Electronic Packaging and Manufacturing
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Lecture - 39
Power Electronics Packaging

Welcome back and we are almost towards the end of our course on Electronic Packaging and Manufacturing. And, what we would do over the next couple of lectures is look at some specialized topics ok. As I say this is such a vast field and there are newer and newer challenges coming up almost every day. And thousands and thousands of engineers across various disciplines are working across different companies, different universities, different research labs all over the world trying to solve these problems and come up with new technologies ok. And, trying to keep up with the current trends in the electronics industry or even in the overall industry.

Because, more and more you know our life is getting more and more involved or integrated with electronic products right. You think about it, the car that we used to drive maybe 50 years back it was primarily mechanical maybe with a few electrical circuits for the lights the headlights and so on. Today automotive electronics itself is a field where thousands of people tens of thousands of people are working ok. Avionics on the other hand of course, aircrafts did have a lot of some electronics traditionally, but now the amount of electronics that goes into the aviation industry it is mind blowing ok.

Printing press that I think we all know we have seen printing press me as it we as in my generation maybe who were born in the 70's we are seen printing press completely mechanical ones. But you know the how the printing presses look today and how much involve we are how we have got involved or our printing process itself has had the impregnation of electronics inside it ok. So, what we are going to talk about today is one such field where the electronics is becoming so, important and that is energy ok.

So, we are going to talk about power electronics packaging and that is the topic of today's lecture. We are going to talk about first what is power electronics to start with then power electronic devices, what are the packaging challenges and then a summary ok.

So, these are just to give you a flavour of some very important fields and some very fields of current relevance where, there is a lot of concentrated research today ok. So, power electronics how do I define that?

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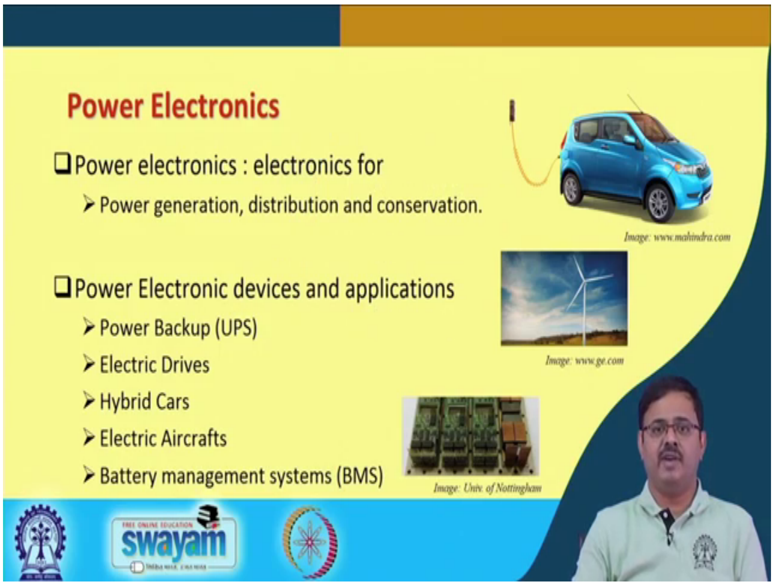

To put very simply its electronics that is used for power generation, distribution that also requires transmission and conservation. Let us think about it what is power generation, what is power generation? If you talk about you know the how do I generate power today from non from non new and renewable sources or non-conventional sources that is a wind that is a solar. You would be surprised and you would be its really mind blowing mind boggling to see how much of electronics is involved today.

Because, if you took about if you look at a photovoltaic panel it is not just enough to convert the solar energy to electrical energy which itself is what the photovoltaic cell does. But thereafter how do I store it, how do I transmit it, how do I transmit it intelligently right? Is it going to be a standalone solar system or is it something that is generating power and supplying to the grid, that comes in the distribution part.

Generation, distribution, conservation batteries the battery management system how much am I going draw out of that all this is power electronics. Look at some pictures that I have put over there, the first one is about the field of electric vehicles. We are talking about plug in the electric vehicles, we are talking about electric hybrid electric vehicles which runs on both electricity as well as fossil fuel or natural gas.

So, these are and if you look at an electric vehicle the electronics is involved in transmission, in the battery, in running the motor, controlling the motor, the motor drive plus running all auxil auxiliaries accessories alright. If you look at power backup right the UPS, we have it for our desktop the smaller versions that is electronics. Electric drives, hybrid cars, electric aircrafts no more aviation transmission fuel ok, battery management systems your battery is something that we look at for energy storage. Then how do I store it intelligently, how do I look at its health and draw the current during discharging phase intelligently that is controlled by electronics and smart electronics right. Wind turbines, in wind if you talk about wind energy wind turbine how do you control the storage of the wind energy ok.

