An Introduction to Electronics Systems Packaging
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Module No. # 07
Lecture No. # 38
Lead-free solder considerations
Green electronics
RoHS compliance and e-waste recycling issues

We will continue with module 7 in this Electronic Systems Packaging course and this will be the last lecture in module 7. Now, if you recollect, we will take a quick recap.

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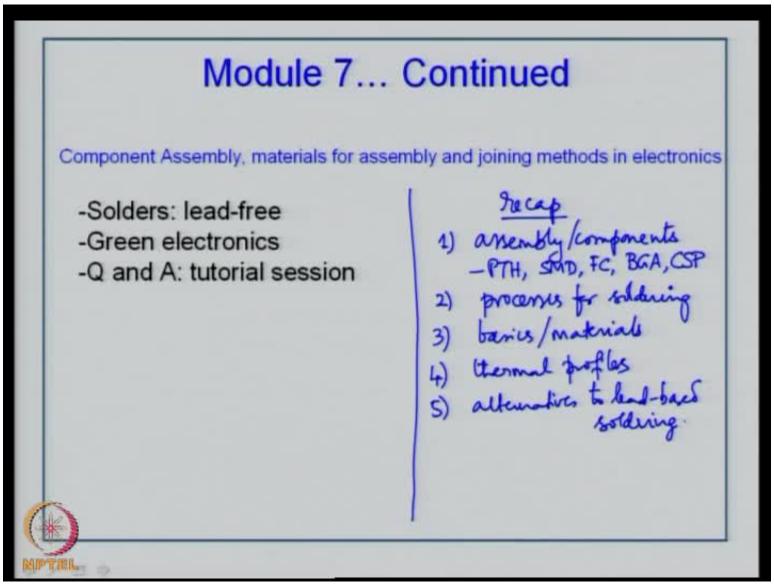

Module 7... Continued

Component Assembly, materials for assembly and joining methods in electronics

- -Solders: lead-free
- -Green electronics
- -Q and A: tutorial session

Recap

1) assembly/components
   -PTH, SMD, FC, BGA, CSP
2) processes for soldering
3) basics/materials
4) thermal profiles
5) alternatives to lead-based soldering.

If you recollect, we have been looking at basically, assembly details of components and we have seen various types of components being used, platted through hole, SMD devices. Earlier in the lectures, we have seen flip-chip; we have also seen BGA assembly, because BGA is with solder balls; the same things have got to do with CSP components. We have also seen mixed type of components in certain complex designs; secondly, we have seen the various processes for soldering. We have also seen the basics of soldering process in terms of materials that are being used for soldering process. Then, we also have spent some time on the thermal profiling for reflow procedures.

We have also spent some time on alternatives to Lead based soldering; that is, the use of Lead-free soldering in systems packaging; so, we will continue with that. We will also look at Lead-free materials; then, in this particular lecture, we will go into some aspects of green electronics and conclude with this module. Finally, at the end of this lecture, we will have a question-answer session - a tutorial session; a set of questions that will be worked out here in this particular lecture so that you can clear all your doubts that you had during this particular module.

Now, at the outset, I want to mention that, in this particular packaging course, we will have different sets of question papers that will be posted in the website, which can be tried as a home assignment and it can be communicated to the instructor; if you have any questions on this, it can be e-mailed to the instructor at your convenience.

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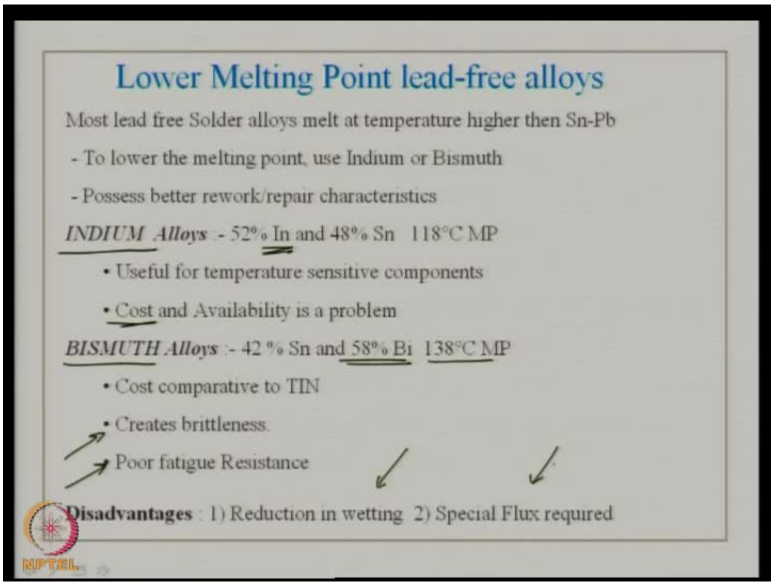

Lower Melting Point lead-free alloys

Most lead free Solder alloys melt at temperature higher then Sn-Pb

- To lower the melting point, use Indium or Bismuth
- Possess better rework/repair characteristics

INDIUM Alloys :- 52% In and 48% Sn 118°C MP

- Useful for temperature sensitive components
- Cost and Availability is a problem

BISMUTH Alloys :- 42 % Sn and 58% Bi 138°C MP

- Cost comparative to TIN
- Creates brittleness
- Poor fatigue Resistance

Disadvantages : 1) Reduction in wetting 2) Special Flux required

So, we will move with the technical aspects. Now, in the earlier lecture, we talked about low-melting Lead-free alloys. Now as you know, Lead based alloys have been used for a long time; of them, the eutectic composition Tin, Lead 63, 37 with the melting point of 183 degree centigrade is the most commonly used. Now, because of RoHS legislation, we are moving into Lead-free. Now, if you look at the alternatives of Lead-free, of Lead based, in using Lead-free alloys, the idea is to lower the melting point, but most compositions of Lead-free alloys are above 183 degree centigrade - the normal eutectic temperature that we have been used to working for a long time.

Now, the first alternative that we briefly discussed in the last lecture is Indium based alloys; that is, if we use tin in combination with indium, you can lower the melting point to as much as 118 degree centigrade. It is useful for temperature sensitive components that are being used in that particular design so that you can have minimal thermal shock on the components.

Now, cost and availability is a problem. Cost because indium is used, which is expensive and then availability in terms of the manufacturers of this particular type of alloy; so, there is not enough global market for indium-tin alloy as of now, but there are many players in the market who have been using indium-tin for specialty applications.

Now, the next alternative is using bismuth, where you use bismuth to the extent of 58 percent and the rest 42 percent is Tin. Here, the melting point is 138 degree centigrade; a very convenient temperature profiling can be done for components that are susceptible to thermal shock. Cost is comparative to tin and the problem here is, it creates brittleness in the solder joint after reflow soldering process. It also has a poor fatigue resistance. So, on one hand, you are looking at lowering the temperatures, but on the other hand, you have problems with the solder joint reliability issues. Therefore, when you convert from Lead base soldering to Lead-free soldering, please have a look at the reliability issues once again. So, disadvantages in using indium and bismuth could be reduction in wetting; may be you will have to use a special flux material.

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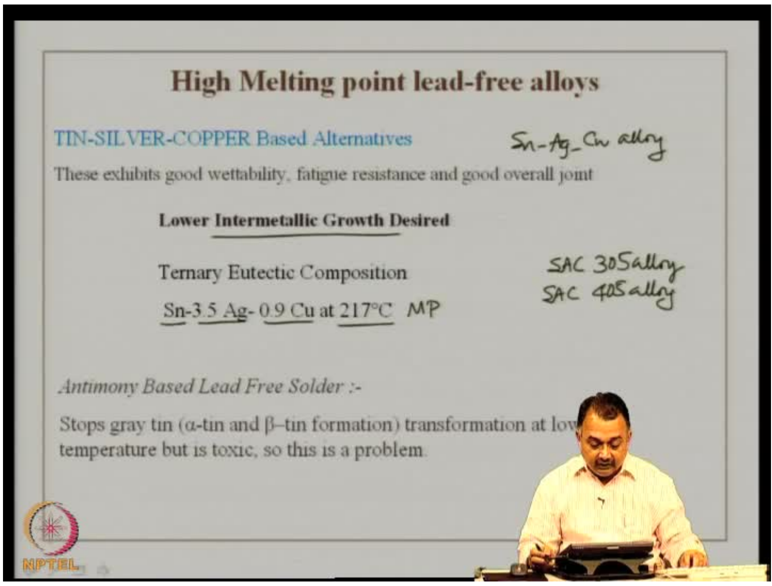

High Melting point lead-free alloys

TIN-SILVER-COPPER Based Alternatives Sn-Ag-Cu alloy

These exhibits good wettability, fatigue resistance and good overall joint

Lower Intermetallic Growth Desired

Ternary Eutectic Composition

Sn-3.5 Ag- 0.9 Cu at 217°C MP

SAC 305 alloy

SAC 405 alloy

Antimony Based Lead Free Solder :-

Stops gray tin (α-tin and β–tin formation) transformation at low temperature but is toxic, so this is a problem.

