Micro Electro Mechanical Systems for mechanical engineering applications

Lecture 9:

(Bio)MEMS fabrication: Bonding and Packaging techniques

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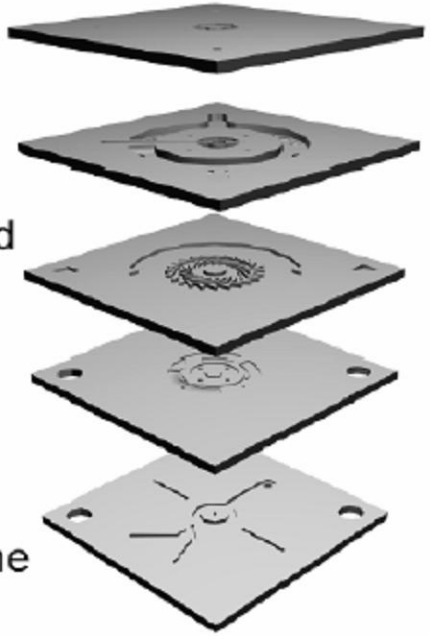
Wafer Bonding

- Direct bonding fabrication
  - Anodic bonding
  - Fusion bonding

- Indirect bonding fabrication
  - Eutectic bonding
  - Epoxy bonding

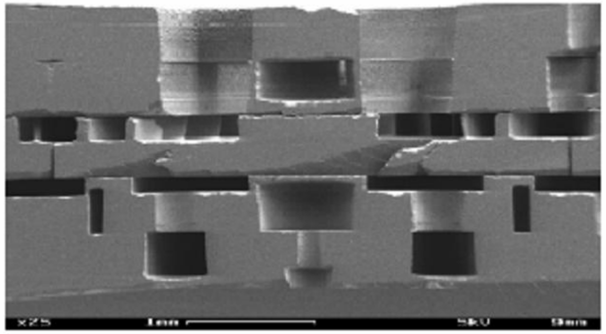
Wafer Bonding Example

- Combine complex shapes from multiple wafers
- Si-Si wafers
  - Low temp (450ºC)
  - Fusion – high temp (1000ºC)
  - Adhesive – epoxy, PR
- Si-Glass wafers
  - Anodic – low temp, high voltage (700V)



Fusion bonded wafer stack

MIT Microengine Project



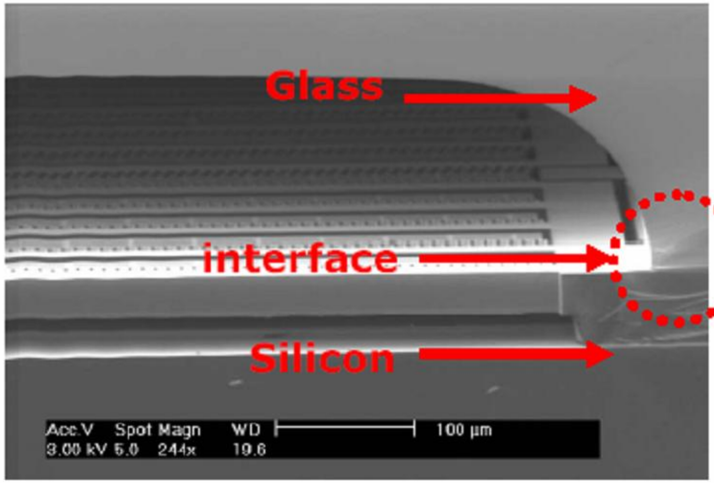
M. Schmidt, 2000

Anodic Bonding (1)

- Electrostatic bonding or field-assisted (thermal) bonding
- Bonding between Si wafer and glass with lots of Na+
- Merits
  - Good adhesive strength
  - Glass bonding: Optical transparency
  - Vacuum hermetic sealing possible
- Demerits
  - Outgas (H2) emerges at the bonding interface
  - Possibility to destroy circuit devices due to strong electric field which was produced when bonding
  - Sodium ion is incompatible with CMOS

Anodic Bonding (2)

- Principle of Anodic bonding
  - Sodium ions move to the cathode
  - Silicon wafer is positively charged
  - Strong electric field appears at the interface between silicon wafer and glass
  - Chemical reaction at the interface form a strong bonding (covalent bond)



