Fundamentals of Package Materials

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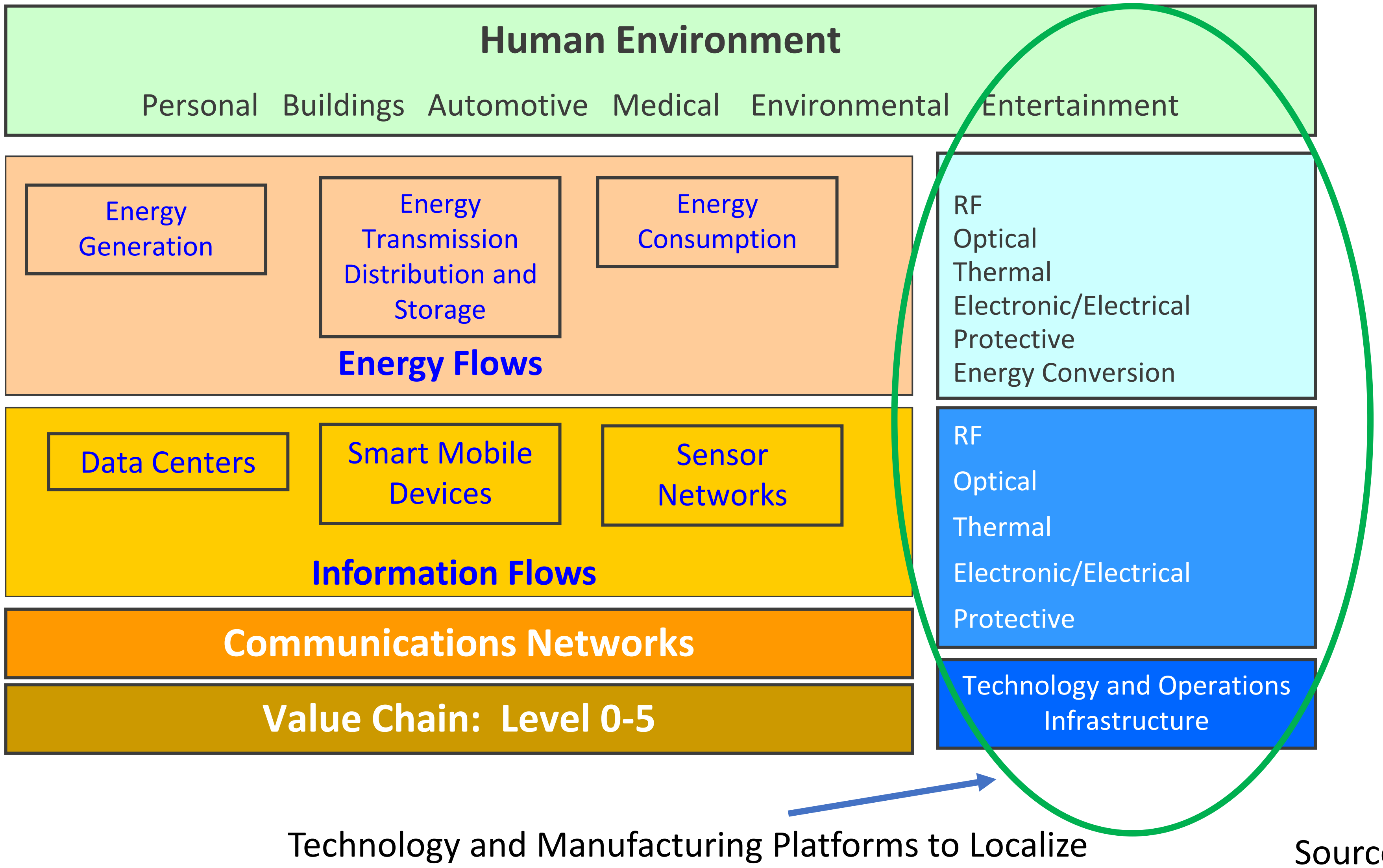
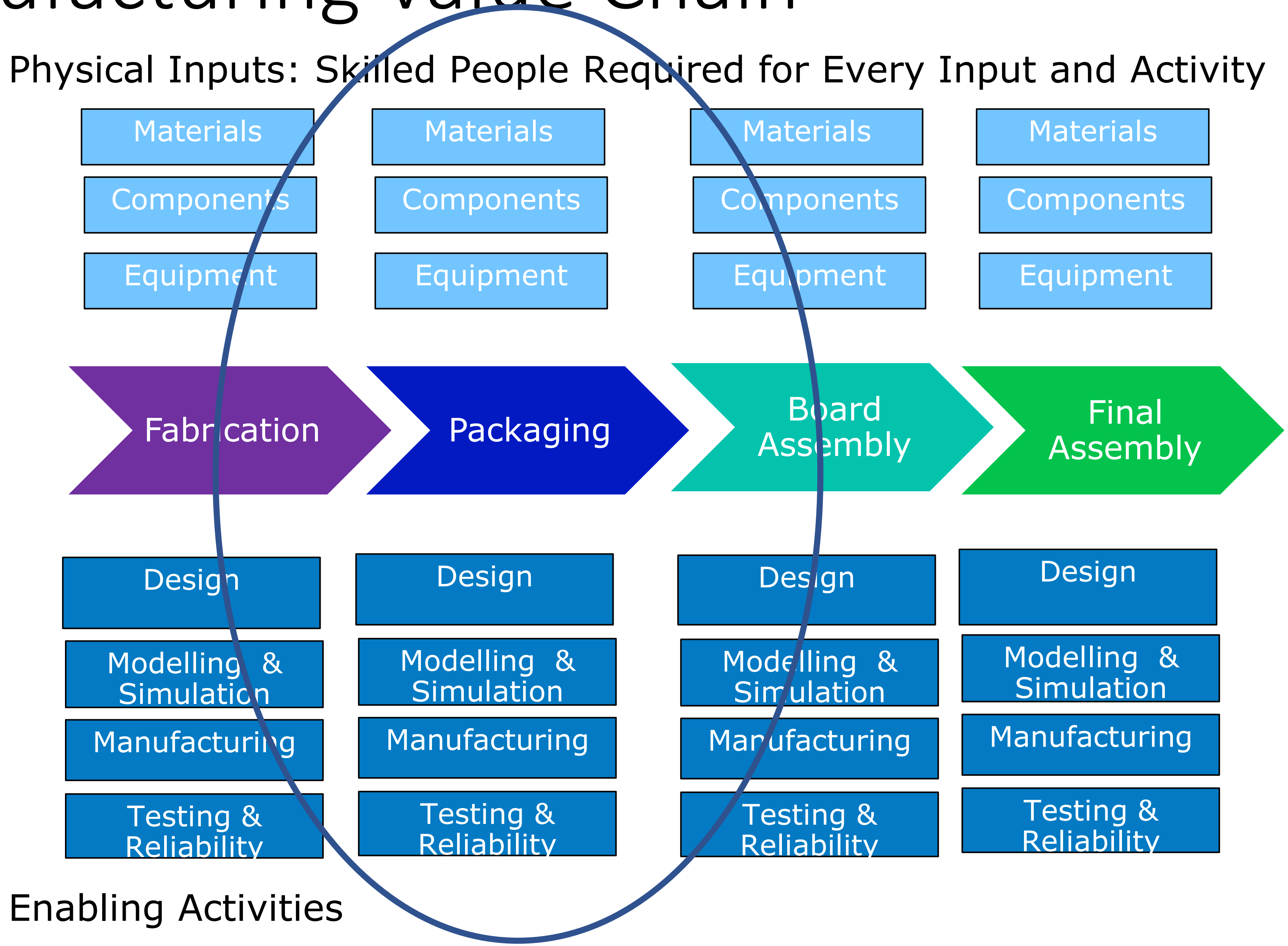
Our Ecosystem



Source: R. Bhatkal, MacDermid Alpha

Manufacturing Value Chain

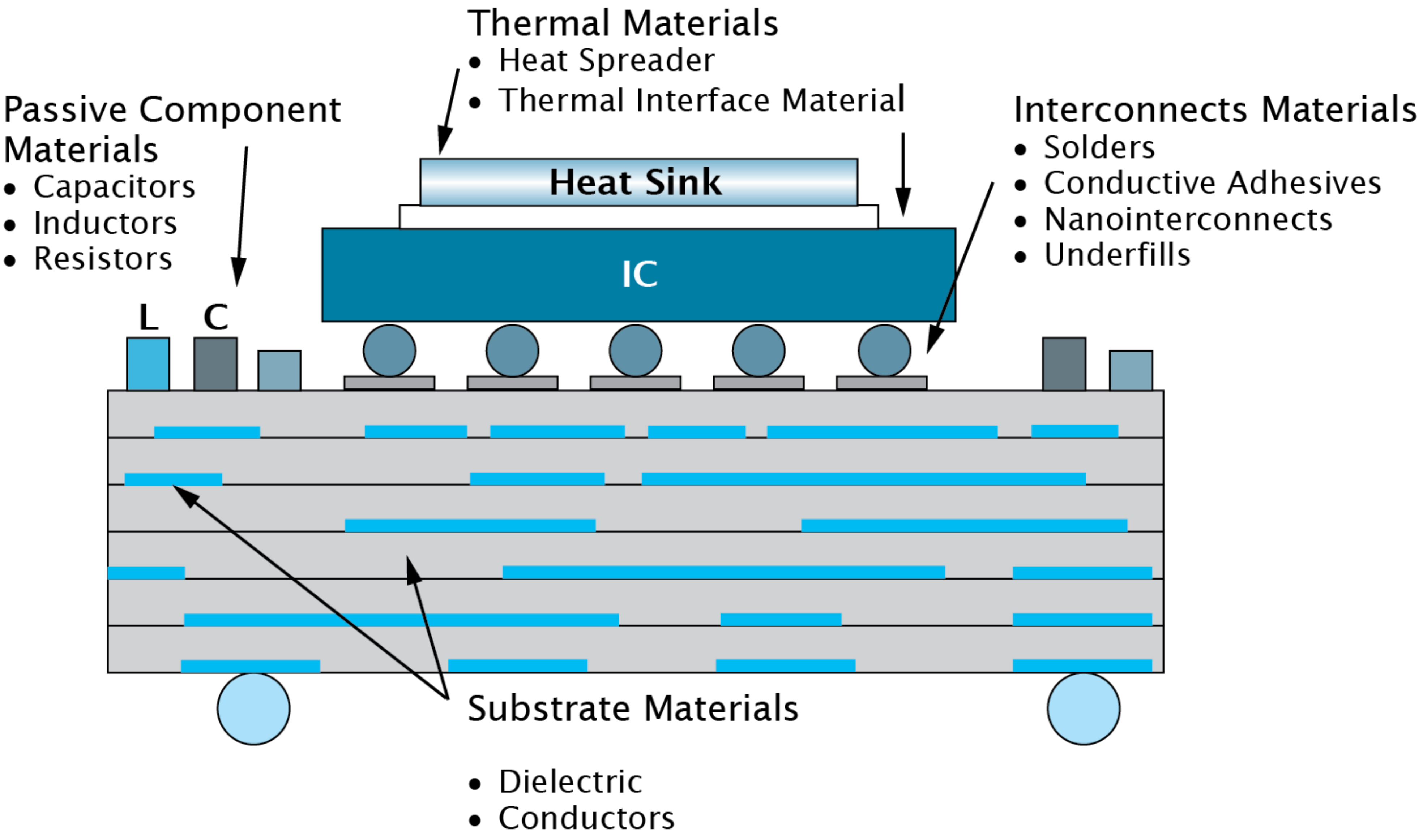


Source: iNEMI

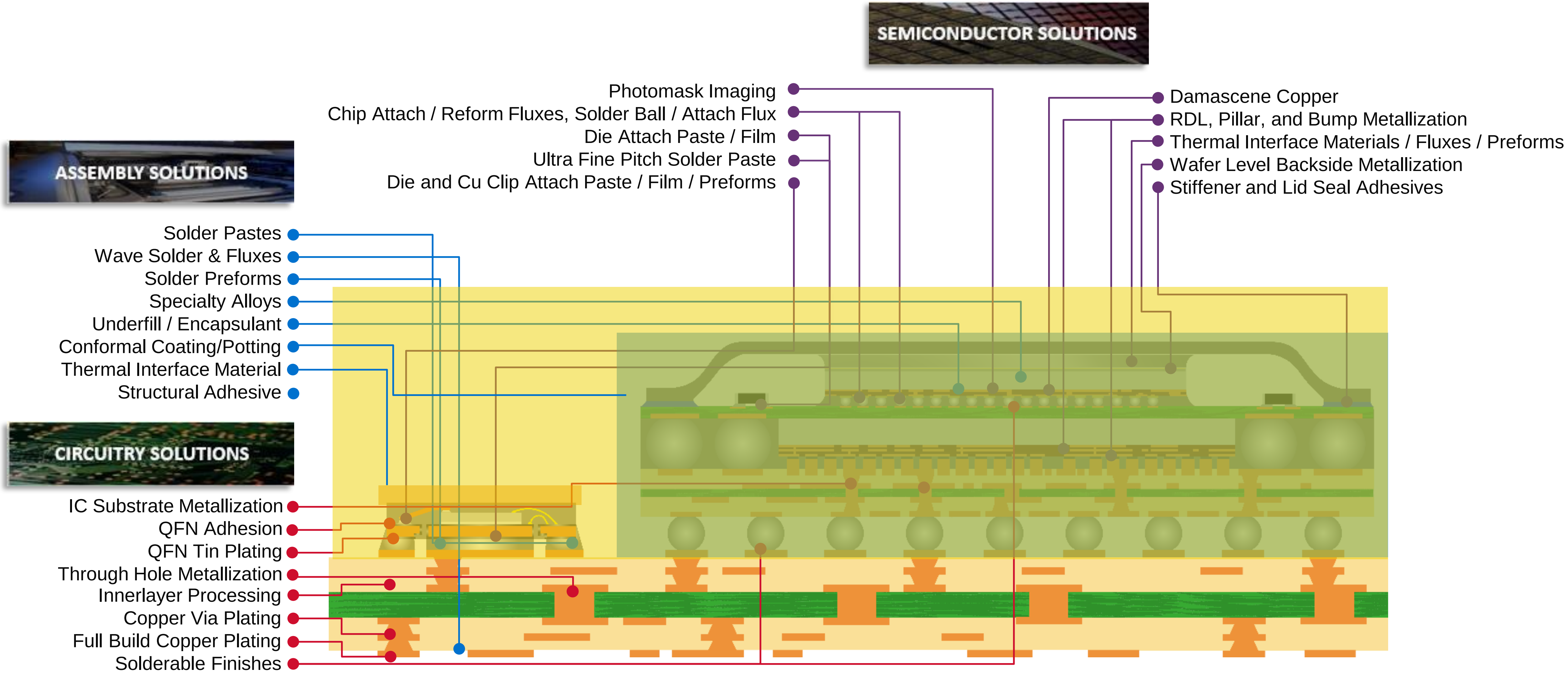
Role of Materials in Semiconductor Packaging

- Materials are the “heart and soul” of all electronic systems.
- Four main categories in an electronic system:
  - Devices
  - Packages
  - System Boards
  - Interconnections between device, package and board.
- Role of materials in semiconductor packaging is to provide:
  - Interconnection
  - Power
  - Cooling
  - Protection