The mechanical energy to electrical energy using the generator very important and how do you transmit it to the grid alright. So, power electronics is some is an is an area which is extremely important today and it has its own challenges. Because see so, far even though the concepts that we were discussing in this course are very generic. And, in the examples that we were drawing are kind of products that we use every day smart phones, tablets, laptops, desktops servers mostly in the computing world. But here the main differences, but over there is not much of power energy storage or distribution conservation or forget generation. All these have a power source either from the plug point in the wall socket or in a battery from a battery.

But, here in power electronics this is about generation conservation and distribution or transmission right. You see a power electronic module over here this is a converter University of Nottingham one of the very one of the universities across the world with a we you which is very strong in power electronics research both in the electronics part, packaging part reliability and thermal management part ok. They ran there the hub of a very large consortium in Europe alright.

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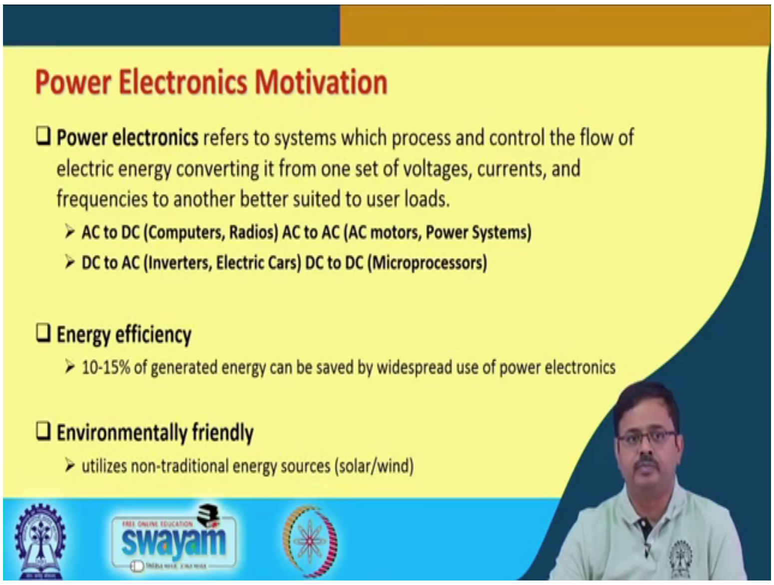

So therefore, what is the motivation? If you look at power electronics its everywhere it refers to systems which process and control the flow of electrical energy converting it from one set of voltages. So, this part we did not talk about I am going to come to that; voltage step up step down ok. One set of voltages currents and frequencies to another which is better suited for user loads. If you look at a power station the generation is in kilovolts right. The high tension wires that run over our fields you touch it will be electrocuted in an instant.

What comes to our wall sockets? 220 volts in India, that itself is quite high of course, you have seen some generation houses maybe or generate the generators are stored or these electric distribution panels are stored you will see danger 440 volts. So, there is a further step down to 220 volts from 440 before it reaches our household and it is still not safe; you touch it is going to be very very harmful even fatal in certain cases. In USA its 110 volts it can lead to electric shocks, but probably the impact is going to be less dangerous or probably not fatal ok. That is why they have it at 110 volts of course, their currents are higher right.

So, energy efficient so therefore, if you look at the power converters and inverters; AC to DC right or DC to AC correct. So, AC to DC you require where in computers, in radios, in cell phones when you charge a cell phone it is a DC output, but what comes out is a socket right; often we call it an adapter. If for people who are who are into music or at least are fond of music the synthesizers are the keyboards the Yamaha, the Korg, Roland. If you look at them the input that comes in which is the adapter is DC 12 volts DC right. So, that black box is actually converting the AC 220 volts from your from your plug point to the required DC volt that is required as input for your synthesizer to play alright.

AC to AC in AC motors power systems it is still AC, but I am stepping it down from kilovolts to 220 volts. DC to AC inverters where do you need it? Solar energy photovoltaic right you need an inverter, you store it in batteries then you need an inverter DC to DC micro processes ok. Step down transformers for example, so for example, I state few years in USA during my postgraduate studies, doctoral studies. And, and later I also work for a few years there before coming back to India. And, when I moved back I had several appliances that were bought from USA and I either they were good or they are some fond memories associated. For example, when I was a student I bought a microwave oven I still have that; I wanted to have that one piece of memory from my student days.

