Electronic Packaging and Manufacturing
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Lecture – 17
2nd Level Packaging: PCB- II

Welcome back to the course on Electronic Packaging and Manufacturing. So, in the last glass we had started our discussions on 2nd Level Packaging and we discussed about printed circuit boards or printed wiring boards ok. So, today what we will do is well continue from there, we had just discussed about multi layer motherboards. We will just do a recap of that and then go to circuit board materials and this is going to take us some time. So, that is the concept that we are going to cover today ok.

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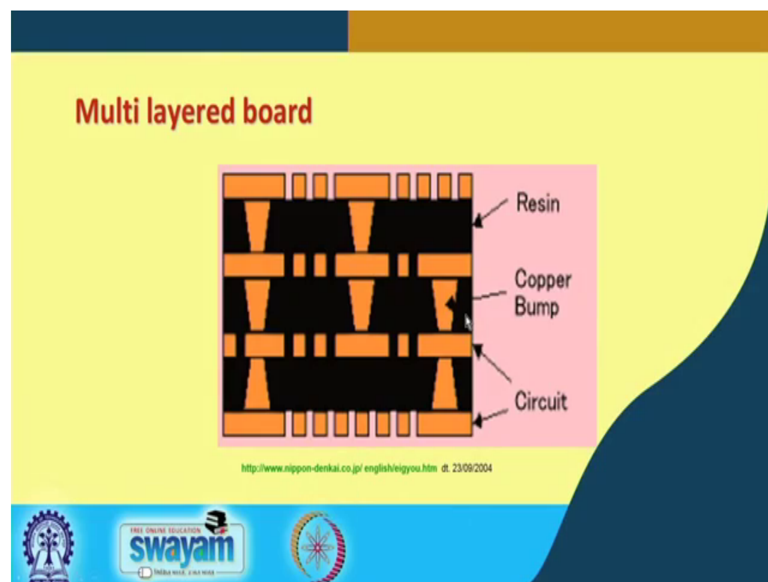

So, circuit board materials as you can see over here is what we are going to cover today. So, before that just a recap from last time we talked about multi layer boards and where we said that there are internal wiring traces. So, if you see over here, so this is a picture what you see here is there this is like a cross section of the motherboard; if you take this green thing that, you see a few millimeters. And, you actually take a cross section and look along the side under a microscope, this is what you should be able to see. You see here, these are internal layers, you can see this copper these are like wire, wire wiring

traces ok. Now this interconnection point probably needs to talk with this connection point or the wiring trace.

So, how is it being done? It is going to be done with this vias, which are small holes, but then connected by, filled in by this copper or conducting material ok. So, these are also sometimes called copper bumps alright and then you see traces at the top layer and the bottom layer. So, this is a circuit board 4 layer circuit board with as you can see 4 layers of wiring traces, the top and bottom and then 2 internal layers ok.

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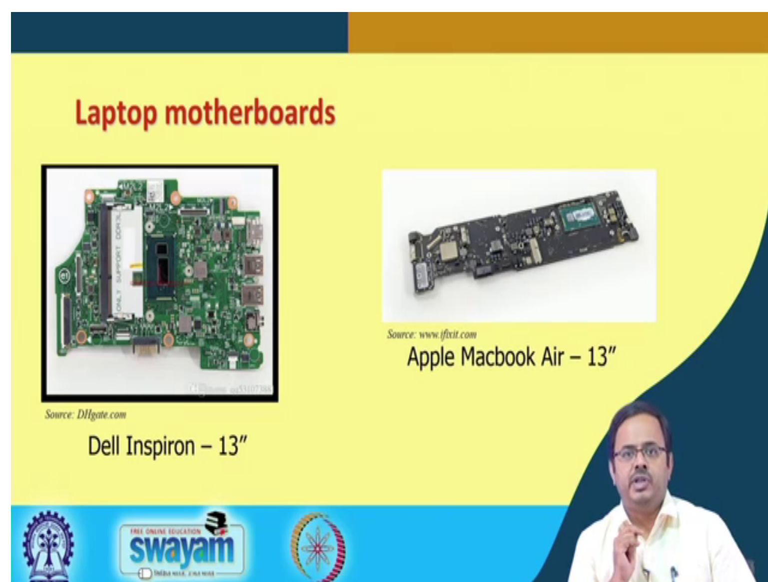

Now, one thing that I want to show you over here is an example of laptop motherboards ok. Now, look at these motherboards, these are both from 13 inch laptop computers. On the left you have Dell Inspiron and on the right you have an Apple Macbook Air ok. You can see all these so many materials densely packed, these are typically double sided I mean double sided motherboards in the sense components and both sides. But, one thing that you readily notice is the fact that the motherboard for the Apple computer is so much smaller compared to the Dell computer. And, the reason is the Apple motherboard has more layers compared to the motherboard on the left in the Dell product ok.

