Introduction to Microsystems Packaging
MKM105

Tutorial 1

Objectives of Tutorial 1

The student should be able to:

Objective 1:

Be able to define microsystem and microelectronics

Objective 2:

Understand the role of packaging and why it is important

Objective 3:

Consider a ”real world problem”

Procedure

- Try to find the answer in groups of 3 people

- Question/Problems are given
- Discuss/solve and write down an answer to the questions/problems.
- Present answers
- Carl shows an answer/solution

Chapter 1

1. What is a microsystem? Compare and contrast with microelectronics
2. Why integrate microsystem technologies into single products?
3. What is the role of packaging in Microsystems?

1. What is a microsystem? Compare and contrast with microelectronics

A microsystem is a microminiaturized and integrated system based on microelectronics, RF, photonics, micro-electro-mechanical systems, and packaging technologies. A microsystem provides a number of integrated functions such as computing, communication, consumer and sensing to serve a variety of human needs.

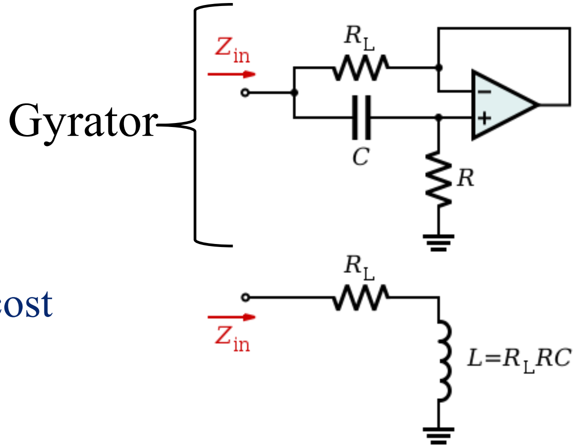
In contrast, microelectronics refers to the circuit elements; (most commonly transistors, capacitors and resistors) fabricated at sub micron dimensions as an "integrated circuit" or IC. The IC forms the basis for most of today's microelectronic systems of which computers are an example.

Digital ICs: mostly of transistors.

Analog circuits: transistors, resistors, capacitors

Inductors used in high frequency analog circuits.

Inductors are replaced by gyrators in many applications to save cost



2. Why integrate microsystem technologies into single products?

Microsystem technologies which includes digital, RF, optical, MEMS and sensing technologies are integrated into single miniaturized products in order to provide services and functions in the least amount of space and at low cost.

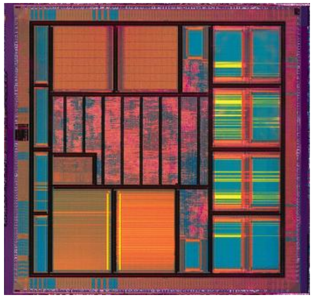
A cell phone is an example of a microsystem.

It is a microminiaturized, integrated system; a computer and a wireless product, based on processors, RF passives, MEMs switches, display technology, image acquisition and human interface technology via key or touch pad. It is compact and convenient to use and is cheap to manufacture because of high volume fabrication.

An airbag deployment system in an automobile consists of a computer, an electrical switch based on a MEMS accelerometer, a bag, an electrically activated blasting cap and nitrogen- producing chemicals such as Sodium Azide and Potassium Nitrate. All this is miniaturized and packaged to fit into a small space.

3. What is the role of packaging in Microsystems?

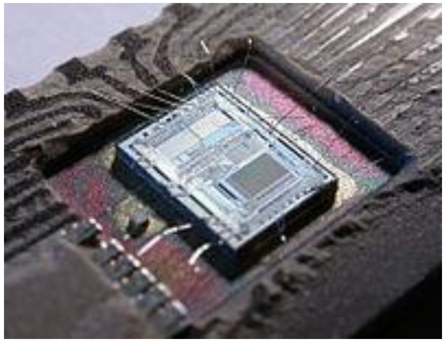
- Packaging provides a set of interconnections at IC or device level as well as at the interface and interconnections between ICs, MEMS, photonic, RF, and other components into a System- level board to form electronic products. Historically, these interconnections have been electrical. As microsystem performance increases, we may see photonic interconnections in the near future.
  (Intel Thunderbolt, previously called Lightpeak is one example)



