Chapter 15

Sealing and Encapsulation

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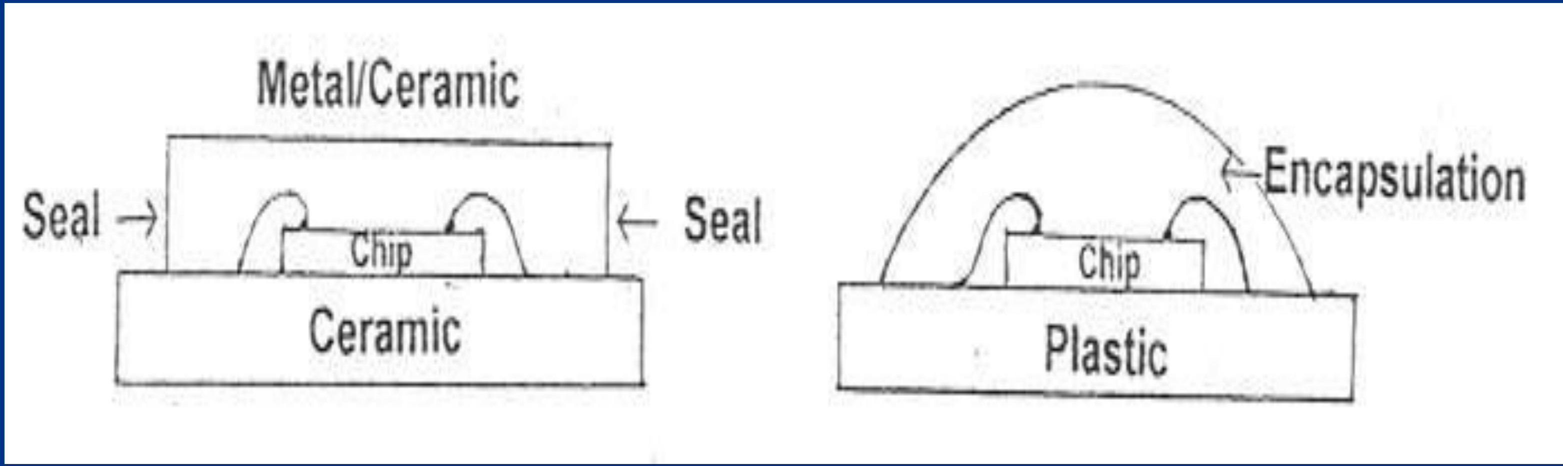
What is sealing and what is encapsulation?



- Two protection techniques:
  - **Sealing:**
    - IC devices are protected with *inorganic* materials (metal or ceramic).
    - Protection is *hermetic*.
  - **Encapsulation:**
    - IC devices are protected with *organic* materials (polymeric encapsulant).
    - Protection is *non-hermetic* typically done by means of low temperature polymers (either in the form of molding compound or liquid underfill).

Sealing vs. encapsulation

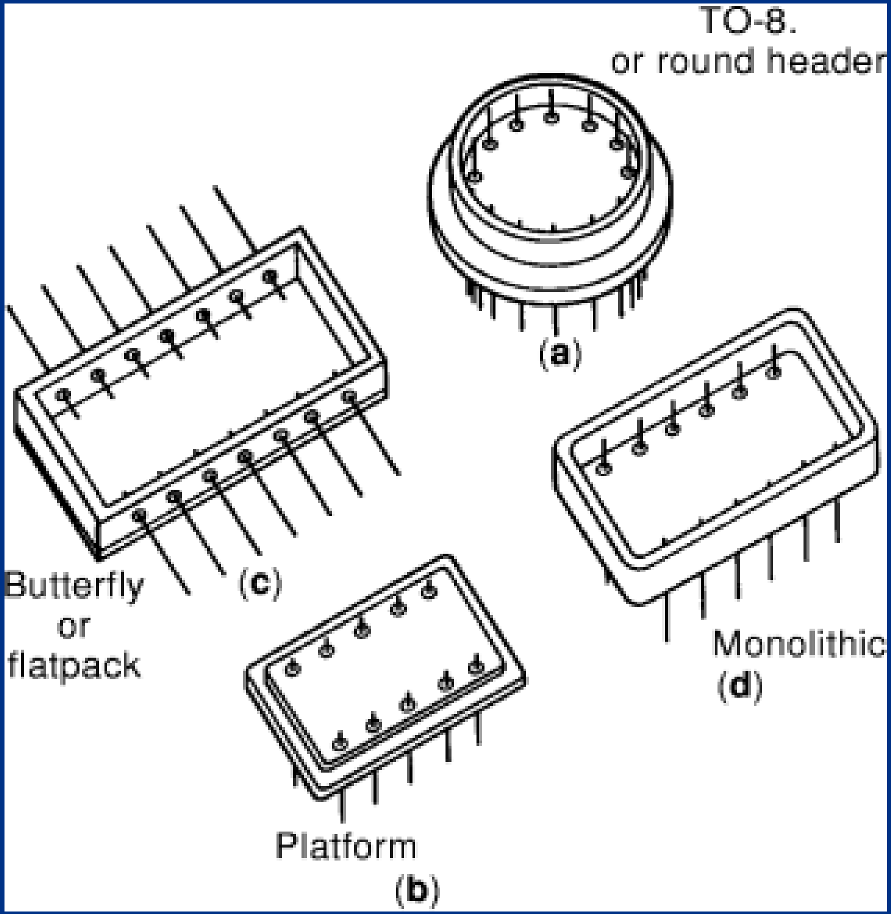
Sealing

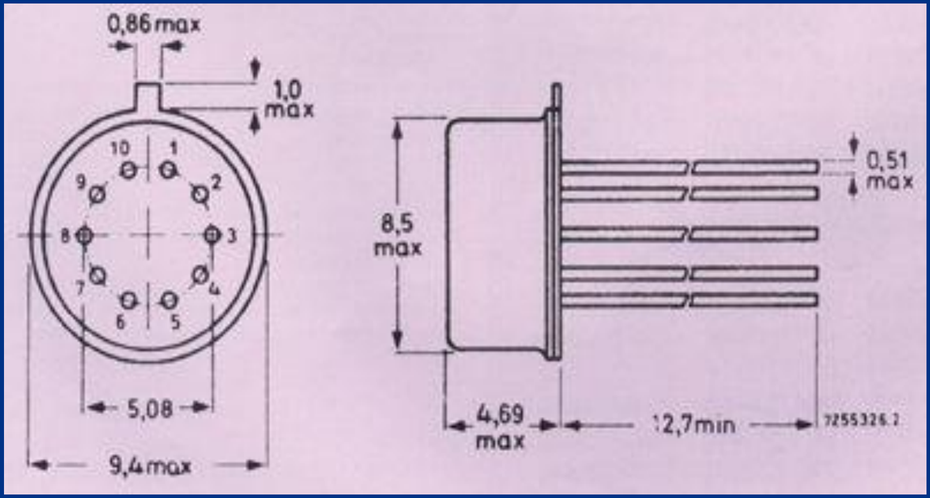
- *Metal packaging*
- Hermetic
- Inorganic materials:
  - – Metals, ceramics or glasses
- Expensive
- High reliability
- Military and aerospace applications

Encapsulation

- *Polymer packaging*
- Non-hermetic
- Organic materials:
  - epoxies, cyanate esters, urethanes, silicones
- Inexpensive
- Lower reliability
- High volume of consumer products

Metal packages



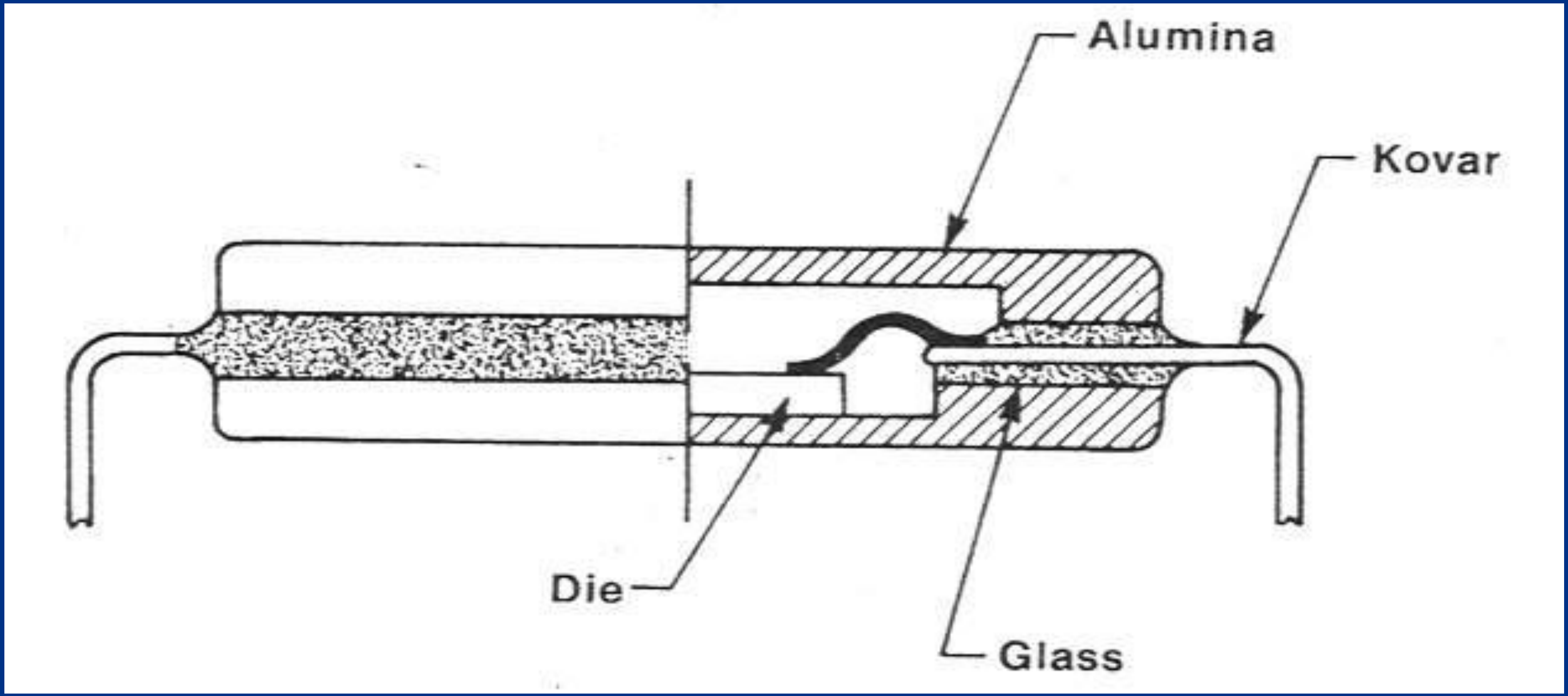


A complete metal can (round header type) package.

