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Challenges Facing the High Temperature Electronics Industry in the Event of Restrictions on High-Pb Solders

Paul T. Vianco

Sandia National Laboratories
Albuquerque, NM
Phone: 505-844-3429
Email: ptvianc@sandia.gov

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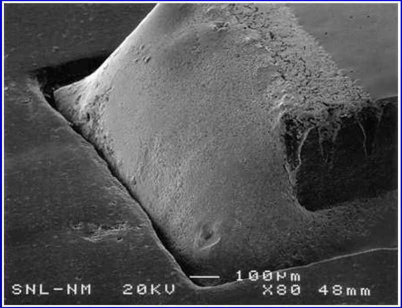
Introduction

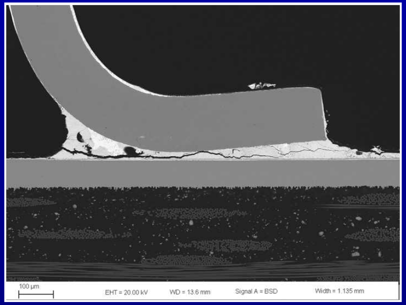
- The exploration and operation of both renewable (geothermal) and non-renewable (fossil fuel) energy sources will rely heavily upon electronic sensors and down-hole data logging equipment.
    - Cost-effective exploration of new reserves
    - Real-time monitoring of down-hole pressure and temperature conditions.
        - Maximize production
        - Optimize preventive maintenance
        - Prevent inadvertent site shutdowns or worse, environmental damage

Courtesy of NASA

Introduction

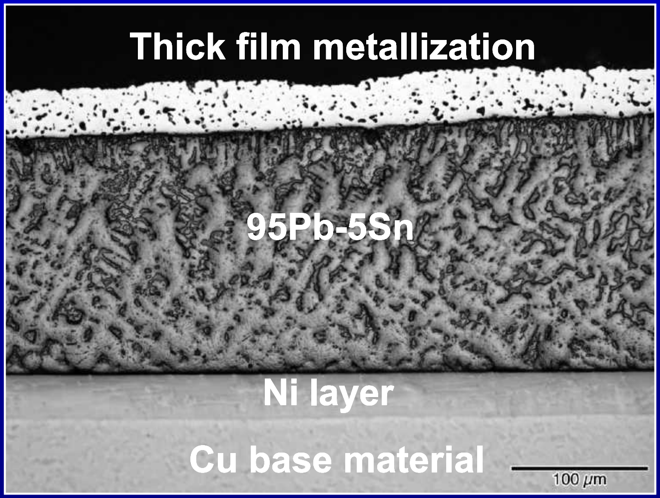
- High-lead (Pb) solders, defined as having > 85 wt.% Pb, continue to be used extensively to assemble high-temperature electronics.
  - The high-Pb solders remain readily available because of exemption 7a in the RoHS agreement.
  - The solidus temperatures provide an adequate margin for service temperatures ≤ 250°C.
  - Excellent fatigue performance:
    - Low-cycle, thermal mechanical fatigue
    - High-cycle fatigue – vibration





Introduction

- **High-lead (Pb) solders …**
  - **Satisfactory corrosion resistant in the event of exposure to well environments.**
  - **The high-Pb alloys containing 5 – 10 wt.% Sn, In, and Ag are compatible with current assembly infrastructures.**
    - **Fluxes**
    - **Heat sources**
    - **Surface finishes**



“ What if … exemption 7a went away ? “

- The loss high-Pb solders would pose a challenge for down-hole electronics assemblies.

  But … the challenge is not insurmountable!

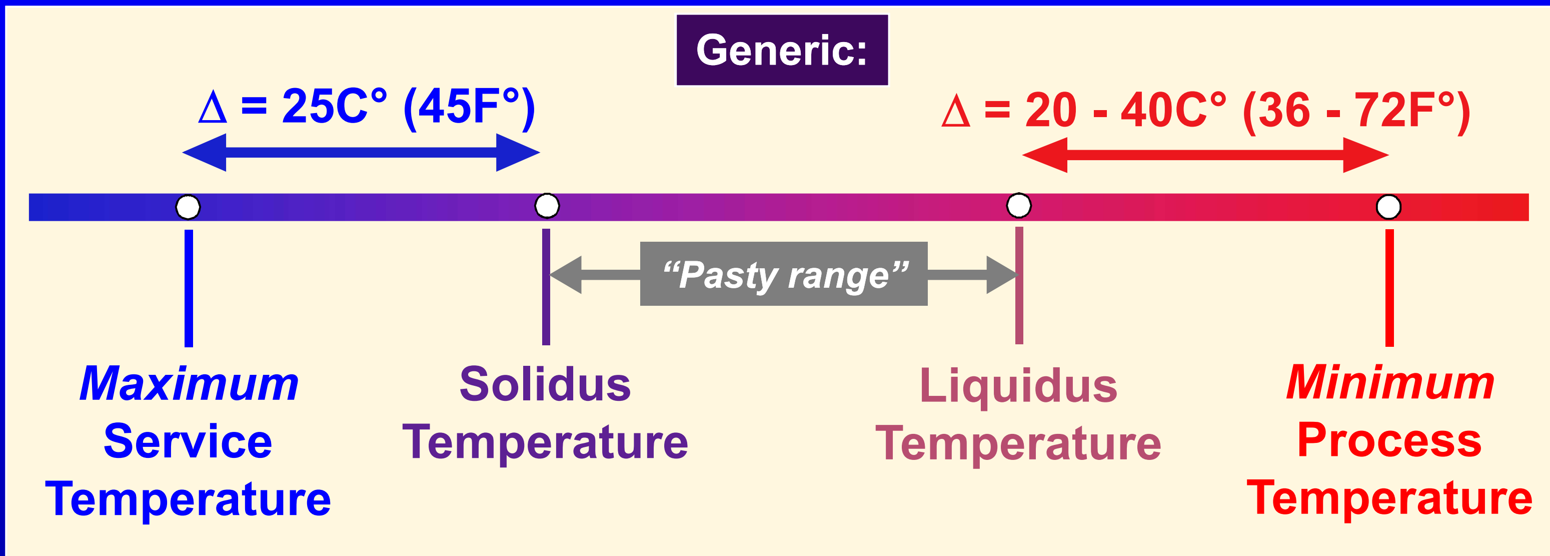
- Alternative interconnection approaches include:
  - High temperature filler metals
  - Mechanical attachment
  - Transient liquid phase (TLP) bonding
  - Nanoparticle joining techniques