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Now, we will move into high melting point Lead-free alloys; in this, specifically we will look at Tin-Silver-Copper based alternatives to tin-Lead soldering. Now, Tin-Silver-

Copper alloy has good wet ability, fatigue resistance, and good overall joint quality. Now typically, what we are looking at, in every solder joint, we have seen that also, that, we want to reduce the inter-metallic growth, as much as possible. We have seen, in the solder joint, a cross section in the last lecture, that there is a base metal rich area and a solder rich area in a solder joint. Depending upon the thickness of the growth of inter-metallic layer, you will have different alloy compositions of the inter-metallic layer formed and these inter-metallic layer compositions are the defining factor in the solder joint quality. So, if you have brittleness, then it is due to the nature of the inter-metallic growth and how it can withstand thermal stress, strain during the life time of the product.

Now, in Tin-Silver-Copper, we have seen a ternary eutectic composition that is Tin 3.5 percent Silver, 0.9 percent Copper; this has got melting point of 217 degree Centigrade. We have also seen about SAC 305 alloy and also SAC 405 alloy in the previous lecture.

Now, the Lead-free solder can also come with antimony as one of the components; so, antimony based Lead-free solder is also available. Now, this one will stop the gray- Tin-formation that is inter-metallic growth involving alpha Tin and beta Tin faces at low temperatures; but, this is toxic and so this is a problem. So, this is not widely recommended.

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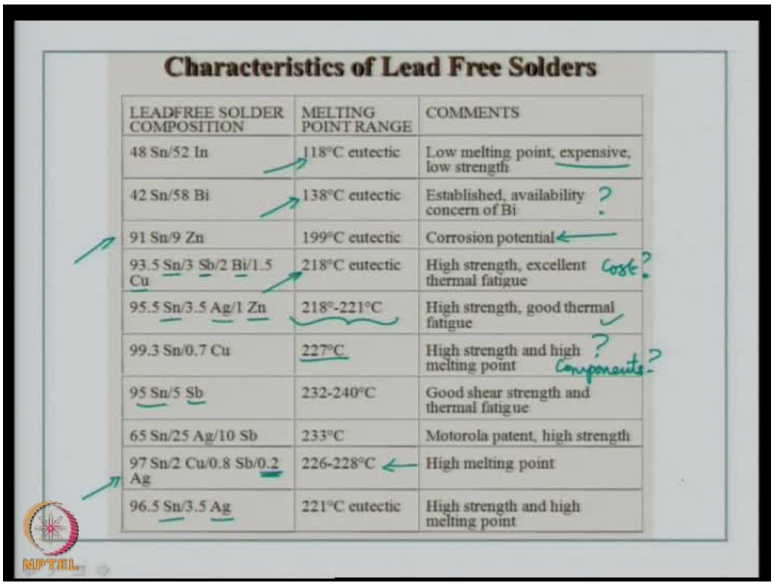

Characteristics of Lead Free Solders

LEADFREE SOLDER COMPOSITION	MELTING POINT RANGE	COMMENTS
48 Sn/52 In	118°C eutectic	Low melting point, expensive, low strength
42 Sn/58 Bi	138°C eutectic	Established, availability concern of Bi ?
91 Sn/9 Zn	199°C eutectic	Corrosion potential
93.5 Sn/3 Sb/2 Bi/1.5 Cu	218°C eutectic	High strength, excellent thermal fatigue Cost ?
95.5 Sn/3.5 Ag/1 Zn	218°-221°C	High strength, good thermal fatigue ✓
99.3 Sn/0.7 Cu	227°C	High strength and high melting point ? Components ?
95 Sn/5 Sb	232-240°C	Good shear strength and thermal fatigue
65 Sn/25 Ag/10 Sb	233°C	Motorola patent, high strength
97 Sn/2 Cu/0.8 Sb/0.2 Ag	226-228°C	High melting point
96.5 Sn/3.5 Ag	221°C eutectic	High strength and high melting point

Now, the characteristics of Lead-free solders as a summary, I would like to project it here. If you look at this particular table, the entities here are the compositions of the

Lead-free solder that are available in the market. The melting point range and some of the comments - those are available from the literature; so, if you look at Tin-Indium, which we have seen just now, the melting point is very low - 118. The strength of the solder joint is of a big question mark in terms of long term reliability and also the cost.

Tin-Bismuth 138 degree centigrade is the melting point; it is an established material; the availability concern of bismuth is always a question. Now again, these are specialty applications. So, unless and until you require these kinds of alloys, you have to look at cost. A solder joint that is established on a printed circuit board will add to reliability problems and if you have so many joints, hundreds of joints on a printed circuit board, then you have to look at the solder joint quality, reliability is an issue, and that is directly related to the choice of the Lead-free material.

Now, some of the literature materials that have been well known or well-studied by various groups, various organizations, or industry have been listed here: Tin-Zinc has also been tried; its melting point is 199 and the problem is corrosion. Then, you have compositions that are as complex as having tin-antimony-bismuth and Copper; so, this is a complex system and then you have the melting point at 218 degree centigrade eutectic; it has got high strength and excellent thermal fatigue. Now, cost could be an issue and we are worried about the continuous availability of such kind of a mixture. Then you have Tin-Silver-Zinc instead of Copper then the range, where it can be used is 218 to 221 - high strength and good thermal fatigue.

Then you have Tin-Copper-Tin to the extent of 99.3, Copper - 0.7 percent. Look at the melting point, well manageable in terms of your reflow zones that you can set in the equipment, 227 - high strength and fairly high melting point. Here, you should look at your components that are being used in this particular design or assembly, and that which can withstand these kinds of temperatures. Because if you say 227, then your peak reflow would be set to let us say 3 to 5 degree centigrade above the melting point and you have to look at the vulnerability of your component at these temperatures although the reflow residence time, peak reflow zone is very short.

Then you have Tin-Antimony - good shear strength and thermal fatigue; Tin-Silver-Antimony - there is a Motorola patent and high strength; then you have as complex combination like Tin-Copper-Antimony-Silver, all of these are added for special properties that can be exhibited by the solder joint; it could be wet-ability; it could be thermal fatigue - good thermal fatigue, or a resistance to corrosion and so on. So, here, the problem is high melting point.

Now, with the kind of substrates that we are using, organic substrates and the kind of packages that we are using, we have to try to keep the melting point of Lead-free soldering to around 220, if you are using in mass production. So, some of these combinations may not really work out for high volume production. Then, you have Tin-Silver; 221 is eutectic and high strength and high melting point.

So, in summary, what you can look at is - in the market, there could be wide variety of Lead-free solders; the most common is SAC 305 and SAC 405 alloy. You could try using that because of the well-known characteristics of the solder joint. Again, if you are looking for special applications, low density board - it could be ceramic packages that you want to use or a combination of ceramic and plastic packages. Then, if you know the handling of these components, you can choose from a wide variety of materials. The only thing is - if it is a mass production, you have to look at continuous availability so that you can standardize your procedure.

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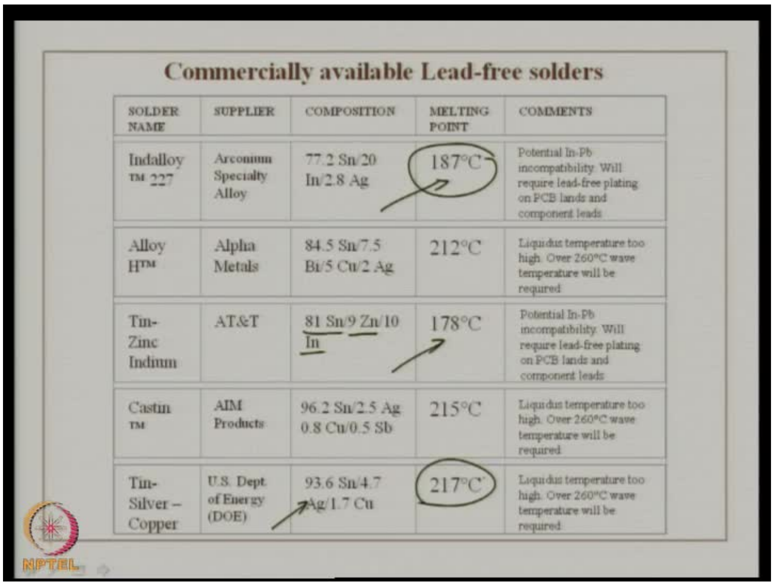

Commercially available Lead-free solders

SOLDER NAME	SUPPLIER	COMPOSITION	MELTING POINT	COMMENTS
Indalloy ™ 227	Arconium Specialty Alloy	77.2 Sn/20 In/2.8 Ag	187°C	Potential In-Pb incompatibility. Will require lead-free plating on PCB lands and component leads
Alloy H™	Alpha Metals	84.5 Sn/7.5 Bi/5 Cu/2 Ag	212°C	Liquidus temperature too high. Over 260°C wave temperature will be required
Tin-Zinc Indium	AT&T	81 Sn/9 Zn/10 In	178°C	Potential In-Pb incompatibility. Will require lead-free plating on PCB lands and component leads
Castin ™	AIM Products	96.2 Sn/2.5 Ag 0.8 Cu/0.5 Sb	215°C	Liquidus temperature too high. Over 260°C wave temperature will be required
Tin-Silver – Copper	U.S. Dept. of Energy (DOE)	93.6 Sn/4.7 Ag/1.7 Cu	217°C	Liquidus temperature too high. Over 260°C wave temperature will be required

Commercially available Lead-free solders - just for interest for people, who are interested in knowing the kind of products that are available. Obviously, this is not an exhaustive and complete list; these are representative examples that have been taken from the literature. Solder name, for example Indalloy, where this is a specialty alloy; it contains Tin-Indium-Silver, and melting point is very ideal - 187 degree centigrade. There are problems like potential Indium-Lead incompatibility, will require Lead-free platting on PCB lands and component Lead; so, the preparation of your PCB surface has to be tuned if you are using this kind of a material.