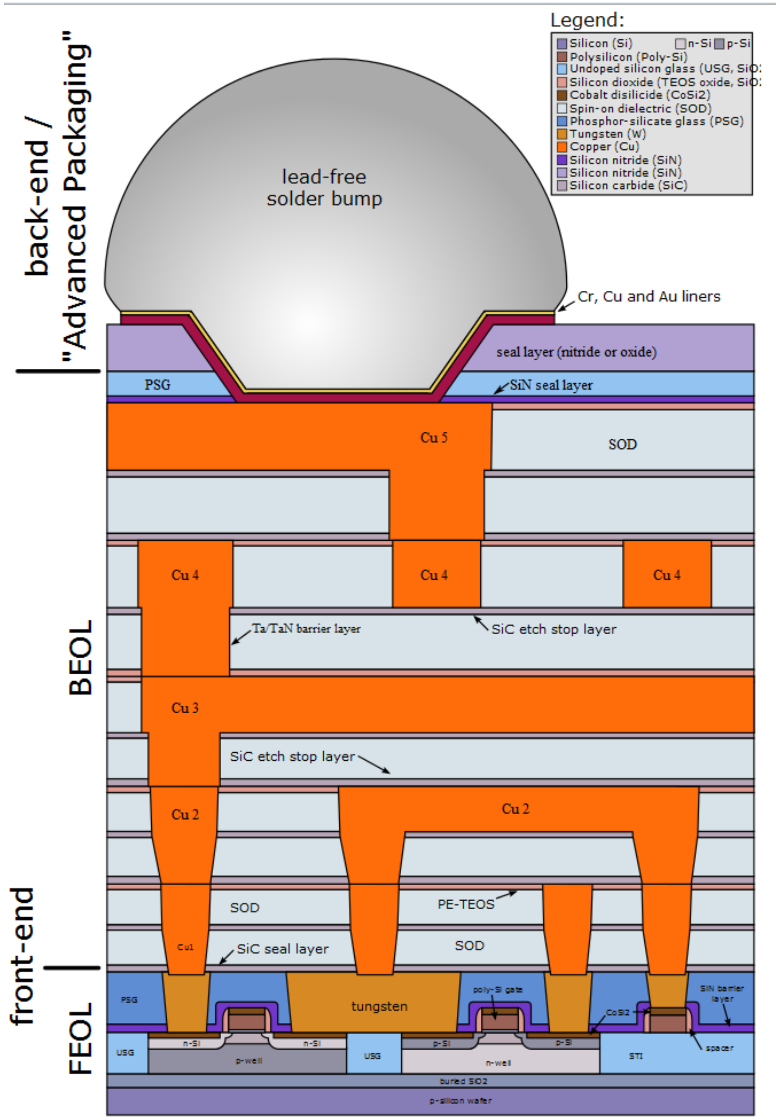
Integrated Circuit - IC

6.8 billion transistors on one FPGA chip

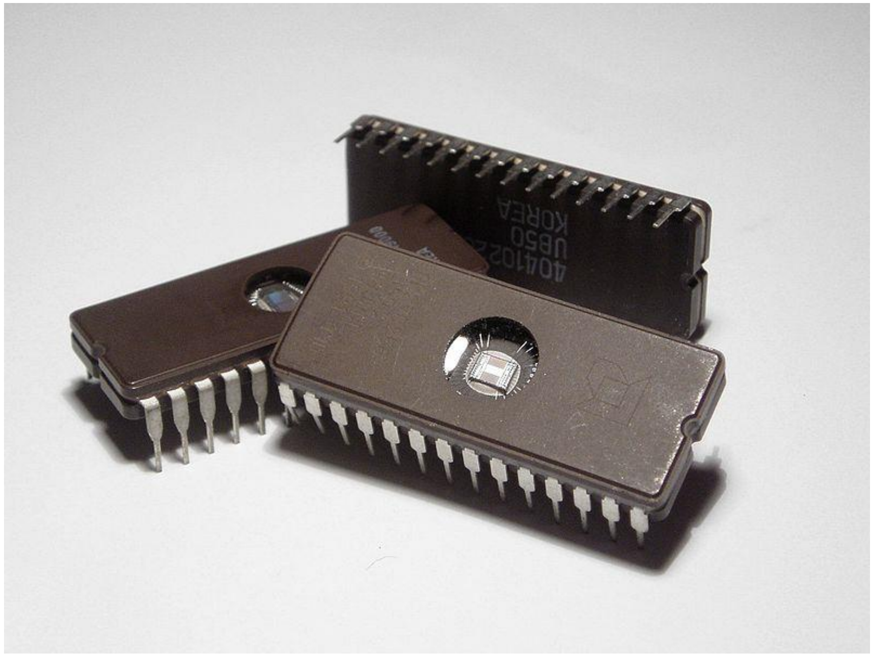
Intel Thunderbolt 20 Gbs
(USB 3.1 10 Gbs)



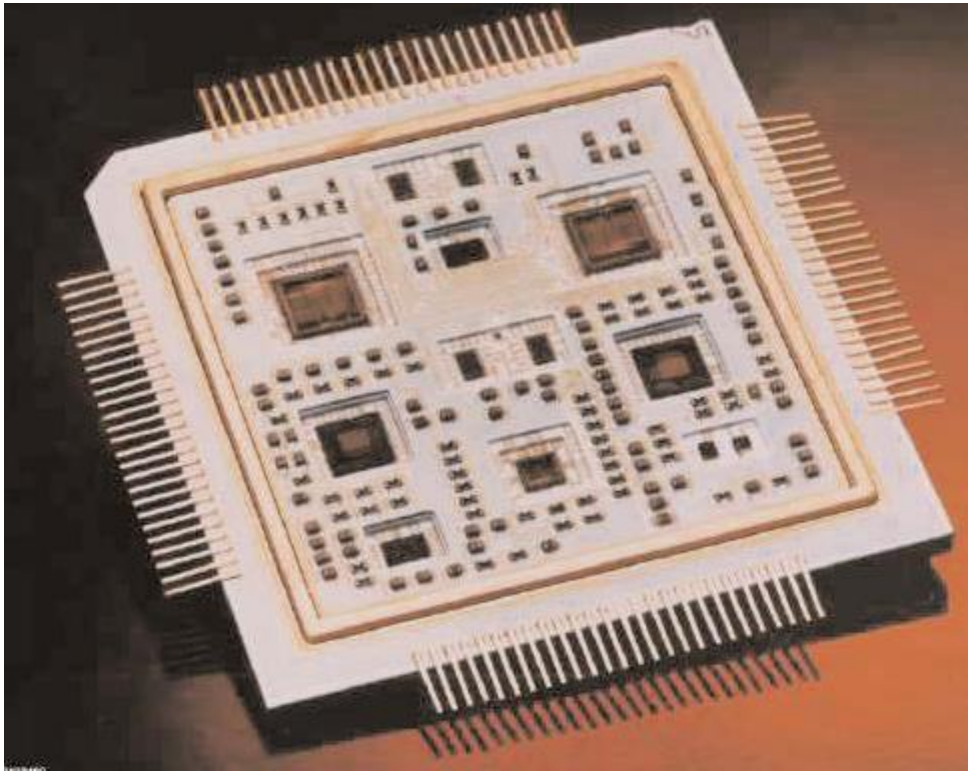
The die from an Intel 8742, an 8-bit microcontroller that includes a CPU running at 12 MHz, 128 bytes of RAM, 2048 bytes of EPROM, and I/O in the same chip



