Electronic Packaging and Manufacturing.

Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 11
Flip Chip Technology

Welcome back friends, we will continue with our course on Electronic Packaging and Manufacturing. And today we are going to discuss a very very important and critical concept which is known as Flip Chip Technology ok.

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CONCEPTS COVERED

Concepts Covered:

❑ Flip Chip Technology

❑ 1^{st} Level Interconnections

So, we will take off from our interconnections the 1st level packaging and today we will introduce you to or we will get introduced to flip chip technology. And then we will talk a little bit about 1st level interconnections and this will continue to the next lecture as well as well as a I think next as well as the following one all right.

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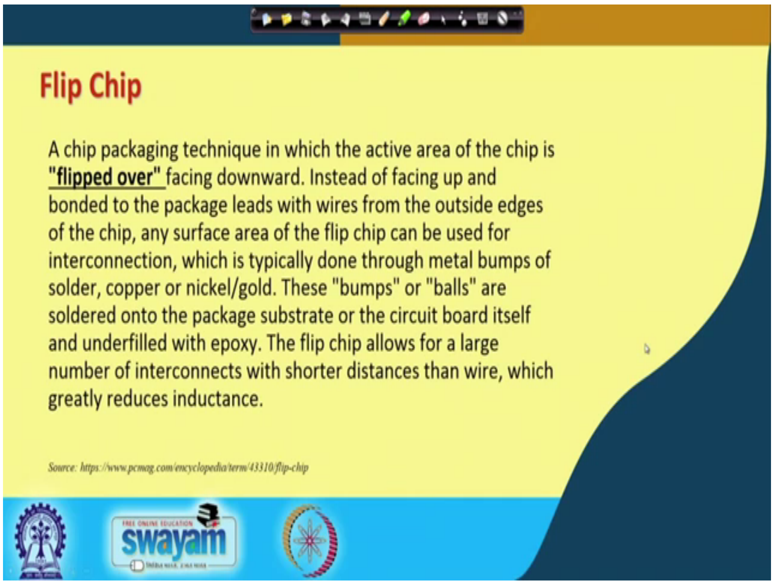

Flip Chip

A chip packaging technique in which the active area of the chip is **"flipped over"** facing downward. Instead of facing up and bonded to the package leads with wires from the outside edges of the chip, any surface area of the flip chip can be used for interconnection, which is typically done through metal bumps of solder, copper or nickel/gold. These "bumps" or "balls" are soldered onto the package substrate or the circuit board itself and underfilled with epoxy. The flip chip allows for a large number of interconnects with shorter distances than wire, which greatly reduces inductance.

Source: https://www.pcmag.com/encyclopedia/term/43310/flip-chip

So, if we go on move on to the next slide we will start with a definition of flip chip ok. And will spend a few minutes over on this one, trying to understand what each of these term mean ok. Let us first talk about what is a flip chip ok. This is definition from PC Mag and it says that a flip chip is a chip packaging technology or a technique in which the active area of the chip is flipped over facing downwards.

So, remember friends so, far what we said was or what we had discussed so, far is you have the piece of silicon and you have you know this connection points on the top surface and from where we were taking out these wire bonding or these wire bonds, and these wire bonds were in turn connected to these leads or interconnects right. Now, what we are saying is, know instead of these connection points being on the top I will flip the die over.

So, the connection points now are at the bottom. So, that is flip chip technology. So, instead of facing up and bonded to the packaged leads with wires from the outside edges which we have seen before, any surface area of the flip chip can be used for interconnection. Why because now you do not need to be constrained to the edges or close to the edges. Now, if I flip it over then the entire bottom surface can be used to form bonds with the substrate right.

So, the entire surface is now available and typically these connections are done by again remember we talked about ball grid array, which were solder balls in an array. So, now, at the silicon level itself you can have these ball grid array connections between the chip and the chip carrier or the substrate. So, these solder bumps or solder balls are soldered onto the package substrate or can be the circuit remember we talked about chip on board right when we are talking about package packaging efficiency. we also talked about a fact also I talked about a scenario where the silicon instead of being mounted on a chip carrier can be directly bonded on the motherboard.

