Electronic Packaging and Manufacturing
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Lecture - 38
Electronic Packaging Reliability – 4

Welcome back Electronic Packaging and Manufacturing and we will continue and wrap up our discussion on reliability today. So, today's electronic packaging reliability lecture number 4.

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The concepts that we are going to cover today is the physics of failure modes again some of those we will see some we will get introduced to some new or some modes of failure and PoF models which is physics of failure models ok. Not necessarily in this order I mean we are going to probably jump from one topic to other just to maintain the flow of the lecture, but these are the basic concepts that will cover today all right.

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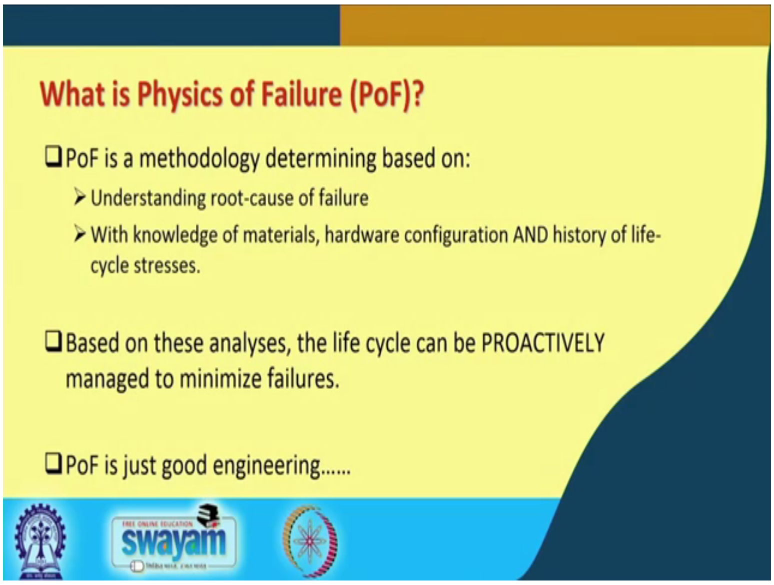

So, what is physics of failure? See in the last lecture we talked about accelerated degradation testing and modelling. So, that involved you know taking a lot of data on the field or under accelerated degradation conditions in the lab, and then using some statistical modelling tools to extrapolate the degradation under normal operating conditions all right. Physics of failure on the other hand is more about trying to understand what is happening what is the root cause that is responsible for a certain particular failure or mode of failure.

So, it is a methodology that is based on understanding the root cause of failure and with the knowledge of materials hardware configuration and the history of life cycle stresses. So, for all these it is not just going and collecting a lot of data, it is about understanding that what can happen under these conditions, under these operating conditions. With this set of materials that I am talking about and with this history of this product or component ok. I can buy a second hand computer or I can be selling a refurbished computer right. So, I need to and I need to know that during the previous during its tenure under the previous owner, what kind of operations and stresses did it go through right.

So, these days a lot of we here a lot of data analytics, using data science deep learning, taking a lot of data using sensors and trying to result in something or model something which is called a digital twin right. So, a lot of it depends on what is; if you if you for example, you take 2 cars and I drive one same model from the same factory same lot, I drive one and my friend drives another. Our driving patterns techniques practices are completely different. So, you take both cars again back to the factory after 6 months and do a health monitoring you will see that they are very different. Both of us have driven it let us say for the same condition for the for the same time maybe for the same number of kilometres.

So, now from that point of time if somebody has to predict the life, he needs to know that what has the scar been subjected to before that ok. So, that is what I mean when I say history of life cycle stresses. I may be a very aggressive driver my friend may be driving only you know particularly in mostly in third gear and fourth gear at optimally between 40 and 60 kilometers per hour. He may be slowing down well before bumpers and its a bump before speed bumps, but I do not do that. So, therefore, both of us have driven 10,000 kilometres in 6 months, but thereafter the condition health of the health condition of both cars will be very very different right ok.

So, based on these analysis the life cycle can be proactively managed to minimize failures. So, what will I do I am taking the car example again? The engineer in the factory will tell me that sir your car is not in good condition you need to service it much more frequently than his or you need to get your brakes changed because your driving practices probably involves a lot of this frequent and strong braking all right. So, at the end what is physics of failure? Physics of failure is just good engineering there is no rocket science, it is about understanding why the condition the health condition of a product what it can go through? And try to predict based on physics trying to predict how this product is going to degrade with usage and with time all right.

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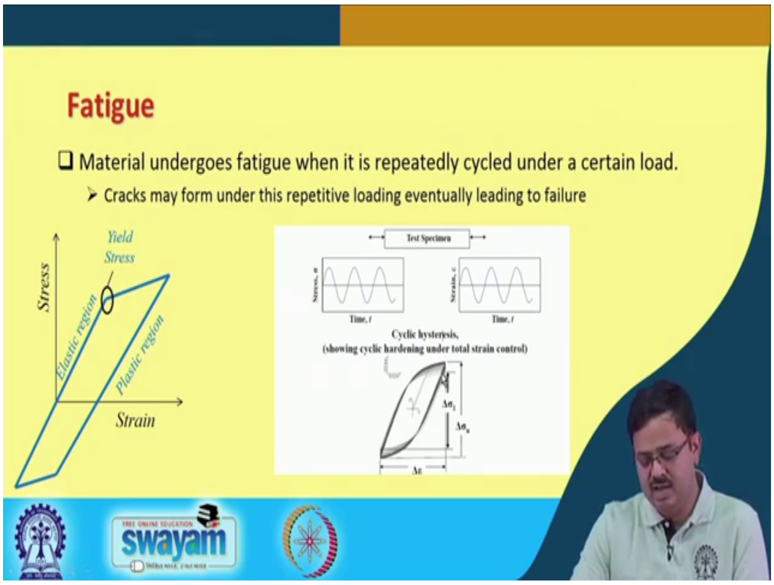

