Designers Guide to Lead-Free SMT
Components, PCB Materials, Plating and Surface Coatings

Vern Solberg
Solberg Technology Consulting
Madison, Wisconsin

Abstract
For decades the manufacturers of electronic components have furnished products that were most compatible with soldering processes that employed a eutectic alloy composition that contained tin and lead. In recent years the European Union (EU) developed the 'Restriction of Hazardous Substances' (RoHS) directive that forced the global electronics industry supply chain to modify their materials and processes to accommodate lead-free soldering. Component suppliers responded by furnishing lead-free alloy terminal plating. To accommodate the lead-free components, board suppliers developed a number of lead-free surface finishes and coatings. The circuit boards base material has required change as well to meet the requirements of higher temperature lead-free soldering processes needed for assembly.

Although most of the companies supplying finished electronic products to consumers in North America are not required by legislation to comply with the EU directive, many are being forced to modify their assembly process because some of the alloys plated on the lead-free components and printed circuit boards are not really compatible with lead-bearing solder materials. The other issue is the components and boards originally developed for eutectic soldering can not be used in a lead-free process due primarily to the mold compounds and base materials lack of capability to hold up at the elevated temperatures required for lead-free soldering. In this paper the author will address three key issues a designer will need to consider during the planning phase of a new products development; Component selection for lead-free applications, Product exemption criteria and Specifying compatible PCB material and finish

Component selection for lead-free applications
There are two issues to consider when selecting components for electronics products destined to be sold into European Union (EU) markets; responsibility for managing a recycle or obsolete product return program and the elimination of certain substances deemed harmful to humans. The EU has enacted the Waste Electrical and Electronic Equipment (WEEE) Directive to guide manufacturers in managing 'take-back' programs and the RoHS (Restriction of Hazardous Substances) Directive to define substances that, even when recycled, could be harmful to the environment or to those involved with the recycle operations. The RoHS Directive requires that manufacturers be able to demonstrate minimal levels of six substances;

- Lead (Pb) - 0.1% ppm
- Hexavalent chromium (Cr +6) - 0.1% ppm
- Mercury (Hg) - 0.1% ppm
- PolyBrominated Biphenyl (PBB) - 0.1% ppm
- Cadmium (Cd) - 0.01% PPM and
- PolyBrominated Diphenyl Ether (PBDE) - 0.1% ppm

Lead alloy, widely used in semiconductor manufacturing, is the primary target for substance limitation or, when possible, complete elimination. The majority of semiconductors are furnished in the lead-frame packaged format. In anticipation of the European regulation, most component suppliers have already eliminated lead alloy from terminals, lead-frames and the ball contacts used for array packaged semiconductors. The packaging process for these lead-frame based products includes many homogeneous materials; electroplated tin alloy, the gold-bonding wires and the plastic molding material used for encapsulation. A number of concerns that North American manufacturers must consider; regulatory and market developments within the electronics industry, the potential impact of lead-free components on product reliability, component manufacturers' specifications and marking methods, selecting the best Pb-free compatible surface finishes for the circuit boards, and the status of standards developed for Pb-free materials. Lead-free is usually interpreted as having no lead-bearing components, although RoHS allows trace amounts of lead as long as it is less than 0.1% ppm (measured by weight). Of concern by many companies manufacturing product that are not aimed at the European markets or products that have been qualified with lead-bearing alloy soldering is the availability of components with a tin-lead alloy plating or ball composition.

Many users were unaware that, although alloys and molding compounds had changed, the component manufacturers have no plans to change part numbers. In fact, unique part numbers will only be created for those parts that will impact the components functionality or performance specifications as a result of the change to lead-free and/or RoHS compliance.

The difference between RoHS compliant and lead-free is not always clear to the user. Some of the manufacturers simply state that their products are 'RoHS Compliant' or 'Pb-free' while other will clearly define the alloy compositions used in the plating processes. Table 1 is a partial supplier survey defining available lead-frame plating alloys.

Table 1
Supplier Survey of Plating on Lead-Frame Packaged Semiconductors

Supplier	RoHS Compliant	100% Sn	Sn/Ag	Pd/Au	Sn/Bi
Amkor	X	X	X	X	X
ASE Group	X	X			
Intel	X	X			
LSI/CSI	X	X			
National Semi	X	X			
Panasonic	X			X	X
NXP (Philips)	X	X		X	
Samsung	X				X
Texas Inst.	X			X	
Toshiba	X	X	X	X	

IC Package Variations

Although the majority of surface mount semiconductors in use today are furnished in the small outline and fine-pitch lead-frame based package, many of the newer product offerings are furnished without leads. The small outline no-lead (SON) and quad flat pack no-lead (QFN) package for example, has become very popular due to small outline and low cost (the package outline is often only slightly greater than the die outline). Another dominant methodology is the array package, ideal for high-performance applications, especially for more complex die or multiple die (3D) packaging needing greater pin count. In regard to semiconductor interface, the majority of the array packaged devices rely on high-density organic dielectric printed circuit structures. The array packaged semiconductors are very popular for higher density electronics because all of the contacts remain within the package outline. As I/O increases and contact pitch decreases, semiconductor packaging methodology will continue to evolve with new innovative solutions. For portable and hand-held electronics there is an increasing use chip-scale packaged ICs and uncased wafer-level packaged ICs (see Figure 1) with an alloy bumped or ball array format to accommodate board-level circuit routing efficiency.

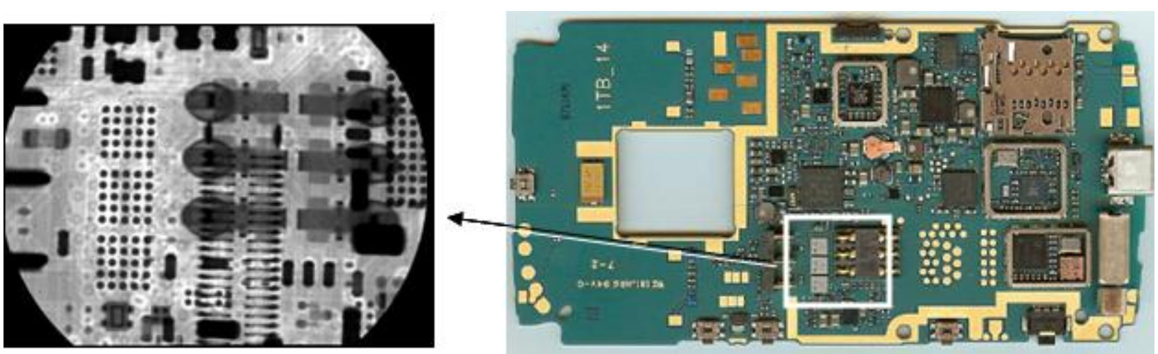

Figure 1. Example of wireless handset with extensive use of wafer level BGA packaging.

