Electronic Packaging and Manufacturing
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

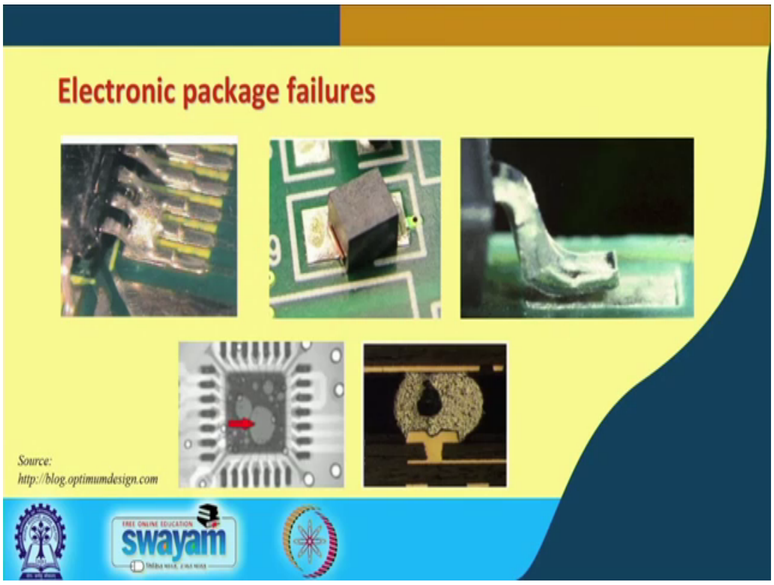
Lecture – 37
Electronic Packaging Reliability – 3

Welcome friends, welcome back to this course on Electronic Packaging and Manufacturing. As you recall we were discussing Electronic Package Reliability or the importance of reliability and reliability engineering in the field of electronic packaging. So, today is the 3rd module on that ah; so the concept that we are going to cover today or as follows.

(Refer Slide Time: 00:42)

So, we look at some failure modes and mechanisms and then we are also going to look at some reliability predictions methods and we will start with the topic on accelerated degradation testing ok. So, these are primarily what we are going to cover as part of this lecture which is lecture number 3 under reliability.

(Refer Slide Time: 01:05)



So, let us move on and what our electronic package failures if you look at this picture or it at the slide you see several pictures and whatever you see here are all examples of failures in an electronic package. Now as I said before these are failures; so the package cannot either cannot run at all or cannot run at its space at its specifications or according to its specifications.

So, the first one as you can see in this picture I will briefly go over each of them this is called bridging these are two interconnects or draw the three interconnects next to each other which are supposed to be separate from each other. But during the solder reflow process probably something has happened as a result of which these two have kind of got fused to each other; so this is called bridging. So, there is a bridge between that is connecting this first interconnect with the second and here in this case with the third as well.

So, this is not desired because what is it doing is it is leading to a short a short circuit between these two right. This one is an example of misalignment it was supposed to be straight, but during the solder reflow process maybe for whatever reason because of unevenness of the surface because of improper this you know dispensation of solder what has happened is the alignment is not proper, when it actually when the solder actually solidified the component had turned a little right.

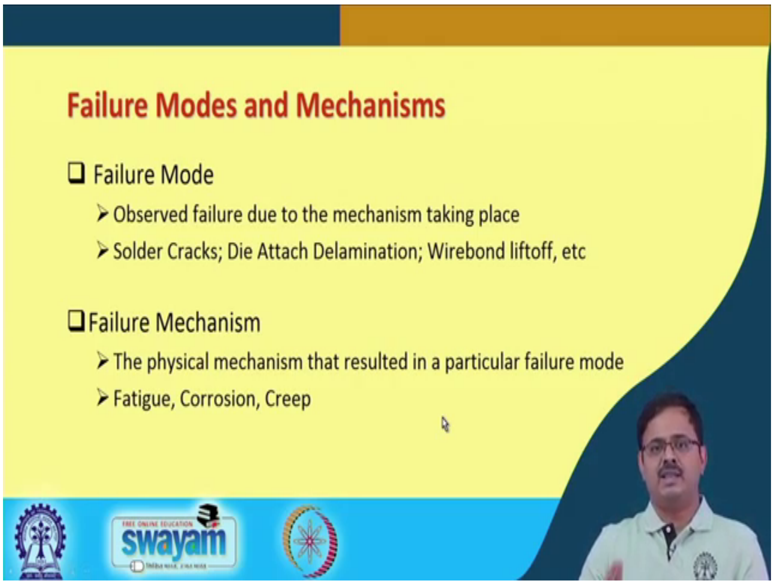
This one is an open the interconnect you know the lead has not bonded with the pad on the board. So, this is coming out of the component a gull wing type lead; if you recall and this is the corresponding solder pad the landing pad, but you can see that this there is an open it has not connected to the circuit is open these are called voids ok.