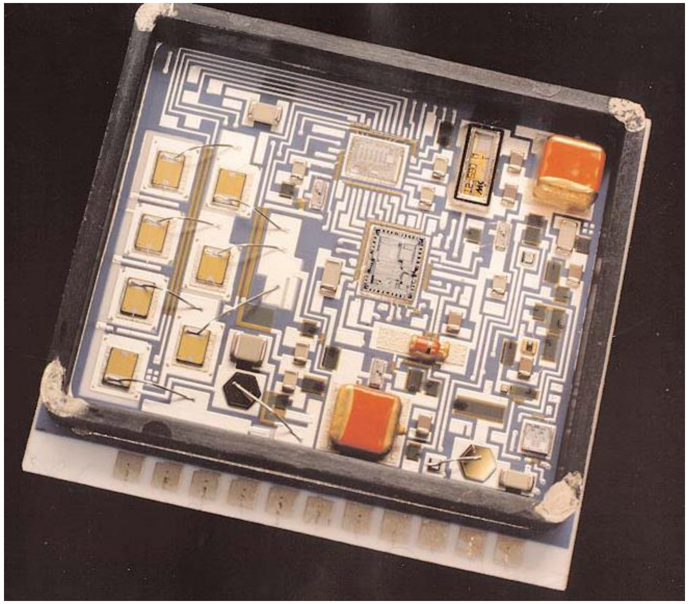
- Every IC has to be packaged before it can be used. Packaging starts where the IC stops. The typical parameters important for IC packaging include I/Os, power and size of the chip.



Microchips (EPROM memory) with a transparent window, showing the integrated circuit inside. Note the fine silver-colored wires that connect the integrated circuit to the pins of the package. The window allows the memory contents of the chip to be erased, by exposure to strong ultraviolet light in an eraser device.

