Overview of Non-Hermetic Advanced Packages

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Brief Outline

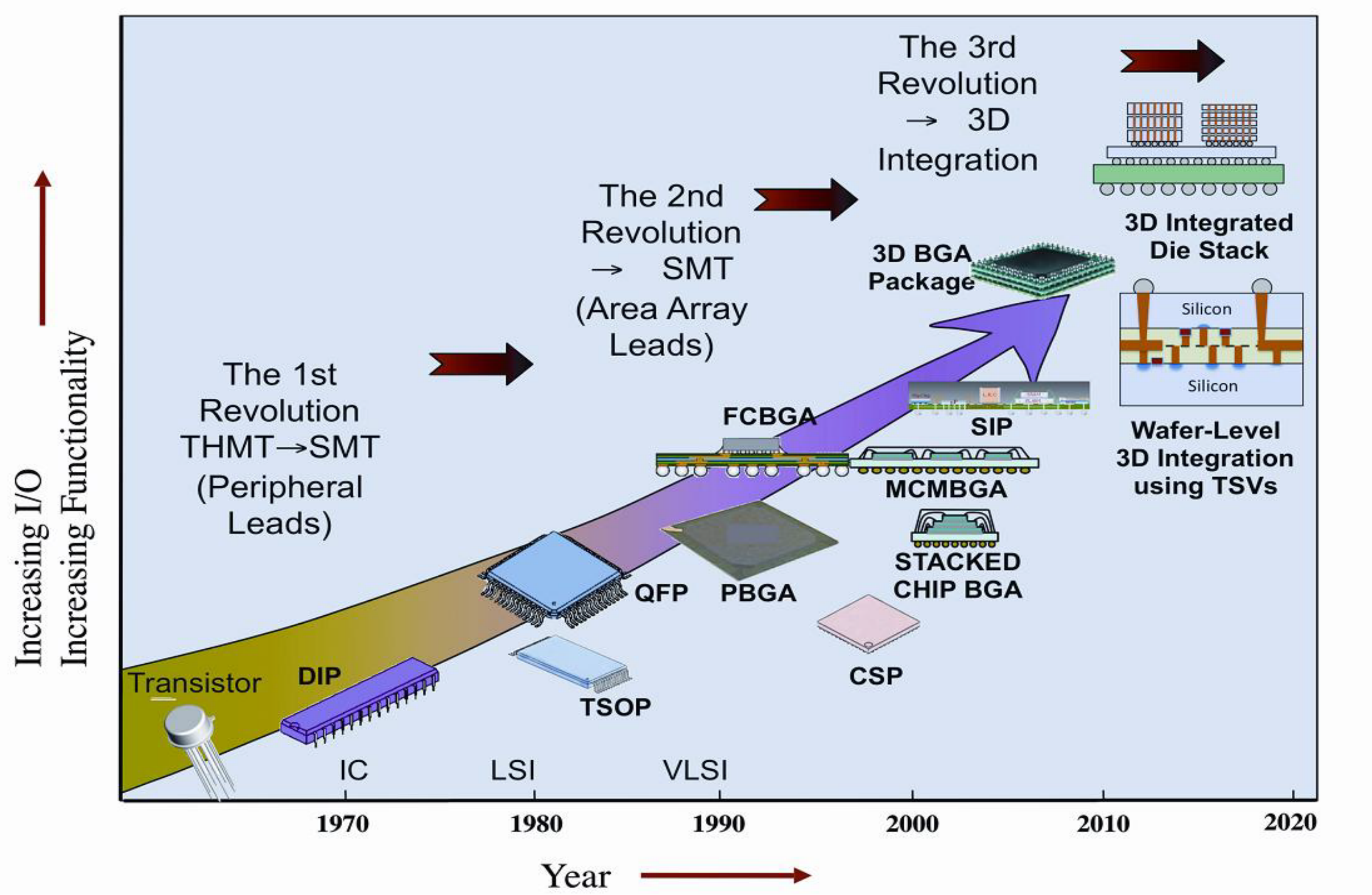
- Polymer packaging evolution (non-hermetic)
- Examples of package types
- Polymers used in advanced packages
- Key use of fillers to control properties
- Moisture absorption
- Reliability testing

Polymers in Semiconductor Packaging

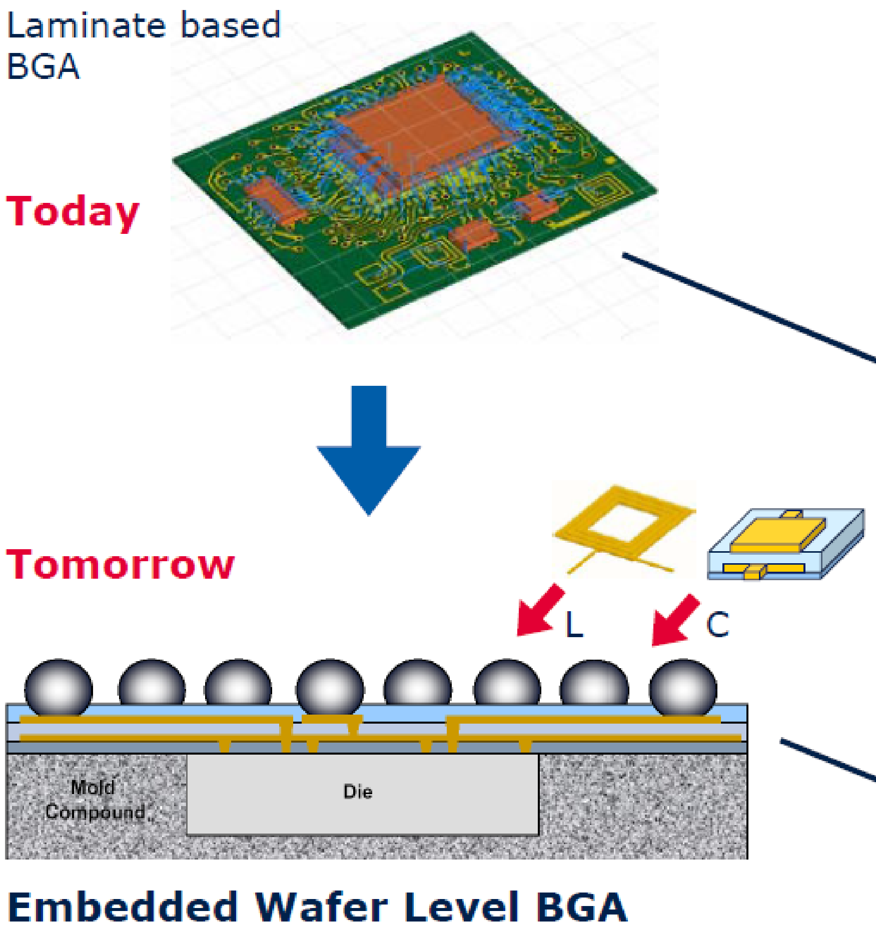
There are some tough material requirements

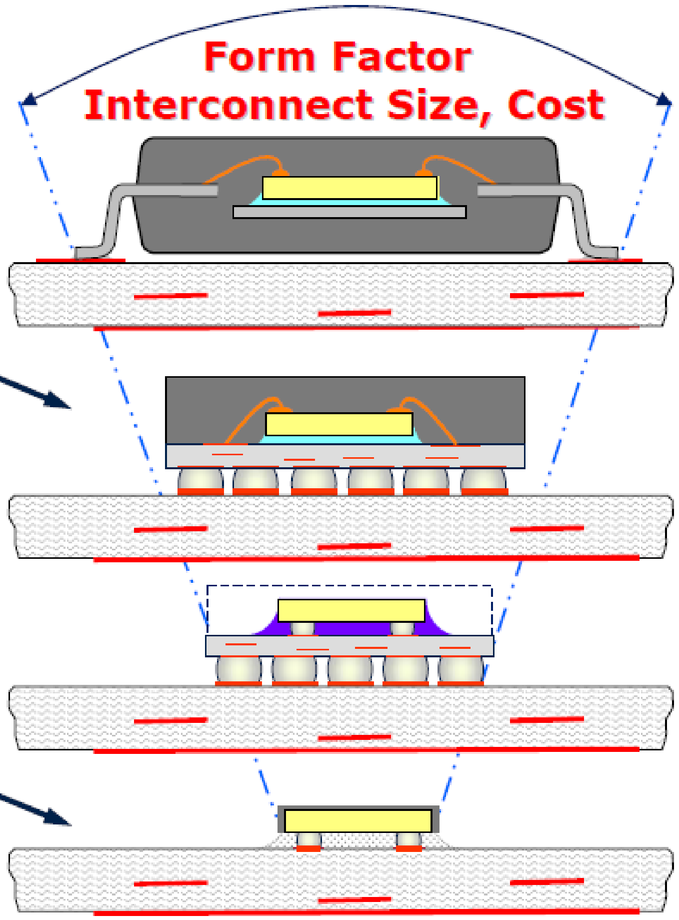
- Low viscosity to flow (die attach, mold compounds and underfills)
- Wide range of cure profiles
  - Thermal (oven, snap and spot cure) and UV cure
  - Partial cure (B-stage) for printable pastes and films
- Tailored modulus depending on the application
- Low coefficient of thermal expansion (requires fillers)
- High temperature stability for lead-free reflow profiles
- Low moisture absorption (JEDEC pre-con)

Non-Hermetic Packaging Evolution



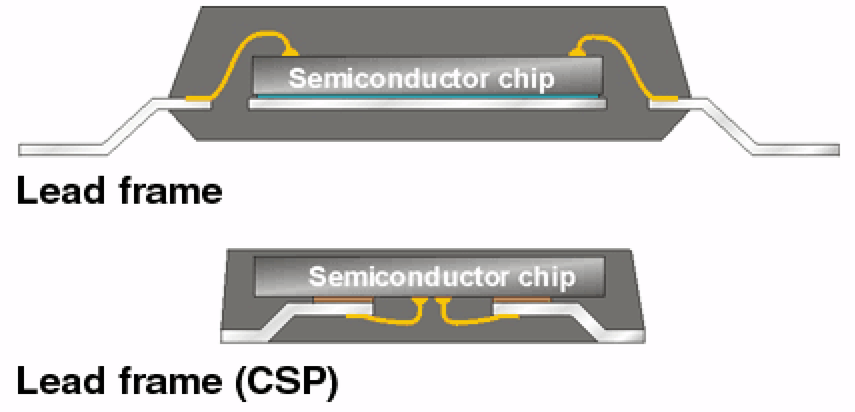
Polymer-based Packaging Examples





Source: Infineon

Leadframe Packages



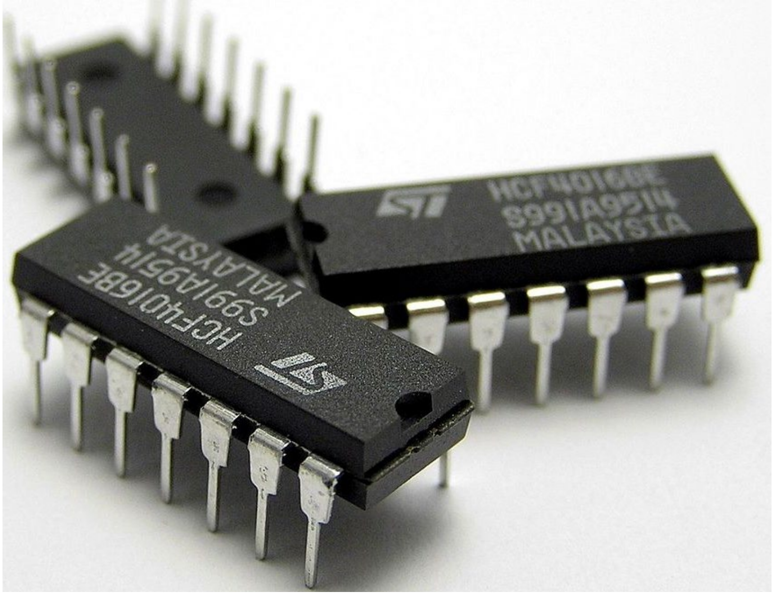
Materials:

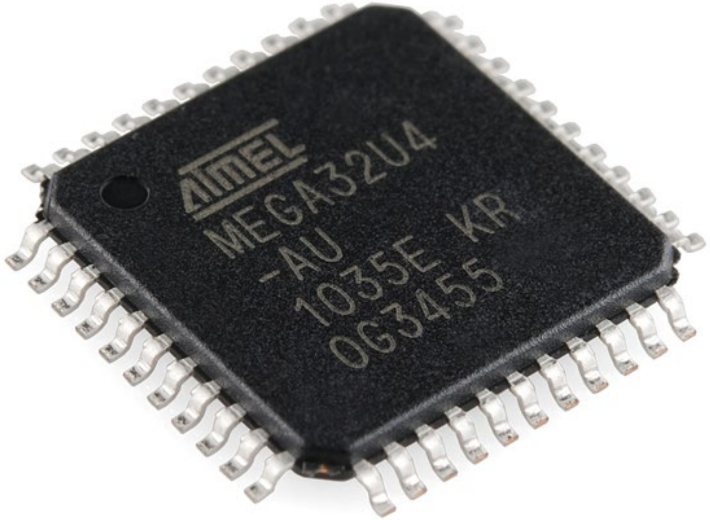
Metal leadframe

Die attach adhesive (epoxy and maleimide/acrylate)