Common types of metal packages:

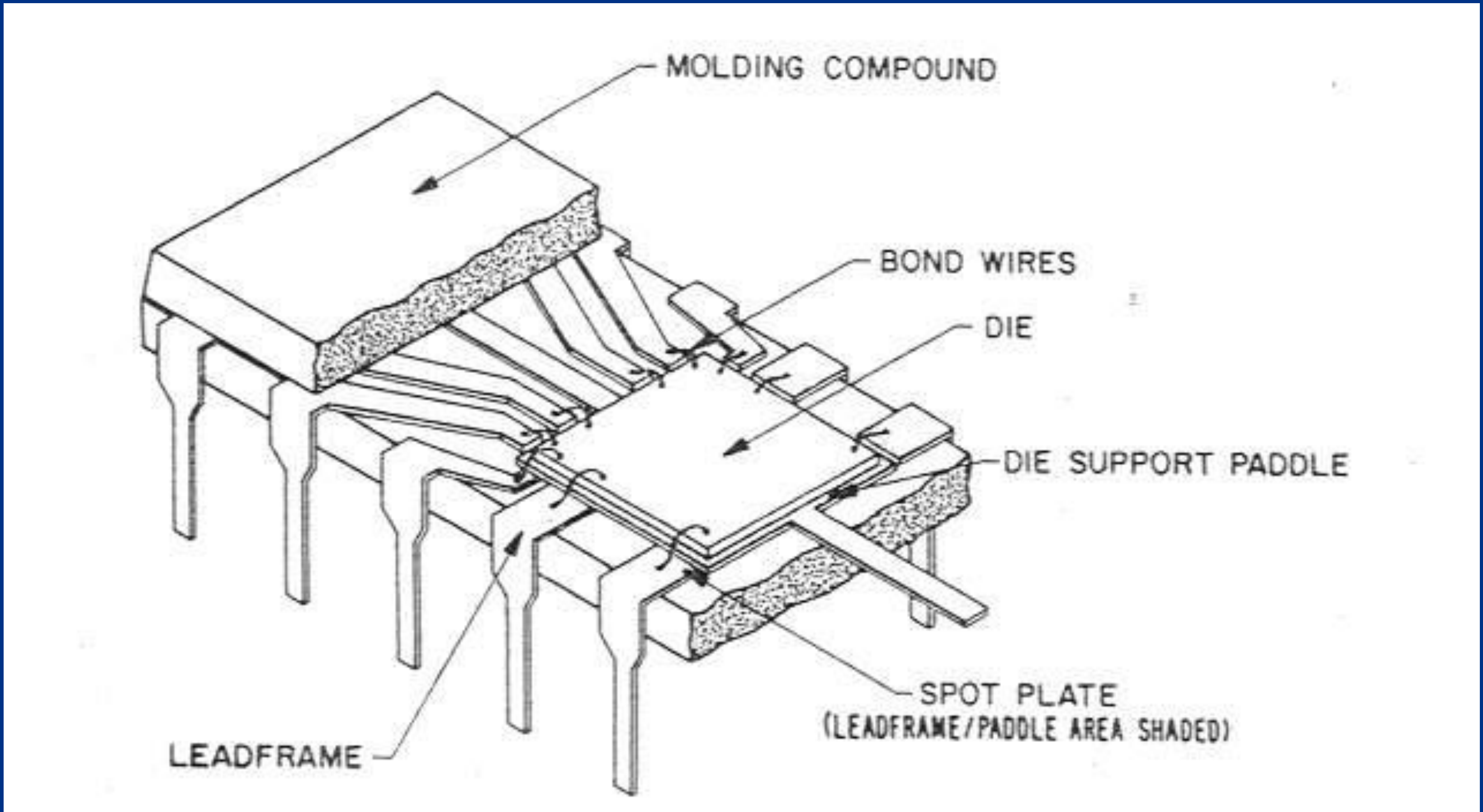
(a) round header; (b) platform; (c) butterfly; (d) monolithic.

Ceramic packages



Sealing of Cerdip ceramic package (After Nixen).

Polymer packages



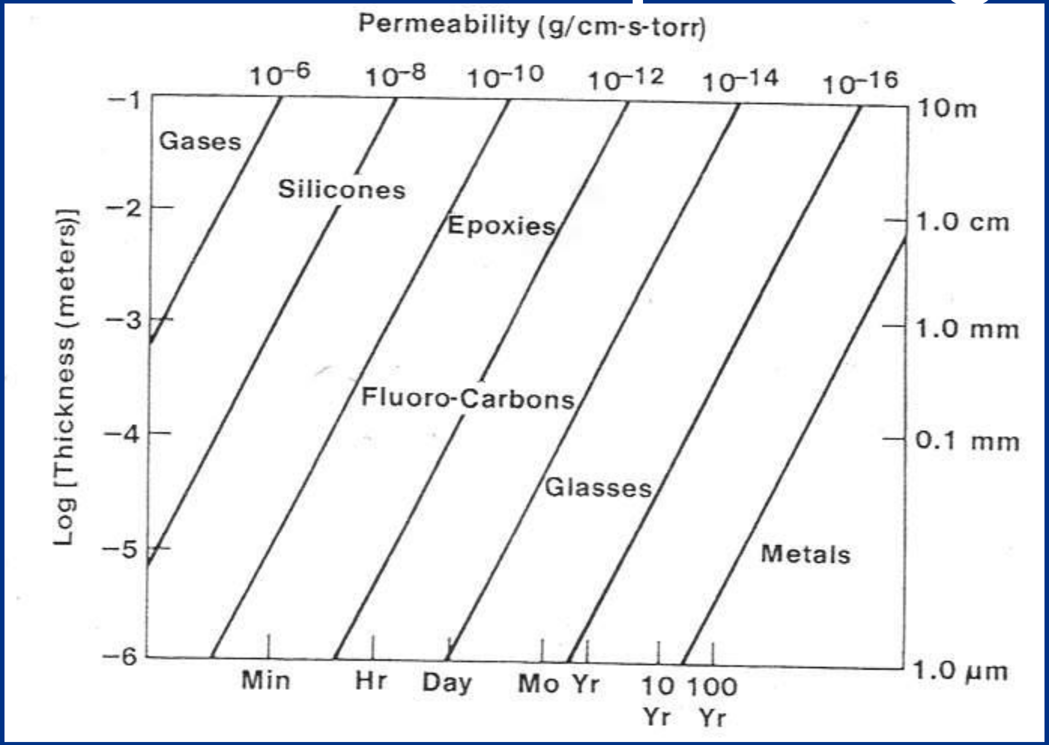
Plastic dual in-line package shows the IC device is protected by molding compound.

Epoxy molding compound

Component	Concentration (wt.% of resin)	Major function	Typical agents
Epoxy resin		Matrix-binder	Cresol-novolac
Inert fillers	68 to 80	Lower CTE, increase thermal conductivity (Al_2O_3), increase modulus of elasticity, reduce resin bleed, reduce shrinkage, reduce residual stress	Ground fused silica (widely used), alumina
Curing agents (hardeners)	Up to 60	Linear/cross-polymerization	Amines, phenols and acid anhydrides
Accelerators	Very low (<1)	Enhance rate of polymerization	Amines, imidazoles, organophosphines, ureas, lewis acids
Flame retardants	~10	Retard flammability	Brominated epoxies, antimony trioxide
Mold-release agents	Trace	Aid in release of package from mold	Silicones, hydrocarbon waxes
Adhesion promoter	Trace	Enhance adhesion with IC components	Silanes, titanates
Coloring agents	~0.5	Reduce photonic activity; reduce device visibility	Carbon black
Stress-relief additives	Up to 25	Inhibit crack propagation, reduce crack initiation, lower coefficient of thermal expansion	Silicones, acrylonitrile-butadiene rubbers, polybutyl acrylate

Components of epoxy molding compounds used in electronic packaging.

Comparing hermetic to non-hermetic packaging



Effectiveness of sealant materials-the time for moisture to permeate various sealant materials in one defined geometry (to 50 % the exterior humidity) (After Stroehle).

Common packaging materials

- Copper, silver, gold, nickel, aluminium
- Alloys (tin/lead and lead-free), Alloy-42
- FR-4, ceramic (Al_2O_3), silicon (Si), GaAs
- Polyimide, PTFE, epoxy, silicone

Important materials properties

- Electrical conductivity (or resistivity [Ωm])
- Thermal conductivity [W/m·°C]
- Thermal expansion, CTE [1/°C]
- Glass Transition Temperature T_g [°C]
- Modulus of elasticity (Young's Modulus) [Pa]

Important Materials Properties

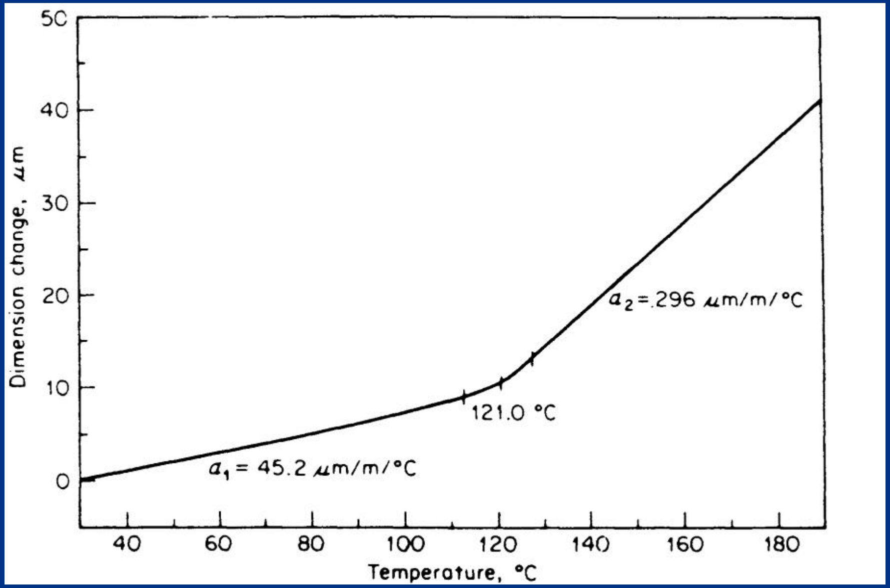
- Dielectric Strength (Breakdown Field) [V/m]
- Loss factor tan δ (Dissipation Factor) [-]
- Dielectric constant ε_r (rel. permitivity) [-]
- Melting (and processing) temperatures [°C]
- Water absorption [wt%]