These WLBGA are typically very small die with a uniform array ball or bump contact pattern for mounting on conventional circuit boards. Many of the uncased array devices will have a relatively low contact array format (from 4 to 25 I/O) but the wafer level process is used for high-end processor die mounting as well. Because of the higher I/O, these larger and more complex die are generally mounted onto an intermediate interposer substrate platform that redistributes the very fine-pitch contact array to a much wider contact spacing for easier PCB circuit routing. In addition to the semiconductor manufacturers, all of the major component suppliers have already modified their products to be in compliance. Array packages developed for the commercial market have adopted solder sphere contacts using a tin/silver/copper alloy composition. This alloy composition is primarily suited for Pb-free soldering processes but attachment using a eutectic solder alloy is likely acceptable for most non-Pb-free applications as well. However, to conform to RoHS Directive restrictions, all components supplied must be clearly identified with labels on each package unit. The lead-free label will include the Pb letters crossed out with 'X' and clearly state the date of manufacture.

Addressing Lead-free IC Package Qualification

Many believe the transition to lead-free plating alternatives and lead-free solder requires additional qualification tests to ensure manufacturability and long term reliability. In addressing lifecycle, some products have a relatively brief intended life cycle while others may require continuous service for years. The key issue for any of the extended use applications is the components physical robustness and reliable operation when exposed to the products actual use environment. There are three basic issues the developer must consider when qualifying components:

1. Will the product meet the performance criteria for the specific application?
2. Will it function reliably within the intended operating environment?
3. Will the components withstand the anticipated physical stresses of the products 'end use'?

The user can find a great deal of guidance from established industry organizations such as JEDEC and IPC. The Joint Electronic Device Engineering Council (JEDEC) and their associated committees are the engineering standardization body for solid state products. A principal function of JEDEC is to promote the development and establishment of guidelines and standards for the components mechanical outline, product characterization and operation and to define test methods to ensure product quality and reliability. For guidance in establishing board level qualification, many companies have adopted testing methods developed within the IPC (the Association Connecting Electronic Industries).

There are a number of JEDEC documents already in place to furnish guidance in component level testing. The JEDEC JESD-22 for example, includes several qualification test methods for semiconductor packaging. The testing methods furnished in the IPC-9700 standard series, for example, address thermal cycling, drop shock testing, strain gage testing and the like. A relatively new IPC 9706, *Guideline on Lead-free Implementation for High Reliability Applications*, provides the technical background and specific information related to reliability test, analyses, modeling, and associated issues that arise as a result of replacing lead alloy in electronic solders. This document was developed by experts from leading member companies to focus on the refinement of the surface mount processes and the recommend changes necessary to comply with differences in solderability, compatibility, material properties, flux chemistries and the higher solder reflow temperatures effect on the printed circuit board.

Product exemption criteria

A number of products currently exempted from EU regulations may require compliance in the future. The EU regulation on '*Waste from Electrical and Electronic Equipment'* (WEEE), for example, focuses on aspects of Pb-free soldering. This directive sets out measures that aim at:

- The prevention of waste from electrical and electronic equipment (EEE).
- The re-use, recycling and other forms of recovery of such wastes.
- Mminimizing risk to the environment associated with the treatment and disposal of end-of-life (EOL) materials.
- Harmonizing international EOL measures.

This means that components containing lead, cadmium, hexavalent chromium, halogenated flame retardants etc, will have to be removed from any end-of-life EEE which is destined for land fill, incineration, or recovery. Because of the lack of statistics on long term reliability of lead-free electronics a number of products remain exempt from WEEE and RoHS compliance. Electronic products developed for aerospace, medical implants and high-end IC packaging may not require RoHS compliance for varying periods, and some will be exempt for several years. In order to be acceptable into what many predict will ultimately become a single global market, manufacturers of electronic products will need to validate that the components and materials selected for these products comply with the requirements of the RoHS regulations. The guidance criteria for assessing "grey area" products (those whose inclusion within the scope of the RoHS Directive is in doubt) that have been discussed in the Technical Adaptation Committee (TAC) of Member States. It should be noted that this guidance represents the WEEE Directive Department's view and, in common with all EU Directives, a definitive view may only be obtained through the courts. Producers must rely on their own legal advice on all questions of scope.

- Control electronics for aircraft
- Electronics for aeronautics and space
- Implanted medical devices
- Communication and IT equipment
- Power supplies
- Military equipment and weapons systems
- Control electronics for automobiles

On the basis that there is an exemption in WEEE, the exemption would be in relation to electronic products intended specifically to protect national security and/or for military purposes. It should be noted, however, that current exemptions do not apply to all equipment that is used to protect national security and/or has a military purpose because some of these products are not designed exclusively for these non commercial purposes.

The automotive industry will also be under pressure to convert all electronic products to lead-free compliance within an established time-table. The exemption of lead in solder used in automotive electronics will be cancelled for autos first registered after December 31, 2010 (batteries are excluded). This date is not practical for a number of products used in automobiles. Car makers and supplier associations (ACEA and CLEPA) have opened dialogue with experts and manufacturers to establish a more realistic roadmap and to identify necessary exemptions. The problem is, these timing factors are most often dictated by politicians that do not understand the physics of the soldering materials in stressful environments (see Table 2).

Table 2

Automotive Environmental Zones

Location	Temp. Range	Humid.	Vibra./Shk.
Interior:			
Dash Board	-40 / +120°C	98%	1G to 20Hz
Rear Window	-40 / +104°C	98%	1G to 20Hz
Chassis:			
Inside Body Pnl.	-40 / +85°C	98%	2G to 2kHz
Nr. Exhaust Sys.	-40 / +125°C	98%	2G to 2kHz
Under Hood:			
Nr. Exhaust Man.	- 40 / +650°C	80%	50G to 1kHz
Intake Manifold	- 40 / +125°C	95%	over 100G
Firewall	- 40 / +140°C	80%	1G to 600Hz
Frontal Zone	- 40 / +85°C	98%	1G to 800Hz

Source: Delphi Electronics

Specifying Compatible PCB Material and Surface Finish

Companies are finding latent defects that have seriously compromised their products integrity when utilizing FR-4 laminates traditionally used for fabricating the majority of printed circuit boards,. A great deal of the electronic product failures are due to the aging affect of materials (decomposition) that cannot withstand repeated exposures to the physical extremes experienced during assembly processing. For example, If the Z-axis expansion of the circuit board is not be minimized, stress induced damage (blistering and delamination) will likely occur within the laminate structure. The cross-section shown in Figure 2 exhibits the adhesion breakdown between dielectric layers and the copper conductors on the core layer.