So, either inside the solder ball itself you can have a hollow structure a hollow void which can be for a variety of reasons or even here as well as you can see when the package when the when the chip is on the lead frame the bonding is not right and there are voids. And this you can see under you know some of this failure what is it called its failure analysis techniques.

You can take a scanning electron microscope image or whatever several microscopic images and it will give you photographic evidence of these defects several others can happen. For example, thermal interface material, if you have a grease what happens is beyond a point you will see that the end if this is my silicon. And you know this heat sink or the heat spreader is on top you will see beyond a point, there is no grease at the center and most of the grid has grease has gone to the outer sides that is called grease pump out it is a very well known mechanism ok.

As a result what happens? The thermal interface material has been lost from above the chip surface and as a result your temperature will go up right ok. So, these are various make it these are some of the ones these are some examples of defects that we are talking about leading to failures; it can lead to failure or in this case may be this connection is not complete the others are. So, therefore, some functionality will not be performed by this package. So, it is a defective package and it may be doing some of the things it is supposed to do, but not all; so, let us move on sorry.

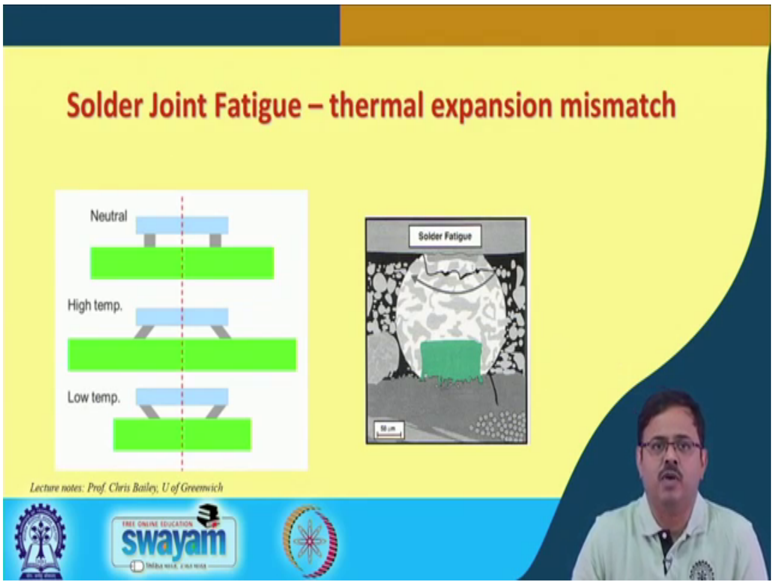
(Refer Slide Time: 04:52)



So, failure modes and mechanisms what are the difference; what is the difference I mean because many a times these are used interchangeably, but strictly speaking failure mode is the observed failure that we just saw bridging die attach delamination a crack in the solder a wire bond lift off an open circuit ah.

So, these are all examples of failure mode how it has happened how it has manifested what is the mechanism, why did this happen that is the failure mechanism ok. The physical mechanism that resulted in this particular failure mode was it fatigue was it corrosion was it creep was it uneven surface was it imbalance of the solder wetting; so, all these are failure mechanisms ok. So, it is like a cause effect all right alright.

(Refer Slide Time: 04:48)



So, let us move on and we will take the example; we will see an example here which is known as a solder joint fatigue wide. Why does this happen? The solder joint fatigue remember we had discussed this before; let us say this is my; motherboard and this is my silicon and these are two representative solder balls.

Now remember that the solder the coefficient of thermal expansion of silicon and the PCB material of the organic laminate here are very different. So, therefore, when you heat it up the PCB expands more compared to silicon right and as a result this is the solder joint or solid ball which is supposed to be in this case, represented by just a pillar that kind of bends in this in this fashion. And when you actually cool it down again, the PCB contracts more than the silicon and then this is the deformed configuration.

So, now if you think of this happening this heating and cooling happening in cyclic modes; every time you switch it on switch it off or every time you run a workload versus you do not run a workload or you stop running that workload this is happening this is temperature cycling. So, as a result what happens that leads to what is called fatigue.