So, it is a chip on board arrangement so, that is also possible. So, this flip chip bonding can happen on the substrate or the chip carrier or on the motherboard directly ok and under filled with epoxy, I will leave that term right now. So, this term we are not going to talk about at this point. So, under filled with epoxy let it be there in the definition, we will not elaborate on this at this point; we are going to talk about it later, why this under filling is required, why this epoxy is required we will talk about that ok.

The flip chip now allows for a large number of interconnections with shorter distances than wire very obvious and which greatly reduces inductance as well as impedance. So, once again let us read through this, a flip chip it is a chip packaging technique in which the active area of the chip which is the place from where you can have this connection points. The active area of the chip is flipped over facing downward. Instead of facing up and bonded to the package leaves with wires from the outside edges of the chip, any surface area of the flip chip can be used for interconnection which is typically done through metal bumps of solder copper or nickel gold.

Typically solder is most common, these bumps are balls are soldered onto the package substrate on the circuit board itself and under filled with epoxy again under filled with epoxy we are not discussing right now. The flip chip allows for a large number of interconnections with short distances and which leads to reduction in both inductance and impedance.

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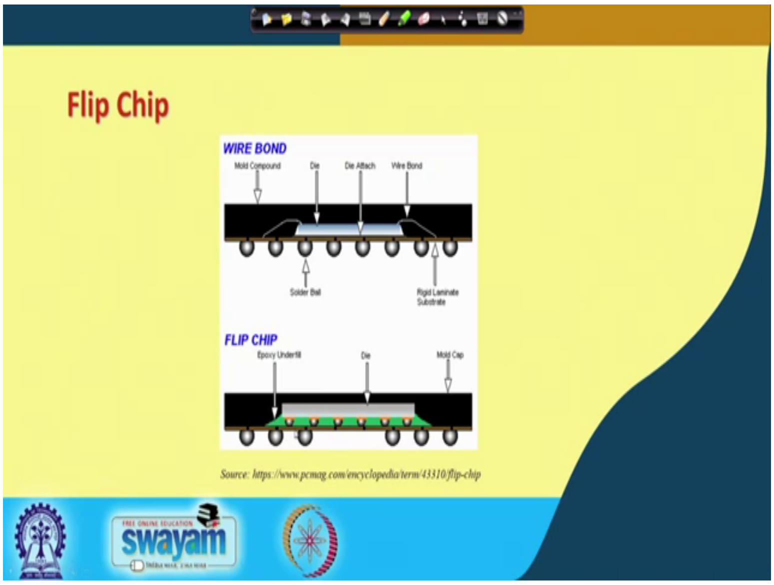

Flip Chip

Source: https://www.pcmag.com/encyclopedia/term/43310/flip-chip

So, let us look at some of these a schematic right now and see what we are trying to say. Again this is a schematic from PC Mag and I think this picture is courtesy from m core we talked about m core technologists before. See a typical wire bond with ball grid array right is shown at the top.

So, the you can see the piece of silicon or the chip is this one the active surface is at the top and so, you have wire bonding, that comes and connects to the connection pads on the chip carrier and then you have solder balls if it is a BGA package, it can be pins also if it is a PGA package it can be just pads if it is a land grid array or LGA package, but this is what it is? Inside the chip carrier the silicon was facing up with the interconnection points at the top surface. In the second case what is happening is this piece of silicon is flipped so, that these connection points now face downward ok.

And then using the solder bumps or solder balls, it is connected to the pads or the connection points on the substrate. So, you see the difference between these two, this picture lies (Refer Time: 06:44) illustrates that you also see this epoxy which is this denoted by this green compound over here, we are going to talk about it later why is this under fill epoxy under fill required.

So, we are not talking about that right now. Except the fact that keep in mind that once it is flip chip bonded, then you also have an epoxy, that fills in the gap between these between these inter connection points why we will talk about that later questions? So, let us move on right now to the next slide.