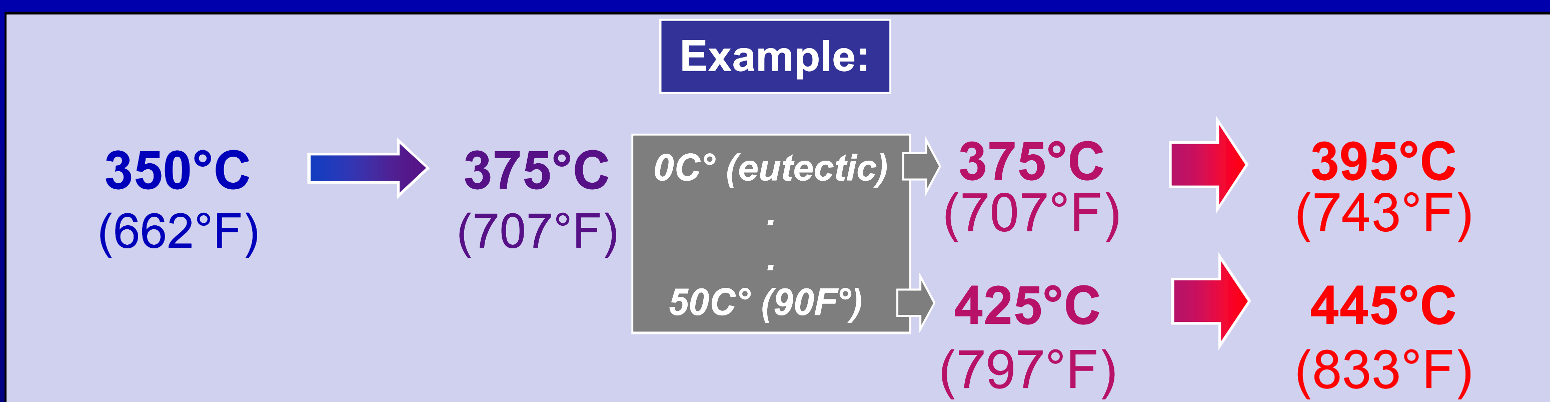
Courtesy of Dept. of Energy

- Interconnection material choice(s) must satisfy:
  - Assembly processes, infrastructure, and supply chain
  - Reliability requirements

High Temperature Filler Metals

- **Solder alloys must be compatible with the *maximum* service temperature conditions and *minimize the* process temperature.**





High Temperature Filler Metals

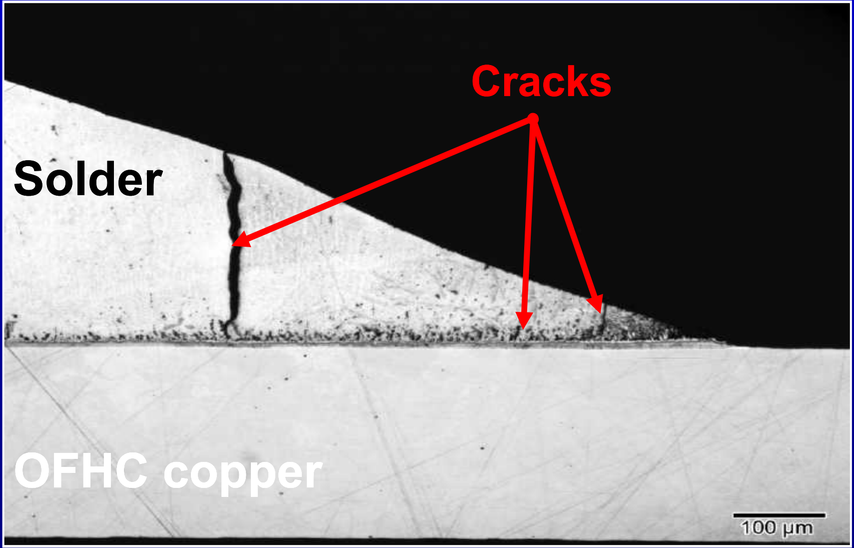
- There are candidate solder alloys, some commercially-available and others newly engineered, that are being investigated for mechanical properties and solderability performance.

- Some newly-developed solder alloys are based on zinc (Zn):

100Zn ….. $T_s = T_l$ = 420°C (788°F)

- At these high process temperatures, controlled atmospheres can replace the flux as the means to reduce surface oxides.

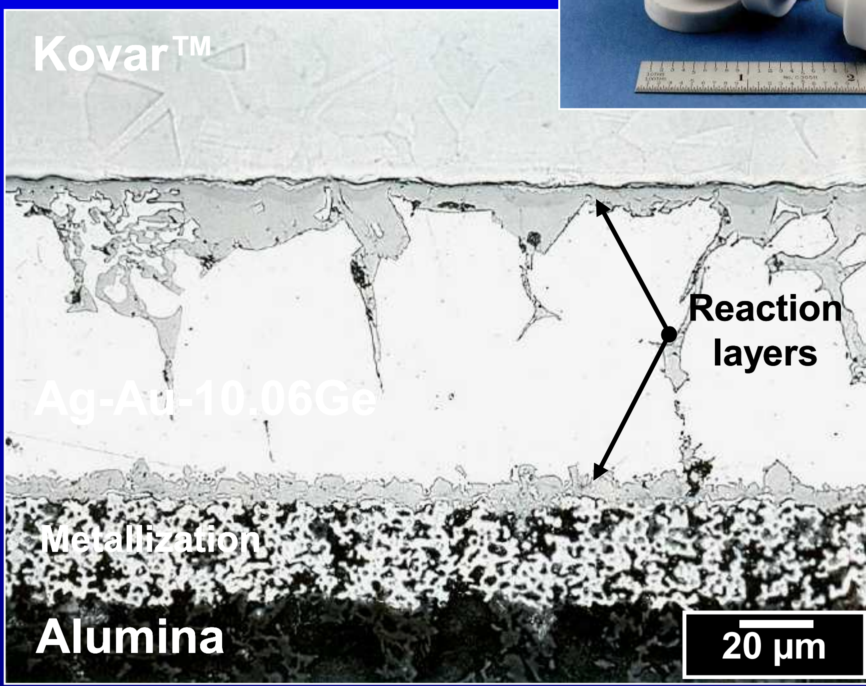
- Sessile drop experiments provide an initial analysis of the alloy physical metallurgy.



