STAKEHOLDER CONSULTATION ON
ADAPTATION TO SCIENTIFIC AND TECHNICAL PROGRESS
UNDER DIRECTIVE 2002/95/EC
OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON THE RESTRICTION OF THE USE OF CERTAIN HAZARDOUS SUBSTANCES IN ELECTRICAL AND ELECTRONIC EQUIPMENT

FOR THE PURPOSE OF A POSSIBLE AMENDMENT OF THE ANNEX

IBM Comments

July 1, 2004

Question #3: Lead in solders for servers, storage and storage array systems, network infrastructure equipment for switching, signaling, transmission as well as network management for telecommunications (with a view to setting a specific time limit for this exemption)

- Do feasible substitutes currently exist in an industrial and/or commercial scale?
- Do any restrictions apply to such substitutes?
- What are the costs and benefits and advantages and disadvantages of such substitutes?

Response:

IBM does not believe that feasible substitutes currently exist for lead in solders for servers, storage, and storage array systems. While alternative lead-free solders are being evaluated for many server and storage applications, these alternatives have not been demonstrated to meet the stringent performance and reliability requirements needed for server and storage products.

Server Systems

Servers are a sophisticated class of computers designed to reliably address complicated applications in the business, scientific, military, and government arenas. Closely associated with Servers are Storage systems which store large volumes of data and route it to the processor units upon demand. The combination of Server and Storage hardware are often the central computing system to which other computers can tap into for information and data processing. Servers are often classified into three categories.

(a) Entry-level Systems (e.g. IBM x-Series) which are popular for small business operations such as inventory control, manufacturing process control, and specialized applications such as patient monitors in hospitals.

(b) Mid-range Systems, some of which are architected to provide efficient management and integration of business operations (e.g. IBM i Series), while others are designed to maximize computing power for scientific applications, including the ability to model complex systems for research, development, and data mining applications (e.g. IBM p Series). Mid-range systems must perform reliably and optimally for business, government, and scientific applications requiring massive scalar integration of computing power combined with reliability.

(c) High-end Systems, often referred to as mainframe or enterprise systems (e.g. IBM z-series, Fig 1) are configured to provide unmatched computing performance, data integrity, security, scalability, and interconnection capabilities. Because of these unique set of combined attributes, these systems are utilized for applications requiring massive, reliable computing power for such applications as insurance, international banking, airline reservations in the business arena; multinational security; governmental operations, research and development, etc.

Storage Systems

Servers must have the ability to store information and access it as required as an integral aspect of data processing and computing. In the case of consumer-level computers, i.e. laptops and desktop units, the Storage function is achieved by the computer's memory section and hard drive. These functions are directly incorporated into the chassis. Separate external units are available to extend the capacity.

However, Server-type computers require an enormous capacity, much greater functionality, and are more sophisticated than their consumer counterparts. Many of these are stand alone units, and can be classed into five categories:

(a) Disk Libraries (Fig. 2), are used to access frequently needed information. These systems are faster than tape systems and are fairly large stand alone systems typically consisting of more than 125 drives, where each drive provides storage of more than 70 GBs of information.

(b) Tape Systems (Fig. 3), are also stand alone units with a high capacity, consisting of about 6,000 tape cartridges, and with tape drives that can both read and write tape media. These units serve as long-term storage and access libraries.

(c) Storage Area Network (SANS, Fig. 4), serve as a switch or a director of information among Servers and / or Storage units. It is capable of very rapid data rates, currently ½ GB, 4GB by Y/E 2004, 10 GB by Y/E 2005.

(d) Midrange Systems (Fig. 5), so-called because these Storage units are typically utilized to support the needs of mid-sized businesses. These rack- mounted units consist of disc drives that allow for the continuous availability of data across Storage networks.

(e) Network Attached Storage (NAS, Fig. 6), are also rack-mounted units that are configured to serve as an interface between a LAN and a SAN.

Reliability Requirements

The key requirement among all Servers and the storage equipment that is utilized in conjunction with them is that they be extremely reliable. While all Servers are utilized for mission-critical applications, when the need arises, Servers are utilized to meet the highest service requirements. For example, a typical Server utilization capability is 24 hours per day, seven days a week, for a period of up to 10 years or more with a total downtime of 4 hours or less over the entire operational period. That equates to an operational percentage of 99.9954% over the field life of 100,000 hours typically expected of mainframe systems. Servers also are expected to remain functional during most repair actions. This maintenance feature is called concurrent maintenance. Examples of concurrent types of maintenance are microcode patches or replacing a channel card.

It is absolutely imperative that Servers have the capacity to operate reliably and continuously for long periods of time. Failure to do so in mission-critical applications can have significant societal impacts. Among them are impacts to health with the potential for loss of human life. Additionally even short down times can result in economic impacts of hundreds of thousands or even millions of U.S. dollars. This pertains to all Servers including entry-level systems. These systems may have a reduced but still substantial life expectancy (approximately 40,000 hours), but they are still expected to meet rigorous reliability requirements over their operating life times.

Concerns with Lead-free Solders

Lead is utilized in Servers and Storage systems for several specific purposes. It is used in the insulation of cables to provide stability (i.e. ability to withstand degradation and deterioration). It is also used in coatings or finishes that protect metal fingers that extend beyond the body of a microelectronic component referred to as leads.

However, the principal use of lead in Servers and associated storage equipment is in solders, and specifically solder joints. The implementation of lead-free solder in Server and Storage systems raises several important and significant concerns. For example, the melting temperature of the most popular lead-free solder candidates under consideration are approximately 40^{o}C higher than the lead-tin (Pb-Sn) solder utilized for electronic assemblies over the last four decades or more. There are serious concerns related to thermally-induced degradation to printed circuit boards (PCBs) and components due to the higher temperatures necessary to process these Pb-free solders.