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Flip Chip - introduction

- ☐ Bare semiconductor chips are turned upside down and bonded directly into the motherboard or chip carrier
  - Connections are made through solder bumps and (solder wettable) pads
  - High I/O count
  - All connections can be made simultaneously
  - Top surface (back side of the chip is available for heat dissipation.
- ☐ First introduced by IBM in 1962.
  - Path breaking technology invention
  - Introduced for ceramic substrates (Solid Logic Technology)
  - Converted in 1970 to C4 (Controlled Collapse Chip Connection) for ICs
  - Initially used for peripheral packages but quickly progressed to area arrays

So, and talk a little bit about the introduction how it came into the into being. So, the first part is what we talked about just now again in bulletized form. Semiconductor chips are turned upside down and bonded directly onto the chip carrier or on to the motherboard.

All right, but what another thing that I want to point out over here is, there is more number of interconnection points because, the entire surface area is available. The other thing is these all these connections can be made simultaneously ok. We will talk about this more in more details when we talk about wire bonding as well as this flip chip bonding technology or how it is done, what is the of the fabrication techniques. But, what I want to say is in wire bonding this each of these bonds have to happen one by one sequentially.

It can be automated ok, but it still happens one after the other whereas, in flip chip what happens is, when you turn it upside down and you flow it through a through an oven all these connections happen play happen simultaneously ok. And the other thing that is important if we just go back to the previous slide is, now look at this even though I am showing that there is a molding compound in the cap do I need that anymore?

Do I need to protect it protect the chip anymore? The answer is no I do not. I mean not necessarily maybe I will I still will; but it is not necessary and in fact, in many of these you know especially for, I think right now for most of these computing packages the micro processors they do not have this plastic molding cap in fact, they are bare silicon. Because, now what happens is the delicate connections are happening on the underside and then you have this epoxy. So, it is well protected the topside is bare silicon no circuitry.

So, now the topside is available for heat dissipation. So, now, if you remove if you imagine that this molding cap or this black molding compound is not present, you have this bare silicon. So, a lot of heat is going to be generated in the circuitry over here at the bottom surface, silicon is a reasonably good conductor of heat. It is thermal conductivity is around 120 watt per meter Kelvin. So, the heat can be conducted efficiently in the upward direction as I am showing through this cursor.

And so, now this entire top surface of the silicon is available for heat dissipation. I can put a heat sink I can put a cold plate whatever is the requirement I can have a thermal solution directly bonded on the silicon or directly attached on to the silicon. So, that is where flip chip is an extremely and it was revolutionary at the time it came out it was revolutionary. Now, I would say most of the except for very low performance packages most of the packages that you see are flip chip.

So, flip chip was first introduced by IBM in 1962. IBM of course, I think I do not need to I think everybody knows about IBM their track record there and their contribution. So, it was a path breaking technology mentioned at that point 1962 remember ok. Introduced for ceramic substrates, at that point it was ceramic substrates for the high end packages where you know there was this driver pushed towards having more number of interconnections etcetera it was introduced.

That was the first instant in 1962, by the time we came to at the early 70s especially in 1970, it became more mature and at that point they used to name it as the flip chip name came I do not know when it came, but at that point it was called C 4 and the C 4 was every beta. So, 4 Cs actually it is controlled collapse chip connection that is what it was called controlled collapsed chip connection. So, initially when it came out it was initially used for peripheral packages.

So, the flip chip the bonds where only at the outer edges the four edges, but soon they figured out that you know why I do not need this area the central area to be vacant I can use it up so, why not. If I have a flip chip the entire area that I we are talking about before the entire area is available. So, it quickly progressed to area arise all right and also from the package point of view if you are still using a dual inline package or a quad flat pack package.

These were first used over there and later on when we talk about pin grid array or ball grid array; it quickly progressed to those packages as well all right. So, today once again I am repeating that most of the computing micro processors that we see whether it is a laptop desktop server, they are all flip chip bonded ok. So, flip chip on the substrate.

