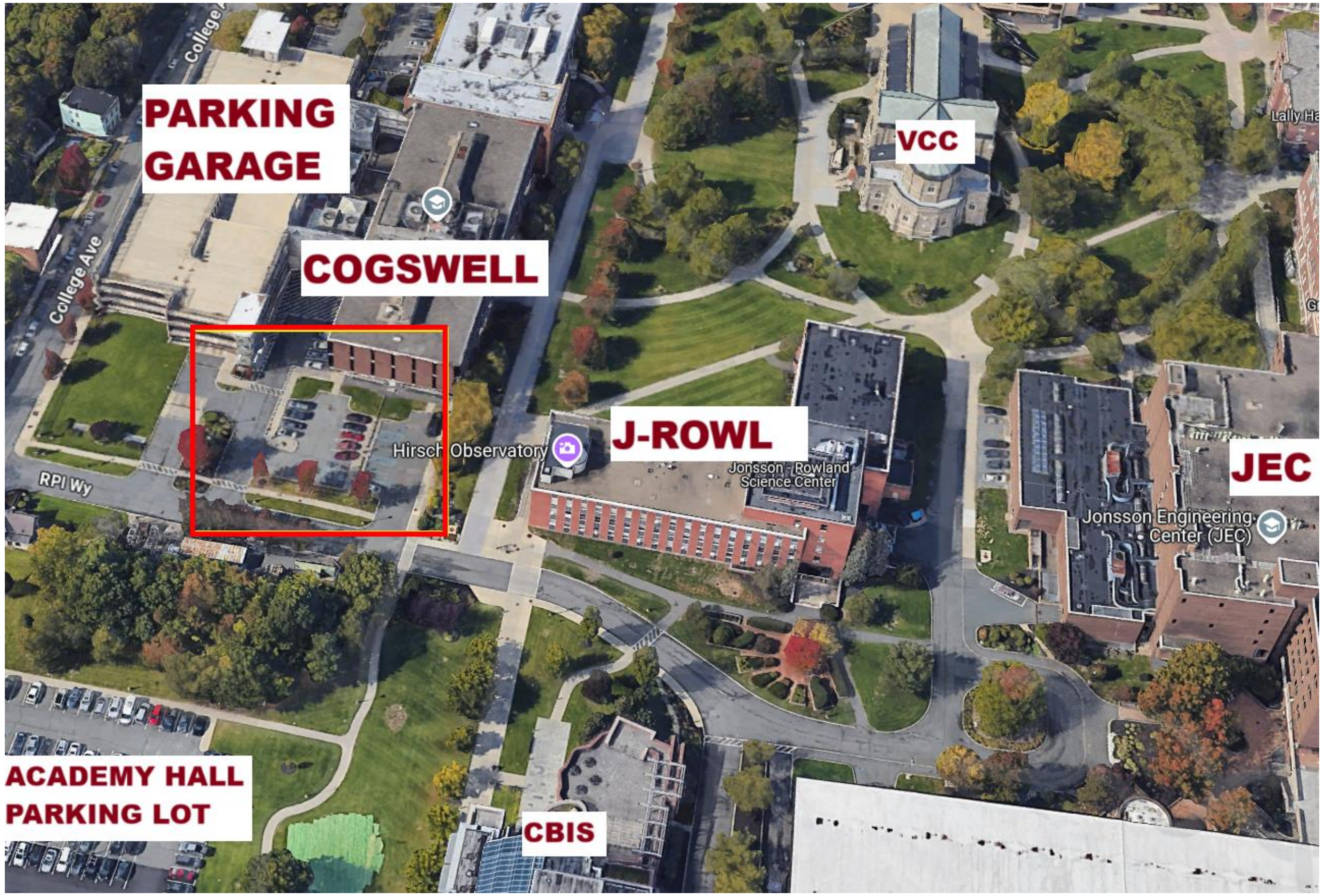
The future of bonding

IEEE EPS @ RPI

David King

IEEE EPS at RPI Updates



Albany Nanotech Complex Tour (11/13)

- Cogswell Parking Lot (11:15 AM)
- Hosts: Dr. Mushin Celik, Alex Rishty
- Shuttle will be provided
- Do not be late!
- Meet with EPS Professionals

ITherm Challenge

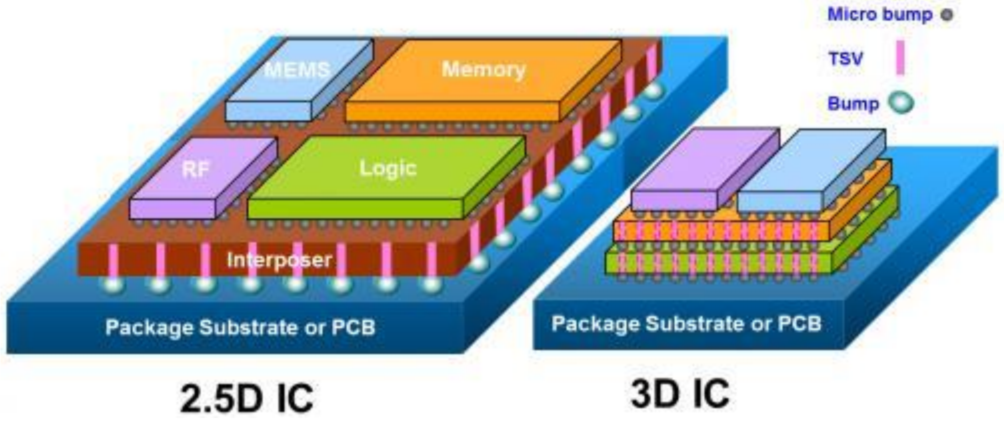
What are we covering today

Interconnect technologies that facilitate:

1. Wafer to Wafer / Die to Die
2. Die to Substrate

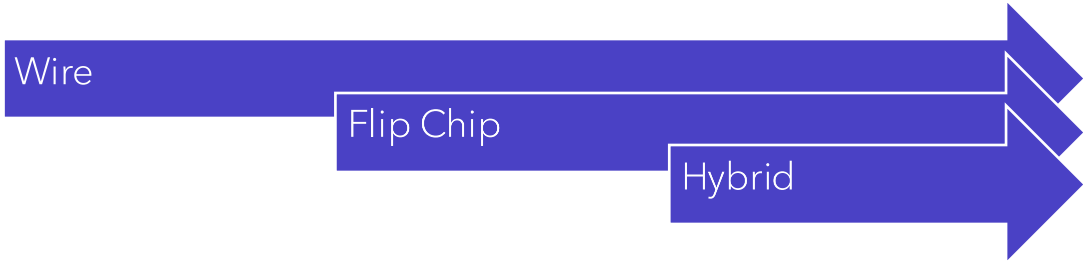
Aspects:

1. Manufacturing Process
2. Design Choices



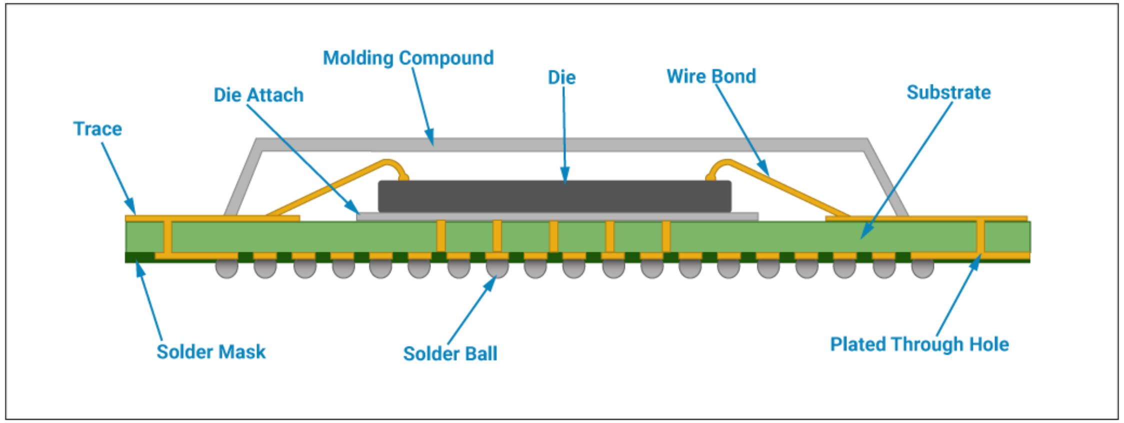
Evolving requirements

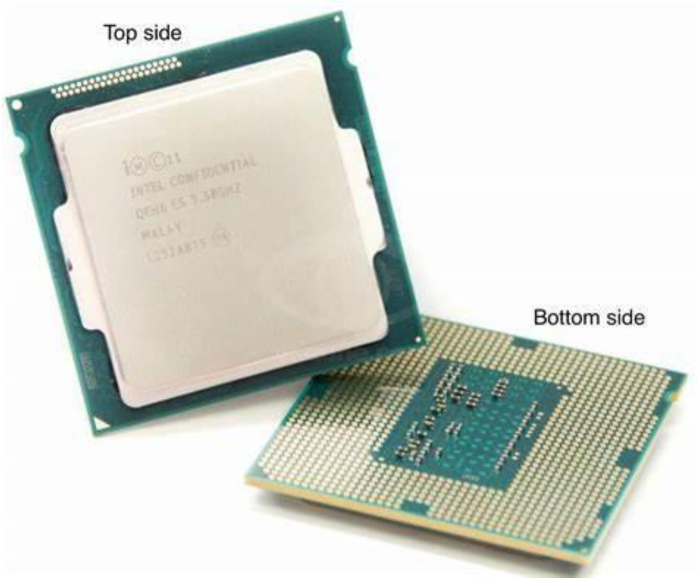
1. Increasing interconnect densities
2. Increasing power / thermal efficiency
3. Increasing space efficiency



Accommodating the bandwidth and power needs of increasingly complex chips

Package Anatomy



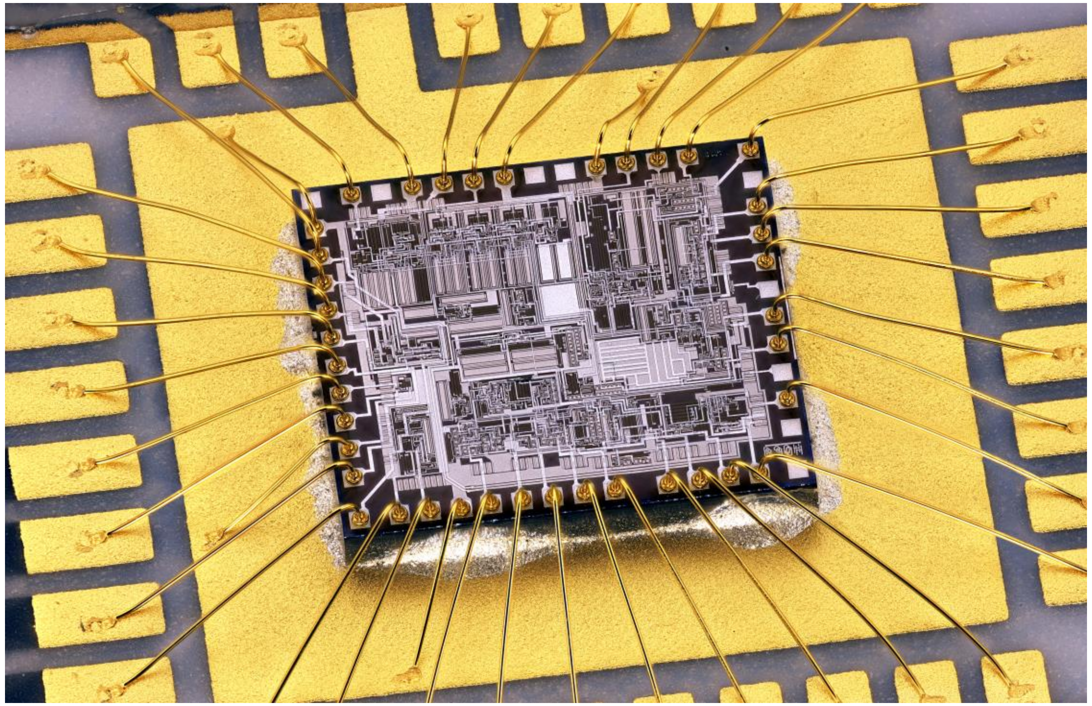


Wire Bonding Interconnects

Around since the beginning of the electronics industry.