I do not know exactly what this is, but it was few years back it was common that most laptops had 6 layer motherboards whereas, the Apple laptops used to have 8 layers ok. So, what does this do? This enables or basically a motherboard or a circuit board in this case of course, I can use our motherboard with more number of layers wiring traces or

layers of wiring traces will enable us to put more number of components. And, connect them interconnect through the interconnection points or interconnect them properly over a much smaller real estate right.

So, that is what has happened whereas, if it is a motherboard with less number of wiring layers, then I need that many that much more of surface area or real estate or footprint area for all these connections to occur or to be to be included. So, basically what happens is in one case I need more surface area, in the other case well I can go vertically up. So, it is like you know if it is a multi storied building, I can have 10 families stay one on top of the other, but if it is a single storey house then I will need 10 such small houses, single storey houses.

So, that will take up a lot of floors, lot of space on the ground, a lot of land same thing over here right. So, you see the 2 now the point is however, nothing comes for free and as you keep increasing the number of layers in a motherboard its cost also goes up ok. So, it is quite evident. So, therefore, if you look at the other side, there was a time when we are talking about Netbooks even today also we have these smaller computers ok.

So, here which are not functionally, which are good enough for your day to day use, but otherwise in terms of performance speed and all which are they are not top of the line. So, in so these computers sometimes have motherboards that are 4 layer ok, lesser number of layers because you do not have so much of functionality, so many interconnection points and so on ok. The processors are not that powerful, not that many interconnects. So, in such cases you can go with lesser number of mother lesser number of layers in the circuit board ok. If you look at tablets smart phones these days probably, they will have primarily not too many layers inside them definitely not 6 or 8 ok.

So, here we see this and that gives you a feel of how having more number of layers or wiring layers inside the motherboard helps us to go smaller in size and sometimes even thinner in size ok. This Dell laptop for example, this motherboard is placed towards the backside if you look at your keyboard, it is more towards the top side or ok. So therefore, when you look from the side it is, it appears so thin because for most of the things it is just the keyboard and nothing else, keyboard in the bottom chassis and maybe some connecting wires or cables. Whereas, if you look at the Dell system, you will have the motherboard extent for a large extent or occupy a large part of this footprint area. And

therefore, this motherboard having components on both sides that need clearances etcetera; the laptop if you look from the side will also be thicker, the thickness will be higher ok.

So, just to give you a small example taking our taking a cue from our discussion on multi layer motherboards ok.

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So, let us now go with circuit board materials. So, what is the selection criterion for circuit board materials ok. Before we go into what materials to use, if I have to choose a material what are the considerations that I should keep in mind. And, number 1 cost is extremely important in this industry, it is a very very cost sensitive industry unless you are talking about military defense applications and all aerospace which are different, but consumer electronics is an extremely cost sensitive market ok. So, therefore, any means of reducing cost will be welcomed with open hands ok.

Alright, next electrical characteristics, what is the surface resistivity ok, you do not want leakage of current from the surface right. What is the dielectric constant? A low dielectric constant is desired because, that helps in signal processing and signal integrity ok. Then dissipation factor, what is the measure of leakage power or leakage current right. So, loss of leakage of power, that is the dissipation factor very very important for the circuit board material ok. So, that cost those are electrical characteristics very important.

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Circuit board materials

- Selection criteria
  - Mechanical properties
    - Flexural strength, modulus of elasticity
    - Dimensional stability, CTE
    - Glass transition temperature
    - Resistance to humidity
  - Physical properties
    - Corrosion and moisture resistant
    - Able to drill through
    - Thermal conductivity

But, so are mechanical properties. So, from mechanical properties; what do we see? What is the, what are the ones what are the desirable characteristics or the properties of importance. Structural point of view, modulus of elasticity and flexural strength ok, very important, then the dimensional stability ok; so these motherboards should be I should be able to design in various shapes, I should be able to have cutouts etcetera. And, the other thing that we need to keep in mind is CTE, the Coefficient of Thermal Expansion.

