Electronic Packaging and Manufacturing
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Lecture – 14
1st Level Interconnections – III

So, welcome back and we will continue with our discussion on flip chip bonding process. You recall that in the last lecture, we had discussed we had started the process of lip chip bonding. The first step as we saw in flip chip bonding was to was called the bumping of the die and we discussed that and today we will take off from there.

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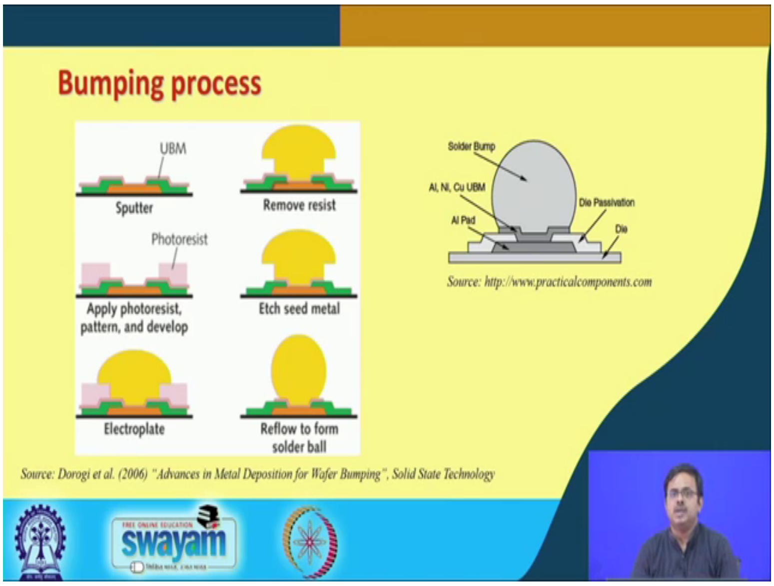

So, let us first recap a little bit the over here, this was the bumping process as you can see right, the bumping process again with the two step process the first one was under bump metallization as we saw here, where the aluminum connection pad was coated with a metallic layer.

And typically this is done if you recall by a sputter process a dry sputter process or an N aquit is called electroless nickel gold immersion ok. So, here in this case, we write sputter. So, this was which is the most common method and thereafter the next step was to form this. This solder ball or the solder bump and for that what is done is we first use a photo mask made of photoresist material so, that what happens is just the location, where I need to deposit the solder ball is exposed as is shown there ok. Thereafter electroplating is done by which the solder is kind of deposited and thereafter the photoresist is removed ok.

So, photoresist is not required so, we remove that and then we also do not need the UBM layer which was under the photoresist correct, because the UBM was required to form the connection to facilitate the connection of the solder to the aluminum connection pad on the silicon. So, therefore so that unnecessary UBM layer is also etched away. And finally, the solder is just reflowed in a dry oven. So, that it just melts for a short period of time and takes the shape of a solder of a ball or a bump using the due to the surface energy minimization ok, if you look at the right hand side. So, this is the different layers that we talked about, the silicon which is the die followed by the aluminum connection pad followed by the UBM layer and then finally, the solder bump ok.

So, now therefore after this process, I have a piece of silicon with an array of these solder bumps ok, but that is not enough. So, that is still on the die side, I need to now put it on the package which will provide me the connections to the other components or to the motherboard.

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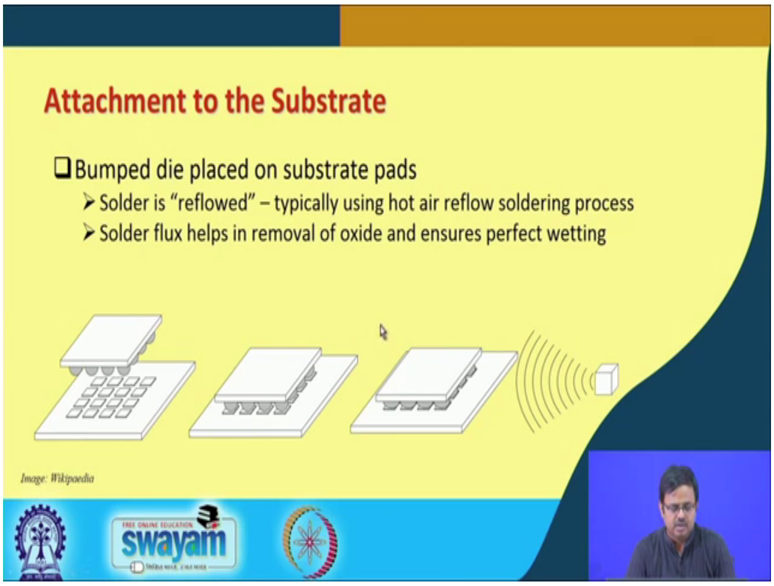