Anatomy of a Package



Anatomy of a Package – Complex Integrated System



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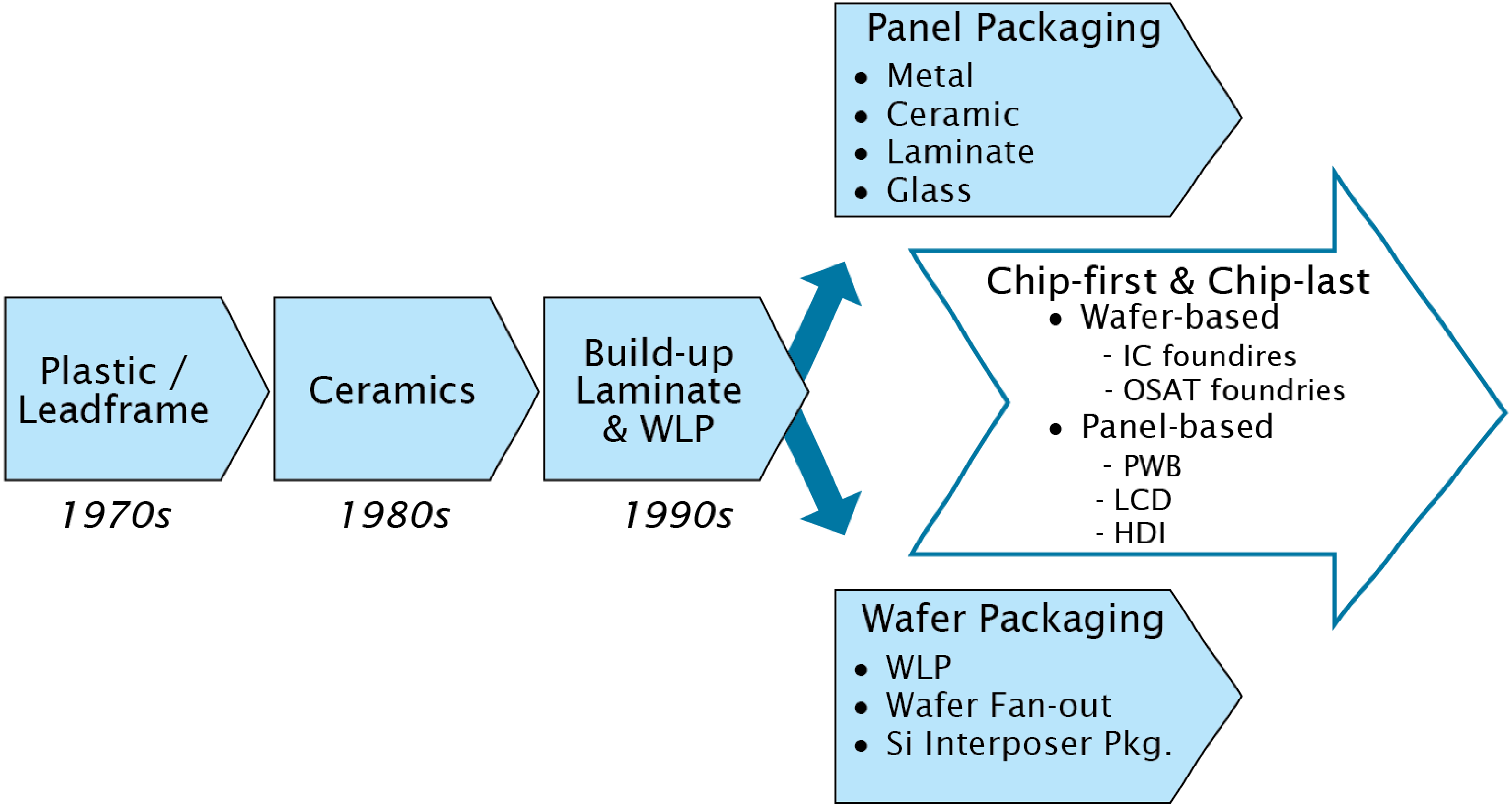
Evolution of Package Technology



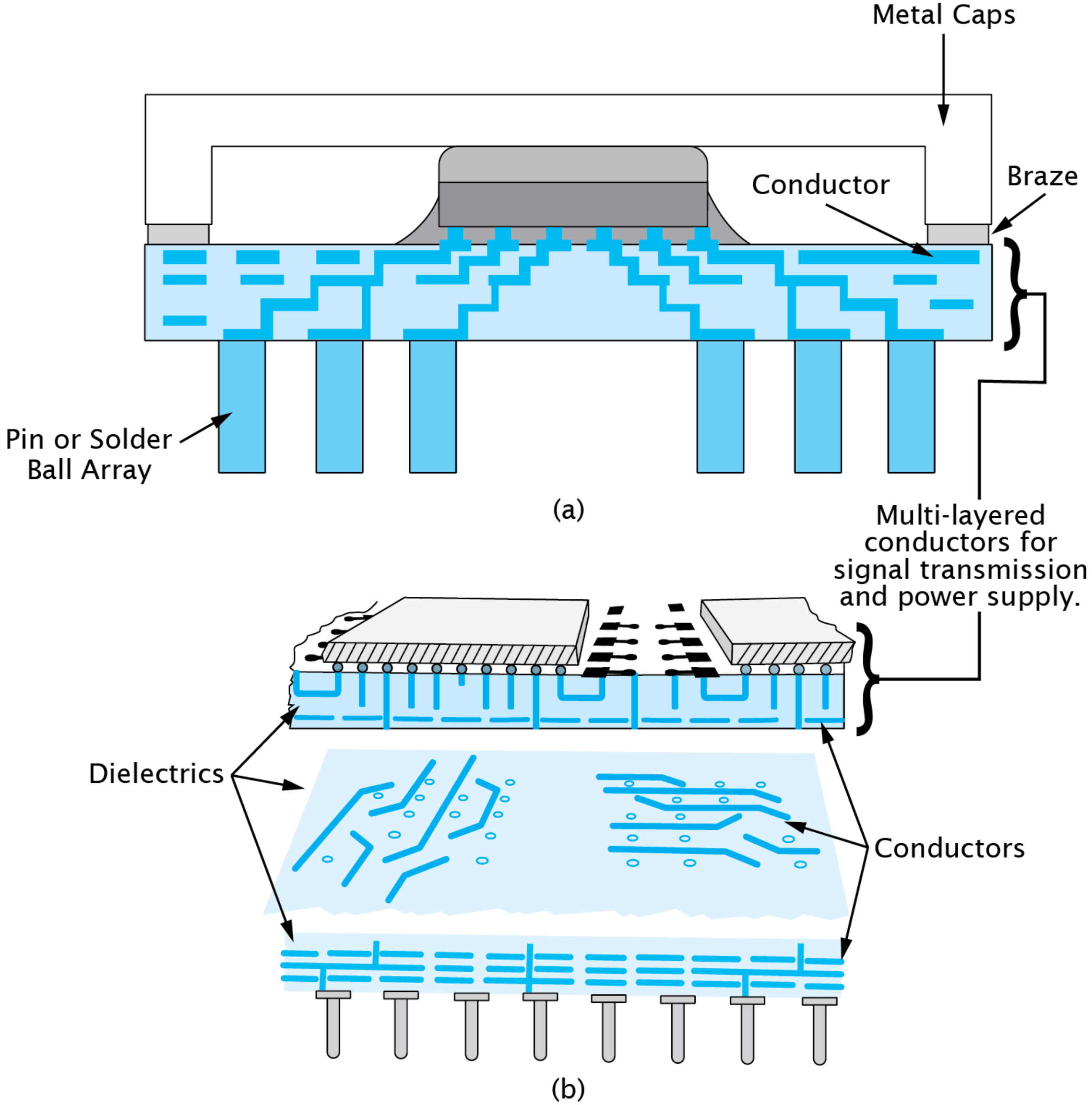
Substrate Materials

- Package substrates are the foundation of electronic packaging
  - Semiconductors
    - Silicon
  - Insulating substrates
    - Aluminum oxide, glass or organic laminates (FR4 or BT)
  - Metallic substrates
    - Copper, Aluminum, Kovar
- Substrate technology has evolved from low density thick film wiring with low I/O to high density thin film wiring with high I/O, to form single chip, multi-chip or functional modules.
- Main drivers for substrates
  - Number of wiring layers with signal integrity, efficient power distribution and heat transfer.
- Key today is to produce smaller and smaller traces with microvias with improved tolerances.

Substrate Materials

	Function	Typical Material	Important Properties
	Core		
1	Ceramic	• Alumina • LTCC	• Coefficient of Thermal Expansion (CTE) • Glass Transition Temperature • Young's Modulus • Surface Smoothness • Dielectric constant and Loss • Thermal Conductivity
2	Organic	• FR-4 • BT	
3	Silicon	• Si	
4	Glass	• Glass	
	Wiring Layers		
1	Dielectric	• Ceramics • Polymers	• Dielectric Loss • Dielectric Constant • Resistivity • Interfacial Adhesion
2	Conductor	• Copper • Silver • Silver-Palladium	• Electrical Conductivity

Ceramic Substrate Applications

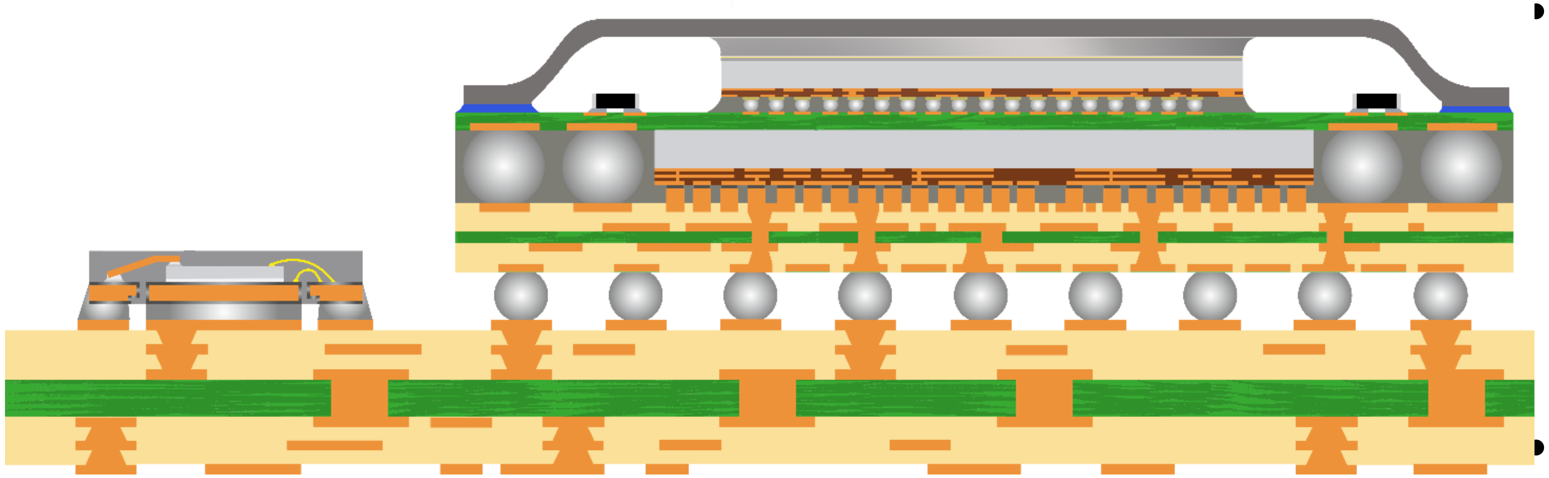


Single chip and multichip

Advantages of Ceramic Substrates

- Properties
  - High Temperature Stability
  - Low Electrical Loss
  - Low-Med Dielectric Constant
  - High Modulus
  - Low CTE
  - High Resistivity
  - High Insulation Strength
- Suited for High Temp, High Power Applications
  - Computing
  - Automotive
  - RF

Organic Substrate Applications



Advantages of Organic Substrates

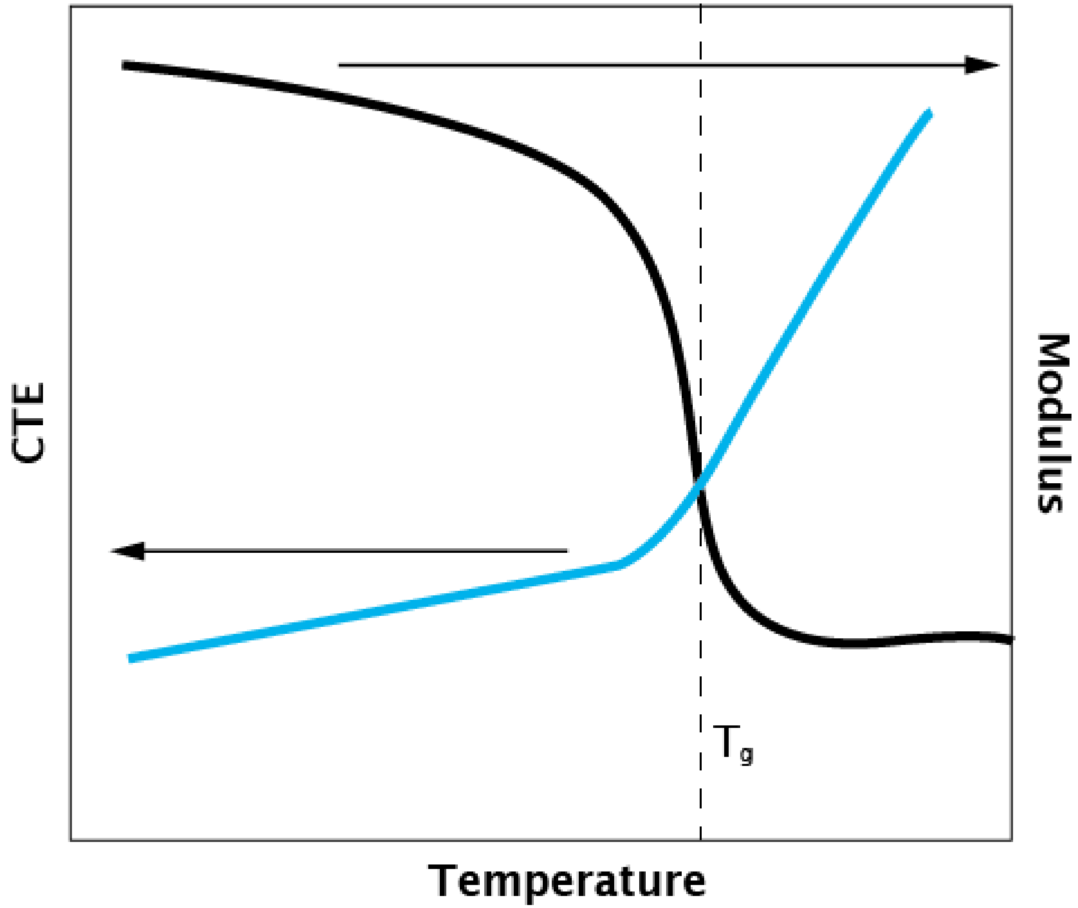
- E.g. FR4 and BT Laminates
- Properties of BT Laminates
  - High Thermal Stability
  - High Tg
  - Low Dielectric Constant
  - Low Loss
  - Good Insulation Properties
- Suited for High Volume Applications
  - ASICS for Telecom
  - Gaming and Graphics
  - Automotive

Source: MacDermid Alpha

Desirable Properties of Substrate Materials

- Core:
  - Stiff with high modulus to prevent warpage
  - Capable of forming micro-vias with high throughput
  - CTE matched as much as possible with other layers of the stack
- Dielectric:
  - Appropriate dielectric constant
  - Low modulus
  - High elongation to failure
- Conductors:
  - High conductivity / Low resistivity
  - Good adhesion

Glass Transition Temperature (Tg)



Glass Transition Temp

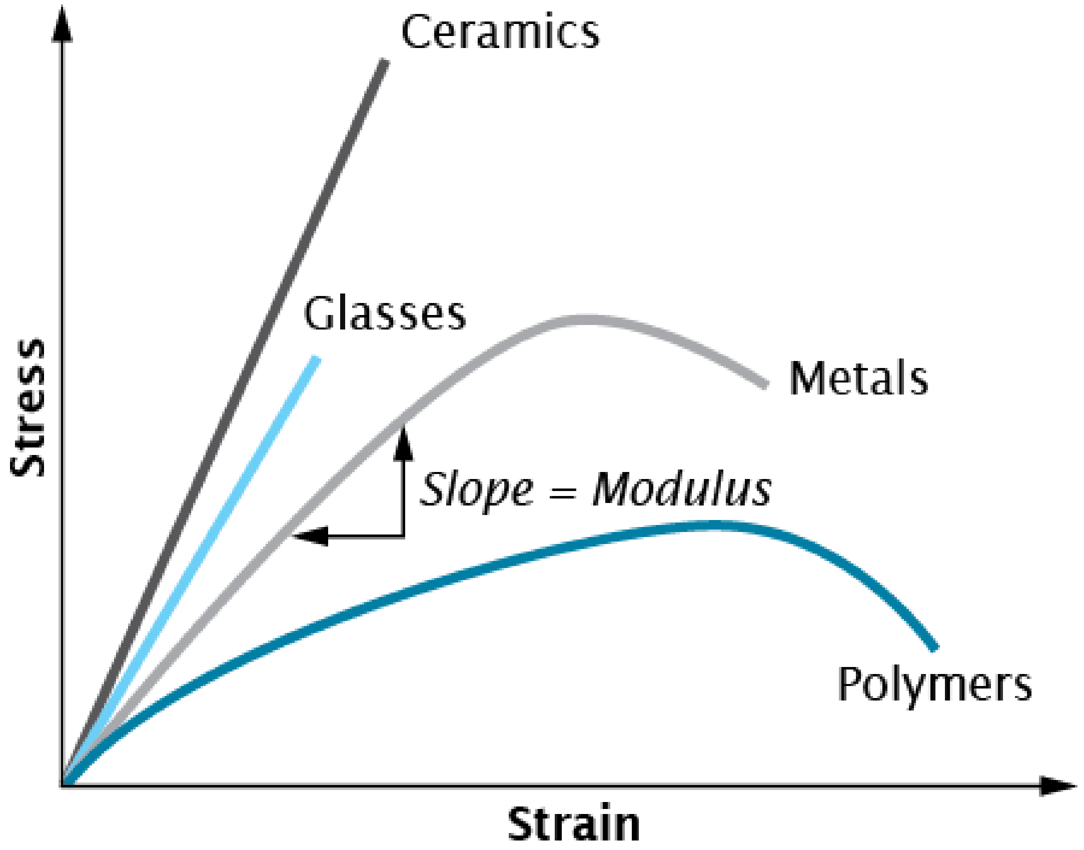
- Importance of Glass Transition Temperature (Tg)
- Defined as transition temperature of an amorphous material from a brittle state to a rubbery state.
- Crystalline materials undergo this transition only at melting point.
- CTE increases dramatically and modulus reduces beyond Tg.
- High Tg polymers help increase thermo-mechanical reliability of the package.
- Tg can be engineered through proper materials selection and chemistry.