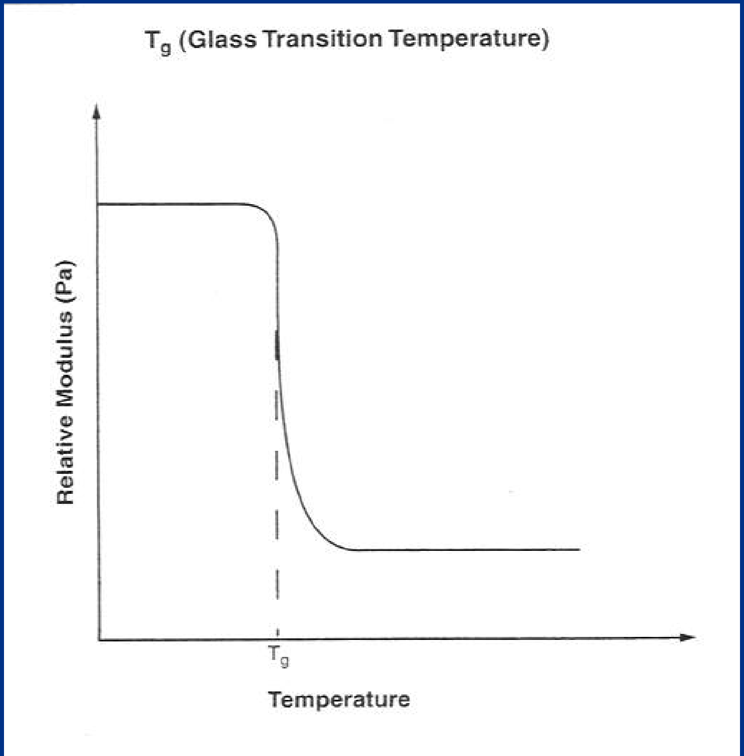
Material features

- Silver is a better electrical and thermal conductor than both gold and copper.
  - *Problem* : reacts with ambient sulphur
- Iron alloys (A-42 . . .) match the low CTE of silicon,
  - but have poor electrical and thermal conductivity,
- Ceramics are better heat conductors that polymers, and have low CTE,
  - but ε_r may still be too high for high-frequency applications

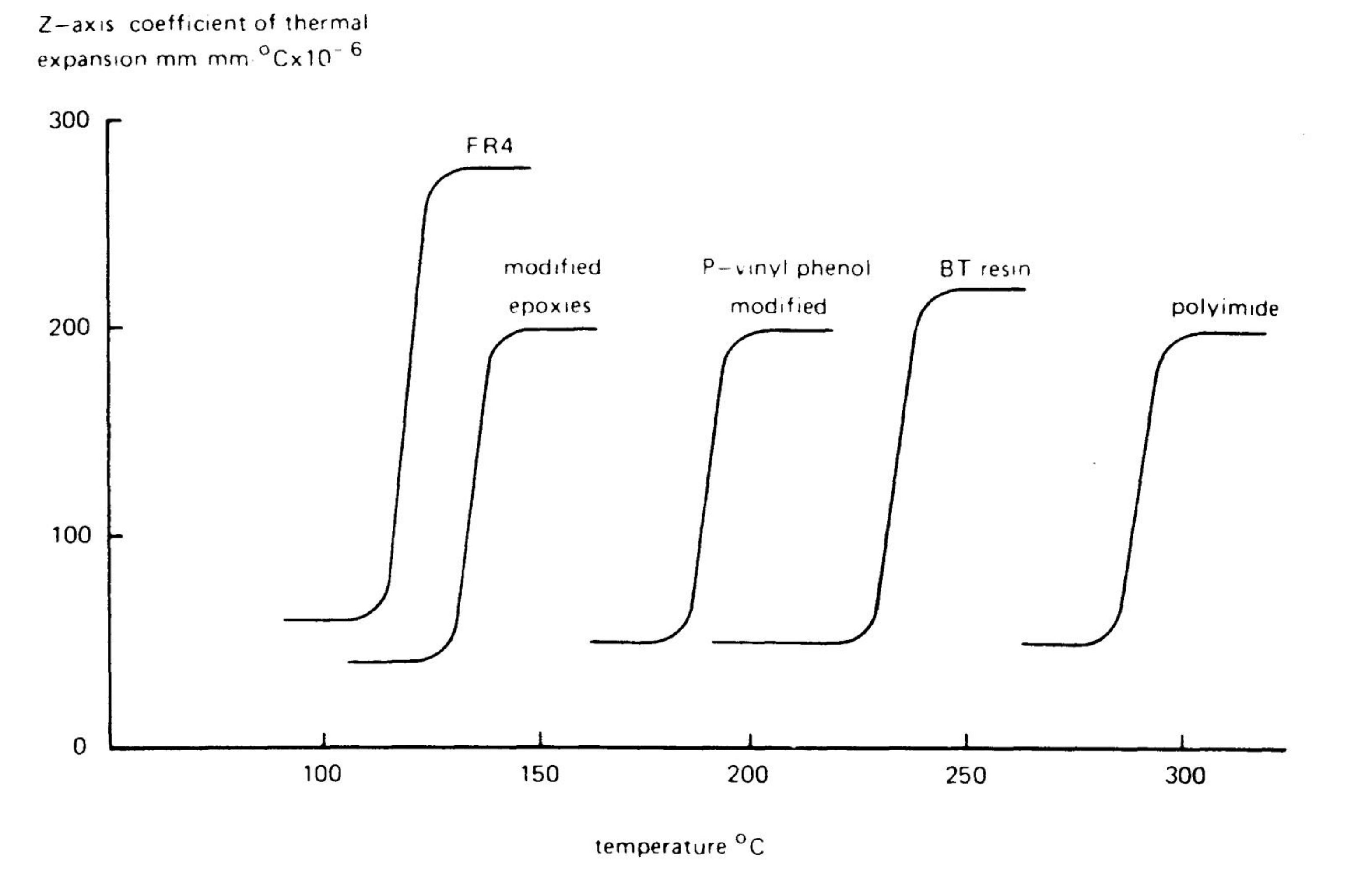
Glass Transition Temperature T_g

T_g is the temperature (usually a range) at which a polymer starts to soften”





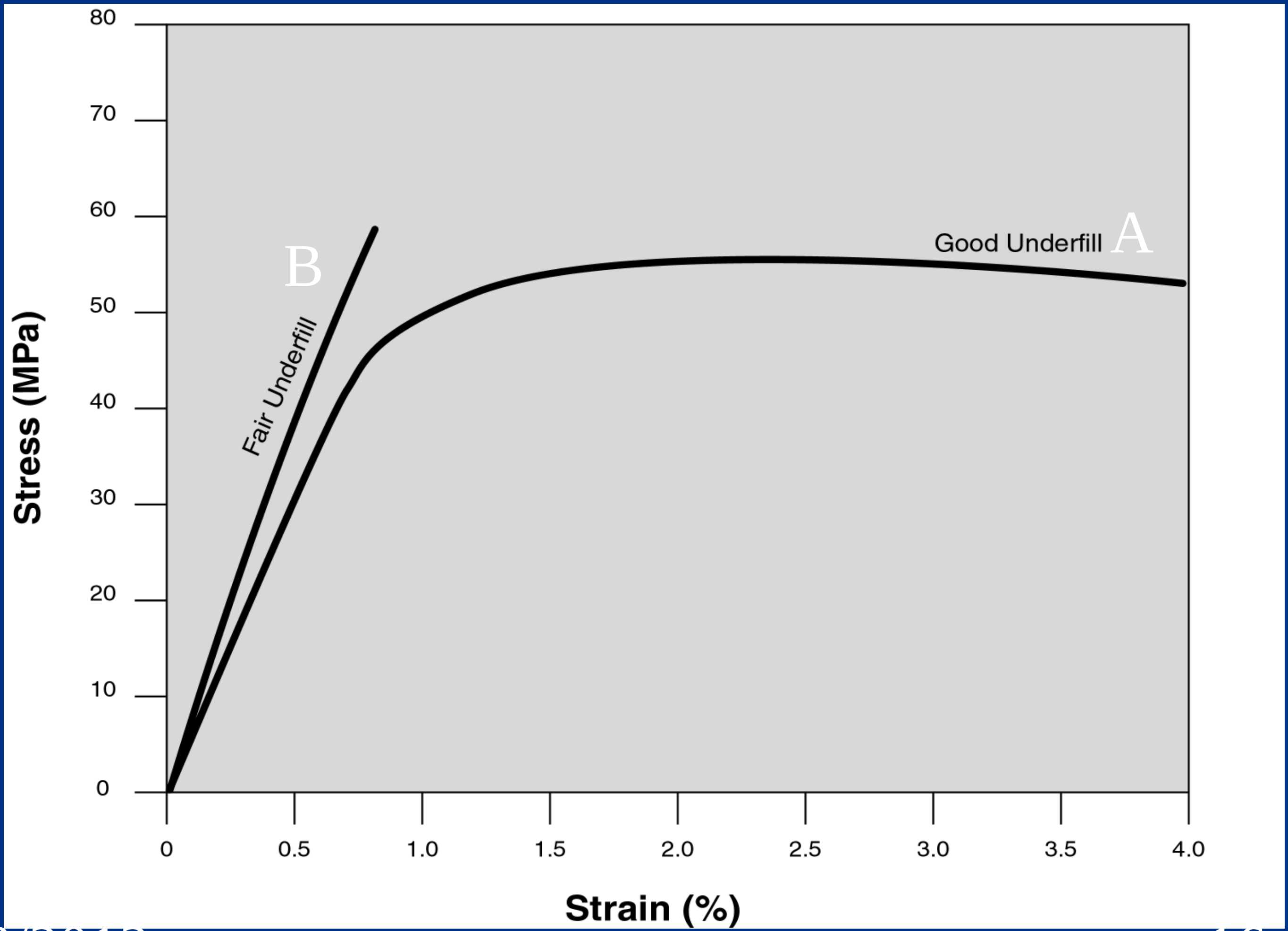
T_g of various substrate materials



Encapsulation requirements: mechanical properties

- **Thermomechanical considerations:**
  - Good CTE match,
    - Si (2.6 ppm) and molding compound (close to 2.6 ppm)
    - solder (25 ppm)/underfill (close to 25 ppm)
  - Residual stress (after cure): low residual stress is needed;
  - Addition of epoxy modifiers to reduce shrinkage.