The interconnect technology used by 80% of packages manufactured today!

1. Versatile
2. Cost-Effective
3. Reliable
4. Simple



Design Considerations

Consideration 1: What material will we be using?

- Price
- Electrical and Thermal Conductivity
- Elasticity
- Chemical Stability

Material	Advantages	Challenges	Applications
Gold (Au)	Stable, corrosion-resistant, dependable	High cost	Semiconductor packaging standard
Copper (Cu)	Cost-effective, high conductivity, smaller diameter	Needs advanced tech, oxidation issues	Gold replacement in packaging
Silver (Ag) Alloy	High conductivity, lower resistivity, easy bonding	Higher cost than copper	Power electronics
Aluminum (Al)	Room-temp bonding, low energy, alloy-compatible	Needs alloying for strength	General applications

Design Considerations

Consideration 2:

What bonding technique will you use?

Wire Bonding Method	Operating Temperature	Wire Materials	Pad Materials	Note
Thermo-compression	300-500°C	Au	Al, Au	High pressure, no ultrasonic energy
Ultrasonic	25°C	Au, Al	Al, Au	Low pressure in ultrasonic energy
Thermo-sonic	100-240°C	Au, Cu	Al, Au	Low pressure in ultrasonic energy

Design Considerations

These should be considered.

Depend on too many variables to be fit into this presentation

Other design considerations:

1. Bond pad size
2. Pitch between bond pads
3. Wire Length
4. Wire Orientation
5. Corner Distance
6. Partitioning of bond pads

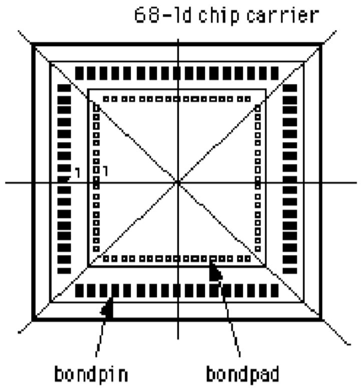


Fig. 3: Partitioning of the bondpads

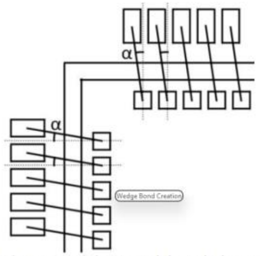
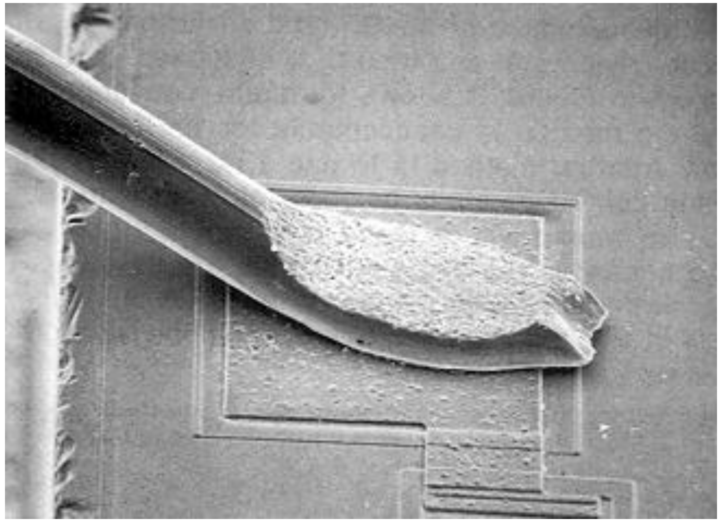