So, let us take the example of fatigue. So, we were discussing in the last class again what is fatigue? Material undergoes fatigue when it is repeatedly cycled under a certain load ok. In case of a solder joint you may form a crack under this repetitive loading, which will propagate with time with more number of cycles and eventually lead to failure ok. So, this is a classic stress strain curve that you remember right we have studied this.

So, the first part if I what is stress? When you take any sample and put a load then the load per unit area is known as stress. What is strain? Because of the loading, it can either it will go deformation either it will get compressed and therefore, shrink in size or it will expand which will or grow in size if you pull something the length is going to increase if you push something it is going to decrease. And strain is this delta change this incremental change in dimension over the original dimension.

So, a material we call it elastic when it is in this first when stress is proportional to strain, the constant of proportionality is known as Young's modulus we have all learnt it in our high school physics. So, that is elastic. But if you keep on increasing the load and therefore, increasing the stress, then what happens? We reach something known as the plastic region right. In the a plastic region what happens is, it is no longer proportional. In fact, with a little increase in stress there is a lot the increase in strain is much more. So, it is kind of yielding. Earlier it was resisting, now I give it a little more load and it is said I give up I have yielded to the pressure all right. So, this is known as the yield stress and the rest of it this one.

So, now if you come to this point and then start withdrawing the stress withdrawing the load and bring it down, it is not going to come back to the original position it is going to come back with some residual strain right. So, this is how it goes same thing. If you now apply if you now apply compressive load it is going to go down till here, will be this will be in the elastic region, but again then what happens is, there will be this plastic deformation and again as you bring it down this is how it is going to happen it is going to be. It may or may not come back to this exact point and these 2 have to be exactly equal, but I am trying to illustrate this one right.

So, when you apply a certain cyclical load, what happens? You take a stress specimen this is how the stress is going up and down this is the strain is also going up and down and let us say I do this repeatedly and I go to the plastic region what do I see? At the beginning this maximum stress and maximum strain or for a given strain for example, if the strain is held constant at the beginning this is how it was right. But later on what is happening is, you know here I started I went like this I came down in the next cycle as I increase the number of cycles you can see for the given strain the stress goes up and also for a given stress the strain goes up. So, this is fatigue right earlier I could withstand a certain load with a certain amount of strength strain but.

Now, or I would bend I would you know undergo a certain strain at a much higher load, but if I if you do it repeatedly I am I am going to lose my strength and slowly I am going to yield much earlier ok. So, this is what happens as you can see, the hysteresis curve grows up grows or grows bigger this goes up this goes down.

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So, fatigue in solder joints if you look at it again the same thing, you can look at it as high cycle fatigue which is which operates in the elastic region sorry there is a slight mistake on this slide I am sorry for that. It can undergo something which is known as high cycle fatigue. So, high cycle fatigue operates in the elastic region, where the stress is below the yield stress ok. But here the number of cycles is much more frequent and that load leads to what is called a high you know high cycle fatigue. Low cycle fatigue on the other hand is when von mises stress is greater than yield stress. So, in this condition actually the failure is dominated by something called sorry the failure is dominated by the stress and in plastic deformation or low cycle fatigue it is dominated by strain all right.

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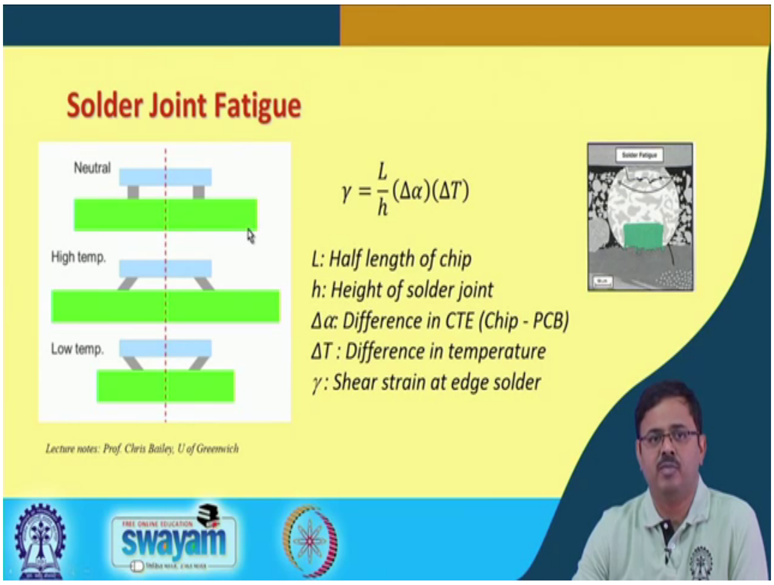

So, let us look at this one, this picture we had seen before. Now if you look at the strain on the solder what will it be? It is going to be L over h if the solder height is h and L is the distance in this case the distance of the solder joint that is farthest away from what is called the neutral plane. Then what is its deformation going to be? So, it is going to be L alpha delta T for the PCB and it is going to be L alpha silicon delta T for the chip ok. So, therefore, what is the net deformation? The board is going to deform more and the silicon is going to deform less.

