



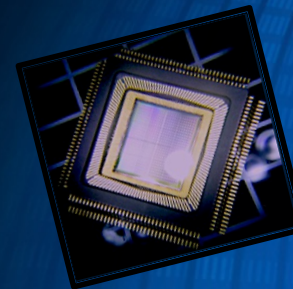
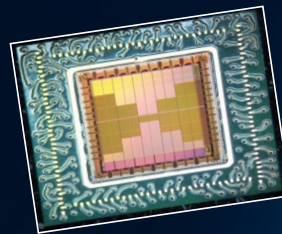
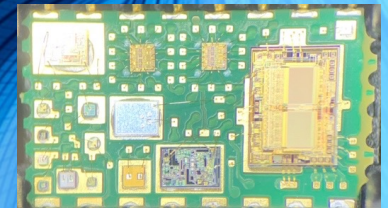
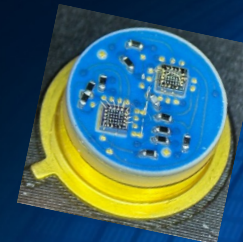
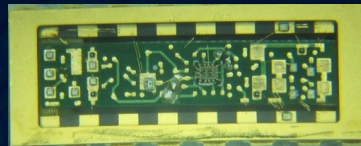
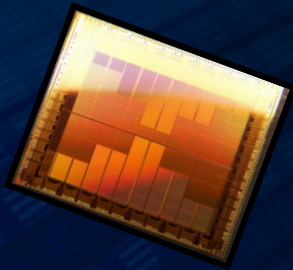
Ceramic Interconnect and  
Ceramic Microsystems  
Technologies Conference  
(CICMT)

# *Mitigation of Corrosion and Inter-Metallic Diffusion for SAC 305 Solder Paste on Silver/Palladium Ceramic Traces by Controlling Moisture Content*

by

Erick Spory, Global Circuit Innovations. +1 (719) 649-0947

**April 15, 2025**



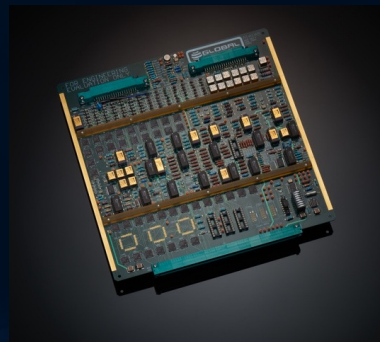
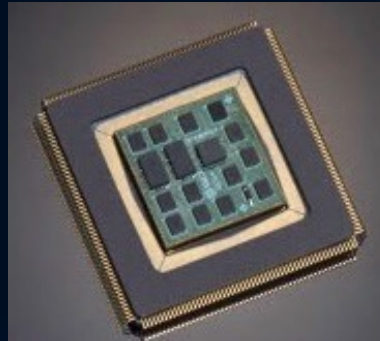
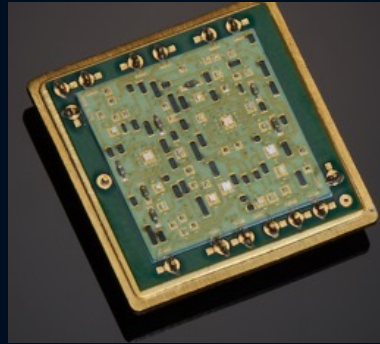
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# Introduction To Global Circuit Innovations

- Founded 2006 in Colorado Springs, Colorado - 25 Employees
- Established design and manufacturing engineering solutions house for Industrial and DoD electronics in extreme environments, rugged COTS replacements, and electronics obsolescence solutions
- Thorough understanding of Integrated Circuit (IC) device physics, fabrication processes, design, and IC failure mechanisms
- GCI currently holds 21 patents