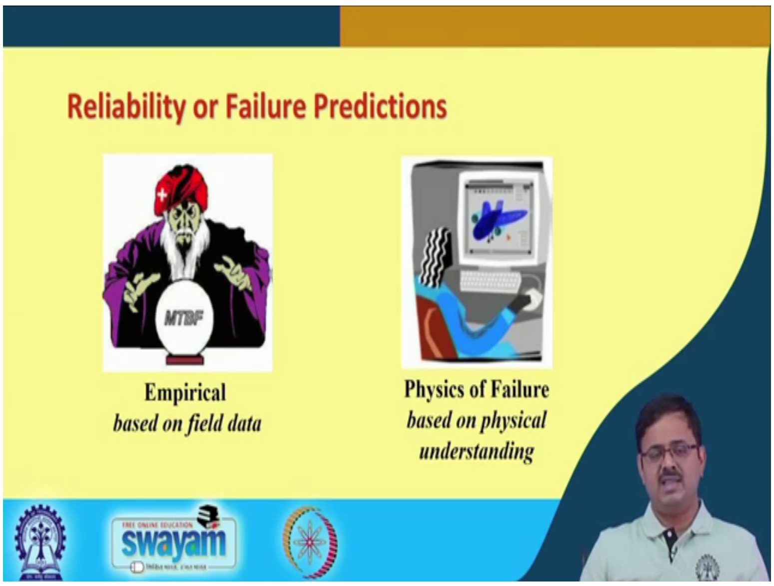
We will discuss this even in more detail in the next lecture, but fatigue what happens is see if you take something ; let us say if you take a pin or let us say if you take kind of a wire or slightly thick rigid wire of stainless steel or some metal and you bend it bend it. Once it will bend; straighten it will straighten again maybe after 5 minutes, you bend it again it will bend, it will straighten all that, but you keep repeating this beyond a point it will break it will snap that is called fatigue.

What happens is when you keep you know when you keep loading something cyclically repeatedly one after the other, then what happens is its strength goes on its ability to withstand a certain load goes down in the other. Or in other words either its stress under the same load or the strain under the same stress goes up there will again discuss all this in the next lecture ok.

So, that is fatigue we are going even in our real life we say you do something repeatedly at the end you are fatigued you do not want to you do not have that energy. You cannot withstand what you could do on day one for example, you know cricket team when they play too many matches and towards the end they look very fatigued if they do not have energy; they look tired.

And that is what this that is what we say that there is I mean they need to recoup they need rest right. So, it is the same thing over here as well for materials. So, here you see; so, this eventually leads to cracks in the solder balls and you can see one of these scanning electron microscope image of a solder. And you can see this crack that has happened because of fatigue and if the crack completely propagates then there is an open circuit as shown here, otherwise there will be a crack which eventually will propagate and lead to failure right.

(Refer Slide Time: 09:00)



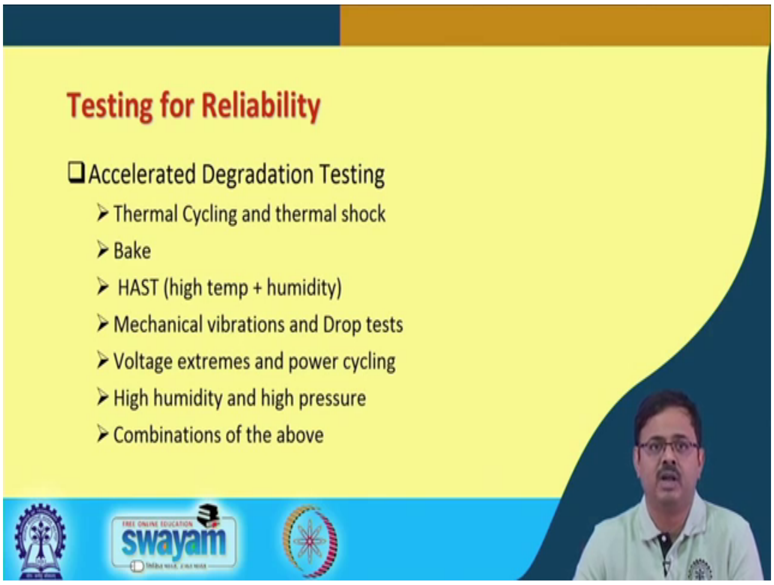
So, now how do I do this? How do I predict the reliability when is it going to fail etcetera how fast will it degrade? So, there are two ways the first one is known as is empirical method where you do a lot of tests a lot of field data you collect that you do a lot of statistical analysis.

These days you call it data science more mature and more sophisticated tools are available. And then you say that you know this is based on the field data and exponential and all the experiential data; this is what we think is going to happen ok. The other thing is what is called the physics of failure; I need to understand the mechanism why this failure is happening if I know that. For example, fatigue why is it happening? It is happening because or why is a solder crack coming in that is coming in because of fatigue resulting in from temperature cycling.