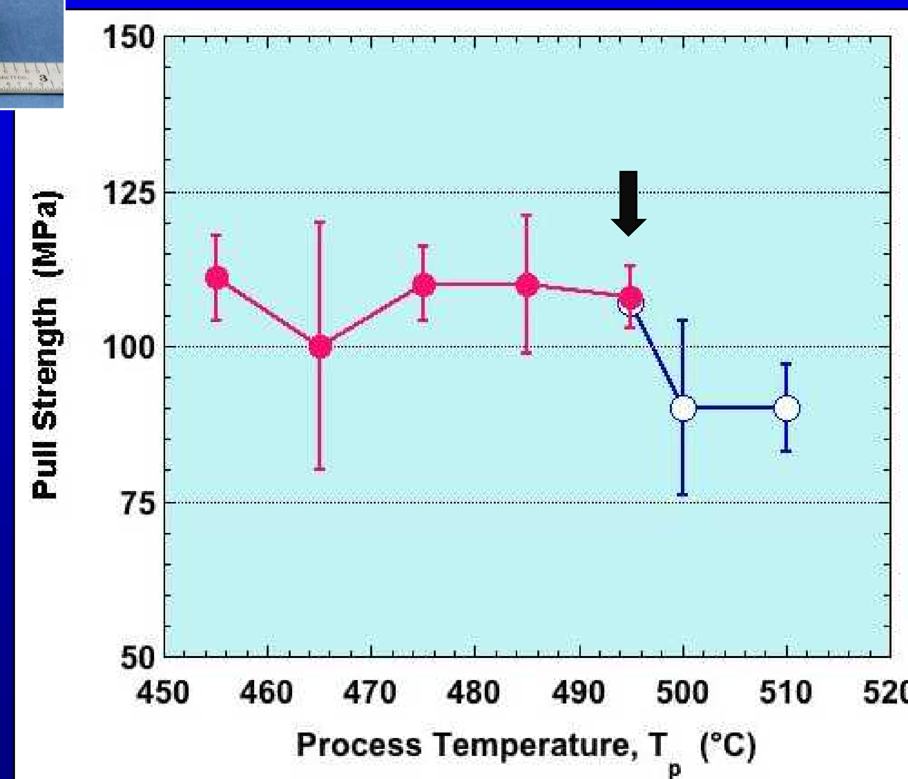
High Temperature Filler Metals

- The 12.62Ag-77.32Au-10.06Ge (wt.%) alloy (T_s, 400°C to T_l, 450°C) has been considered as a candidate for down-hole applications.

P. Vianco, et al, SMTAI (2013)

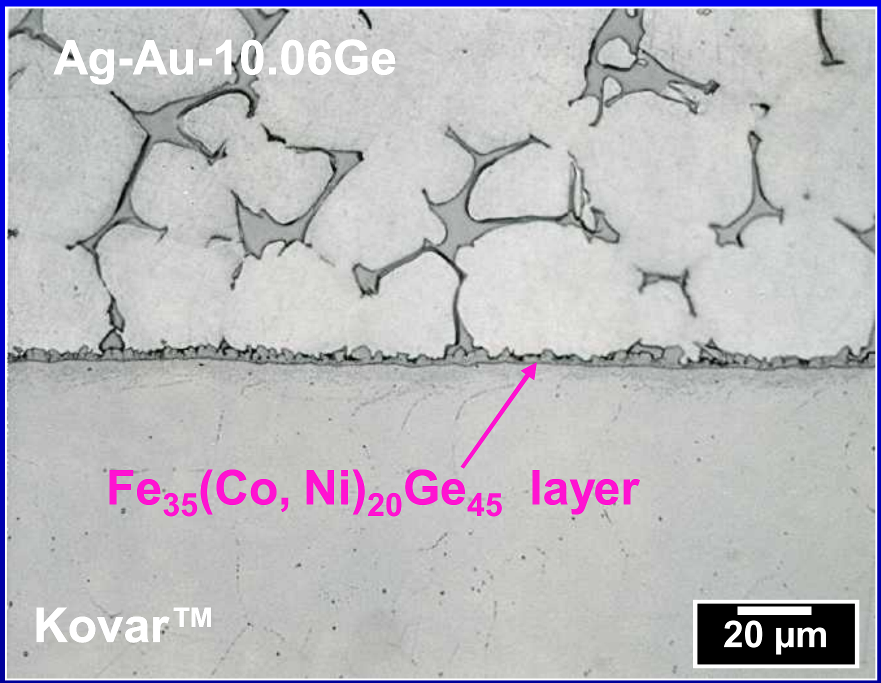


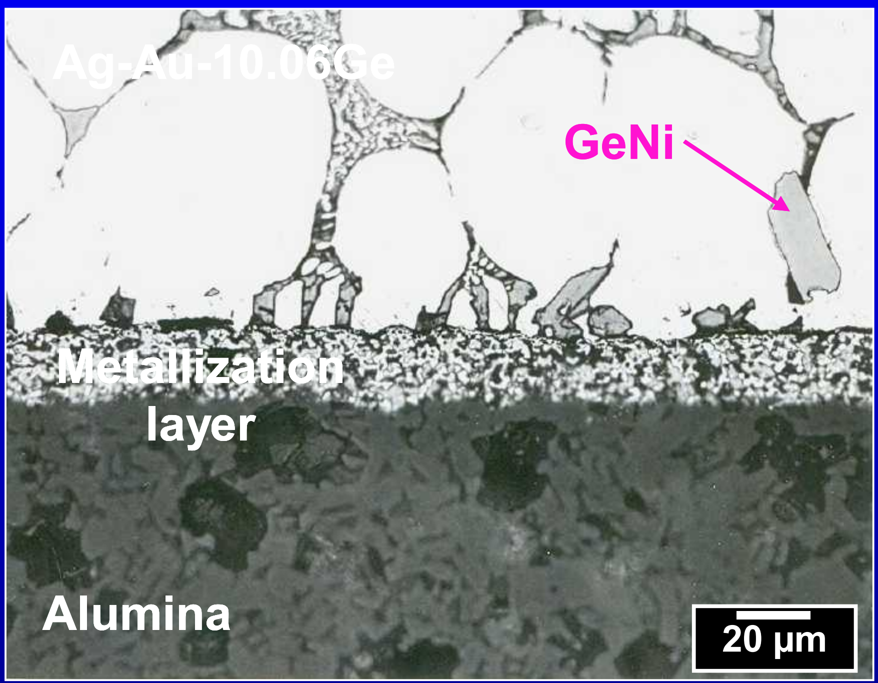
495°C, 5 min



High Temperature Filler Metals

- It is critical to fully understand the interface microstructures that develop between high temperature filler metals and the substrate.