Stress-Strain curves of encapsulation materials: good (A) and bad (B)



Encapsulation requirements: thermal properties

- **Coefficient of thermal expansion (CTE):**
  - CTE matching (compromise)
- **Glass transition temperature**:
  - Tg should be larger than intended reliability testing temperature (e.g. 125 or 150 °C) for underfills
- **Flow during encapsulation**:
  - Good flow during operation
  - Good wetting to the surfaces to be encapsulated that produce a void free filling are also considered good flow characteristics.

Encapsulation requirements: physical properties

– **Adhesion**:
  - Adhesion is defined as the measure of the strength between two interfaces.
  - Good adhesion is always required.
  - Adhesion enhancement by:
    - the addition of adhesion promoters in the encapsulation formulations to improve chemical bonding and
    - surface roughening of device-substrate interfaces by plasma etching).

Encapsulation requirements	Controlling factors (properties and processes)	Comments
Minimize mechanical and thermo-mechanical stress	Coefficient of thermal expansion (CTE), shrinkage, glass transition temperature (Tg), modulus	Stress on the device may affect electrical and/or mechanical properties. Cure time and temperature have a significant affect on stress and Tg.
Optimize electrical performance	Dielectric constant, dielectric strength, ionic purity	A high dielectric constant is important for high density application, to prevent parasitic capacitance.
Process results and repeatability	Method of application, shelf life, pot life, moisture absorption, viscosity, wet ability, homogeneity, thixotropy.	Changes in the material properties will affect processing.
Reliability	CTE, modulus, shrinkage, moisture absorption, chemical resistance, adhesion to surfaces.	Among other properties these these significantly affect reliability

Flip chip underfill – a typical formulation

Component	*Weight, %*	*Major function*
Bisphenol A diepoxy	5.8	Matrix-binder
Cycloaliphatic epoxy ERL 4221	12.5	Diluent, cross-linker
HMPA anhydride	13.8	Cross-linker, hardener
2-Ethyl-4-methyl-imidazole	0.3	Curing accelerator
Carbon black	0.1	Colour coding
Spherical silica filler	67.5	CTE reducer

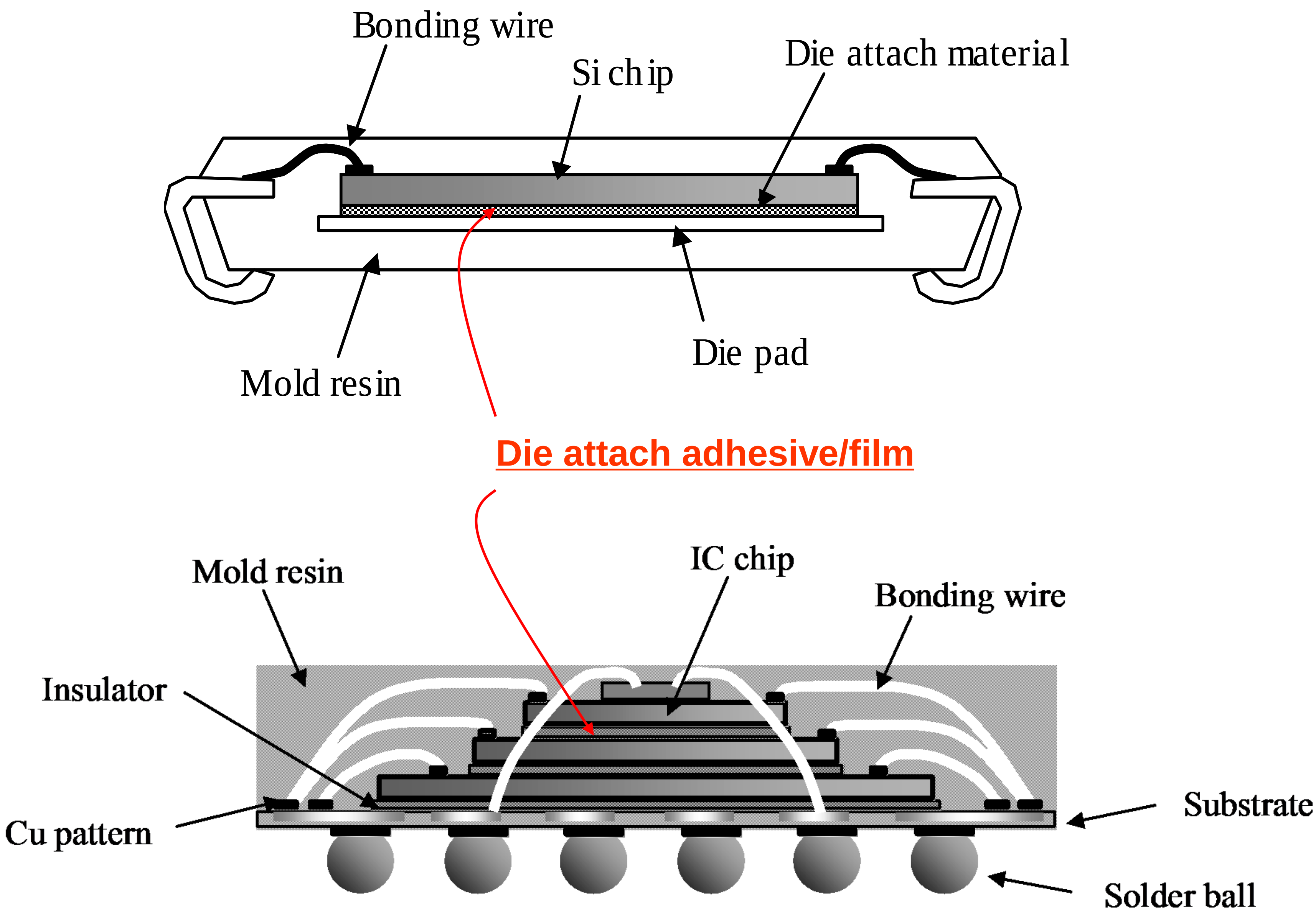
Underfill material requirements

Property	*Desirable value*	*Comments*
Flow	> 0.5 mm/s	Fast flow with no air bubble entrapment
Adhesion	> 50 MPa shear force	Key to device protection
CTE	18-30 ppm/°C	Matches CTE of solder
Modulus	5-8 GPa	Provides mechanical coupling
Tg	> 130 °C	Dimensional stability
Stress after cure	< 10 Mpa	Minimizes internal stress caused by shrinkage of polymer
Water pickup	< 1 %	Reduces moisture-induced failures
Ionic impurities Na^+, K^+,…	< 10 ppm	Prevents corrosion & metal electromigration
Thermal stability	> 260 °C (1% wt loss)	Prevent underfill decomposition during solder reflow
Curing time at 160 °C	< 0.5 hr	Good product output
Volatility during cure	< 1 % weight loss	Maintain correct stoichiometry
Pot life at RT	> 8 hr	Long stable usage life

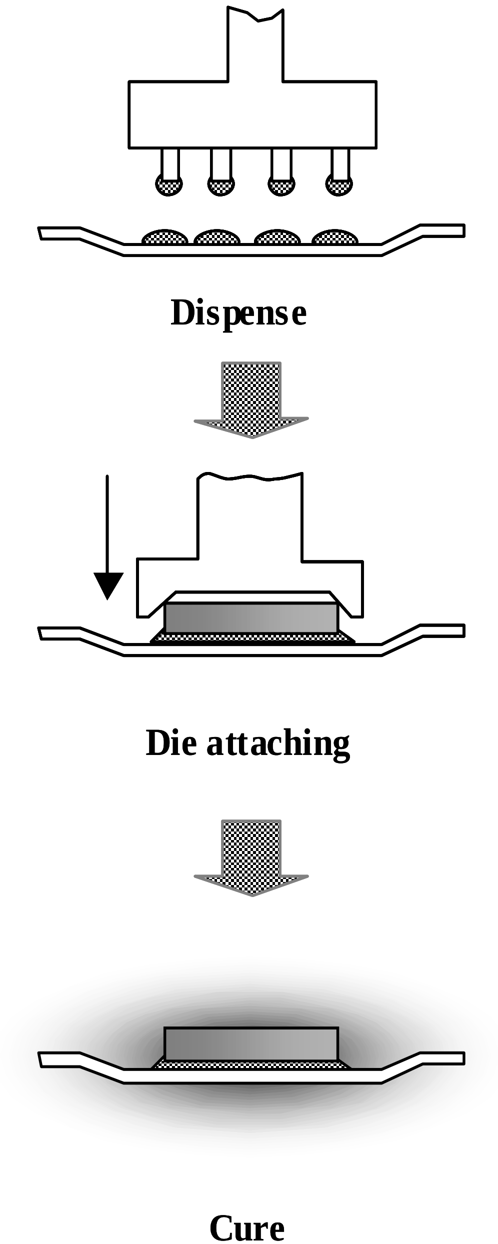
´Table 15.1 Flip chip underfill material requirements