Epoxy mold compound

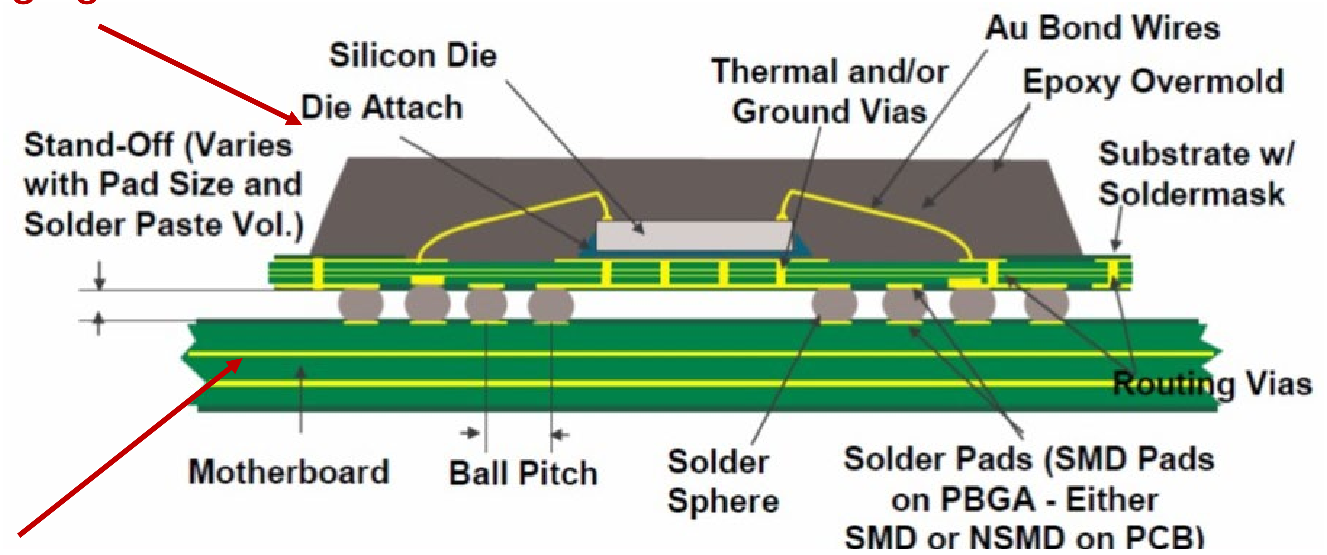
Gold or copper wire



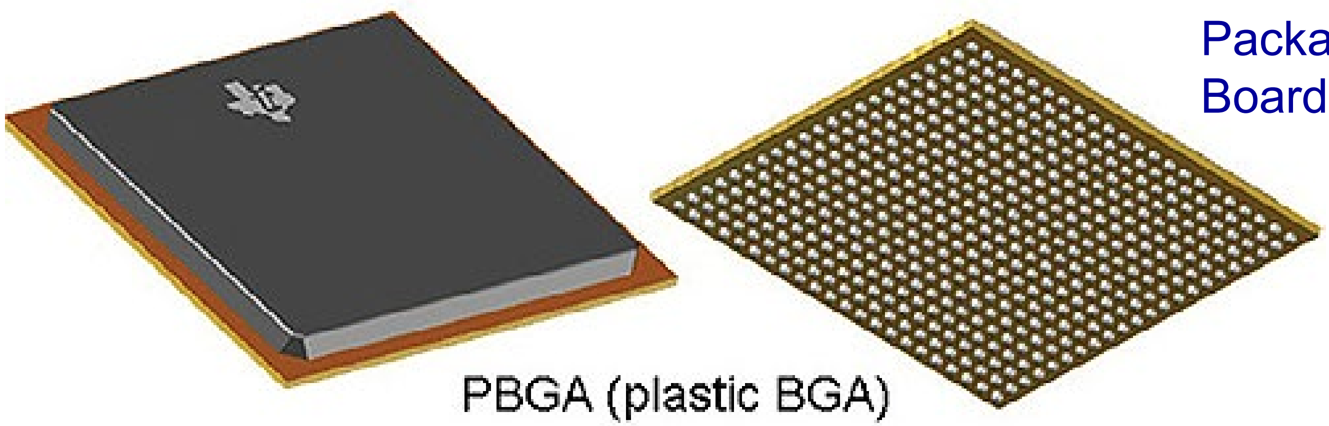


Plastic Ball Grid Array (PBGA)

Packaging Level 1



Packaging Level 2



PBGA (plastic BGA)

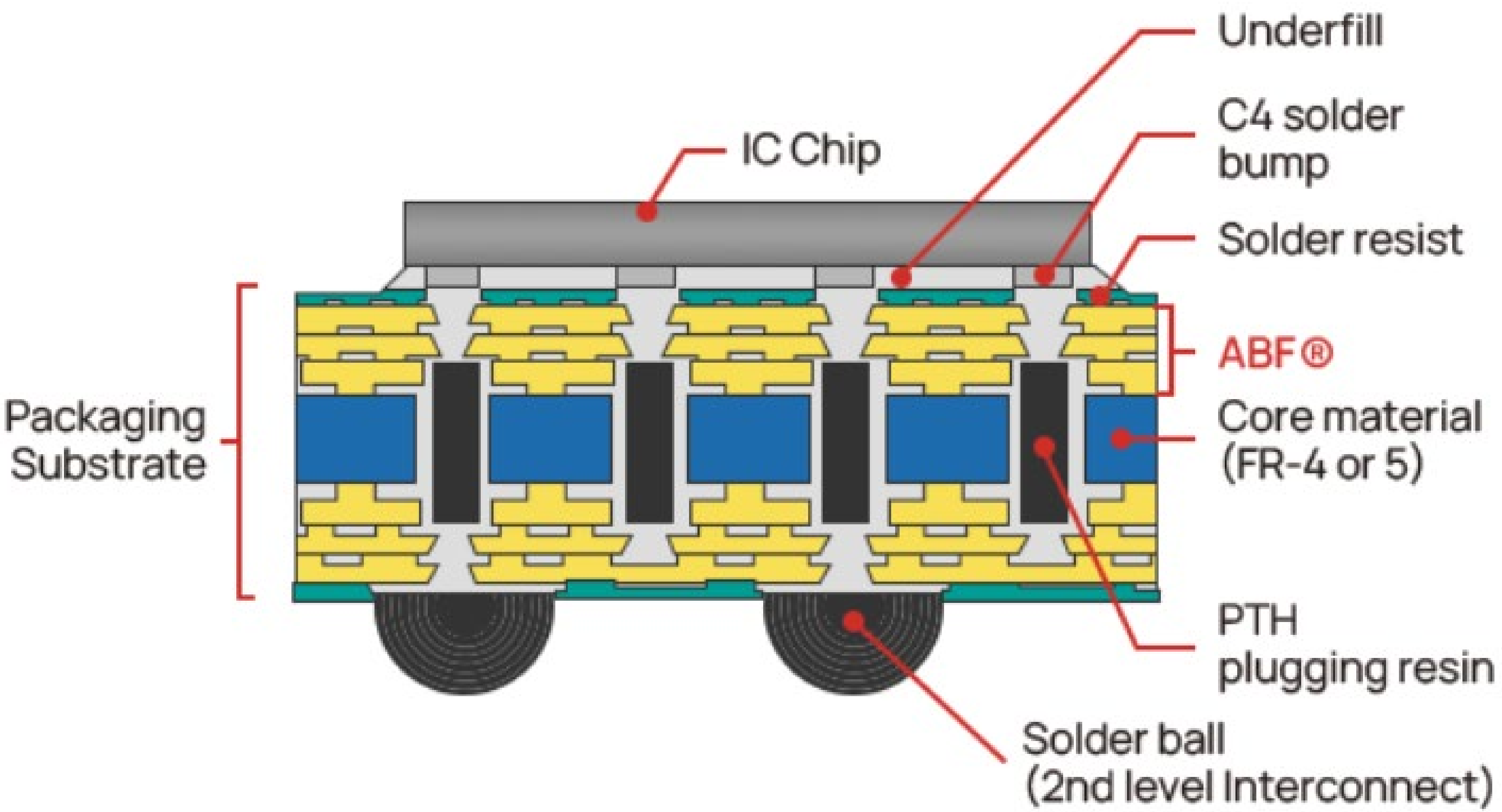
Materials:

Bismaleimide triazine epoxy substrate
Die attach adhesive
Epoxy mold compound
Gold or copper wire bonded

Packaging Level 1 – semiconductor encapsulation including substrate

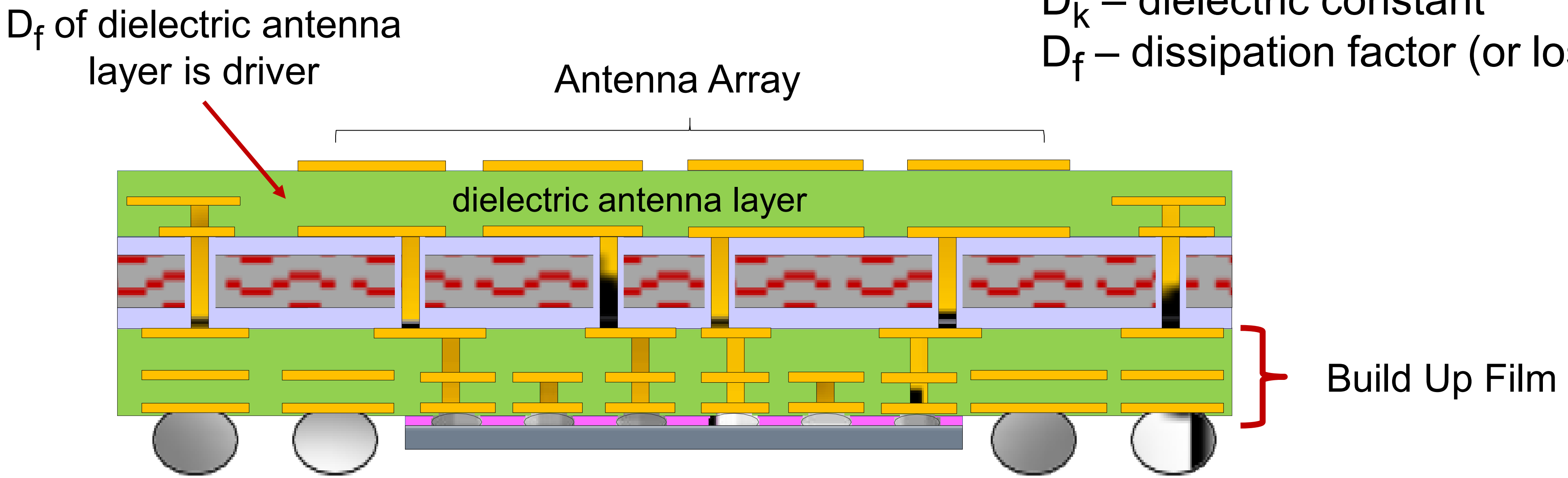
Packaging Level 2 – Printed Circuit Boards

Flip Chip BGA on HDI Substrate



ASE Package with Integrated Antenna

D_k – dielectric constant
D_f – dissipation factor (or loss factor)

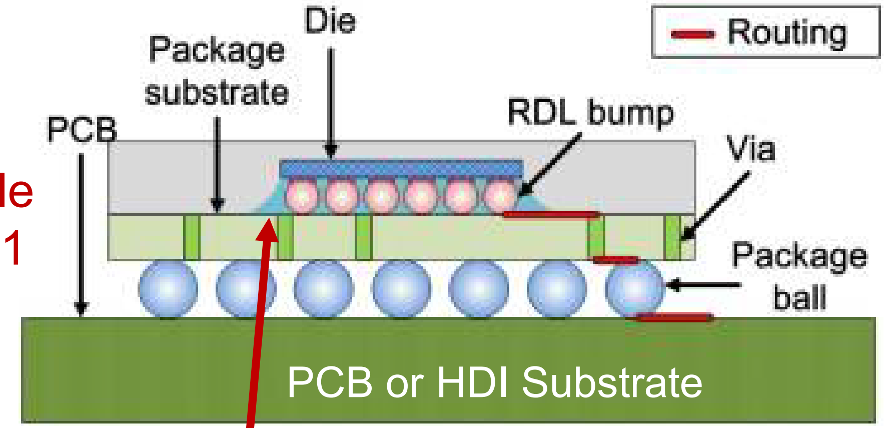


Printed Circuit Board (PCB) process using advanced low D_k and D_f materials for antenna layer and build up films

Source: Advanced Semiconductor Engineering (ASE)