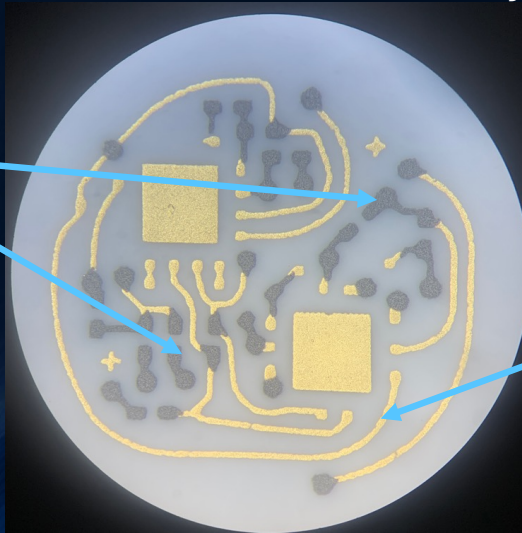




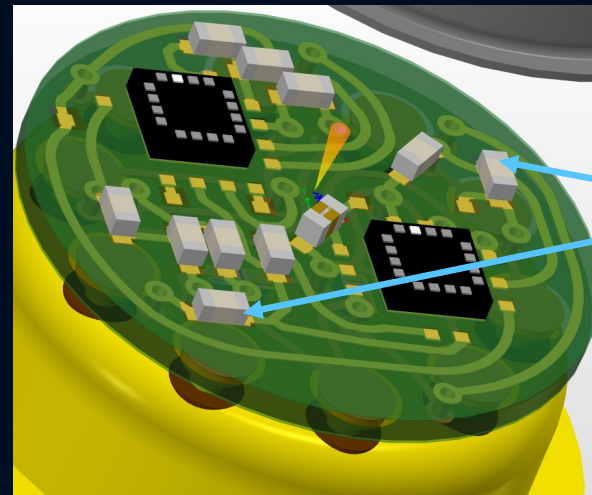
# Problem Statement

- Silver/Palladium (3:1 ratio) metal traces are commonly deposited as more economical pastes on ceramic substrates (rather than pure Gold) to form solderable connections of passives and routing layers. Ag/Pd also used because bondable Gold (Pt) can be Consumed with Sn solders.
- In the presence of moisture at levels as low as 100,000 ppm and temperatures greater than 125°C, SAC 305 solder paste (96.5% Tin, 3% Silver, 0.5% Copper) or 63/37 Sn/Pb can produce a corrosion assisted non-conductive and brittle inter-metallic compound (IMC) within as little as 15 days when soldered to Silver/Palladium (Ag/Pd) metal traces (Electrical 'Opens' and Passive Component Solder Embrittlement on Hybrid Module)

3:1 Ag/Pd  
Deposited  
Traces for  
Soldered  
Passives



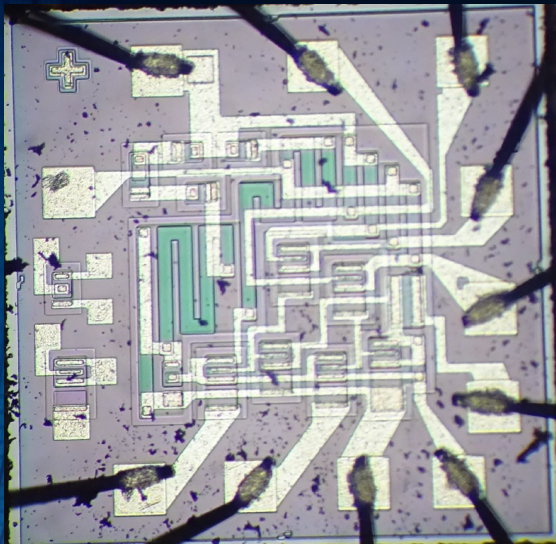
Gold  
Traces for  
Routing  
and Wire  
Bonding



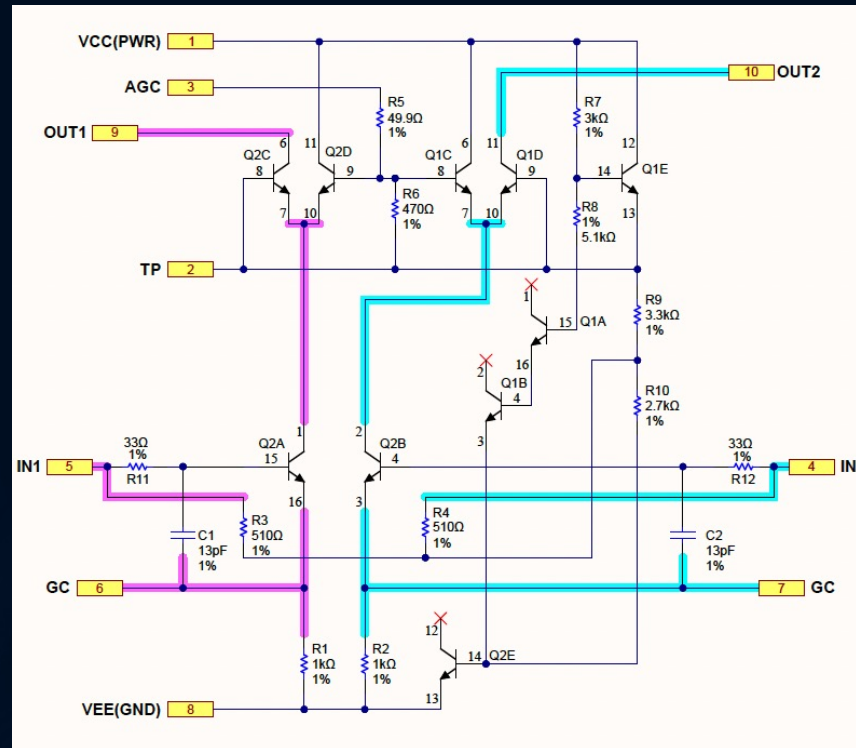
3D Rendering  
of Passive  
Components  
Soldered to  
Ceramic Board



# Project Background

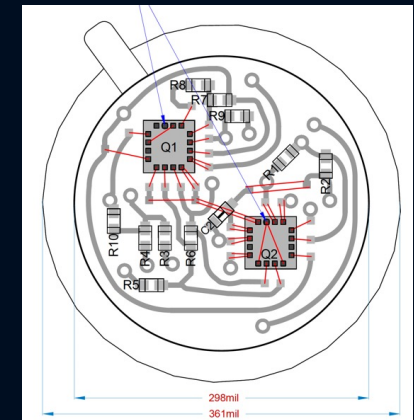


Original 1986 Era Motorola P16377A RF Amplifier Monolithic IC – Now Obsolete. Input and Output Impedance Characterized and Modeled