So, now I can go and look at the physics of temperature cycling; why it happens; you know do this physical analysis and kind of predict that what is what happens over there ok. So, that is the physics of failure based on physical understanding. So, in this lecture what we will talk is, we will talk a little bit on this empirical method, in the next one we will talk about POF or the Physics Of Failure methods alright.

So, physics of failure methods as you can see is vast because the kind of defects the failure modes are also vast ok so, for each of them there can be multiple reasons. So, we will just take a few examples just to give you the flavor of what is physics of failure right. So, but that is in the next lecture this one we are again going to talk about some of these statistical methods, based on data alright. And this will also expose us or basically introduce us to the concept of what is called accelerated degradation testing.

(Refer Slide Time: 10:53)



So, testing for reliability as I said accelerated degradation testing what does it mean? What it means is see in a real environment in a real working environment; let us take your the example of your desktop computer, it is supposed to last for probably 5 to 7 years 5 to 10 years.

Let us say now it is not possible it is not rational or practical to test desktops under normal operating conditions for 7 years and then certify that this lot is good and by that time the technology would become obsolete ok. I cannot come up with the technology and then make a desktop and run it for 7 years and say what is not failing; therefore, let us ship these products out it is not possible that is not practical.

So, what we do is; we run these stresses these workloads this make this device undergo these operations under harsh condition conditions so that the failure the onset of the failure is expedited ok. So, for example, thermal cycling and thermal shock just to give you an example; we can switch on and switch off and maybe a million times under room temperature and say that this is fine.

On the other hand, I can take it to what is called a thermal cycling chamber and cycle it let us say from minus 40 degrees to plus 150 degrees and rapidly ok; with some dwell time some rise time some dwell time sign some cool time cooling time etcetera. Do this repeatedly and measure whatever is the whatever is the metric of interest after a certain number of cycles and see how much it has degraded. And from there I can extrapolate and say that you know beyond a point it is either going to fail or it is going to degrade in to such an extent that it is no longer acceptable.

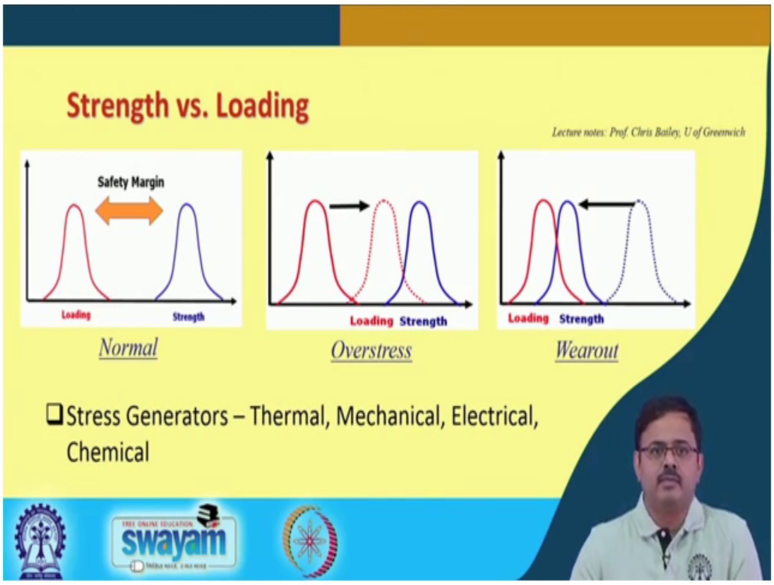
Thermal cycling is one bake; bake is it just introduce it to a high temperature for a long time especially for thermal interface materials which degrades with temperature ok. So, and it will degrade with degrade more with higher temperature. So, can I let us say look at the degradation when it is subjected to 125 degrees 150 degrees.

And based on the data that we get predict what will be the rate of degradation when it is operating let us say at 70 degrees or 90 degrees; which is its normal operating condition mechanical vibrations and drop tests ok. So, vibrations well you have heard before; now you have you already heard about vibrations before when you know the product or the component is subjected to vibration during its shipment during its maybe during a storage during transportation or maybe under certain conditions during operation right when it is in aircrafts. When it is in defense organizations in sorry in defense equipments like tanks fighter tanks in cars right in automotive electronics; so, there mechanical vibrations is important.

So, what will I do? I can do some accelerated degradation testing by putting it on a mechanical vibrator table and do a vibration at a much faster rate at a much faster frequency vary the amplitude; look at various configurations. And look at how much it degrades how many cycles does it withstand at that frequency at that amplitude and then based on that extrapolate to the normal operating conditions ok.