Fig. 4: Angle between the wire and the normal through the middle of the bondpad

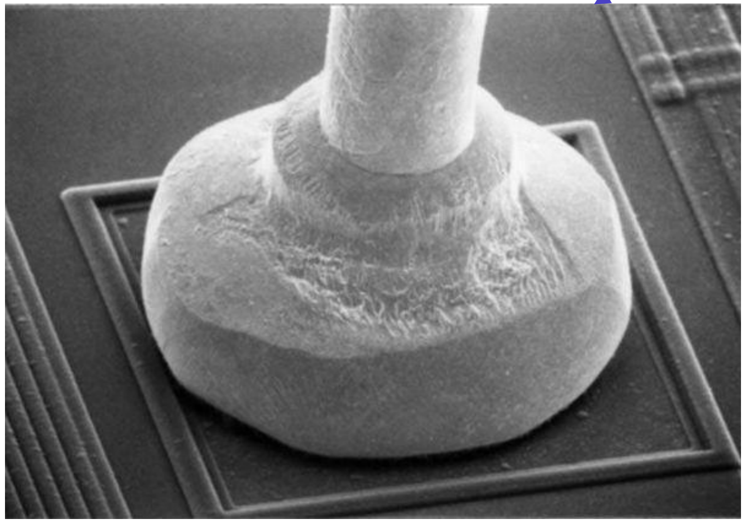
Wire Bond Creation

Wedge Bond

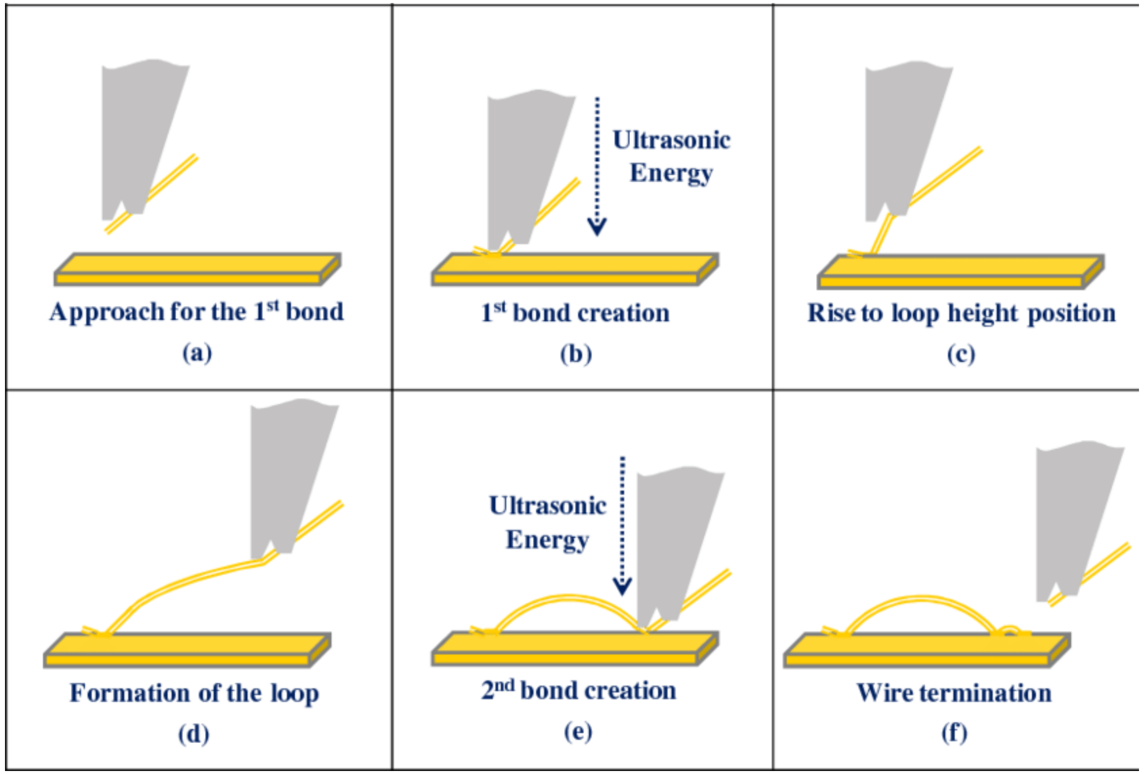


Ball Bond

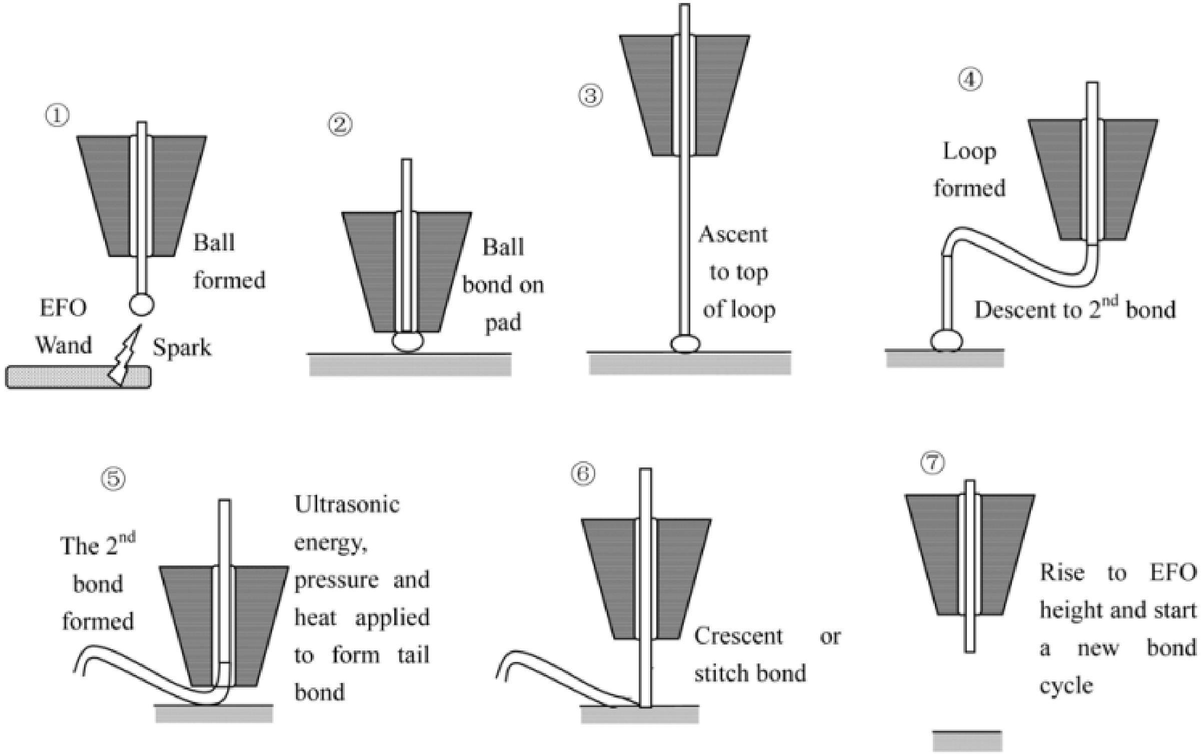
Constitutes for 90% of all wire bonds



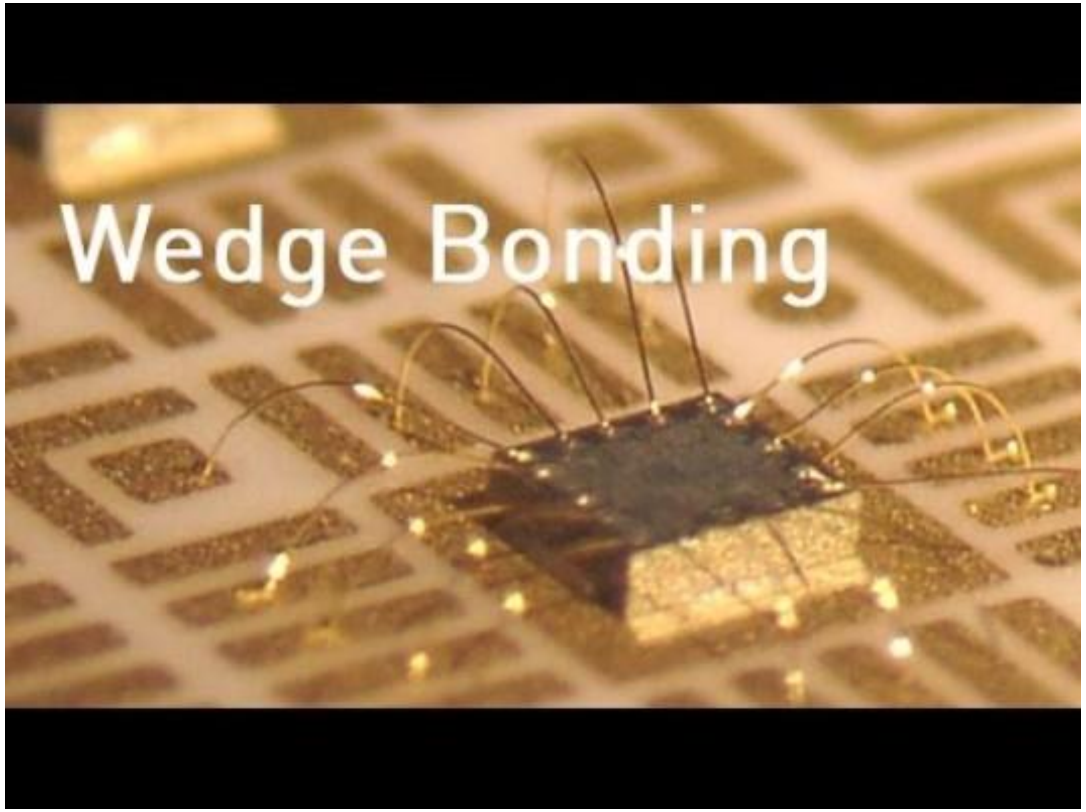
Wedge Bond Creation

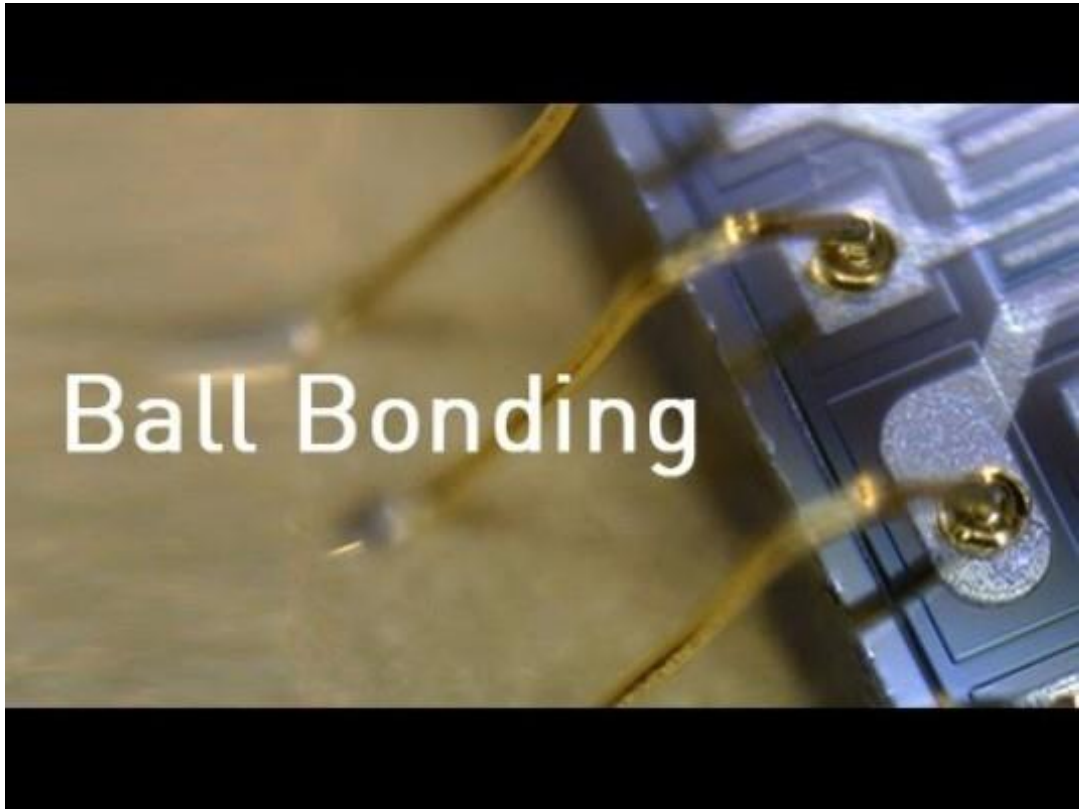


Ball Bond Creation



Lets watch it happen





Advantages of Wedge Bonds

Capable of handling high mix environments

Compatible with many materials

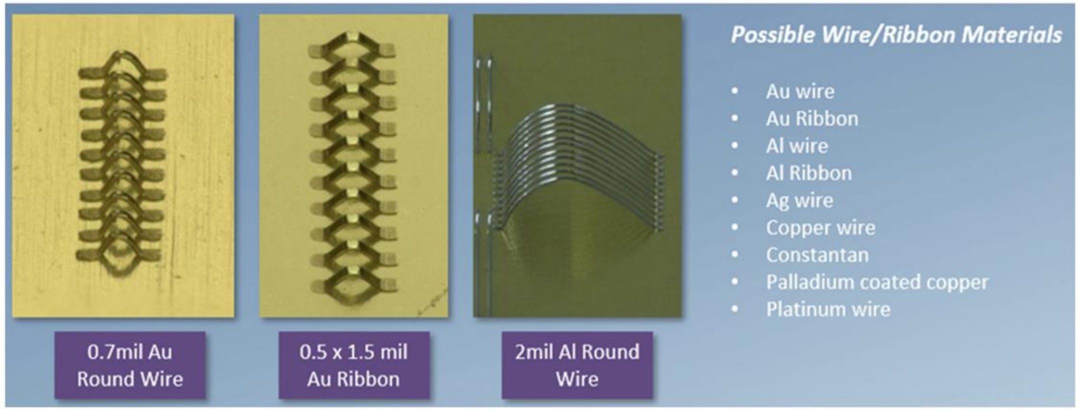


Figure 5: There are a wide range of materials that can be wedge bonded.

Advantages of Wedge Bonds

Ribbon Bonding

High-Frequency Performance:

- Preferred for **high-frequency applications** due to **high surface-to-cross-sectional area ratio**:
    - **Lower resistance** at high frequencies (reduces skin effect impact).

Stiffness and Stability:

- **Stiffer than round wire** for increased **resistance to sway**.
- Larger bond area provides **stronger connections** for enhanced reliability.

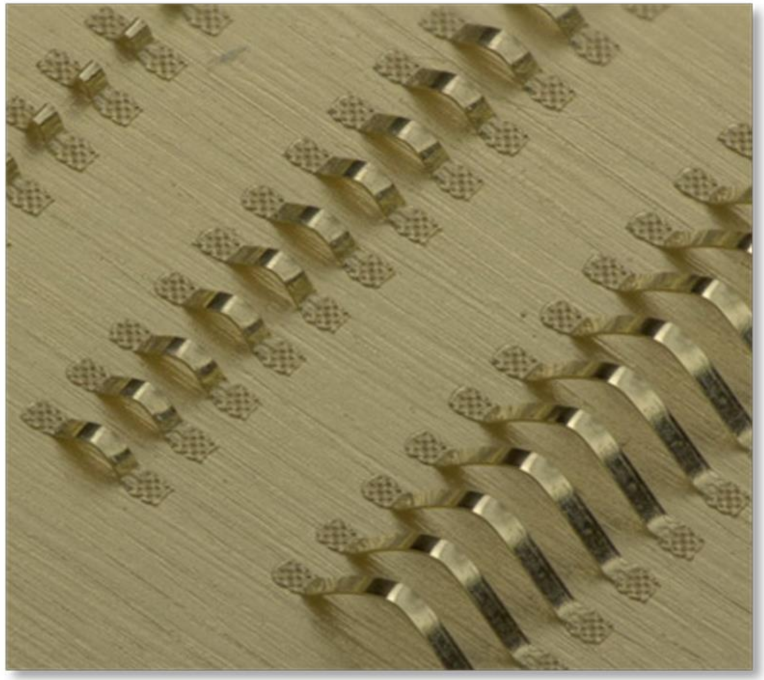


Figure 7: Typical ribbon bonding.

Advantages of Wedge Bonds

Bond Shape and Pitch:

- Wedge bonds are typically **longer than wide**:
  - Allows **tighter pitch** while maintaining sufficient bond area.
- Exception: **Ribbon bonding** requires a different approach for width and pitch.

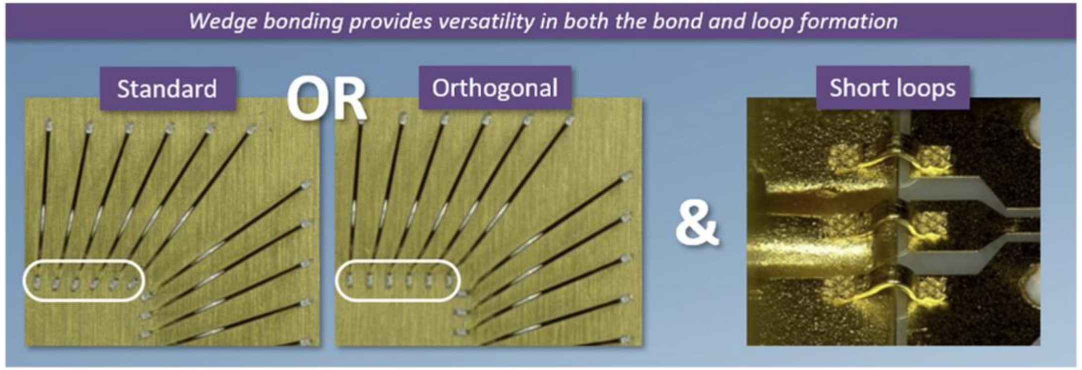


Figure 6: Wedge bonding can create standard or orthogonal bonds and short loops.