So, in order to do that recall flip chip, what we will do is the next one step is for attachment to the substrate ok. So, the first step is the solder balls which were deposited on top is inverted upside down flipped upside down the name flip chip comes from there. And then you have the substrate with corresponding landing pads or connection pads. So, the silicon is perfectly aligned with the substrate. So, that when it comes down the solder balls align and land right on top of its corresponding connection pad on the substrate which is shown here ok.

Now recall again, I want to mention here that if you go back to the last lecture, we talked about tape automated bonding. This process is quite common there I mean this is the process where this whether silicon is flipped over and put at the connection region of the tape automated bonding process, or on the film for the tape on which this connecting traces were there ok. So, this process is the same except now this is the substrate on which the solder balls come and land. Now, this is not enough even though they are now just slightly touching each other, this is not good enough for the electrical connections I need to do better.

So, next what is done is what we call the reflow of the solder. Solder is reflowed what does it mean? Reflow of the solder means that the solder, which had solidified before is again converted to the fluid state, where it can flow a bit. How is this done? So, again this is done in what is called a reflow oven soldering reflow soldering process. So, it is a hot air oven where this you know this bump dies sitting on the substrate is passed through this oven, where what happens is the solder again this and again when it passes through this oven the time temperature characteristic of this oven is very important ok. So, this bumped die on the substrate should remain inside the oven just that long so, that the solder balls just melts and forms a connection. And as it comes out as I solder as when it comes out the solder again solidifies back ok. So, therefore, what happens is the final structure is not a perfect you know spherical contact or a point contact, but it is kind of a surface contact. So, it is kind of a flattened at the sphere the solder ball is flattened, where the connection is made and that ensures better impedance less or other lesser impedance and lesser inductance ok. So, this reflow oven reflow process is very important the especially the time temperature characteristic.

See if it is heated for or if it is kept inside for a longer time, what will happen? The molten solder will flow and will connect with the neighboring solder pad and then there will be all kinds of short circuits shorting of these points we do not want that ok, but at the other hand if it is therefore, too less that it does not melt and you do not have a wetted joint that is the problem as well that is number 1. Number 2 is that is about the time and the temperature, you want to heat it to a point, where it just melts you do not want to really heat it very hard very high. So, that it melts immediately as it goes and neither we wanted to it so, low that it does not even melt it does not have enough fluidity ok.

And there is another thing that a solder flux is also deposited is also used other and this flux has seen number 1, or rather prevents the formation of salt of oxide and as well as ensures perfect wetting ok. Solder flux is you can even when you do this you know soldering iron that, we do on the on our lab tabletops. They are also use the flux right. So, the solder flux is important I think we all know why that is important so, but I just want to mention that here also in this process as well, it is a soldering process. So, therefore, the flux is or well be required ok.

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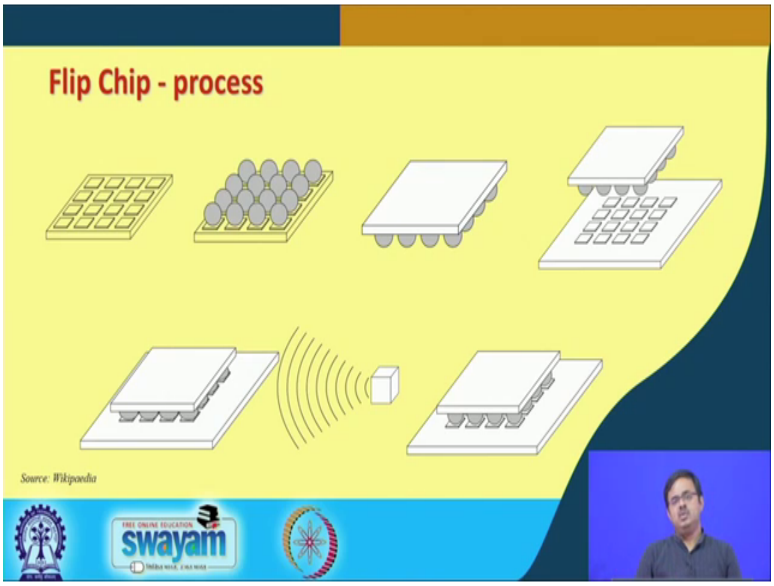

So, therefore, now let us just recap this picture that we saw about 2 lectures back of the flip chip process ok. And just go through this in our minds and see that have we looked into all this.