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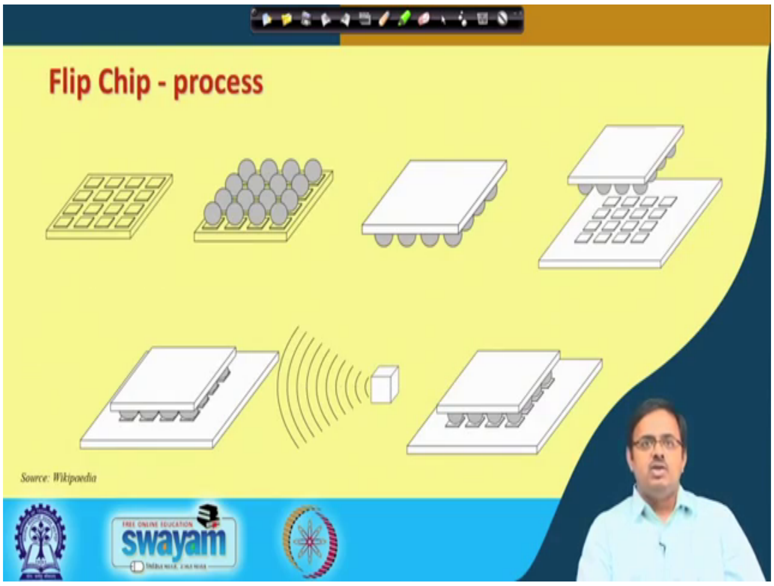

Flip Chip - process

Source: Wikipaedia

So, the next one actually is a sequence from Wikipedia. So, this is the underside of the sorry this is the piece of the chip or the microprocessor and these are all the connection points on top.

So, next what we do? We attach these solder bumps or solder balls on those packages sorry on those connection points on this up on the on this chip and that is shown by the second figure. And the next is the flip chip these connections are on the top flip it so, that these solder balls as you can see in the third picture they are all on the bottom surface they are all on this bottom surface.

So, that is what the name flip chip comes into picture it is flipped over ok. Now, once we do that then what happens? You have then this is the chip and this is the chip carrier or the substrate and the substrate will have corresponding pads or the interconnection points. So, over there what happens is we have to perfectly align them so, that they the pads and the solder bumps are directly completely aligned with each other. So, when we put the flip chip on the substrate, they are perfectly in contact.

But now that is not enough now the connection has to be made it is a solder ball and the solder pad it is touching, but that is not enough. So, then what happens is, there is some process some sort of energy you can think of it that you pass it through an oven or somewhere, where what happens this solder will melt just a bit so, that these connections are made.

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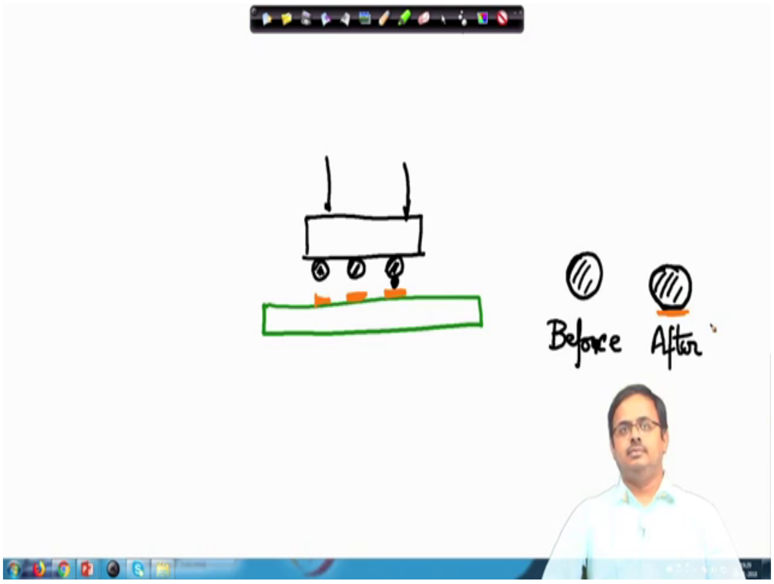

So, in such a scenario what happens is, if I draw. So, if this was my substrate sorry my chip, with the solder ball and then this would have been my motherboard and I am exaggerating with corresponding pads. Now, what happens is when we bring them together on top of that then what happens is, then this solder over here it will just melt and form the connection over here.

So, therefore, now later once the connection is made, the solder ball is no longer a sphere like this, this is before what it becomes is now like this and then on the bottom we will have this connection agree? So, this is what it is. So, this is after let me write that down this is after all right. So, let us go back and this is what we were talking about. So, I will just leave it for a few minutes for a few seconds now, for you to just look at this picture once more and make sure that you understand the process.