So, therefore, the next strain which is the deformation divided by h is going to be L alpha 1 minus alpha 2 or delta alpha minus times delta T clear. So, this is a shear strain at the edge solder edge solder balls the ones that are in the inner planes that or the closer to the neutral plane, that will be less because this L is going to be lesser for those right.

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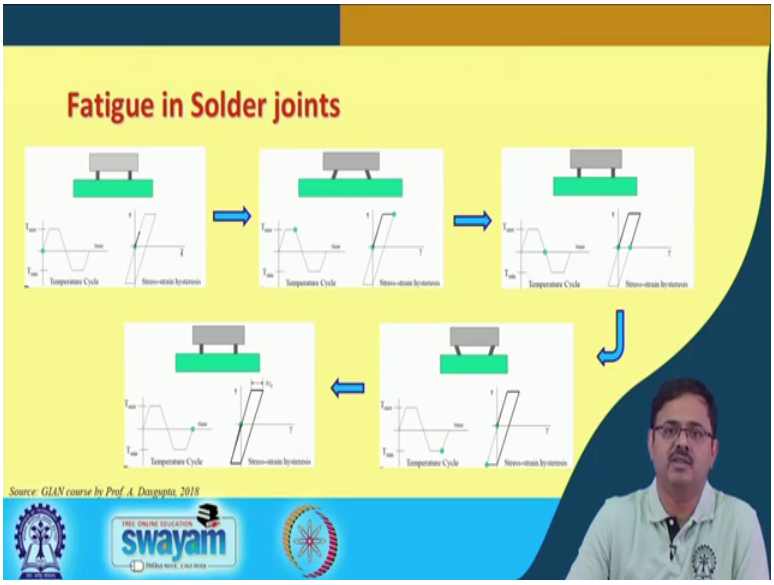

So, now if I look at fatigue in solder joints this is the neutral condition all right and I am just starting from this point, this stress strain curve in the next one I go to the plastic region. So, this is my point and this is the condition where the PCB definitely has expanded more. Next as the temperature goes down or comes to a state original state which is probably under the room temperature, this is what it is it comes back again. But it does not come back to the original condition because it has undergone plastic deformation. You cool it down it goes to this point and then it comes back, it may or may not come back to this point by the way well this is just a schematic representation all right. Again I must acknowledge Professor Abijit Das Gupta who taught who presented a Gian course earlier this year in 2018 and what I am taking what I am showing are from his lecture notes. But he very nicely depicted this I mean it is known to all of us, but I think this was very nicely put ok.

Again repeatedly you will see on the slides I am acknowledging 2 pretty well known stalwarts in this field Professor Abijit Das Fupta from university of Maryland and Professor Chris bailey from university of Greenwich they are both very well known in the field of electronic packaging.

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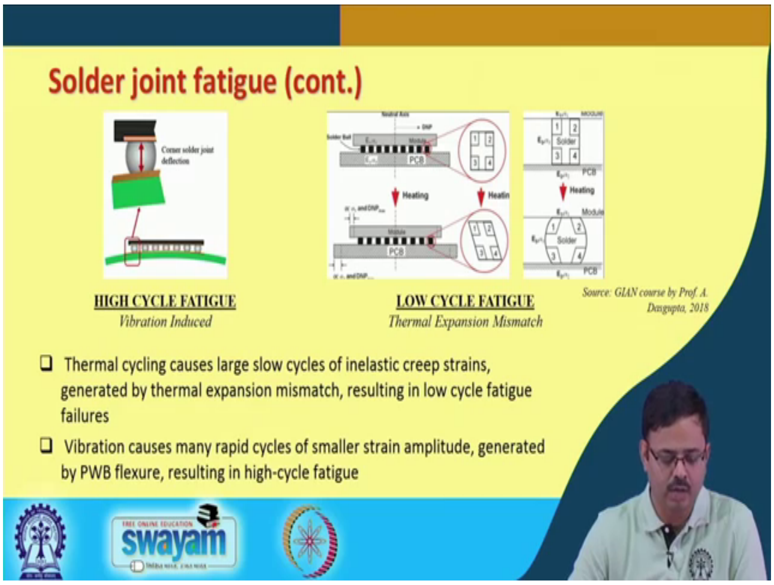

So, if you look at the solder joint fatigue in more details, high cycle fatigue is more vibration induced you see here. Low cycle fatigue is more due to thermal expansion mismatch and if you look at you know this one what we were talking about before was kind of a global mismatch right. So, this solder joint we were seeing it as a single body undergoing deformation because of unequal expansion right. So, this was the original condition, this is the on heating this is what it is. But on the other hand in reality if you look even within the soldered joint or the solder ball, if these are the four corners you see the four corners are going to undergo stresses differently correct. So, we need to understand these this will see more strain this will see more strain these 2 not so much 2 and three not so, much 1 and 4 much more right.

So, thermal cycling results or causes large slow cycles of inelastic creep strains generated by thermal expansion mismatch and resulting in low cycle fatigue. But the vibration on the other hand these are much rapid cycles or smaller amplitude because of flexure, if you are if you have you know clamped on the 2 sides and you are vibrating then what happens it is. You know undergo this flapping motion, flexural rigidity is kind of challenged and it results in high cycle fatigue all right.