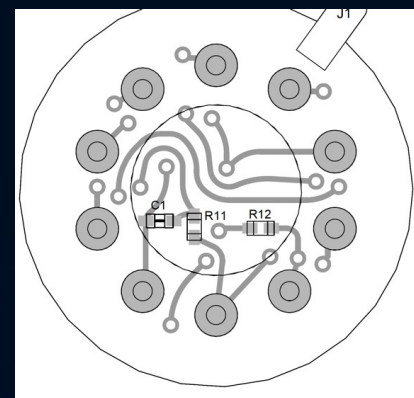


Equivalent Circuit with New Generation NPN Transistor Matrix (Higher Beta, Higher  $f_T$ , and Lower Base-Emitter Resistance/Capacitance)

Layout of Adjacent Circuit for Hybrid Module Form, Fit, Function Amplifier Equivalent



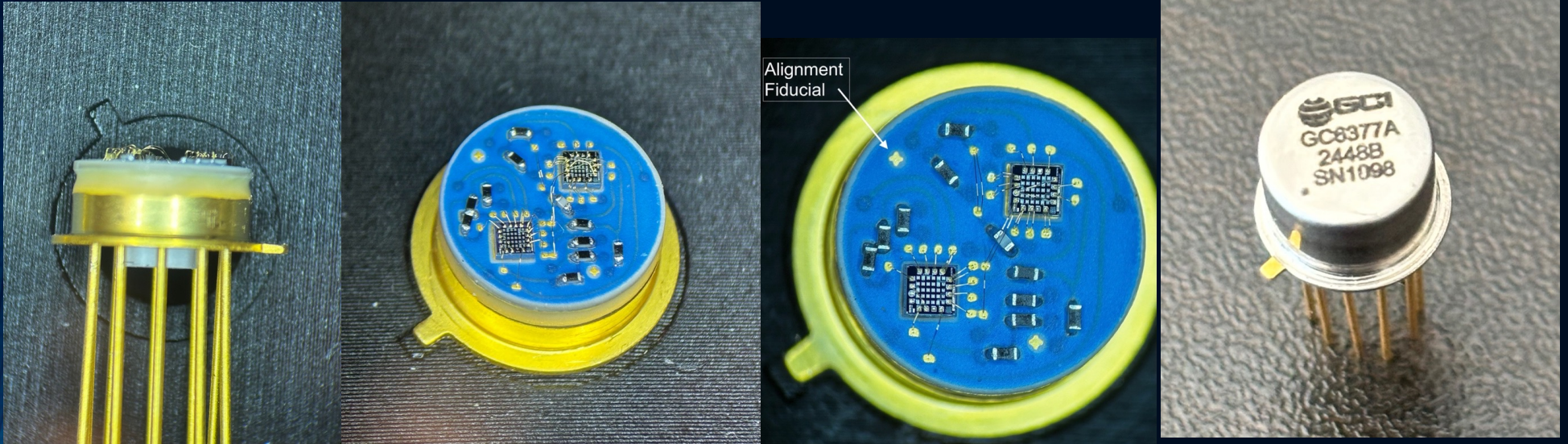
Top



Bottom



# Final GCI RF Amplifier Equivalent



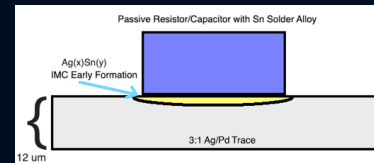
- Hybrid Ceramic Substrate Soldered to 10-Pin TO Can Header and Underfilled with Thermally Conductive, Electrically Non-Conductive Epoxy. Top and Bottom Side of Ceramic Contains Passive Resistors and Capacitors Soldered to Ag/Pd Traces.
- Sealed TO-05 Can Traps Epoxy Outgassing (Moisture, Oxygen, and Organics)



# Problem Statement

- To meet the original Motorola P16377A RF Amplifier MIL-STD screening, in addition to Centrifuge, Shock, Vibration, Temperature Cycling, 168 Hour 125°C Biased Burn-In, it also had to meet a Stabilization Bake criteria of 24 hours at 150°C

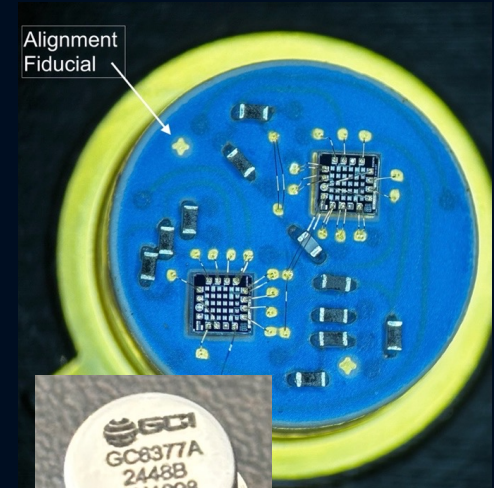
Electrical Failures noted Electrical 'Opens' for Resistor Components at Resistor Ag/Pd Interface



- 3 Data Points\* for 150°C Stabilization Bake,  $t_f =$ 
  - 22.5 Hours ( $H_2O$  @ 29.65%,  $O_2$  @ 1.78%); No Pre-Bake
    - Possible Moisture Accelerated Failure Mechanism?**
  - 151 Hours ( $H_2O$  @ 15.38%,  $O_2$  @ 18%); 30 min 200°C Pre-Bake
  - 2609 Hours ( $H_2O$  @ 5.85%,  $O_2$  @ .03%); 60 min 200°C Pre-Bake

Worst-Case Scenarios involved actual electrical Non-conductance across the entire trace