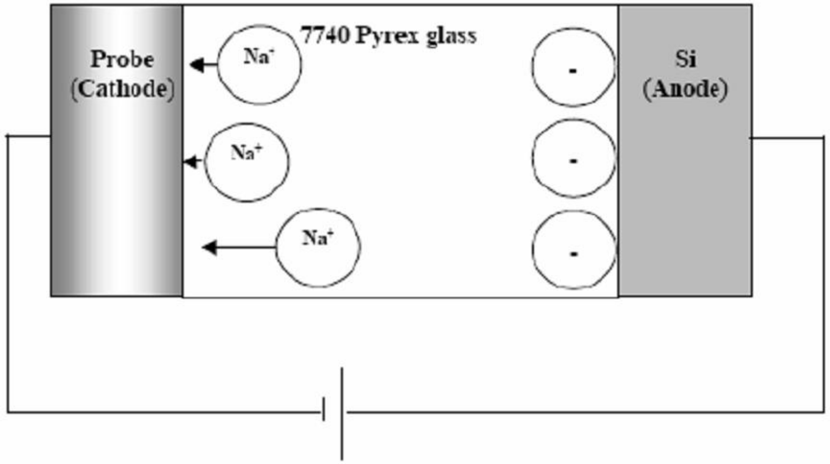
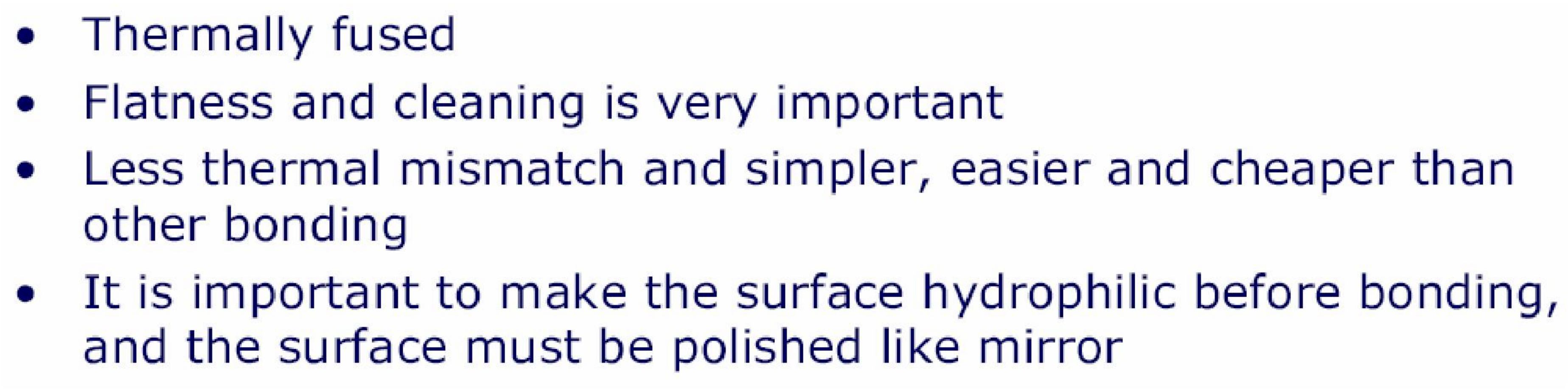


Figure 2: The Anodic Bonding Process between Silicon and Pyrex 7740 glass

Anodic bonding

Fusion Bonding (1)



- Thermally fused
- Flatness and cleaning is very important
- Less thermal mismatch and simpler, easier and cheaper than other bonding
- It is important to make the surface hydrophilic before bonding, and the surface must be polished like mirror

Fusion Bonding (2)

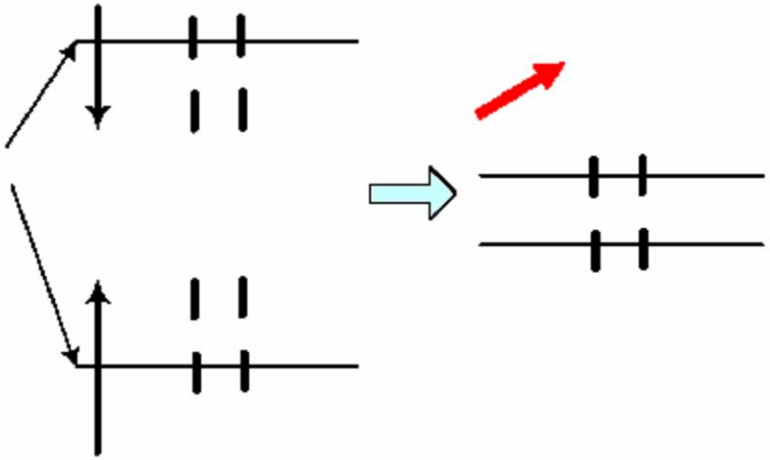
- Process of Fusion bonding

Surface preparation

Contacting

Annearing

  - Roughness<10Å
  - Cleaning surface form hydrate surface



Fusion Bonding (3)