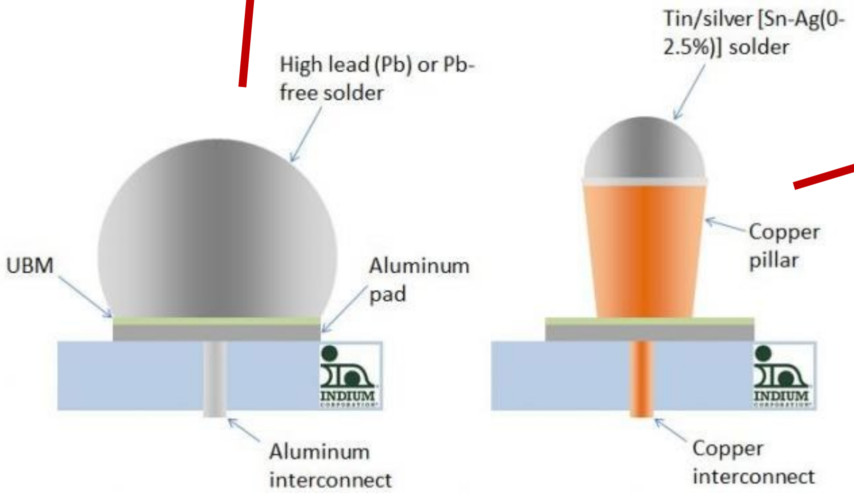
Flip Chip Ball Grid Array (FC-BGA) Package

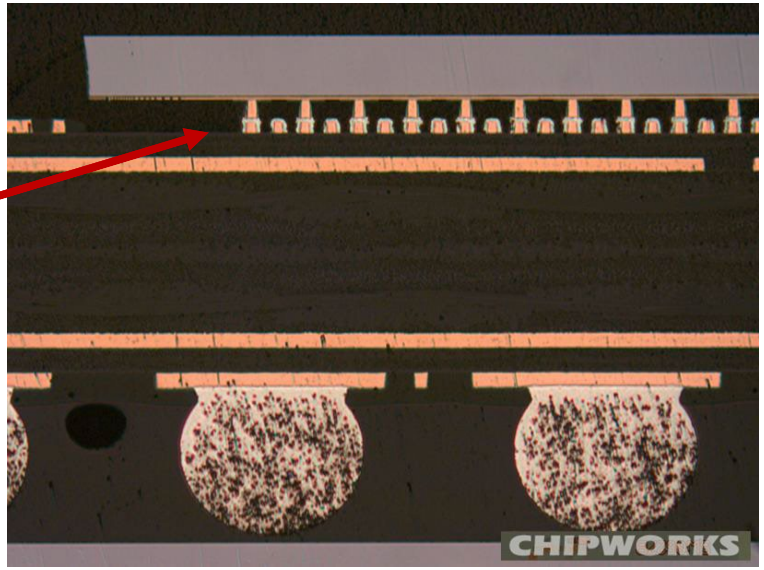
Example of multiple packaging Levels 1 and 2



Materials:

Bismaleimide triazine epoxy substrate
Epoxy Underfill
Epoxy mold compound
Lead-free solder balls
Copper pillars

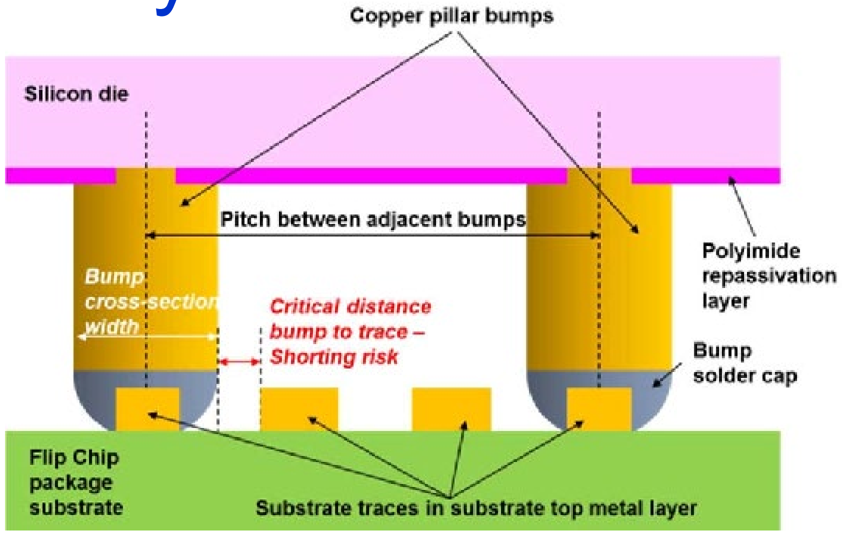




Challenges with Capillary Underfill

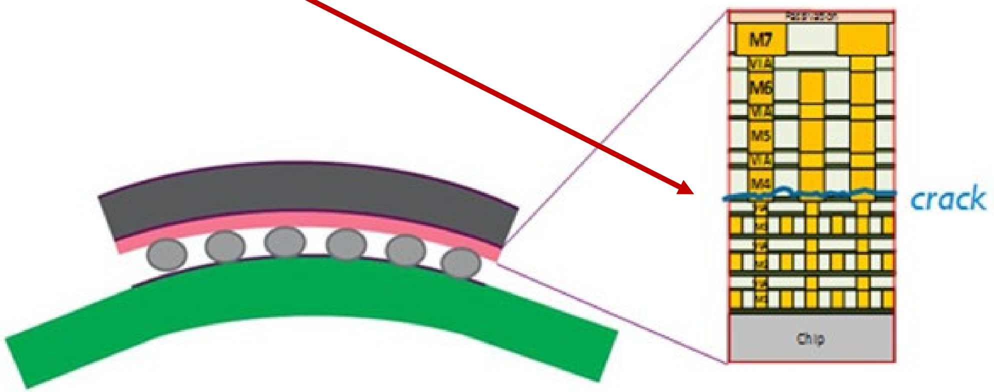
Flow issues with capillary underfills

- Cu pillar pitch is going to 35 μ and less
- Pillar diameter is moving < 30 μ
- CTE requirements impact flow
- Work underway in alternate fillers, packing geometries, low viscosity polymers



Low k inner layer dielectric (ILD) drives material properties

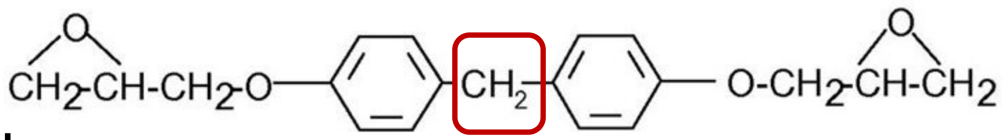
- Stress management
- Prevent cracking



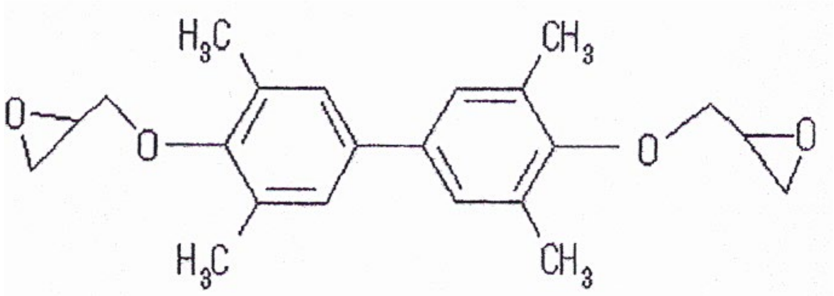
Capillary Underfill Formulations

Resins and hardeners

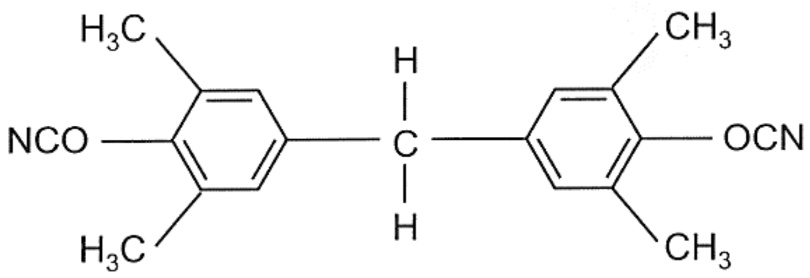
- Liquid Bis F epoxy – amine



- Liquid Bis F epoxy – anhydride
- Biphenyl epoxy



- Liquid cyanate ester – metal coordination catalyst



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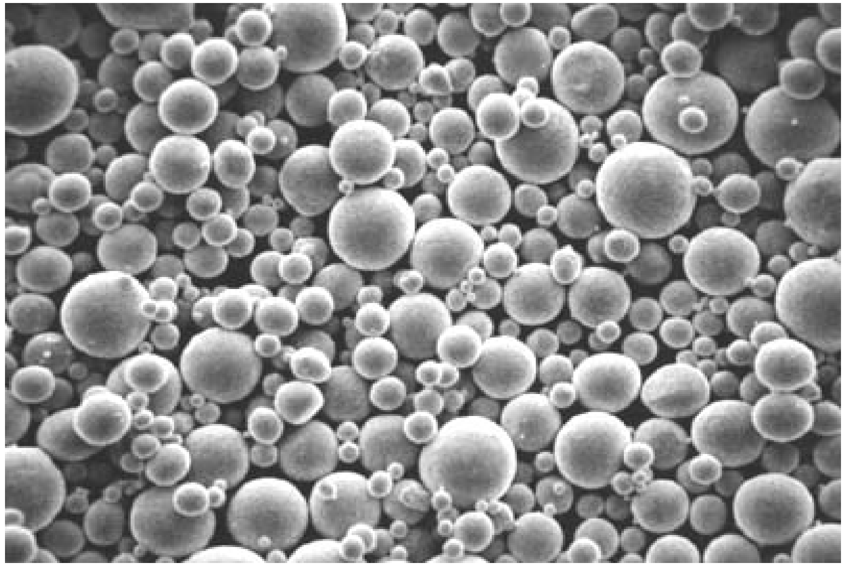
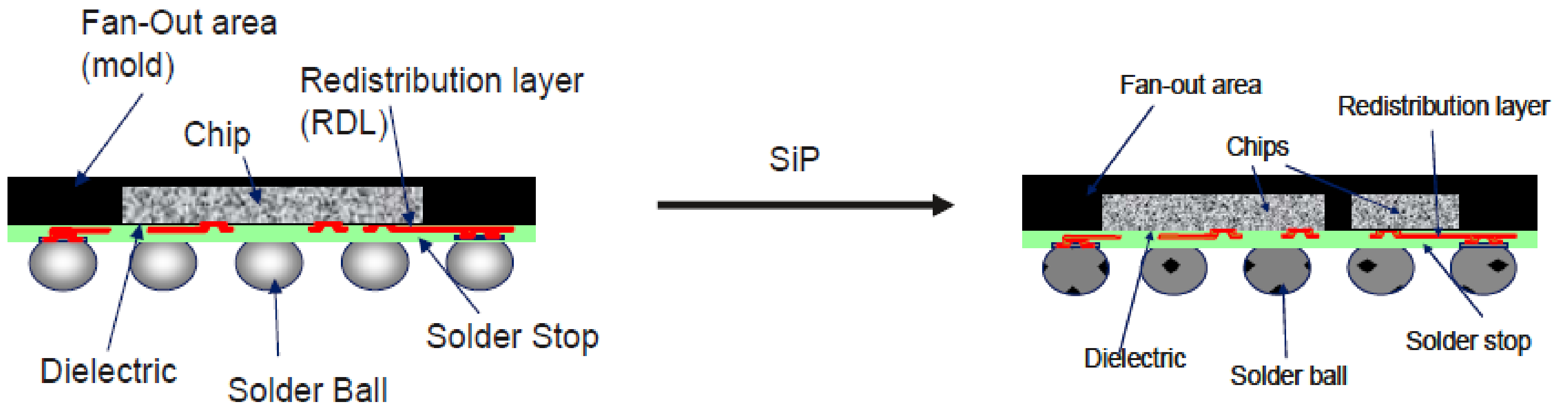
Fillers are Key to Tailoring Underfill Properties

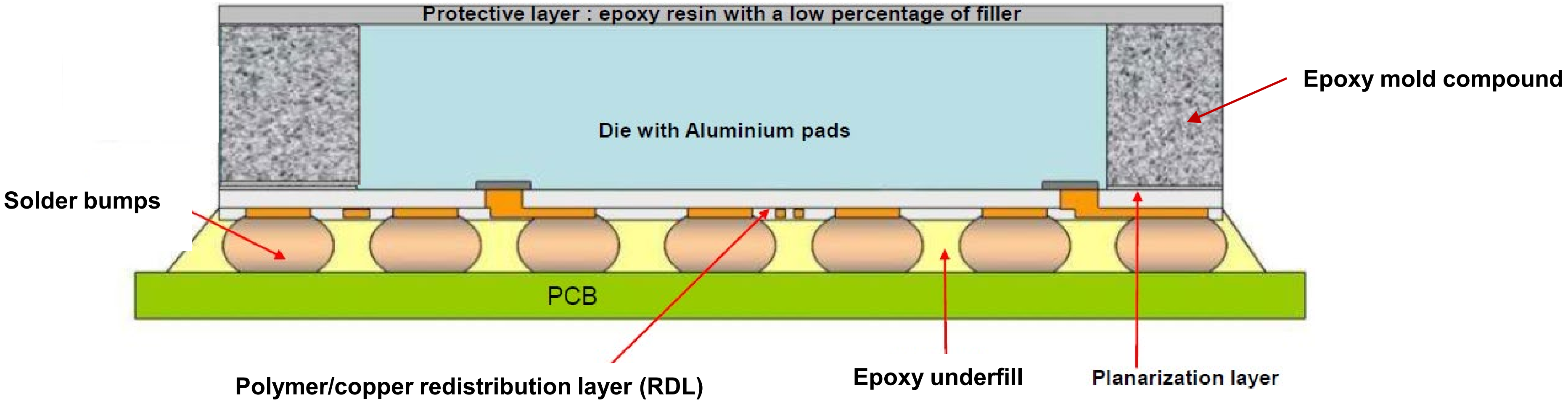
- Non-conductive, electrically insulating
  - Fused silica is widely used; high purity, chemical resistance and low coefficient of thermal expansion (CTE)
  - Spherical fused silica is the most common filler
  - Used in high filler loadings (> 65 wt%)
  - Has smaller impact on viscosity
- Surface treatment is key
  - Lower viscosity
  - More Newtonian flow behavior
  - High filler loadings