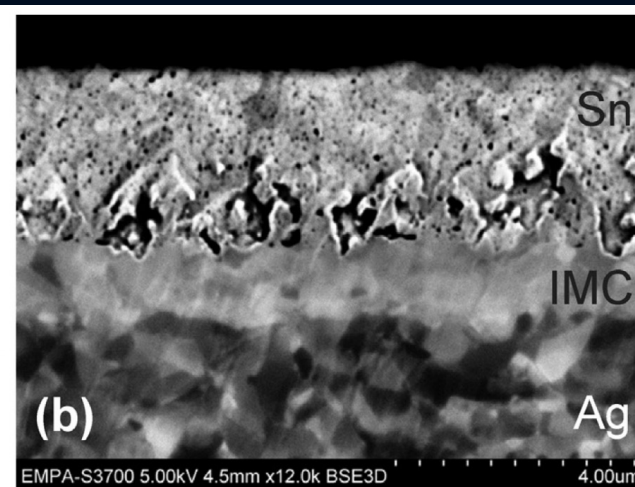
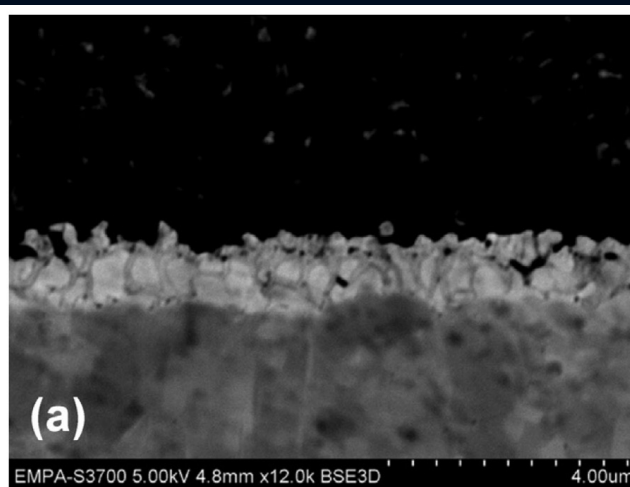
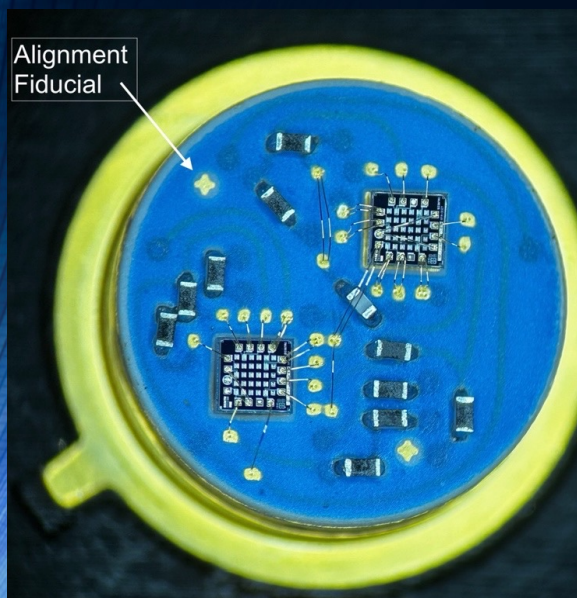
\*RH% Values Obtained from IVA testing at ORS (Oneida Research)





# Responsible Failure Mechanism

- Electrical Failures were Always Isolated to a Resistor/Capacitor Soldered Connection over Ag/Pd Traces
- Research Pointed to Intermetallic Compound (IMC) Formation at the Sn/Ag Interface<sup>(1)</sup>. See below for IMC layer growth of 1.6  $\mu\text{m}$  at 200°C for 0.5 hours.