- Room temp. ~ 300 0C
  - Hydrogen bond and initial bond between two substrates occur
- 300 0C ~ 700 0C
  - H2O molecules go out
  - Hydrogen bond by OH (bonding start)
- 700 0C ~ 1000 0C
  - Oxygen molecules participate in bonding
  - Elasticity of Si substrate increases and bonding starts at the interface which is not combined yet
- Over 1000 0C
  - Viscous flow of oxide film occurs due to oxygen molecules
  - Elements at the interface diffuse into inside and outside and become extinct
  - Very high bonding strength

Eutectic Bonding (1)

- Intermediate layer bonding
- Reactive metal bonding
- Melting point lowers in eutectic alloy state
  - Sn : 231.9 0C, Pb : 327.4 0C, Sn/Pb : 183 0C
  - Si : 1410 0C, Au : 1064.4 0C, Si/Au : 363 0C
  - There exists a thin liquid layer at the interface.
  - Diffuse into another layer over eutectic temperature

- Au/Si Eutectic alloy
  - Gold layer diffuses into silicon over eutectic temperature
  - Eutectic ally : 97.1% Au, 2.84% Si
  - T (eutectic point) :363 0C

Eutectic Bonding Au/Si (2)

- Removal of the oxide on the surface of Si
- Gold deposition
  - Bare Si + Au/Si +Au/Si
- Removal of organic compounds
- Temperature : about 363 ^0C
- Bonding by diffusion of Au into Si

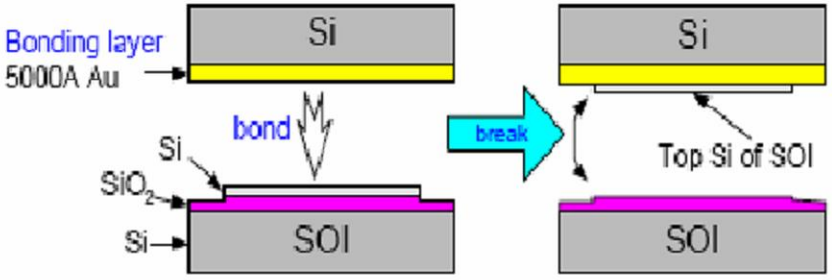
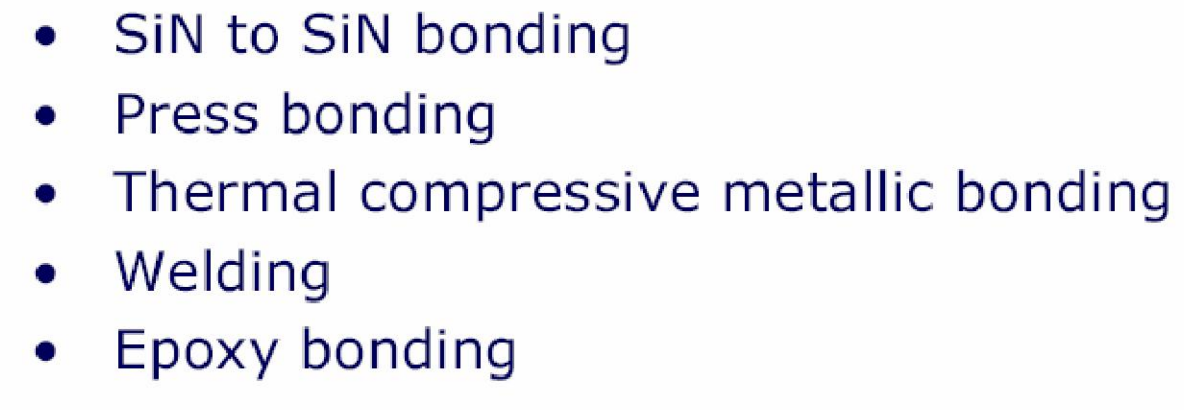


Figure 4: Au/Si eutectic bonding and test for bonding strength.