Source: Sumitomo

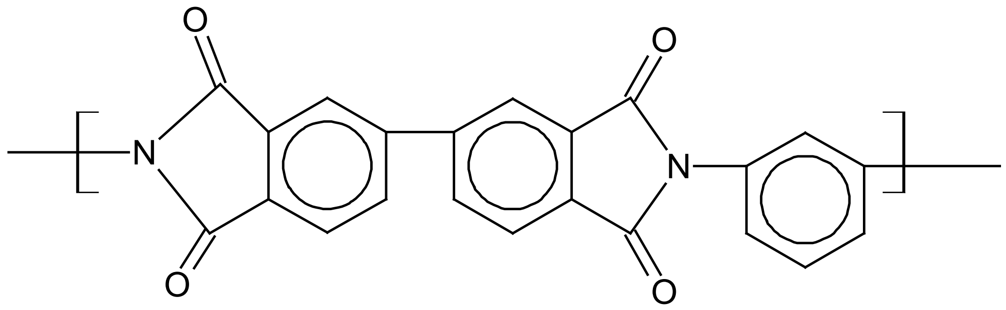
Embedded Wafer Level Packaging (eWLP)



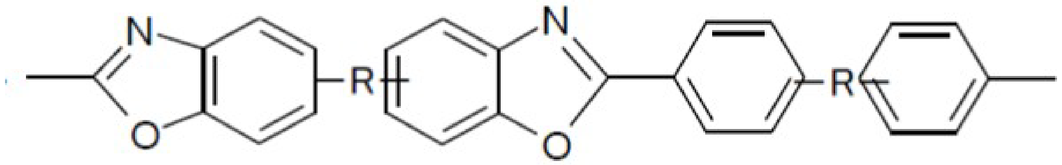


Source: Infineon eWPL fanout package

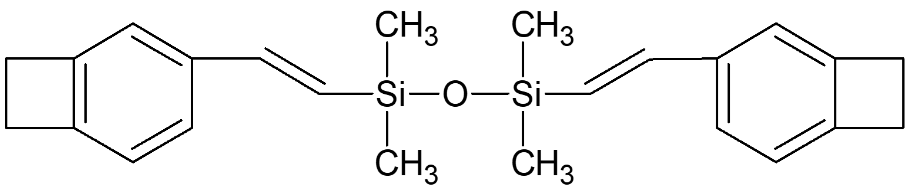
Polymers Used in Redistribution Layers (RDL)



Polyimide (or photosensitive (PSPI))

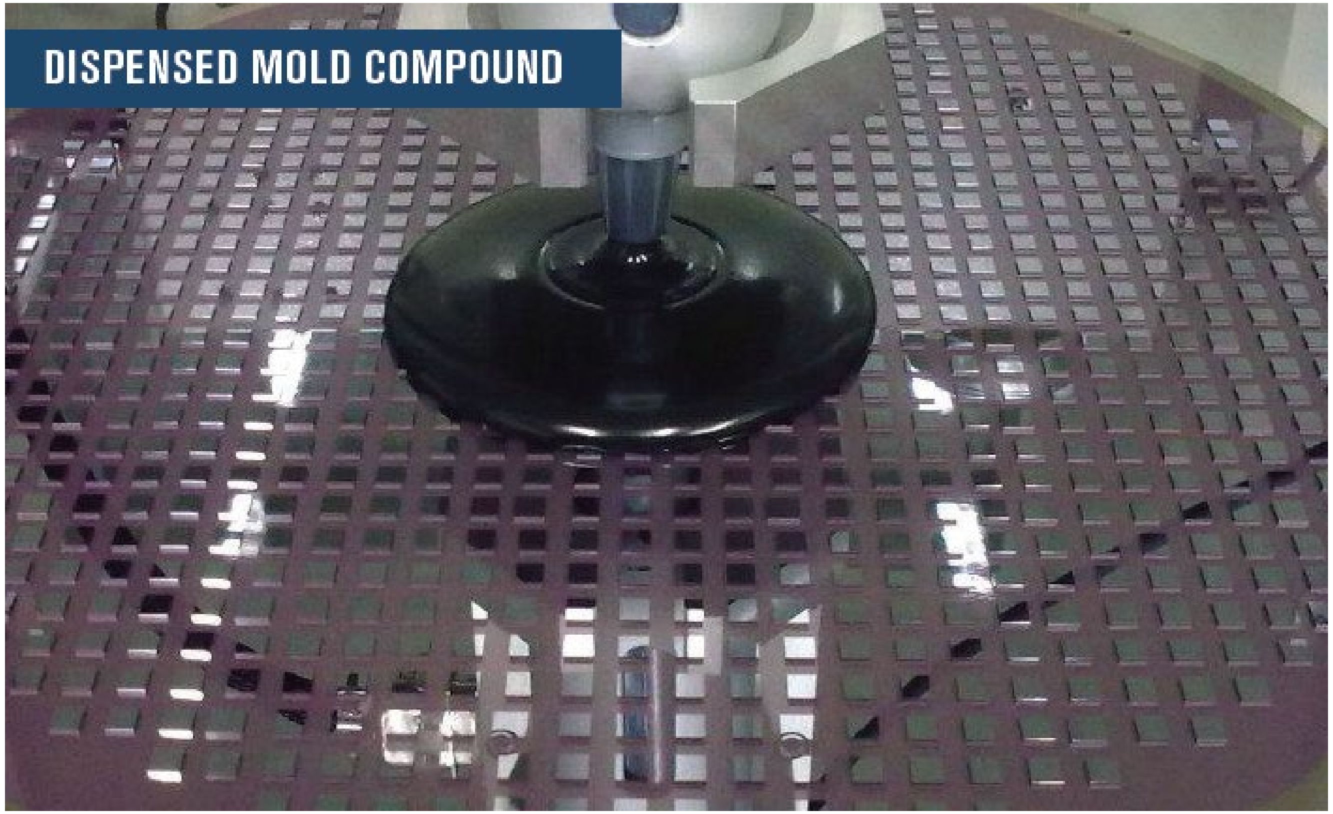


Polybenzoxazole (PBO))



Benzocyclobutene (BCB)

Liquid Epoxy Mold Compound on Reconstituted Wafer



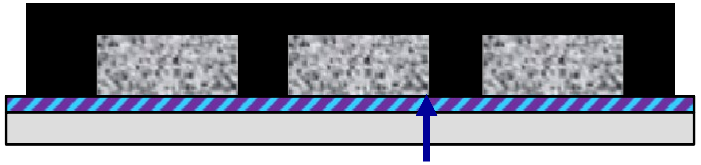
Source: Nanium

Reconstituted Wafer Example

Chips mounted on temporary adhesive layer and with liquid EMC for encapsulation

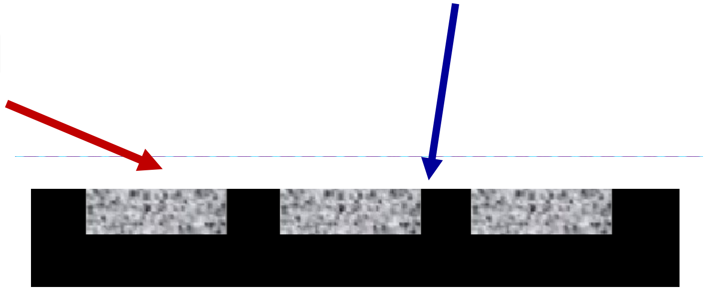
Molded reconstituted wafer

Reconstituted wafer on carrier



Temporary adhesive layer

Planar surface for RDL layers

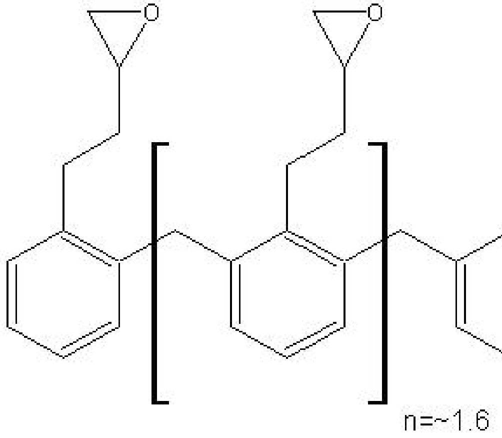


Reconstituted wafer after carrier release

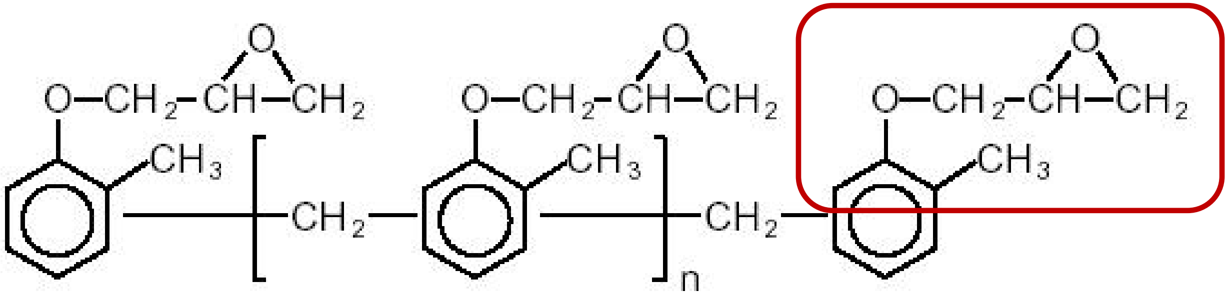
Source: Nanium

Epoxy Mold Compound Chemistry

Epoxy novolac

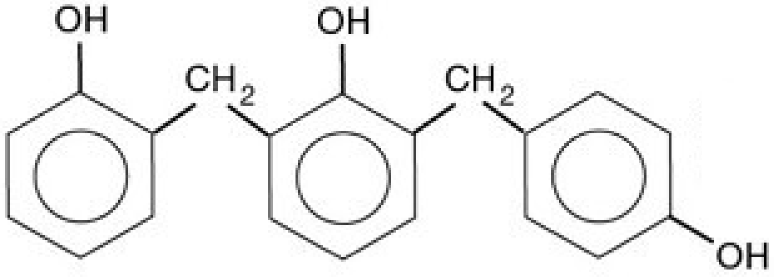


Epoxy cresol novolac



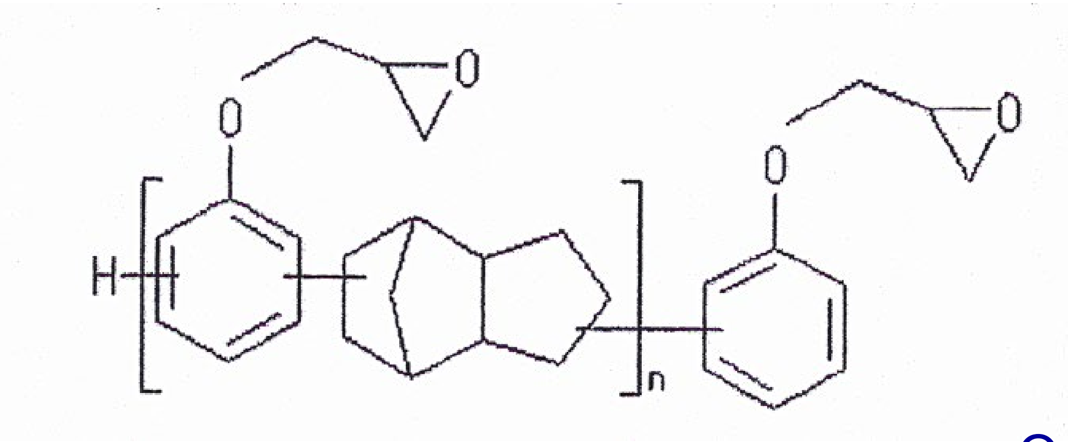
Steric hindrance around epoxy linkage lowers moisture absorption

Phenolic novolac
(curing agent)