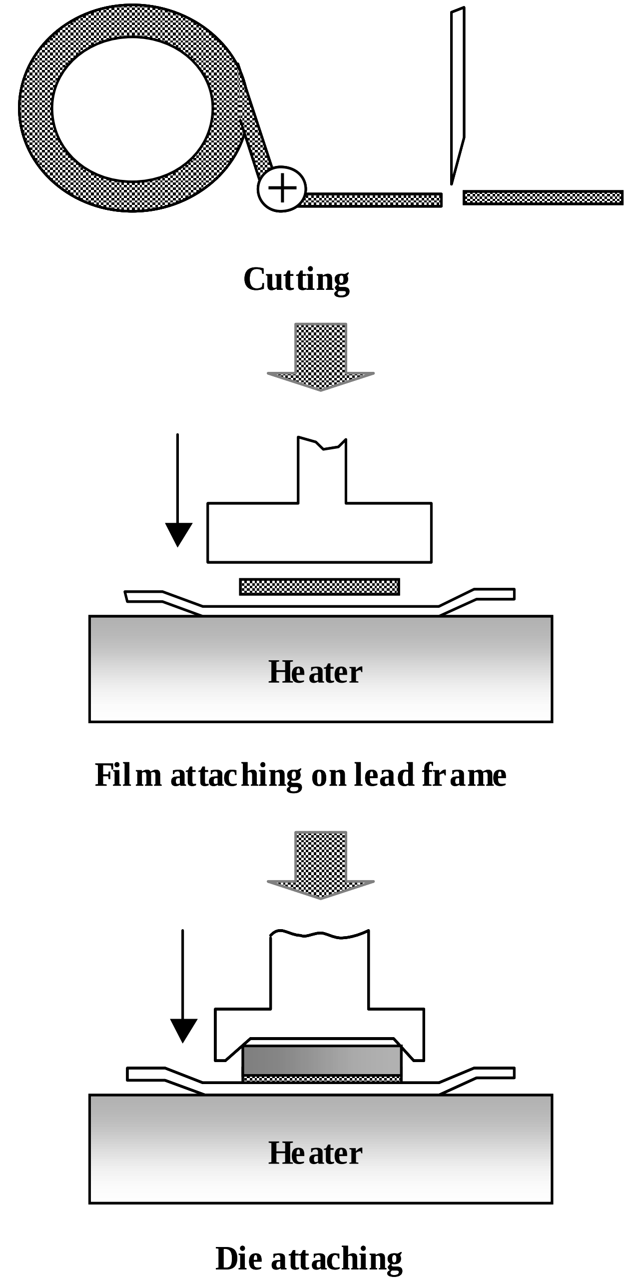
Encapsulation processes

Die Attach Adhesive/Film

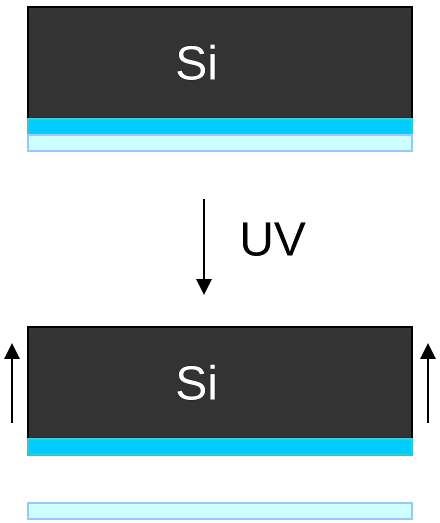


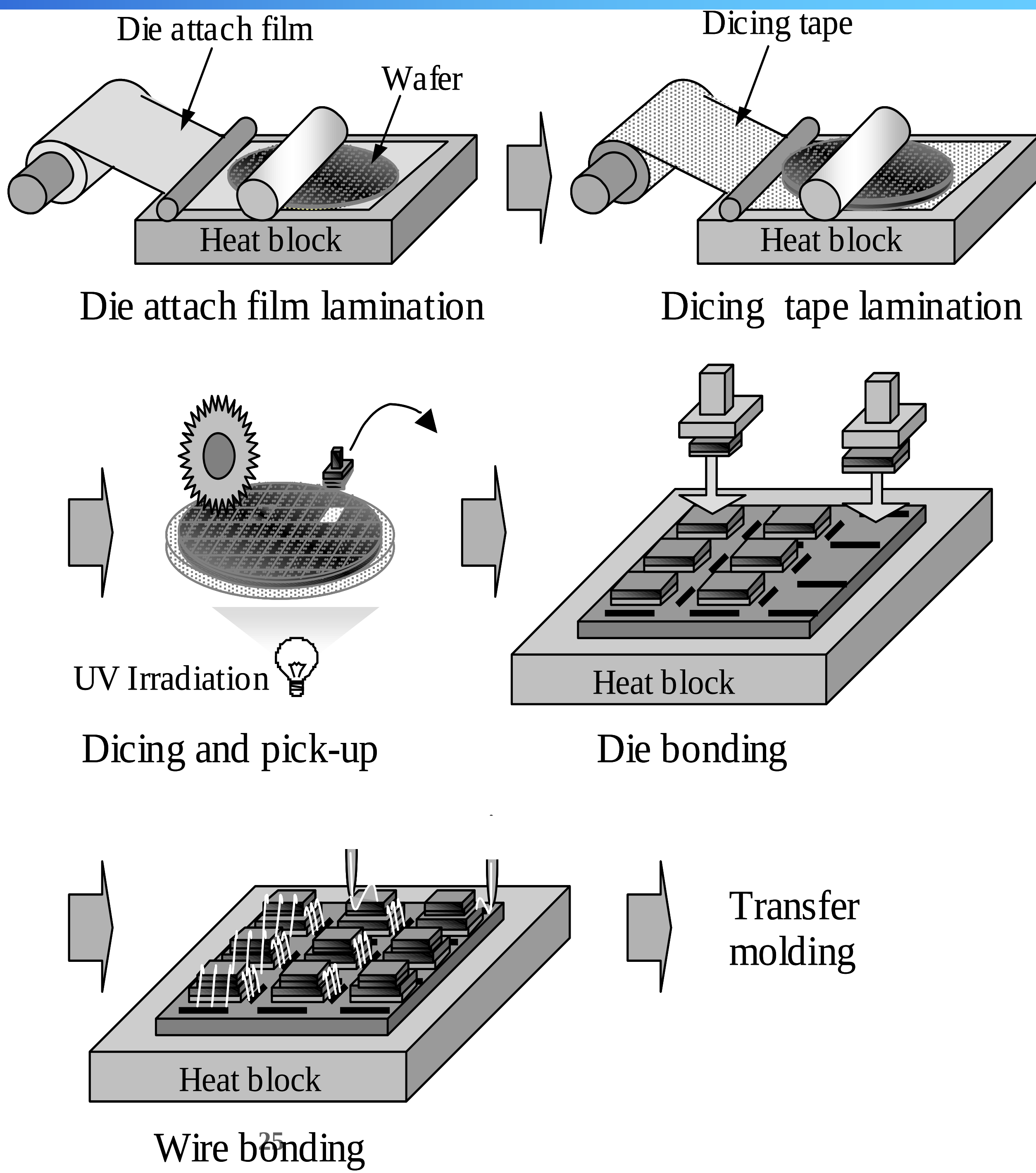
Die Attach Adhesive/Film



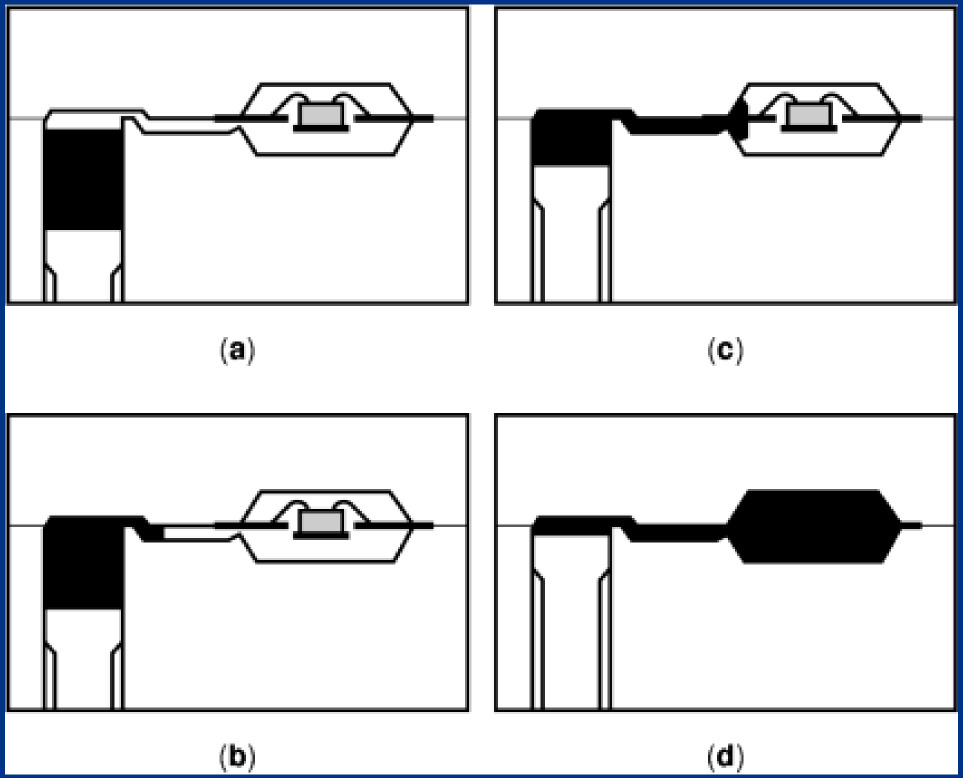


Die Attach Film





Transfer molding



Schematic of the transfer molding process (cross section of the closed mold).
The illustration shows only one cavity with a lead-frame and wired die).

- (a) The mold is closed and the preform of molding compound (MC) is in the transfer pot.
- (b) The transfer ram begins to transfer the warm MC into the molding runners.
- (c) The MC has now entered the cavity through the gate.
- (d) The cavity is completely filled and the pressure increases to compress any remaining air pockets.