SiN to SiN Bonding

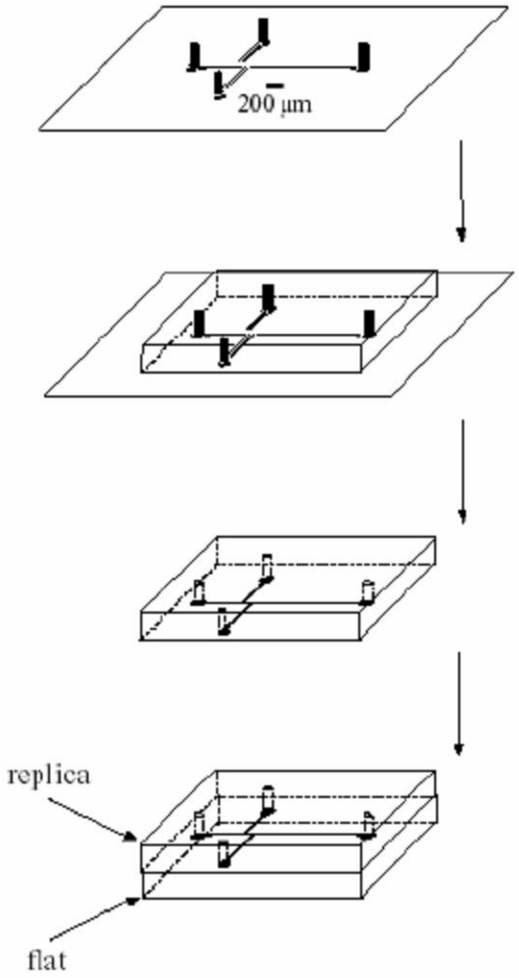
- Bonding of Silicon nitride to silicon nitride surfaces at 90 ~ 300 ^{0}C
- Plasma enhanced LPCVD Silicon nitride
- Wafer flatness and surface roughness is important
- Mechanism
  - Si-N-H + N-H-Si <---> Si-2N-Si + H_2

Other Bonding



- SiN to SiN bonding
- Press bonding
- Thermal compressive metallic bonding
- Welding
- Epoxy bonding

PDMS Bonding (1)



Place posts on master to define reservoirs

Cast prepolymer and cure

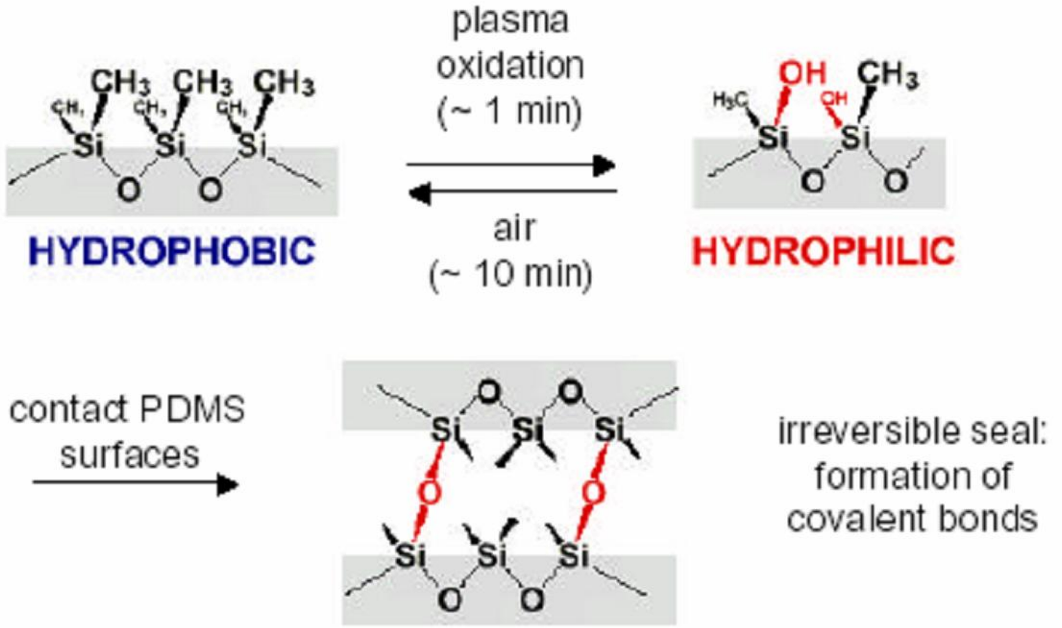
Remove PDMS replica from master

Oxidize PDMS replica and flat in plasma to seal

Duffy, McDonald, Schueller and Whitesides, *Anal. Chem.*, **70**, 4974 (1998).