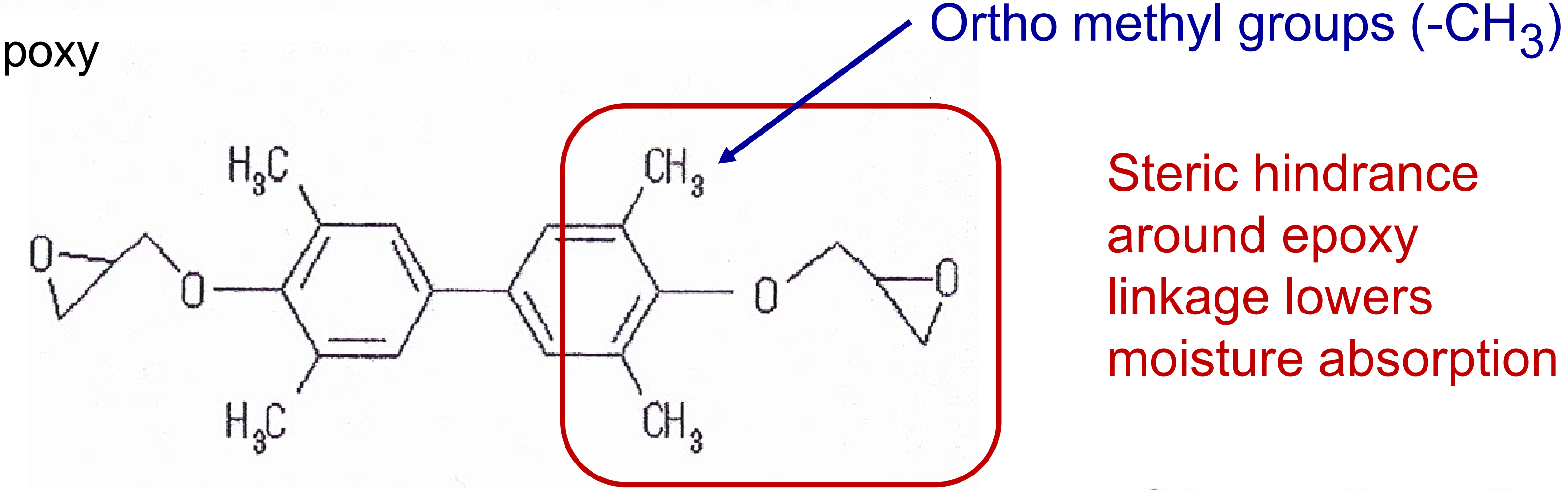


Second Generation Epoxy Mold Compound Chemistry

Dicyclopentadiene type novolac epoxy



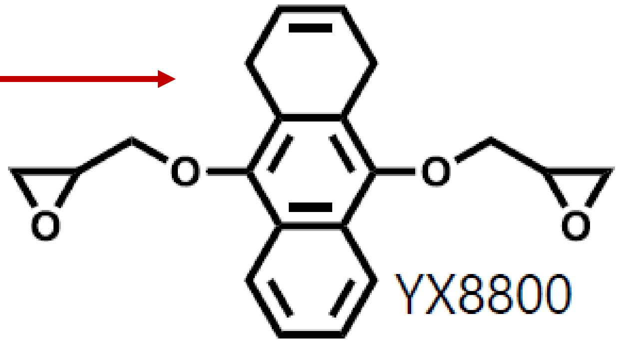
Biphenyl type epoxy



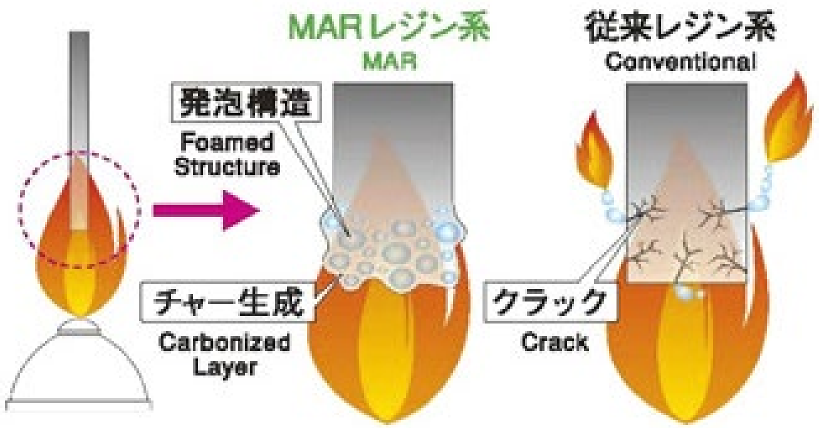
Steric hindrance around epoxy linkage lowers moisture absorption

Green Approach to Flame Retardancy

- Incorporating Multi Aromatic Resins (MARs) into the EMC can achieve flame resistance without halogens or antimony
- MARs have high oxygen index and are resistant to combustion
- At high temperatures, form a surface protection film which blocks oxygen and heat



Mitsubishi Chemical jER Epoxy



Source: Sumitomo

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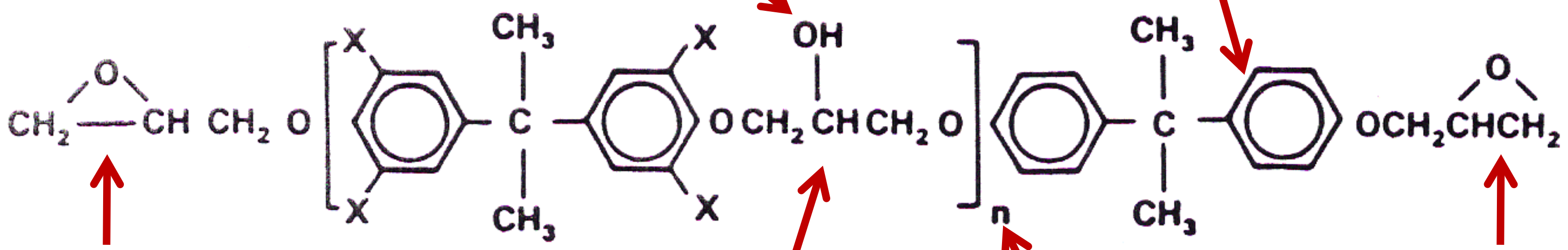
Epoxy is Most Common Thermoset

Adhesion, reactive site, wettability, drawback hydrogen bonds with water molecules

Aromatic rings give high temperature performance and rigidity



Epoxy reactive site

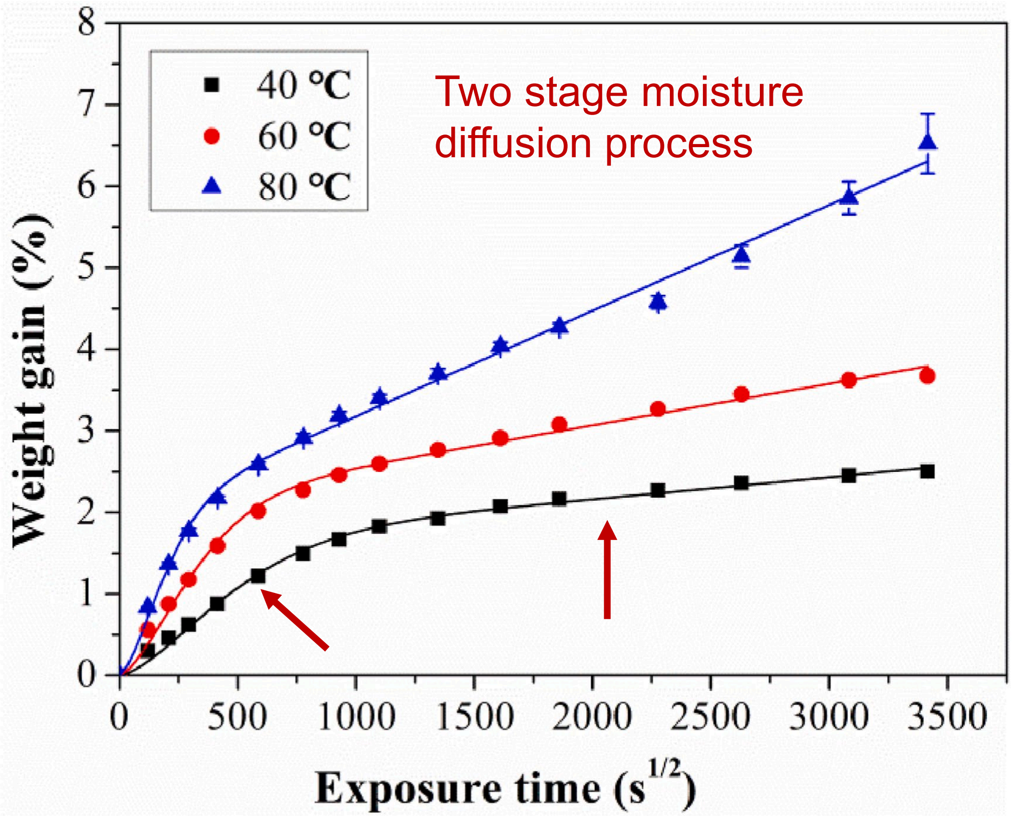
Epoxy reactive site

Molecular weight

Toughness

Bisphenol A epoxy; X=H, for tetrabromobisphenol A; X- Br

Epoxies Absorb Moisture



Bisphenol A epoxy + anhydride hardener
(underfills, coatings, circuit boards etc.)

$$M_t = M_\infty (1 + k\sqrt{t}) \left\{ 1 - \exp\left[-7.3 \left(\frac{Dt}{h^2} \right)^{0.75} \right] \right\}$$

D is the diffusion coefficient

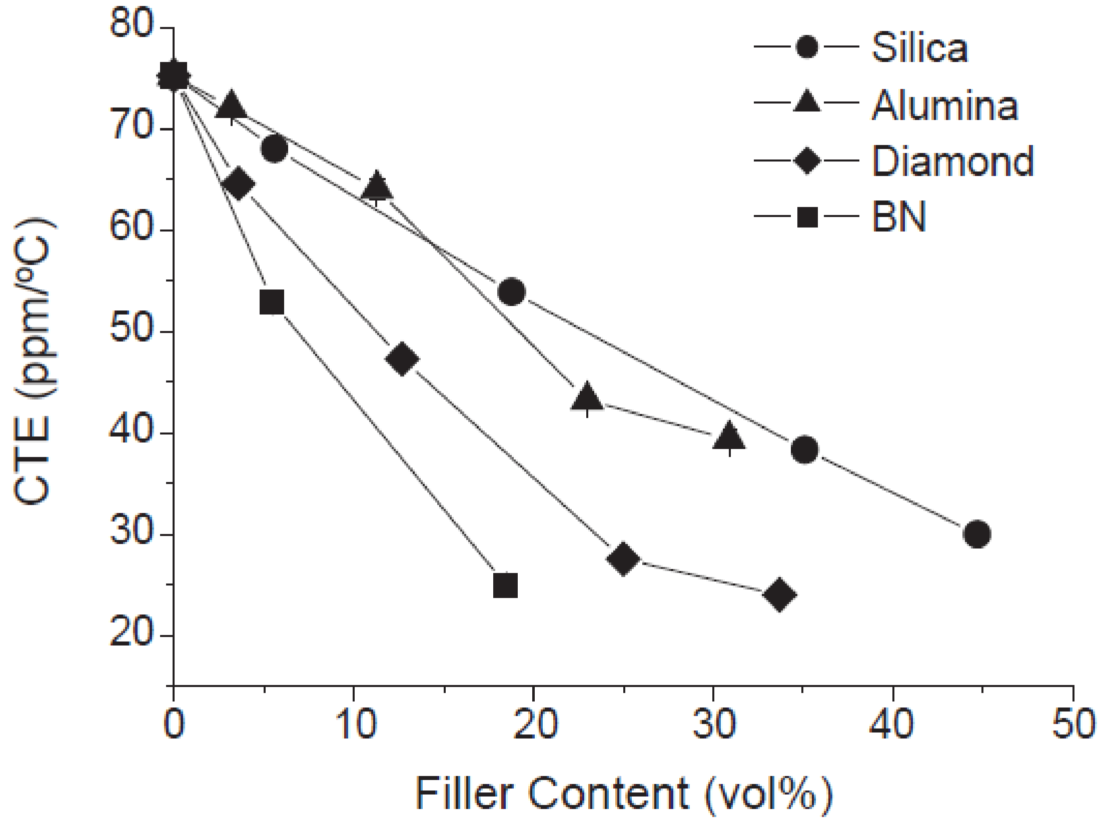
$$D = D_0 \exp\left(-\frac{E_a}{RT} \right)$$

D_0 is a constant and E_a is the activation energy

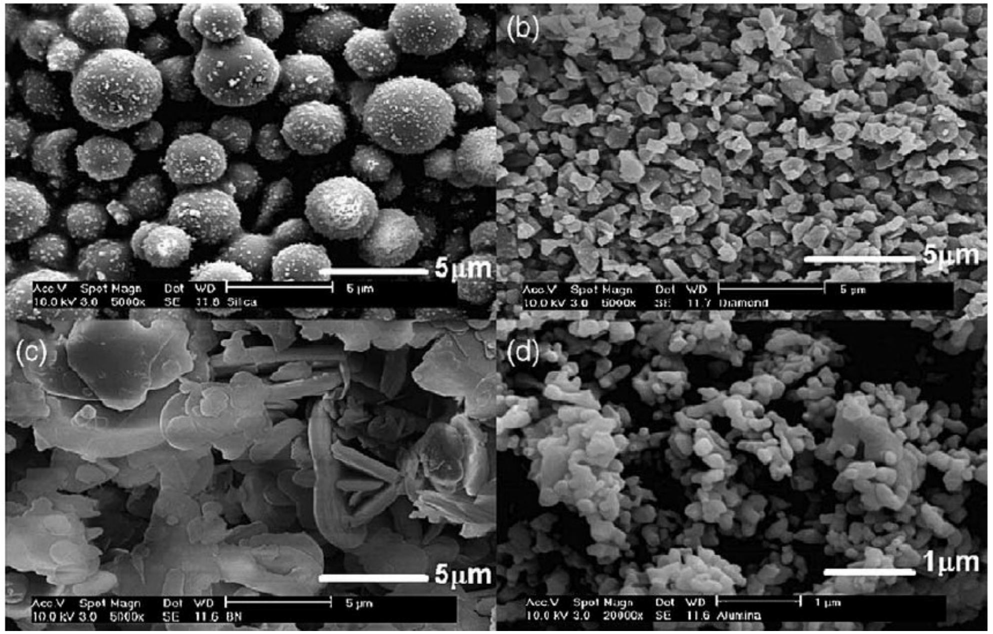
Source: Xian et. al., Journal of Materials Research and Technology, 31, (2024) 3982 https://doi.org/10.1016/j.jmrt.2024.07.123