Step 1 you had the silicon with the connection pads and today and day before with an today and the lecture before, we discussed and we came to know that most of these connection pads on the silicon are aluminum and sometimes copper ok. So, this aluminum cannot be used for you know putting the connection of the solder balls and that is why you need under bump metallization followed by what we call the bumping of the die. So, that is step number 2, the second figure is after the die has been bumped figure 3 4 5 and 6 is the attachment to the substrate process, where the die is first flipped over then aligned perfectly with the substrate. So, that the landing pads the connection pads and the solder balls perfectly align and connect with each other.

And then now this is still a point contact right here, there they just touching each other where it's supposed to but that is not good enough, you need a better contact. So, in order to do that it is passed through a reflow oven where the solder melts just adequately. So, that the connect junction is wetted and then it is solidifies. So, now I have a better connection so, if I again try to sorry all right sorry. So, I was trying to draw something, but it looks like it is not possible here. So, now, what we are going to do is we will go to the third step of the flip chip bonding process. Step on 1 was bumping of the die, step number 2 was attachment to the substrate we covered those.

Now, this one is step number 3 and which is known as the epoxy underfill ok. Now what is epoxy underfill?

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It is a needle dispensed along underfill is actually an epoxy, which will go you see the spaces in between the solder balls ok. So, here the epoxy underfill will go and fill up all these spaces in this ball grid array ok. So, wherever whatever is the void or the space between 2 adjacent solder balls it is going to be filled up not by air, which is what it is now, but that air is going to be displaced by an epoxy ok. Now let us understand why.

So, why is the underfill required which is what I am showing in the bottom half of this slide the most important reason is as follows think about it. The substrate is a different material compared to silicon which is a die right. Now, what we are saying is we are going to take this assembly what we see over here and put it in an in a system ok. So, this is your semiconductor package, the microprocessor package that goes into your computer. Now, when you are using the computer or when you are using this electronic product, what happens? The product is going to be powered on, the product is going to be powered off ok, when it is powered on because of the current flowing through these various circuits. There will be heat that is generated due to joule heating I squared R and as a result of which the temperature will go up ok.

Now, as the temperature goes up what happens most materials expand right a material typically expands, when it is heated. Now to what extent material expands to the extent which is defined by its coefficient of thermal expansion ok. If you have a certain length l and you heat it up by a temperature delta t, then we know that the final length becomes l times 1 plus alpha delta t, where alpha is a coefficient of thermal expansion to be more correct coefficient of linear thermal expansion because we are talking about a 1 length right.

So now, the problem is what you have on top is silicon what you have on bottom is a substrate, which can be an organic substrate like an FR 4, it can be a ceramic substrate it can be some other material, but the problem is that the coefficient of thermal expansion of these two are going to be different. So, what does it mean? Therefore, it means that when it is heated up the silicon and the substrate are going to have different coefficients of sorry the silicon and substrate due to their different coefficients of thermal expansion are going to expand differentially one will expand more than the other.

And this is going to give rise to a lot of stresses, whether it is compressive or sorry are the shear stresses, whether it is inverter outward on these solder balls ok. And this can lead to failure of these solder joints with time ok. So, this differential expansion between the chip and the substrate has to be arrested. And therefore, in order to do that what is done is this epoxy material is injected or introduced into the spacing between the solder balls all right.

So, that is one of the main reasons of underfill using epoxy underfill, this is used to compensate for any thermal expansion difference between the chip and the substrate. So, typically the epoxy will have a coefficient thermal expansion, that lies between the chip and the substrate the epoxies shows in that way. And in mechanically locks together the chip and sub the substrate. So, the differences in thermal expansion do not break or damage the electrical connection of the bumps ok, it will itself take up a lot of these stresses that is induced, because of this differential expansion. So, that is a very very major function that the underfill epoxy performs, it is extremely critical from the point of view of reliability.

So, that is why remember when we started talking about flip chip, we were repeatedly seeing the occurrence of underfill epoxy, we kept on saying that yeah we will come back to this we will come back to this this is important, but as you can see that it is it is so important ok. So, that is the major reason why epoxy and refill is required. Now, it has some other as well other uses or benefits as well, it protects the bumps from moisture and or other environmental hazards.