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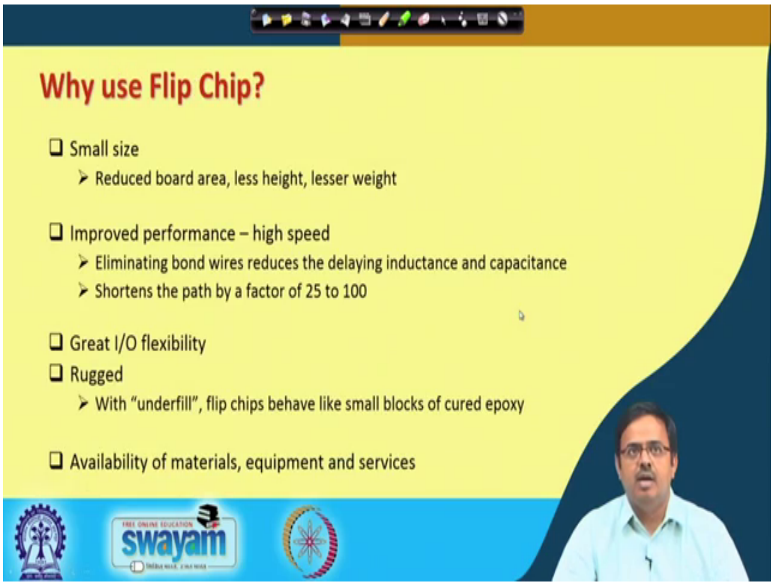

Why use Flip Chip?

- ☐ Small size
  - Reduced board area, less height, lesser weight
- ☐ Improved performance – high speed
  - Eliminating bond wires reduces the delaying inductance and capacitance
  - Shortens the path by a factor of 25 to 100
- ☐ Great I/O flexibility
- ☐ Rugged
  - With "underfill", flip chips behave like small blocks of cured epoxy
- ☐ Availability of materials, equipment and services

So, why you slip chip we already talked about some of those it is a small size. So, now, you can have a large number of interconnections over us because the entire area is available right now right. So, if you have certain n number of interconnections provided that your IC technology allows you to do that, you can miniaturize it that is one. So, reduced area lesser height lesser weight agree improve performance high speed why? Because, your electrical routing paths become so much shorter so, lower impedance lower inductance.

Shortens a path by a factor of 25 to 100 depending on what was the size of the your wire bond and what is the size of your flip chip solder connections. Great I O flexibility in interconnect flexibility because you have so, much of area available for you know exactly because it is you no longer have to put the connection points right at the periphery from where you could draw out these wires, you can put it anywhere if you have an area you can put it anywhere so, that gives you the flexibility and then you flip it over right.

So, from the circuit point of view also it gives you a lot of flexibility. To the VLSI designer, it gives him a lot of flexibility in terms of placement of these features inside the silicon rugged with underfill the flip chips behave like small blocks of cured epoxy again we will come to this. Because, this underfill as you can see even though we have not discussed so far, it is so, important we already have had three mentions of this.

So, why is it so, important? We will talk about that when we discuss the bonding techniques in more details. And availability of materials equipment and services; well this is this as basically you know this is as of today because, even if we talk it was first invented in 62, it by the time it became very popular and mature it was 70’s. So, we are still talking about a technology which is close to 50 years old or rather more than 50 years old half a century old.

So, today it is therefore, it is expected that the technology has matured so far so much sorry that today there is an available abundance in terms of availability of materials equipment and services. So, it is not a it is not a surprise anymore ok. And the other thing that I wanted to say is which is not mentioned in this slide is the availability of the top area which is also called the back side of the silicon why back side? Because this is the front side where the circuitry and the connection points are.

You flip it over the back side now becomes exposed and this back side of the silicon is now available for placing my thermal solution, it is available for heat dissipation. Because, I no longer need to protect it any further; earlier I was using this chip carrier I was using a ceramic lid or a plastic molded compound molding compound, in order to protect these connections I no longer need to do that because it is on the underside and this underfill actually does that job.