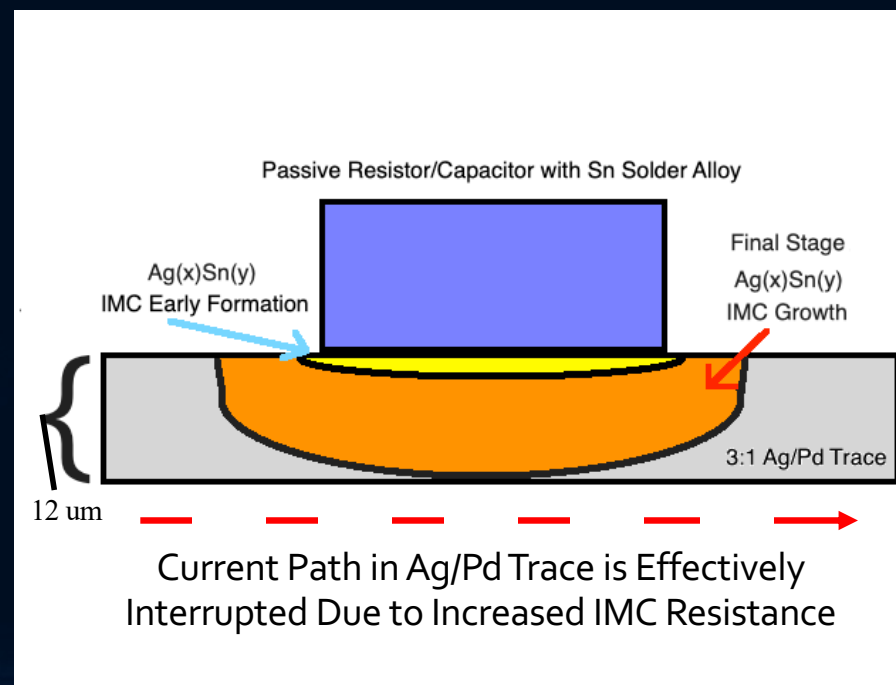
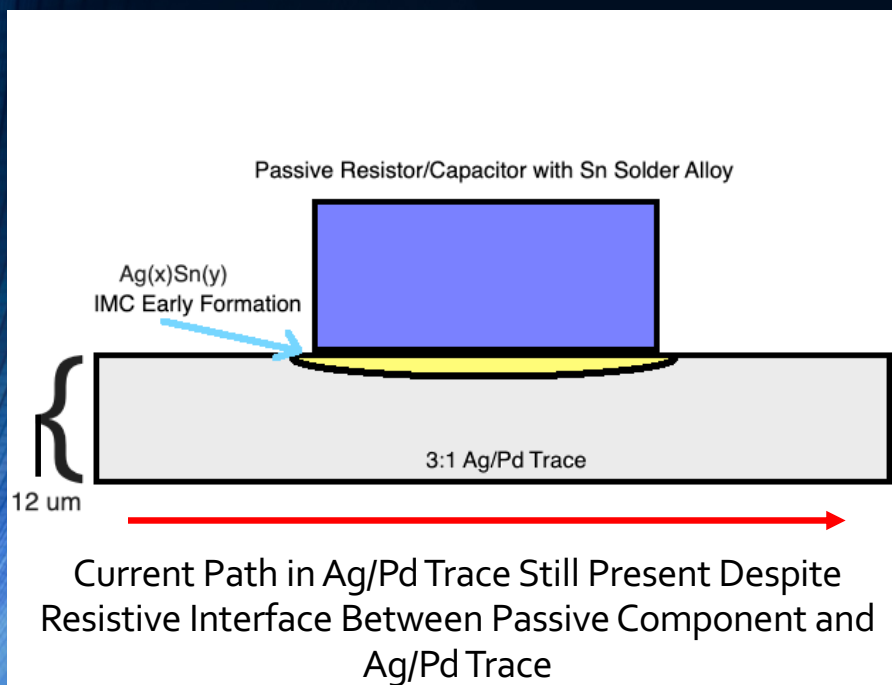


Microstructural evolution of Ag-Sn IMC at 200 °C after 60 s (a) and 1800 s (b).



# Responsible Failure Mechanism

- Initial IMC Growth only Affects Resistor or Capacitor to Ag/Pd Trace Interface
- Later Stage IMC Growth can Completely Choke off Conductivity of Below Trace
- Although not All  $\text{Ag}(x)\text{Sn}(y)$  IMCs are Non-Conductive, some are (Possible Oxide Formation as Well)





# Governing Equations for Intermetallic Compound Growth

Peck's Relationship Between Humidity and the Arrhenius Equation<sup>(2)</sup>:

$$t_f = C(RH)^{-n} e^{E_a/kT} \quad \text{from} \quad t_f = C e^{E_a/kT}$$

To Determine the Acceleration Factor (AF), we can Factor out C:

$$AF = \left(\frac{RH_u}{RH_t}\right)^{-n} \exp \left[ \frac{E_a}{k} \left( \frac{1}{T_u} - \frac{1}{T_t} \right) \right], \quad \text{or} \quad AF = \left(\frac{RH_u}{RH_t}\right)^{-n} \quad @ \text{ Constant } T$$

Where:

$t_f$  is the time to failure

$C$  is a constant dependent on the materials, process, and conditions

$RH$  is relative humidity

$n$  is a constant

$E_a$  is the activation energy

$k$  is Boltzmann's constant,  $8.617 \times 10^{-5}$  eV/K

$T$  is temperature in Kelvin ( $273.15^\circ + ^\circ\text{C}$ )

$T_u$  is the actual temperature,  $T_t$  is the stress (reference) temperature

$RH_u$  is the actual relative humidity, and  $RH_t$  is the stress (reference) relative humidity



# Determining the $n$ Value in Peck's Equation<sup>(2)</sup>

$$AF = \left( \frac{RH_u}{RH_t} \right)^{-n}$$

Eq. 1)  $151/22.5 = (15.38\%/29.65\%)^{-n}$ ,  $-n = \log(151/22.5)/\log(15.38/29.65)$ ,  $n = 2.89$

Eq. 2)  $2609/151 = (5.85\%/15.38\%)^{-n}$ ,  $-n = \log(2609/151)/\log(5.85/15.38)$ ,  $n = 2.95$

Eq. 3)  $2609/22.5 = (5.85\%/29.65\%)^{-n}$ ,  $-n = \log(2609/22.5)/\log(5.85/29.65)$ ,  $n = 2.93$

If one could control the moisture in the hermetic cavity to 10,000 ppm (1%), what would the Predicted Lifetime be at 150°C? Using  $n = 2.92$  (avg.),

Eq. 4)  $X/22.5 = (1\%/29.65\%)^{-2.92}$ ,  $X = 447,193 \text{ Hours, or } \underline{51 \text{ Years at } 150^\circ\text{C}}$