So, similarly we do these degradation and in chambers which has high humidity high pressure has its high temperature plus humidity and combinations of the above. So, accelerated degradation testing is something that is commonly done routinely done in the in the field or basically in the electronics industry or rather in most industry abuse in many industries I would say ok.

(Refer Slide Time: 14:56)



So, that is what we are talking about; so, what is accelerated degradation testing? As I said it is making the environment more adverse more harsh. So, that the stress generators stress in this case is used a little loosely stress as in the failure mechanism or what generates a failure whether its a thermal condition with a mechanical electrical chemical we make them more and more adverse.

So, normally what happens? This is what this is the strength this is what I can withstand I have the capability to withstand that ok, but then my loading is something what I am actually have to withstand is something much lower right. Now, for example, I can run a marathon, but probably I am I am participating in a 10 k race alright. So, therefore, this is the full marathon is my strength, but this is what I am currently doing alright.

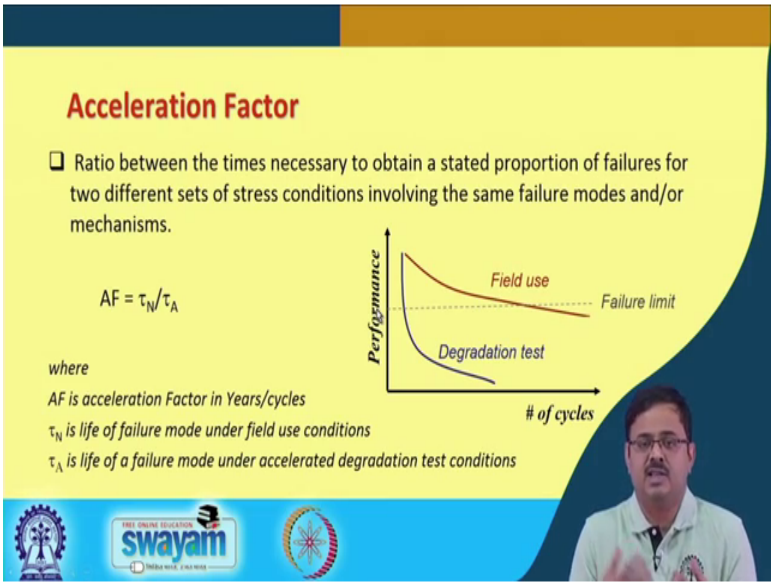
So, therefore, what we can do is we can over stress the product so, that the loading which is what we do under accelerated testing the actual loading condition is made more adverse this is this would be under normal operating conditions, but during accelerator degradation testing I make it something that is close to its strength. So, in with this case I am going to I am asked not 10 k not 10 kilometers, but you have to run 40 kilometers.

Let us see whether you can really withstand that or they may say you know you have to run one and half times the full marathon in which case I will wear out I mean I do not have the capability to do that alright. The last one is wear out where you know, but again let us say I won is I am asked to run 40 kilometers, but I can run a full marathon I know I can do it. But then I am asked you run a 40 kilometers you come back rest for 5 minutes again run 40 kilometers will I be able to do that? No way.

So, then I am going to wear out beyond a point in this case what happens therefore, is due to this repetitive stressing my capability my strength comes down I can no longer run a marathon alright. And even whether can I run a 10 k that also is doubtful under in my current state right a cricket team can play for 5 days most test cricketers have their stamina.

But if I ask that ask somebody to play a 5; 5 day test again start tomorrow play another 5 day test do you think beyond the third fourth test; they will be able they will have the capability or if I ask them though actually this is an 8; 8 innings test match you have to bat for you have to play for 10 days continuously not possible right; so, that is what it is ok.

(Refer Slide Time: 18:01)