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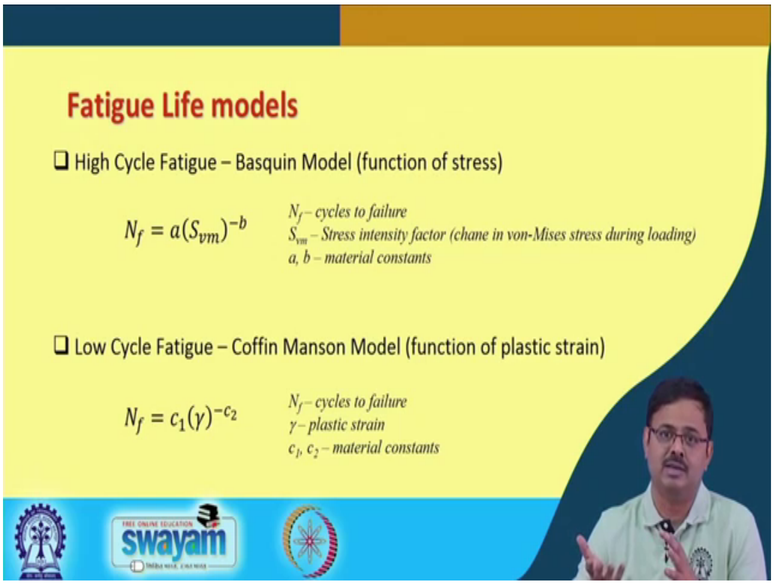

Now, one may say that actually what happens is, high cycle fatigue and low cycle fatigue in actual solder joint it may be a combination of both. So, fatigue life models. So, if its high cycle fatigue is function of stress as we talked about and Basquin model is something very well known. So, we have understood why this happens that understanding is there. Then what happens is, you can now do a lot of analysis once you know once you have characterized a material you can do a lot of you can do now analysis using all these mathematical and computational tools that we have in our at our disposal today and come up with an equation like this. N f is the number of cycles to failure and that is given by this kind of equation. Where S v m is a change in von mises stress during loading and a and b are material constraints material constants sorry.

Low cycle fatigue which is probably more dominant in solder joints due to temperature cycling there is a function of plastic strained ok. And what you see here is, again it is the gamma is the plastic strain and the dependence as you can see c 1 a constant times gamma to the power another constant or one over another constant ok. So, this is how it is. So, the second one is known as Coffin Manson model and after the people to people who came up with this formulation and we see a lot of variations of Coffin Manson model today all right.

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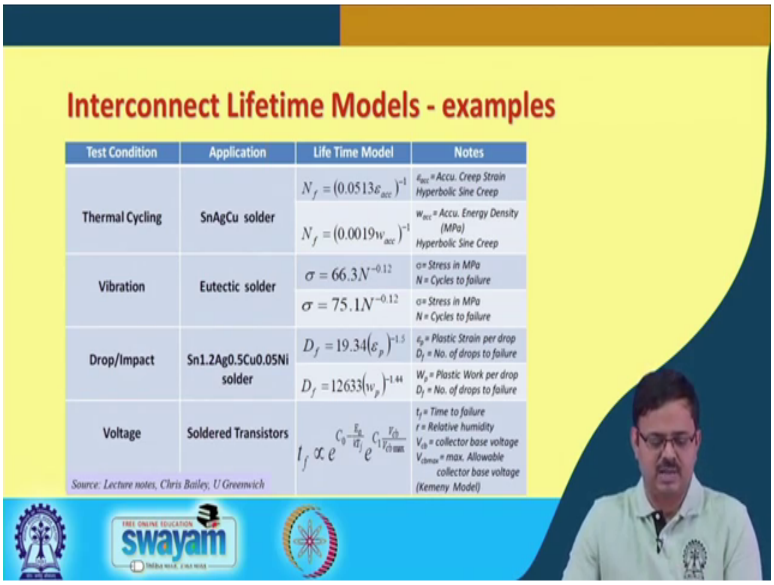

So, these are some examples interconnect lifetime models under different conditions thermal cycling we already talked about. So, you can see these are kind of variations of Coffin Manson model except what is epsilon that c 2 is minus 1 over here under vibration ok.

It is more about high cycles high cycle fatigue and there it is a stress that is important. So, the number of cycles to failure N is related to the stress in mega Pascals drop impact and voltage. If you apply especially under you know components like transistors solid if you apply much higher voltage of rise and drop repeatedly and under and mix it under go through cycling voltage cycling, then under and this is actually you see you can see this is sort of the 2 variable PEX model that we talked about in the last lecture here the 2 what should I say the 2 variables can be temperature or can be relative humidity and it can be the voltage all right.