# Determining the Acceleration Factor (AF) at Various Temperatures

To Determine the Acceleration Factor/Model (AF) for another T (e.g., 50°C), we can Factor out the  $-n$  term:

$$AF = \left(\frac{RH_u}{RH_t}\right)^{-n} \exp \left[ \frac{E_a}{k} \left( \frac{1}{T_u} - \frac{1}{T_t} \right) \right], \quad \text{or} \quad @ \text{ Constant RH}$$

$$AF = \exp \left[ \frac{E_a}{k} \left( \frac{1}{T_u} - \frac{1}{T_t} \right) \right]$$

Using  $E_a = 0.929 \text{ eV}^{(2,3)}$ ,

$$AF = \exp \left[ \frac{0.929 \text{ eV}}{8.617 \times 10^{-5} \text{ eV/}^\circ\text{K}} \left( \frac{1}{323^\circ\text{K}} - \frac{1}{423^\circ\text{K}} \right) \right] = 2,672$$

At a constant RH of 5.85% (58,500 ppm), the new Life Time would be  $2609 \times 2,672 = 20,585$  Hours or **796 Years @ 50°C, 31 Years @ 85°C, and only 9.1 Years @ 100°C.**

Therefore, the RH of the Hermetic Cavity should be controlled to 10,000 – 100,000 ppm H<sub>2</sub>O with a Pre-Lid Seal Vacuum Bakeout when using this Epoxy, a Sn solder alloy, and Ag/Pd Traces



# Conclusions

## Ag/Pd Metal Trace Limitations with Sn/Pb or SnAgCu Solders

- Silver/Palladium metal traces are commonly deposited as pastes on ceramic substrates to form solderable connections and routing layers. However,. Studies have shown that 20 - 30% moisture content within a hermetically sealed package will produce electrical 'opens' within 20 - 24 hours at 150°C in those regions where the SAC 305 solder meets the Silver/Palladium traces.
- In some cases, internal cavity epoxies can sufficiently outgas to create 20 - 30% (200,000 - 300,000 ppm) moisture levels following hermetic sealing. However, if exposed to a proper pre-bake prior to hermetic lid sealing (typically 200°C for 1-2 hours) this corrosion assisted inter-metallic diffusion can be substantially mitigated by controlling the moisture to levels to 10,000 – 100,000 ppm. This mitigation becomes a necessary step for hermetic systems with Sn/Ag/Cu solder on Ag/Pd traces, and for the requirement of higher operational temperatures or stabilization bakes (150°C) as part of a reliability screening flow.



# References

- 1.) Lis, Adrian; Park, Min Soo; Arroyave, Raymundo; Leinenback, Christian. “Early stage growth characteristics of Ag<sub>3</sub>Sn intermetallic compounds during solid–solid and solid–liquid reactions in the Ag–Sn interlayer system: Experiments and simulations.” Journal of Alloys and Compounds, 2014.
- 2.) Peck, D. Stewart. “Comprehensive Model for Humidity Testing Correlation.” Reliability Physics Symposium, 1986. 24<sup>th</sup> Annual (1986): 44-50.
- 3.) Chen, Yuanming; Huang, Junjie; Huang, Yunzhong; Li, Qingyuan; Zeng, Hong; Tian, Ling; Li, Jingsong; Wang, Shouxu; Hong, Wei He & Yan. “Microstructure Evolution and Growth Kinetics of Intermetallic Compound in SAC305/AG and SAC305/Cu Solder Joints During Solid-State Aging.” Journal of Materials Science: Materials in Electronics, 2024.