So, there is no need to protect this entire piece of silicon anymore right. So, that is also a very big advantage and we are going to talk about it in mean great details, we are going to look at different types of thermal solutions available etcetera when we go to the thermal management side which will be towards the second half of this course all right.

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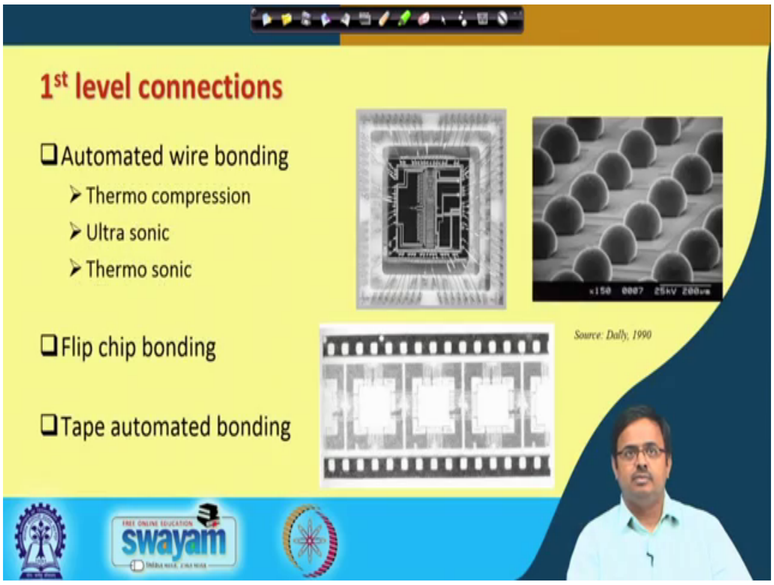

1st level connections

☐ Automated wire bonding
  - Thermo compression
  - Ultra sonic
  - Thermo sonic

☐ Flip chip bonding

☐ Tape automated bonding

Source: Dally, 1990

So, before we end this lecture, let us just guest get introduced to the different types of connections. We have talked about this is kind of a wrap up of what we have discussed over the last few lectures and also provides the lead in to the next section where we are going to talk about these processes.

So, far when we talked about you know this chip carrier all that stuff the 1st level connections, we talked about wire bonding right. We also talked about flip chip bonding and what we have not talked about so far is tape automated bonding; now how would this? Flip chip you know yeah their solder balls, but how do you make them? How do you have this solder balls connected on the silicon or for a ball grid array? How do you have this solder balls connected on the substrate? What is the process we are going to study that? Wire bonding yes there are connection points on the periphery of the chip and there are connection points their interconnection interconnect leads etcetera, but how do you make these connections ok?

What is the process, how do you even have these wire bonding, how do you know make this wire bonding happen? So, we are going to talk about that what are the different processes of automated wire bonding ok. And finally, we are also going to talk about a technology known as Tape Automated Bonding or TAB T A B all right.

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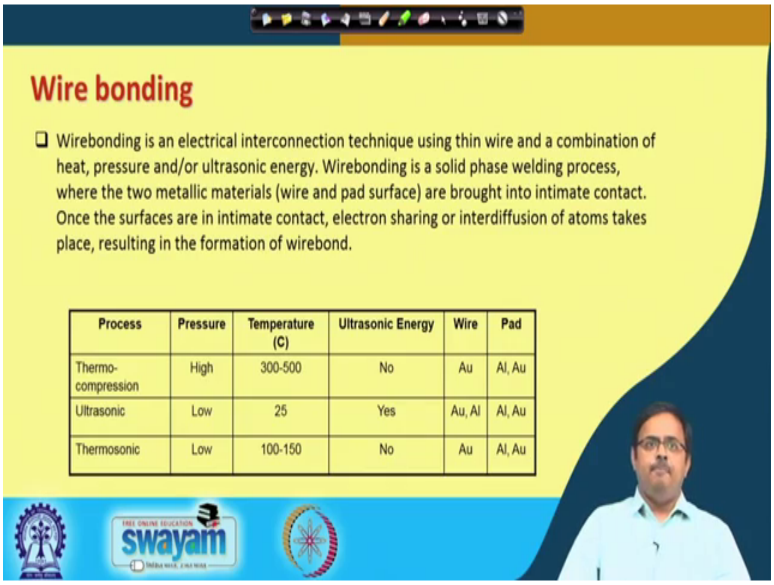