PDMS Bonding (2)

Irreversible Sealing of Polydimethylsiloxane (PDMS)



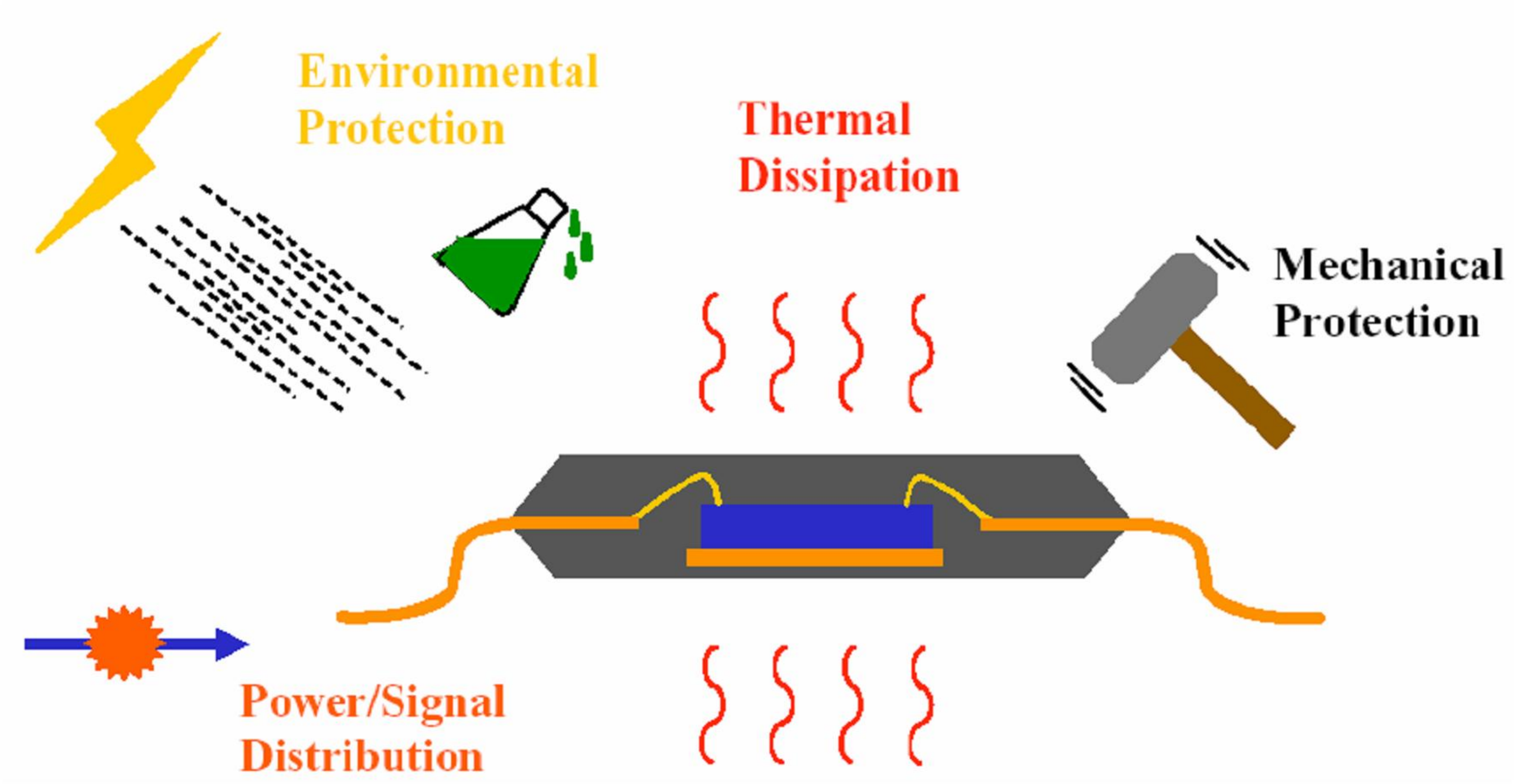
- PDMS seals to itself, glass, silicon, silicon nitride, LDPE, PS
- PDMS seals after exposure to plasma of air, dry air or oxygen

Glass Bonding

- Gluing
  - Fast-setting glues
- Thermal diffusion bonding
  - Pressure-assisted thermal bonding at several 100°C for several hours
  - Joining of two polished glass wafers
  - By diffusion, new chemical bonds form at these temperatures
  - Strong bond after cooling without application of adhesive reagents etc.
- Glass soldering
  - Interesting alternative to thermal bonding
  - Diffusion bonding may not be possible for instance due to high thermal stress on substrates
  - For these structures, vacuum-tight bonds may be accomplished by low-melting point solder deposited via screen printing
  - Glass soldering applicable to glass-glass interfaces as well as to bonding of glass with other materials
- Leakage problems common with glass after assembly!