Fillers Play a Key Role in Lowering CTE

Coefficient of Thermal Expansion



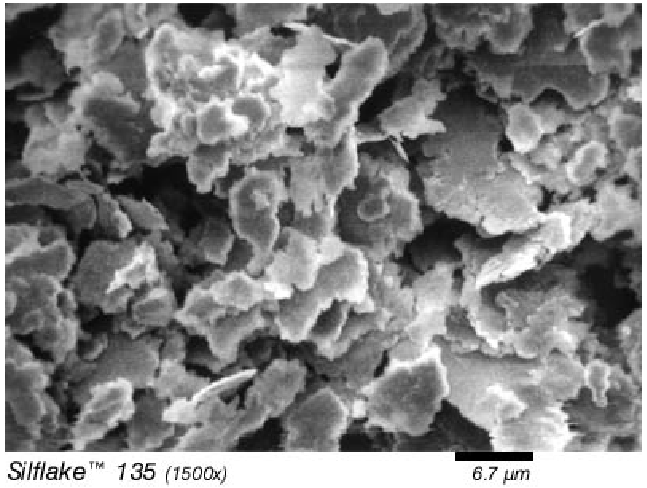
Silica Diamond



Boron nitride (BN) Alumina

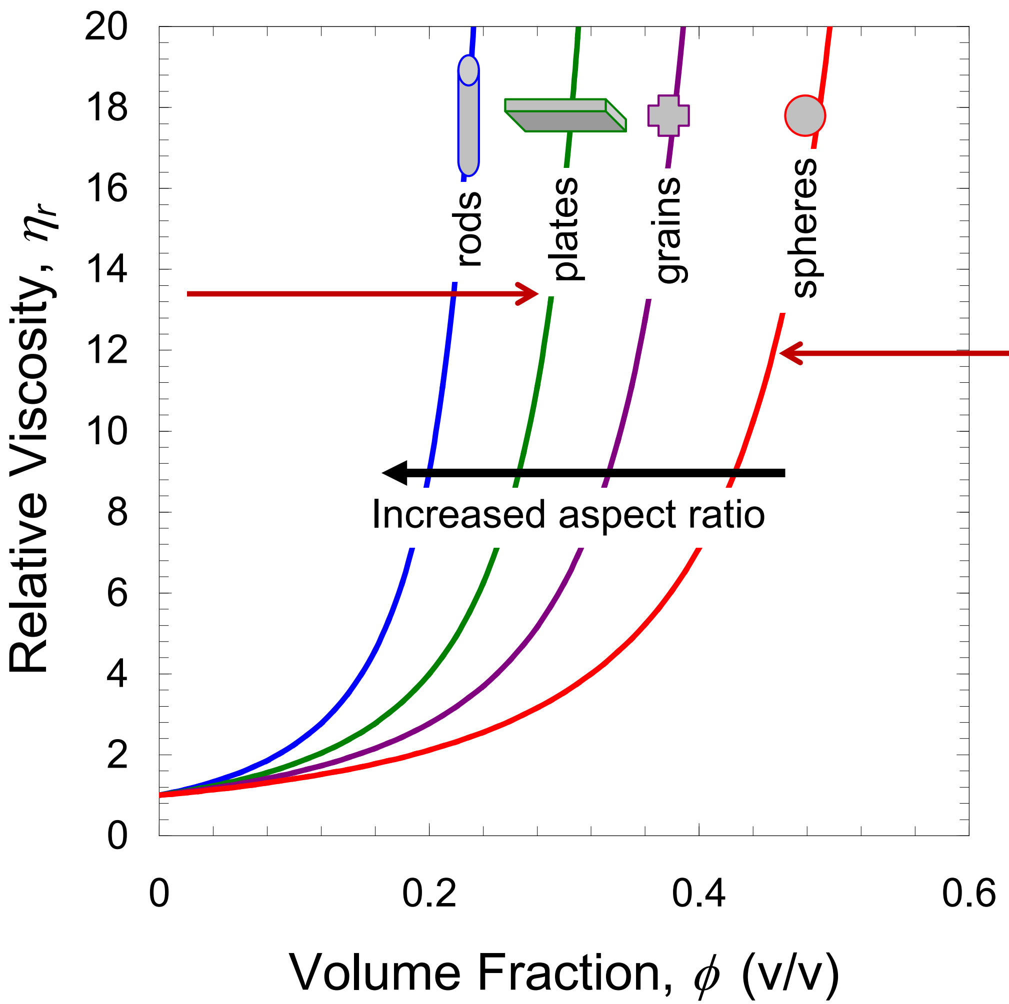
Source: W. Sun Lee, J. Yu, Diamond & Related Materials, vol. 14, p.1647-1653 (2005)