Transfer molding

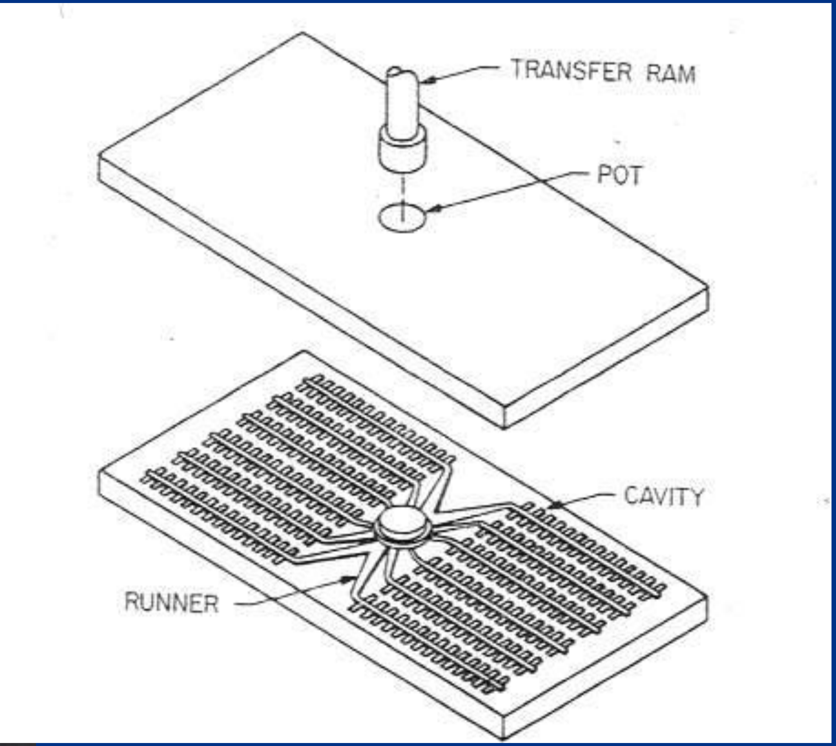
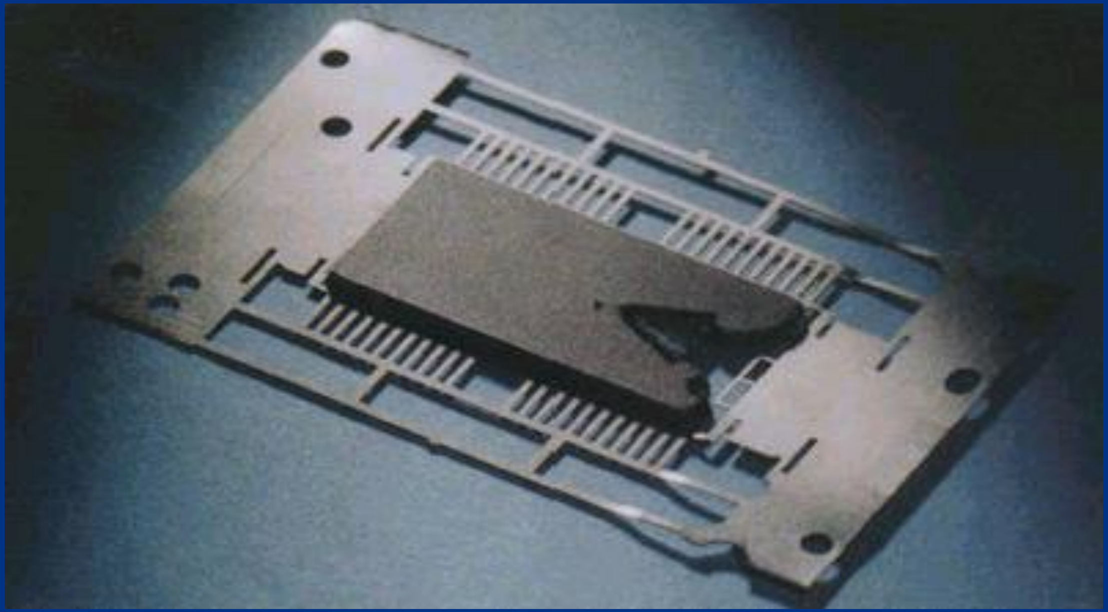


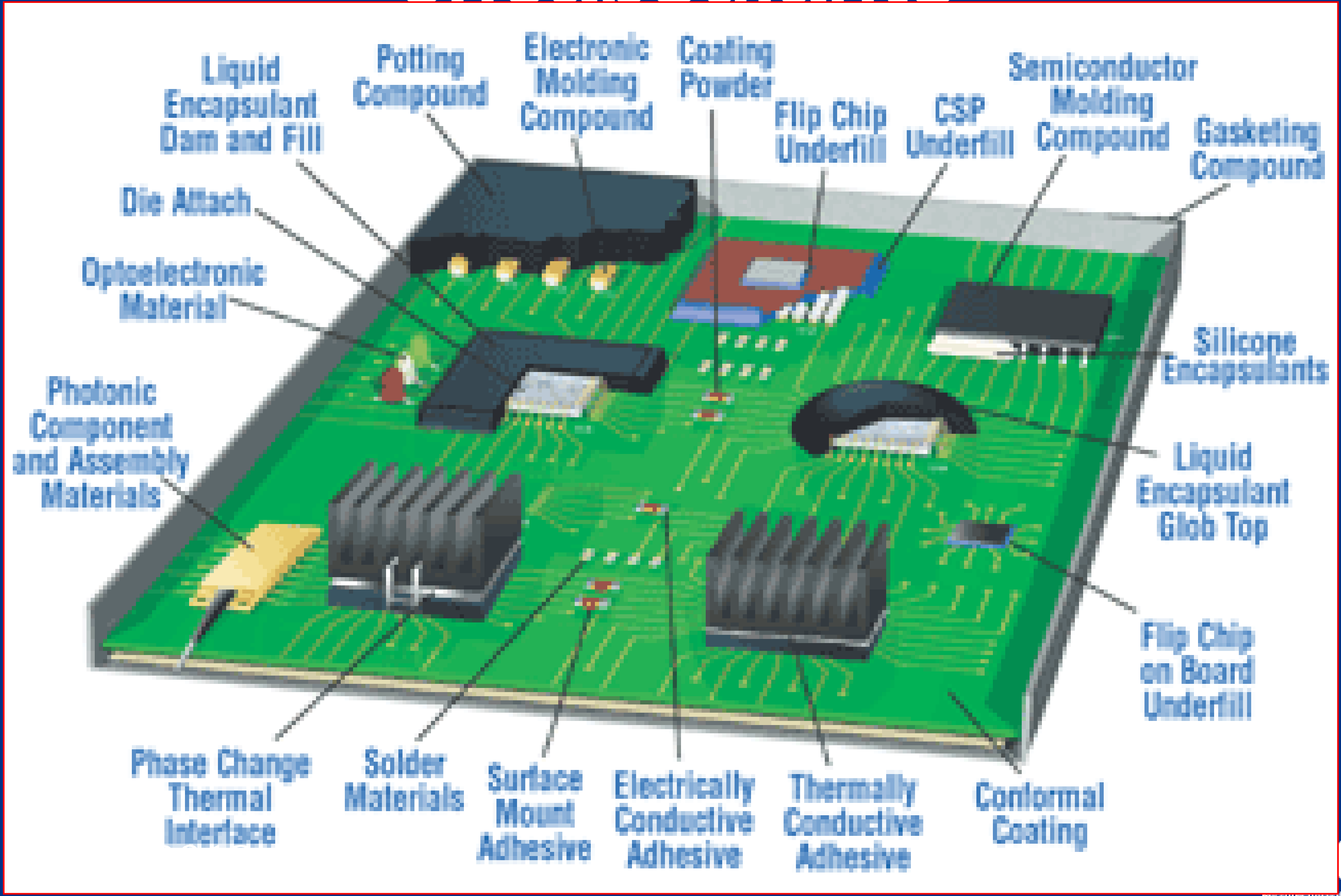
Photo and schematic of a 168 cavity transfer mold.

Transfer molding

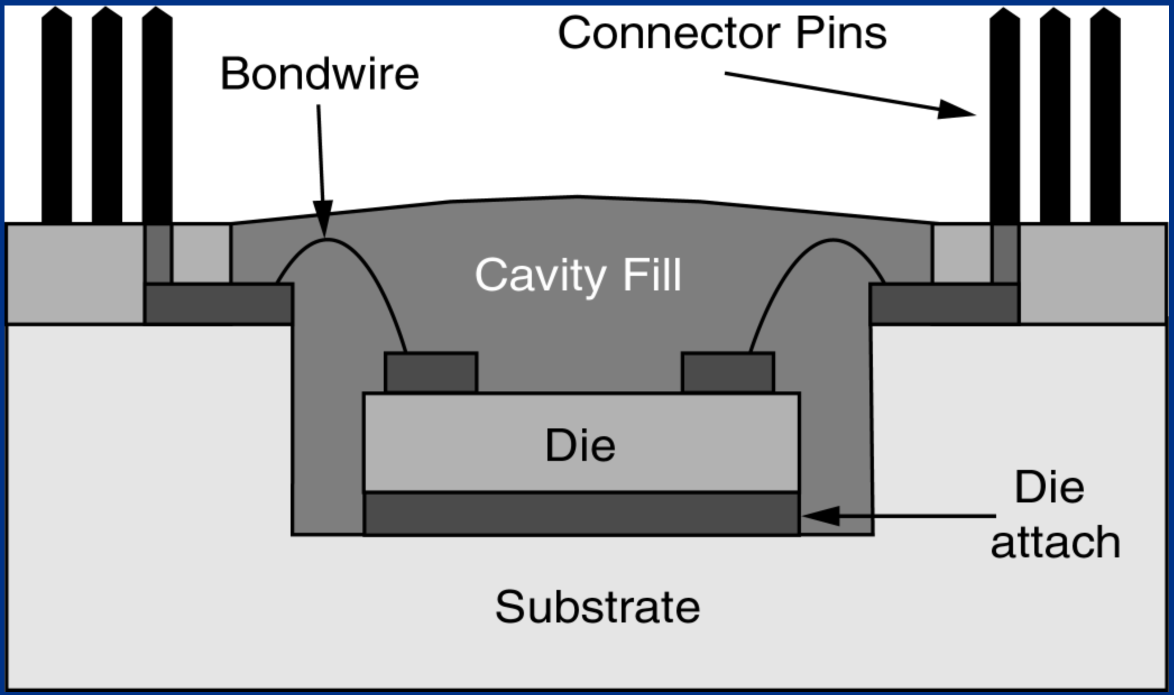


Cavity filling as observed during actual molding.

Liquid encapsulation: polymer encapsulants



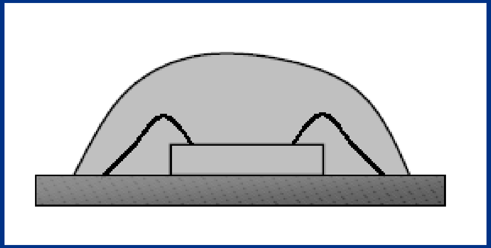
Cavity Filling PGA



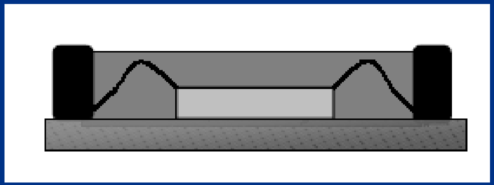
Cavity filling is mainly used in ceramic chip carrier.

The die is attached in a cavity, then the cavity is filled with a liquid encapsulant.