So, now if I go back to the previous picture again these solder bumps are now subjected to atmosphere, atmospheric moisture subjected to corrosion, if it is your exposed let us say to hot and harsh environments ok. In military applications avionics so, in such deep sea deep sea drilling so, in such cases protecting the solder balls from the environmental, environmental conditions is important.

And the underfill epoxy does that and the third one is when the epoxy dries up, it forms a very rigid structure and gives therefore, gives mechanical strength and rigidity to this package ok, this whole assembly of the chip solder balls and the substrate this entire package that we have it get is a lot of mechanical strength, because of this underfill epoxy. You recall let us say your dendrite or erudite that we use as epoxy in our household, if you harden it what happens it becomes really stone hard once it is cured it becomes really hard so, this is that type of an epoxy ok.

Similarly this underfill epoxy also once it is cured it is like almost a very hard structure and that gives this package a lot of mechanical strength and rigidity ok. So, from reliability point of view in terms of protecting the solder joints from failure, due to differential expansion that being it is major function. It also protects the solder balls from environmental factors and as well as it provides additional mechanical strength to this entire assembly. So, therefore, underfill epoxy is very very important.

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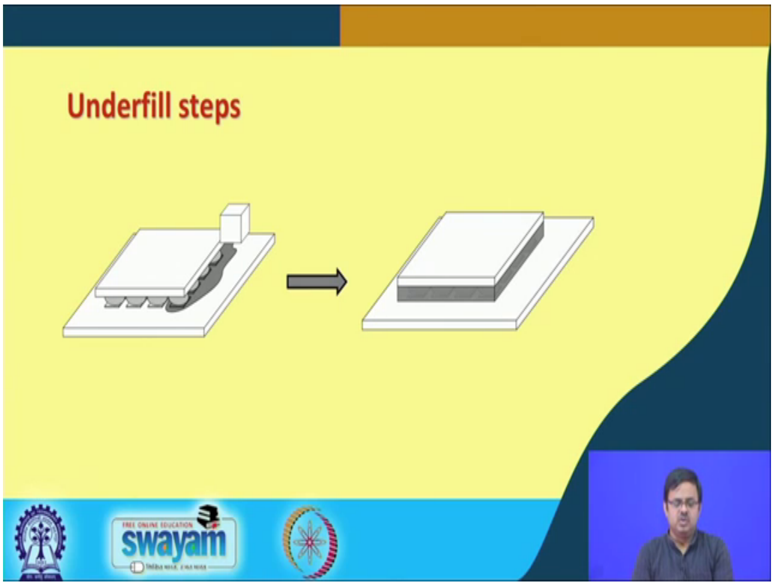

So, what are the steps you look at this picture? So, somehow if you put this epoxy it will go through and you know fill up the void spaces between these solder balls and finally. It will give you this structure and as you can see over here. I do not know how visible it is on the screen, but as you will see that there is a little bit of transparency. In this epoxy inside, you can see the solder ball on the connection pads and the epoxy is protecting all of them ok. So, how do we do this epoxy that is the next question ok.

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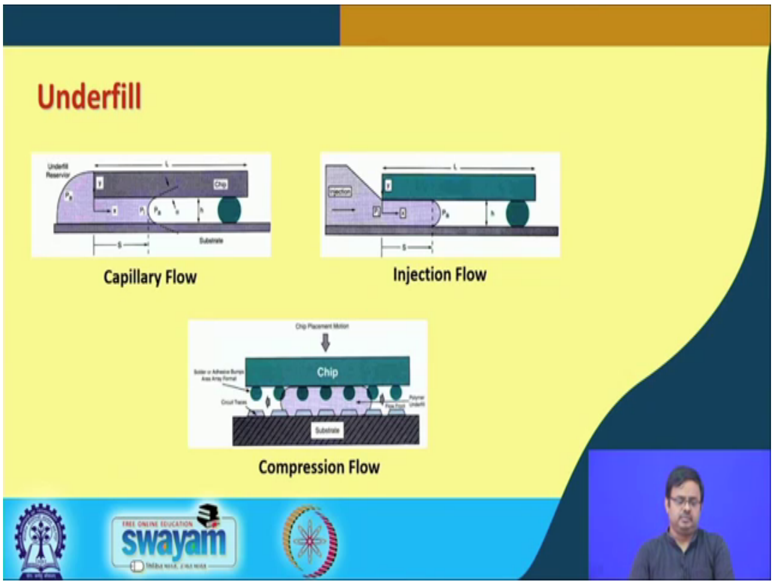

So, this underfill epoxy the flow of this underfill epoxy this topic itself has been a subject of research for many years ok. Once again I want to mention I think I mentioned it in the introductory lectures electronic packaging is such a vast multidisciplinary field, that each of these concepts that, we are talking about under bump metallization pumping method underfill epoxy even going back wire bonding. Later on we will see many other concepts, when we talk about motherboard the second level packaging.