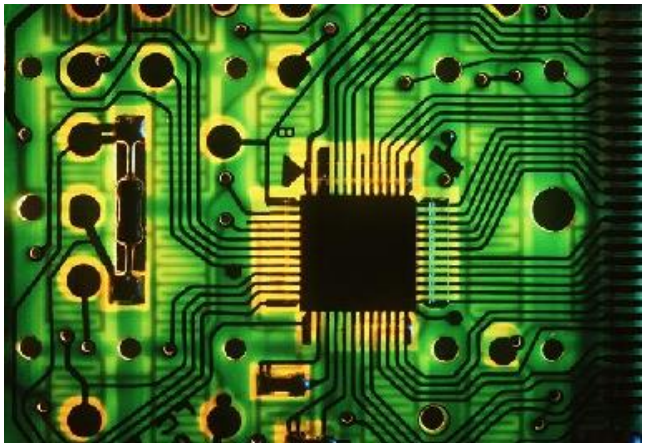


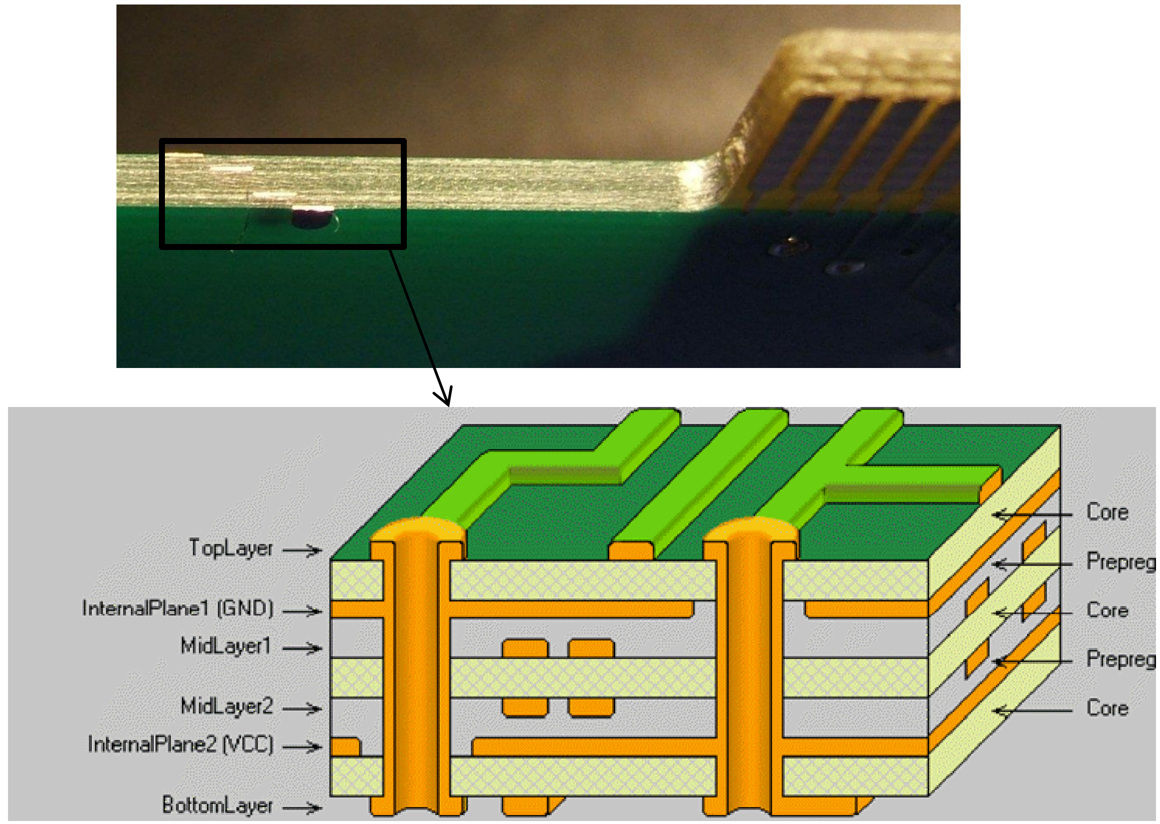
High density LTCC module



A thick film MCM for high temperature use

PCB

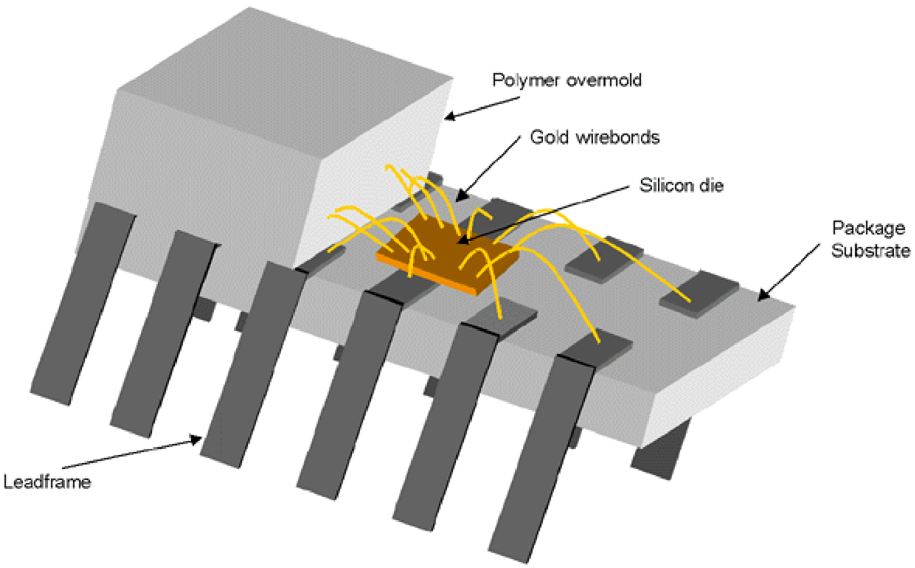




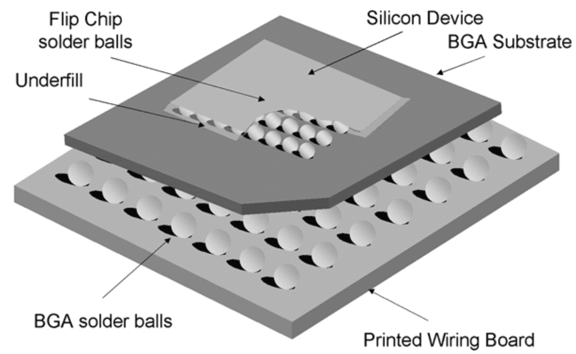
Multiple layers to route interconnects

Vias – Connects between layers

Package cross section



An isometric-section schematic that illustrates a peripheral package showing a dual-in-line-package (DiP) that is wirebonded.



A schematic of an area-array package with a flip-chip device interconnect and a ball-grid array package.