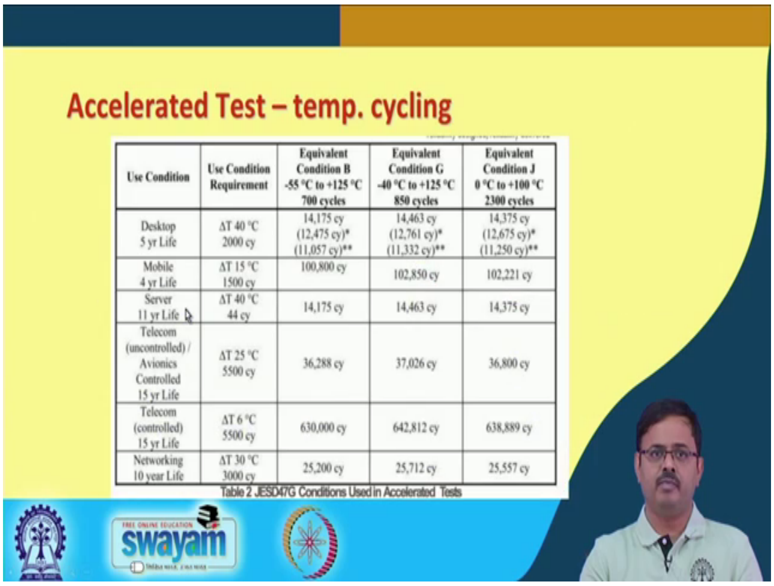
So, I hope and I hope I made it clear as to what is over stress and what is wear out right. So, now if we talk about this over stress condition which is what accelerated degradation testing is all about then we talk about something called an acceleration factor. So, what is the acceleration factor? So, let us say the y axis is the performance again since my bias towards thermal; let us say this is the thermal interface resistance thermal weighs degree c per what. I know I have put a grease and it will degrade then it goes to a number of cycles in this case number of operations alright.

So, in field use the performance degradation is going to be like this, but because now I am doing it in an adverse condition that is in the field my thermal interface material probably the maximum temperature; it will see is around 100 degrees, maybe 90 degrees nominal, but I am running it at 100 and 50 degrees right now inside an oven.

So, the degradation will be much faster; so, performance will go down ok. So, as you can see it is going to leach reach the failure limit much faster compared to what it will do under field use and I should have the capability to predict the field use from this data under the degradation test ok. So, the acceleration factor is given by the ratio between the times necessary to obtain a stated proportion of failures for two different sets of stress conditions involving the same failure mode and or mechanisms.

Now, what is this acceleration factor that is what that is; what the statistical analysis is about right. So, if under actual condition the failure time the number of cycles in this case or the time to failure is T a; the life is tau A and sorry tau N under normal field conditions N for normal then A is the acceleration accelerated time; so, it is much earlier. So, tau A is going to be much smaller than tau N; so, I have accelerated the failure by this ratio, so that is the acceleration factor clear.

(Refer Slide Time: 20:14)



Use Condition	Use Condition Requirement	Equivalent Condition B -55 °C to +125 °C 700 cycles	Equivalent Condition G -40 °C to +125 °C 850 cycles	Equivalent Condition J 0 °C to +100 °C 2300 cycles
Desktop 5 yr Life	ΔT 40 °C 2000 cy	14,175 cy (12,475 cy)* (11,057 cy)**	14,463 cy (12,761 cy)* (11,332 cy)**	14,375 cy (12,675 cy)* (11,250 cy)**
Mobile 4 yr Life	ΔT 15 °C 1500 cy	100,800 cy	102,850 cy	102,221 cy
Server 11 yr Life	ΔT 40 °C 44 cy	14,175 cy	14,463 cy	14,375 cy
Telecom (uncontrolled) / Avionics Controlled 15 yr Life	ΔT 25 °C 5500 cy	36,288 cy	37,026 cy	36,800 cy
Telecom (controlled) 15 yr Life	ΔT 6 °C 5500 cy	630,000 cy	642,812 cy	638,889 cy
Networking 10 year Life	ΔT 30 °C 3000 cy	25,200 cy	25,712 cy	25,557 cy

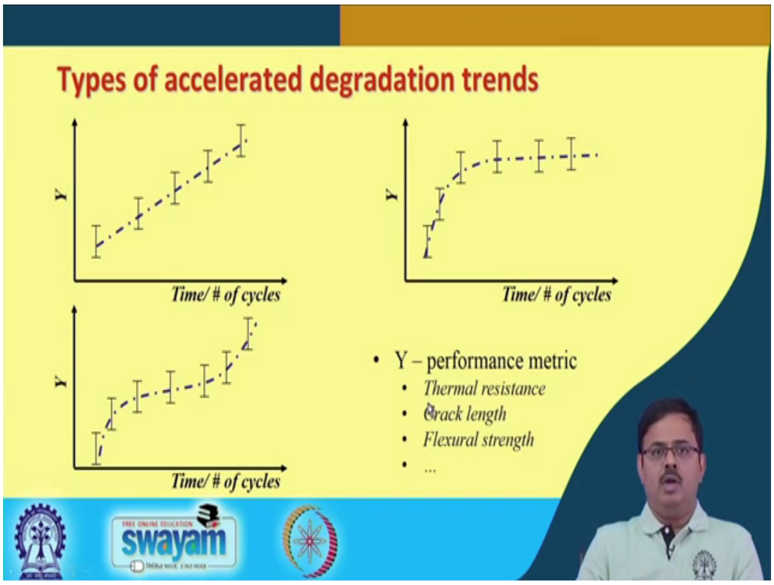
Table 2 JESD47G Conditions Used in Accelerated Tests

So, let us take this; this is a table from a JEDEC standard or JST standard sorry JESD and you see some of these condition this is just a table. But we are not going to go through every cell of this table let us take one of the desktop has a 5 year life and normal use condition is delta T of around 40 degree centigrade and it is supposed to withstand around 2000 cycles.