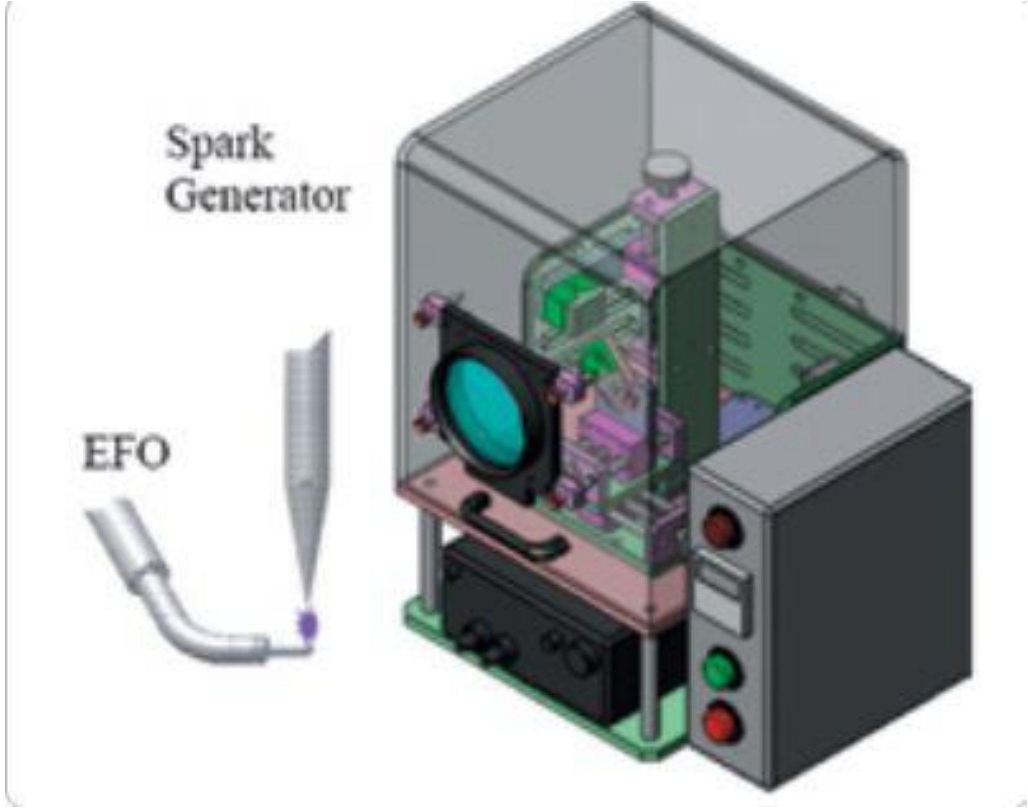
Advantages of Wedge Bonds

No Ball Required:

- Wedge Bonders: No ball formation needed, allowing for lower, shorter loops (depends on tool design).
- Ball Bonders: Requires a ball formation step, leading to longer loops.

Access and Clearance:

- Wedge Bonders: Deeper access possible due to lack of flame-off requirements.
- Ball Bonders: Requires extra vertical clearance for EFO (Electronic Flame Off) wand to clear the part. Capillary to clear the EFO wand.



Advantages of Ball Bonds

Increased Bonding Strength and Durability:

- Alloyed gold wire (with added elements like Cu, Pt, or Pd) is stronger and more durable, making it more resistant to mechanical stresses over time.
- The ball bonding process takes advantage of this strength by forming robust spherical bonds that withstand repeated thermal cycling and mechanical movement.

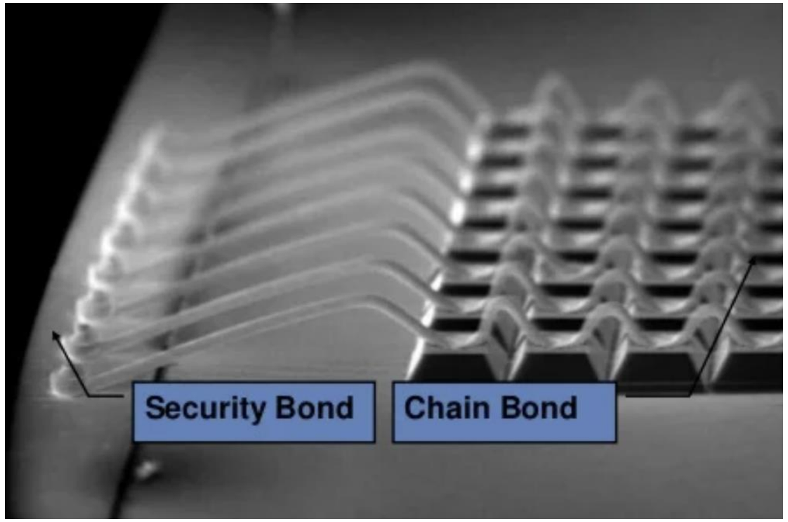
Advantage	Ball Bonding with Alloyed Gold Wire	Wedge Bonding Limitation
Increased Strength	Stronger, more durable bonds.	Limited without alloyed elements.
High-Temperature Stability	Suitable for high-speed, high-frequency, high-temp applications.	Limited to lower-temp settings.
Thermal Efficiency	Lower-temp bonding without performance loss.	May require higher temp for strength.

Advantages of Ball Bonds

Versatile Bonding Capabilities:

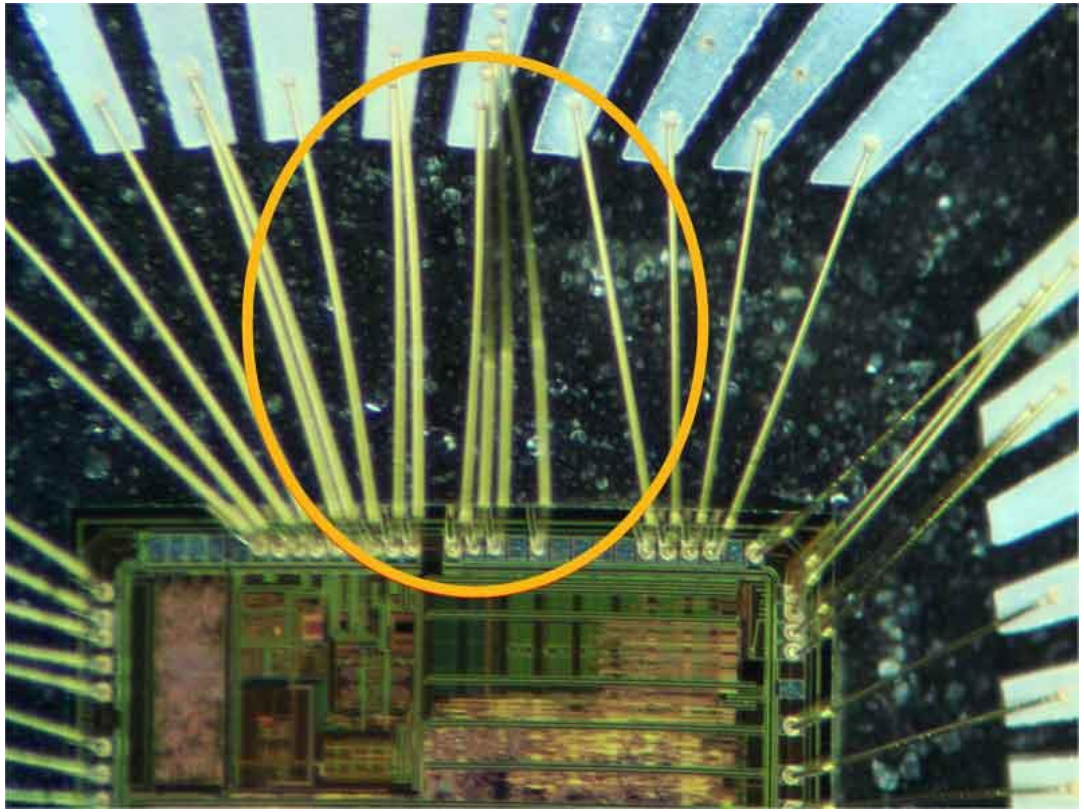
• A **single capillary** can bond various wire types, including:

- Standard wires
- Chain wires
- V-bonded wires
- Security Bonds



Disadvantages of Wire Bonding

1. Performance Limitations
    1. Increased signal path length
    2. High inductance and capacitance
2. Reliability Concerns
    1. Mechanical Stress
    2. Oxidation



Looking to the future

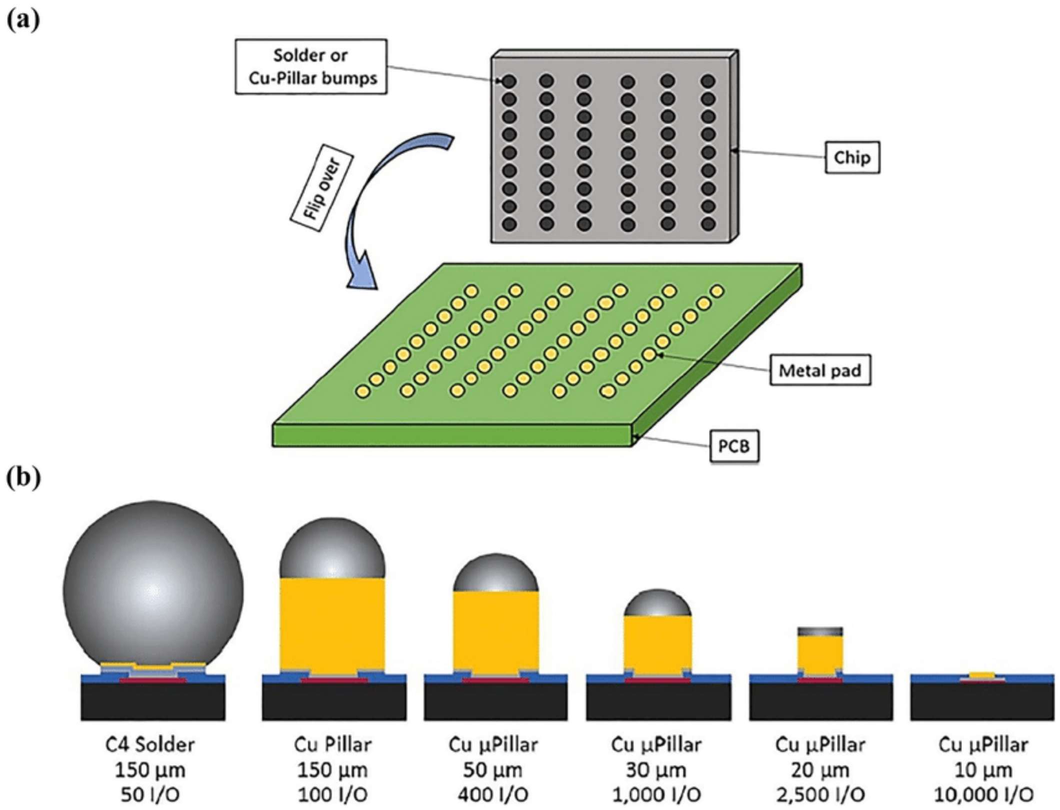
Limited advancement, only recent advancement is switching to copper

You can also only make the pitch size so small, especially in a world that values data movement and high IO counts.