Then alpha metals produces alloy HTM, where it is Tin-Bismuth-Copper-Silver 212 degree centigrade and liquidous temperature is too high. If you are using it for applications other than reflow, if you want to use it for a wave soldering process, then there will be concerns. Then, you have Tin-Zinc-Indium, AT and T, the composition is 81 percent of Tin, 9 percent Zinc and 10 percent Indium. If you look at the melting point - very attractive in terms of working conditions; again, the compatibility of the PCB has to be looked into. If you are migrating to Lead-free, your PCB surface is also recommended to be Lead-free surface finish. So, you could either have a Tin finish or you could have a Nicke-Gold finish.

Then, you have Castin from AIM products which is basically Tin-Silver-Copper-Antimony 215 liquidous temperature - too high, but unless you do a kind of a trial and error method. If you do such careful examination of the solder joint alloy, after the product has been established and is in working condition for over an year, it is very difficult to precisely write the failure aspects of each of these materials.

Tin-Silver-Copper from DOEUS: so, the various percentages are mentioned here, again 217; so, these are the comments that are available from the literature - current literature.

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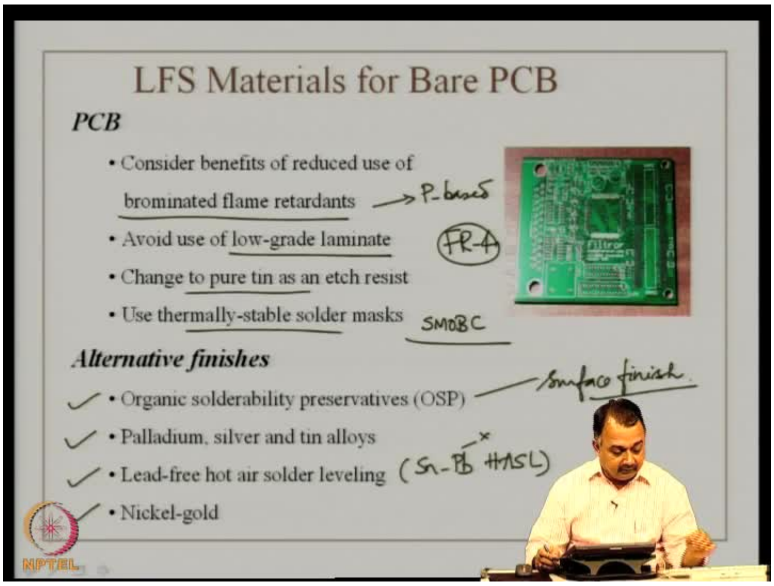

LFS Materials for Bare PCB

PCB

- Consider benefits of reduced use of brominated flame retardants → P-bases
- Avoid use of low-grade laminate FR-4
- Change to pure tin as an etch resist
- Use thermally-stable solder masks SMOBC

Alternative finishes Surface finish

- ✓ Organic solderability preservatives (OSP)
- ✓ Palladium, silver and tin alloys
- ✓ Lead-free hot air solder leveling (Sn-Pb HASL)
- ✓ Nickel-gold

We will summarize with some of the opinions or comments that have been seen over a few research papers and experiences of various manufacturers who have migrated to Lead-free soldering. Now, in general, we can summarize that, if you are using Lead-free solder materials, what are the situations or what are the conditions that you need to look at, for a bare printed circuit board?

Now, at the PCB side, you must consider benefits of reduced use of Brominated flame retardants. Now, as you know, all these FR materials: FR4, FR3, FR5, and so on, the classifications that we have seen in the earlier classes contains Bromine as one of the key components used to exhibit the property of fire retardants or flame retardants. But that is also being looked at carefully worldwide, as a material that needs to be banned from the PCB industry or electronics industry because of the RoHS regulation. So, if you are using Lead-free material for interconnect, assembly then you also have to logically look at removing Bromine from your base substrate. So, reduced use of FR materials which contain Bromine as one of the components is a key issue.

Now, there are other alternatives - you could use phosphorous based substrates. Japan is one of the countries which have taken a lead in reducing Bromine based organic substrates; they have moved to phosphorous based substrates, organic and they have been found to be as reliable as glass epoxy Bromine based substrates; so, currently the cost could be prohibiting, but eventually, we have to look at alternatives.

Avoid use of low-grade laminates, because as you know, if you work with Lead-free, you are going to work with higher temperatures. So, choose laminates or substrates that have high Tg so that, it is compatible with the various processes; it could be reflow process or it could be wave soldering process.

Now, as I repeated in the previous slide, change to pure Tin as an etch resist. So, your process sequence should be including Tin as an etch resist. The top and bottom layers of your multi-layer printed circuit board could either be finished with Tin, or you can use some kind of a thermally-stable solder mask. So, you can avoid a metal etch resist completely; use SMOBC that is Solder Mask Over Base Over Bare Copper; SMOBC stands for Solder Mask Over Bare Copper. So, many companies move into this kind of a finish. So, instead of having Tin or Tin-Lead as a finish, the only requirement is that your Copper should be well treated to avoid corrosion during its life or the product life. You can have a very good solder mask that is highly stable at the temperatures of operation of the PCB and which can take care of the heat that is generated from the surface of the PCB during the operation of the product.

So, these are some considerations that you can have when you parallelly move into Lead-free solder materials. It is not enough that you just look at Lead-free soldering; you have to look into totality - a holistic view of the entire system including most importantly your printed circuit board.

Alternative finishes could be, as I said firstly, Nickel Gold; it is a very good option; you could go for Lead-free hot air leveling. Most of you are aware of Tin-Lead hot air leveling – hot air solder leveling. Now, since you have to avoid Lead, you can look at Tin-hot air solder leveling. Then you can look at Palladium-Silver and Tin alloys as a finish, although it could be prohibitive in terms of cost.

Then, you also look at organic solder-ability preservatives. So, these are typically, you are going to use some kind of an organic coating on the Copper surface and when this coating is cured or thermally cured, it could be a very good base for Tin-Lead soldering. It would have good wetting; it could avoid corrosion; so, there are different manufacturers who offer OSP finishes. So, this is a surface finish that many people have been using over the last decade and it needs a very good understanding of the type of material that is coated over Copper.

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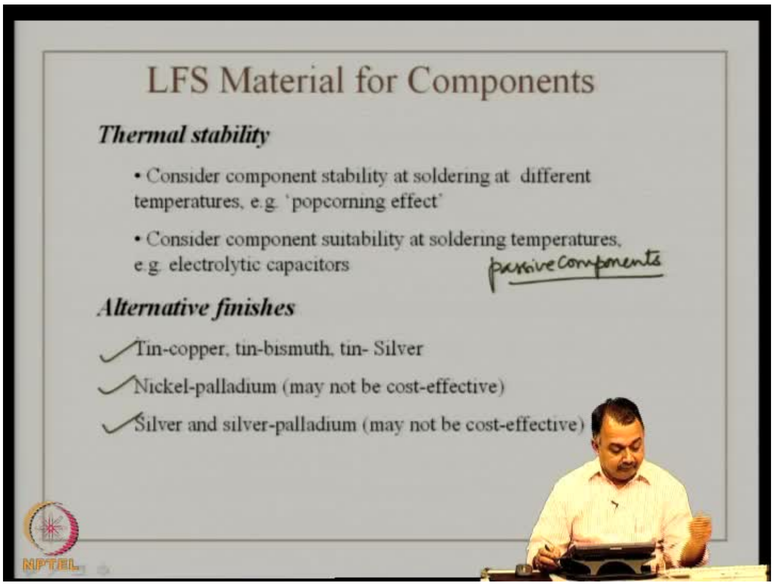

LFS Material for Components

Thermal stability

- Consider component stability at soldering at different temperatures, e.g. 'popcorning effect'
- Consider component suitability at soldering temperatures, e.g. electrolytic capacitors

passive components

Alternative finishes

✓Tin-copper, tin-bismuth, tin- Silver

✓Nickel-palladium (may not be cost-effective)

✓Silver and silver-palladium (may not be cost-effective)

Now, let us look at components. So, if you are going to Lead-free soldering, what are the things that you have to take care from the component side? Thermal stability of the component because you are going to work at different temperatures compared to Tin-Lead. So, consider component stability at soldering temperatures which are going to be high; especially, if you are going to work with BGAs, the popcorn effect will always keep reminding us. If you have not taken care of certain precautions like - removing moisture from the BGA package before reflow soldering and the behavior of these plastic packages at higher temperatures. You also need to look at the coating of the Lead components. If you are using QFPs, what kind of coating has been given on the Iron-Nickel alloy that is primarily the Lead frame? So, a good understanding will help you in providing a very high reliability at the assembly stage with Lead-free.