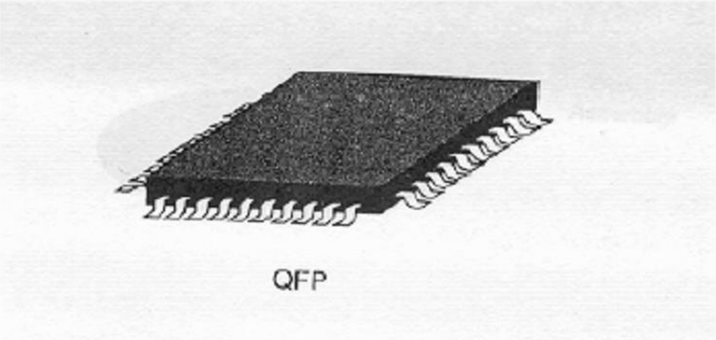
Packaging (1)

- **Function of MEMS packaging**



Packaging (2)

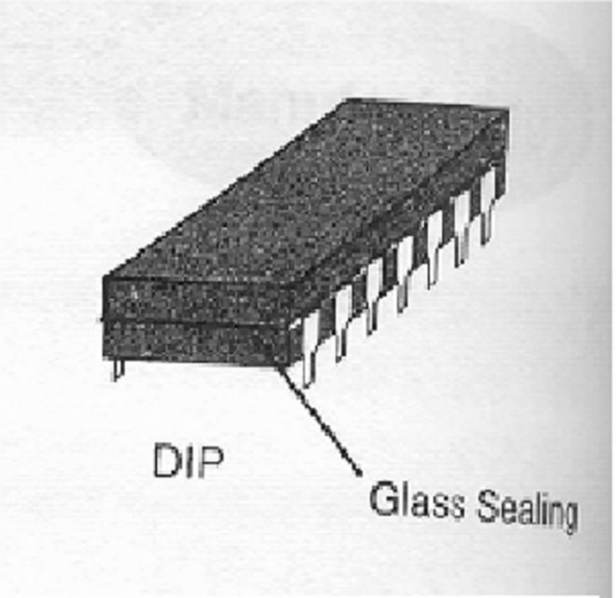
- Encapsulation
  - Economical way to protect device packages by isolating the active devices from environmental pollutants
  - The protection can be an organic overcoat
    - Inexpensive way of protecting devices, but their protection is not permanent


QFP

Plastic encapsulated (non-hermetic sealing) package

Packaging (3)

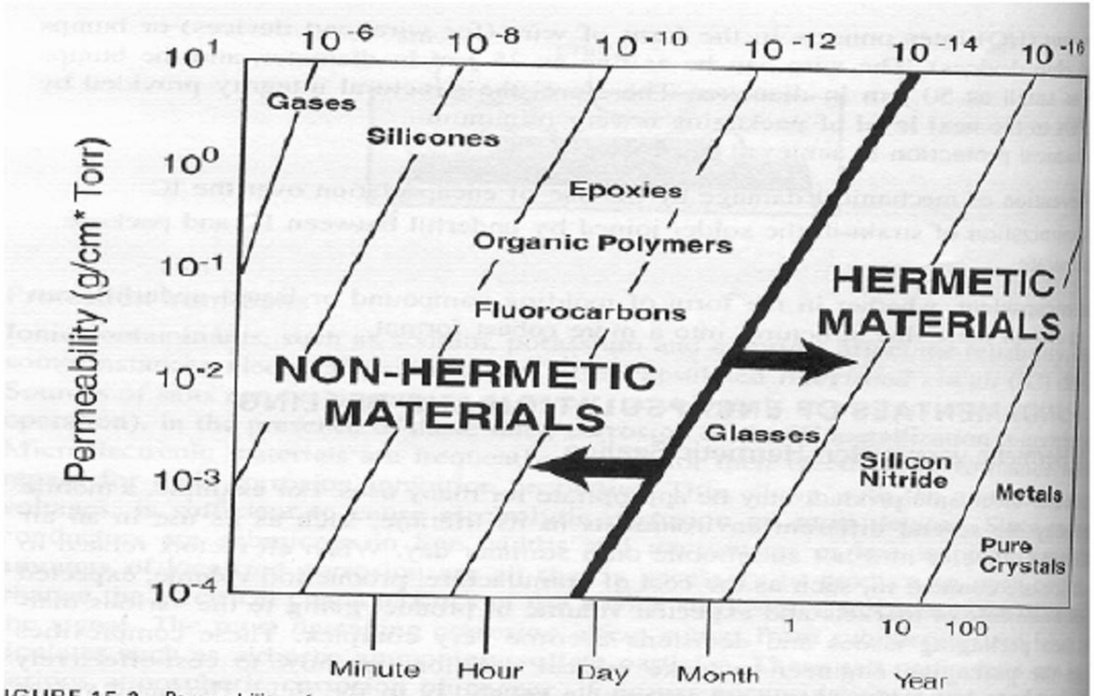
- Sealing
  - The protection of the devices is permanent by being hermetic
  - The cost of this process is high