Coefficient of Thermal Expansion (CTE)

Material	CTE ppm/C
Si Substrate	2.6
Filled Organic Dielectrics	30-45
Alumina Substrate	7
LTCC Substrate	3.5
PCB / Organic Laminates	17-21
Underfill (Unfilled)	>50 below Tg
Underfill (Filled)	30 below Tg

- Importance of CTE
- CTE (Coefficient of Thermal Expansion) : Dimensional change that occurs per unit rise in temperature per unit length.
- CTE is low for ceramics but higher for polymeric materials.
- For polymers, CTE rises rapidly above Tg.
- CTE engineering of the materials stack in package is critical for reliability of the package in use.

Modulus



Stress-strain behavior of materials

- Importance of Modulus
- Young's Modulus is the stress to generate a unit strain in a material.
- Stress-Strain curve is generally linear until a critical stress is reached after which plasticity results.
- If CTE mismatch exists between various layers of the package stack, a low modulus layer, such as a low modulus dielectric, can help enhance the thermo-mechanical reliability of the package.

Dielectrics

- Key Properties Required
  - Low loss
  - Low dielectric constant to desired GHz frequencies
  - Engineered CTE values (typically between that of Si and Board)
  - High strength
  - Low moisture absorption
  - Stability at operating temperature
  - No outgassing
  - Wide processing window below degradation temperature of all other materials in the package.
  - Good adhesion to substrate and metal interconnections.
  - Low moisture uptake.
  - Ability to produce micro-vias.

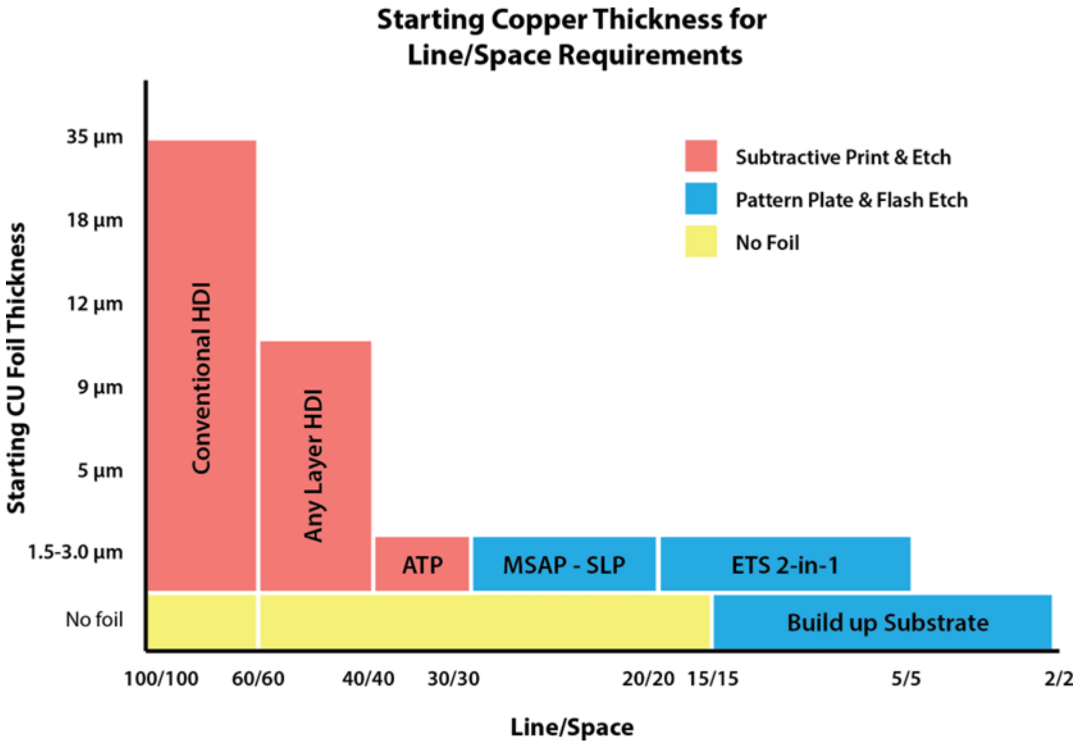
Dielectrics, Microvia Processes and Properties

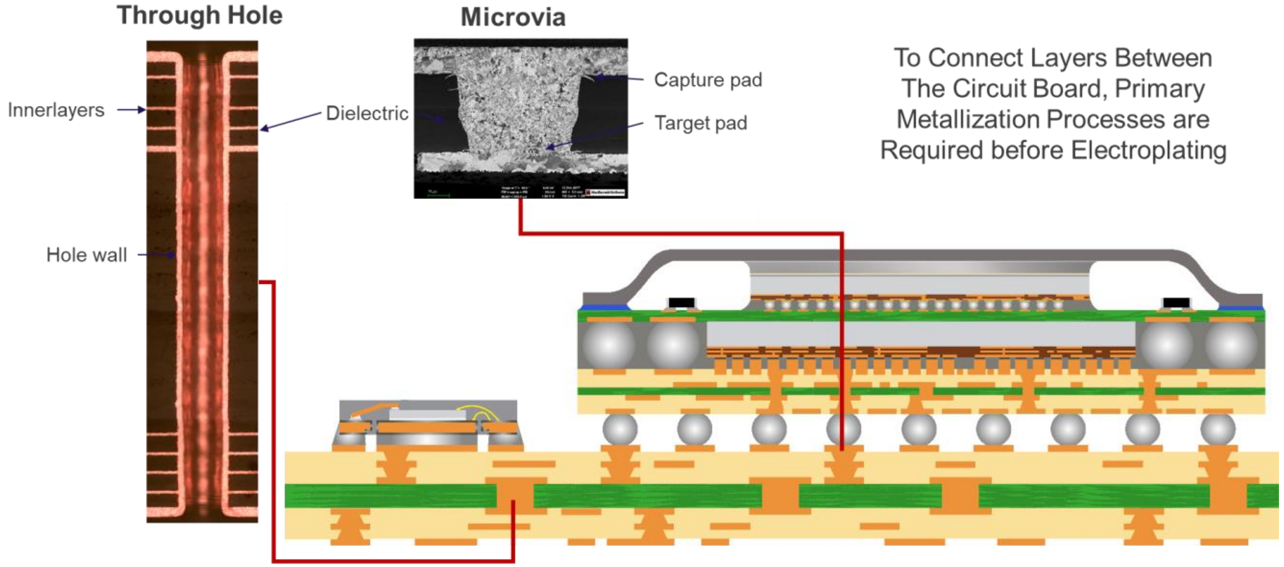
Dielectric Material	Dielectric Constant @1GHz	Loss Tangent @1GHz	Modulus GPa	X, Y, CTE ppm/C	Availability	Via Formation	Via Seed Metallization
Polyimide	2.9-4.0	0.002	2.5-9.5	3-20	Film, Liquid	Excimer Laser, Photo	Sputter Seed
BCB	2.9	<0.001	2.9	45-52	Liquid	Photo, RIE	Sputter Seed
LCP	2.8	0.002	2.25	17	Laminate	UV Laser, Mech. Drill	Electroless Copper
PPE	2.9	0.005	3.4	16	RCC	UV, CO2, Laser	Electroless Copper
Polynornornene	2.6	0.001	0.5-1	83	Liquid	Photo, RIE	Sputter Seed
Epoxy	3.5-4.0	0.02-0.03	1-5	40-70	Film, RCC, Liquid	UV, CO2, Laser, Photo	Electroless Copper

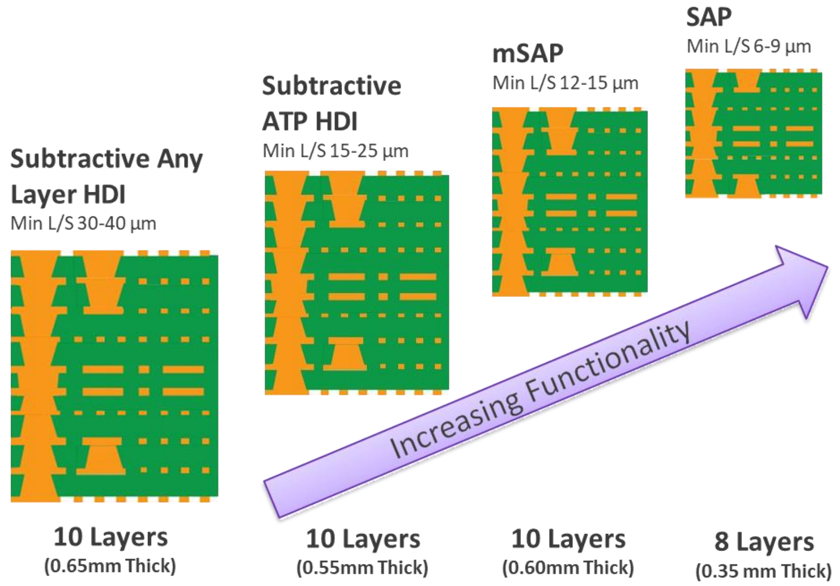
Note: Advanced carbon-based direct metallization is used for primary metallization processes, replacing electroless copper

Conductors

- Key Properties Required
  - High conductivity
  - Excellent adhesion to the dielectric and via surfaces.
  - Fine line capable processes







Source: MacDermid Alpha

Interfacial Adhesion

- Interfacial adhesion is a key property for reliability.
  - Adhesion between dielectrics to copper and dielectric to substrate
  - Adhesion mechanisms – physical bonding and chemical bonding
  - Chemical bonding – ionic or covalent bonds
  - Physical bonding – mechanical interlocking, physical adsorption, weak Van der Waals bonding.
  - Adhesion enhancement techniques:
    - Plasma cleaning of surfaces enhances adhesion – helps both physical and chemical bonding.
    - Coupling agents (functional compounds based on Si, Zr, Ti) help “couple” inorganic substrates to polymers.
    - Surface roughening mechanisms.
    - Using lower modulus resins to be adhered.

Interconnection and Assembly Materials

- Two categories of interconnections
  - Single or multiple wiring layers in or on the substrate, leading to I/O pads or bumps.
  - Solder or other interconnection joints between substrates and chips.
- Wiring interconnections
  - Wiring interconnections – conductors and dielectrics
  - Copper is most common conductor (high conductivity and processability)
  - Dielectrics-ceramics, polymers, glasses, to prevent migration of ions.
- Die-to-Substrate interconnections
  - Wire bonding with Al, Cu or Au wires
  - Flip chip bumps (high lead solder, SnAg solder, gold or copper pillar)
  - Advanced solders, conductive adhesives
  - Sintered die attach

Key Interconnection Materials

<table>
<tr><th>Function</th><th>Typical Interconnection Materials</th><th>Important Properties</th></tr>
<tr><td>Solders
Metals</td><td>• SnPb, Pb Free
• Al, Cu, Au</td><td rowspan="4">• Electromigration resistance
• Electrical Conductivity
• Fatigue resistance
• Moisture absorption
• CTE
• Modulus</td></tr>
<tr><td>Conductive Adhesives</td><td>• Epoxy-Ag composites</td></tr>
<tr><td>Nanomaterials for Interconnects</td><td>• Sintered Ag materials
• CNT interconnects</td></tr>
<tr><td>Underfills</td><td>• Silica-filled polymers</td></tr>
</table>

Solder Based Interconnects and Alternatives

- High Pb solders have historically been most commonly used. Alternatives are AuSn.
- High Pb solders are being replaced by alternatives such as SnCu and SnAg.
- Manufacturability, cost, ductility, fatigue performance and electromigration resistance are key criteria for selection.
- Transient Liquid Phase Bonding and Ag Sintering are alternatives. Cu Sintering is also emerging.
- Ag Sintering has been implemented at scale for power electronics (especially SiC attach) and some ultra-high power LED applications.

Lead Free Solders and Their Melting Points

Alloy	Melting Point
Sn96.5/Ag3.5	221C
Sn99.3/Cu0.7	227C
Sn/Ag/Cu	217C (Ternary Eutectic)
Sn/Ag/Cu/X (Sb…)	Ranging according to composition above 210C
Sn/Ag/Bi	Ranging according to composition
Sn95/Sb5	232-240C
Sn91/Zn9	199C
Sn42/Bi58	138C
Sn/Pb (comparison)	183C

Conductive Adhesives

- Low modulus compliant organic conductive adhesives
- Polymers filled with silver flakes.
- Percolation theory dictates % of Ag content to form continuous conductive paths.
- Percolation threshold is the point at which particles start to form continuous conductive pathway.
- Depending on % and orientation of conductive particles, adhesives can be non-conductive, anisotropic or isotropic.
- Volume fraction of conductive particles at percolation depends on form and size of conductive particles, but is typically in the 15-25% range.

Nanomaterials for Interconnections

- For sub-100 micron pitches, and ultra-high thermal load (e.g. power electronics) applications, solders impose process, electrical and thermal performance and reliability limitations.
- Key technology platforms
  - Plated copper to enable solder-free Cu-Cu bonding, using Thermo-Compression Bonding (copper pillar bumping) and nano-twinned plated copper to enable hybrid bonding in heterogeneous integration.
  - Sintered Ag technology using temperature and pressure process for very high power SiC based power electronics.
- Both these technology platforms utilize solid state diffusion technology using temperature and pressure.
- Solid state diffusion is accelerated in nanomaterials due to their high surface energy.

Interconnection Properties

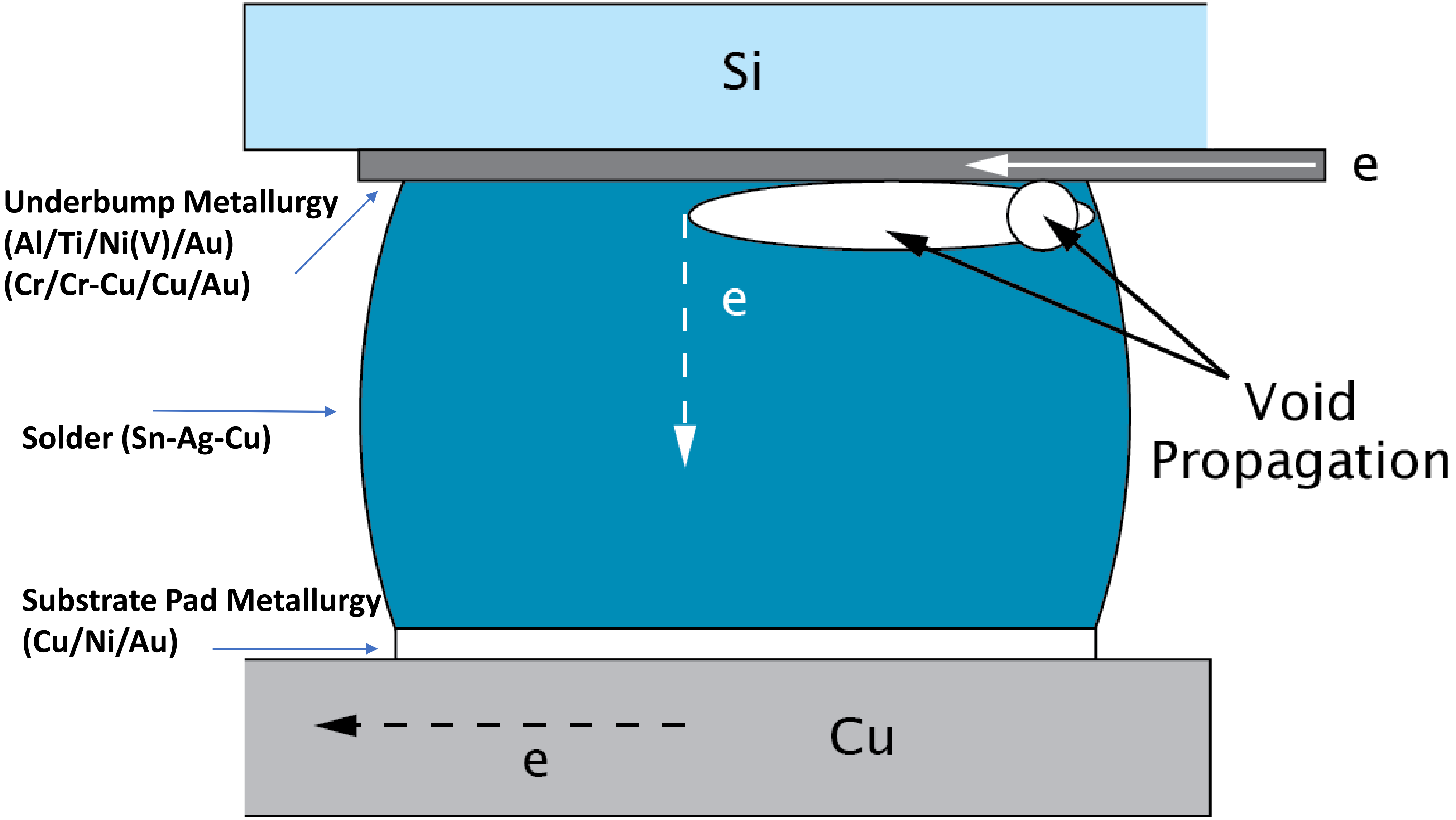
- Electrical conductivity
  - When an electric field is applied to a conductor, the electrons drift towards the positive potential, resulting in a current.
  - Electrical conductivity is the ratio of current density and the applied electric field.
  - Electrical conductivity depends on the material and temperature.
  - Generally independent of applied voltage and current results from electronic and ionic conduction.
- $J = \sigma E$
  - J = Current Density (A/m2)
  - σ = Electrical Conductivity (1/(Ohm-m))
  - E = Electric Field (V/m)

Interconnection Properties

- Electromigration
  - Electromigration happens through diffusion under an electric driving force, where atoms are displaced within a conductor due to an applied electric current.
  - This causes increased accumulation at the anode end, causing short circuits while vacancies occur at the cathode end because of atomic depletion, causing open circuits, and crack initiation and propagation.