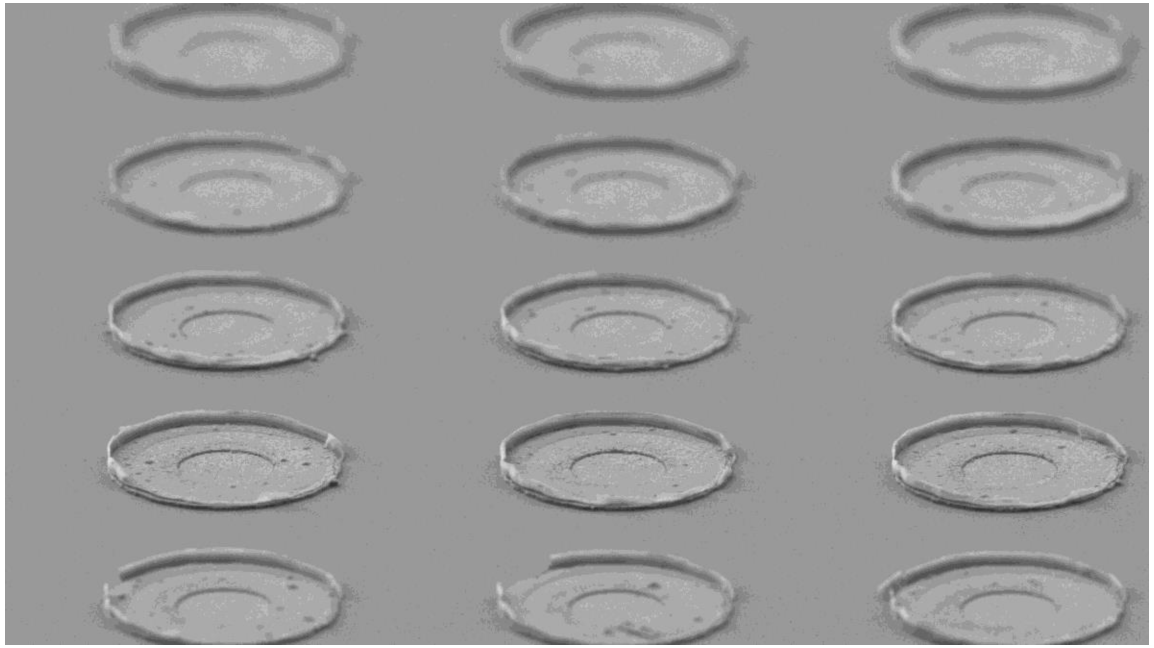
"And the major advances include going to copper wire, which is a little more conductive, but a big savings over the cost of the gold. That's been the most important change that I see in wire bonding in recent years." – CEO of Promex Industries

Flip Chip Interconnects

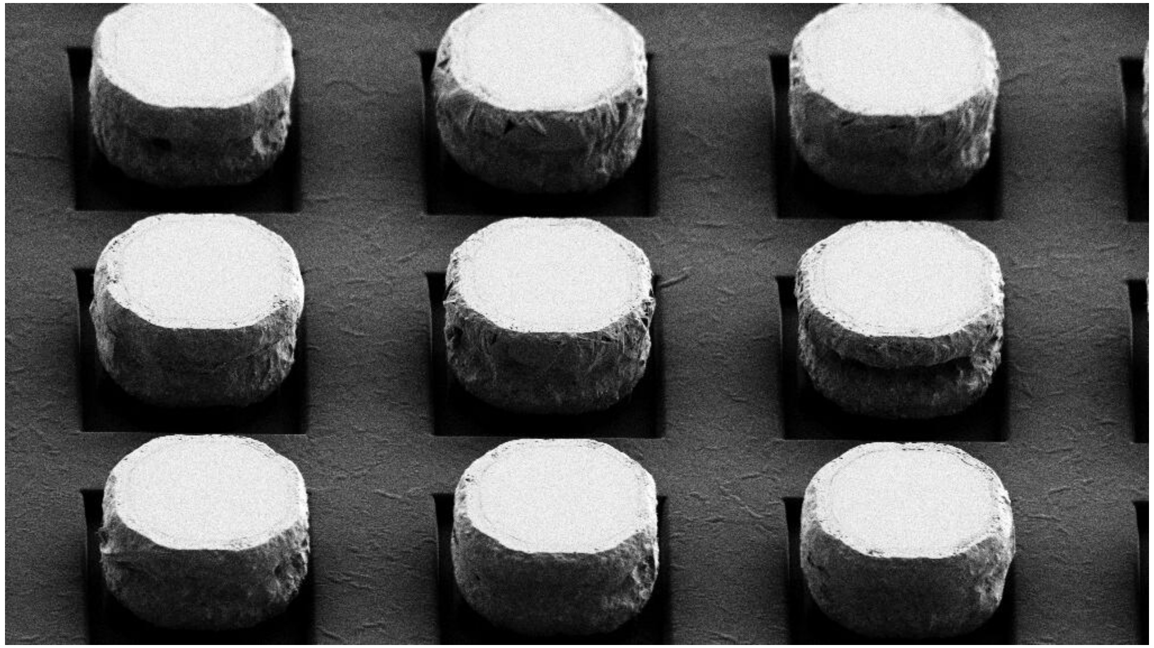
- Ball bonds deposited on chip pads and Under Bump Metallization replaced wire bonds and enabled flip-chip style connections
- Allow for a shorter, more direct connection from the die to the substrate
- More reliable than wire bonds with better performance



Flip Chip Anatomy



Under-Bump Metallization



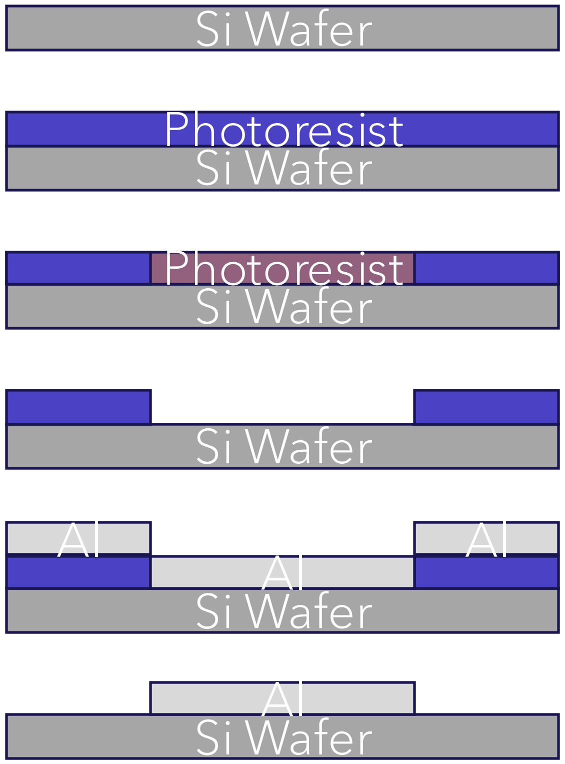
Solder Balls Deposited

Fabrication Process

Step 1 – Pad Creation

Typically made of aluminum, connects die to UBM.

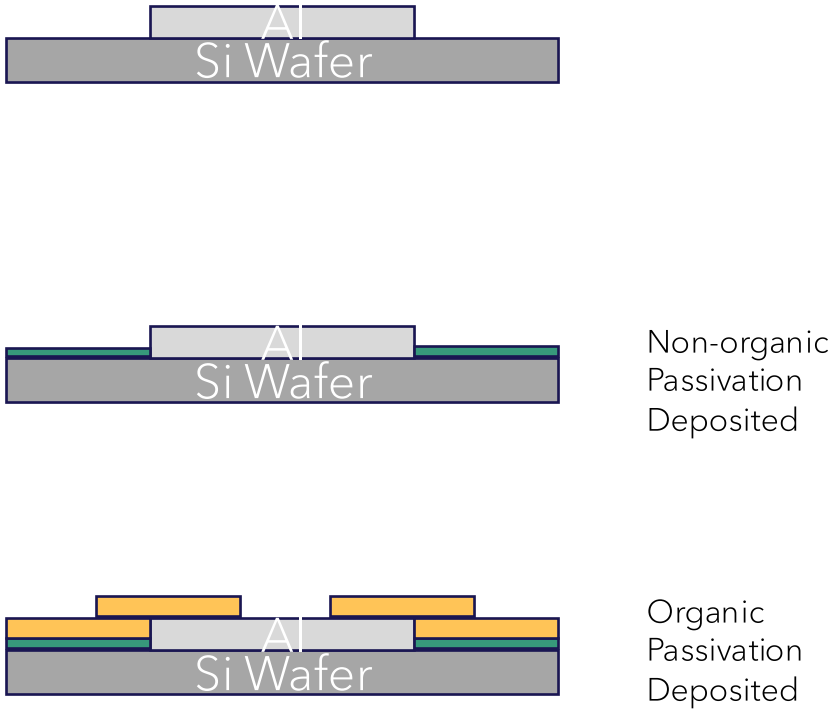
This process will be repeated across the entire fab process.



Fabrication Process

Step 2 – Creation of passivation layer

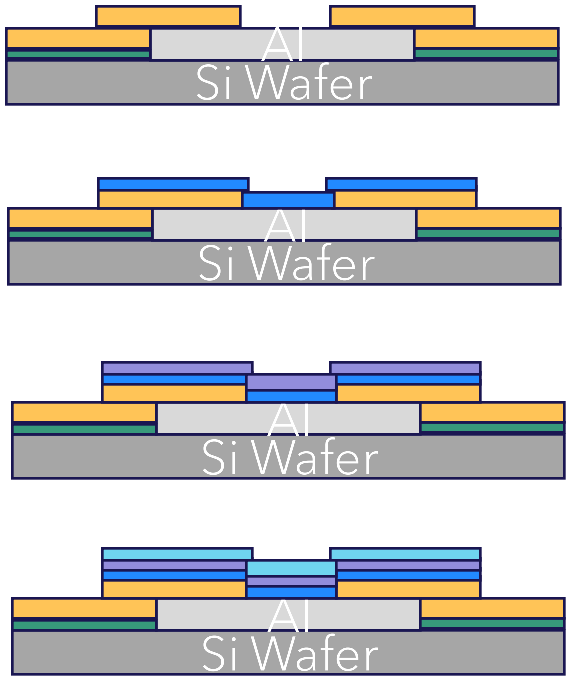
- Electrically insulates metal layers from each other
- Acts as mechanical protective barrier, shielding wafer from environment.
- Absorbs some of the mechanical stress from CTE mismatch.



Fabrication Process

Step 3 – UBM Layer Deposition

Layer	Material	Function
Adhesion	Titanium (Ti) or Chromium (Cr)	Improves adhesion between the silicon and the metal layer.
Barrier	Nickel (Ni) or NiVanadium (NiV)	Prevents diffusion between the solder and silicon.
Wetting	Copper (Cu)	Ensures strong adhesion between UBM and the solder bump.