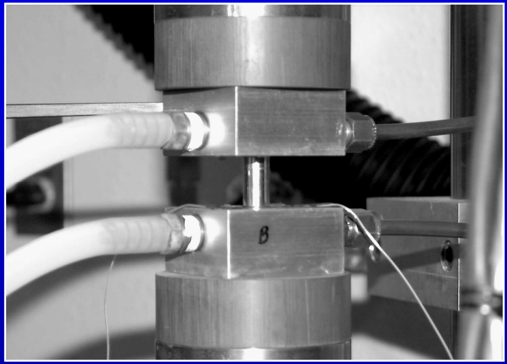




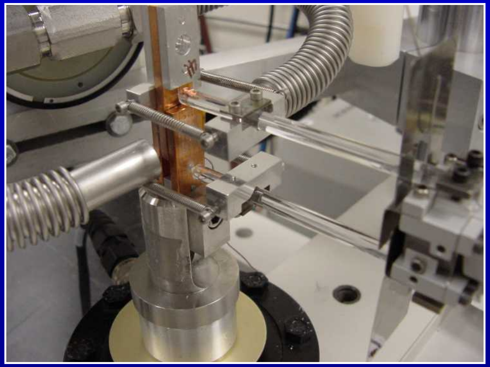
- The Ag-Au-10.06Ge / Kovar interface is comprised of a 2 – 3 µm reaction layer, $Fe_{35}(Co, Ni)_{20}Ge_{45}$ (as determined by EPMA).
- At the Ag-Au-10.06Ge / ceramic interface, the Ni layer was often dissolved into the solder, precipitating as GeNi phase particles.

High Temperature Filler Metals

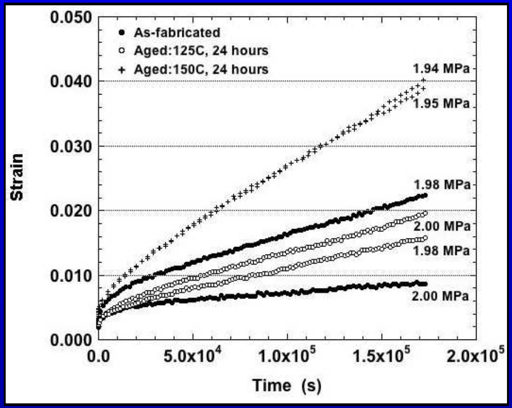
- High temperature testing will be required in order to obtain both monotonic as well as cyclic (fatigue) mechanical properties for:
  - Screening candidate compositions
  - Input parameters for computational models

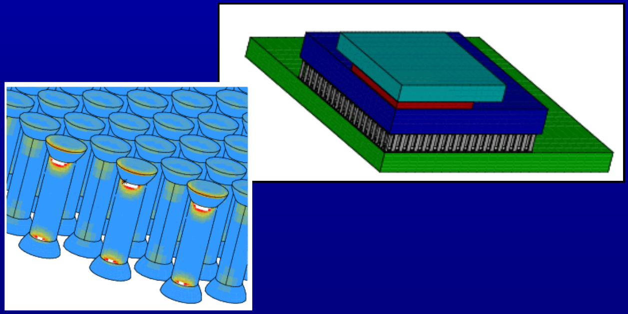


Stress-strain tests



Fatigue tests

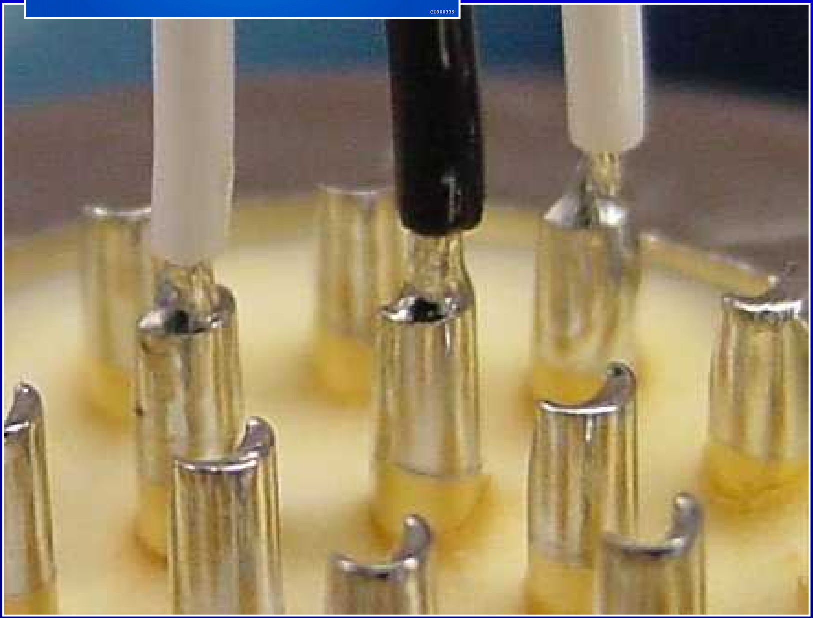




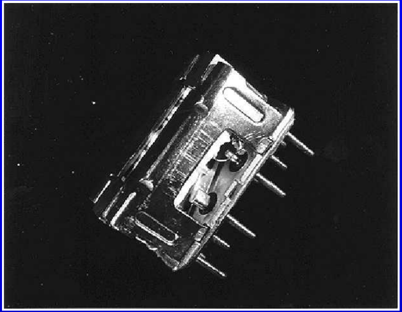
High Temperature Filler Metals

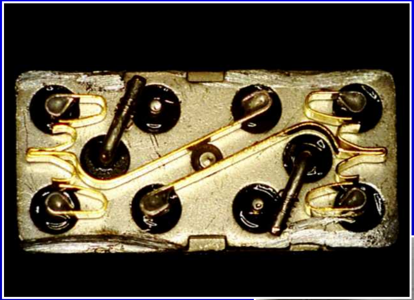
- New materials sets will be needed for other critical components that include switches, relays, and connectors.