So, we are saying I am going to switch it on and switch it off for 2000 times actually it is much more, but let us under use conditions if it is 2000 cycles, then equivalent condition. If I take it let us say 700 cycles in a condition in a temperature cycling of minus 55 to plus 125 which is very harsh; normally it is going to see room temperature to room temperature plus 40, but here I am subjecting it to cycle 700 cycles from minus 55 to 125 ok. So, these are some of the standard conditions T C B, T CG, T C q, T CJ that temperature cycling right.

So, 700 cycles under minus 55 to 125 is actually 14175 cycles under this condition. So, if somebody can withstand 700 cycles. So, is way ahead of what it is supposed to do similarly minus 40 to 125 this was minus 55 this is minus 40. So, an 85 cycles there is equivalent to 14463 alright; 0 to 100 equivalent condition 14375 cycles; clear? So, similarly; so this is how it is acceleration factor to give you an idea.

(Refer Slide Time: 22:09)



So, now if you look at the degradation trends and let us say here in this case Y is the performance metric and an increase in Y means the it means that the product is degrading.

For example, thermal resistance is an example thermal resistance if that is what is my is why the performance metric. Then as the product degrades the thermal resistance goes up right it is therefore, for a given power dissipation and given ambient temperature the component temperatures will go up and eventually leading to failure alright.

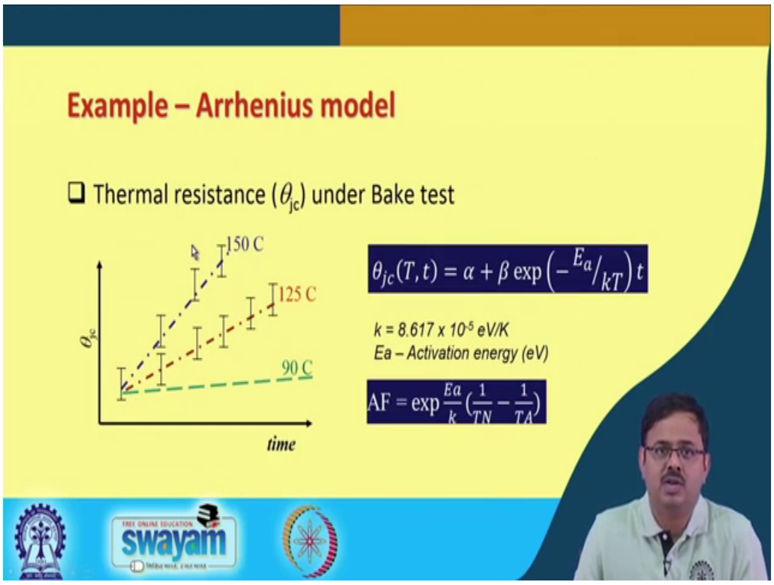
Again I want to mention here you will see that probably not so much in this course because we are not going to go to that level of depth, but I mean just this failure mechanism reliability itself can be a full fledged course. And when we look at the various modes etcetera, we will see temperature actually accounts for most of the failure modes ok; the mechanism is driven by temperature ok.

Whether you are talking about stress generated under fatigue solder joint fatigue we talked about why; why does it happen? Because of c t mismatch and c t why does it come into picture? Because there is a difference in temperature why does something burn because temperature went up. So, finally, a lot most of the failure modes if you look at the mechanism or at least a root cause it goes back to temperature alright.

So, coming back here; so why is my performance metric I can see that the time or the number of cycles along the degradation trend can be linear it can be saturation type. So, it degrades at a faster rate early in the life and then it degrades or it can be something else in this manner. What can be the performance metric as I say thermal resistance is one crack length is another.

For example, if there is a small crack in your solder joint because of fatigue then along with cycles the first the crack forms then it initiates and then it propagates and then finally, it goes from one end to other and where the circuit is not broken right. So, the crack length will propagate and we will see with number of cycles that crack length will increase flexural strength. On the other hand, in this case is not correct flexural stress probably is a better term ok, but you get an idea what I am talking about these are the different types of accelerator integration trends.