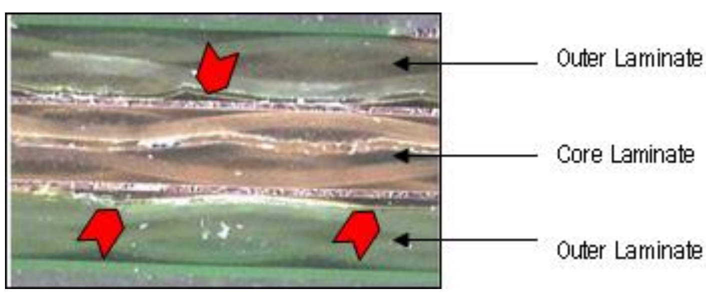

Figure 2. Inner-layer separation within the PCB structure. *(source: Cookson)*

The example may have been the result of thermally induced stresses and/or material decomposition. In addition, circuit board warping can cause undue stresses on the solder joints when the assembled board is mounted or encased in its final configuration. Laminate materials unrestricted expansion in the Z axis can also stress the thin copper via hole plating. The copper plated via holes connecting the inner layers and outer surfaces will likely experience stresses resulting in the formation of tiny cracks within the hole barrels surface that, in time, can interrupt the circuits interconnect between conductive layers and components. Lead-free assembly processes, after all, can reach temperatures ranging above 235ºC and exposure to this temperature may be repeated two or more times depending on the assembly complexity.

As the assembly is subjected to the thermal excursions, the Z-axis expansion, if not limited, may further compromise the integrity of the laminate structure and the circuit it supports. This repeated thermal stress can ultimately result in catastrophic material decomposition and cracks that, in time, will interrupt the circuits interconnect between components and further impact the products performance potential, functionality and long-term reliability expectation.

Selecting RoHS Compliant Substrate Materials

Laminate suppliers have already committed to meeting the requirement for higher temperature soldering processes established for the lead-free alloy compositions. The new laminate material systems are formulated to slow the thermal decomposition rate (T_d) and minimize the materials expansion in the Z direction. The industry experts developing the specification recognized that limiting the Z-axis expansion, increasing the decomposition temperature (Td) and improving the inter-laminar adhesion is more critical for higher temperature assembly processing. With the lower expansion ratio, PCB suppliers are more confident that they can now furnish multiple layer circuit boards that will not exhibit the often damaging stresses currently experienced during the lead-free solder processes. Another requirement for EU acceptance is the reduction of halogen levels. Many of the new base material resin compositions are rated as halogen-free (HF), but, being compliant does not mean the base material must actually be 100% free of halogens. The IEC (International Electrotechnical Commission) standards define "*Halogen-Free*" as meaning the maximum percentages of halogens are limited to the following levels:

- 900 ppm maximum chlorine
- 900 ppm maximum bromine
- 1500 ppm maximum total halogens

Certain brominated elements, including the most popular brominated flame retardant for FR-4, TBBPA, are accepted by RoHS. The data furnished in Table 3 represents the most current material specified in the IPC-4101C document that are designated as RoHS compliant due to the very lower halogen level flame retardant compositions.

Table 3

Low Halogen FR-4 Base Materials

Slash sheet #	Glass transition Temp.	Filled/unfilled resin system	Moisture absorption
IPC-4101C/99	High Tg	inorganic fillers	0.4% max.
IPC-4101C/101	Low Tg	inorganic fillers	0.4% max.
IPC-4101C/121	Low Tg	no fillers	0.4% max.
IPC-4101C/122	HF, Low Tg	no fillers	0.8% max.
IPC-4101C/124	High Tg	no fillers	0.4% max.
IPC-4101C/125	HF, High Tg	no fillers	0.8% max.
IPC-4101C/126	Ultra High Tg	inorganic fillers	0.4% max.
IPC-4101C/127	HF, Low Tg	inorganic fillers	0.8% max.
IPC-4101C/128	HF, High Tg	inorganic fillers	0.8% max.
IPC-4101C/129	Ultra High Tg	inorganic fillers	0.4% max.

Source: Doug Sober, Kaneka Texas Corp

RoHS Compliant Low Halogen (HF) Solder Mask

Having already selected a RoHS compliant base materials for the PWB, the designer must then consider selecting a solder mask material, a material that is also compliant as well as one that is compatible with fluxes and temperatures associated with lead-free solder processing. Since flame retardant chemistries are not actually added to the solder mask materials any halogens present in the coatings are introduced as ingredients or impurities. These halogens generally come from additives such as pigments used to create the color (green in particular) and/or by way of the residual catalysts from resin manufacturing. Pigments with lower halogen content are available for alternative colors (blue, red, black) but, during the transition to develop a material that can be classified as halogen-free (HF), any one of these less-traditional colors may be offered at a slightly higher cost than the more common green solder mask. Although the materials utilized in the manufacture of electronic products are usually required to have an Underwriters Laboratory (UL) Fire Retardant (FR) rating, the rating of the mask coating are really assessed after its applied to the substrate. This should not be a show stopper because, the solder mask coating is usually significantly thinner than the base laminate, the circuit board qualification relies upon the flame retardant element within the laminate to provide overall flammability protection for the finished substrate.

In regard to solder mask color, the green tinted material has been a traditional preference for decades but, it contains a high level of chlorine.

Chlorine is contained mainly at a molecular level in the “Green” pigment of all suppliers’ masks; therefore, it is almost impossible to get a true green pigment that does not contain some level of chlorine. On the other hand, chlorine levels are not significantly relevant in colors like blue, yellow and red. This means that pretty much all non-green solder mask products can be classified as halogen-free and may explain why many products sold in the market do meet the HF definition are tented ‘blue’ and have a very low and acceptable total halogen level.

Solder mask products formulated with lower halogen content has not really affected the adhesion quality of solder mask materials and is expected to meet all established performance criteria. The most commonly referenced specification for solder masks is the IPC-SM-840, “*Qualification and Performance Specification of Permanent Solder Mask*”. Another source for evaluation of PCB circuit coatings is the Underwriters Laboratories Inc. Standard 94 (UL-94), “*Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances*.” These requirements are for all solder mask coatings regardless of their composition so they apply equally to halogen-free products. Furthermore, the basic properties of a HF version of a solder mask are not significantly different from solder mask materials that are not labeled specifically as ‘halogen-free’. Suppliers state that, “experience has shown little to no difference in fabrication processing parameters for a halogen-free solder mask compared to a non halogen-free (green) version of the same solder mask”. Any difference may be attributed to a possible change in pigment that could have a minor effect upon the exposure of a photo-imageable solder mask. This difference, however, would usually have minimal impact on the application process. Manufacturers typically have a wide selection of solder mask products readily available (liquid and dry-film) and note that nearly half of North American production utilized HF solder mask in 2008 because most of the current PWB products offered are also designated as RoHS compliant and qualify as halogen-free. When the polymer mask coating has been applied and cured, the board is made ready for the final surface finish process.