- $J = C\mu F$
  - J = Atomic Flux (net atoms per unit area)
  - C = Free Electronic Concentration
  - μ = Mobility of Atoms
  - F = Driving Force directly related to the Electric Applied Field (E)

Electromigration



Electromigration

Underfills

- Role of Underfills
  - Role of underfills is to redistribute and thus reduce mechanical stress in solder balls and high K dielectrics.
  - A large CTE mismatch between the package substrate and the chip induces significant stresses that cause failure in the solder joints. This stress increases with chip size and power density.
  - Underfills such as epoxy mechanically couple the IC and the substrate, reducing the strain on the solder.
  - By adhering to all surfaces under the die, the underfill redistributes the load across the die area, and reduces the effective load on the solder bumps.
  - Underfill also keeps solder bump in hydrostatic compression, holding it intact under strain.
  - An underfill with low CTE similar to solder and between that of Si and the substrate is desirable. Various filler types can be used.

Underfills

- Underfills are typically composites of polymers such as epoxy, cyanate ester, silicone and urethane, with inorganic fillers.

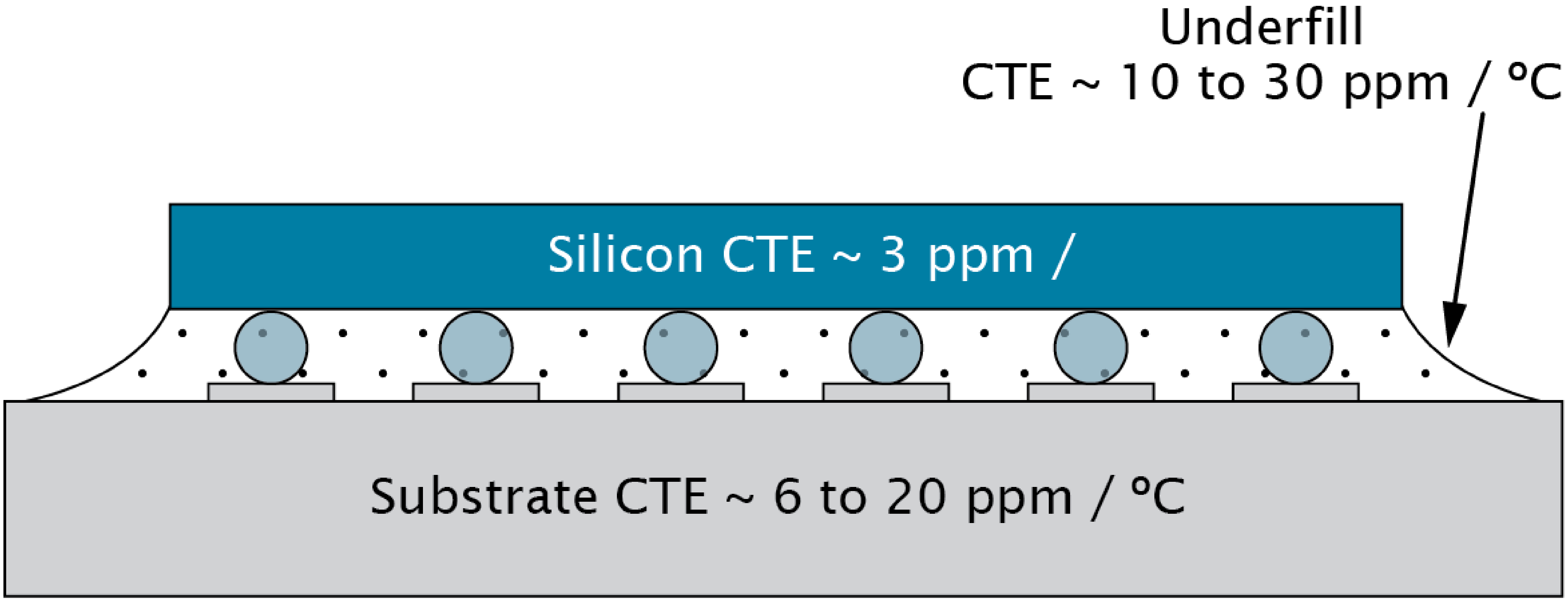
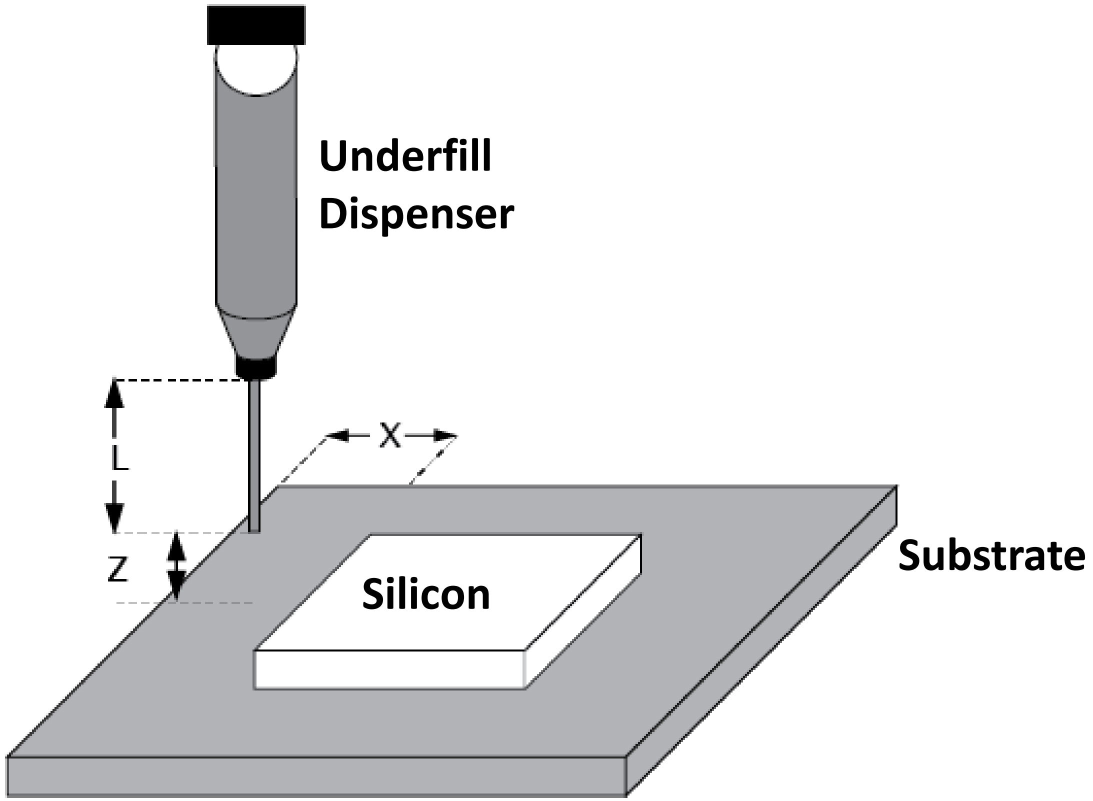
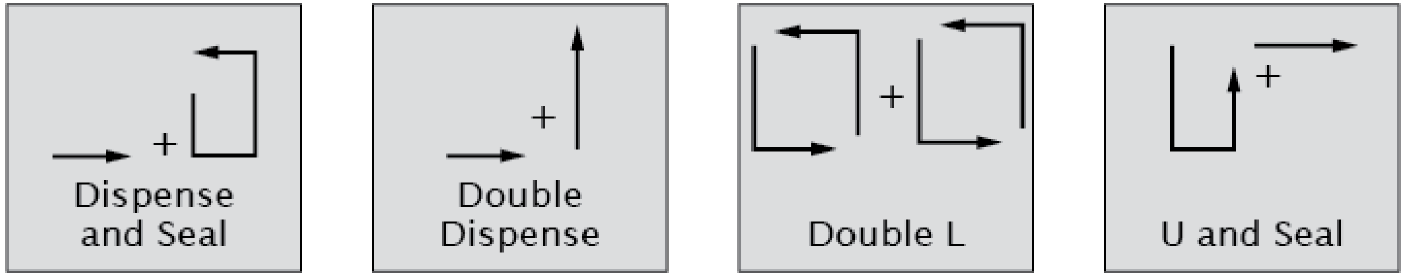


Illustration of underfill between IC

Underfill Process – Capillary Underfill

- Assembled devices placed on temperature controlled stage at 70-100C
- Underfill dispensed from a syringe barrel with needle.
- Screw and linear displacement pumps used.
- Various dispense patterns can be applied.
- Underfill with lowest viscosity, highest surface tension and smallest wetting angle is the material of choice for a given die-substrate gap and die size.





Underfill Dispensing

Key Underfill Requirements

- Key Properties
  - CTE
  - Modulus
  - Adhesion
  - Viscosity
- Key Requirements
  - High Modulus (5-10 Gpa)
  - Mid-range Tg (approx. 150C)
  - Low CTE (target < 25 ppm/C)
  - Low cure temperature
  - Low cure shrinkage (stress control)
  - >1% elongation at break
  - Tailored rheology – application-specific
  - High flow speed
  - Good wetting and adhesion to chip and substrate surfaces.

Passive Component Materials

- Passive Components
  - Electrical components that do not require additional signal or power besides their input or output, for their basic function.
  - Passive components sense, monitor, transfer, attenuate and control voltage in an electrical system.
  - E.g. Two terminal devices such as capacitors, resistors and inductors, that form the building blocks for various digital, RF, and mixed signals functions.
  - Passives take up almost 50% of the area of an electronic system board. Influence the size, cost and reliability of the system.

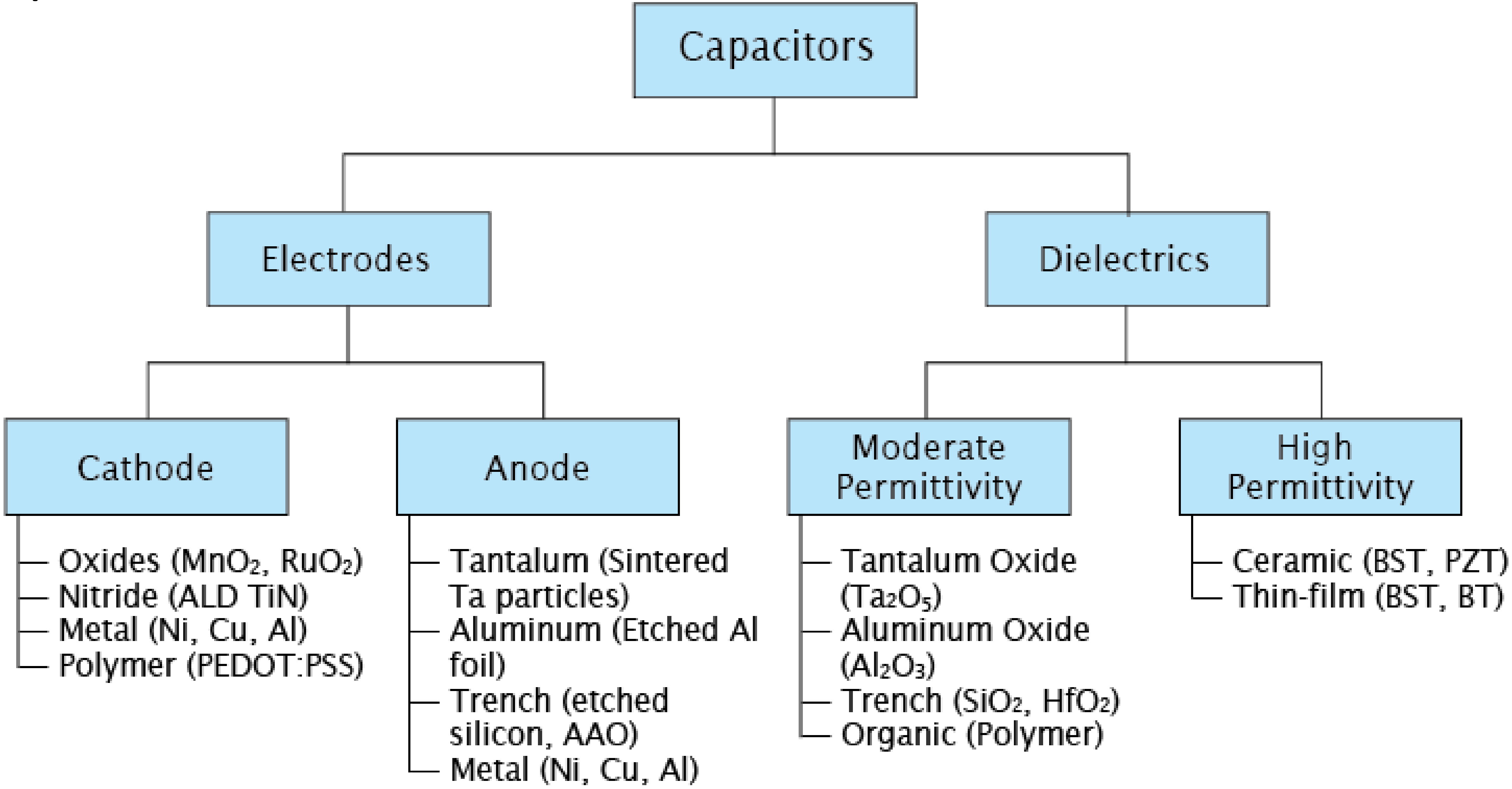
Passive Component Materials, Functions, Properties

Function	Typical Material	Important Properties
Capacitors • Dielectric • Electrodes	• BaTiO3, BST, Ta2O5 • Ni, Al, Ta, Pd • PEDOT:PSS, MnO2	• Electrical conductivity • Dielectric permittivity, Moderate and High • Self healing
Inductors • Magnetic Core • Metal Traces	• Ferrites • Metal-Polymer composite • Cu	• Inductance • Magnetic permeability • Magnetic loss
Resistors	• NiCr, NiCrAlSi, CrSi	• Temperature coefficient of resistance (TCR)

Capacitor Materials

- Typical role of capacitor materials is to store electrical charge and supply it to offset peak current demands.
- Simple form- two metal plates separated y an insulator/dielectric
- Range from few picofarads to 100s of millifarads, with applications such as decoupling switching noise suppression, bypass filtering, ac/dc converters, signal termination.
- Capacitance in Farads (Coulombs/Volt) is given by
  - Capacitance= Charge stored in a material / applied voltage ($C0=Q/V$)
  - Q is the charge in Coulombs, V is potential difference between conductors
- Dielectric Constant = Flux Density in the Material/Flux Density in Vacuum
- Dielectric Constant = Relative Permittivity
- Relative Permittivity = Capacitance of a Material / Capacitance of Vacuum