Here I take you back again to our discussion in first level packaging wherein flip chip bonding, we talked about the under fill epoxy. Remember what was the primary function of the under fill epoxy, it is because the solder balls that are connecting the silicon to the substrate which can by the way be a printed wiring board material. And, it can be an organic substrate have is undergoing a lot of thermally induced stresses because, of the mismatch in coefficient of thermal expansion between silicon and the substrate ok.

So, if I now attach a package, a substrate on the motherboard, the same consideration should be taken into account ok. Because as you power on your product, due to flow of current and all, there will be localized heating which is going to increase the temperature and these materials are going to expand. So, that coefficient of thermal expansion, the material has to be chosen. So, that the CTE is something that we can sustain, we can you know we can we can handle ok.

Glass transition temperature, that is the mechanical property Tg as we call it. So, that temperature is also important. Because, when you are fabricating the motherboard, during the fabrication process as well as during operation; we should not be exceeding the glass transition temperature of that material; otherwise there will be big-big change in physical properties or even chemical properties as well ok. And finally, extremely important under mechanical properties is resistance to humidity, moisture is a big enemy of electronic products and there will be moisture ingress you cannot help it.

For organic materials there will be for the regular motherboards that we see, for plastic molded packages there will be, for interconnect silicon, any of these epoxy materials it is bound to happen, moisture ingress is inevitable ok. If you want hermetic, hermetically sealed packages etcetera you have to go for ceramics, specialized ceramics, very very expensive ok. But, then even among the materials which are cost effective resistance to humidity is of paramount importance and we must keep that in mind when we select the material.

What else? Physical properties, corrosion and moisture resistance we talked about that especially moisture resistance. Able to drill through because many a times as we saw in that picture you were we are required to have these holes in the motherboard, plated through holes in the motherboard and that is important. And finally, thermal conductivity, it is a thermo physical property extremely important because from the point of view of heat dissipation ok.

The component is going to generate heat and that heat has to be conducted through the motherboard, a lot of that heat if I can conduct it through the motherboard then it will help me in maintaining the temperature below the acceptable limits ok. Even for flip chip packages, where the silicon is inverted or flipped over, so that the back side of the silicon is available for placement or positioning of a thermal solution, even then if some of the heat can be conducted through the motherboard and dissipated it helps us.

So, to this end thermal conductivity becomes very very important. And the thermal conductivity is going to be number 1 anisotropic because what is there? This is a laminate structure, you have copper traces, wiring traces and then you have this organic laminate made of glass cloth in a polymer binding ok.

So, these are in the form of laminates therefore, the inclined thermal conductivity and the out of plane normal plane thermal conductivity are going to be different. Normal plane in plane different thermal conductivities and we must keep that in mind also in areas where there is very dense circuitry the thermal conductivity will be more because you have more copper more traces over there ok.

So, knowledge of this thermal conductivity is very important especially, when we do thermal modeling and particularly for those packages which are not flip chip package, where you do not have a dedicated thermal solution on the backside of the silicon and you depend primarily on the conduction through the motherboard. Alright what next?

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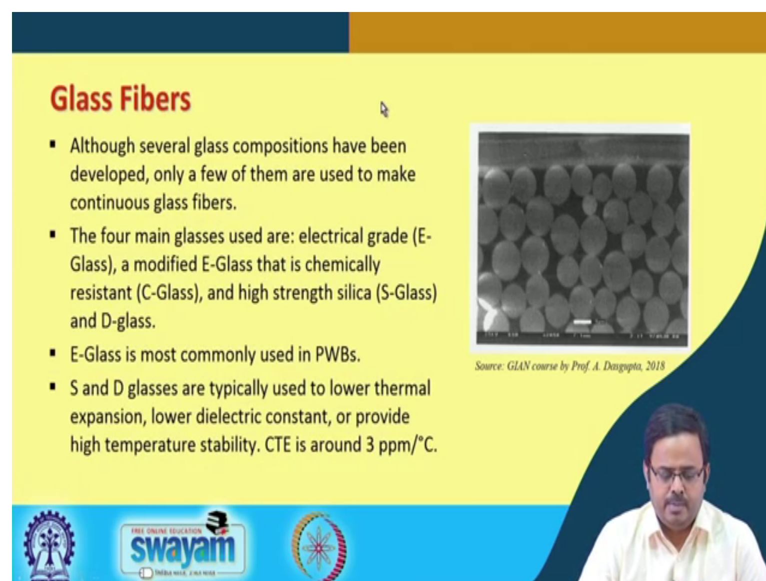

So, now let us look at some of these materials that we are talking about ok. So, glass fibers you see this, so glass fibers are there that are that make up you know the one of the major materials of the printed circuit board the laminate part.

