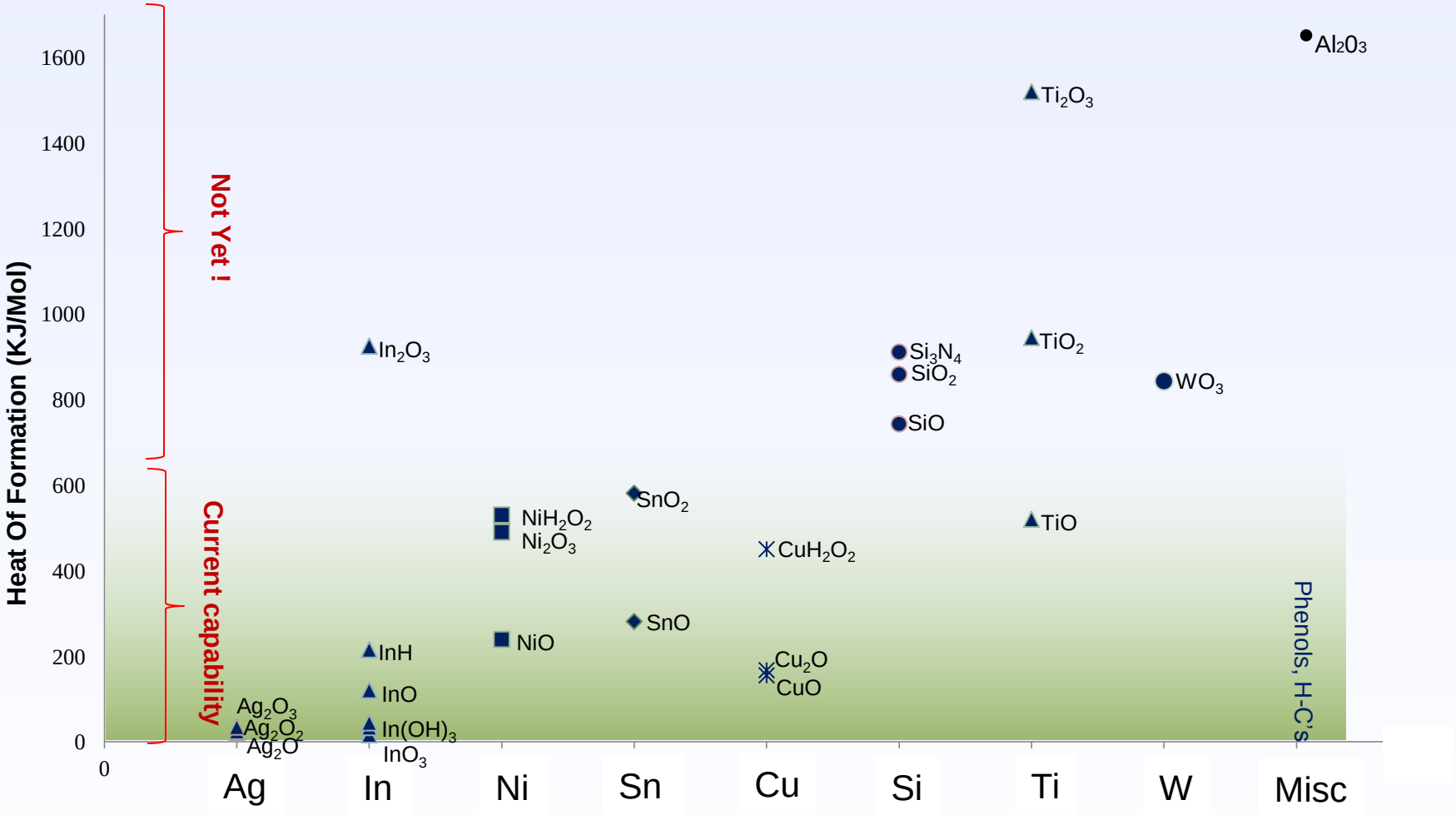
- Indium bump to Indium bump (IRFPA 20µ c-c)
  - Both surfaces treated.
  - Bonded at room temp, no reflow.
    - 0.1 gram per bump.
  - Pull-apart shows ideal tensile rupture in indium bulk.



Should Indium Be Considered For 3D Interconnect?

- Mil-Spec. reliability in Infrared Focal Planes:
  - Decades of application experience.
  - Mega-bump 3D structures in routine production.
  - Ideal for high-strain heterostructures.
- Instant bonding at room temperature:
  - No reflow required.
- But pure Indium melts at 156C – not good for subsequent reflow assembly.
  - Alloys of Indium provide broad range of melt temp:
    - Beyond 260C while still R.T. bondable.
  - ❖ **Could enable sequential 3D stacking without reflow**

Limitations:
Not All Oxides Are Created Equal



Conclusions

- Atmospheric Downstream Plasma provides rapid effective surface preparation for an important variety of metals.
- Addresses both oxidation and contamination issues in 3D assembly.
- Enables new paradigms in 3D assembly:
  - Wider range of acceptable contact metals,
  - Potential for non-reflow assembly,
  - Possibly even room temperature!

Future Work

- More XPS analysis to verify theories about the last few monolayers.
- Optimize passivation for Copper.
- Enable additional metals with higher Δ*Hf* capability.
- Explore the use of low-modulus alloys for room temperature 3D assembly. (Partner?)

Acknowledgements

- Sandia National Laboratories for numerous samples, XPS support, SEM photos.
- Dr Gerald Garwood, Garwood Analytical Group, for XPS support and interpretation.
- Mike Stead, SETNA, for bonding support.