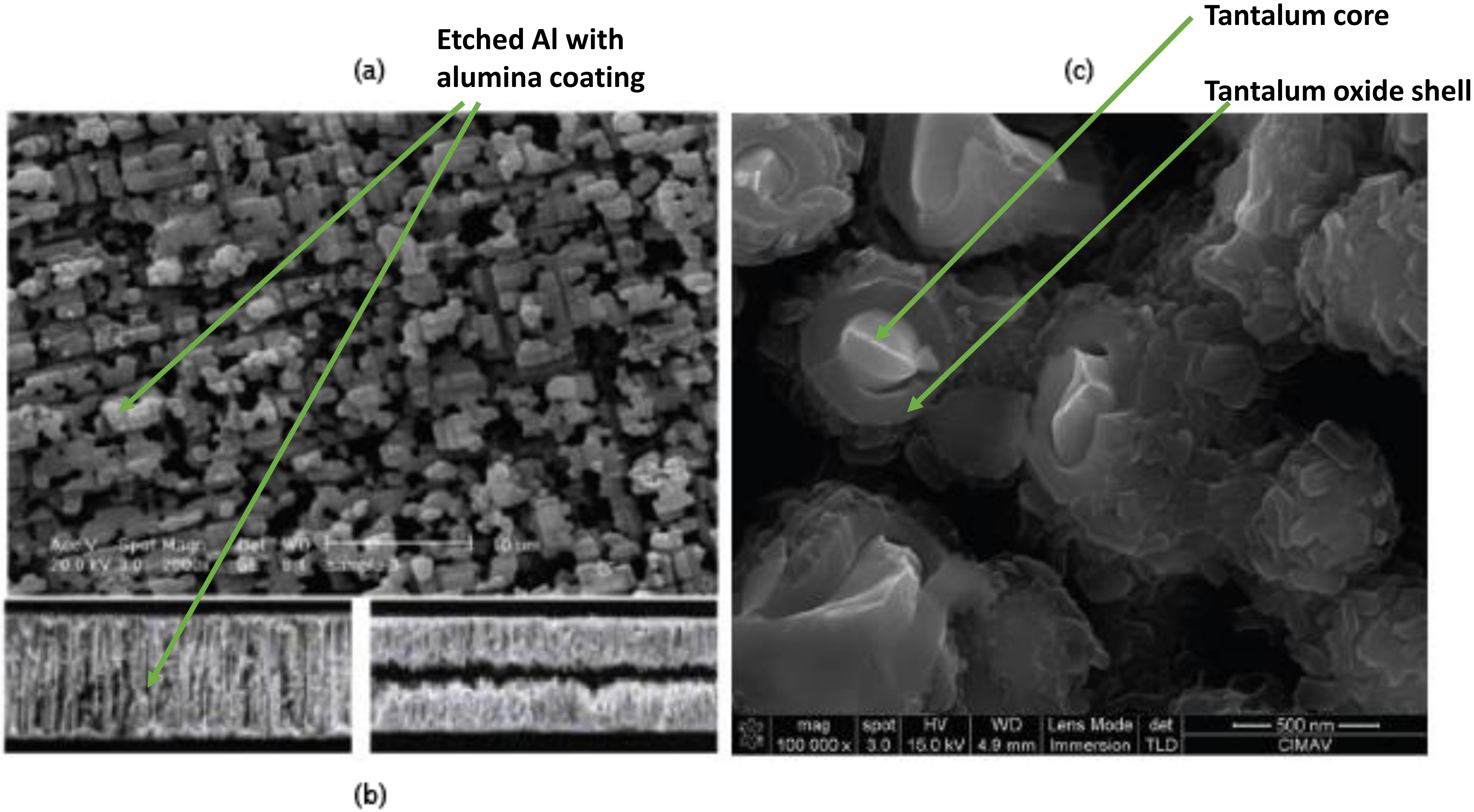
Capacitor Materials



Capacitor materials and their roles

Moderate Permittivity Dielectrics for Capacitors

- Metals that for stable, passivating oxide layers when they come in contact with air (valve metals): Al, Ta, Ti, Si, Nb, Zr, Hf, W.
- Al2O3 and Ta2O5 show very good dielectric properties.
- Valve metal oxides (e.g. Al2O3, Ta2O5) are formed via anodization.
- Application of positive voltage to anode in an electrolytic bath. Insulating oxide layer is formed.
- Relative Permittivity of Al2O3 is 9 and Relative Permittivity of Ta2O5 is 25
- Capacitance is enhanced by high surface area anodes, via chemically etched Al foils and sintered nanoporous Ta, conformally coated with their oxides.
- Metal-Insulator-Metal layer stacks for trench capacitor technology formed by Reactive Ion Etching (RIE) of Si and Atomic Layer Deposition (ALD)of dielectrics and electrodes.



SEM images of alumina on etched Al and Ta/Ta2O5 core shell particles

High Permittivity Dielectrics for Capacitors

- Perovskites such as Barium Titanate (BT), Barium Strontium Titanate (BST) and Lead Zirconium Titanate (PZT) have permittivity >1000 and are the most common dielectrics used in MLCC capacitors.
- MLCCs have the highest market share in the capacitor market due to high reliability and low cost.
- MLCCs fabricated by casting ceramics in a slurry form in green tapes, applying electrodes by screen printing of metal powders, stacking these sheets, cutting, de-binding and firing / sintering at high temperatures.
- Conventional MLCCs based on BaTiO3 have heat treatments in the 1300C range.
- High K dielectrics can be fired below 1100C by addition of BaO-ZnO-B2O3-SiO2 glass components with Ni base metal electrodes. Permittivities ~ 15,000.

Inductor Materials

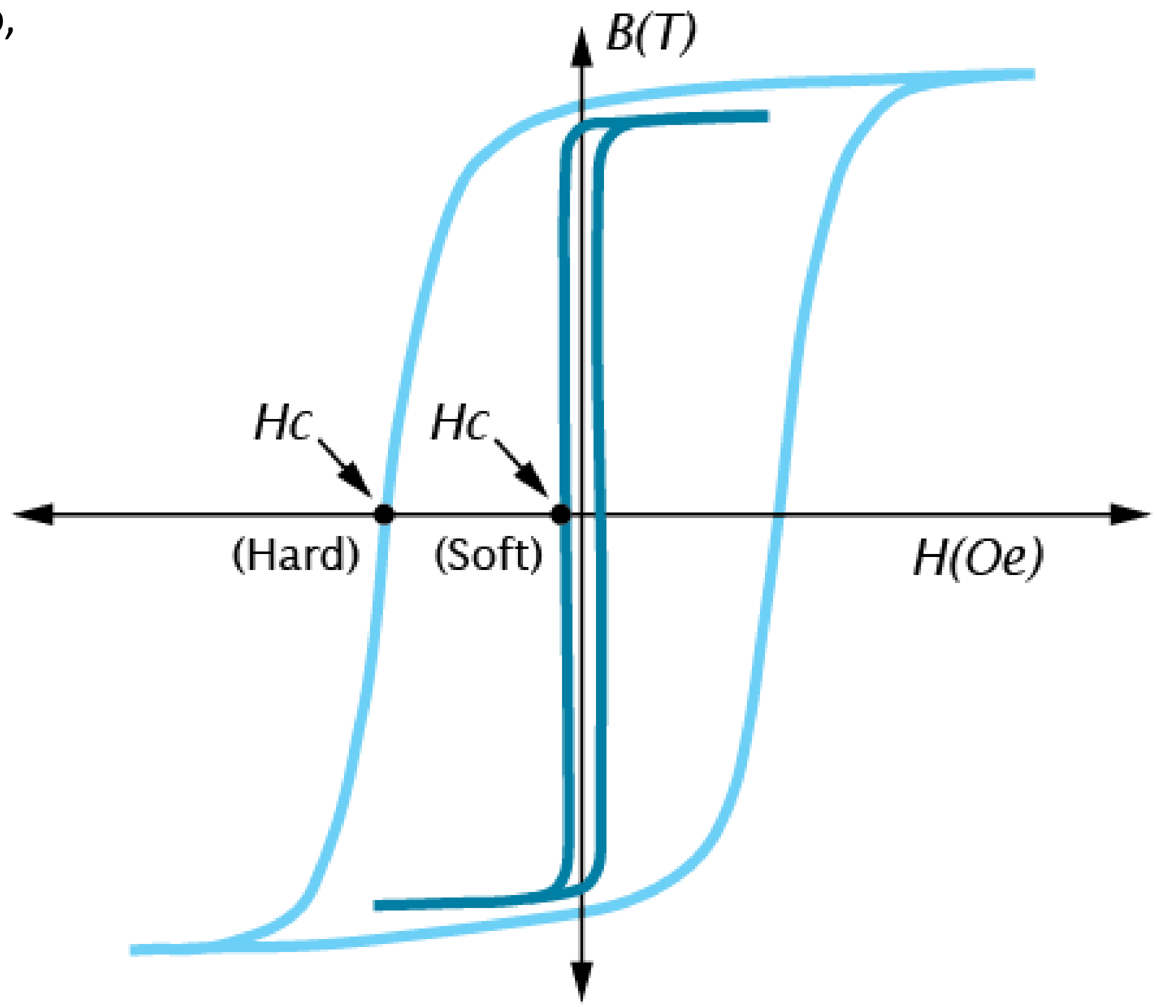
- Inductor is a passive two-terminal electrical component that stores electrical energy in a magnetic field when electric current flows through it. Inductors introduce inductance in a circuit.
- Inductance is the ratio of voltage to the rate of change of electric current.
- Inductors have a core material with coils wound around it.
- The inductor magnetic core multiplies the inductance by the permeability of the core material by increasing the magnetic flux, or by winding a coil with a large number of turns around the core.
- Magnetic materials used for inductor cores have relative permeabilities of 10 to 10,000. Examples of core material include silicon steel, iron powder and ferrites.
- Hard magnets resist demagnetization, while soft magnets do not retain significant magnetism after the field is removed.

Inductor Materials-Hard and Soft Magnet Behavior

Hard magnets include ALNICO, PtCo, NdFeB, CrO2, etc.
Ferrites are the most common soft magnetic materials.

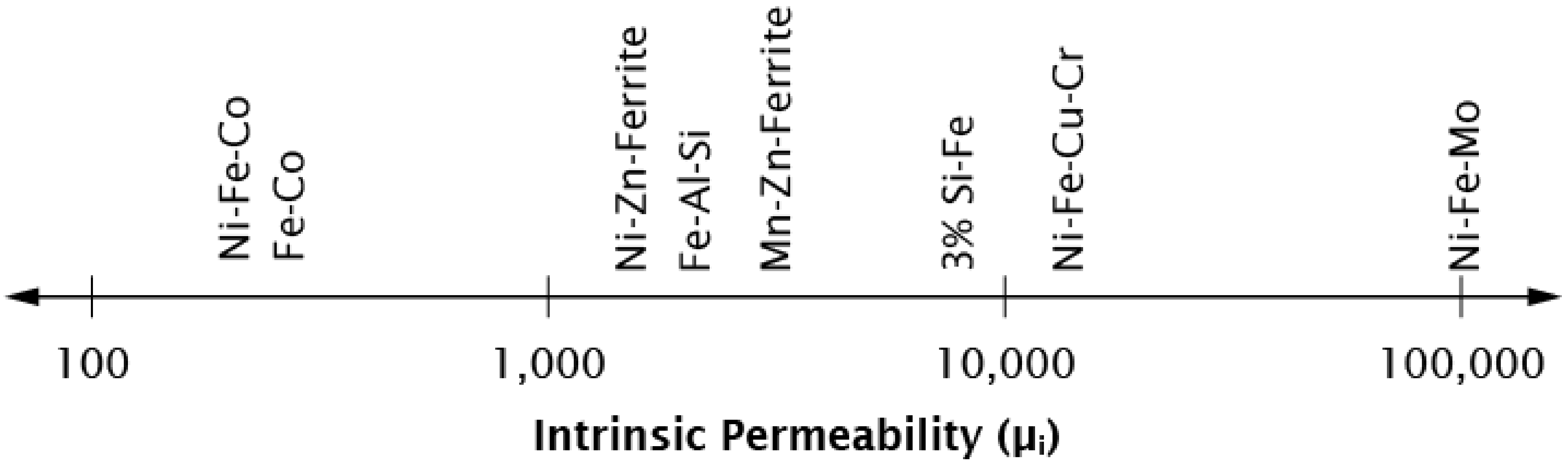
Magnetic Field Strength H (A/m)

Magnetic Flux Density B (Tesla)



Hysteresis curves

Inductor Materials-Typical Magnetic Permeability



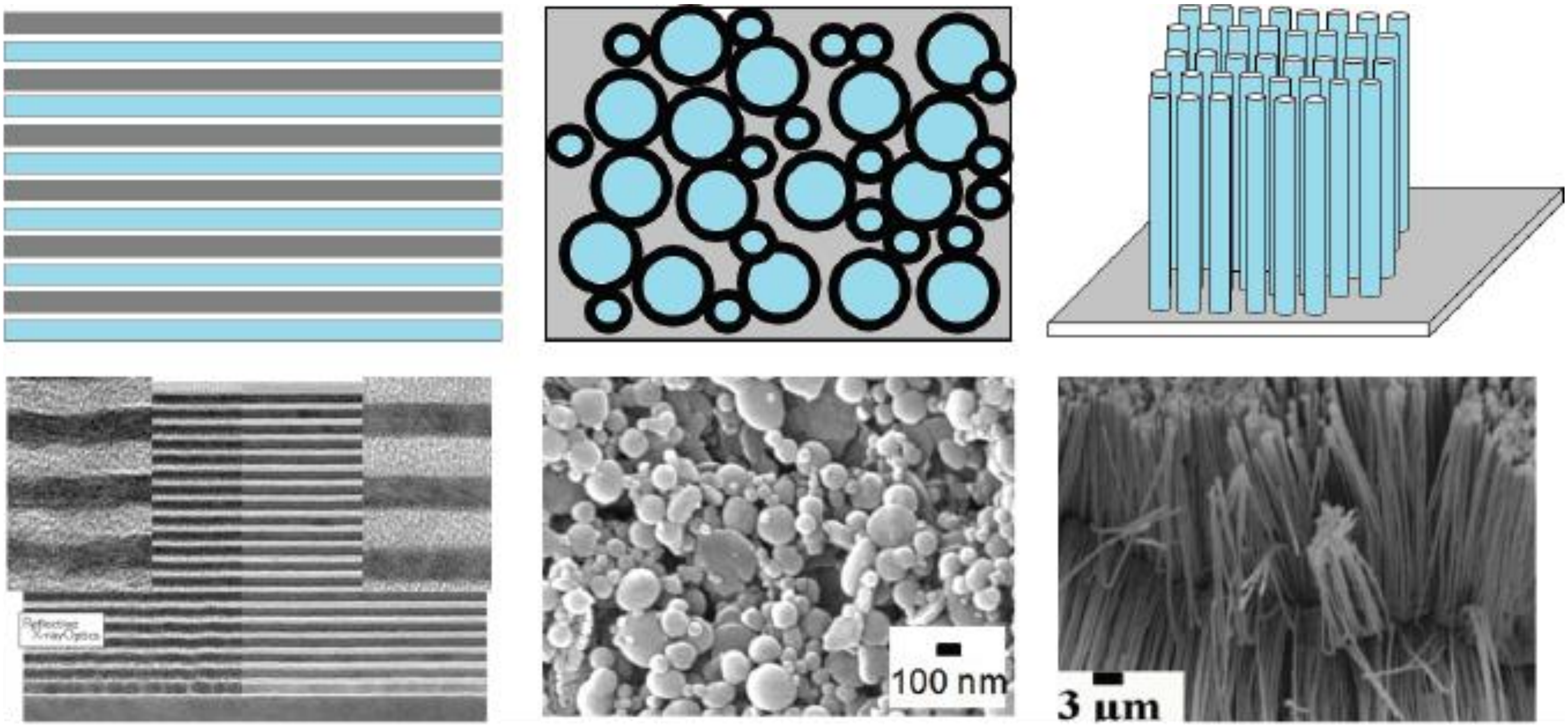
Typical magnetic permeability of key ferromagnetic materials

Permeability is sensitive to geometry, structure and processing and can be different than listed above.

Inductor Materials-Magnetic Nanoparticles

- Nanomagnetic materials have desirable properties such as high saturation magnetization, low coercivity, low eddy current losses, and anisotropy.
- Enhances key parameters such as permeability, quality factor, frequency stability, improving performance for power and RF inductors.
- Reducing particle size to eliminate domain walls, and reducing inter-particle distance is key.
- Promising for applications requiring magnetic properties at higher frequencies.