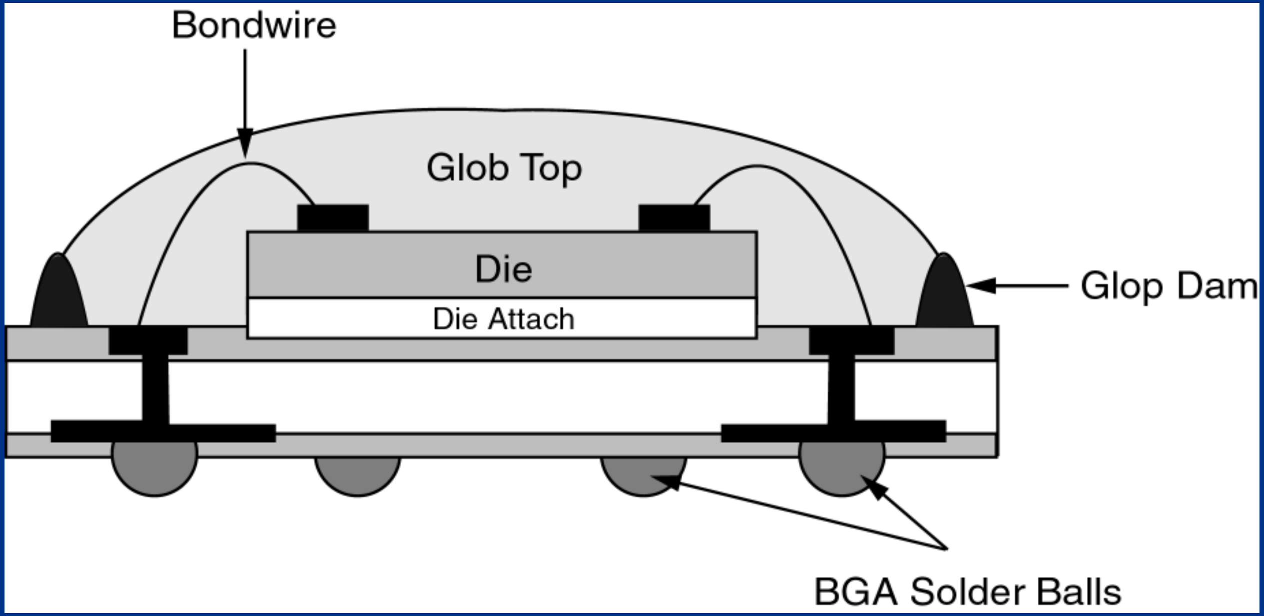
Glob Toping



Single resin process

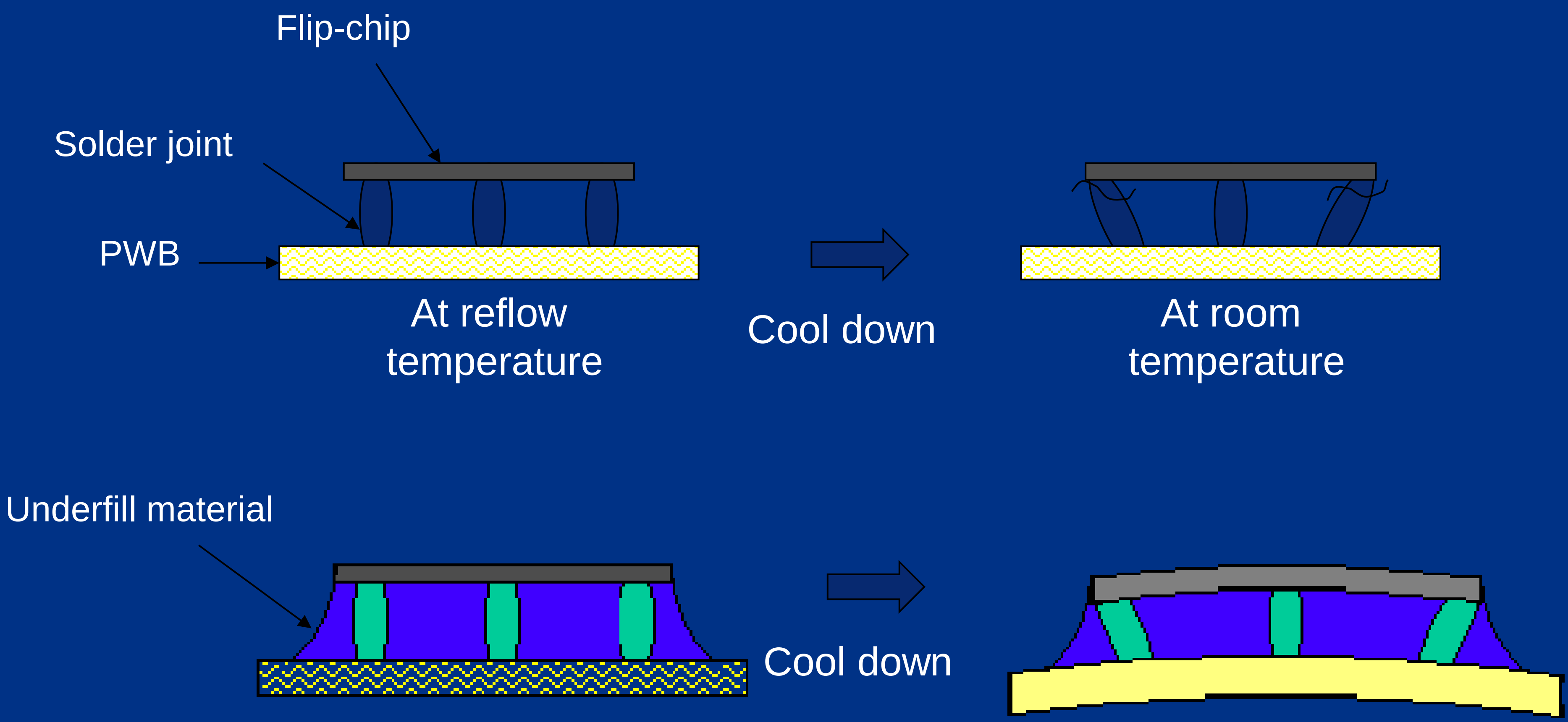


Two-resin process



A standard glob-topping process consists of die attach, wirebonding, dam dispensing, glob-top dispensing and cure.

Underfill function

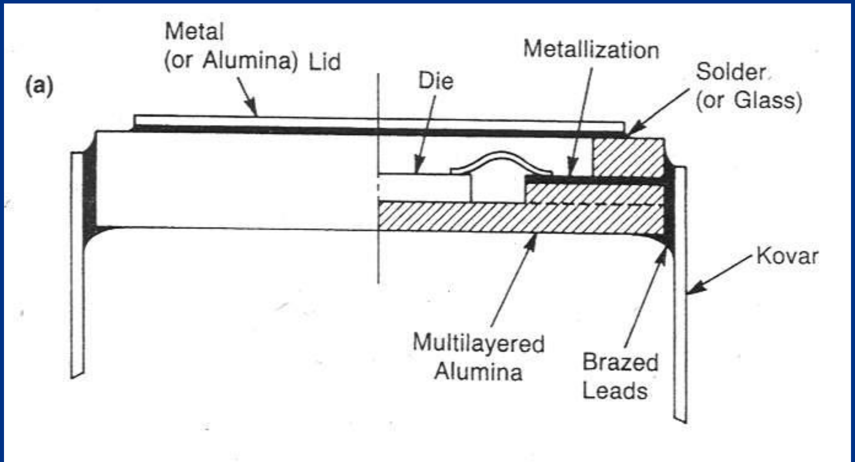


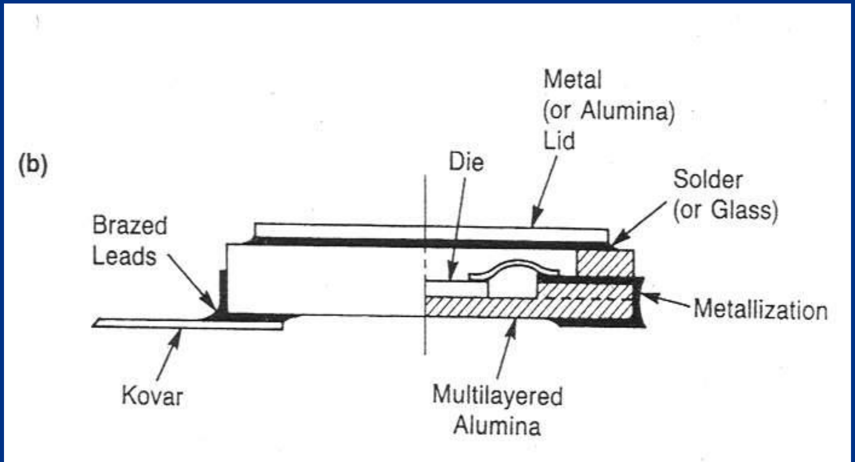
Hermetic sealing: Soldering, brazing, welding and glass sealing

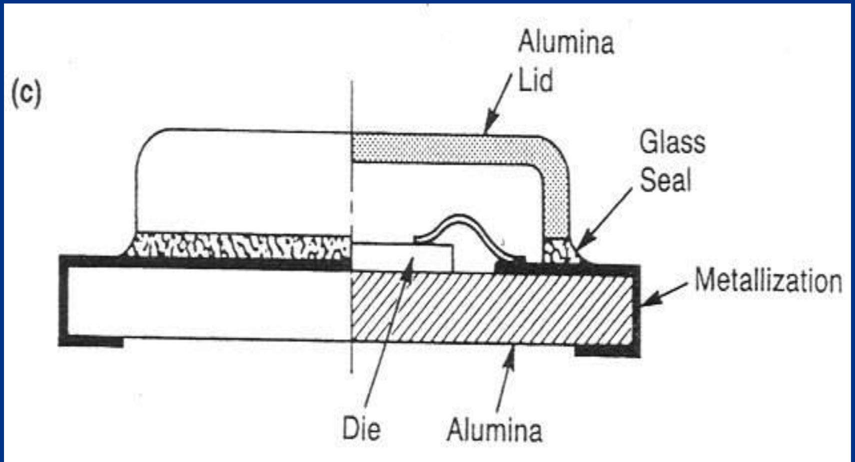
Using a lid or cap to seal the semiconductor device mounted on a suitable substrate.

- In *brazing and soldering*, a low-melting braze or solder alloy forms the sealing.
- In *welding,* the cap itself is partially melted to effect sealing.
- *Glass sealing* is used for ceramic package sealing.