Consider component suitability at soldering temperatures; example, electrolytic Capacitors; can they with-stand, these soldering temperatures? If not, can you move into some other capacitors? So, in one sense, you also look at passive components on their suitability for Lead-free soldering, use ceramic packages, use materials that have a larger size. So, these are all design issues that you can look at alternative finishes from the components side. You can look at Nickel-Palladium; It may be cost; may not be cost effective. Silver and Silver-palladium, again may not be cost effective. So, look at Tin-Copper, Tin-Bismuth, Tin-Silver from the component. Lead for BGAs – again, it is a different ball game; you have to use BGAs that have Lead-free solder balls attached to the dye.

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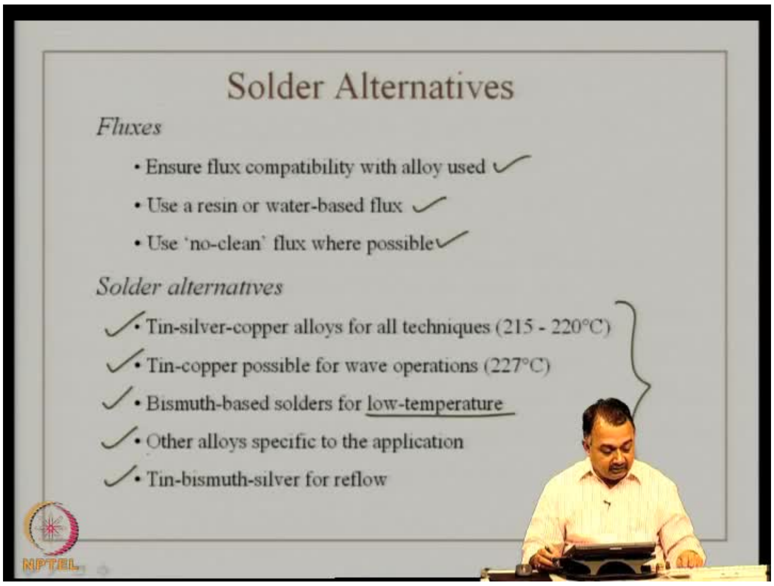

Solder Alternatives

Fluxes

- Ensure flux compatibility with alloy used ✓
- Use a resin or water-based flux ✓
- Use 'no-clean' flux where possible ✓

Solder alternatives

- ✓ Tin-silver-copper alloys for all techniques (215 - 220°C)
- ✓ Tin-copper possible for wave operations (227°C)
- ✓ Bismuth-based solders for low-temperature
- ✓ Other alloys specific to the application
- ✓ Tin-bismuth-silver for reflow

Now, from the solder side, it is very important that you are going to use fluxes or flux; it could be an inbuilt component in your solder paste. When you use solder paste with screen printing or stencil printing, you are going to use flux; you are also aware of no-clean fluxes, but generally there are different fluxes like: mildly activated flux, low activated flux, and then super activated fluxes. You need to understand what kind of flux is being used in that particular process.

As we saw a couple of lectures ago, the thermal profiling is based on these components. So, insure flux compatibility with the alloy that is used. Use a resin or water based flux so that the post cleaning process using aqueous based cleaning chemicals becomes compatible; use no-clean flux wherever possible. So, as you recall, when you say you are using no-clean flux, the board after assembly need not be clean; that means, there are residues that are minimal, firstly; Secondly, if there are any residues, they are not going to affect the board; that is even if the pads are close to each other or tracks close to each other, the residues would not be harmful in terms of corrosion inducement or electro-migration, or any other shorting problem.

Solder alternatives: we have seen, the best thing is Tin-Silver-Copper alloys for all techniques; Tin-Copper possible for wave operations. So, we can consider that Bismuth based solders for low temperature; so, this is the summary of the various situations that you can probably enter into, for various designs and applications. Other alloys, specific to the application, which we have seen during the last 4, 5 slides, you can select and you can use Tin-Bismuth-Silver for reflow, provided the temperatures are suiting your process.

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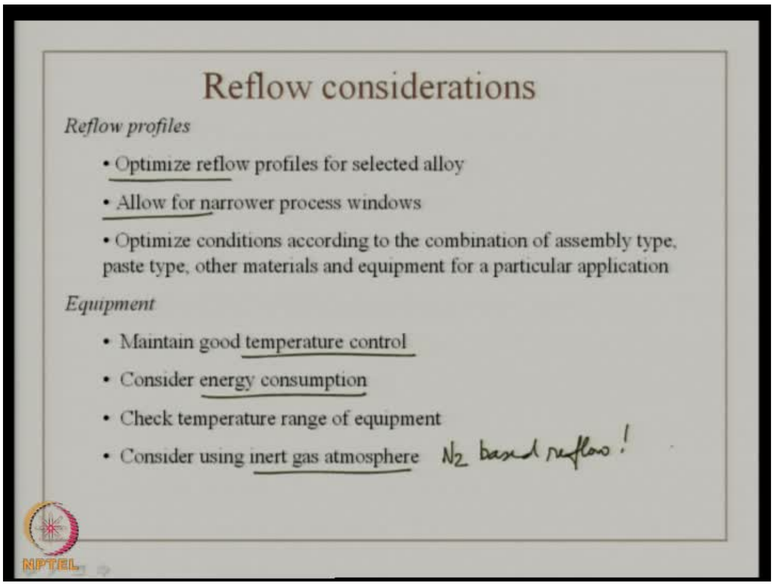

Reflow considerations

Reflow profiles

- Optimize reflow profiles for selected alloy
- Allow for narrower process windows
- Optimize conditions according to the combination of assembly type, paste type, other materials and equipment for a particular application

Equipment

- Maintain good temperature control
- Consider energy consumption
- Check temperature range of equipment
- Consider using inert gas atmosphere N_2 based reflow !

Now, coming to the process side, if you are using Lead-free, have a look at the reflow profiles; optimize your reflow profiles for the selected alloy; do not work with earlier profiles that you have been using for Lead based. Whenever you use a new material, change the reflow profile, do a trial-run and optimize it, and then store that for all subsequent operations involving the same set of components, the same substrate, and the same solder paste material that you are using. So, optimize the reflow profiles.

Allow for narrower process windows: Here, again, the conditions should be based on the total time taken for a particular batch to be completed. That again is related to the combination of the different types of packages that you have used the solder paste material and the equipment; for example, a reflow zone could be a 3 zone or a 4 zone reflow equipment; so, you have to work in tune with those conditions.

The equipment: from the equipment side tries to maintain good temperature control, plus minus 1 degree centigrade. Consider energy consumption - now, the residence time in each of the zones will come into question when you talk about this point. You have to save energy because when you are moving into Lead-free compared to Lead based, you are working at higher temperatures; globally there is larger energy consumption; this is a very big concern in the industry today because sometimes you are working 40 degrees up from 183. So, if you look at global electronics industry, many people have commented about this larger energy consumption for PCB assembly. So, I keep repeating and saying that the thermal profile should be carefully considered to reduce energy consumption for assembly.

Check temperature range of equipment: Sometimes because you are working with Lead-free, you would have been working with Lead base solder, and now your equipment is incompatible for Lead-free; so, make sure your equipment is in place.

Consider using inert gas atmosphere that is nitrogen based reflow: Now, this is an option that need not work for all designs. So, you can consider working inert gas atmosphere to reduce defects, but in some cases, we have seen inert gas atmosphere in fact induces defects like tombs toning, skewing, and so on. So, have a control on the conditions.