So, I still have it actually so, when we came back I wanted to run that now I do not run it anymore; I have another one. It has been 15 years since I came back, but if you think about it when we first came back and I wanted to run I wanted to run them, I needed a step down voltage transformer or a converter. Because, those are designed for 110 volts. If I plug it into our 220 volt supply they will just you know the conk off they will go bad. So, these are all powered electronic devices isn't it right ok. So, earlier the step down transformers would be actual transformers with windings primary secondary, but now you can step down and step up using IC's right.

So, will come to some of those we will talk about BJT's will got IGBTs all that alright, MOSFETS, field effect transistors. So, energy efficiency 10 to 15 percent of the generated energy can be saved by widespread use of power electronics. If you design it properly why power electronics is important because, it has this intelligence built in and you can you know the efficiency the recovery ultimate recovery, the losses can be minimized ultimate recovery can be maximized alright. An environment friendly because, it utilizes non-traditional it helps rather power electronics is essential for your wind turbines, for you for your solar power generation systems to work alright.

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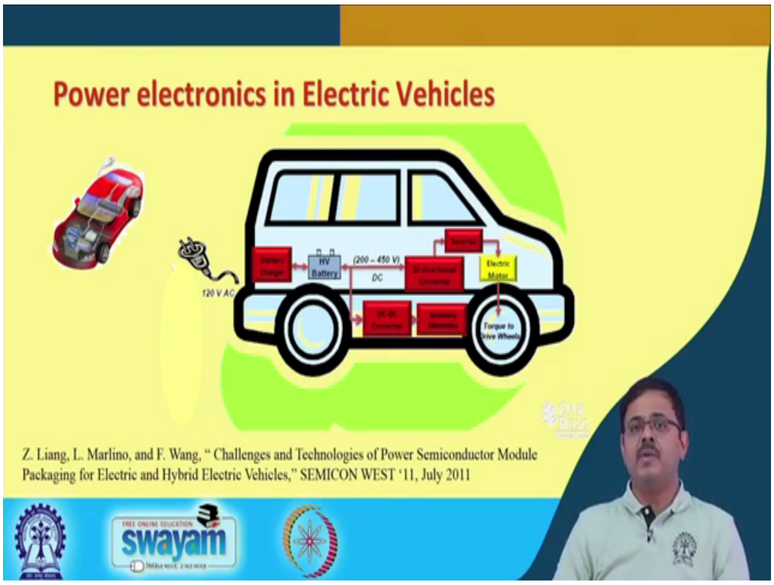

And this is becoming important because now there is so, much of focus on new and renewable energies not so, much and fossil fuels. So, as wind and solar becomes more and more important power electronics is also going to grow in importance; another example is power electronics in electric vehicles. So, you see inside an electric vehicle where all we need power electronics just as an example.

There is a battery and there is a battery charger and that is where you know the high voltage battery that we are going to use the battery charger. And, also the weight how we are going to control the current flow and the current draw and current flow during charging and discharging depends on what is called the Battery Management System: BMS. 120 volts AC or 100 volts AC probably in USA or some European countries.

For our case in our country if this has to become very common the charging stations has to be 220 volts AC ok. And, then in high voltage battery depend thing on the voltage you will have a converter right DC to DC converter. And, then on the other hand to run the accessories and then you will also need an inverter to run the electric motor because, what comes out of the battery is DC and what you need AC. So, you have an inverter then the electric motor which is giving you the transmission they talk to the wheels. So, everywhere these are power electronics, second water its an inverter it is a switch it is a battery management system; all that power electronics this is an example.

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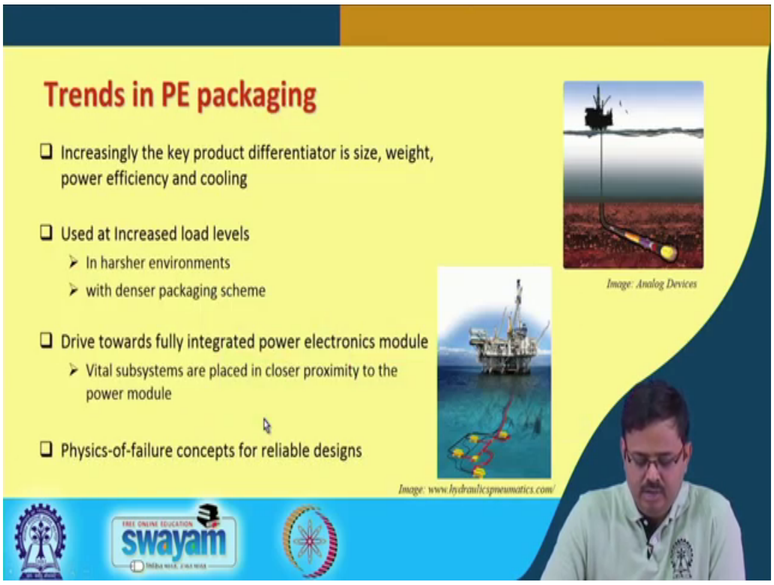

So, what are the trends in power electronic packaging; if I look at it its increasingly becoming the packaging and therefore, and that really and the packaging is so, important because that helps in its reliable operation under certain temperature conditions, under certain workloads, under certain environmental conditions. The packaging will determine how effectively and efficiently it works.