Nanolayers (nanolaminate) **Nanoparticles** **Nanowires**



(a) (b) (c)

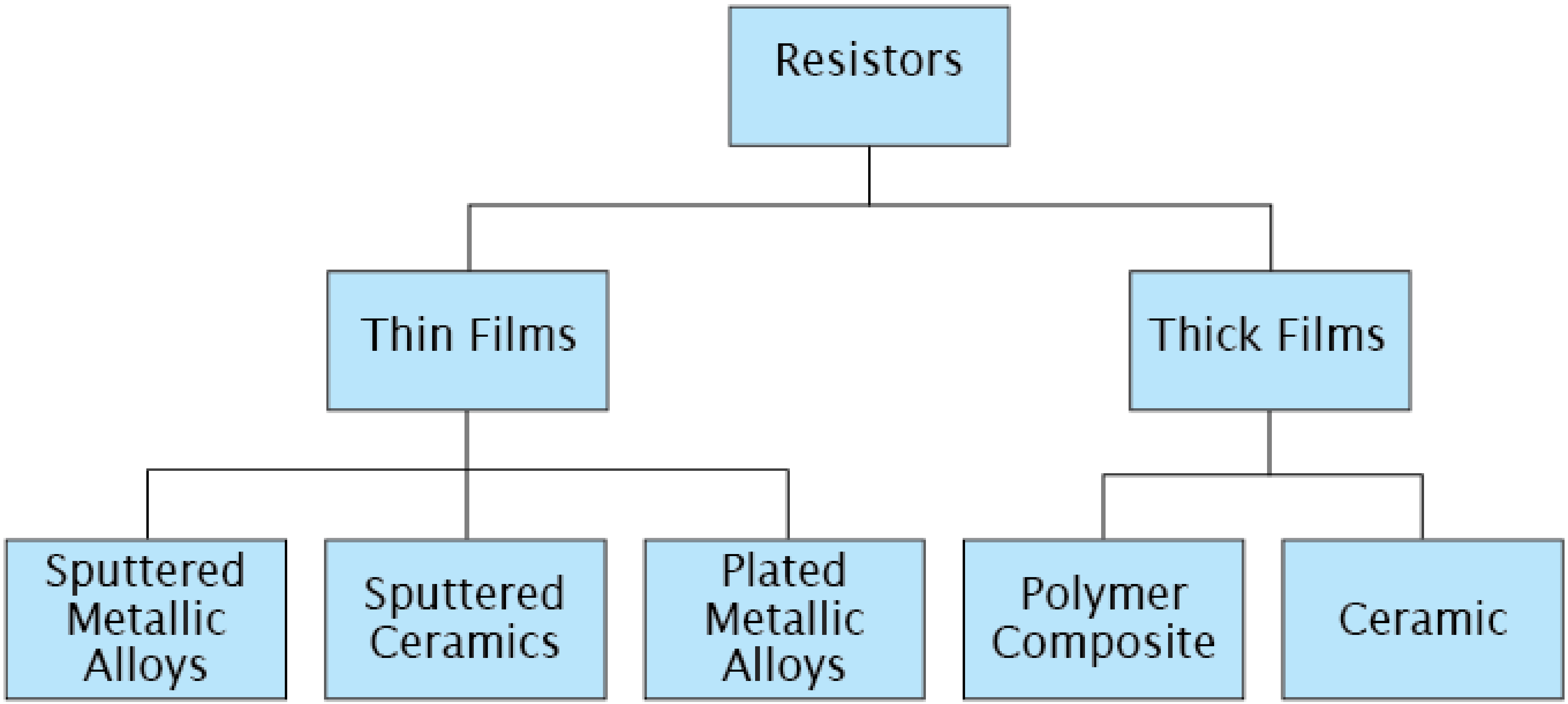
Magnetic structures

Resistor Materials

- Resistor is a two terminal passive component that offers opposition to electric current. Controls electric flow in an electrical circuit.
- In general, resistors absorb power from the circuit and convert it to heat.
- Two types of resistors: Fixed Value and Variable Resistors.
- Fixed Value: Resistances defined by geometry and materials properties. Cannot be varied during operation.
- Variable: Resistance can be adjusted by rheostatic, potentiometric mechanisms.
- Key equations:
  - $V=IR$ (V=voltage, I=current, R=resistance)
  - $R=\rho (L/A)$ (ρ = resistivity, L=length, A=cross sectional area)
  - $TCR = (1/R)(dR/dT)$ (TCR=Temperature Coefficient of Resistance).

Resistor Materials

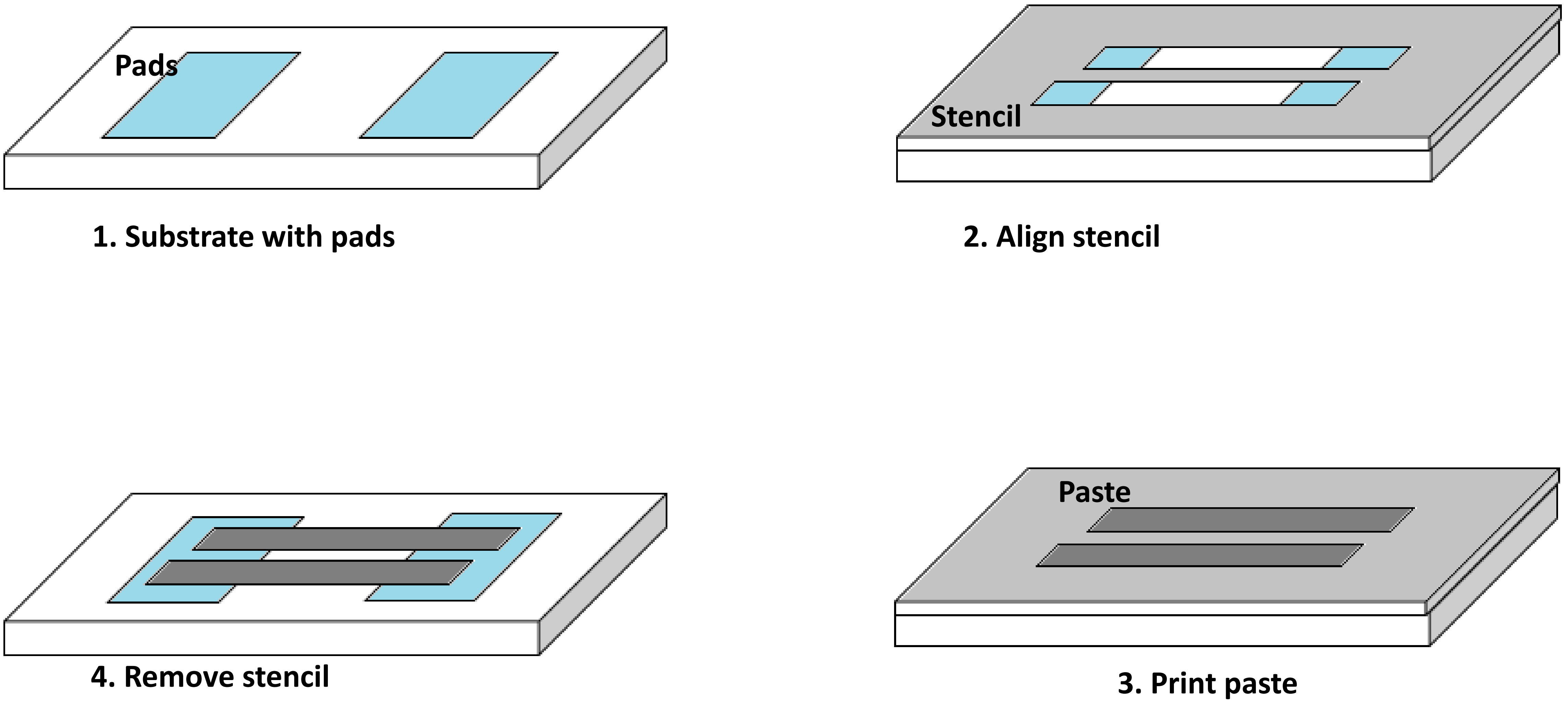
- Resistor materials include resistor metallic alloys, electrically conductive ceramics, ceramic-metal nano-composites, metal or carbon-filled polymers.
- Resistor processes are:
  - thick film (printing). Printing + Sintering or Curing. Additive process
  - thin film (sputtering or plating). Sputtering or Plating of layers few 1000 angstroms thick. Patterned with subtractive process.



Resistor classification

Resistor Materials

- Printed Thick Film Polymer Composite Resistors
  - Polymer Thick Films (metal or carbon-filled particles in liquid resin), targeted to achieve specific sheet resistance by changing particle volume fraction.
  - Wide range of resistances from 1 ohms/sq to 10^7 ohms/sq at relatively low cost.
  - Available in viscous liquid form that can be screen or stencil printed, with relatively low curing temperatures.
- Sputtered Metallic Alloy Resistors
  - Low resistance values NiCr, NiCrAlSi, CrSi, TaNx
  - NiCr and NiCrAlSi in foil form provide 25 – 250 ohms/sq.
- Sputtered Ceramic Thin Film Resistors
  - Ceramics such asTaNxOy 5 kohms/sq with TCR of +/- 100ppm/C.
  - High value resistances 100 kohms with cermets (ceramic metal nano-composites)
  - CrSiO can achieve up to 10 Mohm-cm with near zero TCR and good stability
- Plated Metallic Thin Film Resistors
  - Direct electroless plating with surface activation (palladium based)
  - Ni alloy deposits yield 10-1000 ohms/sq with thickness 2000-5000 Angstroms

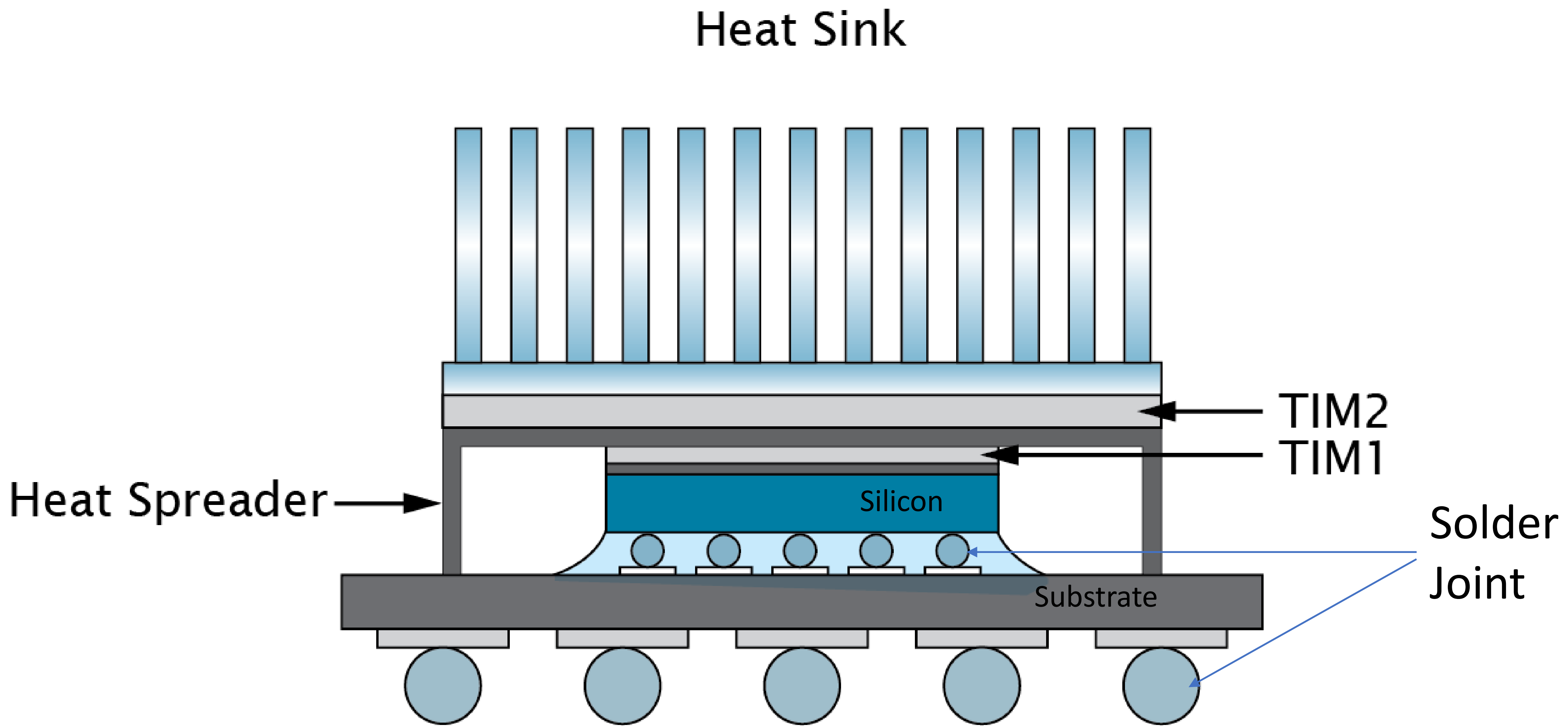


Stencil Printing – Thick Film Resistors

Thermal Management and Interface Materials

- Electronic devices generate heat which has to be conducted away to maintain device temperatures under control and prevent failures.
- Most electronic devices require power ranging from a few watts to a few 100 watts – generates large amount of heat.
- Elevated temperatures reduce the efficiency of processors and significantly degrade overall system performance.
- Effective thermal management is critical.
- Key materials are
  - Heat Sinks
  - Heat Spreaders
  - Thermal Interface Materials (TIMs).

Thermal Management Stack



Thermal Management Stack

Thermal and Interface Materials

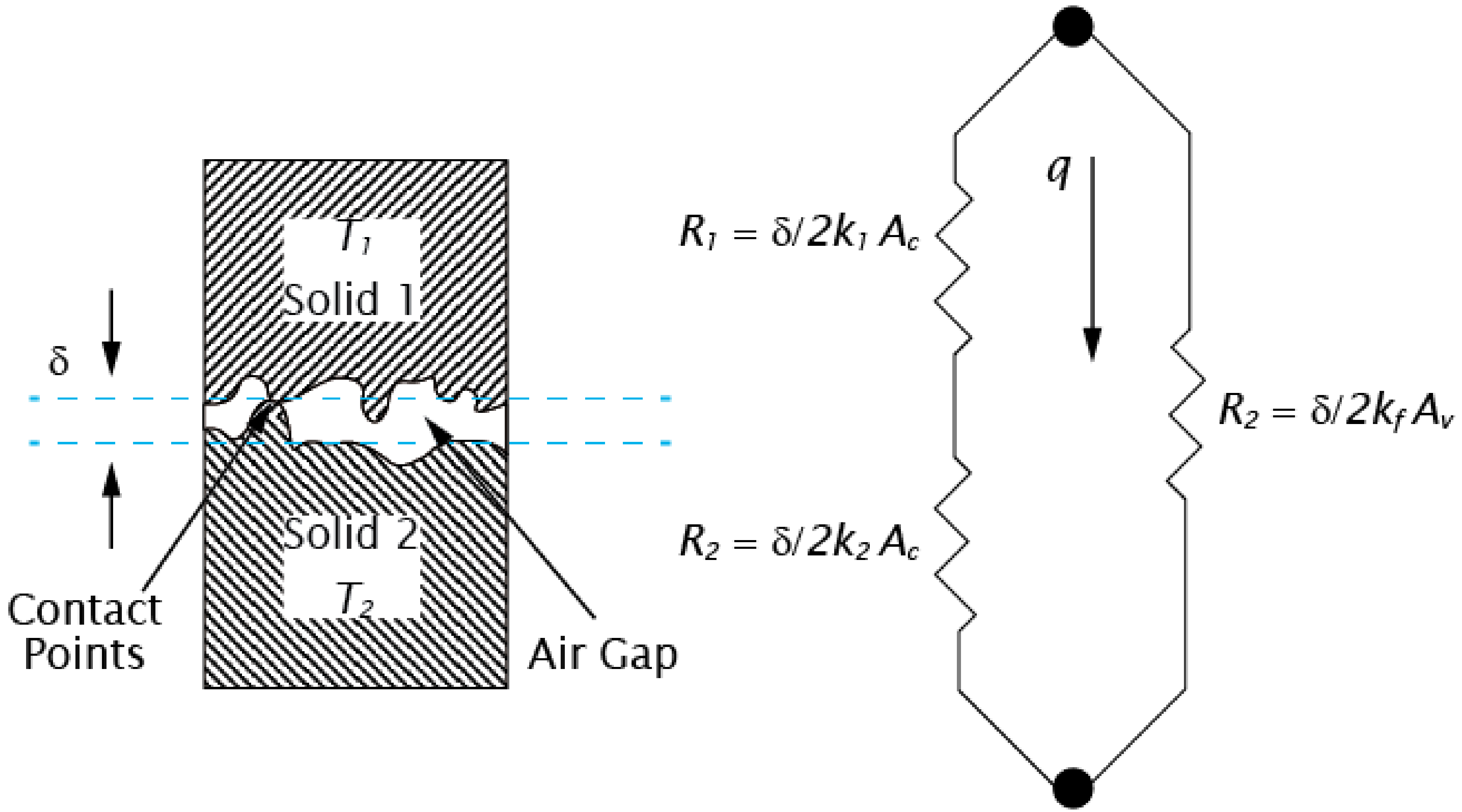
Function	Typical Material	Important Properties
Heat Spreader/Sink	Al, Cu	• Thermal conductivity • CTE • Thermal and Interface Resistances
Thermal Interface Materials	Thermal Grease, (ZnO, Ag, AlN in oil), Thermal Pads, CNT….	

- Heat Spreaders
  - Heat sinks mostly extruded. Usually aluminum. Increase in surface area provided by fins.
  - Increase in heat transfer area provides reduced convective thermal resistance.
- Thermal Interface Materials
  - Thermally conductive materials placed between two solid surfaces (heat generating surface (e.g. microprocessor) and heat dissipating surface such as heat spreader.
  - Applied as a thin layer, typical materials are filled polymers, solders, PCMs.