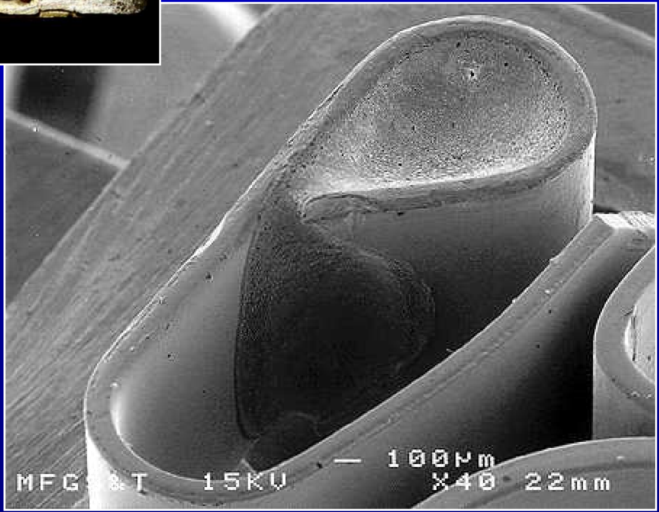
Connector



Relay

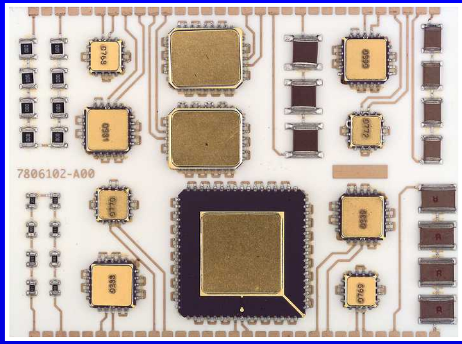




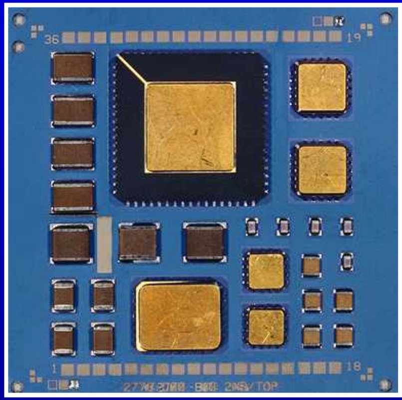


High Temperature Filler Metals

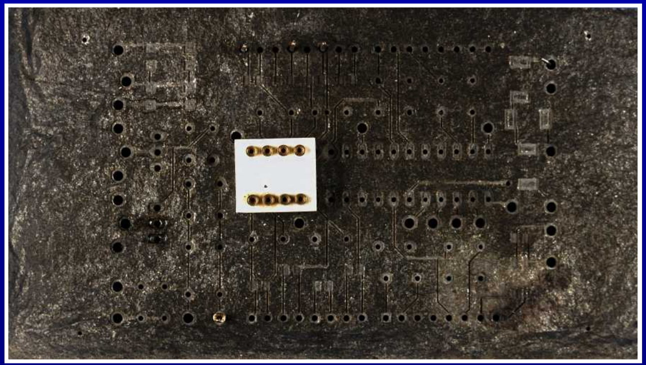
- Traditional printed circuit board laminates are challenged by the higher temperatures.
- Ceramic substrates are finding applications:
  - alumina,
  - beryllia,
  - aluminum nitride,
  - low-temperature co-fired ceramic (LTCC).
- Next-generation substrates include advanced composites and conductors applied by thermal spray or "ink-jet" printing methods.



Alumina



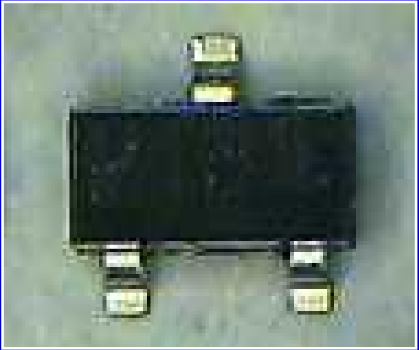
Low-temperature co-fired ceramic (LTCC)



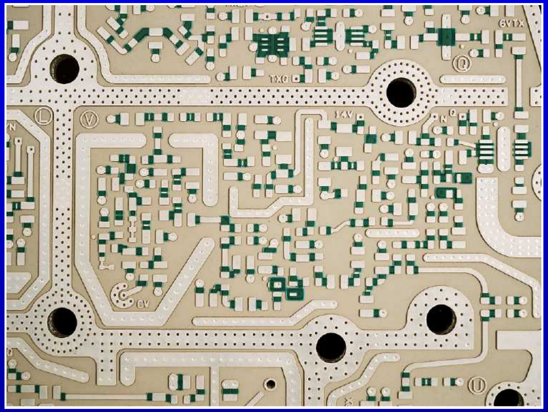
Advanced composites

High Temperature Filler Metals

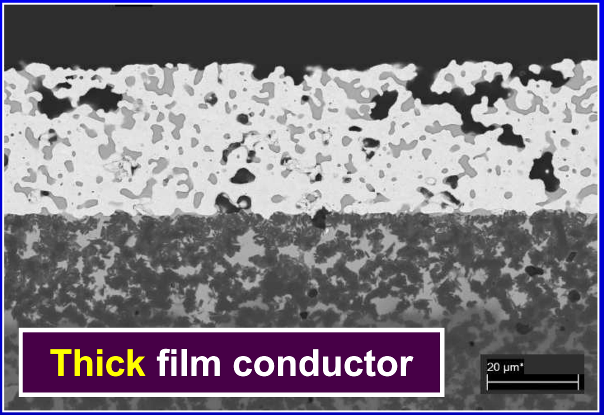
- **Surface finishes** provide another tool to engineer the solderability of high temperature filler metals on components and substrates.