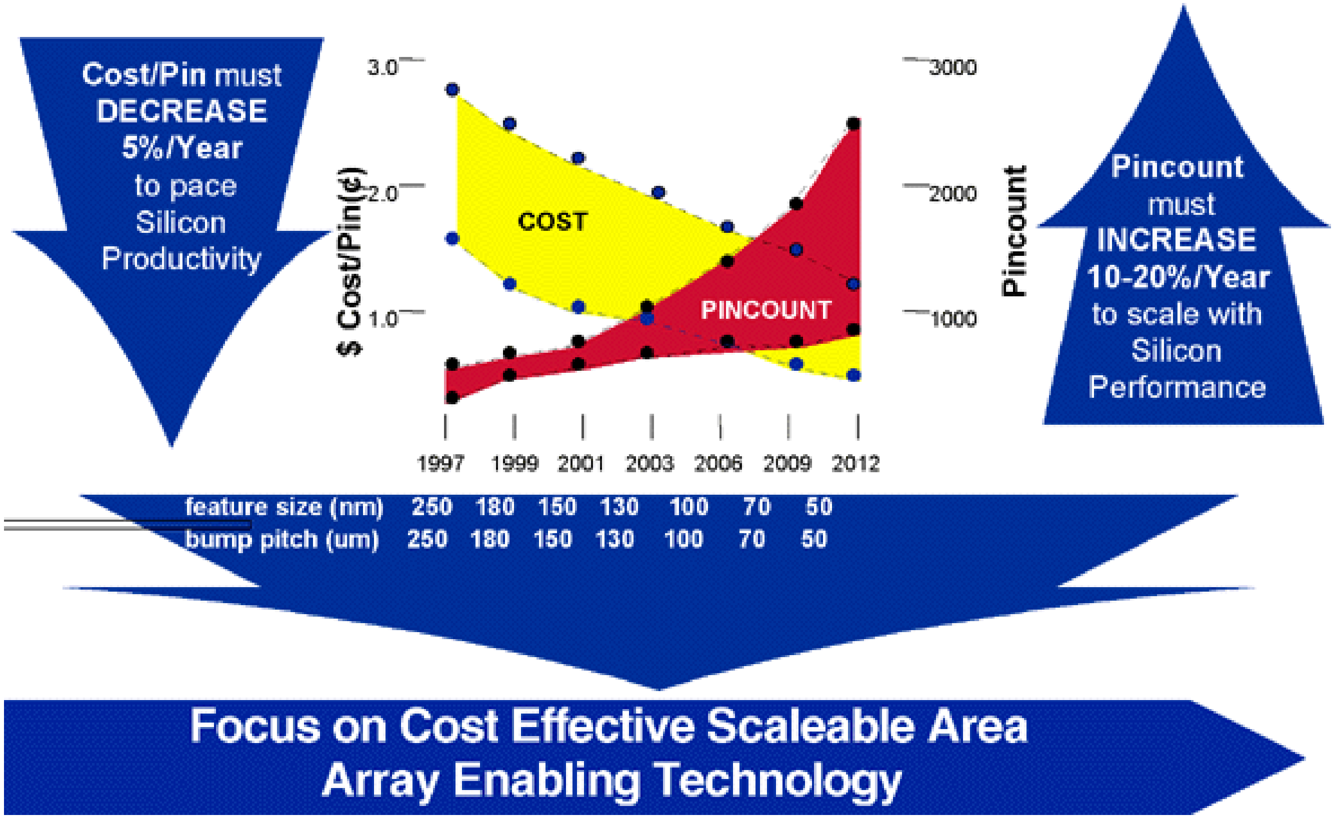
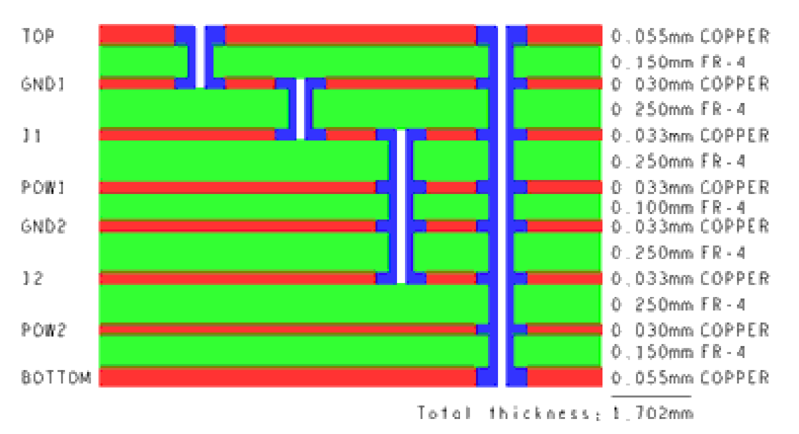

Cost/Pin must
DECREASE
5%/Year
to pace
Silicon
Productivity
3.0
2.0
1.0
$ Cost/Pin(¢)
COST
PINCOUNT
3000
2000
1000
Pincount
1997
1999
2001
2003
2006
2009
2012
Pincount
must
INCREASE
10-20%/Year
to scale with
Silicon
Performance
feature size (nm) 250 180 150 130 100 70 50
bump pitch (um) 250 180 150 130 100 70 50
Focus on Cost Effective Scaleable Area
Array Enabling Technology