Thermal and Interface Materials

TIM	Characteristic Composition	Advantages	Disadvantages
Thermal Grease	Inorganic powders in oil (AlN, ZnO..)	• High thermal conductivity • Good conformity • Less delamination • High reworkability	• Pump out and phase separation in thermal cycling • Difficult thickness control
Thermal Gel	Carbon black, high conductivity metal oxide, metal powders in olefin, silicone oil.	• Easy application • Less susceptibility to pump out • Reworkability	• Curing required • Lower thermal conductivity • Low adhesion
Phase Change Material	Low melting point materials (e.g. wax, polyolefin) filled with high conducting inorganic salts (Al2O3, BN, AlN, ..), CNT, Graphene	• Curing not needed • Good surface conformity • Less susceptibility to pump out • No delamination or dryout • Reworkable • Easy handling	• Non-uniform BLT • Lower thermal conductivity than grease • Contact pressure required
PCMA	Low melting point metals and alloys (e.g. In, InAg…)	• High thermal conductivity • No curing required	• Intermetallics • Susceptibility to high temperature corrosion
Solders	Eutectic binary or ternary alloys	• High thermal conductivity • No curing required	• Reflow needed • Thermo-mechanical stress • Possibility of voids

Thermal Resistances and Heat Flow

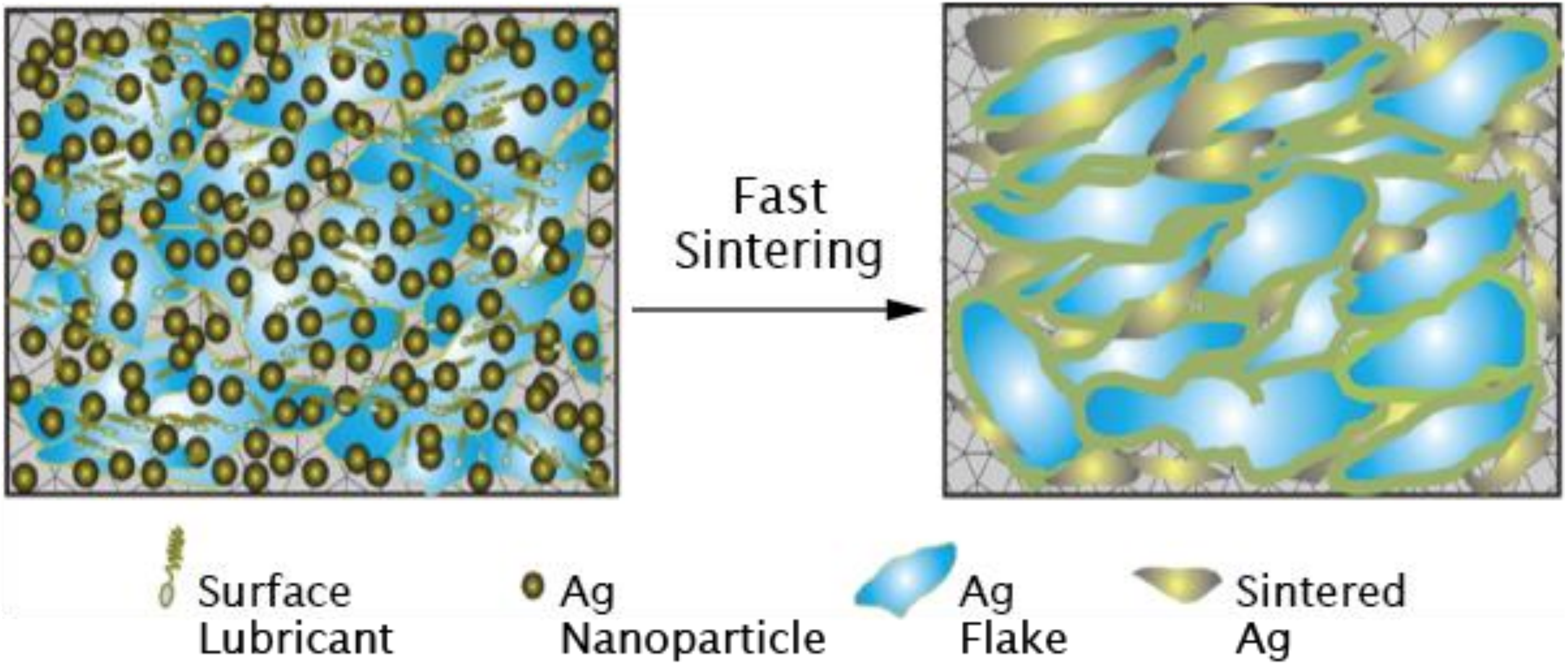


Contact and heat flow

Micro and Nanomaterials for TIMs

- Key desired properties
  - High thermal conductivity
  - Easily deformed by contact pressure
  - Minimal thickness
  - No leakage from the interface
  - Longer shelf life
  - Easy to process
- Potential options
  - Carbon based (CNT, Graphene)
  - Metal micro and nano particle based
- Metal micro and nano particle-based platforms are now in use.
- Both polymer composites with metal fillers (Ag) for and micro and nano particle materials for sintering.

Micro and Nanomaterials for TIMs



Conductive polymer composites-hybrid sintering

Example: Advanced Sintering Technology

Applied to Electric Vehicle Powertrain

Role of Interconnects in EV Powertrain

1. Convey Power

2. Remove Heat

3. Join & Mitigate Stress

Enable High Power Density
Reduce thermal resistance & Inductance

(Lower $/KW & KW/l, Longer Km Range)

High Temp Stability
Mitigate CTE Mismatch Stress

Lower Warranty $ & Longer lifetime

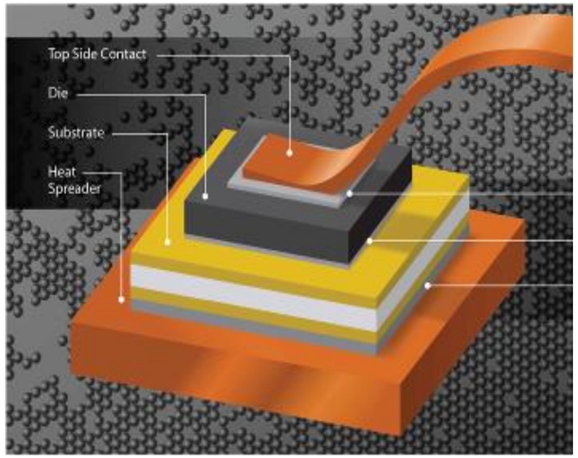
Performance + Reliability

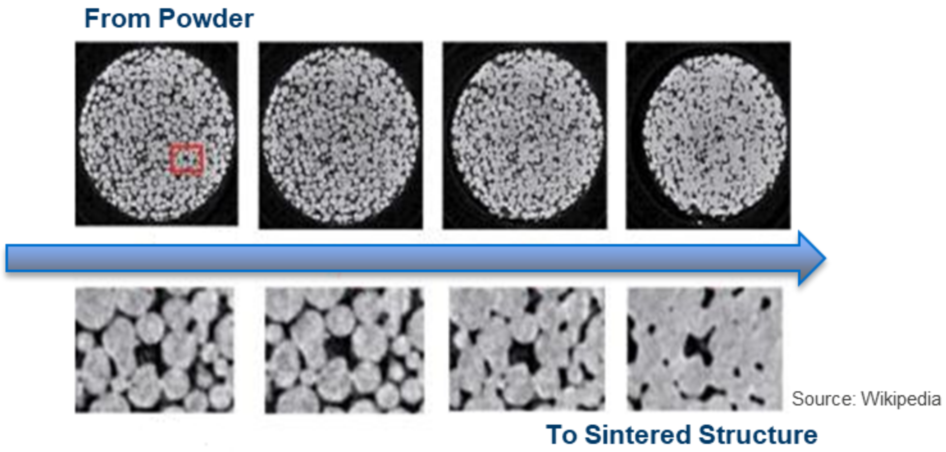
Source: MacDermid Alpha

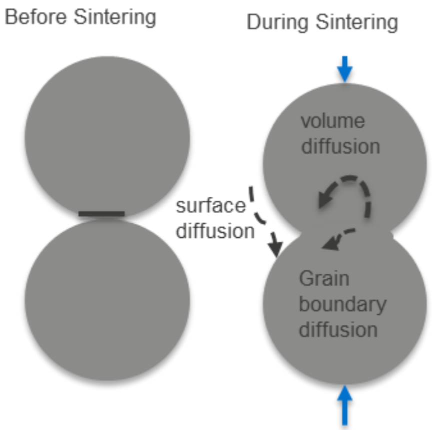
What is Sintering?

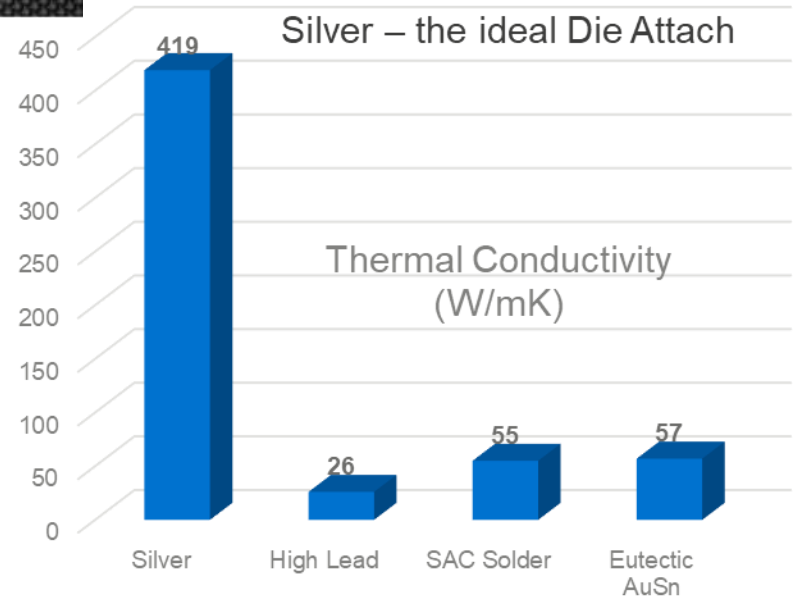
Sintering is diffusion of solid particles below melting point – accomplished with nano metals

- ❑ Driven by change in Internal Interface / Free Energy
- ❑ Mechanism – Mass Transport by Diffusion & Pressure









- ❑ High Thermal
- ❑ No Inter-Metallics (20-30X Reliability)

Source: MacDermid Alpha

What is Sintering?

Sintering is an effect of:

- Temperature
- Time
- Pressure

- Clip view (courtesy of Yole)

- Die attach

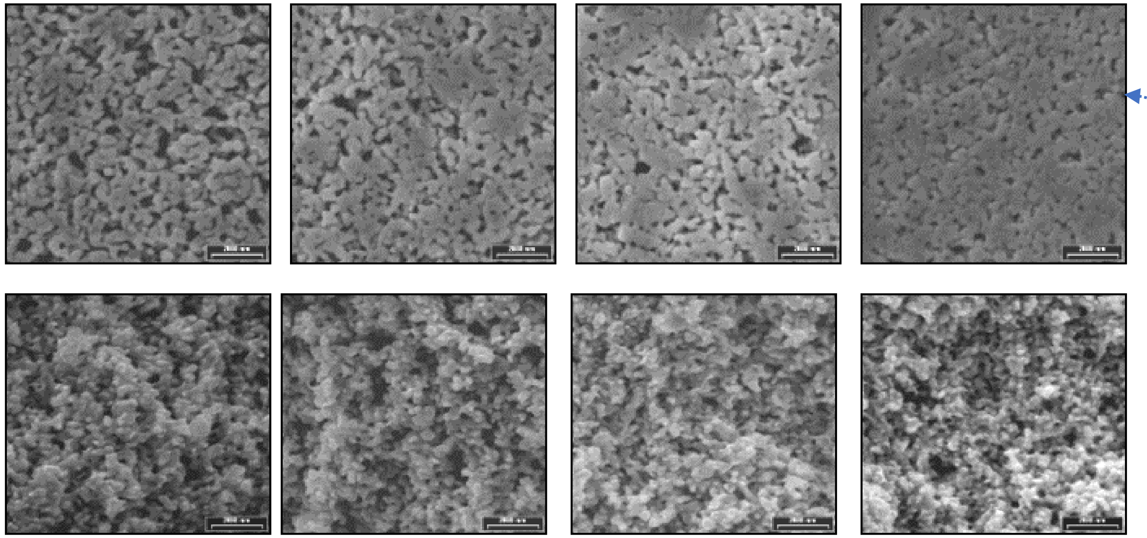
- Module / substrate attach

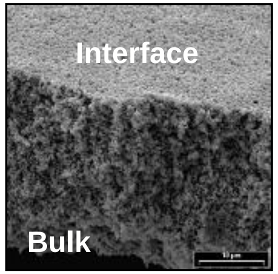
Source: MacDermid Alpha

Effect of Pressure on Sintering

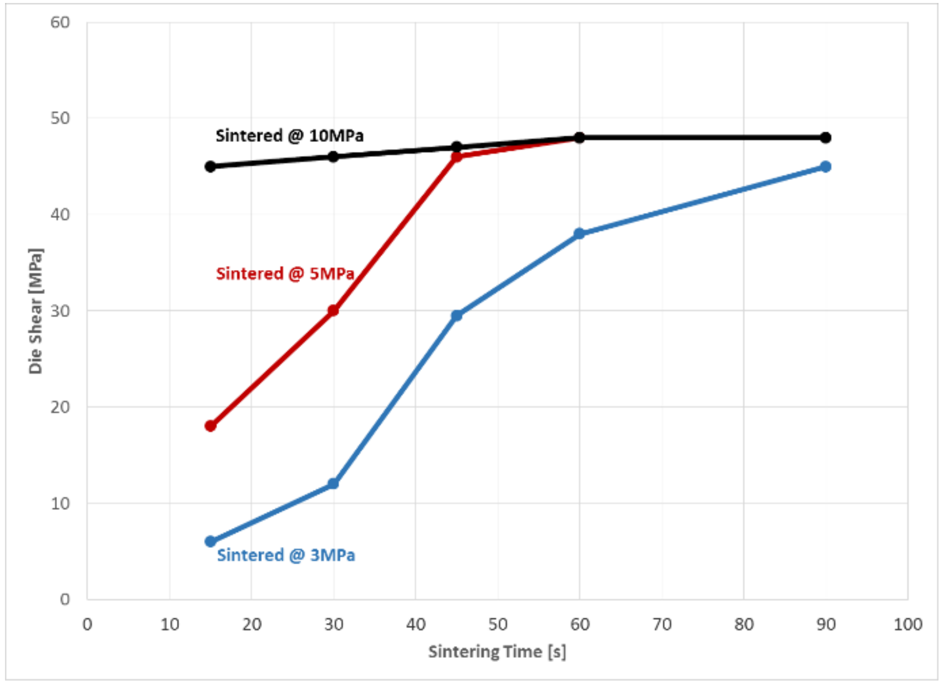
Sintering pressure promotes diffusion at interface

2 MPa **4 MPa** **6.2 MPa** **44 MPa**





Bulk essentially unchanged



Pressure enables rapid adhesion growth

Source: MacDermid Alpha

Power Electronics Applications

Power Electronics Applications

		Automotive		
Markets:	***Consumer & PV*** ***<500V, <50kW***	***Low Voltage*** ***48-200V, <50kW***	***High Voltage*** ***400-1200V, <500kW***	***Industrial & Rail*** ***>1.2KV, >500kW***
Application:				
Advantages:	Efficiency, Power Density, Reliability	Efficiency, Power Density, Reliability, Size and Weight Reduction	Power Density, Reliability, Size and Weight Reduction, Operating at Higher Temperature	Reliability - High Voltage & Frequency & Temperature
Components:	***Discrete*** ***Modules***	***Discrete*** ***Modules***	***Discrete*** ***Mini Modules*** ***Modules***	***Discrete*** ***Thyristor*** ***Press Pack*** ***Modules***

Source: MacDermid Alpha

Varied Approaches in the Automotive EV Segment

Module Approach

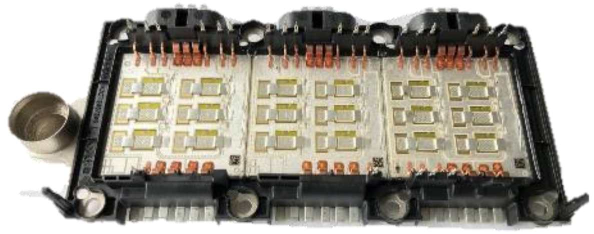
Discrete Approach

Source: MacDermid Alpha

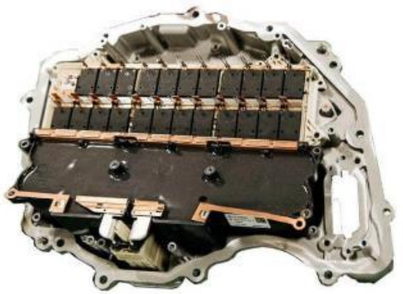
Automotive

Low Voltage 48-200V, <50kW	***High Voltage 400-1200V, <500kW***
	
Efficiency, Power Density, Reliability, Size and Weight Reduction	Power Density, Reliability, Size and Weight Reduction, Operating at Higher Temperature
Discrete ***Modules***	***Discrete*** ***Mini Modules*** ***Modules***