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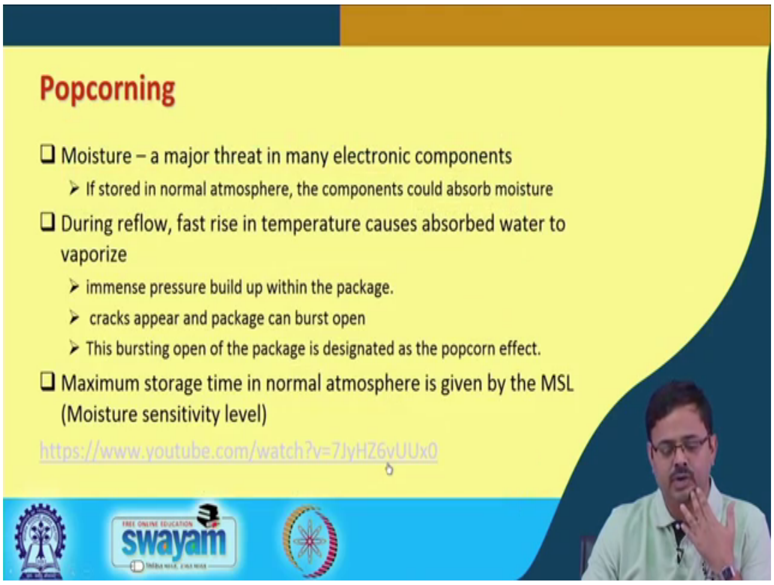

Now, what we will do is it was more on solder joint fatigue; what we are going to talk about now is about a few other modes of failure. So, one of that is called pop corning.

Now, what is pop corning? This is cause number 1 buy. So, pop corning is some failure mode what is the mechanism that is what we are going to discuss now. This is caused by number 1 moisture for a change you may say it is not temperature its moisture what we will see temperature actually plays a role here. So, moisture is one of is a killer; it is a cruel enemy of electronic products, it can really cause you know really bad damage in electronic products can lead to corrosion it can lead to a lot of other things. So, pop corning. So, and every material actually absorbs moisture all right we cannot do anything especially plastic and all the absorb more moisture, ceramics absorb less moisture that is where hermetic sealing and etcetera come into picture, but they are also more expensive. So, mostly for consumer electronics these components will absorb moisture when subjected to certain atmospheric conditions all right. So, moisture is a major threat.

Now, let us say I have some components even at the manufacturing stage itself, and it is stored in normal atmosphere. So, it could absorb moisture. Now let us I put this component on the circuit board and I do the reflow process what will happen? Because of this fast rise in temperature the absorbed moisture will vaporize. As it vaporizes we know when something when water vaporizes its density decreases right. So, it will create immense pressure. So, there is a pressure build up right if you even take a simple p equals to rho r t type of state of equation, as rho goes up everything has remaining constant p has to go the pressure has to go up sorry I am sorry as it needs to expand and it cannot. So, there is a lot of due to boiling, there is a lot of increase in pressure I take back my state of equation argument.

So, immense pressure build up within the package. So, what will that do? This moisture will try to come out. So, it will create lead to cracks in the package. So, because it wants to burst open and escape, and this bursting open is known as a pop corning effect. So, therefore, as a result for an electronic component or system what happens is, depending on the materials the maximum storage time under normal atmosphere is given by something called MSL standing for Moisture Sensitivity Level ok. So, what will do now is will look at a small video.

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So, let us play this the link of which is on the slide will play this and listen to an expert talking about pop corning in package on package configuration pop.

Pop corning (Refer Time: 21:17) like any other component due to moisture in the package also warpage is not uncommon with this type of package.

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Now if packages do popcorn the end result can be open circuits and solder shorts on the top 2 levels. You need to consider palls the proper storage of these components and also the profile being conducted during reflow soldering to eliminate this phenomena. If the top package lifts during the soldering operation when both solder ball and solder paste are in the reflow condition, what can actually happen is separation can occur and some solder can be drawn from one ball to the other ball. This can result in solder shorts depending on the design of the package. Also the components can float.

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So, you can get a top package floating above the terminations on the bottom package this again results in an open circuit package. On package is a fairly new process to many companies, but by thorough investigation by doing production trials you should be able to eliminate any instance of popcorning.

So, we looked at what is pop corning and you can see what can happen right suddenly it is like just a popcorn see if you have ever fried popcorns either in your microwave or in a pressure cooker, you would have you would see this cracking sound that is exactly what happens here. Because as the pressure as it vaporizes, it wants to escape it cannot it is pressurized ok. So, therefore, it wants to therefore, that that internal pressure at some point become so high, that the material cannot withstand it any further and leads to this pop corning effect.

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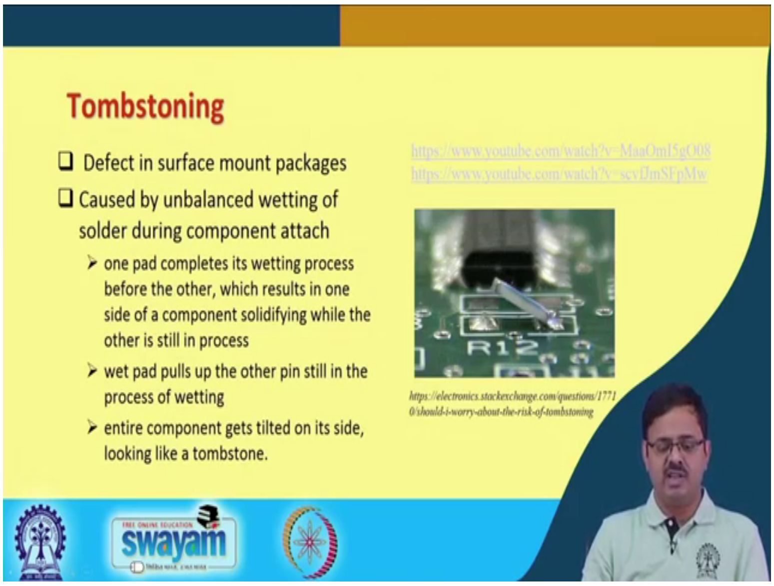

The next one is called tomb stoning and this happens again during solder reflow when you are putting a packaged surface mount package and you reflowing it you will see that this can happen why? Remember how does reflow occur because you have put a little bit of solder, and then when you put it inside the oven the solder melts just that much to form this contact between the component and the board and then its solidifies.