Alternative PCB Surface Finish

Several alternative RoHS compliant surface plating and coatings are available for consideration. A popular ‘lead-free’ surface finish uses a combination of electroless nickel plating followed by an immersion (ENIG) process that furnishes a thin coating of gold alloy to retard oxidation. In the ENIG process, electroless nickel is applied over the exposed bare copper features. Other finishing alloys finding favor are Immersion Tin (IT) and Immersion Silver (IS). These are relatively lower in cost than the ENIG process and have proved ideal as a short-term oxidation inhibitor and a viable finish for lead-free soldering. Immersion Palladium and Palladium/Silver compositions are also finding popularity. Although more costly than Tin or Silver immersion processes, they have proven to be compatible with the alternative lead-free attachment alloy compositions. All of these should be less costly than a finish containing gold alloy, however, Palladium may carry a premium and require a license from the company claiming patents on the application.

Alternatives to alloy plating are available as well. Widely accepted as a means of retarding oxide growth on the bare copper attachment sites and via/test pads, an Organic Solderability Preservative (OSP) coating can be applied to the board to preservative solderability. Chemical coating materials such as Benzotriazole and Imidazole are widely used to replace the alloy finishes. This coating is low in cost and compatible with most organic flux soldering material and can continue its protective characteristics through three to four exposures to high temperature often experienced during assembly processes. Multiple reflow solder exposure capability is important. When surface mount devices are to be attached to both primary and secondary sides of the assembly, a double exposure to reflow soldering temperature must be considered. Assembly steps typical of mixed technology may also include exposure to wave or other solder processes as well.

The coating process is one of the least stress full methods for providing a solderable surface finish. These chemical inhibitor compounds are applied to the exposed copper by dipping or spray coat. Before applying the material, the copper surface must be void of all oxidation and oil residue. A typical cleaning agent for copper surfaces is Alkaline and Nitric Acid. The acid actually acts as a mild etchant leaving the exposed copper with a matte texture.

Concerns of OSP Coated Boards:

1. Deteriorates in High Humidity and Temperature
2. Limited (6-12 month) Shelf Life
3. Physical Contact Will Degrade Coating
4. Exposed Copper Will Tarnish w/o Alloy Coverage

A note of caution, solder mask specified for the PC board must be fully cured before applying the coating and must not be susceptible to damage or degradation by the chemistry of the OSP coating material. And, although copper preservative coatings are generally compatible with both organic and RMA fluxes, the heavy coat thickness needed to withstand multiple solder processes may not be compatible with the lower activation level typical of the rosin based no-clean flux and shelf life of the coated circuit board (as noted) is somewhat limited as well.

Conclusion

The industry has responded rapidly to meet the EU developed RoHS Directive. Although many will continue to question the validity of lead alloy in electronics posing a threat to the environment and human health, its clear that, to compete in the global market for consumer electronics, compliance will be mandatory. In cooperation with the OEM companies' effort to make a smooth conversion away from Pb, the entire industry has moved quickly to qualify components and develop new materials that are robust enough to hold up to the higher temperature required for assembly processing. Most multinational OEM and EMS companies in the electronic industry are already in compliance or are working to comply with all EU regulations. They understand too, that the suppliers are now obligated to certify the compliance of their products, including all sub-components and parts. Another requirement for meeting RoHS compliance is that the product producers are required to keep appropriate records for all materials used for a period of up to four years after the particular product is placed on the market.

In regard to assembly processing with Pb-free solder, several factors must be considered including cost and process compatibility. In regard to lead-free solder assessment, many have found that the appearance of the lead-free solder joint does not exhibit the same smooth surface appearance as the solder joint formed with lead-bearing eutectic solders. Instead, the Pb-free solders, when cooled to a solid state, will often exhibit a dull matte, gray, or even grainy appearing surface finish. The IPC-A-610A standard, however, states that these grainy or dull connections do not compromise the products integrity and are acceptable. The solder connection, however, must indicate evidence of wetting and adherence where the solder blends to the soldered contact and mounting surface.

Tin whisker concerns remain a major issue with pure tin and high tin alloy lead finishes particularly for high reliability users (such as Space, Military, Telecom and Hi-End computing). A major effort is underway by various industry groups including IPC, NEMI and JEITA to understand and hopefully eliminate concerns with tin whiskers. There are a number of mitigation strategies that greatly reduce tin whisker formation, but at this point, they have not eliminated the concern. Experts have stated that matte tin finishes do perform better than bright tin finishes in whisker testing. Similarly, thicker matte tin finishes perform better than thinner matte tin finishes. Other mitigation strategies include reflow of the tin finish after plating, dipping components and unpopulated circuit boards into molten tin or tin-alloy solders, using a nickel barrier layer under the tin plating, and annealing of the plating.

Sources for information on Pb-Free standards and materials www.ipc.org, www.halogenfree-flameretardants.com

Reference:

1. *V Solberg, STC-Madison, IC Component Package Evolution and the Impact of Lead-Free Soldering, Surface Mount Technology Magazine, October 2008.*
2. *B Birch, PWB Interconnect Solutions, Survivability Through Delam at 245C, APEX 2008*
3. *R Lasky PhD, Indium Corp., Assembly of Large PWBs in a RoHS Environment, APEX 2008*
4. *K Sauter, Sun Microsystems, Requirements for Higher Temperature Lead-Free Assembly Processing, IPC Midwest Conference 2004.*
5. *B P Richards, C L Levoguer, C P Hunt (NPL) and K Nimmo, S Peters, P Cusack (ITRI), An Analysis of the Current Status of Lead-Free Soldering, National Physical Laboratory Report, UK.*

Solberg Technical Consulting, Madison Wisconsin
Telephone: 608-224-4220 or 408-568-3734
e-mail: vsolberg123@aol.com

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Vern Solberg
STC-Madison
Madison, Wisconsin USA

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Background

- For decades the manufacturers of electronic components have furnished products that were most compatible with soldering processes that employed a eutectic alloy composition that contained tin and lead.
- In recent years the European Union (EU) developed the 'Restriction of Hazardous Substances' (RoHS) directive that forced the global electronics industry supply chain to modify their materials and processes to accommodate lead-free soldering.