Table I. Materials Used in Electronic Packaging

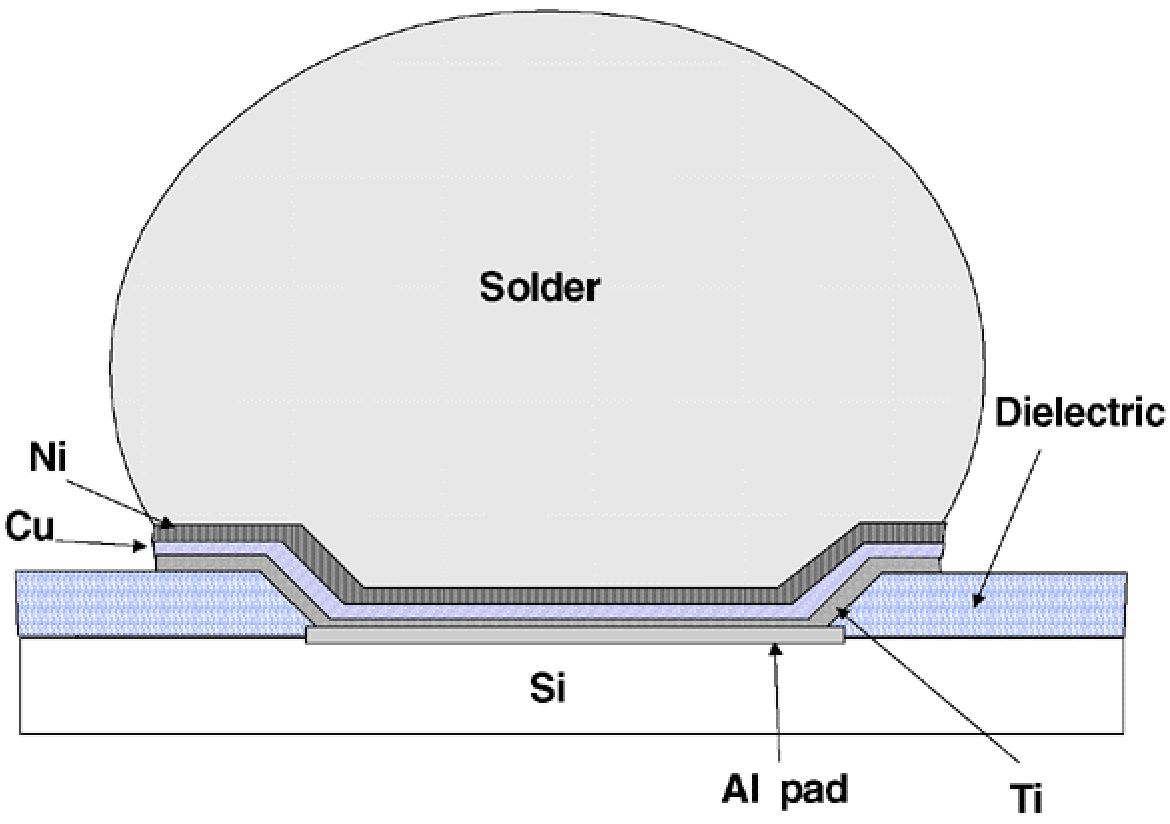
Material	Application
Semiconductors	Si (microprocessors, , GaAs (microwave Ics, IR diodes, lasers, solar cells), GaN (Lasers, LEDs, high temp operation),
Metals	Au (Wirebonds), Aluminum, Copper leadframes (Kovar, CuBe, Alloy 42), copper traces in substrates; molybdenum traces in co-fired ceramics; Ag, Au, Pd for thin/thick films on ceramics; and nickel diffusion barrier metallizations, sintered Ag
Solders	Sn-Pb (restricted use), Sn-Ag; Sn-Au, Sn-Ag-Cu, low melting point solder SnBi, indium,
Ceramics	Al_2O_3 substrates modified with BaO, SiO_2, CuO,etc.; SiN dielectrics; diamond heat sinks.
Polymers	Epoxies (overmold); filled epoxies (overmold); silica-filled anhydride resin (underfills); conductive adhesives (die bonding, interconnects); laminated epoxy/glass substrates; polyimide dielectric; benzoyclobutene; silicones; and photosensitive polymers for photomasks.
Glasses	SiO_2 fibers for optoelectronics; silicate glasses for sealing; borosilicate glass substrates; and glass fibers for epoxy/glass substrates (FR4-4).

Lamination is done by placing the stack of materials in a press and applying pressure and heat for a period of time. This results in an inseparable one piece product.

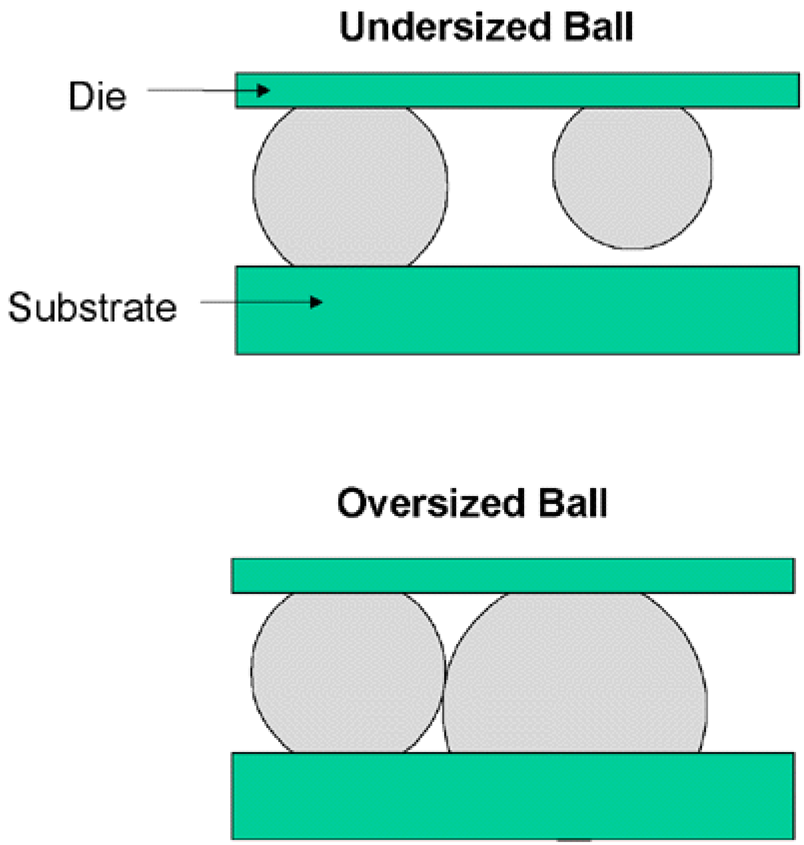
Laminates are manufactured by curing under pressure and temperature layers of cloth or paper with thermoset resin to form an integral final piece of uniform thickness.