Hermetically-sealed ceramic package

Packaging (4)

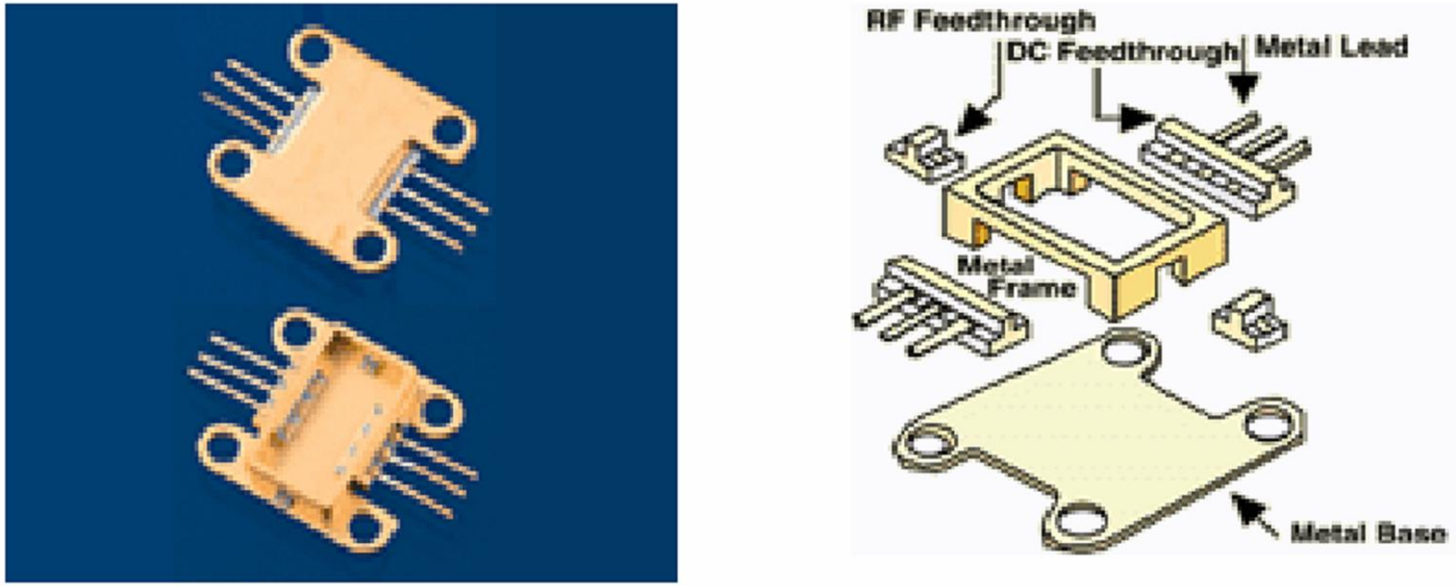
- A hermetic package is theoretically defined as one that prevents the diffusion of helium (leak rate : 10-8cm3/s)
- Prevent the diffusion of moisture and water vapor through its walls.