Affected Substances

- The RoHS Directive requires that manufacturers be able to demonstrate minimal levels of six substances;
  - Lead (Pb) - 0.1% ppm
  - Hexavalent chromium (Cr +6) - 0.1% ppm
  - Mercury (Hg) - 0.1% ppm
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  - Cadmium (Cd) - 0.01% PPM and
  - PolyBrominated Diphenyl Ether (PBDE) - 0.1% ppm
- Lead alloy, widely used in semiconductor manufacturing, is the primary target for substance limitation or, when possible, complete elimination.

Industry Response

- Component suppliers responded by furnishing lead-free alloy terminal plating.
- To accommodate the lead-free components, board suppliers developed a number of lead-free surface finishes and coatings.
- Base material suppliers modified laminates to meet the requirements of higher temperature lead-free soldering processes needed for assembly.

Two steps to RoHS compliance…

1. Lead-free solder process:
   - *Confirm resistance of the components to the higher temperatures -- 245º C / 260 º C.*
   - *Evaluation of solder-joint reliability using Sn / Ag / Cu (SAC) alloy including BGA.*

2. Material change required:
   - *Lead-free solder terminals, BGA ball contacts, internal connections, bumped die.*
   - *Halogen-free molding compound, and RoHS compliant substrate materials.*

Plastic IC Lead-frame Plating

Small outline, TSSOP, QFP, SON, QFN

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Toshiba	X	X	X	X	

IC Package Variations

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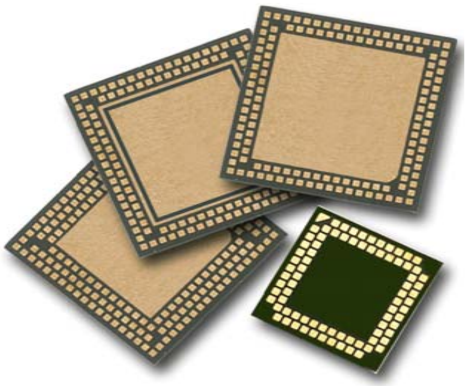

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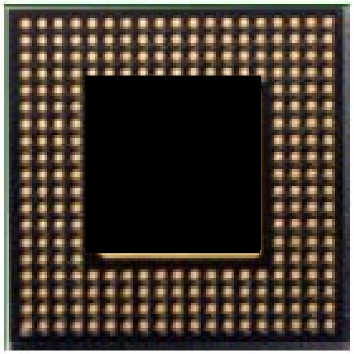
IC Package Variations cont.

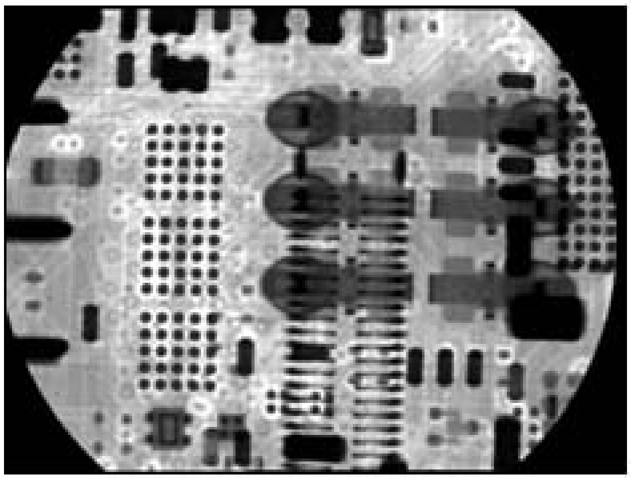
- Another dominant methodology is the array package, ideal for high-performance applications, especially for more complex die or multiple die (3D) packaging needing greater pin count.
- The array packaged semiconductors are very popular for higher density electronics because all of the contacts remain within the package outline.

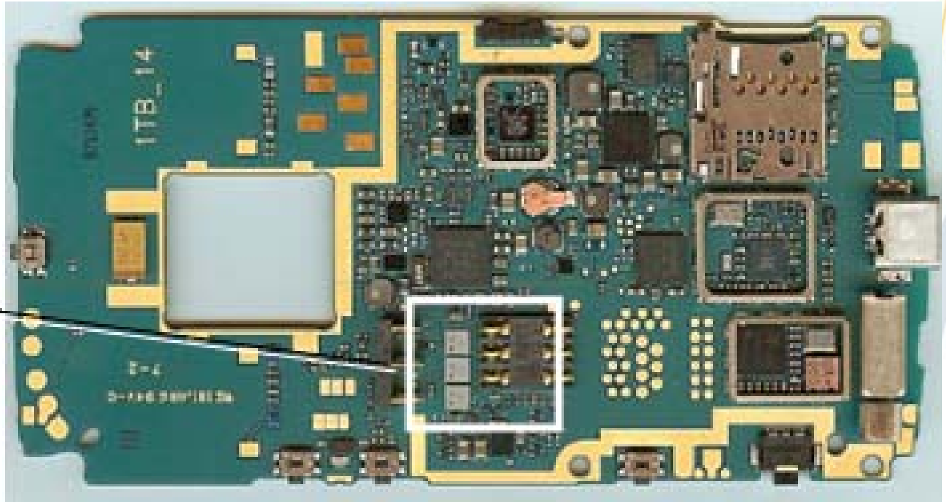


As I/O increases and contact pitch decreases, semiconductor packaging methodology will continue to evolve with new innovative solutions.

WLBGA and CSP

- For portable and hand-held electronics there is an increasing use chip-scale packaged ICs and uncased wafer-level packaged ICs with an alloy bumped or ball array format to accommodate board-level circuit routing efficiency.





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Qualification Testing

- There are a number of JEDEC and IPC documents already in place to furnish guidance in component level and board level testing:
  - JEDEC JESD-22 includes several qualification test methods for semiconductor packaging.
  - IPC-9700 series addresses thermal cycling, drop shock testing, strain gage testing and the like.
  - IPC 9706, Guideline on Lead-free Implementation for High Reliability Applications [1]

[1] document provides the technical background and specific information related to reliability test, analyses, modeling, and associated issues that arise as a result of replacing lead alloy in electronic solders.

EU Compliance

- The EU regulation on '*Waste from Electrical and Electronic Equipment*' (WEEE), for example, focuses on aspects of Pb-free soldering. This directive sets out measures that aim at:
  - The prevention of waste from electrical and electronic equipment (EEE).
  - The re-use, recycling and other forms of recovery of such wastes.
  - Minimizing risk to the environment associated with the treatment and disposal of end-of-life (EOL) materials.
  - Harmonizing international EOL measures.

A number of products are currently exempted from EU regulations but may require compliance in the future.