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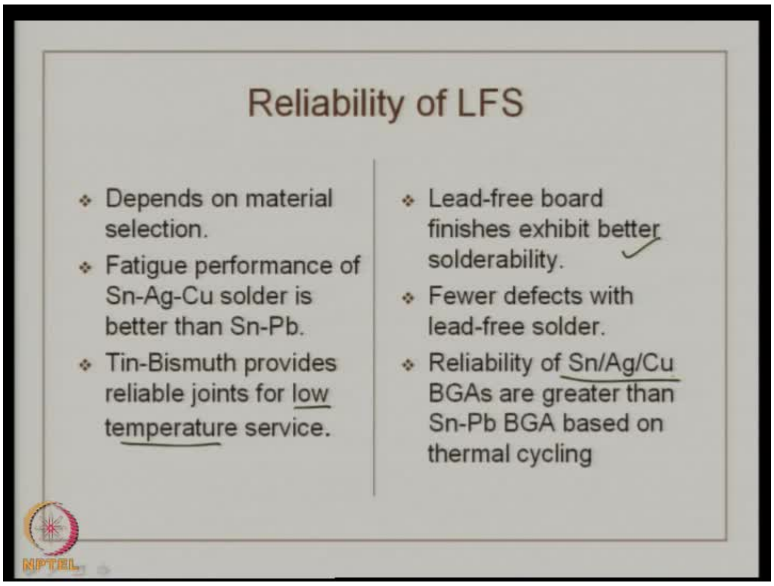

Reliability of LFS

- Depends on material selection.
- Fatigue performance of Sn-Ag-Cu solder is better than Sn-Pb.
- Tin-Bismuth provides reliable joints for low temperature service.
- Lead-free board finishes exhibit better solderability.
- Fewer defects with lead-free solder.
- Reliability of Sn/Ag/Cu BGAs are greater than Sn-Pb BGA based on thermal cycling

So, the reliability of Lead-free solders or soldering process as a summary depends on material selection. The fatigue performance of Tin-Silver-Copper solder is much better than Tin-Lead, as we have seen over the years. Tin-Bismuth provides reliable joints for low temperature service – low temperature assembly. Lead-free board finishes exhibit better solderability. There was a concern about the reliability issues, the wetting and the solderability, but now, having seen the experience of many manufacturers and EMS services, Lead-free board finishes do exhibit better solderability. Fewer defects have been seen with Lead-free solder or probably the process control has been well understood to reduce the defects.

Reliability of Tin-Silver-Copper in BGA - Ball Grid Arrays are greater than Tin-Lead BGA based on thermal cycling. So, definitely we are moving in the right direction in using Tin-Silver-Copper - one of the top preferences in the Lead-free zone. We are replacing Lead based very successfully by many companies and also by prototyping industries.

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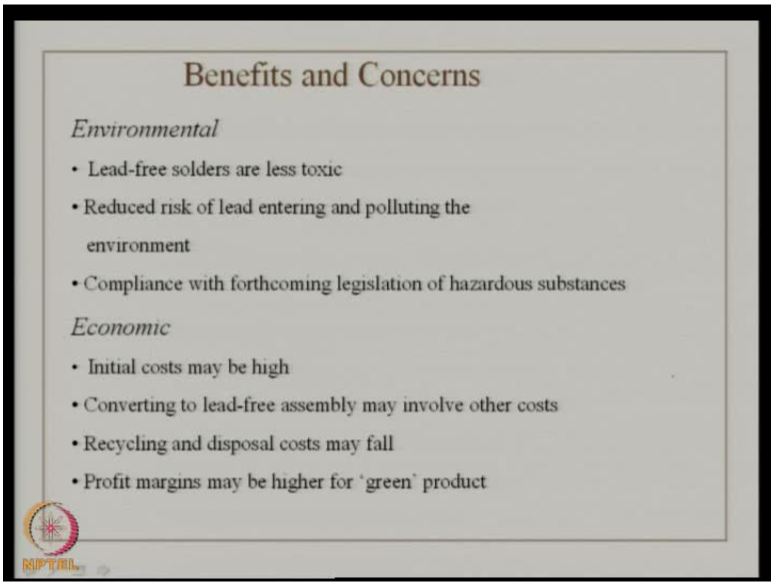

Benefits and Concerns

Environmental

- Lead-free solders are less toxic
- Reduced risk of lead entering and polluting the environment
- Compliance with forthcoming legislation of hazardous substances

Economic

- Initial costs may be high
- Converting to lead-free assembly may involve other costs
- Recycling and disposal costs may fall
- Profit margins may be higher for 'green' product

.

So, finally, the benefits and concerns of all of these issues that we have been talking about is that, there are environmental concerns that have been taken care of; Lead-free solders are less-toxic; reduced risk of Lead entering and polluting the environment; compliance with forthcoming legislation of hazardous substances.

Economically, cost may be very high if you are switching over to Lead-free. Converting to Lead-free assembly may involve other costs also: including training your personnel, getting into quality assessment, understanding the quality assessment in house and certification of your employees and your company into the testing standards. For example, IPC is conducting various training programs; IPC is a global body and may be you have to train your engineers and certify your company so that you will be accepted globally when you sell your product for Lead-free assembly and your product could be certified successfully.

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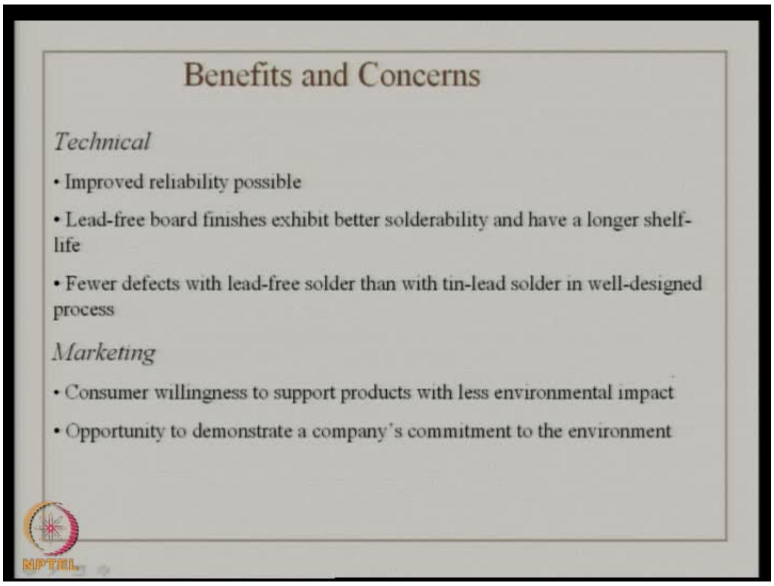

Benefits and Concerns

Technical

- Improved reliability possible
- Lead-free board finishes exhibit better solderability and have a longer shelf-life
- Fewer defects with lead-free solder than with tin-lead solder in well-designed process

Marketing

- Consumer willingness to support products with less environmental impact
- Opportunity to demonstrate a company's commitment to the environment

Recycling and disposal costs may fall because you are using Lead-free; otherwise Lead disposal is a problem. Profit margins may be higher for a green product. Because you are now selling a green product, your tag is green; therefore, you may be having a leading edge currently in the global market; therefore, you could interact and push your product far with higher profits.

Technically, improved reliability is possible if you are expert in understanding the processes. The board will finish, the board will exhibit better solderability and have a longer shelf life compared to Lead. The only thing is you have to avoid pure Tin because we have seen problems with pure Tin, like viscous and so on. Fewer defects with Lead-free solder than with Tin-Lead solder in well-designed processes.

From the more economic and marketing angle, consumer willingness to support products with less environmental impact; so, people are also aware of environment and green electronics; so, there will always be a push for green electronics; opportunity to demonstrate a company's commitment to the environment. So, these are the very general comments.

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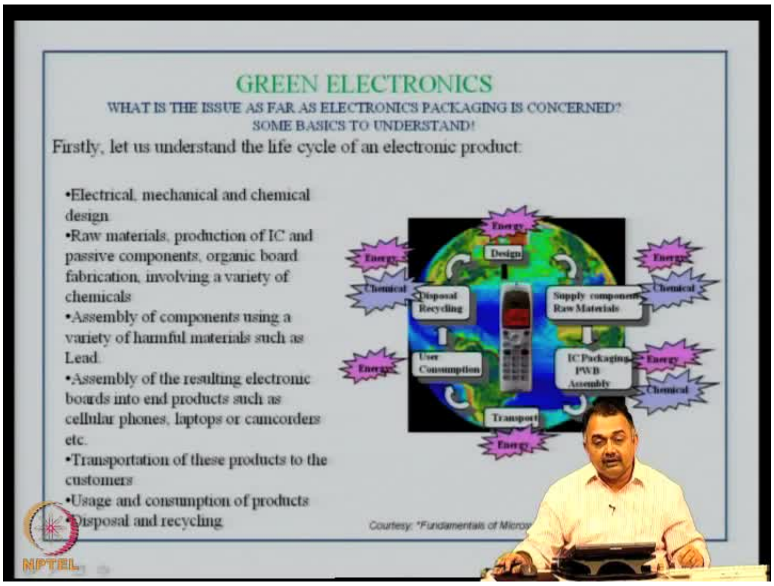

GREEN ELECTRONICS

WHAT IS THE ISSUE AS FAR AS ELECTRONICS PACKAGING IS CONCERNED?
SOME BASICS TO UNDERSTAND!