Power Modules Approach



"SiC Mini Modules" Approach



Sintering Technology for High Voltage Segment

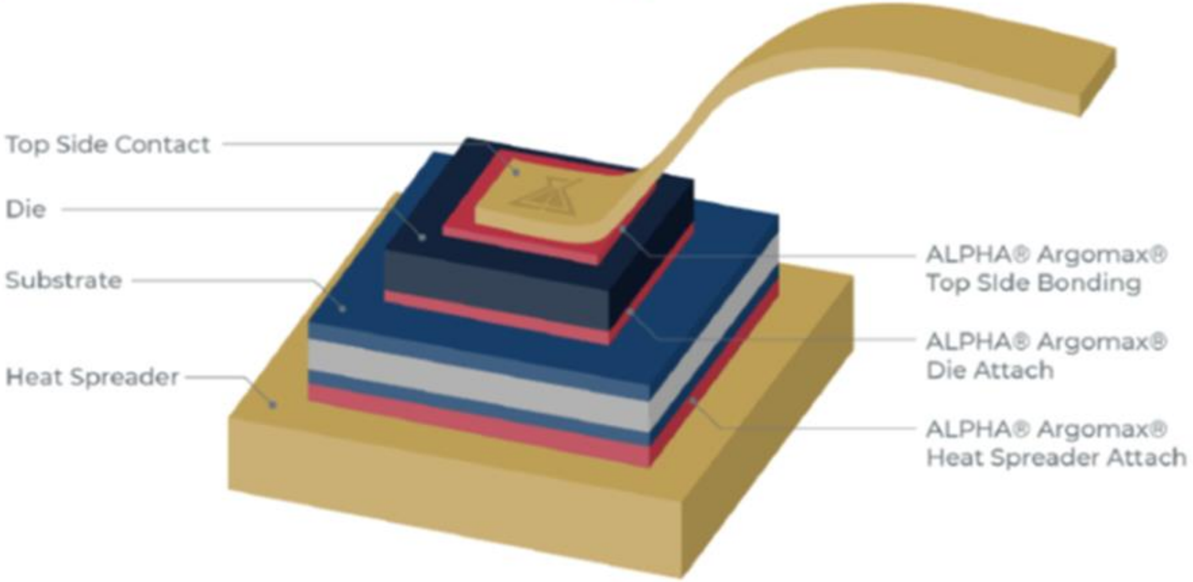
Argomax® - Advanced bonding technology based on silver sintering

Main technical attributes:

- High thermal and electrical conductivity
- High temperature stability

Advantages:

- High reliability
- Ability to shrink dies
- Ideal for SiC, GaN technologies
- High temperature silicon
- Smaller packages
- More power
- More light



<u>Sintering is not Soldering</u>

Bulk Metal vs. Alloy

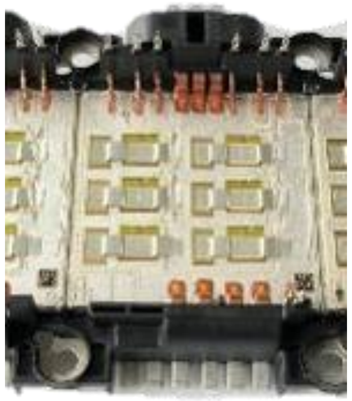
New Process : Temp, Pressure and Time

Source: MacDermid Alpha

Case Studies

- *Publicly available information from teardown reports combined with MacDermid Alpha proprietary test results*

Source: MacDermid Alpha



- Case 1 High voltage - Si power module approach
- How silver sintering helps to increase power density, reduce weight and increase reliability.

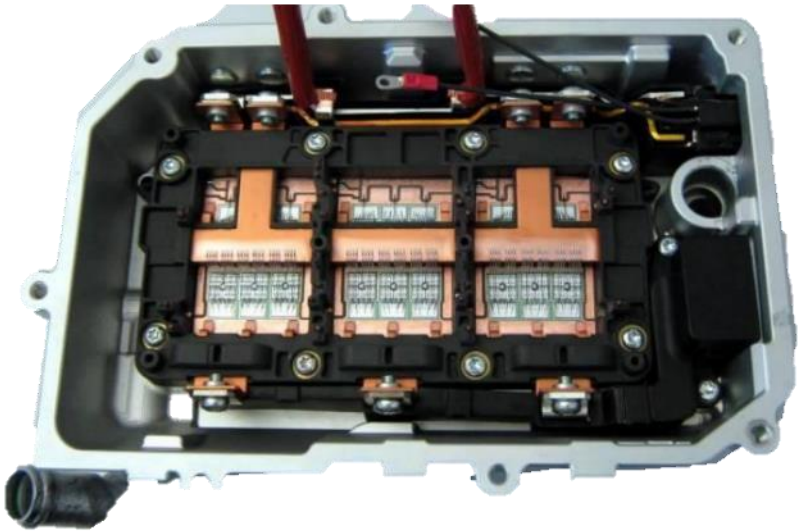
- Case 2 High voltage -“SiC mini modules” approach
- How silver sintering helps to reduce thermal resistance weight and increase reliability.

- Case 3 Low voltage module approach
- How silver sintering helps to increase power density and reduce weight.

Case 1 - High Voltage - Si Power Module Approach

Traditional Approach

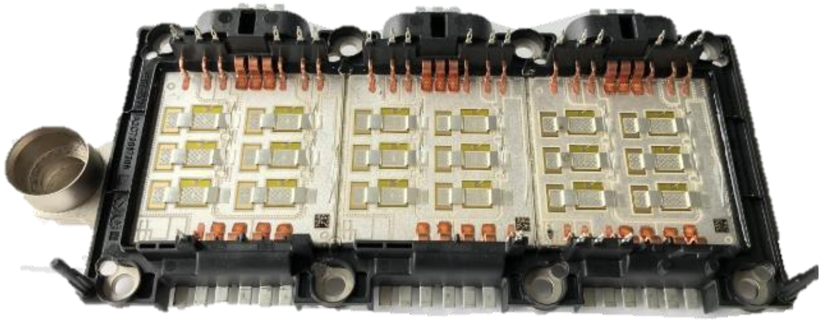
Gen 2 – Wire bonding, Si Dies and Solder Die Attach



- Higher Temp Operation
- Higher Power
- Decrease Size
- Smaller Cooling System

New Approach

Gen 2.8+ - Si Dies, Fully Sintered Top & Die Attach

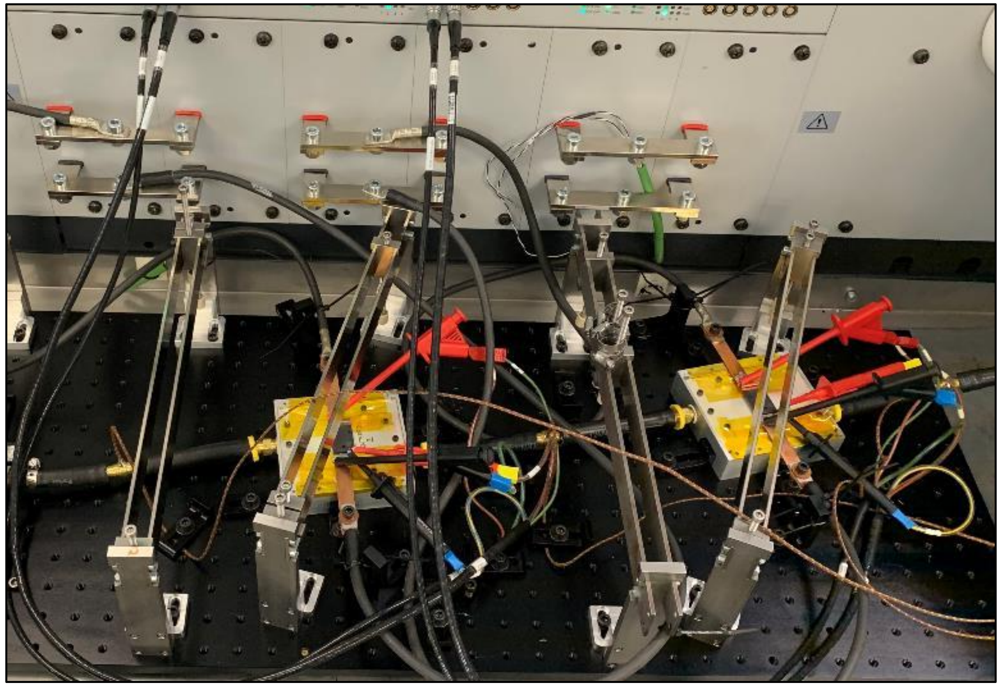


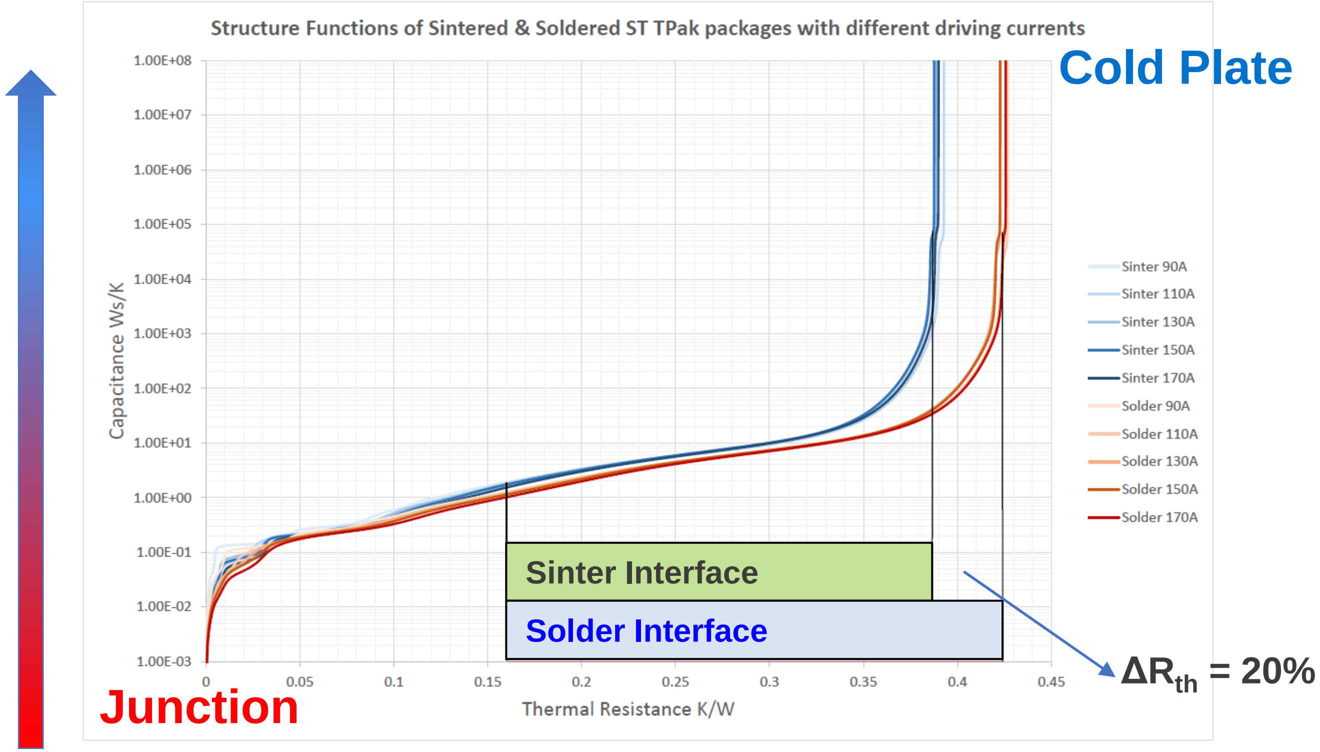
Higher Power Density
Higher Endurance
Lower Weight

Source: Vitesco

Case 2 - High Voltage -“SiC Mini Modules”, Why Sintering? : Rth Measurement

DUT (Devices Under Test)



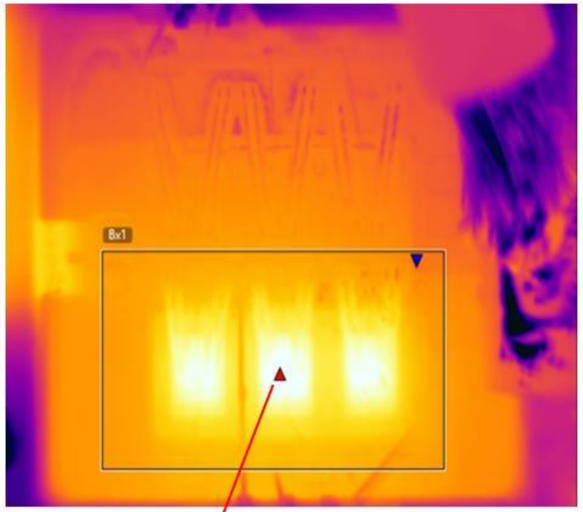


- Using Sintering reduces overall (junction to heatsink) R_{th} by 20%!
- Delta R_{th} is reproducible across different packages and across different currents

Source: MacDermid Alpha

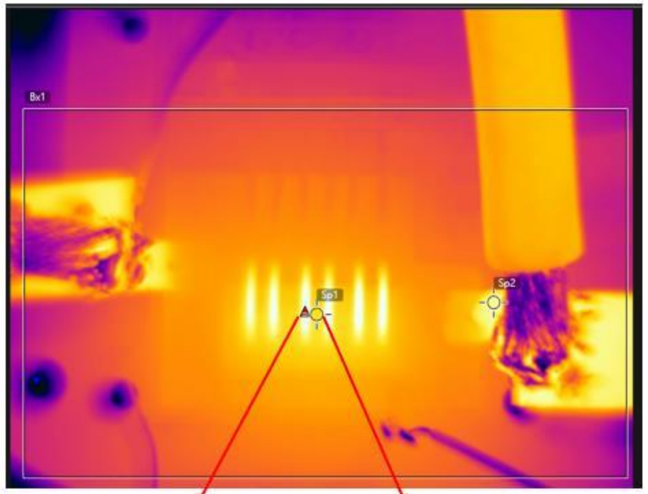
Case 3 – Low Voltage 48/96V System, Module Approach

8kW Air Cooling – Standard Version (Solder)



@280A Chip Surface Temperature: 150.5°C

Air Cooling (12kW) – Improved Version (Sinter)



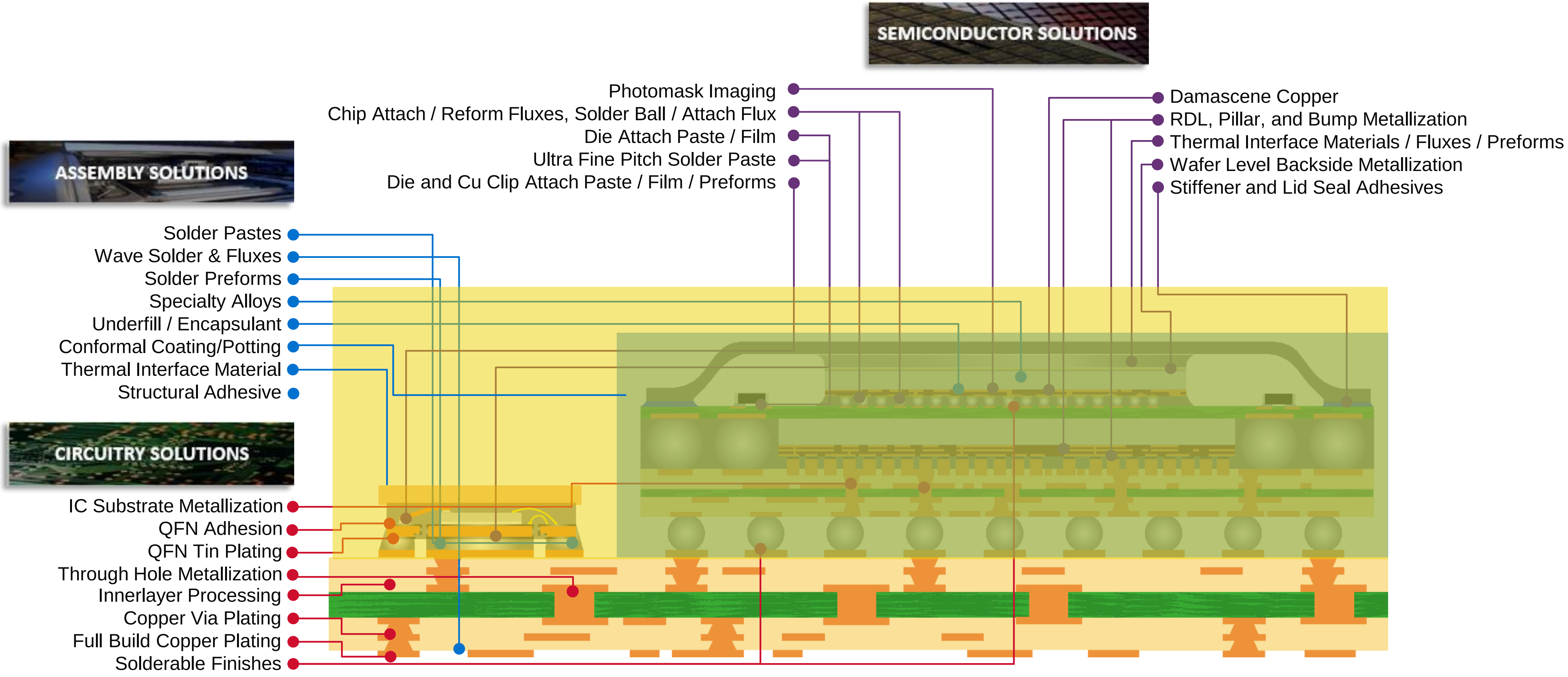
@350A Chip Surface Temperature: 142.2°C

Same external dimensions
Higher Power Density
Lower Chip Temperature
Keep air cooling!

Source: MacDermid Alpha

Recap

Anatomy of a Package



Source: MacDermid Alpha

Thank you

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