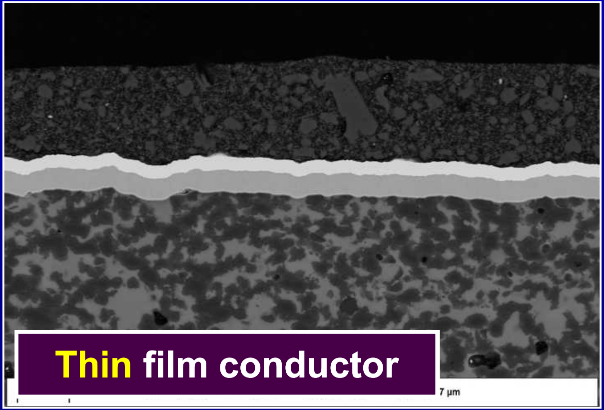


Components



High-temperature PCB laminates

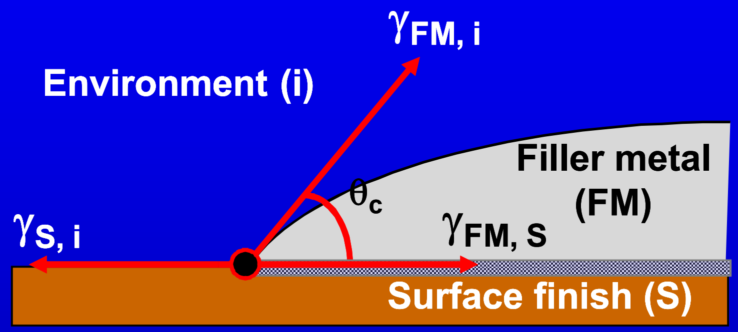




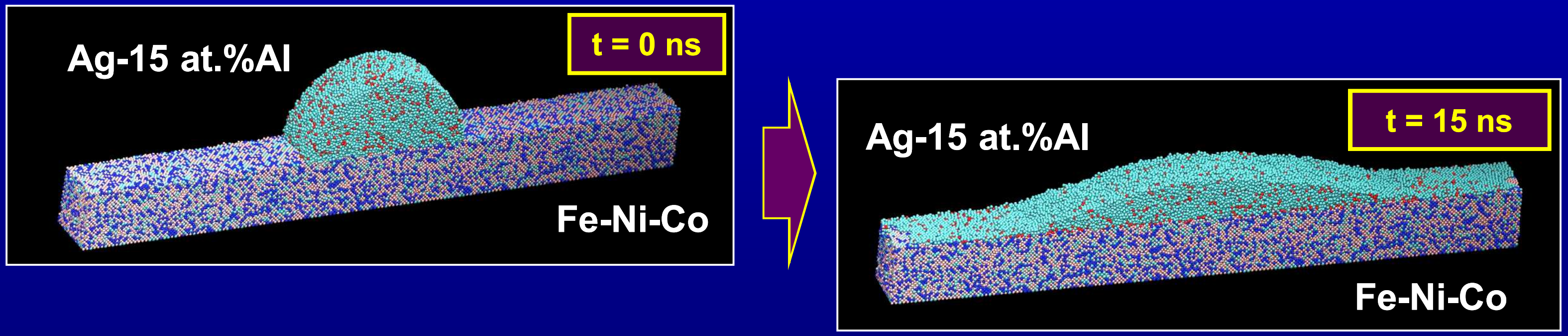
PCB ceramics

High Temperature Filler Metals

- There is a gap in the understanding of the thermodynamics and rate kinetics of interface reactions relevant to filler metal joining.

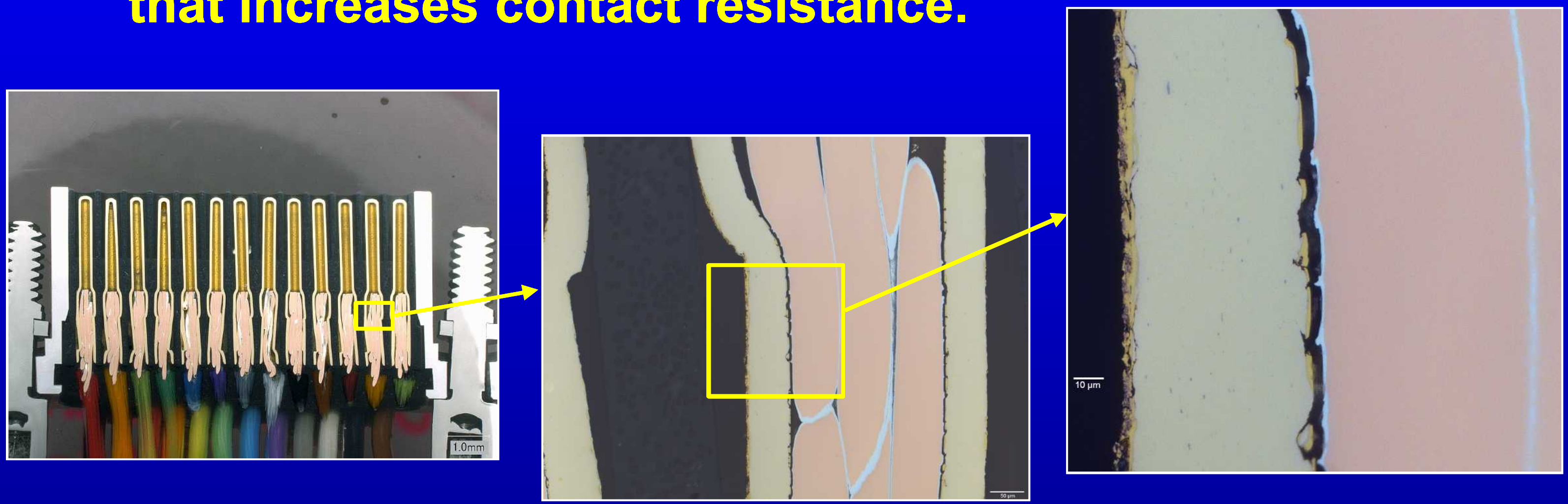


- **Molecular dynamics simulations** can provide first-order predictions of wetting-and-spreading and interface reactions between molten filler metals and the solid substrate.

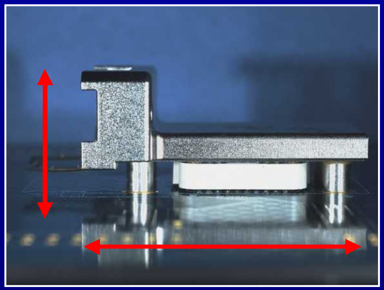


Mechanical Attachments

- Crimped wires/leads as well as pin-in-socket connections are not preferred for down-hole applications:
  - Susceptible to fretting corrosion that increases contact resistance.

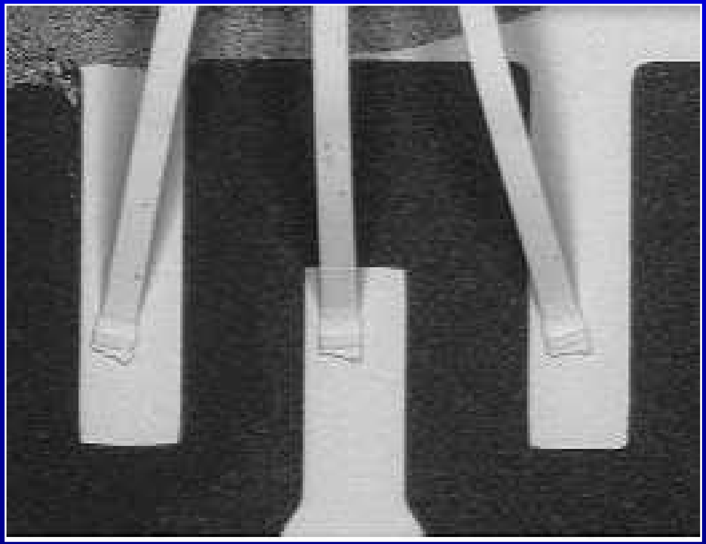


  - Sockets and connectors take away miniaturization and increased functionality.