No Exemptions

General Electronic Products

IPC Class 1

- Consumer or General Use
- Portable and Hand-Held Products
- Computer or Computer Peripherals
- Cosmetic Imperfections are Acceptable

The Primary requirement is functionality

Some Exemptions

Dedicated Service Electronics

IPC Class 2

IBM z10™ EC Server

- Communications Equipment
- Sophisticated Business Machines
- Instrumentation and Measurement Systems
- Automotive Control and Safety Electronics

Extended product life is expected, however, uninterrupted service is not critical or life threatening.

RoHS Exempt

High Reliability Electronics

IPC Class 3

NASA

- Aircraft, Spacecraft or Life Support
- Continued and Uninterrupted Service
- Equipment Downtime Not Tolerated

Field Service is not Practical or Possible

Product exemption criteria

- Because of the lack of statistics on long term reliability of lead-free electronics products developed for aerospace, medical implants and high-end IC packaging may not require RoHS compliance for varying periods, and some will be exempt for several years.

In order to be acceptable into what may ultimately become a single global market, manufacturers of electronic products will need to validate that all components and materials selected for these products comply with the requirements of the RoHS regulations.

Operating Requirements for Aeronautics

Commercial Aircraft:

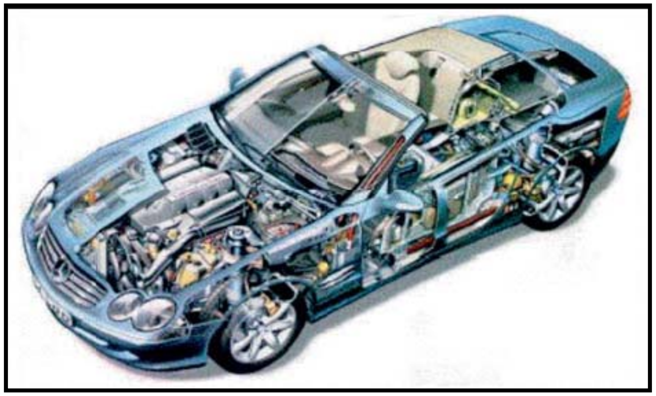
- General oper. conditions
  - -55ºC to +95ºC
- Physical shock (vibration)
  - Application dependent
- Expected product life
  - 10 years (upgradeable)

Source: Boeing

Cockpit electronics, cabin control, entertainment and communication systems

Impact on Automotive Electronics

- The exemption of lead in solder used in automotive electronics will be cancelled for autos first registered after December 31, 2010 (batteries are excluded).



The problem is, these timing factors are most often dictated by politicians that do not understand the physics of the soldering materials in stressful environments

Automotive Environmental Zones

Location	Temp. Range	Humid.	Vibra./Shk.
Interior:			
Dash Board	*-40 / +120ºC*	*98%*	*1G to 20Hz*
Rear Window	*-40 / +104ºC*	*98%*	*1G to 20Hz*

Automotive Environmental Zones cont.

Location	Temp. Range	Humid.	Vibra./Shk.
Chassis:			
Inside Body Pnl.	*-40 / +85ºC*	*98%*	*2G to 2kHz*
Nr. Exhaust Sys.	*-40 / +125ºC*	*98%*	*2G to 2kHz*
Under Hood:			
Nr. Exhaust Man.	*- 40 / +650ºC*	*80%*	*50G to 1kHz*
Intake Manifold	*- 40 / +125ºC*	*95%*	*over 100G*
Firewall	*- 40 / +140ºC*	*80%*	*1G to 600Hz*
Frontal Zone	*- 40 / +85ºC*	*98%*	*1G to 800Hz*

Source: Delphi Electronics

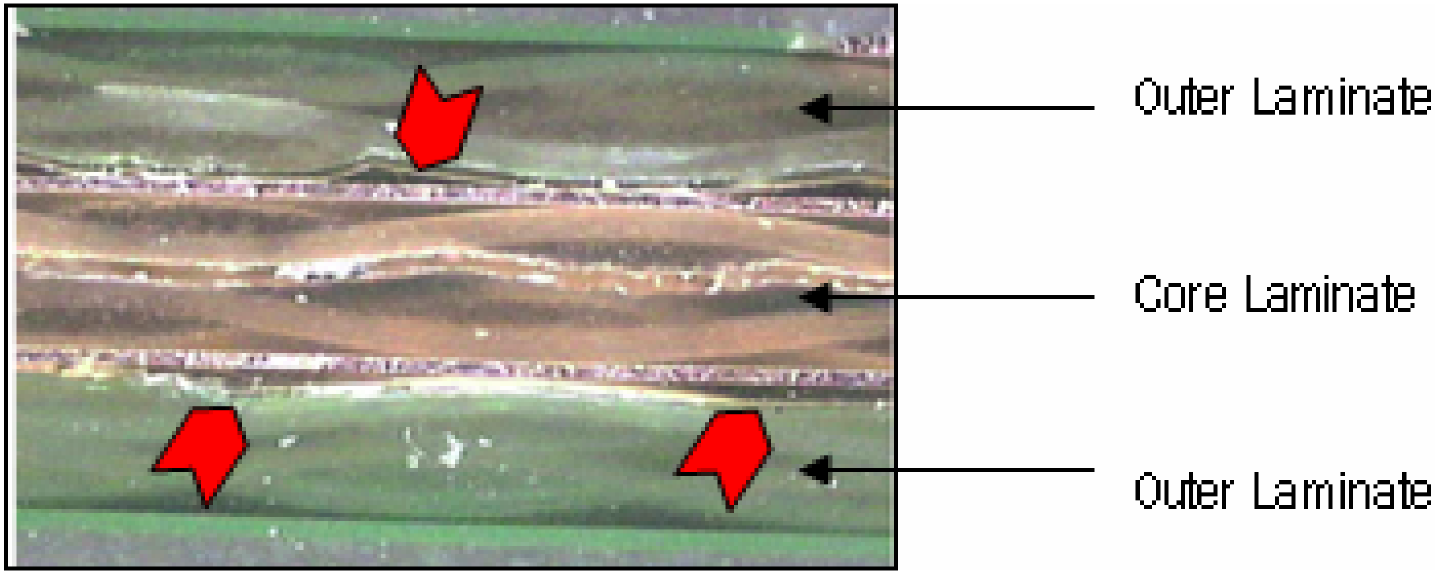
- An extended RoHS exemption would be in relation to electronic products intended specifically to protect national security and/or for military purposes.
  - Current exemptions do not apply to all equipment that is used to protect national security and/or has a military purpose because some of these products are not designed exclusively for these non commercial purposes.

Specifying RoHS Compatible PCB Material and Surface Finish

- A great deal of the electronic product failures are due to the aging affect of materials (decomposition) that cannot withstand repeated exposures to the physical extremes experienced during assembly processing.
- Concern:
  - If the Z-axis expansion of the circuit board is not be minimized, stress induced damage (blistering and delamination) will likely occur within the laminate structure.