Firstly, let us understand the life cycle of an electronic product:

- Electrical, mechanical and chemical design
- Raw materials, production of IC and passive components, organic board fabrication, involving a variety of chemicals
- Assembly of components using a variety of harmful materials such as Lead
- Assembly of the resulting electronic boards into end products such as cellular phones, laptops or camcorders etc.
- Transportation of these products to the customers
- Usage and consumption of products
- Disposal and recycling

Courtesy: "Fundamentals of Micros

Now, we will move into that. So, that completes the section on assembly, including Lead-free. We will now move into a few slides that concern Green Electronics; so, by now, you are aware of the term-green. So, in electronics - green electronics, the term is now a keyword to understanding a system or when you do a packaging of a product. What is the issue as far as electronics packaging is concerned?

Let us look at some basics. If you look at the life cycle of an electronic product, there are various issues that I have listed here and if you look and relate it to the figure, that I have shown here: There are electrical issues, mechanical and chemical issues when you design a particular product. So, it moves from design, supply components, raw materials, IC packaging, PWB fabrication, PWB assembly. Then, you have transport, user consumption, and then comes the important - disposal or recycling. So, raw materials, production of IC and passive components, organic board fabrication involving a variety of chemicals.

So, if you look at the life cycle of this product, these are some of the stages: Assembly of components using a variety of harmful materials such as Lead, assembly of the resulting electronic product into end product such as systems like cell phones, laptops, camcorders, etcetera, transportation of these products to the customers, usage and consumption of products, disposal and recycling of materials that could be harmful to the environment, which so far has been done in a view that has never been well clearly understood by the industry. Now, we are moving into a phase, an era where the entire scenario is redefined. At each stage, we are looking at what are the harmful entities that go into a product? How to remove them? How to replace them with newer materials that are safe? Finally, looking at end disposal and recycling issues.

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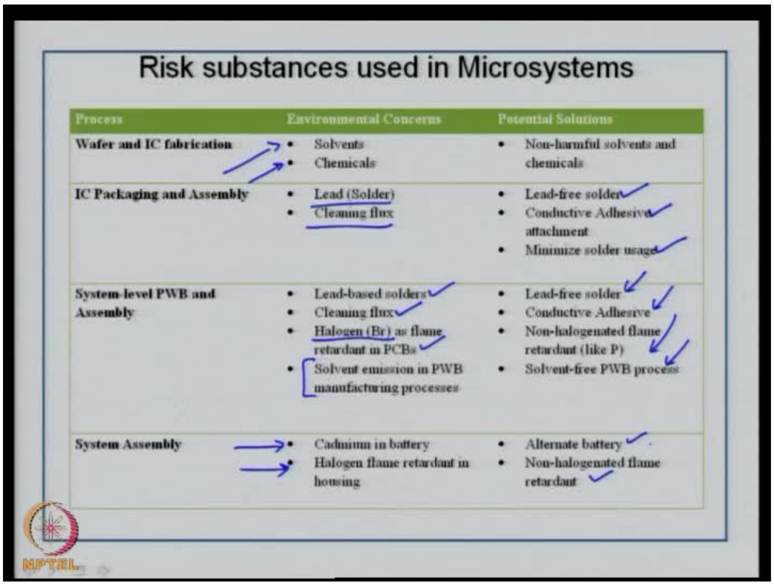

Risk substances used in Microsystems

Process	Environmental Concerns	Potential Solutions
Wafer and IC fabrication	• Solvents • Chemicals	• Non-harmful solvents and chemicals
IC Packaging and Assembly	• Lead (Solder) • Cleaning flux	• Lead-free solder • Conductive Adhesive attachment • Minimize solder usage
System-level PWB and Assembly	• Lead-based solders • Cleaning flux • Halogen (Br) as flame retardant in PCBs • Solvent emission in PWB manufacturing processes	• Lead-free solder • Conductive Adhesive • Non-halogenated flame retardant (like P) • Solvent-free PWB process
System Assembly	• Cadmium in battery • Halogen flame retardant in housing	• Alternate battery • Non-halogenated flame retardant

So, let us carefully look at the various entities in each of the stages of a product, design and product formation. If you look at the first stage - wafer and IC fabrication: there are pretty much, too many solvents used, too many chemicals used. Potential solution is that, try to replace them with non-harmful solvents and chemicals.

IC packaging and assembly: Lead that is used in solder, cleaning flux. There are chemicals that could be harmful to the environment; so, replace it with Lead-free solder; use conductive adhesive attachment instead of using solder material; you can use conductive adhesive as we have seen in flip-chip bonding and so on. Minimize solder usage; that is the way to reduce the risk of such elements.

At the system level printed wiring board and assembly, again you are doing soldering; Lead based solder; cleaning flux in assembly. I mentioned before that Bromine is used as a flame retardant in PCB solvent emission, in PCB manufacturing process, during substrate cleaning and so on. So, these are potentially risk areas for the technician and for the environment; it is a health hazard. So, solutions: use Lead-free solder; use conductive adhesive. Again, for SMD components and fine-pitch components, use non-halogenated flame retardant materials like those, that contain phosphorous instead of Bromine; use a solvent free PWB process; move into more aqueous based cleaning or aqueous based chemistry.

System assembly: If you look at batteries used in system products, cadmium is an issue because that has to be eliminated; then halogen flame retardant in housing and so on. So, use alternate battery; use non-halogenated flame retardant.

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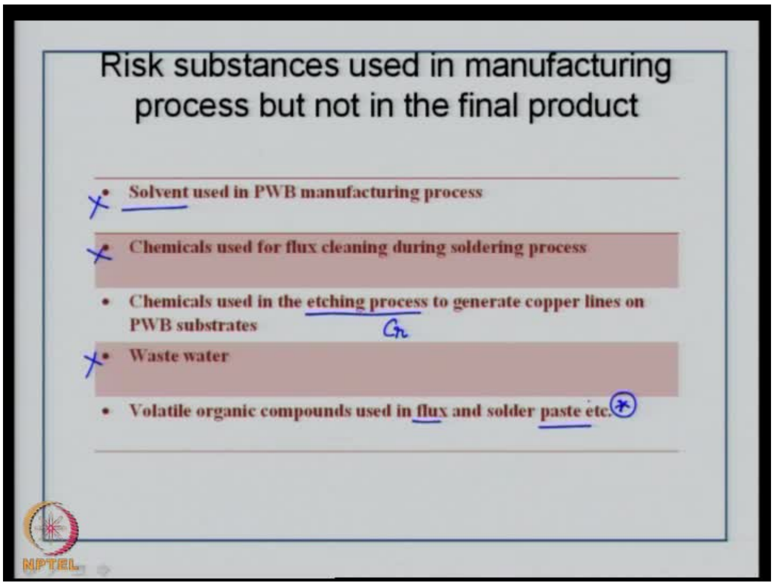

Risk substances used in manufacturing process but not in the final product

- Solvent used in PWB manufacturing process
- Chemicals used for flux cleaning during soldering process
- Chemicals used in the etching process to generate copper lines on PWB substrates
- Waste water
- Volatile organic compounds used in flux and solder paste etc.

So, what is the risk substances used in manufacturing process, but not in the final product? Solvent is a big concern used in PCB manufacturing. So, chemicals used for flux cleaning during soldering process; then chemicals used in etching process; materials like chromium, for example, were earlier used in the etching process. In the PCB, fabrication needs to be eliminated because again hexavalent chromium is banned, but handling chromium which is very corrosive and harmful to the personnel working, needs careful consideration, because there are lots of alternatives available to such chemicals.

Now, how do you treat waste water? Because you know there are various processes in the IC manufacturing and the PCB manufacturing which involve a lot of de-ionized water which gets contaminated during the process cycle; the volumes are very large and it cannot be just like that sent into the municipal drain; you need to look at how water can be treated and recycled? Volatile organic compounds used in flux and solder paste require very careful consideration.

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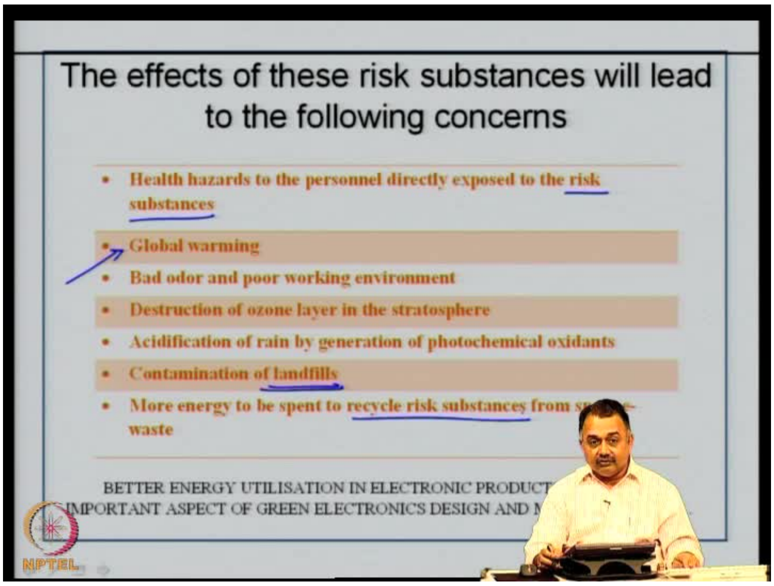

The effects of these risk substances will lead to the following concerns

- Health hazards to the personnel directly exposed to the risk substances
- Global warming
- Bad odor and poor working environment
- Destruction of ozone layer in the stratosphere
- Acidification of rain by generation of photochemical oxidants
- Contamination of landfills
- More energy to be spent to recycle risk substances from waste

BETTER ENERGY UTILISATION IN ELECTRONIC PRODUCT
IMPORTANT ASPECT OF GREEN ELECTRONICS DESIGN AND

The effects of these risk substances will lead to the following concerns: we have seen that, basically the first thing is the health hazard to the personnel directly exposed to the risk substances. Global warming: I do not have to be too vocal about it; most of you are aware of this issue. Bad odor and poor working environment in the industry or the work place; destruction of ozone layer in the Stratosphere; acidification of rain by generation of photochemical oxidants, and contamination of landfills is a major issue.