FR-2 (phenolic cotton paper),
FR-3 (cotton paper and epoxy),
FR-4 (woven glass and epoxy),
FR-5 (woven glass and epoxy),
FR-6 (matte glass and polyester),
G-10 (woven glass and epoxy),
CEM-1 (cotton paper and epoxy),
CEM-2 (cotton paper and epoxy),
CEM-3 (non-woven glass and epoxy),
CEM-4 (woven glass and epoxy),
CEM-5 (woven glass and polyester).



A cross-section schematic of a UBM and solder bump for a flip-chip interconnect.



- The uniformity of ball size on the flip chip is important. **(a)** If the ball is undersized, electrical opens occur. **(b)** If the ball is oversized, electrical shorting is possible.

Chapter 1

4. What is the fundamental building block of an IC? MEMS?
   Optoelectronics? RF?
5. Why is packaging important?

4. What is the fundamental building block of an IC? MEMS? Optoelectronics? RF?

- The fundamental building blocks of ICs are the transistor, the capacitor and resistor.
- The fundamental building blocks of MEMS are the cantilever, the membrane, and the micro- motor, all of which are, for the most part, electrostatically actuated.
- The fundamental building blocks of Optoelectronics are the photonic sources such as laser, the photodetector and the optical medium such as waveguide.
- The fundamental building blocks of RF (30 kHz to 300 GHz) are the local oscillator and passive components such as the inductors and filters.

5. Why is packaging important?

- Packaging is important because it controls the System's:
  - No system without packaging
  - Performance
  - Cost
  - Size
  - Reliability
- Good/effective/reliable packaging design can make a System successful.
- Good/effective/reliable packaging process can make a System reliable and inexpensive.

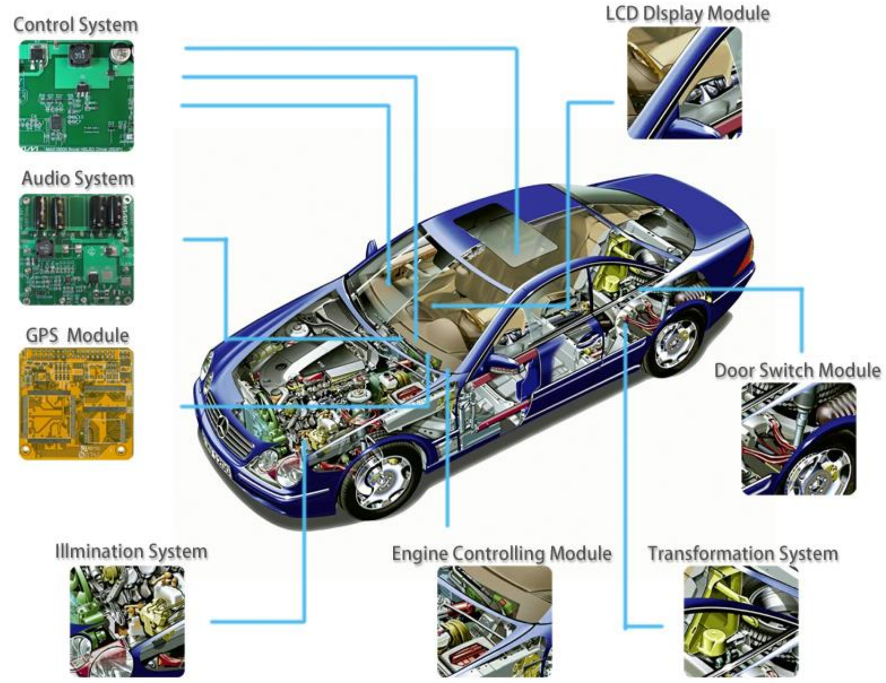
6. What do you do in systems packaging if you are a Physicist? Metallurgist? Ceramist?, Industrial engineer? Computer engineer?, Chemical engineer? Electrical engineer? Mechanical engineer?

- **Physicists** deal with fundamental issues such as the fundamental properties of semiconductors, the mechanism for the electrical conductivity of metals, the mechanism of thermal conductivity, the generation of light, and the mechanisms of superconductivity.
- **Ceramicists** deal with the composition and fabrication of non- metallic, inorganic and inhomogeneous matter. Ceramic substances are generally very hard, very stiff, very high temperature, very resistant to chemicals and often highly insulating.
- **Industrial engineering** is a broad category. As it applies to Systems, industrial engineering generally deals with the operations of production of components or assembly of complete Systems.
- **Computer engineers** deal with the design, architecture and performance of computer systems.
- **Chemical engineers** deal with the processing of organic and inorganic chemicals and the interaction of liquid, gaseous and ionized reactants with one another and with solid surfaces.
- **Electrical engineers** generally deal with signal and power distributions in Systems.
- **Mechanical engineers** deal with thermomechanical design, MEMS, thermo-mechanical reliability, thermal management and heat transfer.

Real world problem

Assume you are to package automotive electronic controller close to the engine in the car.