# Contact Information

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# Additional Capabilities



**In House Bonding  
Assembly**



**Bond Pull, Die Shear  
& Ball Shear**



# Automated Pick-and-Place (MRSI 505)

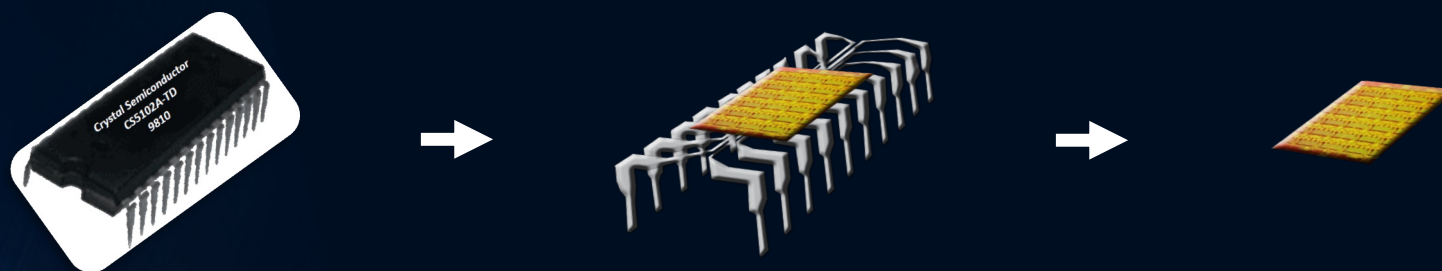




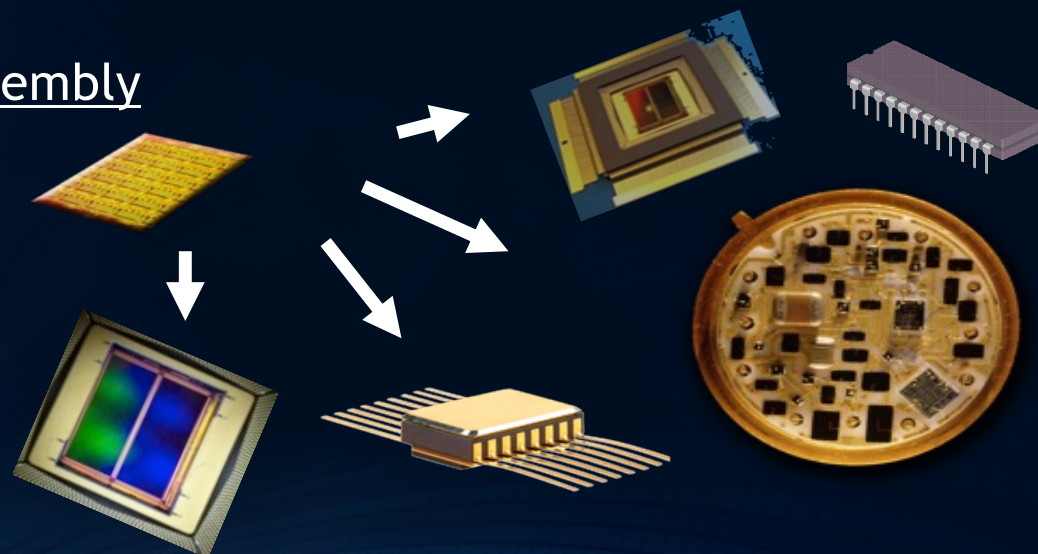
# Definitions of DER™ and ENIPIG Pad Plating

## ■ DER™ - Die Extraction and Reassembly

### - Extraction

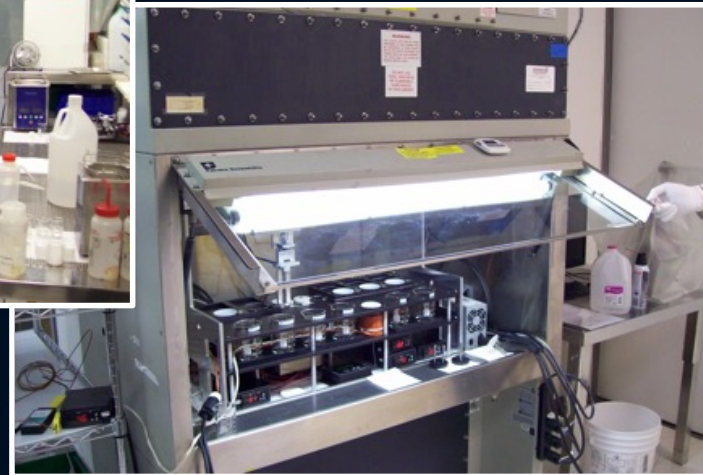


### - Reassembly





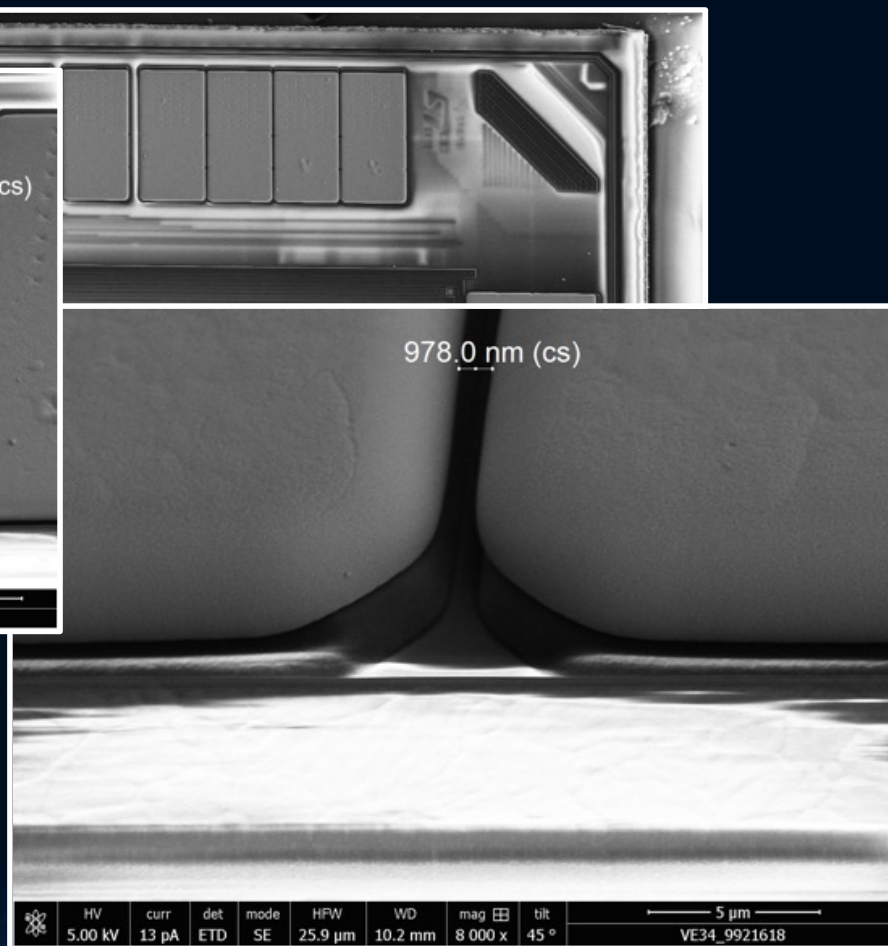
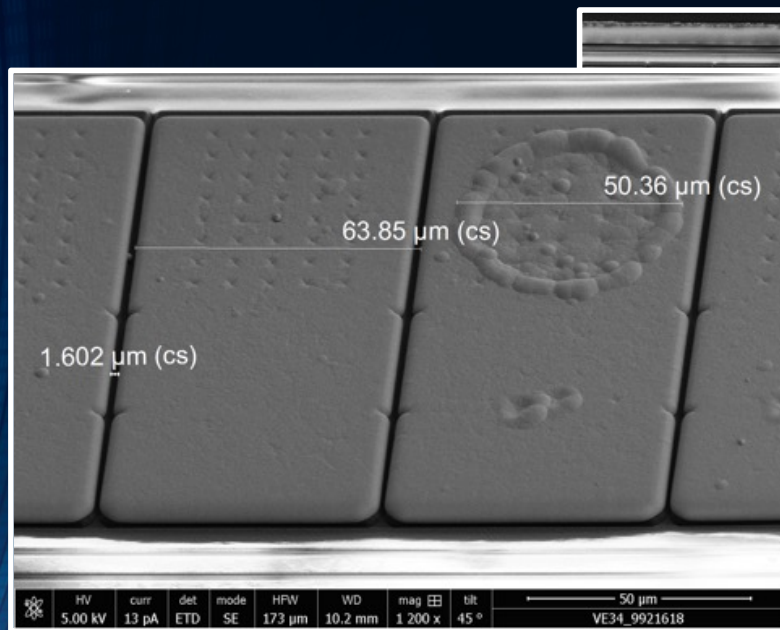
# Gold Ball Removal, Pad Re-Plating with Electroless Ni/Pd/Au Process (*ENEPIG*)