When these electronic substances are being thrown in the landfill, then this is going to penetrate into the earth and then the effects are going to be seen much later. More energy to be spent to recycle and risk substances can be avoided, because if you are using materials that are easy to recycle and cost effective from the spent e-waste, then you can have savings as an industry; from that point of view, it is going to be very important. So, better energy utilization in electronic products is also an important aspect of green electronics design and manufacture.

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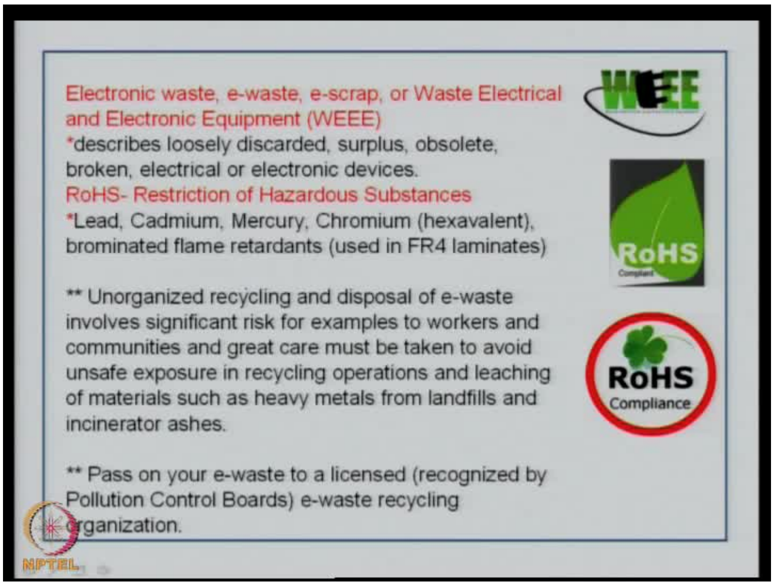

Electronic waste, e-waste, e-scrap, or Waste Electrical and Electronic Equipment (WEEE)

*describes loosely discarded, surplus, obsolete, broken, electrical or electronic devices.

RoHS- Restriction of Hazardous Substances

*Lead, Cadmium, Mercury, Chromium (hexavalent), brominated flame retardants (used in FR4 laminates)

** Unorganized recycling and disposal of e-waste involves significant risk for examples to workers and communities and great care must be taken to avoid unsafe exposure in recycling operations and leaching of materials such as heavy metals from landfills and incinerator ashes.

** Pass on your e-waste to a licensed (recognized by Pollution Control Boards) e-waste recycling organization.

Now, I will conclude with the few slides, by showing you some terms, some kind of a symbol or logo, that all of us will have to be aware of when you buy an electronic product or use an electronic product. If you are in the industry, if you are producing a product, then you have to certify yourself or your product based on global legislation. The first thing is the WEEE logo that you see on the top right corner of the slide; this is the logo of the WEEE organization or council; it stands for Waste Electrical and Electronic Equipment, electronic waste, e-waste, e-scrap or waste electrical and electronic equipment.

This logo defines that or describes loosely discarded, surplus, obsolete, broken electrical or electronic device. So, it is a waste from an electronic product which needs attention; which needs to go for recycling; careful recycling; considered recycling; it cannot just be thrown into the dust bin.

Then the other term that you will see in most products, which is RoHS; that is Restriction of Hazardous Substances. Now, the logos that you see on the slide are not official logos of any organization or anything. If you are producing a product, you have to give RoHS logo; that you can decide. These are just simple examples that have been taken from the literature.

Now, basically you have to comply with the global legislation and you have to certify that your product is RoHS tested. Now, what are the materials that are coming under this list? Lead, cadmium, mercury and chromium which is hexavalent, and brominated flame retardants that are used in FR 4 laminates; so, these are the six materials including diphenyls, diphenyl ethers and so on. So, under the broad category, these are the basic chemicals that are being considered or being written as listed materials that come under the legislation of RoHS.

Unorganized recycling and disposal of e-waste involves significant risk for lives of workers and communities. For example, people who are involved in recycling these electronic product components - great care must be taken to avoid unsafe exposure in recycling operations and leaching of materials such as heavy metals from landfills and incinerator ashes. So, when these are keyboards, monitors, printed circuit boards from computers, desktops are being thrown in landfills, people try to recover this components or separate materials including batteries and so on. These pose a lot of health risk for the workers; so, this is unorganized recycling sector, which should be discouraged.

So, normally, what one needs to do is pass on the e-waste to a licensed recycler that could be identified in your area and that is approved by the government as authorized recycling agency to take care of your e-waste, because they have the right procedures, the right methodologies and the right working environment for their employees to recycle the waste.

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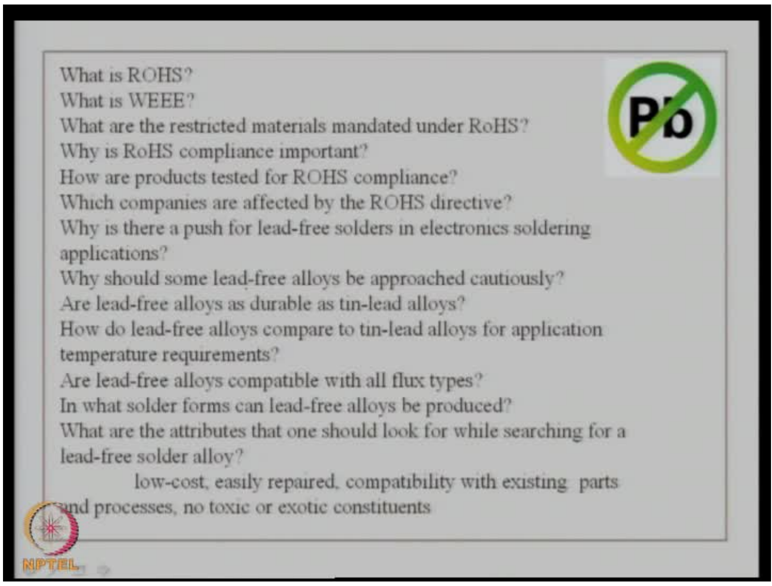

What is ROHS?
What is WEEE?
What are the restricted materials mandated under RoHS?
Why is RoHS compliance important?
How are products tested for ROHS compliance?
Which companies are affected by the ROHS directive?
Why is there a push for lead-free solders in electronics soldering applications?
Why should some lead-free alloys be approached cautiously?
Are lead-free alloys as durable as tin-lead alloys?
How do lead-free alloys compare to tin-lead alloys for application temperature requirements?
Are lead-free alloys compatible with all flux types?
In what solder forms can lead-free alloys be produced?
What are the attributes that one should look for while searching for a lead-free solder alloy?
low-cost, easily repaired, compatibility with existing parts and processes, no toxic or exotic constituents

So, there are many questions. If you look at the slide here, there are many questions that could be asked. Now, these are questions that I have put for us to answer ourselves and see how do we understand this humongous problem-the larger problem of green electronics. So, what is RoHS? You know what is WEEE; You know what are the restricted materials, mandated under RoHS; You know why is RoHS compliance important; only then, you can be at the Leading edge of manufacturing. How are the products tested? Because you know the various materials, you eliminated them from your production line and then you can easily test for compliance.

Which companies are affected? It could be PCB manufacturing; it could be PCB assembly. Why is there a push for Lead-free solders in electronic soldering applications? Because, only then you can get a safer product; because, we are looking for the next generation of people to live in a community that is devoured of these hazardous substances. Now, why should some Lead-free alloys is approached cautiously? I am putting these questions because we have seen these topics already. Now, the reason why we should approach Lead-free alloys cautiously is that we are going to work at higher temperatures; therefore, look at process, look at components, look at your substrate and judiciously take your Lead-free choice.

Are Lead-free alloys as durable as Tin-Lead? Yes, we have seen some of those issues; how do Lead-free alloys compared to Tin-Lead alloys for application, high temperature application requirements experience has shown; literature has shown that Lead-free alloys are as comparable to Tin-Lead in terms of reliability and sustenance in various temperature environments. Now, can they work with different flux types? Yes, only thing you need to know the temperature range and the activation in the reflux-thermal profile; reflux-soldering-thermal profile.