(Refer Slide Time: 24:41)



So, let us take an example of Arrhenius model thermal resistance under bake test is the example. So, let us say the operating condition is 90 degree C, but I am measuring the junction to case ambient thermal resistance and we see that along with time. So, let us say I put it under 4 hours, 8 hours 120, 100 hours, 120 hours, 150 hours this is the rate at which it degrades at 150 degrees this is the rate at which it degrades 125 degrees. So, this blue line and the red line which is 150 and 125 is the statistical data I have a number of samples which I have exposed to these conditions I take them out intermittently from the oven measure the thermal resistance and again put it back and this is the degradation trend that I get correct.

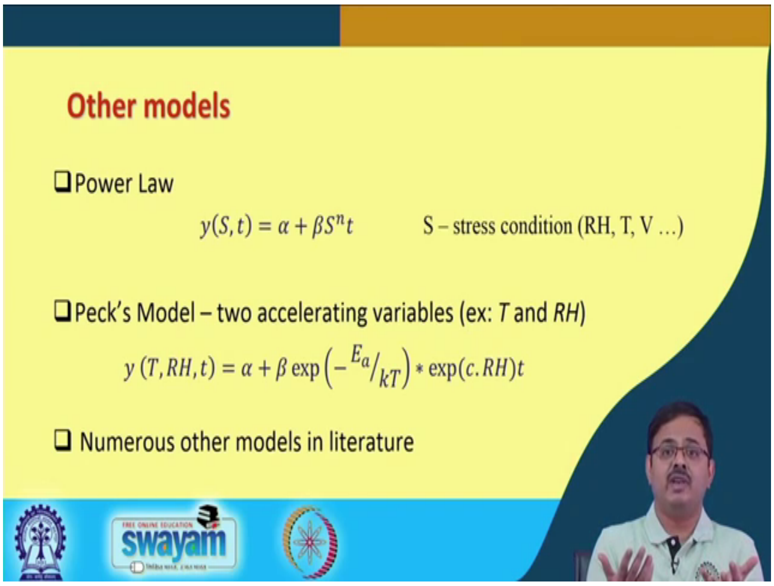
Now, from these two I need to predict what should be theta junction to case under this condition of 90 degree C. So, one of the ways to do that an example is an Arrhenius type of model where theta j c as a function of time and temperature T is small t is time capital T is temperature alpha plus beta alpha is of course, the junction resistance at the beginning of life right; which is this value plus beta times E to the power minus E a over k T times the time ok so, this is how it is ok.

So, now I have a set of how many unknowns do I have alpha is known of course, I will have it is not a big deal beta is unknown. So, then from these two sets of data do I get everything the two unknowns are beta and activation energy E a I have two sets of data I will get those.

And so, therefore, this equation is therefore, defined and so, now, if you say that what would be the condition what would be the time variation at 90 degrees I will put 90 over here or 90 plus 273 over here and I will get that you know at 90 degree C with time the juncture the theta of junction to case is going to degrade in this fashion ok. So, I am able to predict the normal life conditions.

So, therefore, what is going to be the acceleration factor acceleration factor is going to be this TN is the temperature under normal operating conditions TA is the temperature under accelerated operating conditions clear alright.

(Refer Slide Time: 27:16)



There are other types of models that are also there numerable innumerable types of models that are available in the literature power law. An example is the stress condition temperature it can be voltage it can be relative humidity whatever it is alpha plus beta to the S to the power n times T pecks model. Which includes two different you know two different stress conditions or accelerating variables hash that we talked about the harsh accelerated innovation test which was a combination of relative humidity and temperature right by the way hash stands for highly accelerated stress testing ok.

So, there what are the two variables that we are subjecting the products to or the components to one is elevated temperature and high relative humidity ok. So, there are two variables pecks model gives you that; of course, you need more number there are more number of you know more number of unknowns we have a beta you have a activation energy you have this c as well. So, you need three; three different sets of data three different data sets to predict the degradation with time using pecks model numerous other models are available in the literature alright.

So, that is all I wanted to cover I wanted to give you in this lecture; the whole concept of accelerated degradation testing alright. So, we first talked about what we talked about failure mode failure mechanism we saw a little bit of an example of stress in solder joint or other fatigue in solid joint we are going to talk about that a lot more in the next lecture,

And then we went to what is called accelerated degradation testing and how you use the test data to predict gradation under normal operating conditions ok. Thank you very much and in the next class when we come back we will wrap up our discussion reliability with focus on physics of failure testing physics of failure and physics of failure analysis.

Thank you very much.