Lamination Separation

Result of Thermal Stress and/or Decomposition



Source: Cookson

Lead-free assembly processes can reach temperatures ranging above 235ºC and may be repeated two or more times depending on the assembly complexity.

Selecting RoHS Compliant Substrate Materials

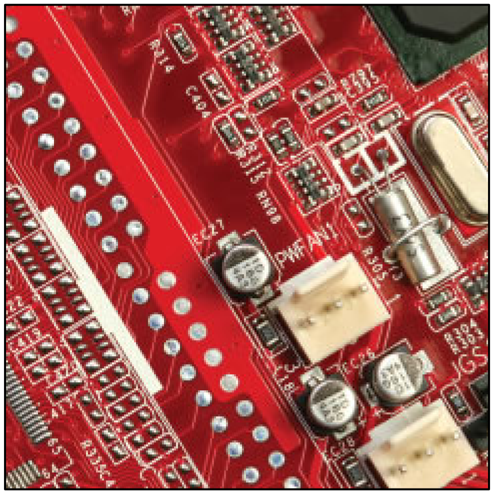
- Laminate suppliers have already committed to meeting the requirement for higher temperature soldering processes established for the lead-free alloy compositions.
- The new laminate material systems are formulated to slow the thermal decomposition rate (Td) and minimize the materials expansion in the Z direction.

Industry experts developing the specifications recognize that limiting the Z-axis expansion, increasing the decomposition temperature (Td) and improving the inter-laminar adhesion is more critical for higher temperature assembly processing.

Halogen Level Reduction

- Many of the new base material resin compositions are rated as halogen-free (HF), but, being compliant does not mean the base material must actually be 100% free of halogens.
- The IEC (International Electrotechnical Commission) standards define "*Halogen-Free*" as meaning the maximum percentage of halogens are limited to the following levels:
  - 900 ppm maximum chlorine
  - 900 ppm maximum bromine
  - 1500 ppm maximum total halogens

IPC-4101 Lead-Free Assembly Compatible Base Materials:



- New specification sheets
- Compositional requirements
- Performance requirements
- RoHS compliant bromine
- Lower Halogen levels

Note: UL has insisted on separate specifications for filled and unfilled FR-4s.

Current IPC-4101C Slash Sheets

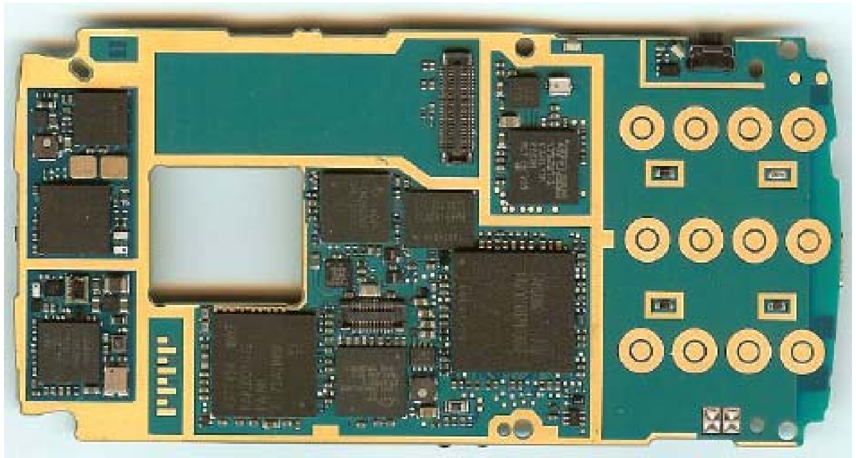
IPC-4101C slash sheet	Glass transition Temp.	Filled / unfilled resin system	Moisture absorption
/ 99	High Tg	inorganic fillers	0.4% max.
/101	Low Tg	inorganic fillers	0.4% max.
/121	Low Tg	no fillers	0.4% max.
/122	HF, Low Tg	no fillers	0.8% max.
/124	High Tg	no fillers	0.4% max.
/125	HF, High Tg	no fillers	0.8% max.
/126	Ultra High Tg	inorganic fillers	0.4% max.
/127	HF, Low Tg	inorganic fillers	0.8% max.
/128	HF, High Tg	inorganic fillers	0.8% max.
/129	Ultra High Tg	inorganic fillers	0.4% max.

Source: Doug Sober, Kaneka Texas Corp

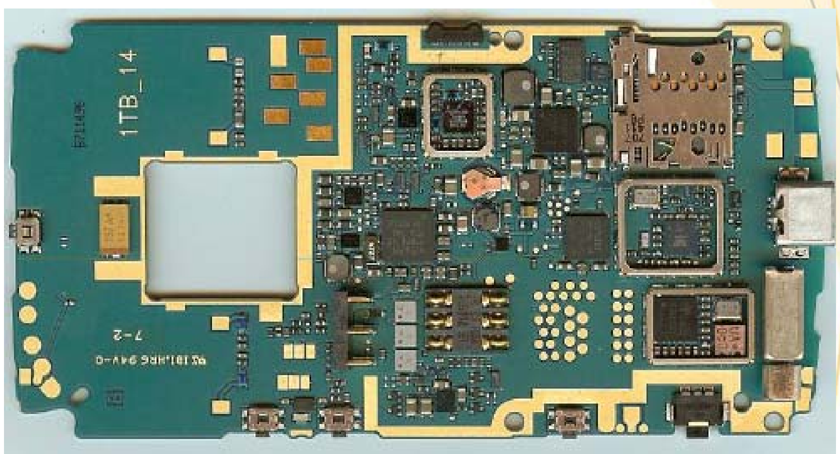
Low Halogen (HF) Solder Mask

- Since flame retardant chemistries are not actually added to the solder mask materials any halogens present in the coatings are introduced as ingredients or impurities.
- These halogens generally come from additives such as the pigments used to create the color (green in particular) and/or by way of the residual catalysts from resin manufacturing.
- Pigments with lower halogen content are available in alternative colors (blue, red, black)

Wireless Handset Assembly



Side A

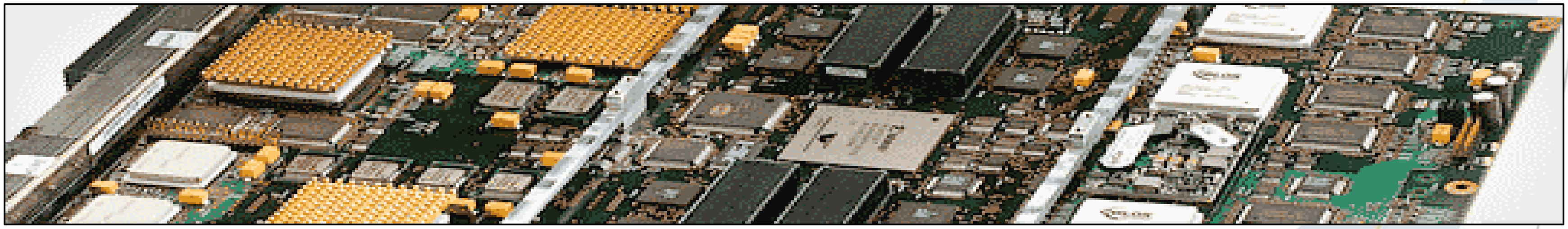


Side B

Nearly half of North American production utilized HF base materials and solder mask in 2008 because most of the current PWB products offered are also designated as RoHS compliant and must qualify as halogen-free.