IGURE 15.3 Permeability of water through organic (non-hermetic) and inorganic (hermetic) materials

Types of MEMS Packaging (1)

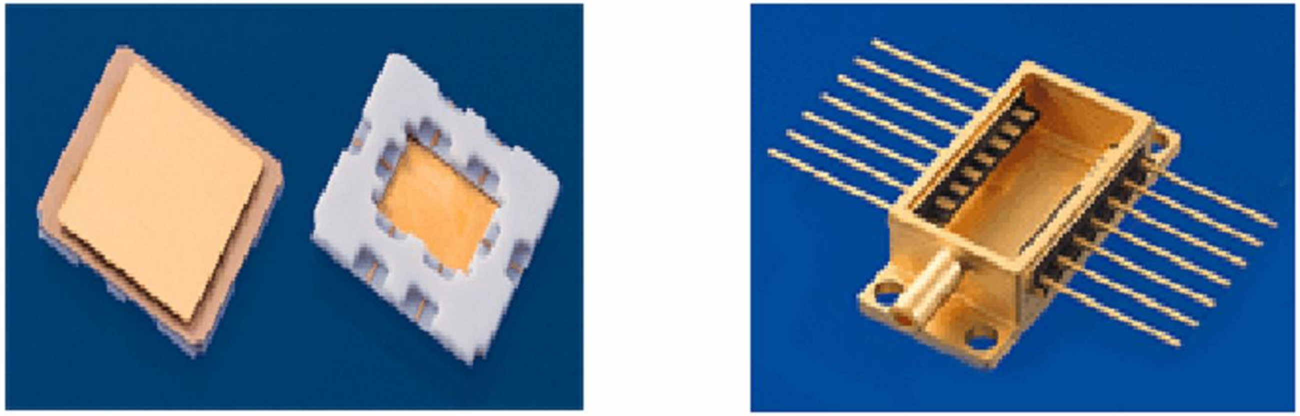
- Metal Packages
  - Robust and easy to assemble
  - Use for microwave multichip modules and hybrid circuits
  - Excellent thermal dissipation and excellent electromagnetic shielding.



Metal wall packages (Kyocera Coporation)

Types of MEMS Packaging (2)

- Ceramic Packages
  - Ceramics are hard and brittle materials with high elastic modulus
  - Consist of a base or a header onto which one or many dice are attached by adhesives
  - Low mass and low cost
  - Easily integrate signal distribution lines and feedthroughs



Ceramic wall packages (Kyocera Coporation)

Types of MEMS Packaging (3)

- Plastic Packages
  - Unlike their ceramic or metal packages, plastic packages are not hermetic
  - Widely used by the electronics industry for many years and for almost every application
    - Low manufacturing cost
  - Susceptible to cracking in humid environments

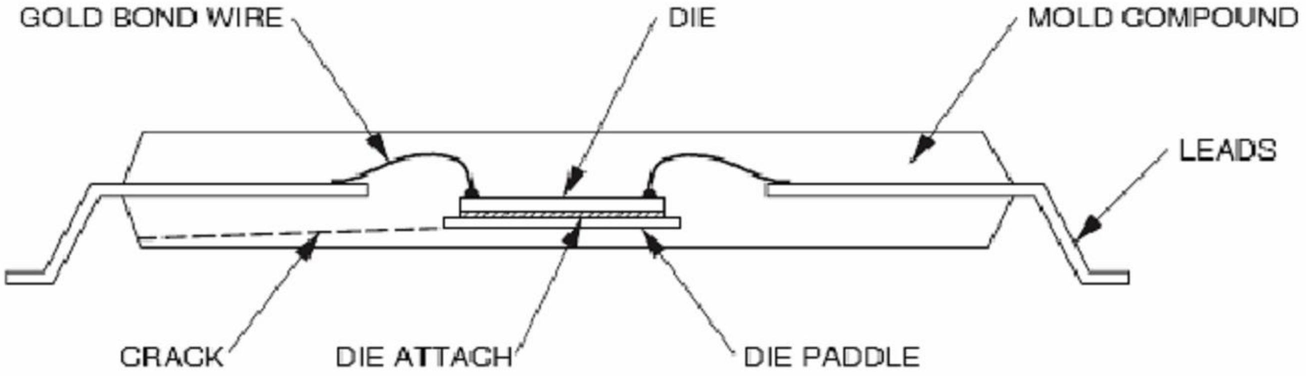


Figure 9-15. Typical plastic package showing the onset of a crack.

Types of MEMS Packaging (4)

- Flip chip
  - Bonding the die top-face-down on a package substrate
  - Electrical contacts are made by means of plated solder bumps between bond pads on the die and metal pads on the package substrate
  - With a small spacing (50~100 um) between the die and the package substrate