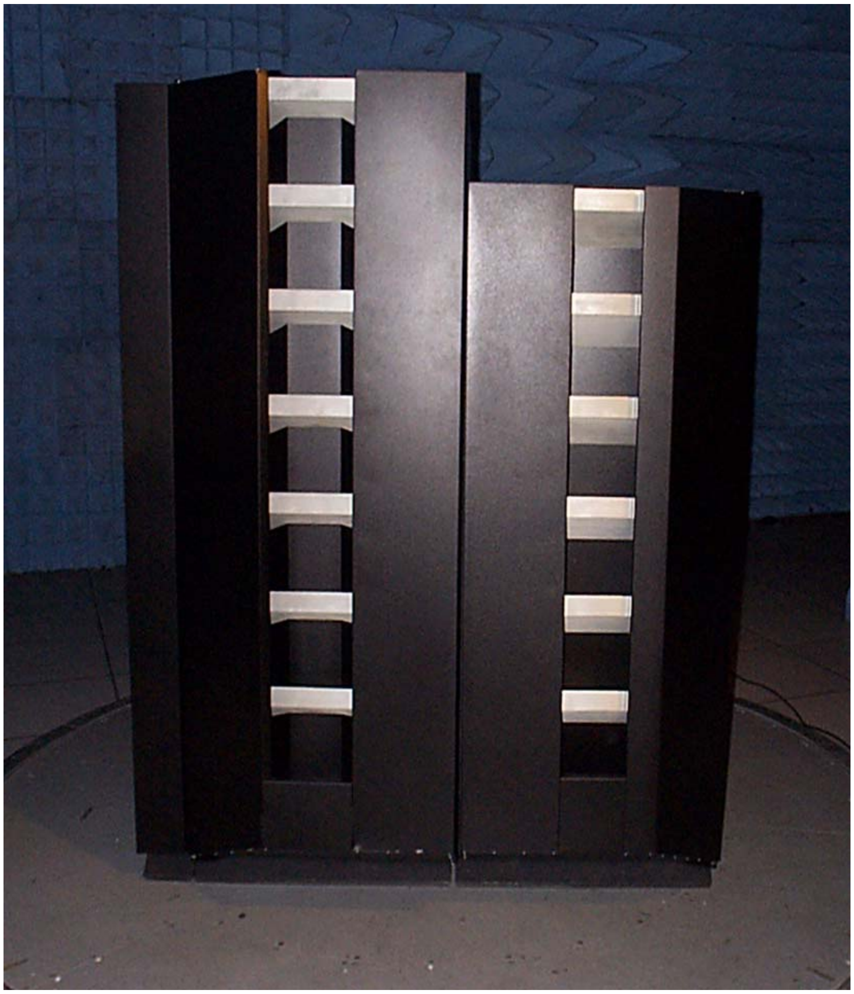
Also, the solder wetting and spreading characteristics are less when compared to Pb-Sn solders, making solder joint integrity more problematic. The inspectibility of unacceptable Pb-free solder joints is much more difficult to identify based on appearance, so there is a greater potential for defective solder joints escaping to the field. Components with lead-free solder also are more prone to cracking and failure from absorbed moisture during assembly operations owing to the higher process temperature requirements.

Lead-free solders typically consist of a high concentration of tin (typically greater than 90 wt.%), which also makes them prone to tin whisker formation and growth. Tin whiskers are very thin hair-like protrusions that grow on the surface of tin-rich solders. These hair-like filaments act as tiny wires and can cause electrical shorts if contact is made to some nearby electrical circuit. Also, one of the leading lead-free solder candidates is known to exhibit a sensitivity to shock and vibration, which is a particular concern for Server systems given the large mass of some of the componentry, printed board assemblies, etc., utilizing solder connections. The sensitivity to shock and vibration stresses increases the potential for solder joint cracking during component handling, shipping, installation, system upgrade, etc. These are but a few of the technological concerns associated with implementing lead-free solders in Servers and associated storage equipment.

Request

The EU ROHS directive wisely granted an exemption for lead use in solder for Servers and Storage systems to expire in 2010. Based on the very stringent and robust reliability that Servers and the associated storage equipment most possess, and the host of reliability issues and concerns that remain unanswered relative to lead-free solders, IBM feels this exemption remains justified. It would not be prudent to implement Pb-free solders in these systems until key issues have been resolved, and a sufficient field database has been established demonstrating the necessary reliability of lead-free solder joints. IBM accordingly requests that the current exemption be continued.

Fig. 1 Typical High-end Server



IBM z-900, Type 2064

Fig. 2 Disk Library

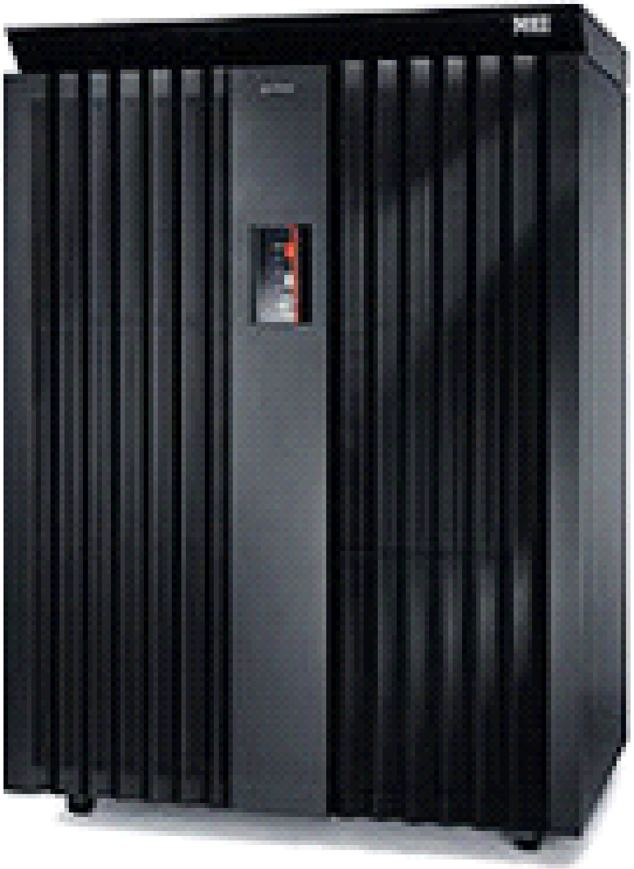


Fig. 3 Tape Systems

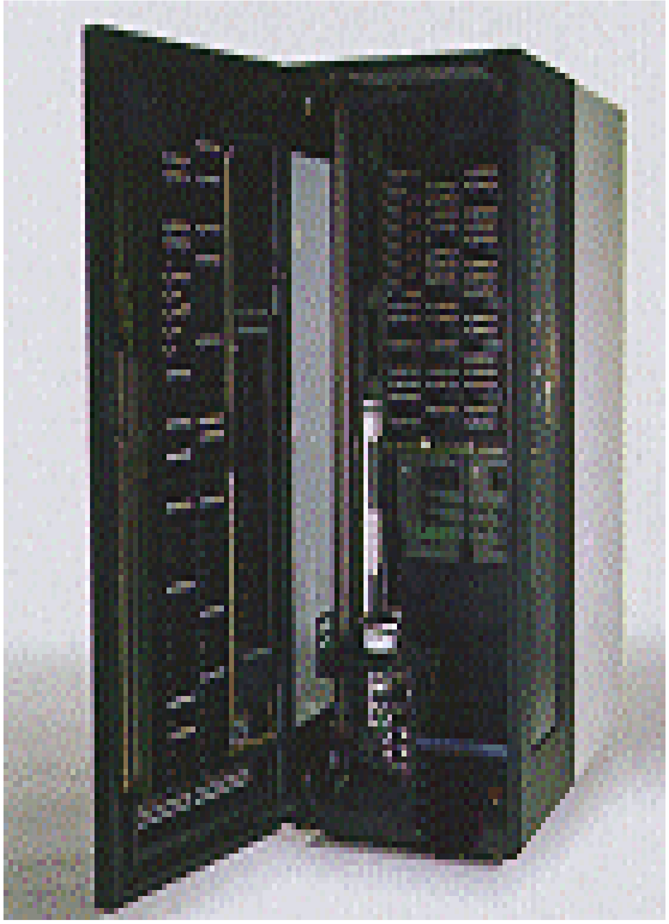


Fig. 4 Storage Area Network (SAN)