Specifying a RoHS Compatible Surface Finish

- All exposed copper surface features on the circuit must :
  - Provide surface oxidation and corrosion protection for the land pattern features.
  - Be compatible with the solder alloy composition selected for component attachment.
  - Enable a reliable solder interface between land patterns and component terminals.



Common Pb-free Surface Finish Options

Source: Endicott Interconnect

- Immersion Tin (IT)
- Immersion Silver (IS)
- Electroless Nickel / Immersion Gold (ENIG)
- Electroplated Nickel and Gold
- Palladium, Palladium Silver, Palladium Gold

Alternative PCB Surface Finish

- An accepted method for retarding oxide growth on the bare copper attachment sites and via/test pads is an Organic Solderability Preservative (OSP) coating.
- Concerns of OSP Coated Boards:
  - Deteriorates in High Humidity and Temperature
  - Limited (6-12 month) Shelf Life
  - Physical Contact Will Degrade Coating
  - Exposed Copper Will Tarnish w/o Alloy Coverage

OSP coatings are lowest in cost and exhibit excellent solder joint formation between component contacts and PCB land patterns.

Summary

- Although many will continue to question the validity of lead alloy in electronics posing a threat to the environment and human health, its clear that, to compete in the global market for consumer electronics, compliance will be mandatory.

- The entire industry has moved quickly to qualify components and develop new materials that are robust enough to hold up to the higher temperature required for assembly processing.

Most multinational OEM and EMS companies are already in compliance or are working to comply with all EU regulations.

- In regard to assembly processing with Pb-free solder, several factors must be considered including cost and process compatibility.
  - Many have found that the appearance of the lead-free solder joint does not exhibit the same smooth surface appearance as the solder joint formed with lead-bearing eutectic solders.
  - when cooled to a solid state, will often exhibit a dull matte, gray, or even grainy appearing surface finish.

The IPC-A-610 standard states that these grainy or dull connections do not compromise the products integrity and are acceptable.

Tin Whisker Concerns

- Tin whisker concerns remain a major issue with pure tin and high tin alloy lead finishes particularly for high reliability users (such as Space, Military, Telecom and Hi-End computing).
- Experts have stated that matte tin finishes do perform better than bright tin finishes in whisker testing.
- Similarly, thicker matte tin finishes perform better than thinner matte tin finishes.

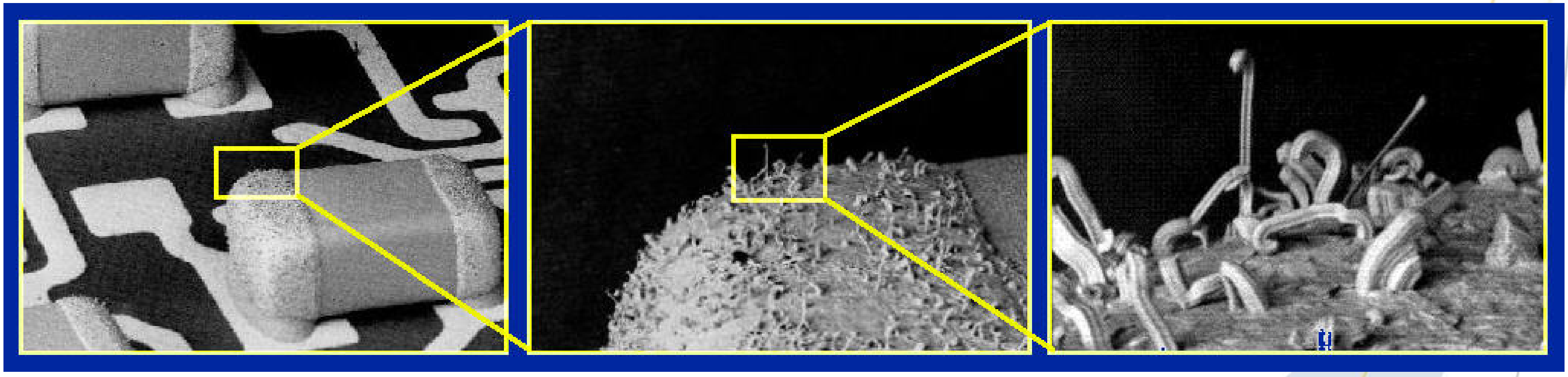
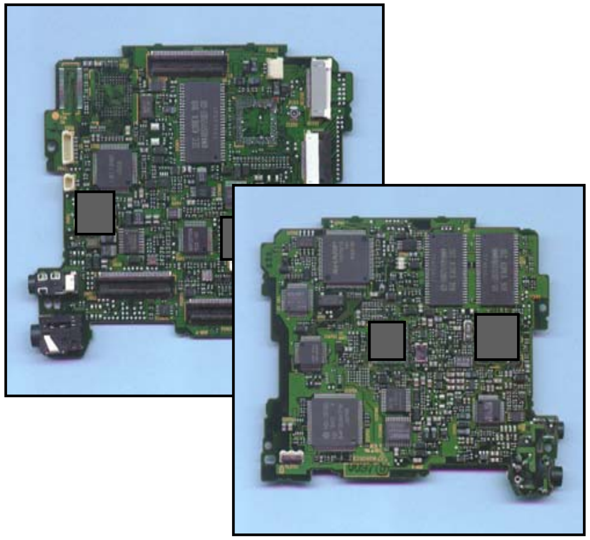


Photo Source: NASA Goddard

Addressing 'End-of-Life' Disposal of Electrical and Electronic Equipment

- Components containing lead, cadmium, hexavalent chromium and non-compliant halogenated flame retardants will have to be removed from any end-of-life 'Electrical and Electronic Equipment' which is destined for land fill, incineration, or recovery.



A key requirement for RoHS compliance is that the product producers are required to keep appropriate records for all materials used for a period of up to four years after the particular product is placed on the market.

Contact information:
Vern Solberg
Solberg Technical Consulting
vsolberg123@aol.com

Solberg
Technical
Consulting