Now, when this contact happens when the solder melts that is where the wetting happens we call it wetting solder wetting that is that is essential for component attached and then it has to solidify clear. Now let us say one pad know this is a now what happens when the component is sitting on molten solder how it behaves, how the wetting happens how much the solder you know expands along the surface of the component that all is driven by surface tension.

So, now let us say if because of whatever reasons certain defects one pad completes its wetting process before the other ok. So, therefore, one side solidifies earlier than the other the other is still in process. So, the wet pad therefore, pulls up the other pin that is still in the process of wetting and these results in the component instead of being straight on the board it kind of detaches at one end and lifts up. And in worst case it can become vertical just like a tombstone you know tombstone where people are buried and you have this stone on top with their names written some epitaph written. So, it almost likes that like it looks like that the component is just standing up like a tombstone on the circuit board, where it is supposed to be horizontally aligned and attached on the board ok.

So, you can see a picture over here now again let us look at a couple of videos which will make it probably more visual and more appreciative.

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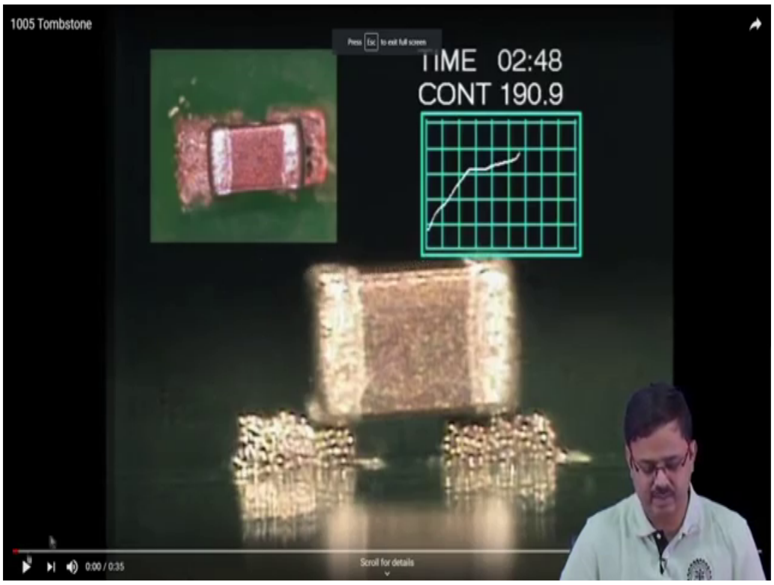

Let us look at this one, you see here the actual picture where a component these are 2 solder pads and this is these are the 2 interconnects this is. So, ideally there should be wetting wetted joint over here or wetter joint over here, but what happens? There is unequal weighting and you see along with time one side the left side is getting wetted the right side not. So, much and you see this detachment right it has left it up and now this one started to wet, but by that time the detachment had already happened and the final configuration is a defective package all right.

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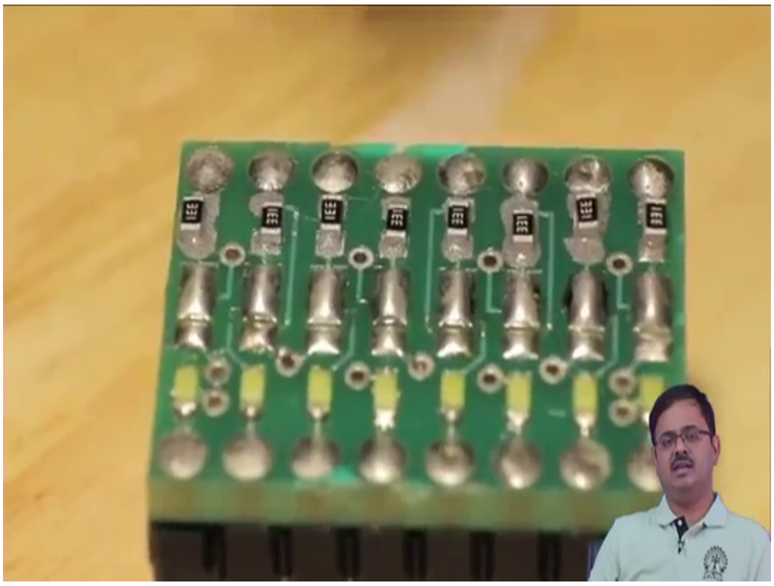

So, let us look further this one is actually another interesting video where somebody is trying to demonstrate the effect. So, this is kind of a manual operation and let us see what happens. You see a bunch of these solder pads, where he is actually the user is actually manually putting some solder dispensing some solder and then he is going to put some components. The solder dispensation is still going on and next what we will do what we will see is, is going to take some components small components with 2 connection interconnections and place them on each of these pairs one.