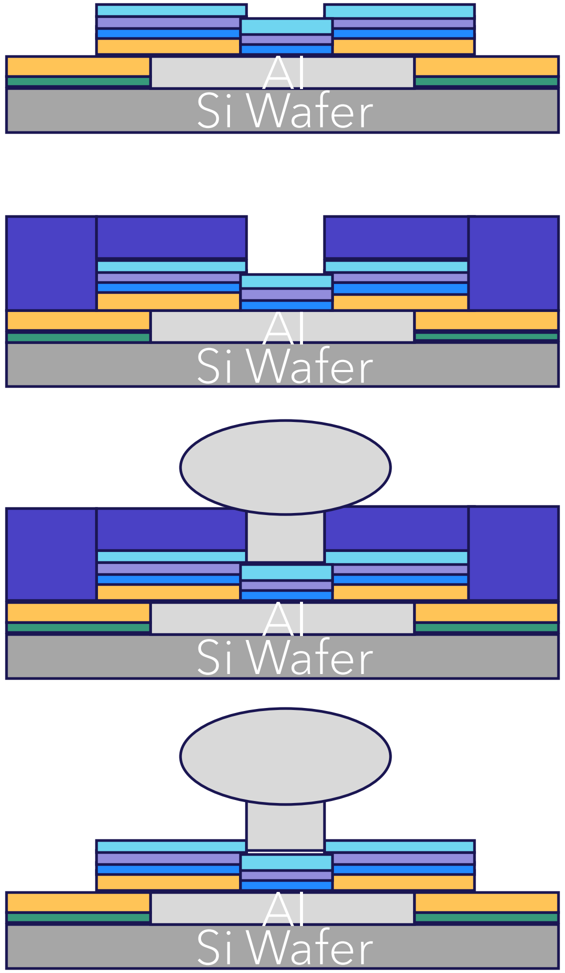
Adhesion Layer Deposited

Barrier Layer Deposited

Solder Wetting Layer Deposited

Fabrication Process

Step 4 – Solder Deposition

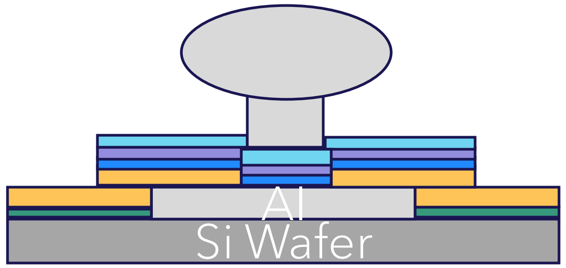


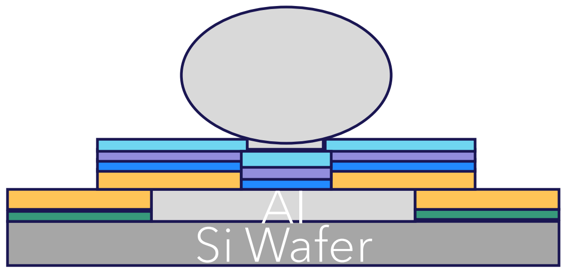
Fabrication Process

Step 5 – Reflow

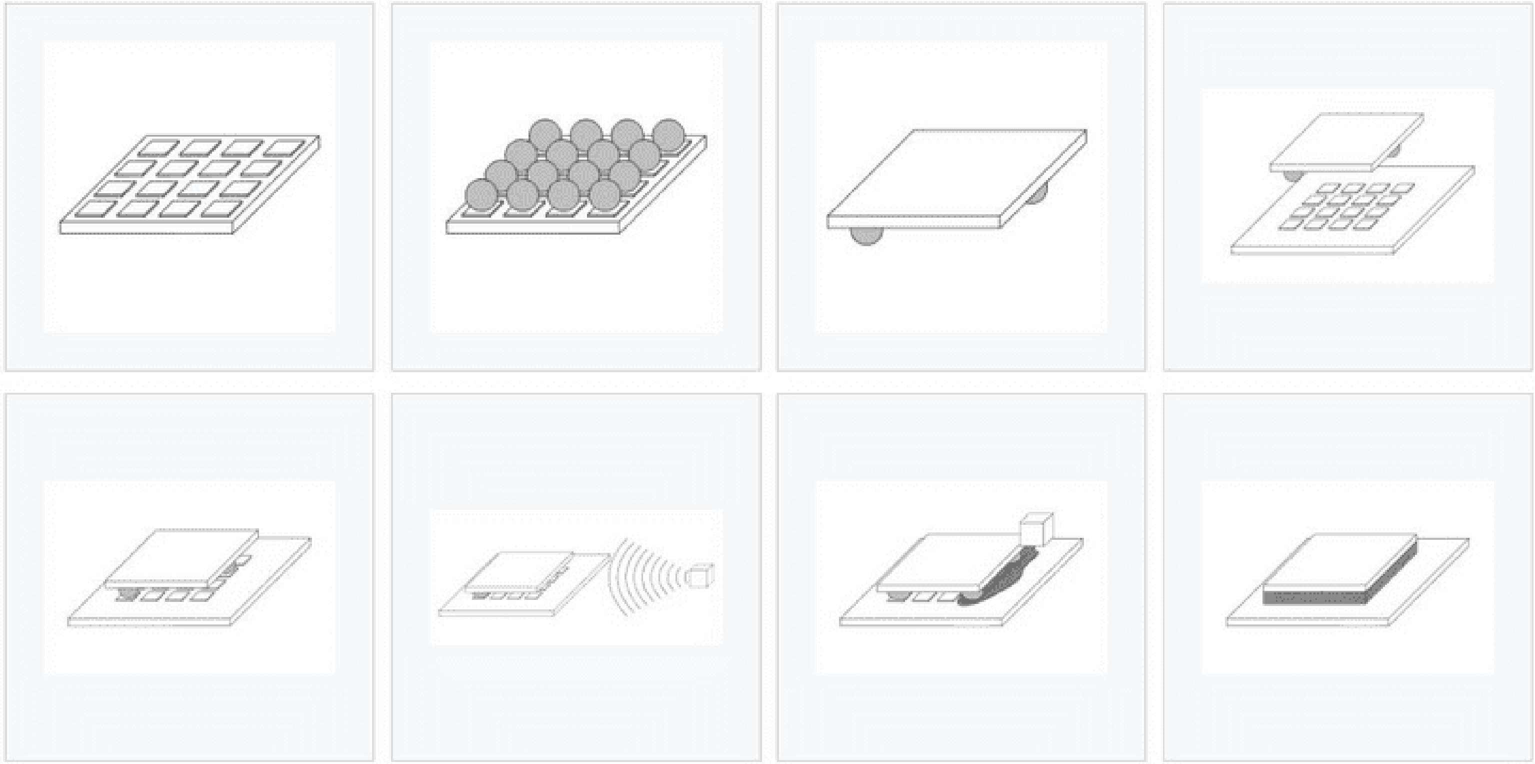
Put it in the oven

You now have a ball bond!





Manufacturing Process



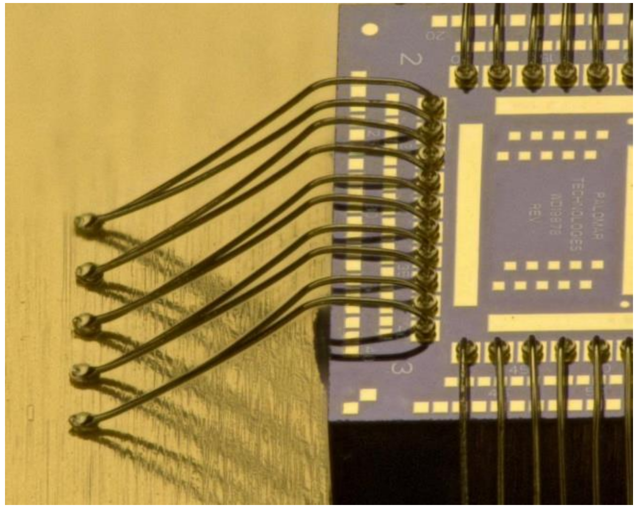
Advantages of Flip Chip

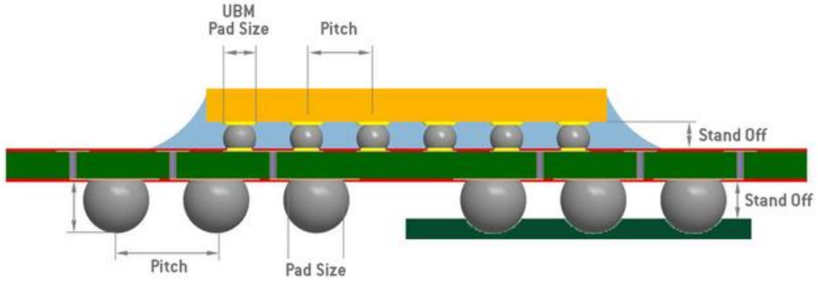
Electrical Performance

- Shorter connection path
- Wider connection path

Less:

- Inductance
- Capacitance
- Resistance

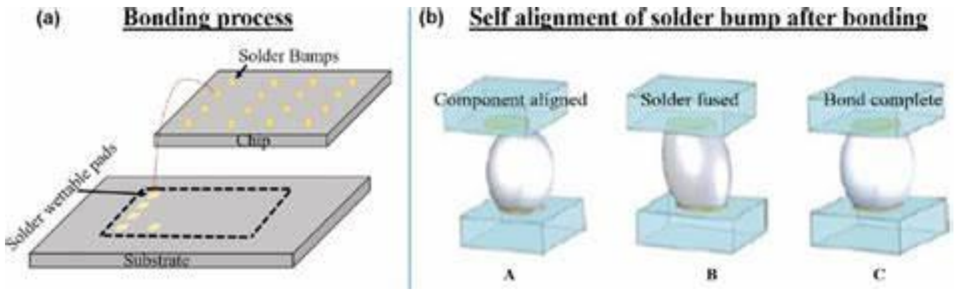




Advantages of Flip Chip

Self-Aligning Property

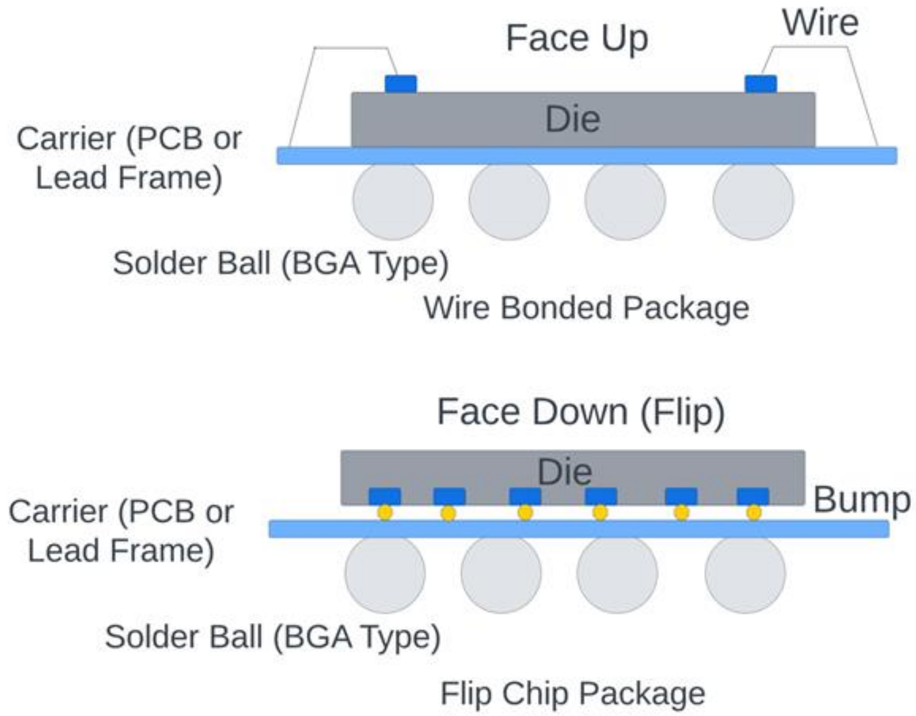
During reflow, surface tension of solder will collapse the ball into the UBM



Advantages of Flip Chip

Space

The connection footprint is much smaller compared to wire bonds.