So, that is increasingly becoming the key product differentiator in size, in weight, in efficiency and cooling. If you look at a power electronic device from one vendor and from another one what is going to differentiate the two? These are the ones size, weight, efficiency and cooling which is related to that. Here I want to mention probably it is there in another slide in one of the later slides as well.

When we are talking about computing products what is rest of CPU power maybe 35 watts 50 watts, server 100 at most, cell phones tablets 1 to 5. When we come here we are talking about hundreds of watts to kilowatts, there is the power levels we are talking about that is being generated clear. And, there 10 to 15 percent of that is other losses and finally, that is what we have to dissipate you can understand how much you have to cool right. So, if you look at it use that increased load levels; so cooling becomes important the losses become more cooling becomes more important.

In harsh environments you look at the two examples: one is down hole you are drilling right, it is coming down several miles into the ground very harsh environment hot harsh environments or deep sea offshore exploration; what do we see there? Right, these are also high pressure may not be so, high temperature, but very high pressure over here and in the down hole there is a lot of dust lot of particulate matter ok. And, there is electronics at the tip of this probe or at the tip of this drill exploration drill that goes down ok. I have seen drilling of bore wells in Bangalore at my home where, I used to stay before this. They had cameras time and again we wanted to see that how is what is the level of water in that groundwater level over there.

If we go down this pipe and there will be a camera and you could see where the water is coming from at some point, when you go down you will see one crevice through which the water is coming its fascinating. But, imagine this is a wire that goes down several kilometres actually; if you are talking about some of the hilly areas in Bangalore you are actually drilling close to a kilometre to get water and that signal has to be transmitted.

So, the electronics the signal transmission the minimization of loss is very important. You have all kinds of sensors when you drill it temperature concentration, pressure and you name it right and denser packaging schemes. So, these are very very small and you need to have a lot of electronics in them. So, there is a drive towards fully integrated power electronics module; we will see what a power electronics module is.

But, what essentially it means is you have a main system and then you have a lot of subsystems and you want to bring them as close to each other as possible. So, again drive towards making more compact electronics at increased power levels very very challenging; minimization of losses and effective cooling. Newer materials, the switches silicon carbide, gallium nitride these are new materials that are being used. Better losses switching with lesser switching losses new materials, different temperature limits, thermal becomes important. Different materials the mechanical reliability becomes important and understanding those its no longer let in solder right alright. So, physics of failure concepts for reliable designs become very very important.

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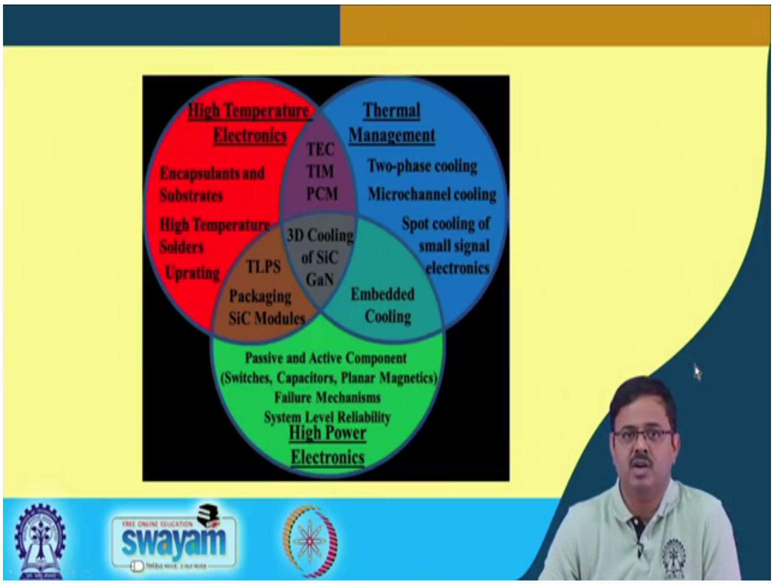

So, what we will do next is will use the remainder of this lecture to just look at some of the current challenges and then looking at some of these what are the important power electronic products that are being designed and packaged today. So, this is just a snapshot again from Professor Abijith Das Gupta's Gian course, I am sorry I forgot to mention I will do that I forgot to mention on the slide.