So, this is how he is now placing the components. Next is going to heat up so, that the solder on both sides do melt and wets the joints see what happens here. So, here its not a reflow oven what the user is, doing he or she is doing is he has taken a kind of I think a hairdryer or some kind of a hand blower heat gun and you see you see the way it is they are all aligning, but this one the fourth one suddenly lifted off right the one that he removed that was an example of tombstone. So, that kind of gives us a visual appreciation of what this tombstoning effect is all about all right.

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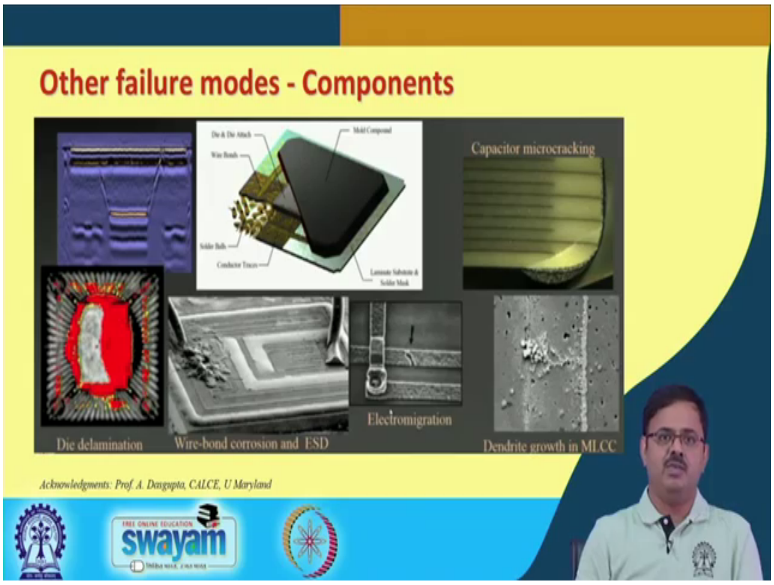

So, let us look at some other failure modes again acknowledge Professor Abijit das Gupta. So, at the component level you see these kinds of these kinds of defects or failure modes capacitor micro cracking, dendritic growth electro migration we have not talked about them in details.

But what happens is, if you have you know some of the atoms of one component does migrate into the other and leading to what is called the dendritic growth. Very very essentially very common failure mode in batteries lithium ion batteries the cathode and anode can go through the you know with time can actually go through the separated membrane and lead to internal shorting. Electro migration, wire bond corrosion very very essential you see the wire bonds have corroded over here probably due to moisture due to some other chemical sorry gases corrosive environment; dye delamination at certain point it has delaminated from the substrate possible right solder joint delamination is possible.

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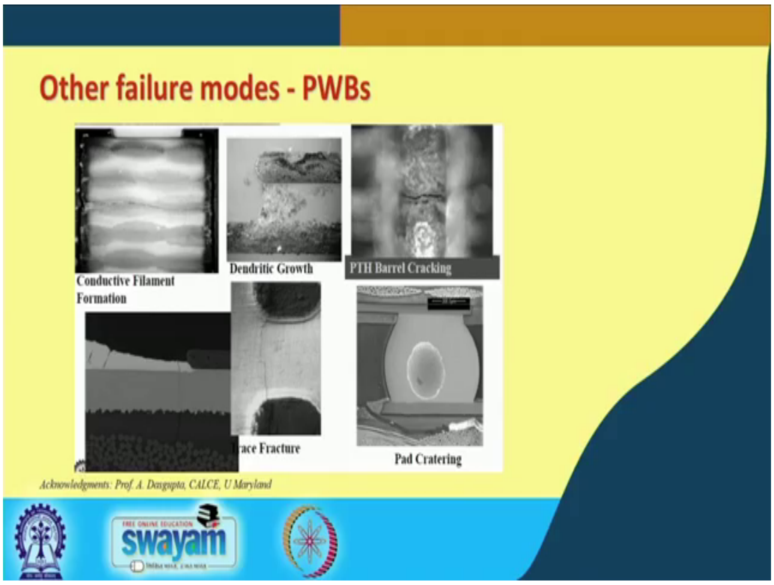

Another thing let us look into the next one in PWBs printed wiring boards dendritic growth we talked about plated through hole barrel cracking ok.

That barrel there may be a crack let it through remember that we in the through hole we did an inside plating either electroplating or electrolytic rating or electroless plating, that can crack that can bea plated through hole that barrel can crack ok. Then phrase fracture pad catering cratering there is a solder pad and inside actually there is a crater there is a void right. It can even be a it can be avoid it can be a foreign substance clear.

The other one again due to CTE mismatch is warpage something that can warp so, much that at one end you know the solder joints at one end may just separate out, because let us take this example of this wire board see if I may have the camera from the top, if I take this wire board for example, and this is you can see this connector at both sides and I am holding it now I heat it up.