In what solder forms can Lead-free alloys be produced? They are available as solder balls, pallets, wires, as bars. So, in all formats, Lead-free alloys are available. You can choose them as required. So, what are the attributes that one should look for while searching for a Lead-free alloy? Basically, what you need to look at? low-cost, easily reparable, joint compatibility with existing parts, packages and processes, and no toxic or exotic constituents which could be cost prohibited; so, this is the summary of the RoHS.

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Courtesy: http://ewasteguide.info

Have a look at these slides, which I have taken from e-wasteguide.info, just basically to show you that the landfills are totally filled with electronic products at the time when there is no organized sector for this. Today, it is a new story. Things are looking organized in this sector because of various organizations, including private NGOs and so on, Government especially taking more efforts in bringing an organized activity, as far as e-waste recycling is concerned.

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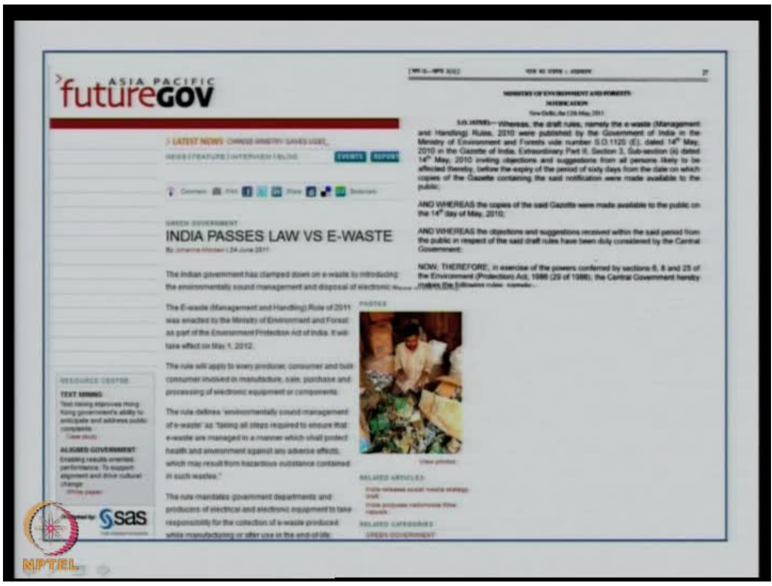

INDIA PASSES LAW VS E-WASTE

The Indian government has clamped down on e-waste by introducing the environmentally sound management and disposal of electronic waste.

The E-waste (Management and Handling) Rule of 2011 was enacted by the Ministry of Environment and Forest as part of the Environment Protection Act of India. It will take effect on May 1, 2012.

The rule will apply to every producer, consumer and bulk consumer involved in manufacture, sale, purchase and processing of electronic equipment or components.

The rule defines 'environmentally sound management of e-waste' as "taking all steps required to ensure that e-waste are managed in a manner which shall protect health and environment against any adverse effects, which may result from hazardous substance contained in such wastes."

The rule mandates government departments and producers of electrical and electronic equipment to take responsibility for the collection of e-waste produced while manufacturing or after use in the end-of-life.

MINISTRY OF ENVIRONMENT AND FORESTS

NOTIFICATION

Whereas, the draft rules, namely the e-waste (Management and Handling) Rules, 2010 were published by the Government of India in the Ministry of Environment and Forests vide number S.O.1125 (E), dated 14th May, 2010 in the Gazette of India, Extraordinary Part II, Section 3, Sub-section (ii) dated 14th May, 2010 inviting objections and suggestions from all persons likely to be affected thereby, before the expiry of the period of sixty days from the date on which copies of the Gazette containing the said notification were made available to the public;

AND WHEREAS the copies of the said Gazette were made available to the public on the 14th day of May, 2010;

AND WHEREAS the objections and suggestions received within the said period from the public in respect of the said draft rules have been duly considered by the Central Government;

NOW, THEREFORE, in exercise of the powers conferred by sections 6, 8 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules, namely:-

To top of all of these, in India - our country, we have finally, a law versus with the e-waste material; so, the Government of India has brought a new regulation and it has given certain procedural steps for manufacturers in the electronic sector as to how they should handle e-waste. The same goes with various organizations. If you are producing e-waste, you have to have certain procedures laid down to handover the e-waste to an authorized recycling agency, and we are now looking at many companies coming and applying for licensing to startup organized e-waste recycling; so, this will be effective from 2012 May 1. Then, you will see that the e-waste will be very properly handled by an organized sector.

So, this concludes the chapter that is module 7 on Surface Mount Assembly, Advanced Packages Assembly Issues with materials, soldering materials, joining processes, soldering processes. We have also seen Lead-free alternatives and we have also looked into very important aspects of green electronics and what you as an individual or as an employee, in industry or a management, in an industry, in the electronic sector, need to look at as far as e-waste is concerned.

Now, we will conclude this module by looking at some questions and answers that will help you finally understand this module very effectively. So, we will spend about 7 to 8 minutes on this tutorial and you can also get back to me on any issues or clarifications regarding this tutorial. More questions in the form of questionnaire or quiz will be posted in this particular course website.

Now, if you look at the first question - some SD resistors have a case form of 0402; what are the dimensions of this resistor? So, we have seen that 0402 means it is 0.04 inches by 0.02 inches. So, this is the dimension of the resistor.

What is the melting point of 63 37 Tin-Lead solder material? All of you are aware of this. It is 183 degrees centigrade and this helps the attachment of various components with the printed circuit board, even if it is a low Tg printed circuit board.

List the different methods of machine soldering? You have seen the different methods: one is reflow and the other is wave soldering. The other machine soldering process that you can think about is laser soldering, although this is used in very small volumes.

So, what is flux? What are the functions of flux during soldering? There is a separate lecture; we have dealt with this; so, flux is very essential because firstly you need to look at wetting; you need to look at solderability issue reducing the contact angle of the joint and providing a good joint; then producing a corrosion-free deposit; that is, you have to remove the oxides from the board. So, these are some of the various points that you can write for this.

Why are adhesives printed on printed wiring boards before SMD mounting? Because, in the case of very small components, light weight components, you want to do double sided reflow to provide a very good gluing or attachment to the board so that the components do not fall; so, especially useful for double sided; wave soldering process requires gluing with adhesives.

So, what is the function performed during IR or thermal reflow soldering? Basically, here if you are using solder paste, solder paste will melt; the board gets activated and the solder pad on the board also gets activated. Then, the component Lead, the coating on that also gets activated. So, at the melting point, the solder paste will reflow and fuse with the component Lead and the pad on the PCB to form a very good joint.

Can SMDs be repaired on board? Yes, you can repair, provided you have the right tools. As you have seen in SMD, there are different sizes; the pitch could be very small. Now, in QFP, again if you are going to 0.3 mm QFP repair and rework, then you should have special tools for this; mostly stencils are preferred to silk screens during screen printing process in a SMT because in metal, you can provide very good imaging and very good dispensing of the paste in the right volumes. That is highly reliable and you could have very good one is to one photo tool to PCB translation of the pad size. Pad size means pad volume dispenses in the right areas.

RMA in flux types stand for what? RMA stands for Rosin Mildly Activated flux; so, can have other types of fluxes also, as you can see in earlier lectures. So, 2 to 3 percent of Silver is usually added to Tin-Lead solders. Why? We have seen this in Tin-Lead-Silver chemistry and we have seen that 2 to 3 percent Silver aids in wetting and also providing a good finish, a good appearance, and also the strength, increasing the solder joint strength. So, we can give these reasons for that question.

What is the function of preheating in machine soldering process when using Rosin fluxes? Is it to activate the flux? So, basically in machine soldering process, you have to preheat to activate the board first, and also remove the solvents and activate the flux because if it is a mildly activated flux or low activated flux, you require more time; so, flux activation is very important.

What is dross? How do you dispose it? During wave soldering, the Tin-Lead molten solder is exposed to air; so, that reacts with air to form oxide; so, this oxide is known as dross. Now, this could be an impediment during the wave soldering process. So, very regularly, you have to remove this dross and then you have to dispose it carefully because it contains Lead and then carefully send it back to the recycler, to recycle the metals.

Give two reasons for tombs toning and skewing in SMD assembly? As we have seen, if you are working in Nitrogen atmosphere, in a reflow process, the different Copper pads of SMD chip component could get different volumes dispensed or it could be different temperatures on the Copper pad, or the time taken for reflow could be slightly different between the two pads; that makes the force exhibited on one terminal of the chip component to pull the entire component to its side, leaving the other pad open; so, this is tombs toning. Please, refer to the library SMD failure library that we have discussed.

Similarly, there are other questions that I have listed here, in this particular pdf. This pdf is available along with this chapter, in this particular course; so, take your time to go through these remaining questions and then you can get back to me for a more detailed answers.