Mechanical Attachments

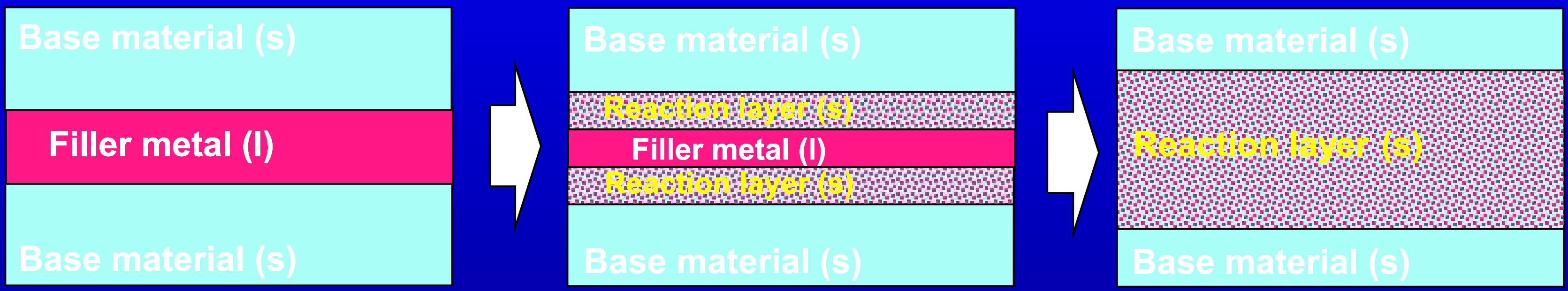
- On the other hand, thermo-compression and stitch wire and ribbon bonds – both forms of cold-welding – are viable methods:
  - Encapsulations or conformal coatings are recommended to prevent handling and vibration damage.
  - Bond pad and loop height requirements can limit miniaturization.
  - Although not always a consideration in the microelectronics field, an attribute is that these bonds are *reworkable.*



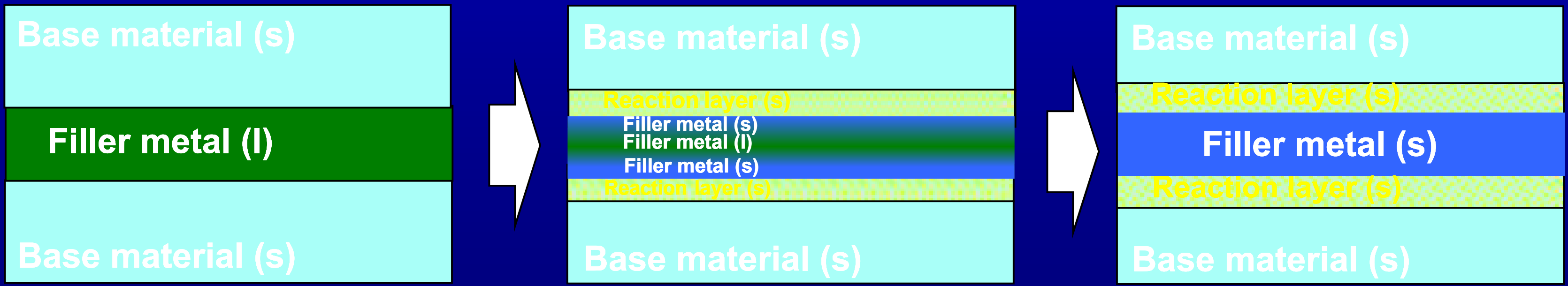
Transient Liquid Phase Bonding (TLP)

- A methodology that has not received a great deal of attention is transient liquid phase (TLP) bonding:
  - A low temperature process is used to make a higher temperature interconnection.

In-situ TLP

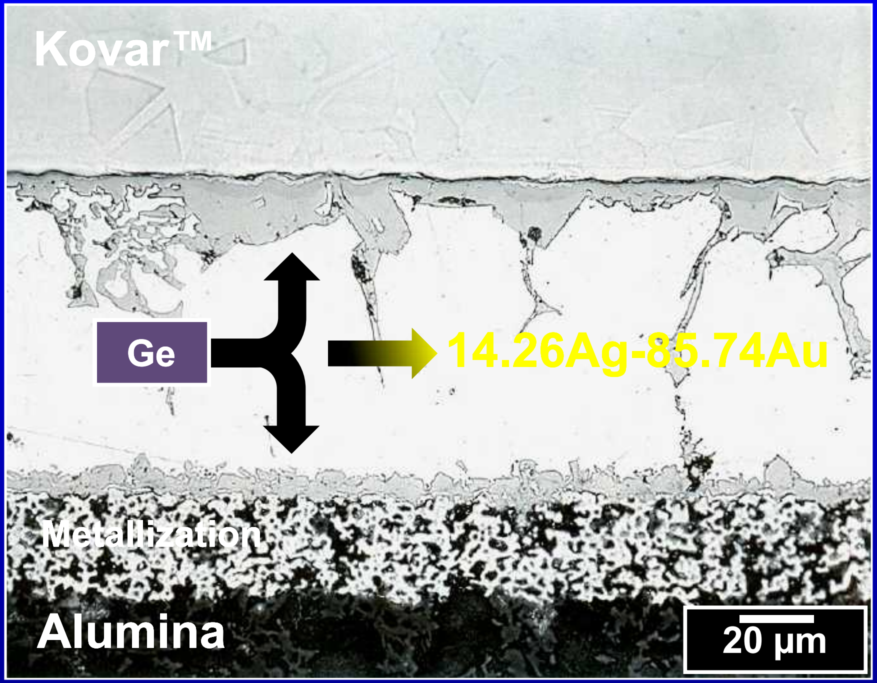


Reverse TLP



Transient Liquid Phase Bonding (TLP)

- A **reverse transient liquid phase (TLP) process** takes place whereby the Ge constituent is removed from the Ag-Au-Ge alloy.

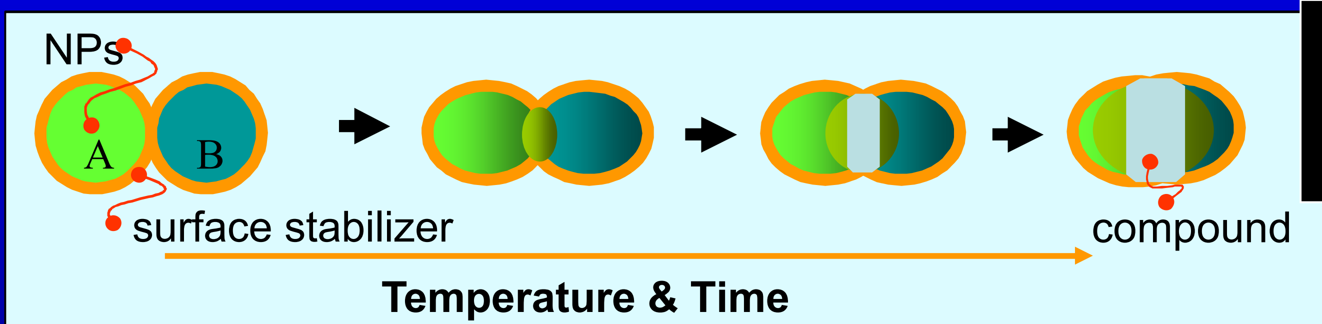


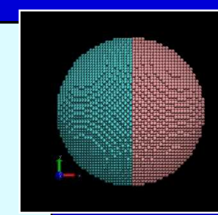
One (1) 76 µm preform … 495°C, 5 min

- The consequences are:
  - Binary alloy: 14.26Ag-85.74Au … $T_s = T_l = 1055°C$
  - Thick, brittle reaction layers formed at both interfaces.