Fig.5 Midrange

Fig. 6 Network Attached Storage (NAS)

Question #5: Lead used in compliant-pin VHDM (Very High Density Medium) connector system

- Do feasible substitutes currently exist in an industrial and/or commercial scale?
- Do any restrictions apply to such substitutes?
- What are the costs and benefits and advantages and disadvantages of such substitutes?

Response:

IBM does not believe that feasible substitutes exist for lead used in compliant-pin (Very High Density Medium connector systems.

Connector Types/Uses

Connectors used in electronic assemblies consist of two main segments. The mating end of a connector provides the electrical interface to another connector, a cable, a component, or a printed circuit assembly. The opposite end, or the tail end of the connector, is used to both mechanically secure the connector to the printed circuit assembly, cable or electrical component and provide an electrical path. The tail end of a connector is available in two basic varieties, the "solder tail," which as its name implies is inserted in a plated-through-hole (PTH) in a Printed Circuit Board (PCB) and soldered in place from the opposite side. The "compliant-pin tail," sometimes called the "press-fit tail," relies on a very precisely controlled interference fit to make the electrical connection and mechanical attachment when it is pushed into a PTH to create a force fit, making intimate contact with the walls of the PTH.

Advantages of Compliant Pins

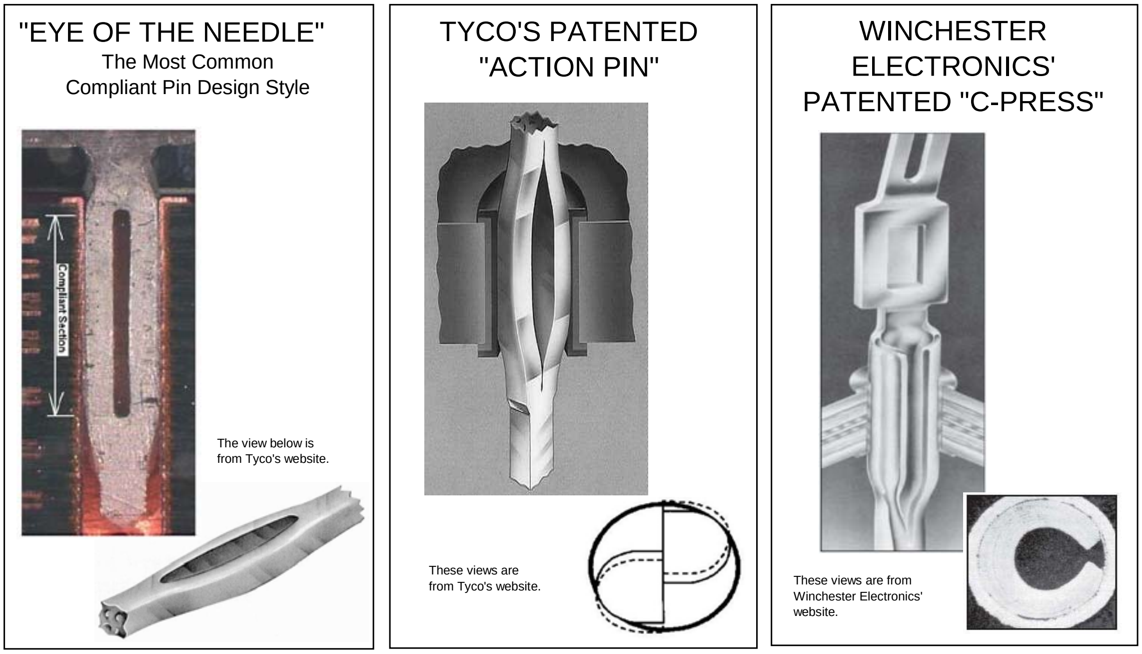
Compliant-pin connectors are widely used in the electronics industry, and IBM uses them extensively in its products. In many applications compliant pin connectors provide significant advantages over their solder-tail connector counterparts. These advantages include:

1. Higher signal density can be achieved within the connector itself.
2. Higher connector density can be achieved on the electronic assemblies.
3. Connectors can be attached to both sides of the PCB, using the same PTH directly opposing each other, or tightly spaced, staggered front to back on the assembly. See figure 1.
4. Provides better signal integrity in high signal density applications.
5. A reliable connection can be achieved without soldering, which allows assembly and field reworkability.
6. Heat is not required to attach a compliant pin connector, thus avoids damage and degradation of the circuit boards, surrounding components, and their interconnections.

Dimensional Aspects of Compliant Pins

Compliant-pin tail designs are often patent protected by connector manufacturers. IBM uses compliant- pin connectors of several different designs, and variations within a design. Three common designs used in IBM Servers are: “eye-of-the-needle,” Tyco’s patented “action pin” and Winchester Electronics patented “C-Press.” See figure 1.

Independent of the design specifics, the operation of all compliant-pin connectors is based on the concept of the compliant pin’s having a tail that is slightly larger than the PTH into which they are inserted. The resulting interference or press fit must have very tight mechanical tolerances on the connector-pin tail metallurgy and hardness, the drilled hole diameter, and the plating thickness and surface morphology (i.e. condition) of both the PTH and the compliant-pin tail to provide a sufficient but not excessive amount of force between the inserted pin and finished plated-through-hole. Functionally the designs are very sensitive to even minor dimensional and surface variations. If the pin diameter is a little too large or the coating too stiff causing excessive friction, insertion of the pin into the hole will damage the PTH and/or compliant-pin tale resulting in an unreliable connection. If the compliant-pin tale is too small with respect to the PTH, it results in a loss of electrical connection and mechanical integrity. The tin-lead plating on a compliant-pin tail is typically about 10% lead by weight, but only an average thickness of about 1.5 microns (0.000059 in.).


"EYE OF THE NEEDLE"
The Most Common
Compliant Pin Design Style

The view below is from Tyco's website.

TYCO'S PATENTED "ACTION PIN"

These views are from Tyco's website.

WINCHESTER ELECTRONICS' PATENTED "C-PRESS"

These views are from Winchester Electronics' website.