Soldering, brazing and glass sealing







Sealing of various ceramic package types:

(a) Side braze;
(b) Chip carrier,

(c) Chip carrier (SLAM).

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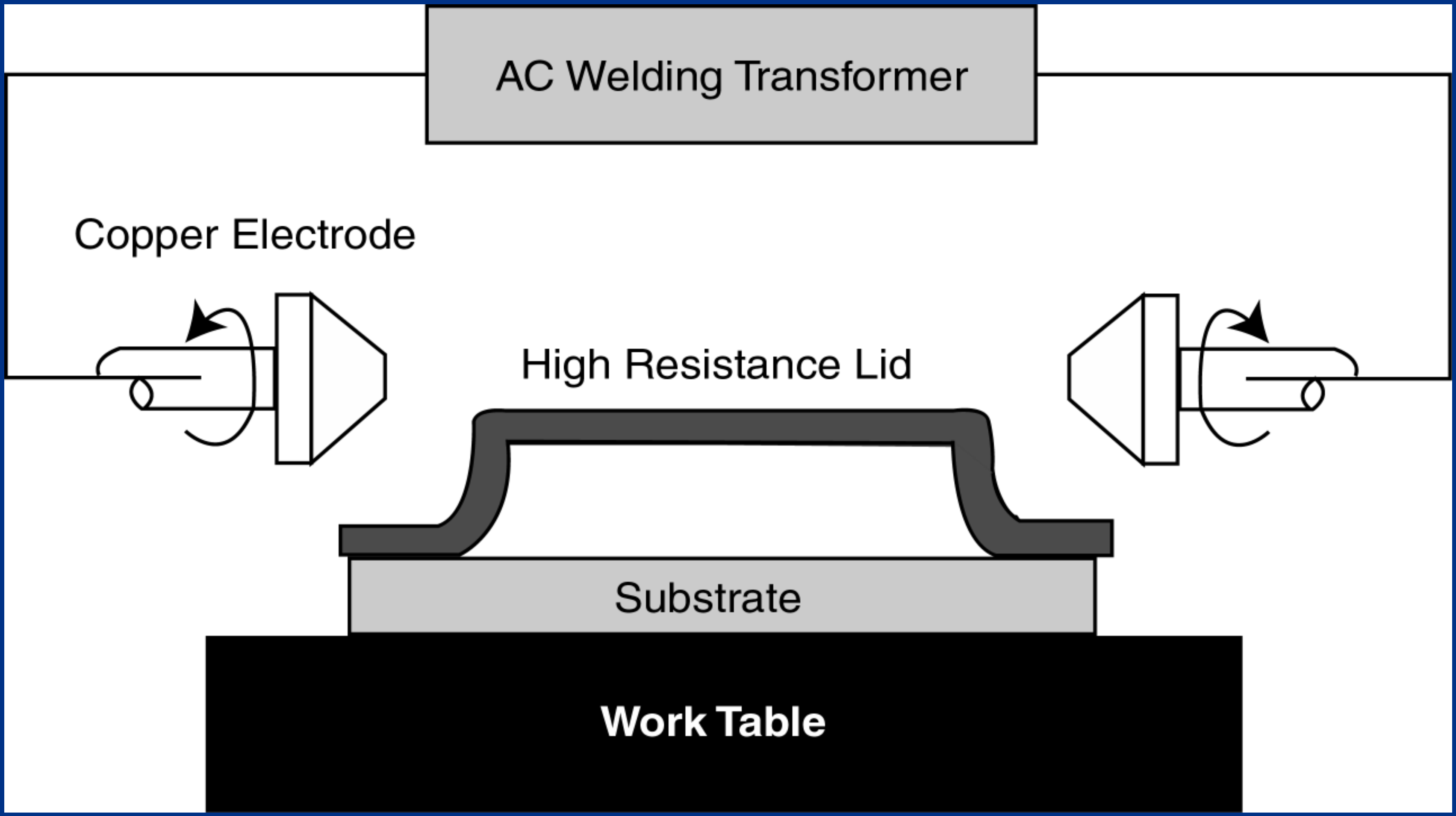
Soldering and brazing

- **Soldering**
  - The selection of solder material is based on:
    - the required temperature for the processes that precede and follow the sealing operation,
    - the desired minimum strength, and
    - Cost
- **Brazing**
  - Eutectic Au-20Sn (280°C) is used when the need exists for stronger, more corrosion-resistant seal, and where the use of flux has to be avoided.
  - The braze is usually used as a thin, narrow preform tack-welded to a Au-plated Kovar lid.

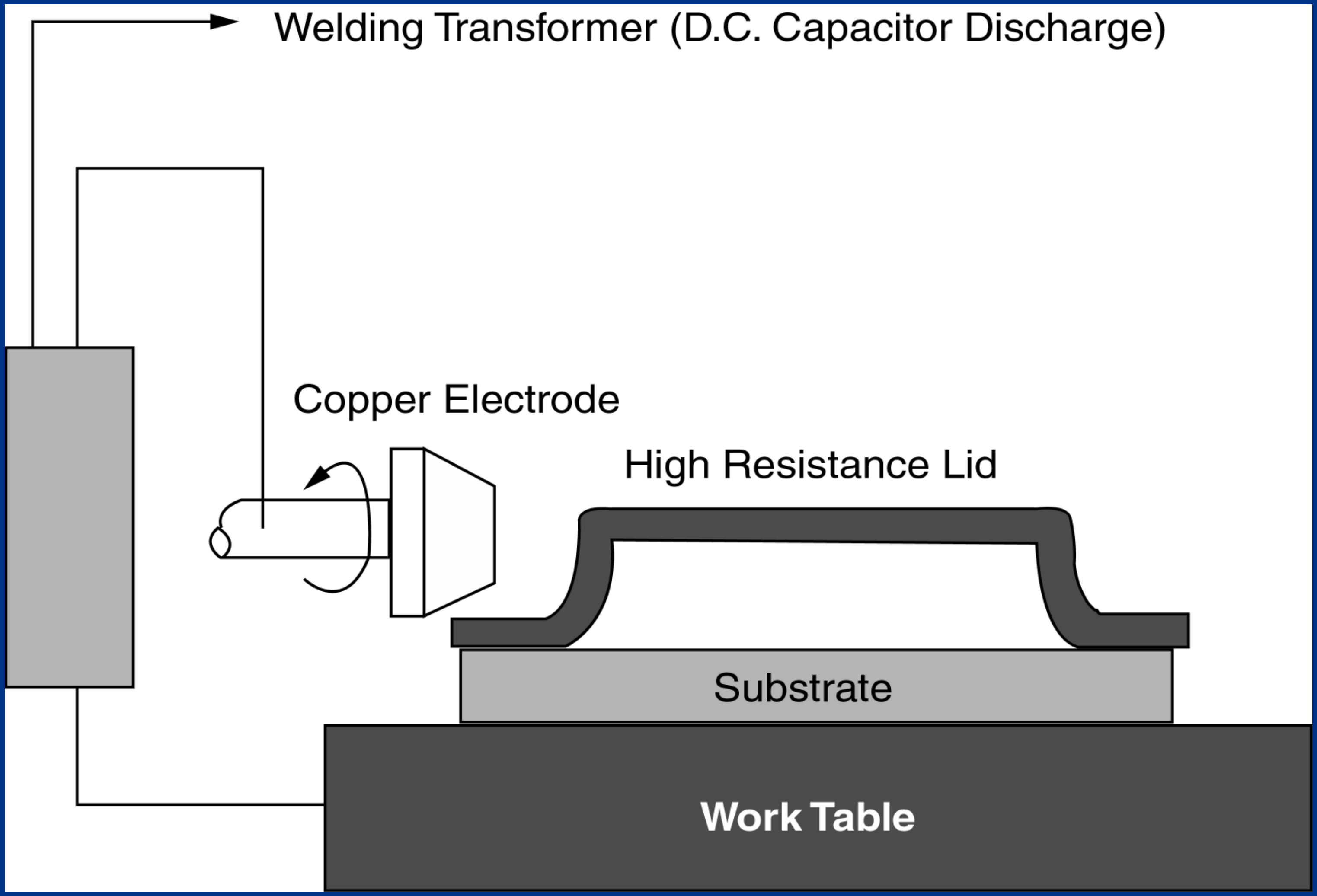
Welding

- Most popular method for high-reliability packages.
- 80 % of military packages are sealed by welding.
- High initial cost for equipment.
- High yield and a good history of reliability.
- High-current pulses produce local heating (1000-1500°C) fusing the lid to the package.
  - The local heating prevents damage to the internal components.
  - The higher welding temperatures at the interfaces volatilize most contaminants => cleanliness is not as critical as in soldering and brasing.

Parallel Seam or Welding

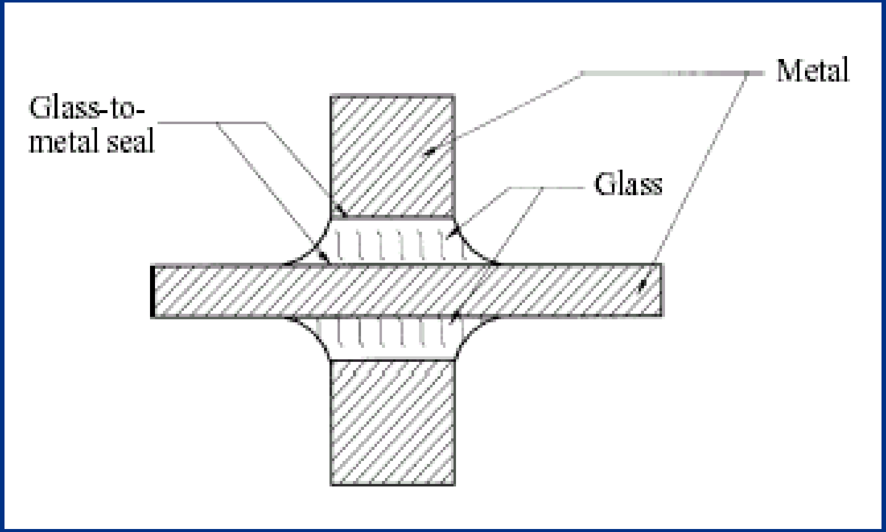


Electrode Welding



Glass sealing

- To form hermetic glass-to-metal seals for the package leads fed through holes in a metal plate or a header.



Lead in a metal package.

- To form a sandwich sealing between a ceramic/metal cap or lid and ceramic/metal substrate.