See there are groups of researchers who have spent their entire careers studying one of these topics there is so much of richness in each of these. So, this underfill epoxy how will you these are pictures from the textbook from professor Route Amala, what do we see here the epoxy can be dispensed in 3 minutes by 3 methods primarily by 3 methods. The first one first one and the first and the second one these are both, you know the last process after the bomb to die has been attached to the substrate we have the first 2 process.

The first one is called capillary flow. So, which is similar to whatever was showing in this schematic where you put the epoxy on one side and at that point of course, it is in the liquid state and what happens is the epoxy just due to capillary action. Because of surface tension forces is going to go through and fill up all the voids ok. So, that is what we are calling capillary flow there is an underfill epoxy reservoir at some pressure and then because of surface tension surface tension driven flow the epoxy is just seeping in into the space between the chip and the substrate and slowly it will just seep in and fill up all these voids so, that is how it is done. Now, the second one is if the capillary flow and the capillary pressure drive driver is not enough, the capillary forces are not enough to let this epoxy flow from one end of the die to the other.

In such a case we use what is called an injection flow. So, you will have to take a needle with a syringe and then dispense it through the needle. So, that the epoxy now has got some initial momentum to flow through this gap and fill up all these voids ok, if it just happens by capillary good enough, but if it does not happen then you have to use some additional it is no longer a passive driven flow, you have to use some additional external energy you have to do some work done on the system, you have to do some work on the system or get some work done on the system. And you what you the one of the ways that it is done is using a syringe with a needle, which is used to dispense this epoxy. So, the epoxy actually comes out with an initial velocity and momentum and can therefore, travel through this space between the substrate and the chip.

And in the space in between the solder ball array and fill up the voids ok. And the third one is known as compression flow ok, is also known as something called no flow underfill. So, what is that this for a change is not the final process. So, earlier we are talking about pumping of the die attachment to the substrate underfill 1 2 3, but here the 2 the process 2 and 3 which is attachment of the bump die to the substrate and the underfill happens some simultaneously, how the way it is done is first you put this epoxy and then you compress it ok, then you bring the chip the bump chip on the substrate.

So, as the as you can see in this picture as the chip comes down, it kind of displaces the epoxy and to move towards the edges and finally, goes and forms the bond ok. Now, you must keep in mind; however, that this; however, runs a risk of having a little bit of this epoxy material which is non conducting electrically non conducting to stick between the solder ball and the connection pad on the substrate ok. So, this must be taken in to keep kept in mind and so, the the underfill material has to be chosen with the right viscosity right density and surface tension such that as the chip comes in and settles on the substrate and with a little bit of force, it is able to displace the entire epoxy.

And there is no layer even a thin layer of epoxy that stays between the solder ball and the pad and thereby you know breaks the electrical connection between the 2 all right. So, this is this compressible compression flow is another method where as we said the attachment to the substrate and the underfill epoxy happens simultaneously ok, but; however, in all these cases what we are saying is then underfill has a very major role, we talked about some of them ok. However, there is a fourth function which typically you should not be requiring, if your ball reader array process is very good, but still the fourth function is in case there is any issue, it clearly you know disconnects the adjacent electrically disconnects or the adjacent solder balls.

So, that even by mistake there is no short circuit between them ok. So, the underfill right now if you think about it is filling up this space between let us say this solder ball and the next one. So, let us say by any means it gets heated the solder melts somehow whatever it is, there will be no short circuit between these 2, because the epoxy after getting hachured and hardened is going to prevent that just in case ok.

Just to think it normally does not happen if your ball read array process is good enough and designed well enough it should not happen, but just in case if it happens the epoxy will come in the way ok, but the major three functions of epoxy remains the most important 1 is reducing the differential expansion due to temperature rise. Number 2 is protecting the solder balls from environmental factors like moisture. And number 3 giving mechanical rigidity to this entire assembly all right ok.