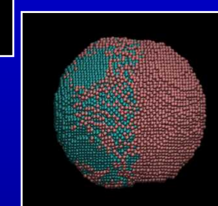
Nanoparticle Joining Technologies

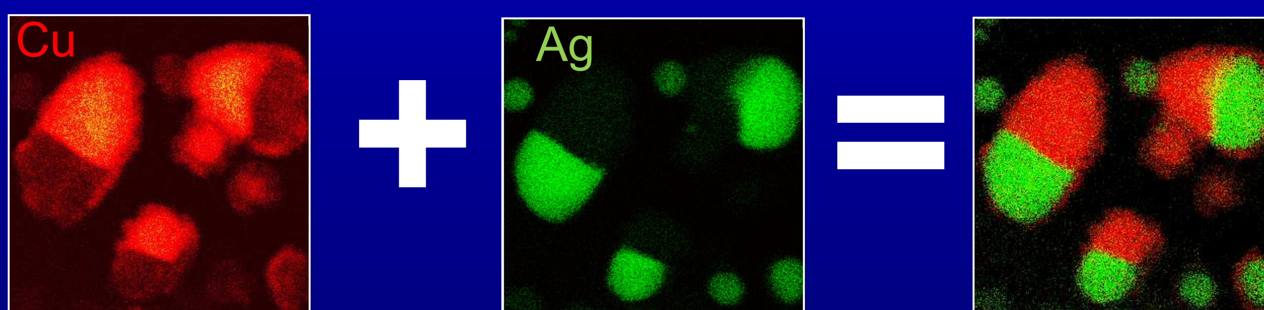
- Much like TLP, nanoparticle joining offers this advantage:
  - A low temperature process is used to make a higher temperature interconnection.
- The objective is a methodology to deliver filler metal alloy nanoparticles to the faying surfaces and form a joint.





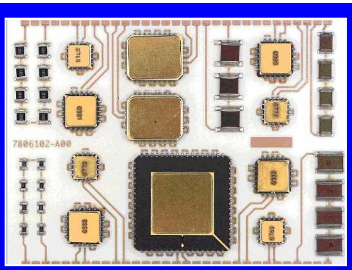
Simulation

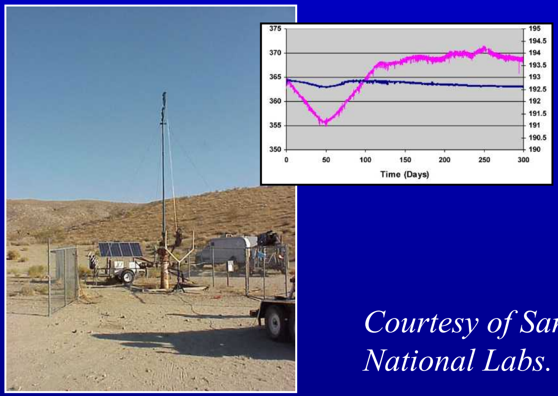




Global Perspective

- There are engineering challenges:
  - **Materials**
    - Interconnection materials
    - Base materials
    - Surface finishes
  - **Manufacturing processes**
    - Low to middle volumes
    - Fluxes or controlled atmospheres
    - Process windows/margins
  - **Reliability testing**
    - Test methods
    - Computational modeling
    - Field testing



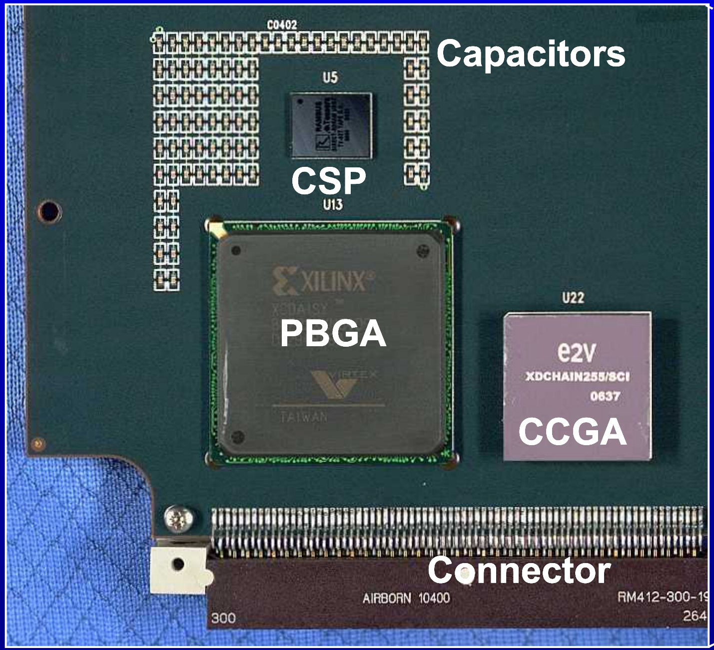


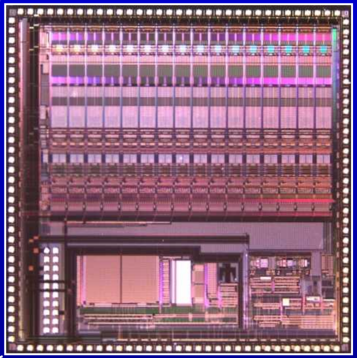
Courtesy of Sandia National Labs.

- In the long-run, an alternative interconnection technology must address cost and time-to-market as important considerations.

Global Perspective

- ***Paradigm shift:*** **Accelerate integration methodologies such as System In a Package (SiP) technologies, to reduce or eliminate discrete components, connectors, etc. and thus, the number of interconnections required in the product.**





Summary

- **Industry costs will continue to grow** that are needed to develop and sustain renewable and non-renewable energy resources.
- **High temperature electronics provide** a cost-effective tool for the exploration and sustainment of down-hole energy sources.
- Besides the development of higher melting temperature filler metals, **alternative interconnection technologies are being assessed** that promise to increase operational margins as needed to accommodate down-hole environments.

Courtesy of Dept. of Energy