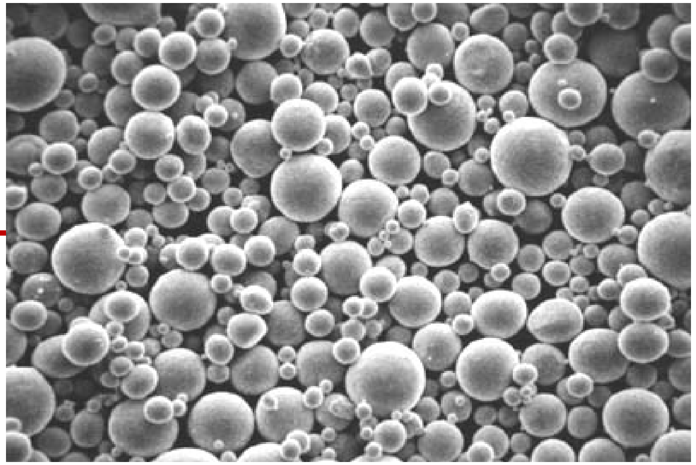
Aspect Ratio Impacts Viscosity



Silver flakes for die attach adhesives

Source: Technic

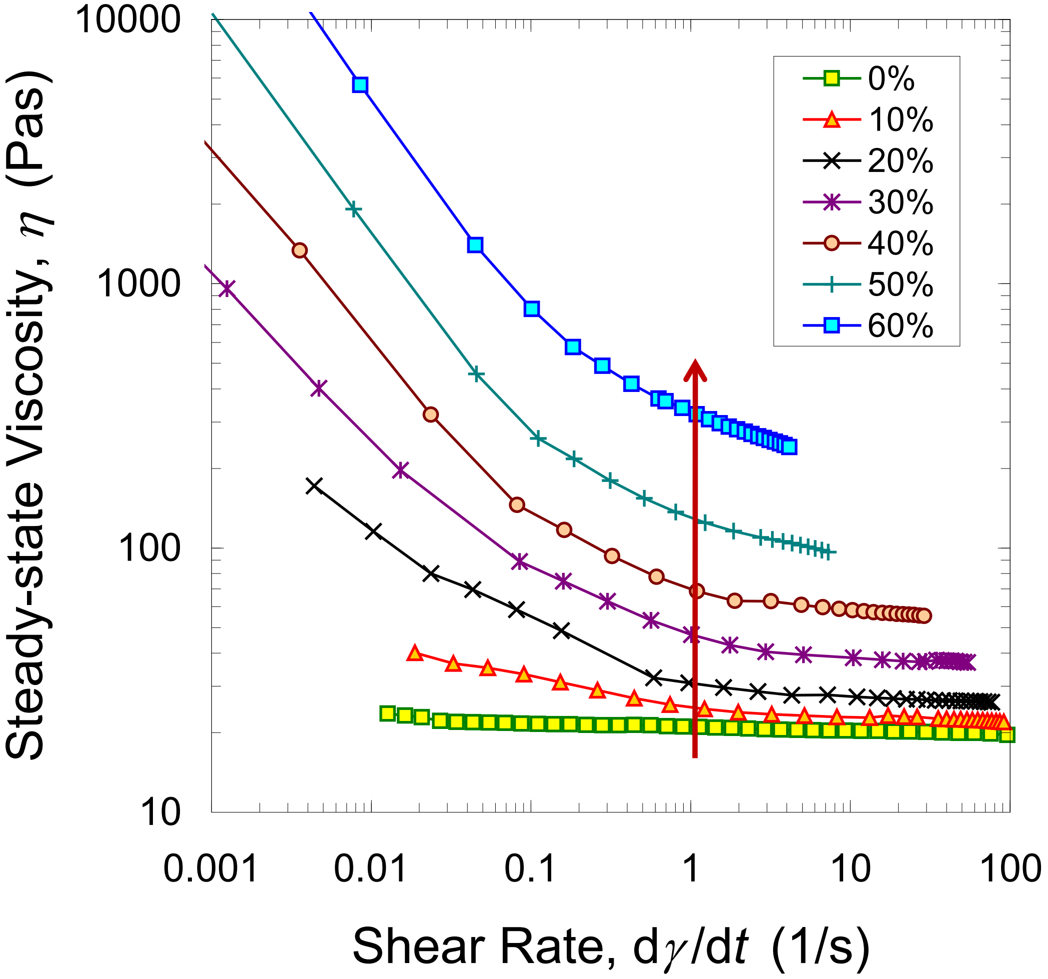




Silica spheres for underfills

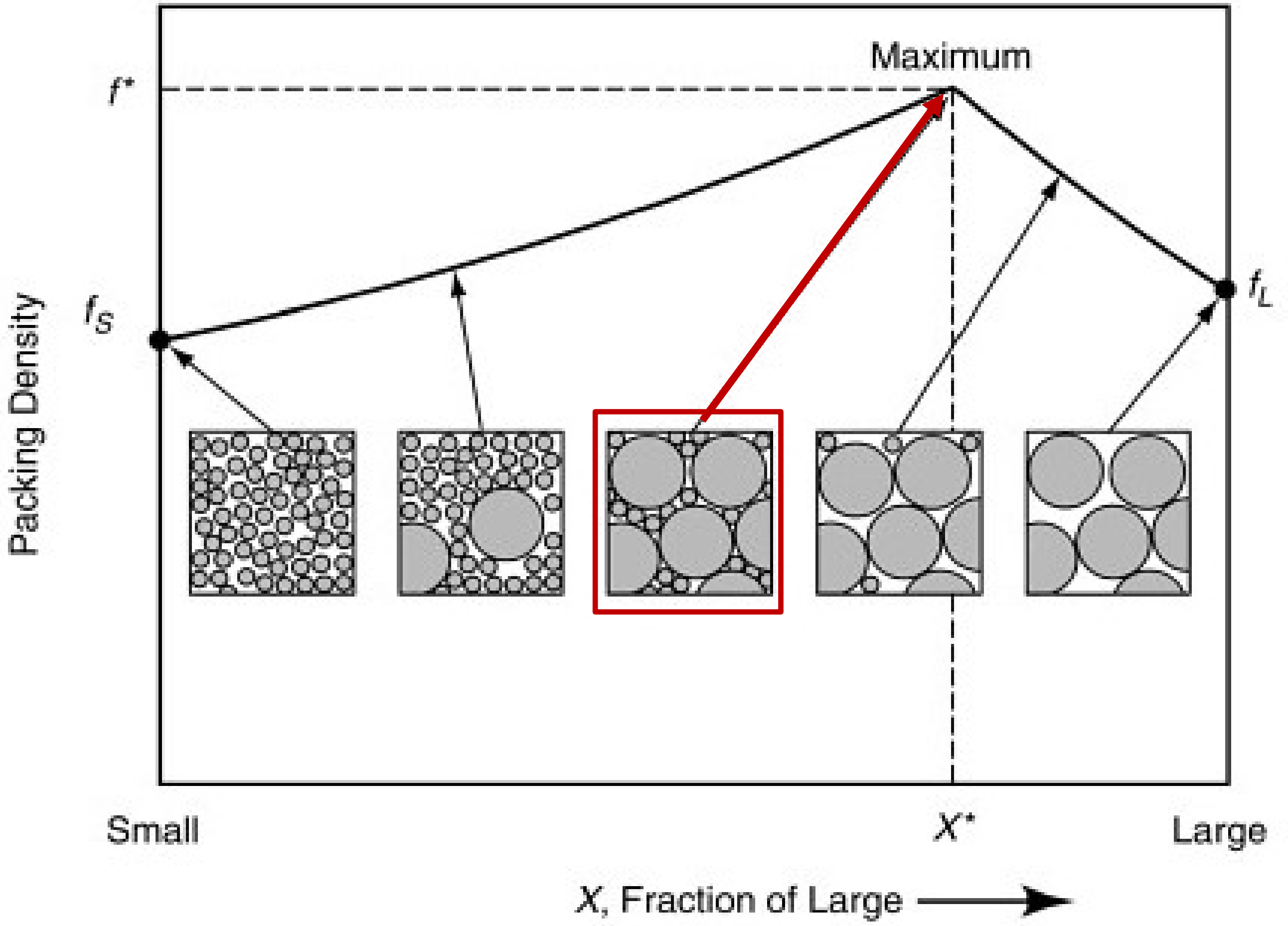
Source: Sumitomo

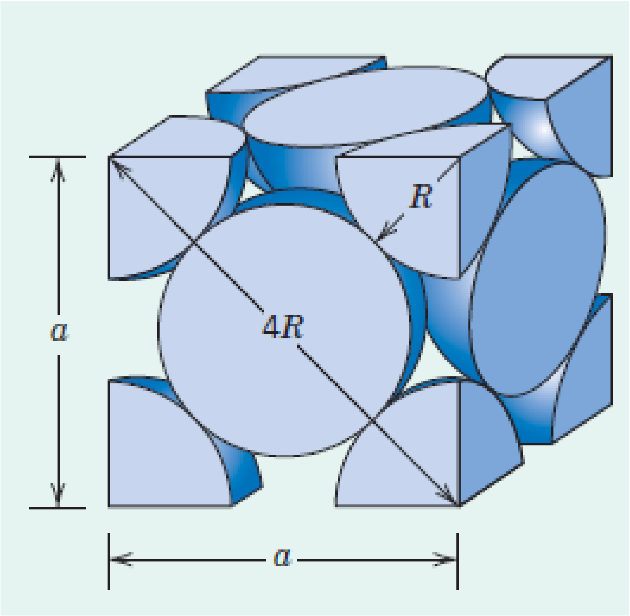
Silica Filler Loading Impacts Flow



Viscosity increases dramatically with filler loading

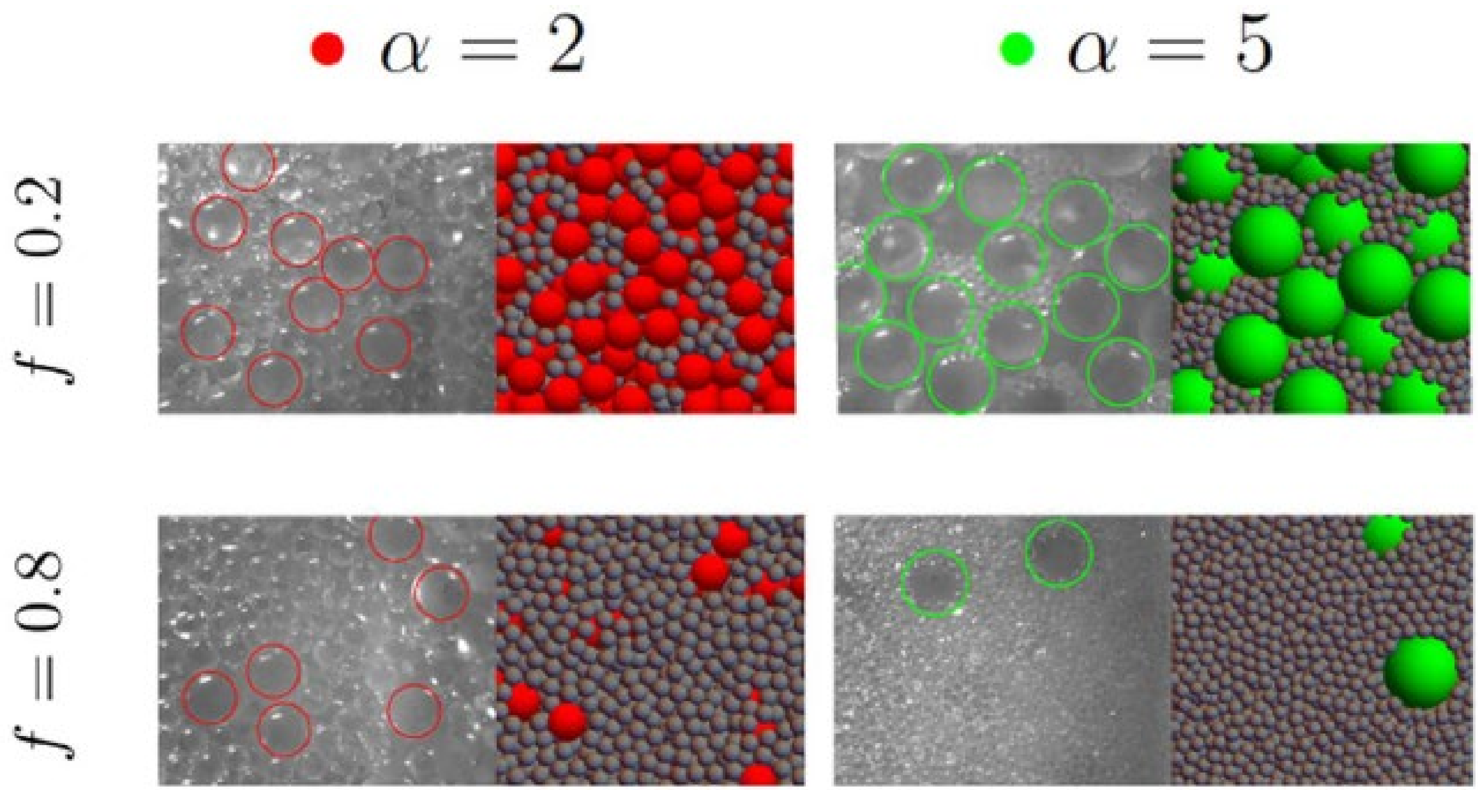
Filler Packing for a Bimodal PSD





The packing density for face centered cubic geometry is 74%

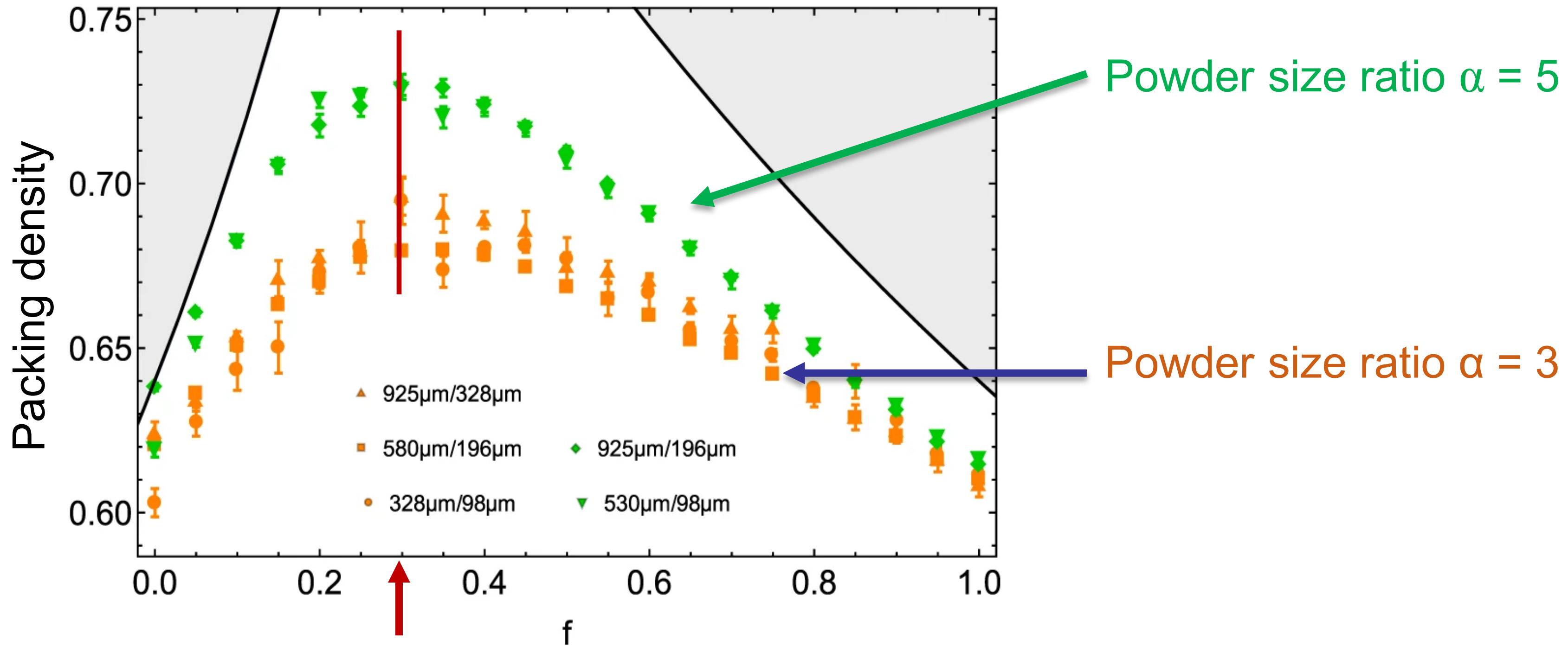
Particle Size Ratio



$$\alpha = \frac{d_L}{d_S} = \frac{diameter\ large}{diameter\ small}$$

Source: Pillitteri, S., Lumay, G., Opsomer, E. *et al.* From jamming to fast compaction dynamics in granular binary mixtures. *Sci Rep* **9,** 7281 (2019). https://doi.org/10.1038/s41598-019-43519-6

Filler Packing for a Bimodal PSD



- Maximum packing density when the volume fraction (f) of the smaller particles is ~ 0.3, when using ideal mono-size powders
- Effect is more pronounced when increasing the size ratio *α*

Source: Pillitteri, S., Lumay, G., Opsomer, E. *et al.* From jamming to fast compaction dynamics in granular binary mixtures. *Sci Rep* **9,** 7281 (2019). https://doi.org/10.1038/s41598-019-43519-6

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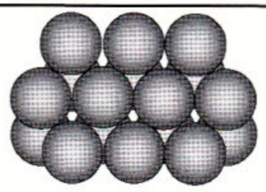
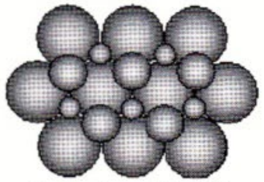
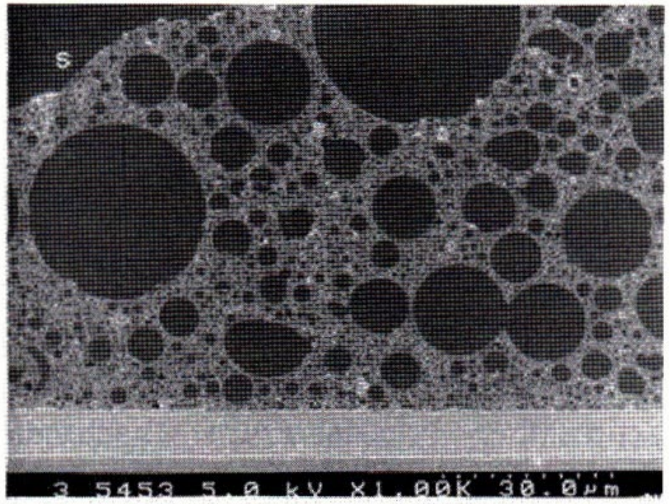
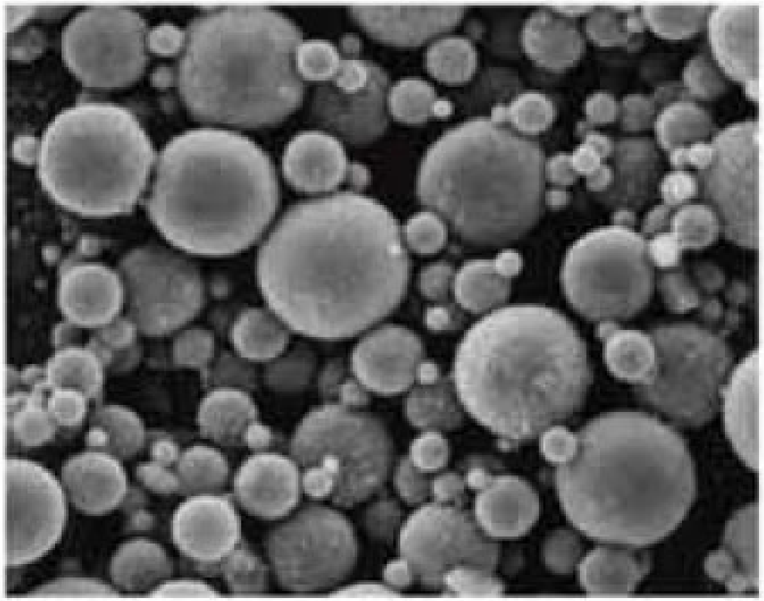
Trimodal EMC Filler Loading

Diameter of the filler	Filler Content	
R 0.414R 0.225R	100% 0 0	91.5% 6.5% 1.85%
Schematic illustration of filler packing	 Porosity: 29.5%	 Porosity: 19.0%

(a)





Source: Sumitomo

Use “generational” packing to increase the packing density

Example of Non-Hermetic Package Reliability Testing

Test	Test Condition	Test Conditions
PC Pre-Cond	JEDEC J-STD-020	MSL1 24h bake @ 125°C 192h @ 30°C/60%RH Reflow simulation (3times) with Lead free profile Tmax=260°C
TC Temp. Cycling	JESD22-A104	Ta = -55/+125°C 1000 cycles
HTSL, High Temp. Storage Life	JESD22-A103	Ta=150°C 1000h
THS, Temp Humidity Storage	JESD22-A101	Ta=85°C, 85%RH 1000h without bias
TCoB	JESD22-A103	-40/125C, 500 cycles
Drop Test	JESD22-B111	1500G , 100 drops