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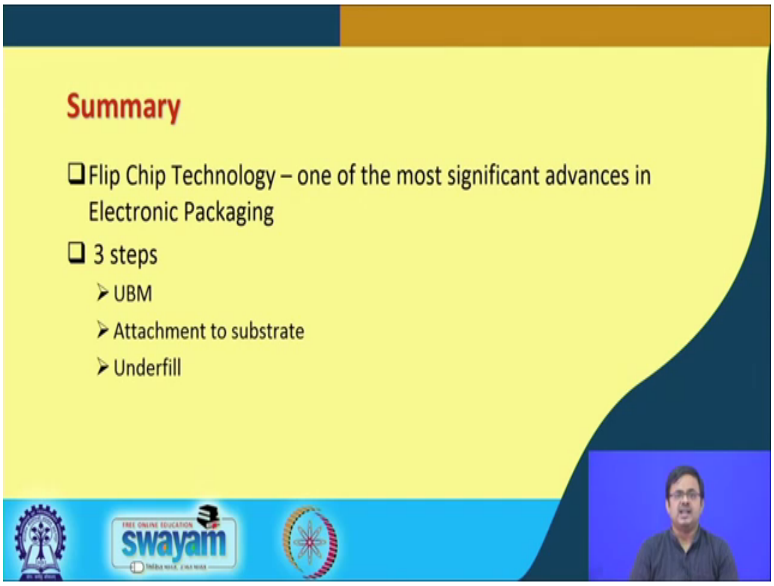

So, that kind of brings us to the end of flip chip technology is I would once again repeat, that it is one of the most significant advances or inventions in the history of electronic packaging ok. The 3 steps that we talked about it is actually bumping of the die not UBM, UBM is again part of bumping of the die. So, it is bumping of the die then attachment to the substrate and finally, underfill epoxy ok. And we discussed about all of them in especially the second and third processes in quite a bit of detail in this lecture ok.

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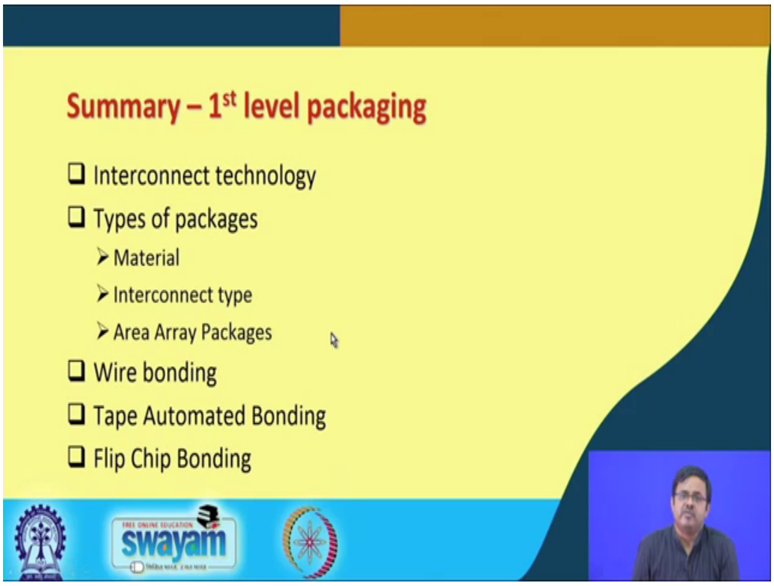

And that my friends also brings us to the end of first level packaging, let us just summarize the topics that we discussed under first level packaging of course, we started with the most basic definition of what is the chip what is the chip carrier and so, on and so forth. And then that let us to interconnect technologies what are the different types of leads leads the wires so on and so, forth. Then we look at types of packages we said that it can be you can classify packages by various means first is by through materials ceramic plastic organic.

Second interconnect types where we talked about the leads all right and we talked about different kinds of leads, you know through hole pinning whole surface mount and surface mount when using this jai leads gullwing leads so on and so forth ok. And then we talked about area array packages we started with pin grid array, we talked about ball grid array we also talked about land grid array ok. So, that was looking at different kinds of packages and then we looked at the manufacturing processes starting with wire bonding, then tape automated bonding and finally, flip chip bonding ok.

So, now, what do we have we have a silicon we have a good knowledge after all these discussions on first level packaging, we ended up with we are we have ended up with a piece of silicon with all the circuitry and now connected to a substrate electrically connected and functionally collected to a substrate. The substrate eventually is now going to lead to the next level where it is going to go to the motherboard, but then also keep in mind that the flip chip interconnect technology, also enables you to get rid of this substrate completely and bond the silicon die directly on the motherboard which is also known as chip on board ok, that is also first level packaging except that the substrate is not there ok. So, when we come back in the next lecture or the in probably the next couple of weeks or next one week at least, we are going to talk about what is second level packaging ok, thank you very much and till the next lecture have a good one.

Thank you.