Figure 1: Three Common Compliant-Pin Designs

Role of Lead-Tin (Pb-Sn) Compliant Pin Coatings

The tin-lead coating on a compliant-pin tail provides a number of important functions:

1. It provides a good, reliable electrical connection between the compliant-pin tail and the PTH.
2. It acts as a lubricant between the compliant-pin tail and the PTH. Without sufficient lubrication the insertion and removal forces are too great causing damage to the PTH, connector, or surrounding components or their attachments. See figure 2.
3. Its metal oxides are easily displaced upon insertion into the PTH, providing a good metal-to-metal, gas-tight connection. Metal oxides, typically do not conduct electricity so result in a poor electrical connection.
4. A gas-tight seal is formed upon inserting a compliant-pin tail into a PTH. The pin's tin-lead coating "creeps" slightly conforming to the surface of the PTH creating the seal which prevents reoxidation and corrosion due to the ambient environment from occurring at the metal-to-metal interface, resulting in electrical open circuit conditions.
5. The presence of lead prevents tin whisker formation in pin coatings consisting of pure tin or solders with high tin concentrations. Tin whiskers are fine hair-like filaments that grow from the surface that can cause electrical shorts between pin contacts. See figure 3.

Other Coatings Evaluated

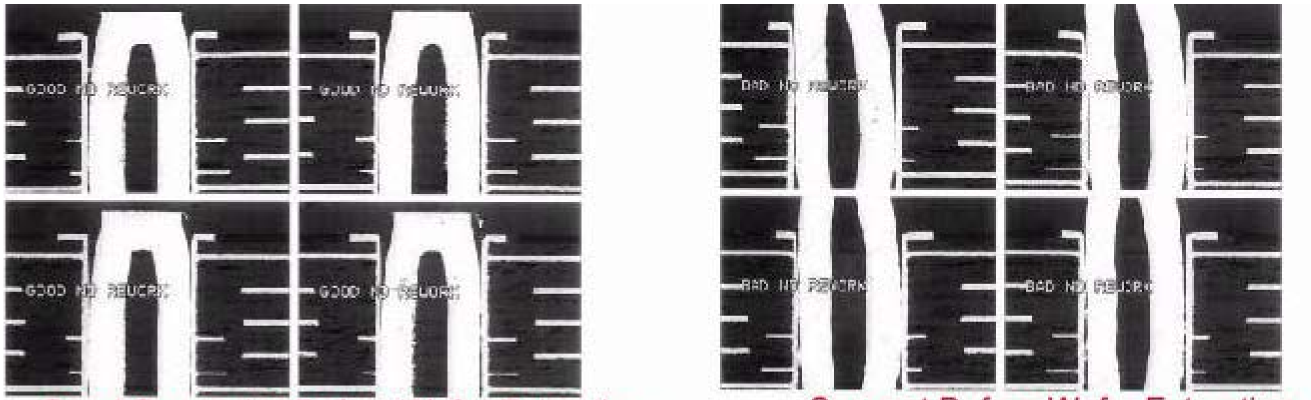
Work is underway to identify a suitable replacement compliant-pin coating.

Gold over nickel used in the contact interface region has excellent electrical properties, corrosion resistance and acceptable lubricity. However, when normal forces are increased to the level required for integrity of the compliant-pin to PTH connection, the friction between the PTH and the compliant-pin becomes too great and damages the PTH, PCB and connector. Thus, this alternative is not currently feasible.

Tin coating has favorable electrical properties as well. However, additional research and development is required to resolve known problems with tin. Tin coating without lead, like gold over nickel, has an increased friction where PTH, PCB and connector are damaged. Additionally, more research is required to find acceptable methods to prevent tin whiskers formation.

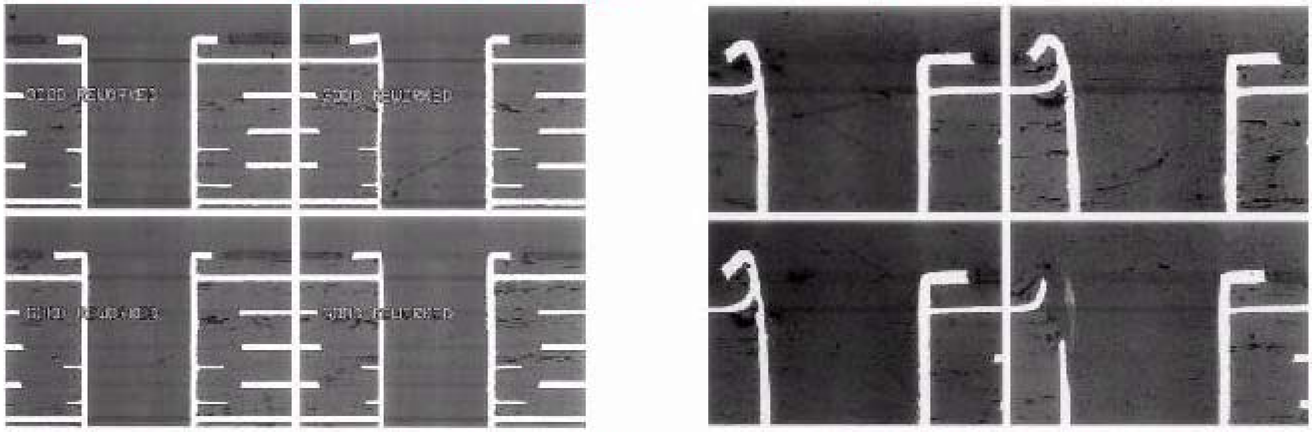
Request

IBM continues to work with connector suppliers to define a suitable lead-free coating for compliant-pin systems. However, until an acceptable alternative is identified, IBM is compelled to use tin-lead as the compliant-pin tail coating. No suitable substitute has been found that satisfies the functional and reliability requirements. For this reason we request an exemption to utilize Pb in coatings of compliant-pins.