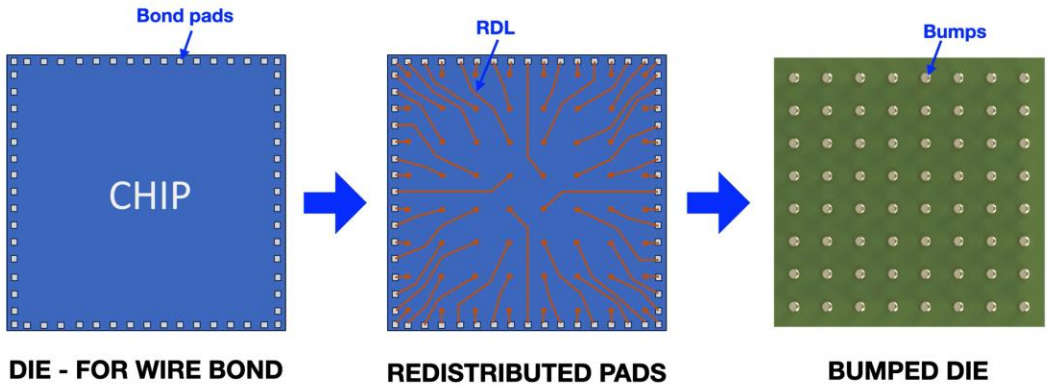


Advantages of Flip Chip

Bandwidth (In theory)

Most dies are designed for wire bonding

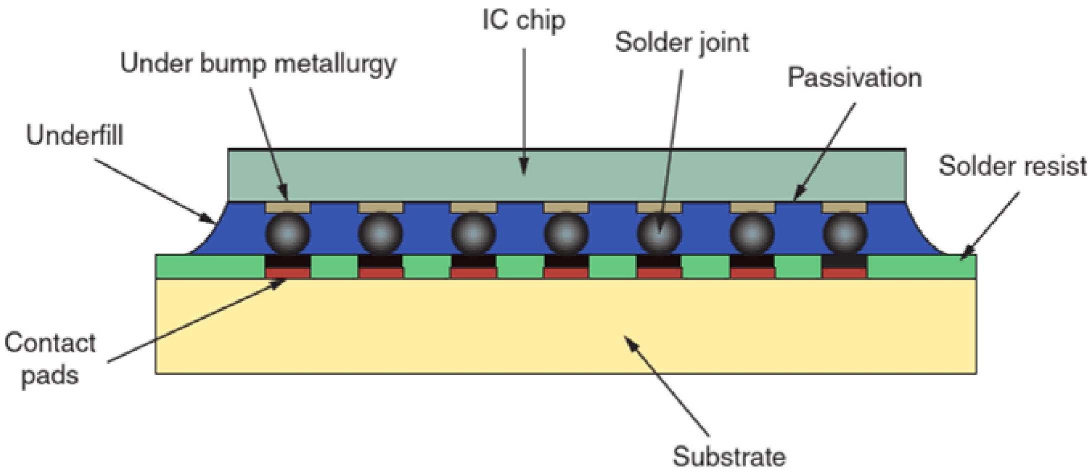
This may require redistribution.



Advantages of Flip Chip

Better mechanical strength

More points of contact + Underfill

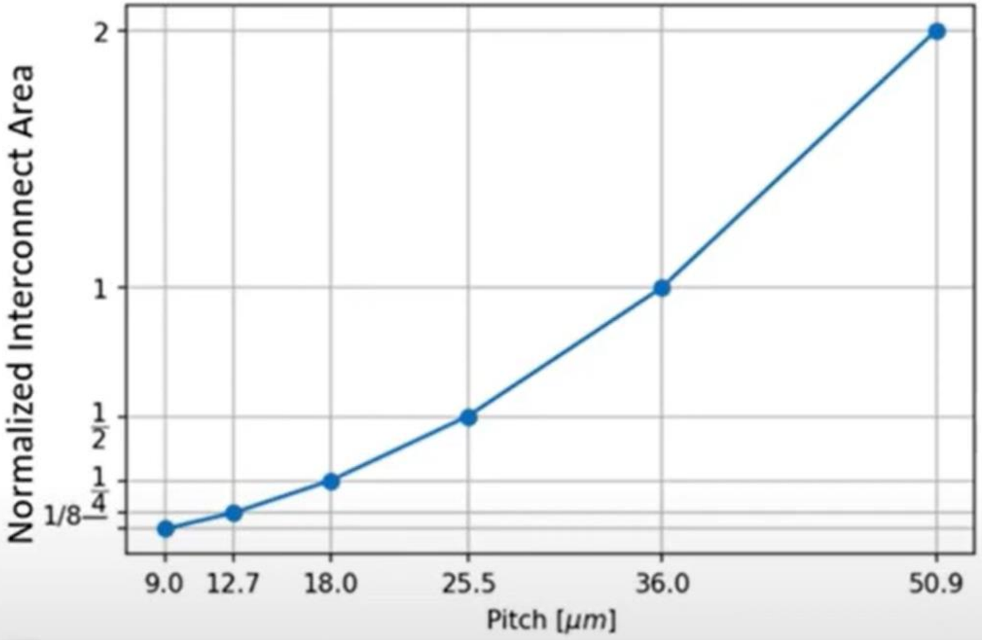


Disadvantages

- Need to dissipate heat to environment faster
- Difficult to inspect the solder joints
- Increased cost past material

We need something more or less in a sense

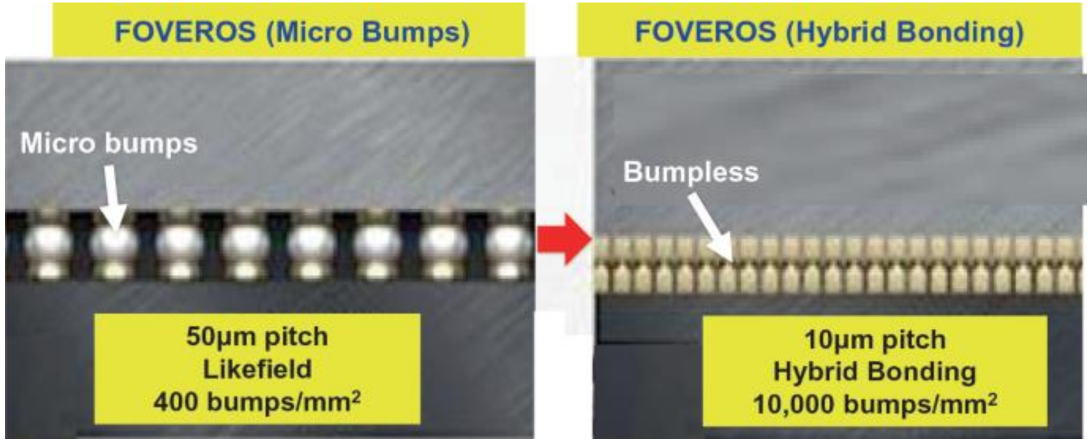
Innovation and miniaturization have created the need for a higher interconnect density.



Normalized Interconnect Area for Fixed Number of Signals vs. Die-to-Die Interconnect Pitch

Hybrid Bonding

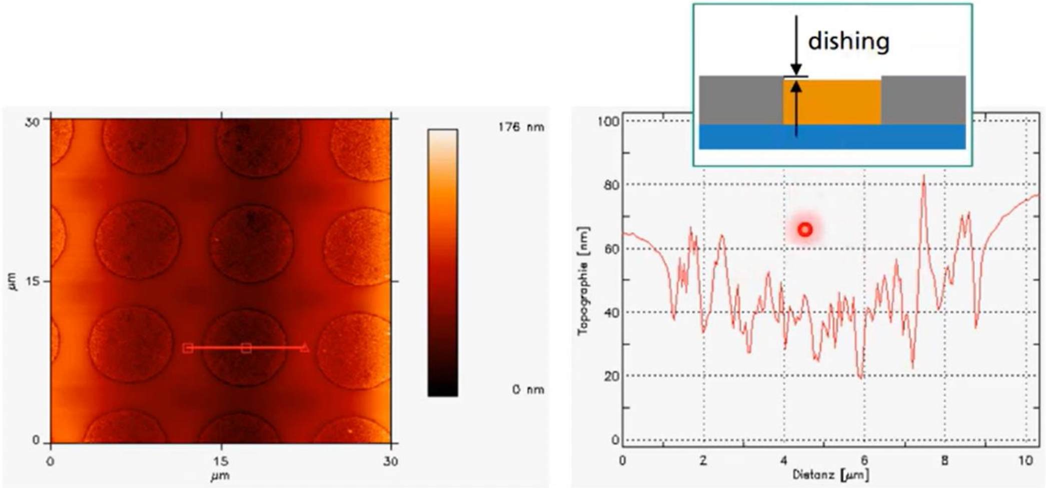
- Hybrid Bonding (HB) is a dielectric bond combined with a metal bond to form an interconnect
- HB allows for a pitch below 10 micrometers where current technology (solder) is limited by electrical and thermomechanical restrictions.
- Effectively replaces the Under Bump Metallization (UBM), underfill, and micro-bumps with a direct connection.
- HB involves D2W or W2W processing a t low temperatures (<300C) to initiate high bond strengths.



Fabrication Process

Step 1: Surface Preparation

- The topography is incredibly important, it must be FLAT. Use CMP.
    - Small particles / surface defects can cause 10s-1000s of failed connections.
- A small recess must be formed on metal pad for strong bond.
- Planarity typically evaluated using atomic force microscope (AFM).