- What factors do you think will come into play for the electronics packaging?
- What will be the conditions for electronics working close to the engine?
- How will the environment around the electronics affect the packaging technology required?
- What temperatures are we dealing with?
- What kind of materials should we be using?



Real world problem

Cost
Size
Weight

The main factor that distinguishes automotive electronics products from consumer electronics products is the environment in which they must perform. Cost, size and weight reductions are also major factors that influence packaging of automotive electronics products.

Different from standard electronics

Automotive control systems packaging requirements are not similar to conventional printed circuit-board-mounted plastic or ceramic units. Processing is distributed around the vehicle as dictated by the locations of sensors and actuators, and packaging requirements are changing accordingly.

High reliability
Harsh conditions

Automotive Electronic Controller modules require exceedingly high reliability, size reduction and thermal durability in volume production, at a low cost. Rigid alumina multilayer ceramic substrates with copper thick film circuitry can have excellent thermal dissipation. Subsequently, direct mounting on engines or power train systems is possible in volume production. The combination of inherent superior design and processing rule of ceramic also achieves miniaturization in size. The "trough" concept of ceramic substrate enables a compact power control unit, with traces of high conductance while providing high durability at high temperatures and through harsh conditions.

The requirements for harsh environment (e.g. on-engine, on-or in-transmission) electronic controllers in automotive applications have been steadily becoming more and more stringent. Along with the environmental concerns come the challenges of meeting overall size constraints required of increasingly complex controllers by utilizing finer features and geometries. Electronic substrate technologists have been responding to this challenge effectively in an effort to meet the performance, size and cost requirements. This is dealt mainly by two primary interconnection substrate technologies: 1) organic laminate based high performance printed wiring boards and 2) ceramic based substrates.

The environments for automotive electronics products differ from location to location within the vehicle. In general, these environments are harsher than the consumer electronics products that are used in more benign home or office environments. The harshness stems from higher temperature, temperature extremes, and high humidity combined with higher temperatures. The following table shows the temperature extremes that would be encountered by the electronic package depending on its location in the automobile.

High temperature
High shock and vibration forces
High humidity

	Environmental Conditions		
Unit	**ECU**	**ECU**	**Sensors**
Environmental Classification	***"Under the Hood"***	***"On the Engine"***	***"On the Engine"***
Temperature Range	-40 to 125 °C	-40 to 150 °C	-40 to 175 °C
Vibration	Up to 3 g	Up to 10 g	Up to 40 g
Shock	Up to 20 g	Up to 30 g	Up to 50 g
Fluid Exposure	Harsh	Harsh	Harsh

The temperatures shown are the temperatures of the heat transfer surface of the module. It should be noted that internal temperatures would be higher due to power dissipation. Typical junction temperatures for IC's are 10-15 C higher than base plate temperature, and power devices can reach temperatures 25 C higher than that of the base plate. At present, automotive electronic modules are designed for an operating temperature of 125C.

Robust
Critical components must not fail

As a general rule automotive electronic products have higher reliability requirements consistent with increasing warranty spans for automobiles. Thus the electronic packages that are designed and built for automotive applications need to be robust while minimizing size, weight, and cost. These requirements are

Choice of substrate, materials

being and will have to be supported by innovative electronic packaging solutions. These solutions begin with an electronic substrate.

CTE concerns

LTCC substrates are well suited for the harsh environment that an automotive application presents. LTCC can withstand temperatures in excess of 500 C and are more capable than organic materials during thermal shock conditions. LTCC substrates also have a better CTE match to silicon than either organic or thick-film ceramic (alumina) substrates. A better CTE match improves the reliability of flip-chip components in thermal cycle testing.

Thermal performance

The thermal performance of LTCC is a concern for designers, when the application requires power dissipation through the substrate. LTCC does offer better thermal performance than organic materials, however, when compared with thick-film on alumina ceramic, it fares much worse. LTCC has a thermal conductivity of 3 W/m-K compared with 24.7 W/m-K for 96% alumina and 1.7 W/m-K for organic laminate FR-4.

Technology to Improve thermal performance

The most common method to improve the thermal conductivity through an LTCC substrate is to utilize thermal vias. Thermal vias are metal filled holes in the substrate that are purposefully placed under the pads of heat generating components. Once the heat has been transferred through the substrate, it can be spread uniformly across the substrate by the application of a metal layer on the backside. By using thermal vias, the thermal capability of LTCC can be greatly enhanced.

The high-density organic substrate technology will be a leading choice for many automotive electronics applications. The Low-Temperature Cofired Ceramic Technology has been well demonstrated in automotive electronics applications. Several issues, notably thermal disadvantages, have slowed down the spread of this particular substrate technology. However, technological and design improvements can certainly make this a viable and popular choice.

Maintain low number of connections to minimize errors

Complete optimized systems can then be realized by integrating individual components of design into a process, rather than the traditional approach that often yields a collection of electrical, mechanical and hydraulic subsystems interfaced together with a control unit. The electronic control circuit uses a number of different interconnect technologies, including rivets, solder, surface mount devices and wire bonding to a silicon die. An electronic microsystem can also be constructed by using a multi-chip module and given connections for robust and efficient interfacing with a motor housing. This type of system would usually have far fewer interconnections than the traditional solution. Both motor control circuits can be connected to a bus via a plug. On a modern automobile, this interface is likely to be a communications bus, linking several motor control circuits (such as window lifters, seat positioners and mirrors).