Integrated Circuit Packaging and Thermal Design

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Introduction to IC Technologies

Packaging

- Die attach
- Wire bonding
- Packaging materials *
- Package types (TQFP, MLF, COB)
- Thermal design *

Refer to:
G. Torelli e S. Donati, “Tecnologie e Materiali per l’Elettronica”, Ed. CUSL
Packaging

Packaging is used to:

- Provide electrical connection between IC pads and PCB lines
- Mechanical and chemical protection from external agents
- Easier handling
- Thermal dissipation

PACKAGING PHASES

Die attach

Wire bonding

Sealing
Die attach

- **Eutectic solder**: wafer is back-plated with Au and package has an Au internal paddle. Eutectic Au/Si is formed at 400°C.

- **Sn/Pb solder**: wafer is back-plated and a tin/lead solution is deposed on the package paddle. Soldering is carried out at 200-350°C.

- **Conductive epoxy**: adhesive epoxy loaded with conductive materials (e.g. Au) is dispensed on the lead-frame. Soldering is carried out by means of epoxy polymerization at 125-175°C.
Wire Bonding

Wire materials:

Au, Al

Typical bonding wire diameter ~ 30µm

Manual bonding machine

Electrical parameters:

- Self Inductance ~ 1nH / mm
- DC resistance ~ 30mΩ / mm
- Capacitance ~ 100fF / mm
Packaging Materials

- **Metal packages: (kovar)**
  - Used for high power and high reliability devices
  - Excellent thermal dissipation
  - EM shield
  - High cost

- **Ceramic packages: (alumina)**
  - E.g. glass-seal (“frit-seal”)
  - Good thermal dissipation
  - Intermediate cost

- **Plastic packages: (epoxy)**
  - Mechanic stress due to different thermal coefficients
  - Low thermal conductivity
  - Low cost
**Plastic Materials**

- **Definition:** polymers (long chains of atoms bonded to one another) These chains are made up of many repeating molecular units, derived from monomers through a process called polymerization.

- Polymerization processes: polyaddition, direct polymerization and polycondensation

- Excellent isolation properties: strong bonds between monomers provide a high electric stiffness ($E_{\text{MAX}}$)

- Mechanical properties can be improved using additives such as glass fibers

For plastic and ceramic materials, refer to:
Dispense di G. Torelli e S. Donati, “Tecnologie e Materiali per l'Elettronica”, Ed. CUSL
Plastic Materials

- **Thermoplastic materials**: teflon (PTFE), polystyrene, polycarbonates
  - Melt reversibly at high temperatures
  - Typically quite flexible
- **Thermosetting plastics**: epoxy resin, silicon resin, polyester, ...
  - Harden irreversibly after it is cured

**Applications**:
- Capacitors dielectric material (polystyrene, polyester resin, polycarbonates)
- Printed circuit board (epoxy, teflon)
- Isolation (teflon)
- Packages (epoxy)
### Relevant Parameters

- **Thermal conductivity** [W/°C cm]  
  - 0.1 - 0.3
- **Thermal capacity** [J/°C cm³]  
  - 40 – 160
- **Resistivity** [GΩ cm]  
  - >1
- **Dielectric strength** $E_R$ [kV/mm]  
  - 10 - 100
- **Loss tangent** $\tan \delta (= - \text{Im}[\varepsilon] / \text{Re}[\varepsilon])$  
  - $10^{-4}$-$10^{-2}$
Ceramic Materials

- Ceramic materials are compounds obtained from various materials reduced in fine particles, as a result of a firing (sinterization) process.

- Features:
  - Hardness, stiffness
  - Immunity to humidity and corrosion
  - Good isolating and resistive materials can be synthesized
Production Process

- **Grinding**
  - Compound materials are reduced to fine particles (Ø~1mm)

- **Compact formation**
  - Usually through mechanical pressure

- **Firing**
  - Liquid phase: sintering is carried out above the melting point of at least one component;
  - Solid phase: grain diffusion; better mechanical properties and reduced aging effects
Exposed Pad TQFP

- The Exposed Pad can increase heat dissipation by as much as 110% over a standard TQFP.
- The Exposed Pad can be connected to ground, reducing “ground” inductance for high frequency applications.
- Used in high performing products such as telecom, disk drives, pagers, wireless, CATV/RF modules, radio and other similar applications.
Exposed Pad Micro-Lead Frame