Extraction Lab and Automated/Robotic ENEPIG Plating Process



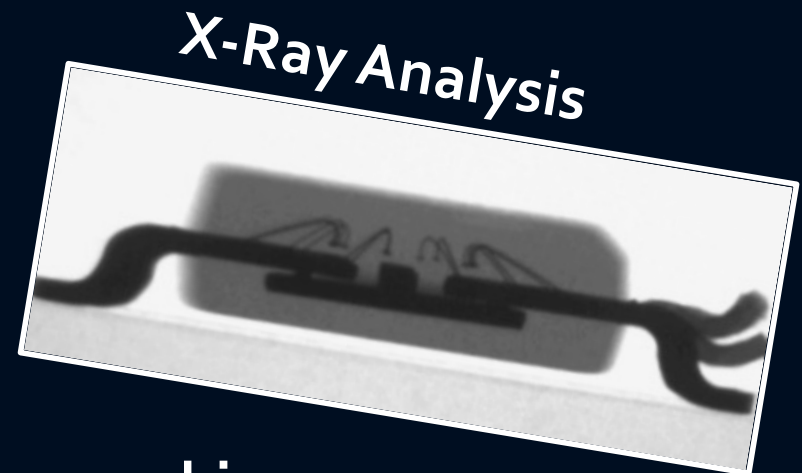
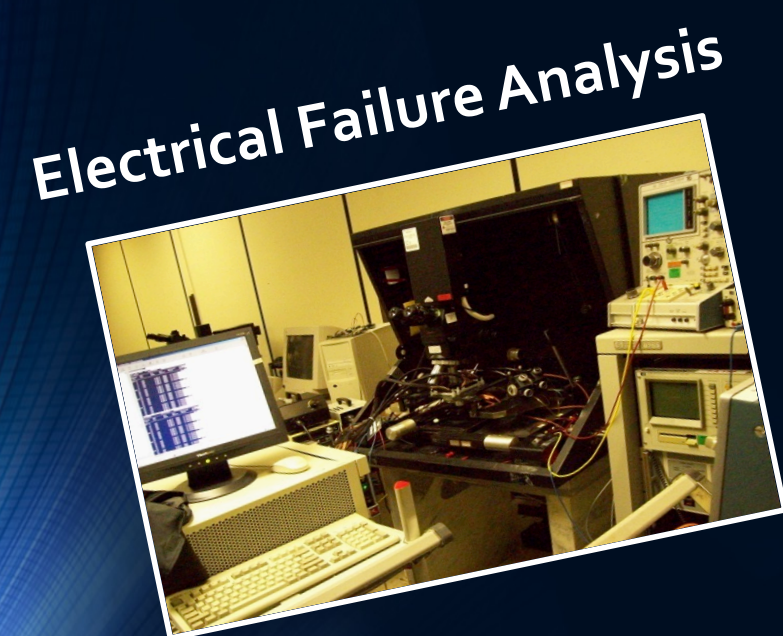
# Gold Ball Removal, Pad Re-Plating with Electroless Ni/Pd/Au Process (*ENEPIG*)



350,000+ Units in  
Field Worldwide



# Inspection/Micro-Probing Capabilities



Microprobing





# Summary of GCI Capabilities/Services

- ☐ Quick-Turn Prototype Development
- ☐ In-house IC & Hybrid Assembly Facility
- ☐ Counterfeit Screening
- ☐ Turnkey High-Volume Production IC Solutions for Extreme Environments (High Shock @ >185C) as well as Aerospace, Defense, and Industrial Applications
- ☐ Failure Analysis
- ☐ Die Thinning and Vacuum Sealing