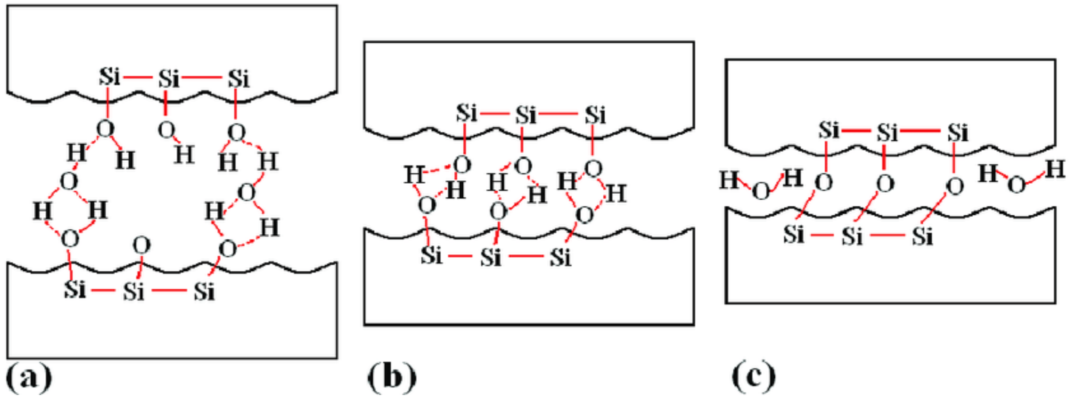


Example of AFM measurement: Cu dishing after CMP ~ 30nm
→ parameter optimization ongoing

Fabrication Process

Step 2 – Plasma Activate / Pre Bond

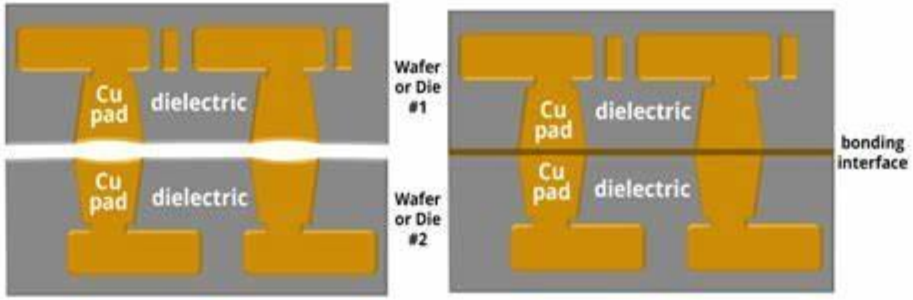
- The dielectric surfaces need to become hydrophilic.
- Two layers are brought together at room temperature and undergo hydrophilic oxide-oxide bonding.



Fabrication Process

Step 3 – Annealing

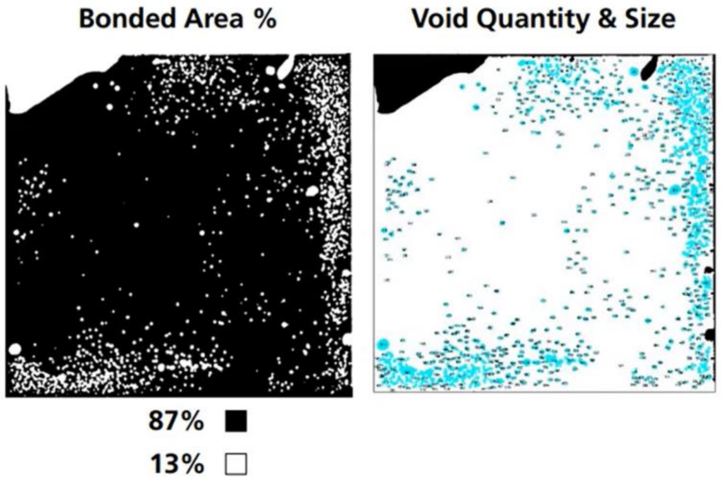
Due to a mismatch in CTE (metal CTE > oxide CTE), the metal expands the dishing gap.

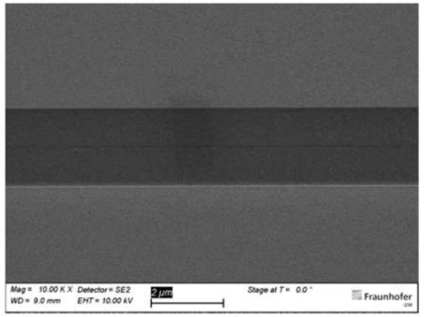


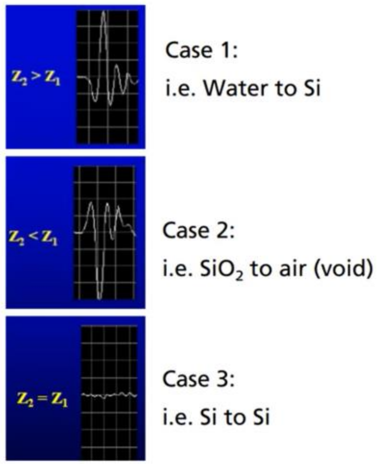
Fabrication Process

Step 4 – Bond Quality Evaluation

- Ideally there should be no voids, defects, or grain boundaries.
- Voids can be detected using Scanning Acoustic Microscopy.
- Scanning Electron Microscope can also be used earlier to evaluate uniformity.



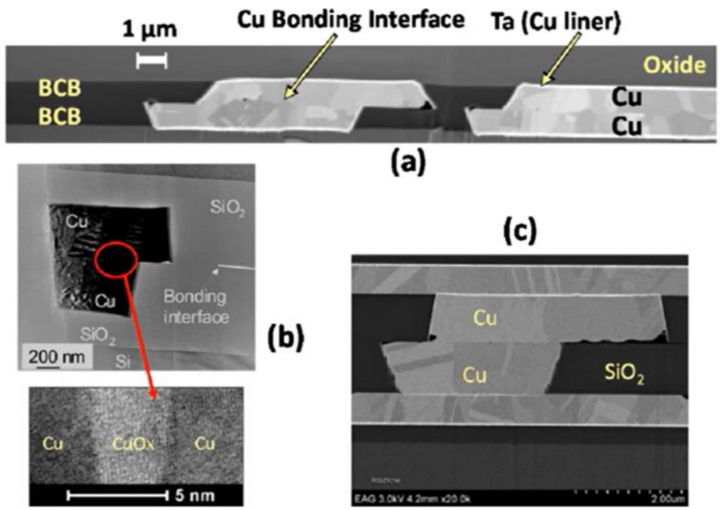

SEM image of oxide-oxide bond interface



Fabrication Process

Step 5 – Placement Accuracy

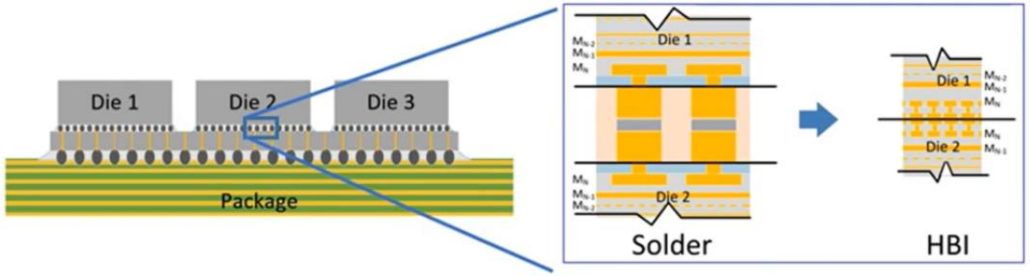
- Due to the extremely small pitch sizes, misaligned bonds can render a die or wafer useless.
- Mitigation techniques:
    - Vibration control
    - Cleanliness
    - Thermal Control
    - Bond Head Parallelism



Advantages of HB

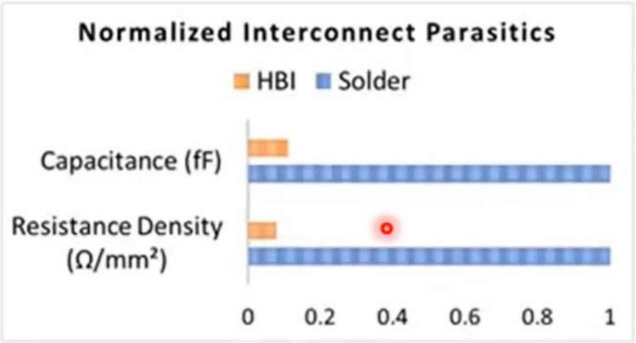
Past bandwidth improvements

Even better electrical properties.



Solder Interposer Package

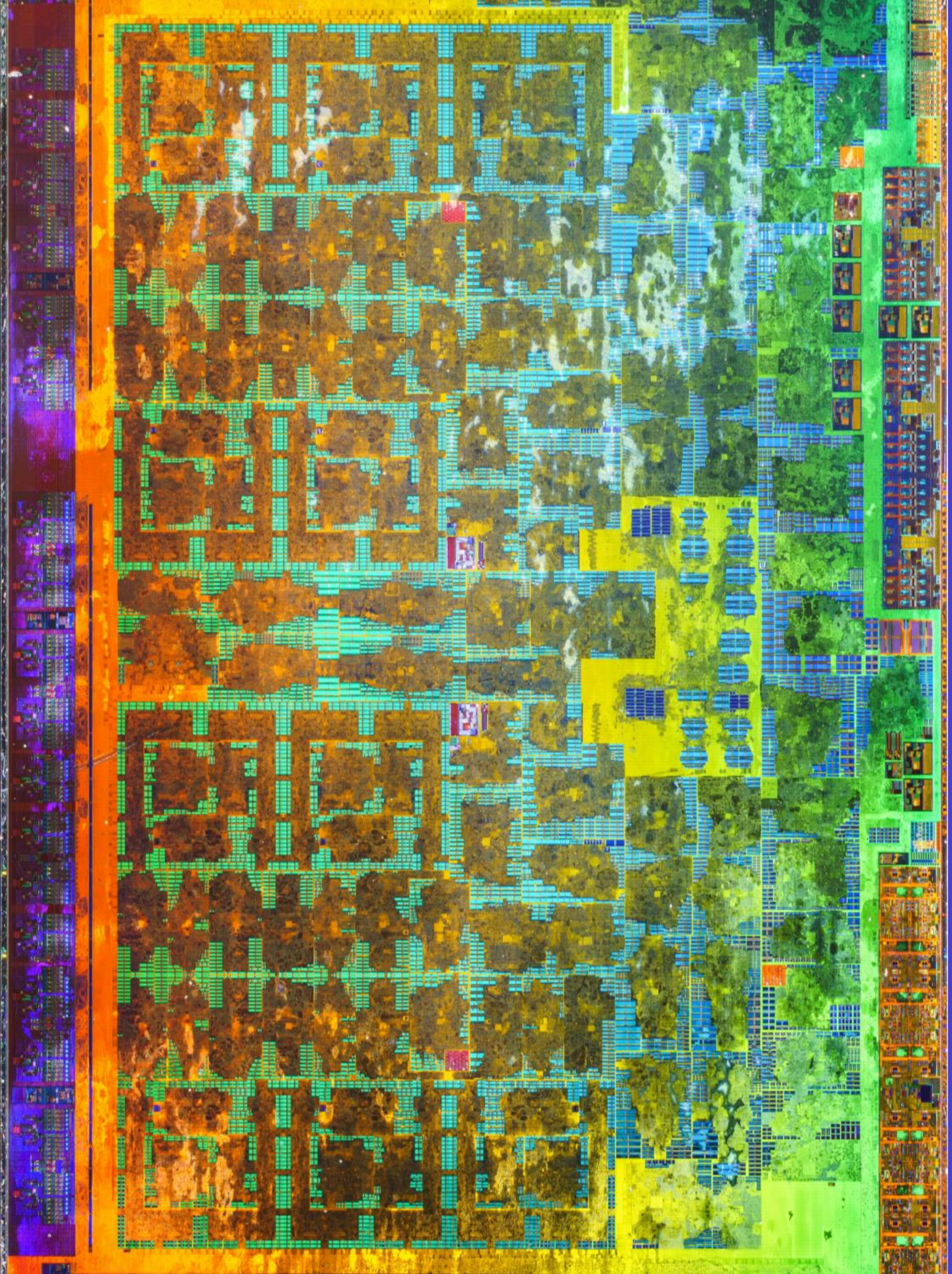
Die to die Interface



Parasitics Reduction

Important Things I didn't Cover

1. Thru Silicon Vias ☹
2. Interposers
3. FOWLP



That's all thank you for coming!

See you next week!