So, the glass compositions have been several glass compositions have been looked at for making these the material that is used in circuit board, but probably right now there are only a few of them which are most popular. And the most popular one is called I mean they are glassified in a nomenclature is like a glass, B glass, C glass, D glass like that, so the one that is most commonly used in printed wiring boards is something called the e glass we are not going to get into the details of all these but, the glass material that is used is one formulation which is known as E glass ok.

These are all electrical trades. So, the 4 main glasses that have been that are used today are the electrical grid or E glass, something called a C glass which is an E glass which is chemically resistant ok. And then there is something called S glass which is high strength silica glass and then finally, something called D glass ok.

So, E C S and D these are the 4 major types of glass materials that are used as one of the components that are used or that goes into making of a motherboard. Remember we use glass cloth glass fibers. So, this is the glass that gets goes into making that cloth of the fiber ok. S and D glasses are also typically used to lower thermal expansion for lower dielectric constant or provide high temperature stability ok.

But E glass today is the most common and it is also and you know because of you know volume manufacturing it is also the most inexpensive among all of these but for specialized applications C D and D are also C S and D are also used ok.

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Fabrics

- Fabrics are planar structures consisting of yarns of fibers
- Yarns are interlaced at right angles to each other to form a fiber arrangement that determines the fabric structure, as shown in the first figure
- The second picture shows a cross-section of a typical fabric weave impregnated in epoxy resin.

Source: GIAN course by Prof. A. Dasgupta, 2018

And then remember we said this is we need glass cloth, so of course, this is a glass but then this glass has to go into a fabric material ok. So, this glass fibers are used to make these fabrics which are planar structures, you can see this crisscross structures on the left hand side, these yarns are interlaced at right angles to each other to form a fiber arrangement all right.

And then so, this is the glass cloth or glass fiber that we are talking about and then what did we say the laminate consists of this glass fiber in a polymer setting matrix ok, it is a binder, so that you see on the right hand side. This is a typical fabric weave impregnated in epoxy resin ok, that is the polymer material. So, that gives me my you know the basic motherboard structure or the circuit board structure. That green thing that you see is actually because of these. Alright, we will come to that more will come more come to that.

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Circuit board materials (cont..)

- Common PCB materials
  - FR1 (XXXP) –Unwoven paper fabric with phenolic resin. Low temperature, low cost material. Used mainly in single-layer unplated boards.
  - FR2 - Similar to XXXP except phenolic matrix has additives to make it fire resistant
  - FR4 –Woven glass fiber fabric in epoxy resin. Moderate temperature (T < 135°C), moderate cost, high reliability material. Used widely for double and multilayer plated boards.
    - High elastic modulus (3-4 MPa)
    - CTE closely matched to copper
    - Low *Tg*
    - Fire resistant

So, what are the common circuit board materials? So, we talked about the glass and then it goes into this polymer and finally, what you get these are named in terms of these are you know the nomenclature is something called F R followed by a number ok. So, F R stands for fire resistant or fire retardant and 1 of the 2 ok. So, F R so under the construction of or depending on the materials that have been used to form the laminate, the nomenclature happens in this form; the first one is F R 1, which is also sometimes called triple x p. This unwoven paper fabric with phenolic resin ok.

So, low temperature, low cost material used mainly in single layer un plated boards ok. F R 2, but here what happens is pretty much F R 1, but the phenolic matrix has some additives to make it fire resistant or rather more fire resistant and the say F R 2, F R 1 is also fire resistant, F R 2 is even more resistant to fire. So, here I my friends I want to just mention the importance of this term F R or fire resistant is very important for the

reliability point of view because short circuits can happen, overheating can happen. But, then this circuit board, because of its nature, resistance to fire sometimes prevents you know the whole system catching fire and leading to some catastrophic consequences, so F R the circuit board material prevents many a times saves us from such consequences ok.