Good Connector-Before Wafer Extraction

Suspect-Before Wafer Extraction



Good Connector-After Wafer Extraction

Suspect-After Wafer Extraction

Figure 2: PTH Damage Due to High Friction during Compliant-Pin Insertion

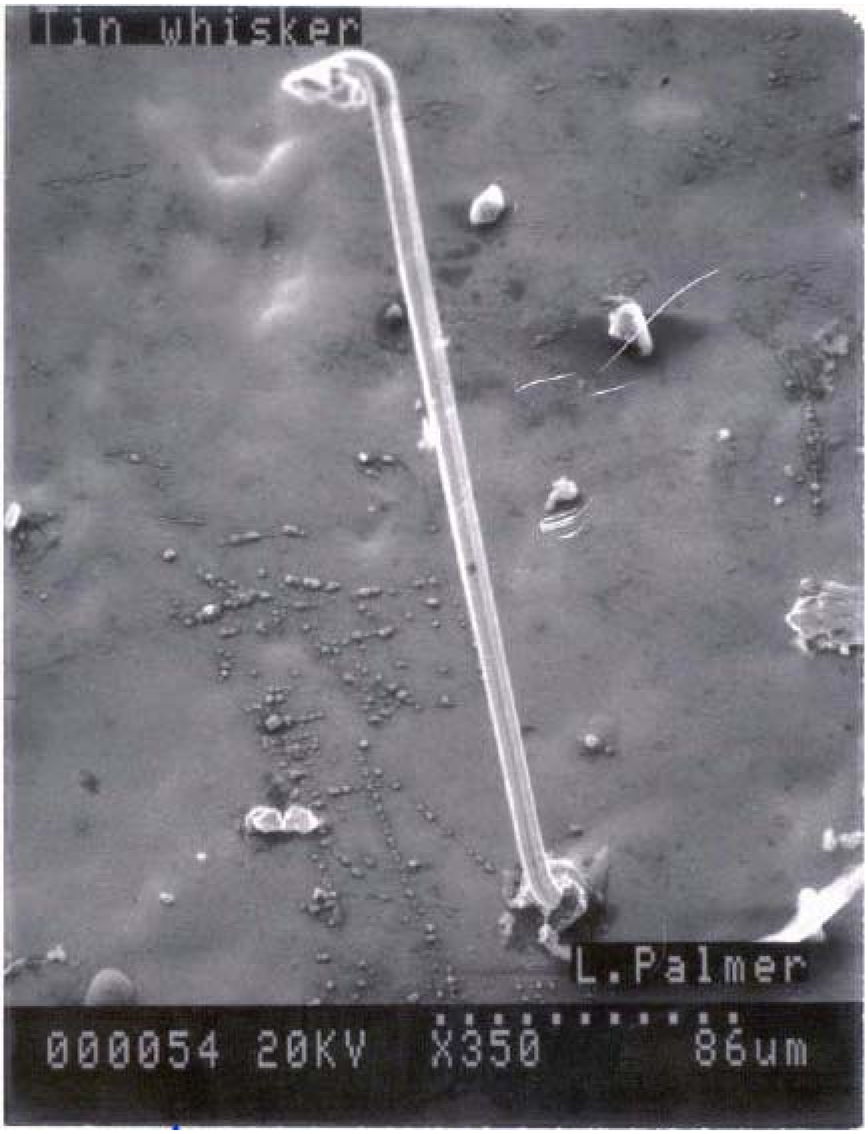


Figure 3: SEM Micrograph of Tin Whisker

Question #6: Lead as a coating material for a thermal conduction module c-ring

- Do feasible substitutes currently exist in an industrial and/or commercial scale?
- Do any restrictions apply to such substitutes?
- What are the costs and benefits and advantages and disadvantages of such substitutes?

Response:

IBM does not believe that feasible substitutes exist for lead as a coating material for thermal conduction module c-rings.

Thermal Conduction Modules (TCMs) are critical to the operation of IBM's highest performance z-series mainframe servers. State of the art, high performance Central Processing Unit (CPU) chips are extremely complex and include hundreds of millions of built in transistors that are interconnected to the "deck" of a TCM surface with hundreds of thousands of fragile solder interconnections.

When these chips are present in close proximity to one another to optimize signal integrity and high frequency performance, they generate a significant amount of heat during system operation which must be dissipated to ensure reliable performance throughout an extended system lifetime. Thermal Conduction modules with lead-plated C-ring seals are a key element of hardware designs that yield an effective removal of heat generated by a massive integration of high power, high performance devices present in these server products.

Thermal Conduction Module

Dense Multichip Carrier Design

The multichip module (MCM) or carrier that IBM uses to put both its processor and memory chips on, referred to as a Thermal Conduction Module (TCM) is unique in several aspects. In size, it is in a class consisting of only the largest of MCM electronic packages. The size of the multilayered ceramic TCMs contained in IBM mainframe computers has ranged from approximately 90 to 128mm on a side. The power dissipation capabilities have ranged from 200 to nearly 2000 watts. Early versions had from 100 to 133 small chips mounted to the chip carrier, while more recent designs have contained from 30 to 36 large chips (approximately 15 to 18mm in size), largely due to improvements and integration in chip technology. In all cases the chips have tiny solder bumps on one side, about twice the diameter of a human hair, used to attach the chips to the TCM. The chips are referred to as flip chips since the side with the solder bumps is "flipped" over such that the solder bumps mate with pads on the TCM that they are soldered to when reflowed in a furnace. With the increases in chip performance and functionality, the electrical power requirements of the TCM have steadily increased. Along with that, so has the need for increased cooling capability to handle the high heat dissipated by the chips. A metal cap is used to encapsulate and cool the chip carrier package and is sealed to the ceramic chip carrier by means of a resilient metal seal in the form of a lead (Pb) plated metal C-Ring. The C-Ring base material is Inconel 718 (Nickel based alloy), 0.381mm thick, plated with 0.063 to 0.115mm of lead.

Over the years, there has been an evolution of TCMs utilized in IBM mainframe computers involving variations on two major internal cooling design schemes. One consists of a piston that makes contact with the chip backside, and the other utilizes a thermal compound or paste to remove the heat generated. Figures 1 and 2 show cut-away views of these two types of thermal designs.

Seal Requirements

TCMs must meet several key design requirements. They must:

1. Be easily reworkable.
2. Hermetically encapsulate the package. This is to protect the flip chip solder connections, ceramic chip carrier and chips' metal circuits from oxidation and corrosion by the ambient environment. This also prevents drying or degradation of the thermal paste used inside the TCM.
3. Reliably withstand the thermally-induced stresses caused by the temperature differences and the expansion mismatch between the ceramic chip carrier and the metal cap.
4. Provide adequate cooling to meet performance and reliability requirements.
5. Securely position and retain the chip carrier relative to the alignment hardware for reliable actuation onto the board connector.
6. Be a field replaceable unit (FRU).

It is important that TCM structures are reworkable because the high complexity of chip devices typically drives very low functional yields when multiple chips are attached and tested. A low yield condition dictates that essentially all TCMs must undergo multiple chip attach, module assembly, module disassembly, and chip removal operations before a fully functional TCM is manufactured. In fact, some TCMs may require multiple reassembly and test sequences in excess of 5 times depending on overall functional complexity.

When a functional TCM is produced, the TCM sealing process and structure must provide a seal that sustains a high internal vacuum level for a time period in excess of 10 years. Although other module sealing technologies exist and are used in x, I, p (entry and mid-range servers, respectively) as well as in other manufacturers' machines designed for similar applications), these alternate module sealing technologies do not provide for the combined and required assembly, disassembly, reworkability, and resultant vacuum levels necessary to ensure reliable module functions. This is particularly true for modules used within IBM's z-series mainframe servers which include an essentially zero allowed TCM failure rate.