L3/260°C

Source: STATS ChipPAC ECTC 2017

Moisture Sensitivity Level (MSL)

	FLOOR LIFE		STANDARD	
LEVEL	TIME	CONDITION	TIME (hours)	CONDITION
1	Unlimited	≤30 °C/85% RH	168 +5/-0	85 °C/85% RH
2	1 year	≤30 °C/60% RH	168 +5/-0	85 °C/60% RH
2a	4 weeks	≤30 °C/60% RH	696[2] +5/-0	30 °C/60% RH
3	168 hours	≤30 °C/60% RH	192[2] +5/-0	30 °C/60% RH
4	72 hours	≤30 °C/60% RH	96[2] +2/-0	30 °C/60% RH
5	48 hours	≤30 °C/60% RH	72[2] +2/-0	30 °C/60% RH
5a	24 hours	≤30 °C/60% RH	48[2] +2/-0	30 °C/60% RH
6	Time on Label (TOL)	≤30 °C/60% RH	TOL	30 °C/60% RH

Holy Grail (Level 1)

Most Common (Level 3)

Moisture Pre-conditioning (Standard columns)

MSL Nomenclature:

- Level
- Reflow temperature

Example:
L3 260°C

Source: JEDEC Std-020D.1

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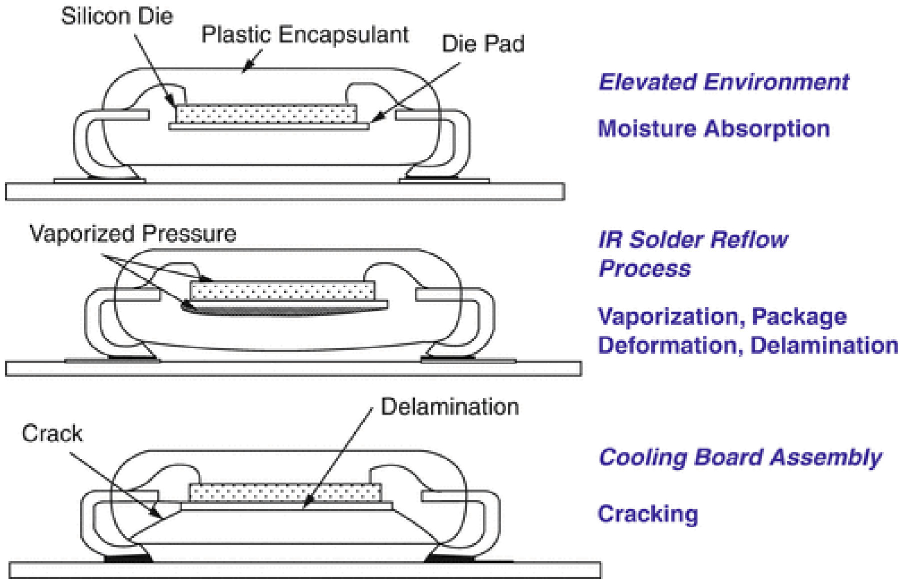
After Reflow Inspect Package for Damage

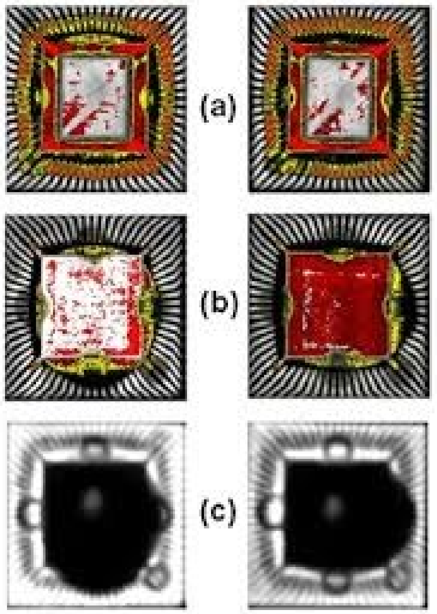
- Popcorning
  - refers to a failure mode where a component, usually a plastic-encapsulated microcircuit, cracks or delaminates due to rapid vaporization of absorbed moisture during the high temperatures of the reflow process



Source: Yi, S. (2014). Hygrothermally Induced Residual Stresses and Failures in Plastic IC Packages During Reflow Process. In: Hetnarski, R.B. (eds) Encyclopedia of Thermal Stresses. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-2739-7_894

<u>Test Methods</u>

- Visual inspection
- CSAM
- Cross-sectioning
- Electrical test



Scanning Acoustic Microscope (CSAM) images of PBGA after reflow showing delamination (red)

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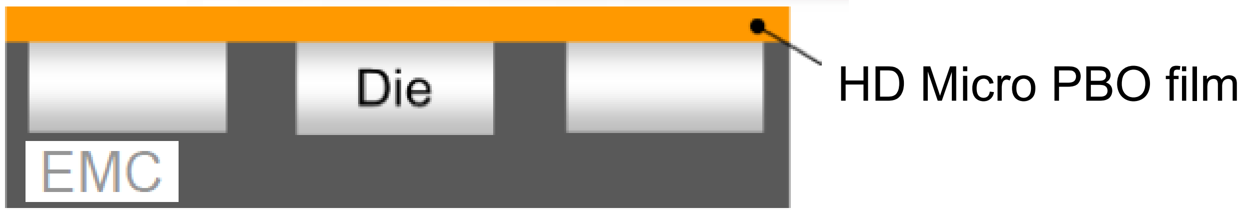
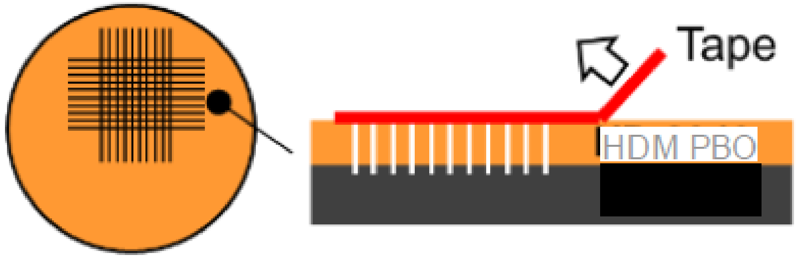
HD Microsystems PBO Adhesion Testing



Cross-section of FOWLP

Cross cut test

Cross cut to dielectric



Condition		Result ※
Pressure Cooker Test	100 h	100/100
	300 h	100/100
	500 h	100/100

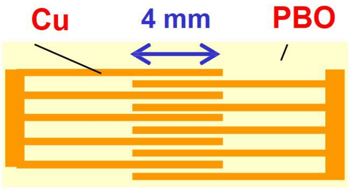
※100/100: all pieces remained after the testing (No failure)

Source: SEMICON Taiwan 2014, Masay Toba, Hitachi Chemical Co., Ltd.

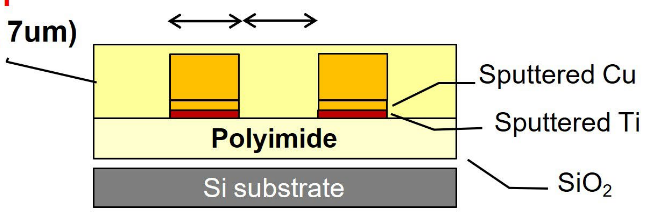
Source: HD Microsystems

Biased HAST Reliability – Two Layer Fine Pitch

Structure of test vehicle



Top view

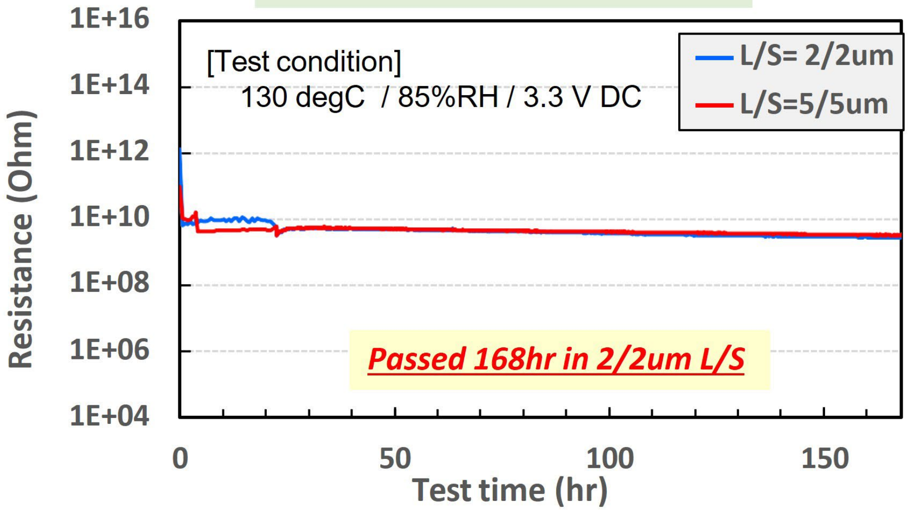


X-sectional view

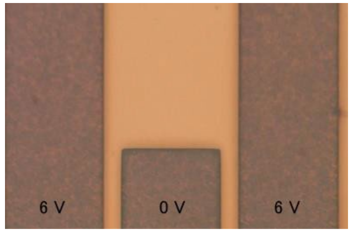
HD8961 PBO

Test results

Resistance after bias-HAST



Appearance after bias-HAST (2/2um L/S)

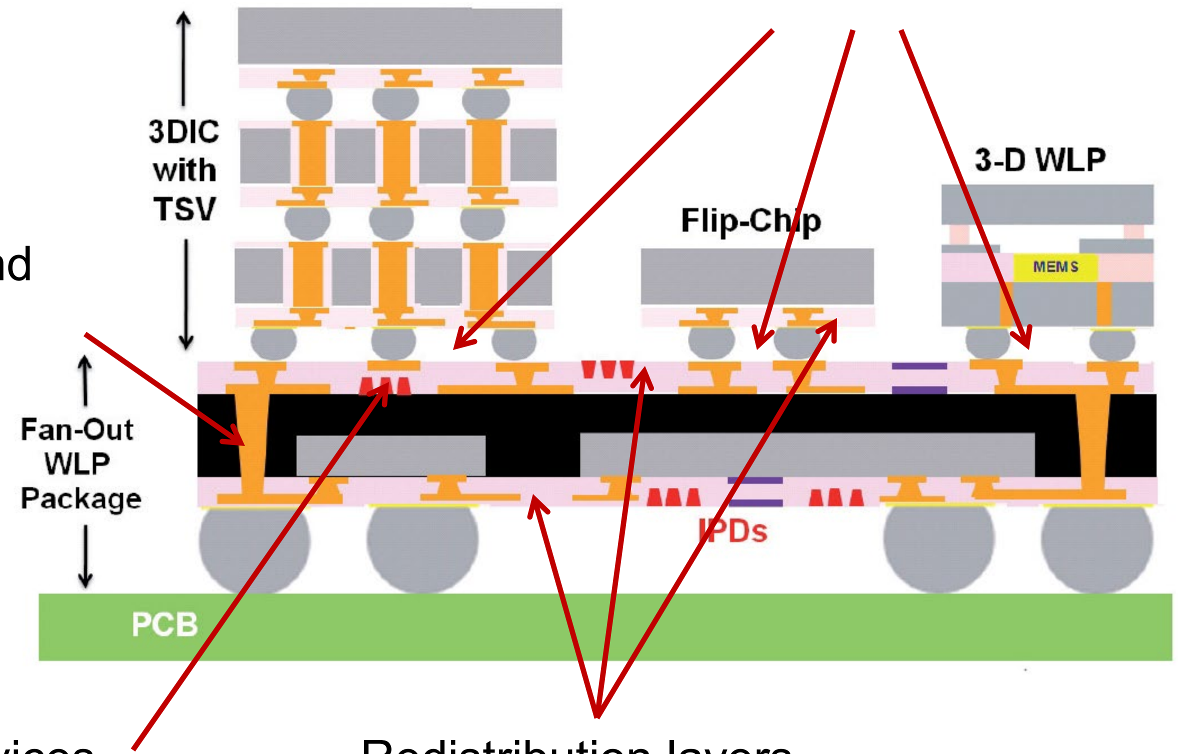
Sample	Result	Appearance after HAST
HD8961 (200ºC/1h cure)	No short circuit No dendrite No corrosion No delamination	

- HD8961 kept good resistance after <u>168h b-HAST in 2/2 and 5/5um L/S</u>
- No significant appearance change in Cu electrode after bias-HAST

Source: HD Microsystems

Polymers are Key Heterogeneous Integration Enablers

Thu-Via technology
- Laser friendly mold compound



Integrated passive devices

Redistribution layers

Source: Yole Developpment

Summary

- Thermosetting polymers are used extensively in advanced electronic packaging
- Processing and extensive materials toolbox established
- Provides a cost-effective method to connect semiconductor chips to substrates and printed circuit boards
- Fillers play a key role in tailoring rheology and mechanical properties
- Drive to use thermosets with lower moisture in improve reliability
- Reliability testing designed to stress the polymeric materials
  - Identify polymer issues
  - Identify processing issues (i.e., interfaces)