Let us go to F R 4, which is the most commonly used material today F R 4 is woven glass fiber fabric in epoxy resin, moderate temperature moderate cost high reliability material, used widely today as I said it is the most commonly used for both double and multi layer plated loads and what are its properties, some of it I have written here, low glass transition temperature, fire resistant, CT closely matched to copper, this is important because the laminate is going to have copper traces in between.

So, if the CT's are very different then it is going to have a problem it may lead to buckling or bending because of differential expansions. So, CT is closely matched to copper and the elastic modulus is also quite high, 3 to 4 mega Pascal's alright.

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Circuit board materials (cont..)

- Common PCB materials
  - FR5 –High temperature, higher cost, tetra-functional epoxy version of FR4 (T < 185°C)
  - Polyimide –Glass (or quartz) –Very high temperature, high cost applications (T < 300°C)

And finally, they are also two of them F R 5, this is also high temperature, high cost, tetra functional epoxy version of F R 4 ok. This can be applicable this can be applied to temperature subject to temperatures below 185 degree centigrade.

So F R 5 definitely is more costly, used for specialized applications F R 4, as I said is most common and finally, if you want to go really high temperature applications polyamide glass or quartz. So, these are very specialized materials, but very high cost as well ok. So, let us quickly recap what we just saw, common PCB materials, fire resistant as we were talking about F R 1. So, this F R 1, F R 2, F R 4, F R 5 and finally, quads these are all glassified based on the materials that are used and when I say materials what are the materials, that goes into it number 1 is the glass fabric or the glass fibers and number 2 is the polymer matrix that binds them together ok.

So, based on this these materials the fire retardant boards or F R boards are glassified into F R 1, F R 2, F R 4, F R 5 and quartz and there are some other variants as well. But out of these what I want to say is F R 4 is the most common ok, that is most widely used with all these green circuit boards that you see when you open your laptop, computers, when you open your cell phones, when you open your I am even if you open your, you know let us say what is called you your USB drives, there also you will see a teeny-weeny circuit board ok.

So, all these are very important ok. F R 4 is woven glass fabric in epoxy resin. So, moderate temperature 135 centigrade, but if you look at most of the consumer electronic products the temperatures do not go beyond this; actually stays well below these temperatures ok. For example, if I talk about a computer, the silicon temperature which is the highest temperature should be kept typically scab below 100 degree C. So, the motherboard or any of the daughter cards of the circuit board temperature will be lower than that ok.

But, however we want to go a little higher because, many a times under you know under cases where it is abused or when it leads to failure the temperatures can overshoot ok, it can lead to overheating. If there is a short circuit or some of these interconnects get shorted, get broken bent or shorted or some whatever happens, so it can lead to some thermal runaway conditions where the temperature can go up ok.

So, that is why F R 4, 135 degree C for most of the common consumer electronic products that we use that is considered to be safe ok. It is moderate cost very important because as I kept saying this is an extremely cost sensitive industry. So, the cost has to be

kept in mind, it is high reliability material. So, it does not go bad unless it is abused all it lasts. So, that is why it is most widely used ok.

And again the other point I wanted to make again because from my thermal background is about the CTE match. You have these laminates and then you have these copper traces going through them the wiring traces. So, they are the coefficient of thermal expansions must be maintained close to each other because, otherwise what will happen is when they heat up and if there is a differential rate of expansion they will just bend and the motherboard will bend and that can lead to a lot of things.

Think about it, a motherboard is bending and then you have let us say ball grid array package on top of it, what will happen? It is going to give a lot of stress to the do the solder balls in the ball grid array package and some of those solder balls can crack and connections may be broken and it can lead to complete failure of the of your product ok. So, circuit mother once again printed circuit board extremely important and today what we talked about are the circuit board materials ok, we talked about basics of what goes into a circuit board. We talked about a laminate and we talked about wiring traces and then what we were looking at are the materials that are used to make these laminates.

So, in the next glass what we will do is now that we have the laminates and we know what the laminates are made of. In the next glass look at how we first of all manufacture this copper and then once I have this laminate and I have the copper, what do I do to bring them together. And what are the fabrication techniques that we use to finally, give shape to the final motherboard ok. So, with that I come to the end of this lecture. Thank you very much and when we come back, we will continue from here.

Thank you.