At the core of IBM’s z-series mainframe computer architecture exists an implementation of TCMs that are specifically designed for ultimate computing performance and unmatched reliability. These attributes are provided by a combination of specific electronic structure and hardware design elements, including the ability of TCMs to effectively remove heat. Specifically, within these modules exist numerous high-power processor chips (CPUs) and associated memory chips (L2s) that are interconnected to the TCM, and share information transferred and generated between the processor devices. This unique configuration of processor devices coupled with shared memory devices ensures that the highest possible number of interconnections can be present and simultaneously run at the highest possible frequency.

To ensure outstanding system performance, it is extremely important that all chip devices are interconnected in very close proximity to one another to minimize signal communication lengths. However, the close proximity of chip devices drives conditions for the generation of a significant quantity of heat in a highly concentrated area, making it necessary to provide an efficient heat removal method and cooling solution within the TCM. These resultant functional and structural attributes are a mandatory feature of the z-series TCM that must be provided to ensure the required functionality and reliability.

Multiple Roles of the Lead-Coated C-Ring

In order to meet these requirements, several technologies were adapted for use in this application. For ease of reworkability, a mechanical design involving clamping to a perimeter flange is employed. Early versions of the TCM utilized a metal frame that was brazed to the perimeter of ceramic chip carrier. A lead (Pb) plated C-Ring sealed the metal frame to the metal cap. Eventually, the metal frame was eliminated by sealing directly to the ceramic chip carrier (Figure 3). A mechanical seal with a C-shaped cross-section and a square or rectangular overall shape, made of a malleable metal that is compressed between the chip carrier flange and the metal hat is required to seal the assembly. The C-Ring seal has characteristics that meet the requirements of items 1, 2, 3, and 5 listed above. This sealing design is the key enabler of TCMs used in IBM z-series mainframe servers.

The square shaped, lead-plated metal C-Ring was selected because of its excellent sealability, reliability and reworkability. The resultant seal provides a leak rate of less than 10-8 atm-cc/sec of Helium. It also has excellent wear characteristics necessary to meet the on-off and intermediate operational requirements of IBM z-series servers. Thermal cycling due to operational conditions results in differential expansion across the C-Ring that in turn results in a relative motion between the metal hat and the ceramic carrier. This causes a rolling or bending of the seal cross-section. The lead plating has the requisite material properties that allow it to remain in intimate contact with all the sealing surfaces while these events occur over a minimum 10 year period. Its excellent wear characteristics allow it to remain hermetic over thousands of such cycles. C-Rings in these assemblies have been successfully stressed to over 3,000 thermal cycles in accelerated reliability tests.

A lead-plated C-ring seal also provides the frictional force needed to prevent the ceramic carrier from moving during thermal cycling and actuation of a TCM into its connector on the circuit board. In early versions, this actuation involved a motion along one of the centerline axes of the ceramic carrier. The C-Ring compression force, which is always present after assembly, provides a retention force equal to the frictional force between the ceramic carrier and C-Ring on one side, and the ceramic carrier and a cushion on the other side. This prevents the ceramic carrier from moving laterally.

As stated earlier, the hermetic seal used in TCMs is square shaped with tight radius corners and has a C-shaped cross section. Forming of corners in the base material results in a non-uniform surface in these corner areas. The lead plating covers over and fills in these areas, exhibits excellent bonding to the base metal, and provides a soft, compliant interface material for sealing to the mating surfaces. In addition, the seal must exhibit low yield stress at the contact surfaces to conform to the surface topography, but have high overall elastic compliance to take up component thickness tolerances and thermal-cycling induced deflections. Another desirable feature of the C-Ring is its curved, or radiused, sealing surface which ensures a circumferential line contact (i.e. only making contact at the top and bottom of the C-Ring). This feature makes it an ideal candidate for the application of soft plating materials. The forces are very high at the C-Ring contact points deforming the plating into any surface irregularities.

Other Solutions Evaluated

IBM uses a silicone adhesive module sealing technology to package a variety of single chip modules and multichip modules in many entry level and mid-range x, i, and p-series server products. This sealing technology is also common throughout the computer industry. However, modules which use this sealing technology are in general less complex, may run at lower powers, do not possess the assembly and rework requirements of their z-series TCM counterparts, and typically require a reliable life span of approximately 5-7 years based on maximum stress or use conditions.

During the development stage and over the past approximately 25 years since TCMs were first utilized for IBM mainframe computers, many other potential TCM seal solutions have been evaluated. Elastomer and metal O-Rings, gaskets made of metals, elastomers and composites, and plated elastomers were all investigated. The C-Ring was the only seal that met all the requirements. Various coatings were evaluated: gold, silver, indium, lead-tin. All alternative solutions investigated exhibited either poor seal reliability with thermal cycling, poor time zero yield, high leakage, or some combination of these problems. These studies were quite extensive and comprehensive and were performed over a long period of time, consuming scores of man-years of effort. Many variations of the C-Ring design were also investigated. The only material that provided all the required attributes noted, including long-term reliability, is a lead (Pb) coating.

Lead (Pb) Quantities Utilized and Ultimate Disposition

The average weight of the lead utilized in each C-Ring is about 3.1 grams. Accordingly, it is projected that IBM's usage of lead associated with TCMs containing a C-ring will be approximately 100 pounds over the next 5 years. TCMs containing a C-ring have a long service life since mainframe computers typically are refurbished after their initial customer usage, and enter the secondary market for several additional years of service. At end of life, the C-rings are removed and properly dispositioned.

Request

IBM is constantly investigating alternative solutions, since the use of C-rings is a relatively complicated and expensive technology. Nothing to date has met the stringent requirements of these systems. Therefore we request an exemption to allow the continued use of lead (Pb) coatings for C-rings that are crucial to the performance of IBM mainframe computers.