Wire bonding

- Wirebonding is an electrical interconnection technique using thin wire and a combination of heat, pressure and/or ultrasonic energy. Wirebonding is a solid phase welding process, where the two metallic materials (wire and pad surface) are brought into intimate contact. Once the surfaces are in intimate contact, electron sharing or interdiffusion of atoms takes place, resulting in the formation of wirebond.

Process	Pressure	Temperature (C)	Ultrasonic Energy	Wire	Pad
Thermo-compression	High	300-500	No	Au	Al, Au
Ultrasonic	Low	25	Yes	Au, Al	Al, Au
Thermosonic	Low	100-150	No	Au	Al, Au

So, what is wire bonding? So, wire bonding is an electrical connection technique using a thin wire or a company and a combination of heat pressure or ultrasonic energy. And it is a solid phase welding process where the two metallic materials, which is a wire and the pad surface are brought into intimate contact. And once the surfaces are in intimate contact electrons sharing or inter diffusion of atoms takes place resulting in the formation of wire bond ok.

And then there are three different types of processes of wire bonding in terms of what you talked about, when we sort say the combination of heat pressure and ultrasonic energy we are going to discuss those in more details in the next lecture and this table shows those.

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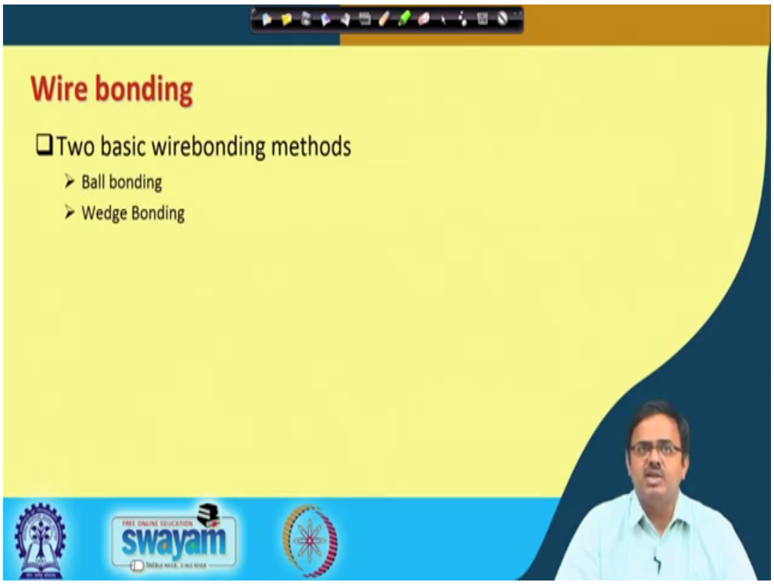

Wire bonding

- ☐ Two basic wirebonding methods
  - Ball bonding
  - Wedge Bonding

And in terms of how what is the process or method of having this wire bonding; there are two basic wire bonding methods which is called ball bonding and wedge bonding and these also we are going to talk about in details in the next lecture all right. So, again just to summarize, what we discussed today; today we discussed a very very important and critical and a groundbreaking invention in the field of electronic packaging, which is more than 50 years old right now, it is called flip chip technology.

It is abundantly used in most of the you know semiconductor chips that we have today, and we spoke about what is flip chip technology, what are it is advantages and how is it done. We did not get into the details of the fabrication techniques but how it is done we discussed about that right.

And thereafter what we did was we went into the 1st level interconnections and we talked about wire bonding, flip chip bonding and tape automated bonding we just mentioned about them and we saw the definition of wire bonding. So, this will lead us to the next lecture where we are going to talk about what is wire bonding, what are the different methods and so on and so forth. So, with that we will end today’s lecture and hopefully you enjoyed that and you learn something new, actually again I want to reiterate again and again flip chip technology, one of the most significant inventions in the history of electronic packaging.

Thank you very much, wire bonding in the next class.