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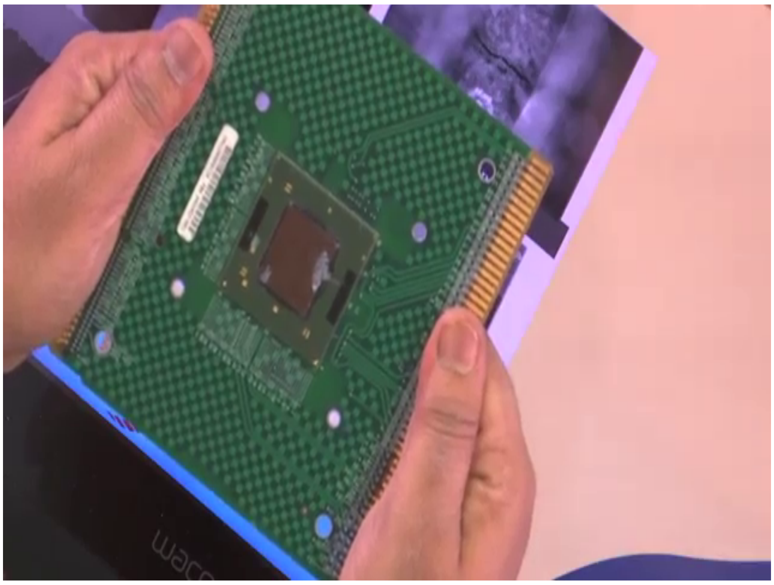

If I heat it up then what happens is, the silicon is going to expand to a certain level the mother board much more.

So, now this because this is held at the 2 ends what will happen? In order to expand it has to warp it is no longer a straight line like this, but it will be a bent like and this warp is therefore, what will happen is from the end the solder the connections may kind of open up all right. So, this is important warp which is another big issue. Now since I am showing this let me also show you show you something very very interesting. Say this is a ball grid array on an organic substrate or a package and on an f r 4 motherboard. So, both are organic the substrate is organic material the motherboard is also an organic material. So, both this is an organic material; this is an organic material similar CTE. Now this is a ball grid array attached BGA attached between the motherboard and the package as well as between the silicon and the substrate.

Now, if you look carefully from the side I do not know how much probably yeah you can, you can see the outer if you look along the edge you can see the series of solder balls right at least the outer the last row of the array other end also you can you should be able to see, but then again this end was more clear right. However, I do not see it see that outer joint over here why? Because we go back to our first level packaging we talked about under fill epoxy. Silicon and f r 4because of the CTE mismatch, we use this under fill epoxy material right which results in reduction of the temperature induced stresses clear, but why do we not have that between the package and motherboard? because there CTS are almost similar. So, why use ok.

So, there is no need to use because both the package and the motherboard expand equally, but the this that is not the case between the silicon and the substrate or the package all right. So, that is something very important and that also since we are talking about solder joint fatigue etcetera, let us also talk about or let us remember the concept of under fill epoxy which is dispensed in order to minimize the effect all right. So, in summary this is a summary slide reliability this is ah. So, we are wrapping up our whole discussion and reliability after four lectures, its a critical component in the design of electronic systems ok. If you do not consider reliability then you are doing a grave mistake.

Because it is not just performance today, but its performance over the entire lifetime you do not want somebody to say that you know this product x from this brand y, fails very early may be very good when you buy it, but you tell me after three months how it is performing ok.

So, after three months you should be able to go and say that you know is it is as good as it was on the first day, then after 3 years also depending on the product you should be able to go and say, oh! it is still as good as it was all right.

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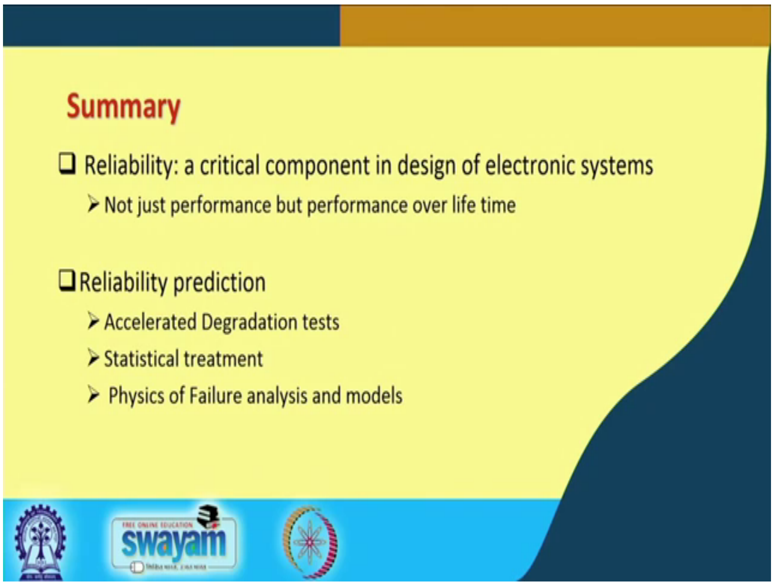

Reliability prediction that is important that some part of reliability engineering. So, we can do it through accelerated degradation tests and statistical treatment or we can do it is physics of failure analysis and modelling ok. The second one is more based on scientific rationale the first one also I will not say it is absolutely unscientific, because just the determination of what kind of what are the accelerated degradation conditions does require understanding of the primary mechanism the root cause for failure mode and determining what those conditions should be.

But there after it is no longer about scientific modelling. But it is more about collecting field data or experimental data in the lab and using that data to predict what should be the conditions under normal operating or what should be the degradation under normal operating conditions ok. So, that brings us to the end of this lecture as well as the entire discussion on reliability of electronics packages. So, what we will do is, in the next lecture when we come back, we will start on a new topic all right.

So, thank you very much and we are going to come back again in the next lecture bye.