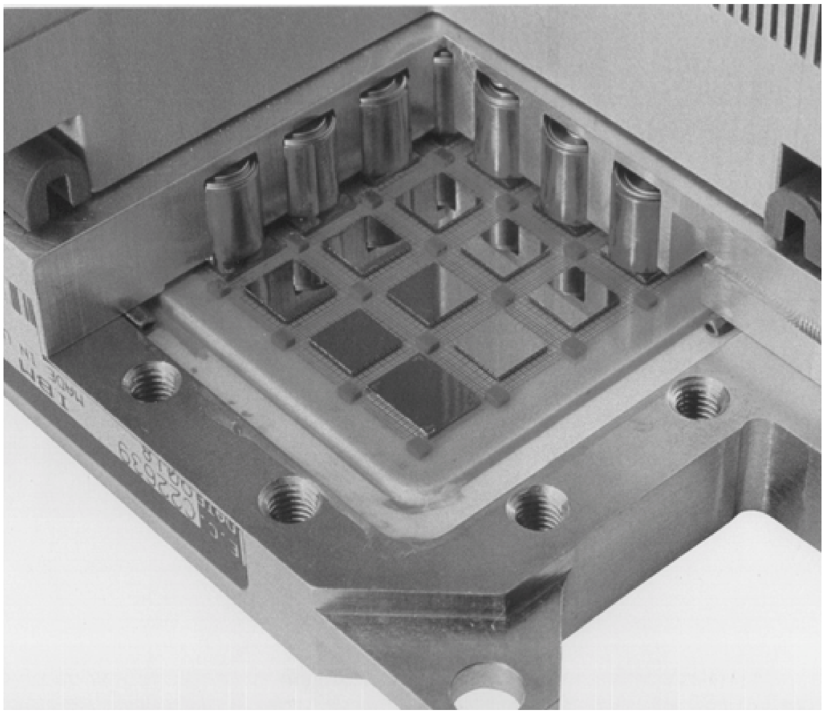


Figure 1: Cross-Section of a TCM with spring loaded pistons contacting the backside of individual chips. The heat dissipation path was from a chip to the piston to the water cooled coldplate or air cooled heatsink.

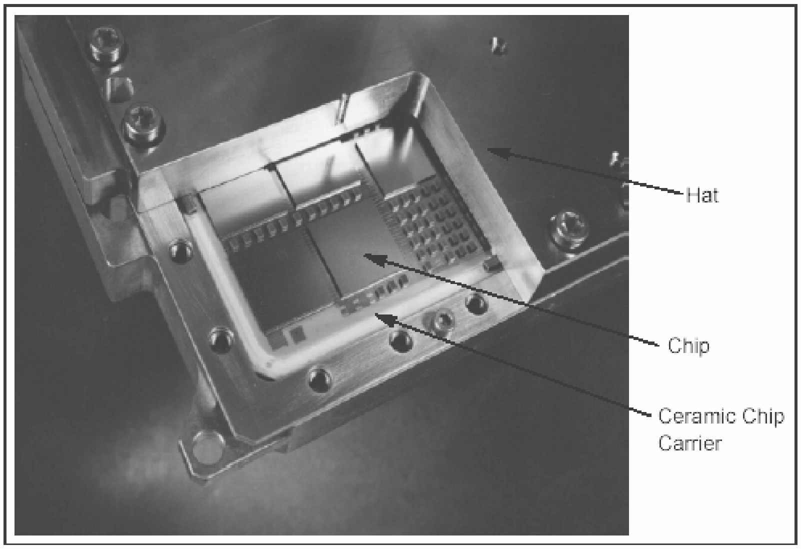


Figure 2: Cross-Section of a TCM with thermal paste in the gap between the top of a chip and the hat (also see Figure 3).

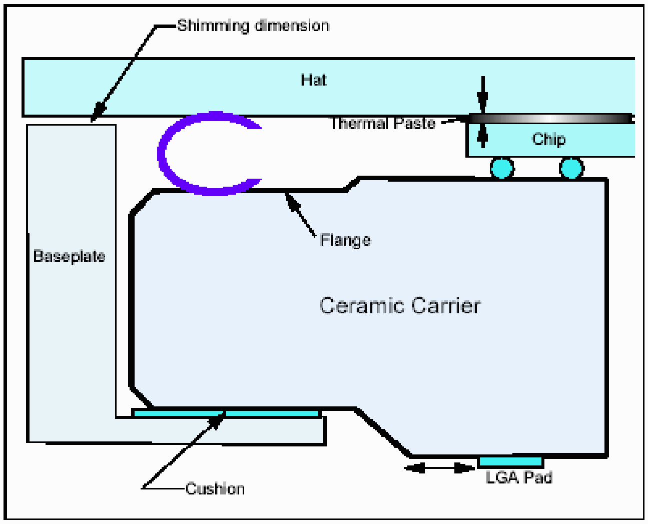


Figure 3: TCM assembly showing direct sealing to the ceramic chip carrier.

Question #10: Lead in high melting temperature type solders (i.e. tin-lead solder alloys containing more than 85% lead) and any lower melting temperature solder required to be used with high melting temperature solder to complete a viable electrical connection

- Do feasible substitutes currently exist in an industrial and/or commercial scale?
- Do any restrictions apply to such substitutes?
- What are the costs and benefits and advantages and disadvantages of such substitutes?

Response:

IBM does not believe that feasible substitutes exist for lead in high melting temperature type solders (i.e. tin-lead solder alloys containing more than 85% lead) and any lower melting temperature solder required to be used with high melting temperature solder to complete a viable electrical connection. These solders are used in critical flip chip assembly operations used throughout the electronics industry.

What Are Flip Chips

Flip chips are electronic devices that have an array of very small diameter solder bumps (about 2X the diameter of a human hair) located on the functional side of the device. See Figure 1. These bumps serve several purposes:

1. They are used for attachment to the next level of assembly (i.e. a chip carrier or a printed circuit board) providing a metallurgical interconnection and mechanical support;
2. They provide the electrical path between the device and the chip carrier or printed circuit board, and
3. They provide a thermal path into the chip carrier.

Solder Joint Requirements for Flip Chips

The solder bumps of flip chips are typically made of a high lead-tin (97Pb / 3Sn wt%) solder alloy. The purpose of the high lead (Pb) content is to provide the solder joint a high degree of resistance to fatigue failure. This failure is the type that occurs when a paper clip breaks when repeatedly bent back and forth. Solder joints can also fail by being bent back and forth due to a difference in the degree of expansion experienced between the chip and the carrier it is attached to when heated. Heating and cooling occurs every time a computer is turned “on” or “off,” respectively, causing the solder joints to be stretched or bent back and forth. This same effect occurs to a lesser extent during the time that the computer is “on”, but between periods of active performance. Lead (Pb) provides the joint with the ability to withstand many cycles of being bent back and forth without failure.

In addition, high-melting temperature solders have the ability to carry high levels of current over a long period of time. This current-carrying capability is related to the melting point of the solder. Lower melting point solders are not able to support the types of high-performance electrical characteristics that are required for many computer applications. The current requirements for microelectronic devices are increasing as processing speeds also increase. In addition, performance requirements are driving an increasing number of interconnections and greater interconnection densities, leading to a decrease in interconnection dimensions. This combination of increased current and decreased dimensions greatly increases the current density per flip chip solder joint. If the flip chip bump structures are not composed of the proper materials, these high current densities can result in functional failure of the device caused by the migration of solder atoms from the solder joint interface leading to the development of voids at these interfaces.