- Plastic encapsulated package with a copper leadframe substrate
- Reduced lead size strongly reduces the parasitic inductances and capacitances
- An ideal choice for handheld portable applications such as cell phones and PDAs or any other application where size, weight and package performance are required issues.
A true Chip Scale Package. Used for ICs with large pin count (e.g. memory, analog, ASICs, RF devices and simple PLDs requiring a small package size).
System-in-Package (SiP) Example

Multichip and Stacked Dice

Chip-on-Board

- Eliminate package parasitics
- Minimize size
- High speed / power applications

Chip-to-PCB wirebond

Flip-chip

Solder bumps

Board
Thermal Design

- Temperature range:
  - Commercial: $0^\circ\text{C} < T < 70^\circ\text{C}$
  - Industrial: $-40^\circ\text{C} < T < 85^\circ\text{C}$
  - Military range: $-55^\circ\text{C} < T < 125^\circ\text{C}$

- Thermal exchange mechanisms:
  - Conduction
  - Convection
  - Radiation
Electrical-Thermal Equivalent

Dissipated Power \( \Delta T \)

Electrical Current \( P \)

Temperature \( T \)

Electrical Potential (Voltage) \( E \)

Equivalent Thermal Resistance \( R_{TH} = \frac{\Delta T}{P} \)

Electrical Resistance \( R = \frac{\Delta V}{I} \)

Fourier Law \( \Phi = -K\nabla T \)

\( J = \sigma E = -\sigma \nabla V \)

\( K \) thermal conductivity [W/°Ccm]

\( \sigma \) el. conductivity [S/cm]
Thermal Modeling

Thermal Equivalent Circuit

- Package
- Chip
- Board
- Air

Thermal Equivalent Circuit:

1. Power source (P)
2. Resistor $R_{CP}$
3. Resistor $R_{PB}$
4. Resistor $R_{BA,C}$
5. Resistor $R_{BA,R}$
6. Temperature $T_{CA}$
Thermal Conduction

During transients *thermal capacitance* must be taken into account:

\[
C_{TH} = \rho c LS
\]

During transients thermal capacitance must be taken into account:

\[
\frac{\partial T}{\partial t} = \frac{K}{\rho c} \frac{\partial^2 T}{\partial x^2} = \alpha \frac{\partial^2 T}{\partial x^2}
\]
(Free) Thermal Convection

- The **Nusselt number** \( N_{NU} \) measures the enhancement of heat transfer from a surface that occurs in a 'real' situation, compared to the heat transferred if just conduction occurred.

\[
N_{NU} = \frac{hL}{K}
\]

- Convection heat transfer coeff.
- Effective thermal conductivity
- Characteristic length (Volume/Surface)
- Th. Conductivity

**Convection thermal resistance:**

\[
R_{TH,CONV} = \frac{1}{hS}
\]

**Empirical expression:**

\[
h = 0.4 \left( \frac{\Delta T}{L} \right)^{1/4} \text{[mW/°C cm}^2\text{]}\]

where \( \Delta T \) is in °C and \( L \) in cm.
Thermal Radiation

- *Thermal radiation* is electromagnetic radiation emitted from the surface of an object which is due to the object's temperature. The total amount of radiation, of all frequencies, **goes up very fast as the temperature rises**:

\[ P = \varepsilon \sigma S T^4 \]

- \( \varepsilon \) emissivity (<1)
- \( \sigma \) Stefan-Boltzmann constant = 5.67 \( 10^{-8} \) W/m\(^2\)K\(^4\)
- \( S \) surface area

Power radiated toward ambient:

\[ \Delta P \approx 4\sigma S T_a^2 \Delta T \]

Radiated Thermal Resistance:

\[ R_{TH,R} \approx \frac{1}{4\sigma S T_a^3} \]
Thermal Diagram
Homework

10 devices over an 8cm x 12.5cm printed circuit board.

$R_{CP}=20^\circ C/W$

$R_{PB}=3^\circ C/W$

Maximum ambient temperature: 40°C

Maximum operating temperature of each device: 85°C

Find the maximum power dissipated by each element.
References

● References:
  ● www.amkor.com

● Reading Material:
  ● Dispense di G. Torelli. Introduzione alla tecnologia dei circuiti integrati su silicio. 2006. (IC Technologies)
  ● Dispense di G. Torelli e S. Donati, “Tecnologie e Materiali per l’Elettronica”, Ed. CUSL
  ● Dispense del corso Microfabrication Technology, UCB
    http://organics.eecs.berkeley.edu/~viveks/ee143/