Flip Chip Assembly Processes

When a flip chip is joined to a ceramic chip carrier, the assembly process is a straightforward reflow (i.e. melting) of the solder bumps to join them to mating metallized pads on the chip carrier. Ceramic materials are very robust and can withstand the 300C and greater temperatures that are required of high-melting point solders. See Figures 2 and 3.

However, more flip-chip applications are moving to plastic chip carriers for cost and electrical performance reasons. These chip carriers are typically based on epoxy-glass materials that cannot withstand temperatures greater than 260C. In the case of fully melting the high-temperature solders, the plastic chip carriers would thermally degrade (e.g. char the material, etc).

To still obtain the reliability benefit provided by the high-lead-tin solder bumps, a lower-melting temperature solder, typically 63Sn/37Pb, is applied to the metallized pads on the plastic chip carrier. See Figures 4 and 5. The reflow temperature to join a flip chip is then limited to the temperature that will melt the low-temperature solder to allow the attachment of the high-temperature solder bump. The high-lead solder bump contributes about 70%, and the low-temperature solder applied to the chip carrier pads contributes about 30% of the final solder joint volume. The amount of lead in a typical solder joint of this type is approximately 10 micrograms, with 9 micrograms coming from the high-lead bump and 1 microgram coming from low-temperature solder applied to the chip carrier pads. The total amount of lead in a typical flip chip with 1000 bumps attached to a chip carrier such as a plastic ball grid array (PBGA) component would thus be on the order of 0.01 grams.

Necessary RoHS Exemptions

The high-temperature flip chip solder bump is already exempted from RoHS requirements today based on the current Annex exemption for “Lead (Pb) in high melting temperature type solders (i.e., tin-lead solder alloys containing more than 85% lead).”

However, the exemption needs to be extended to allow the use of lower temperature solder that is less than 85%Pb to join flip chip solder bumps to a plastic chip carrier. Given the fact that this is already the industry standard methodology for flip chip assembly, this exemption request is essential to meet the functional and reliability requirements for many current and future electronic applications.

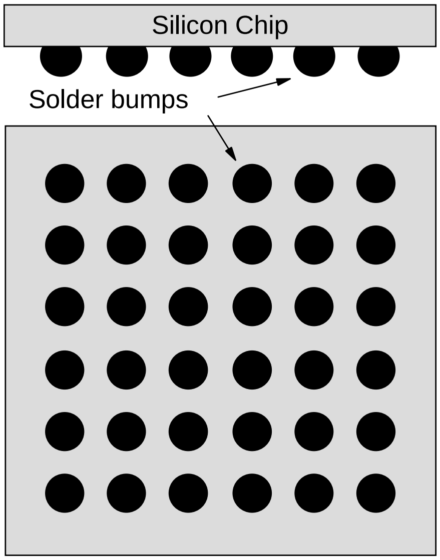


Figure 1. Flip chip device: side view (top), bottom view (bottom)

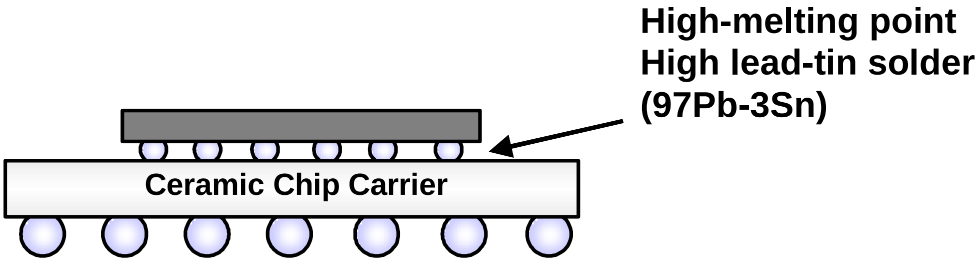


Figure 2. Attachment of a flip chip with high-melting point solder bumps (97Pb-3Sn) to a ceramic chip carrier.

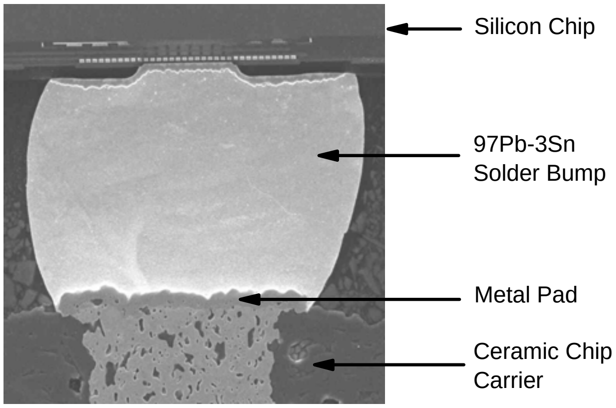


Figure 3. Vertical Cross Section of a flip chip solder bump (97Pb-3Sn) reflow attached to a metallized pad on the Ceramic Chip Carrier.

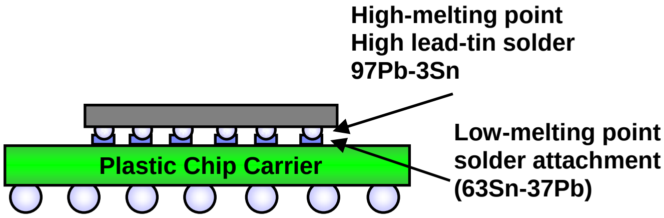


Figure 4. Attachment of a flip chip with high-melting point solder bumps (97Pb-3Sn) to a Plastic Chip Carrier with a low-melting point solder (63Sn-37Pb).

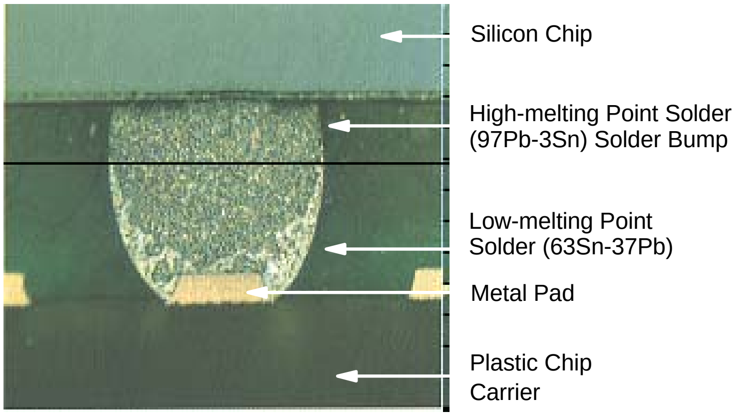


Figure 5. Vertical Cross Section of a high-melting temperature Flip Chip solder bump (97Pb-3Sn) attached to a metal pad on a Plastic Chip Carrier with low-melting point solder (63Sn-37Pb).