But I will do that, but I am verbally acknowledging his help here contribution here. So, you see if you look at these the 3 pillars of research today high temperature electronics, high power electronics and thermal management right. The cooling reduction of losses, the losses go up as temperatures goes up go up. If you keep the temperature within limits the losses will also come down and then the losses are the heat generation that must be dissipated.

So, all of these are kind of interrelated right; if you have losses they do not cool it effectively then the temperature goes up. As the temperature goes up the losses go up even further, the kind of thermal runaway and as a result temperature goes up even further. So, thermal runaway conditions clear; what I am trying to say is in other words the same power electronic module if under with a certain thermal solution it can run at 100 degree C then the losses is something l 1; let us say some l 1 percentage. And, I have another cooling solution which can cool it better and instead of 100, it is at 80 degree C.

Then you will see that the loss l 2 in the second case is actually in percentage is going to be less than l 1 alright.

So, you see some of these some of these terms over here we are not going to go through each of them; TEC, TIM if you look at the thermal management which is you will always see this bias when I talk about thermal TEC: Thermal Electric Coolers. We have talked about TIM: Thermal Interface Materials, PCM: Phase Change Material which is one of the thermal interface materials. So, these are enablers for high temp high temperature electronics. For high power electronics where I need to dissipate more power I really need very what should I say very very innovative cooling solutions embedded cooling 3D cooling; I am going to talk about a little bit about these.

Embedded cooling is actually inside the silicon itself or inside gallium nitride or inside the device itself you have the cooling passages; it is no longer this no longer the chip and then a cooling solution on top embedded inside. 3D cooling is when you have multiple layers. Let us say you have flow of a liquid through channels you have multiple layers of those inside the same device ok.

Spot cooling you need some area this one field effect transistor which is probably giving or an IGBT bipolar transistor insulated gate bipolar transistor which is generating a lot of heat in a very concentrated area; I need spot cooling of that what can I do right these are different challenges alright. So, high power electronics involves switches capacity high high power capacitors and we need to understand what is very important here system level reliability actually all of these; both in high temperature high power.

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So, let us look at some of these power electronic components or devices power converters or converters or inverters converter is actually changing the voltage from one value to another well. But, it is typically AC to AC or DC to DC inverter on the other hand we know is DC to AC ok. Now, these are used in a wide range of applications we saw some of those I mean both converters and inverters we saw in electric vehicles because, a battery is the source of energy. But then to run the motor you need to convert you need to rather invert DC to AC.

And, to run some of these low power auxiliaries inside the car some of the sensors whether it is your parking brake system or whether it is your music system the lights, the indicators, the odometer, the speedometer all these you need lower voltages. So, you need step down converters. So, power converter actually combines a number of non-power electronic packaging technologies; that can switch switching devices, control circuitry, sensors and large passive components; I means it is a passive components is like the capacitors the resistors these are passive components ok. So, power converter is going to have these components inside; power converter module is going to have these components alright.

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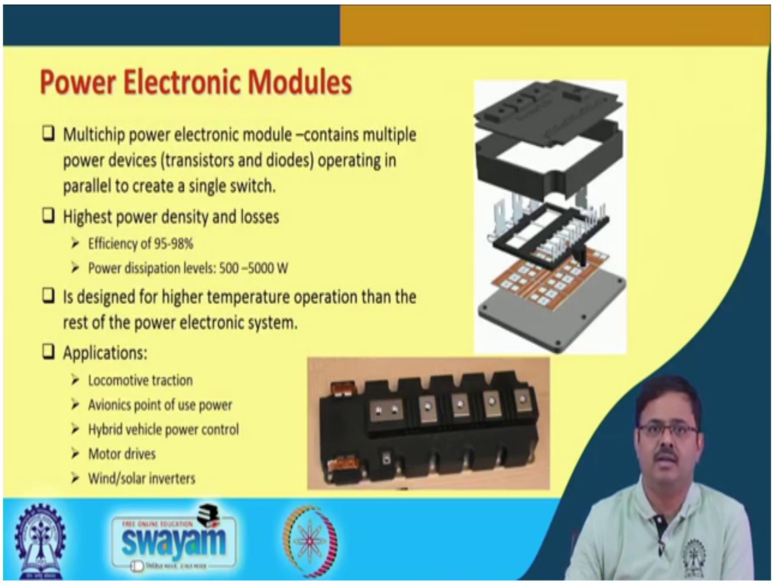

Power electronic modules sometimes these are used very interactive interchangeably, but power converter many people use it I myself use module in the last slide. But, actually strictly speaking if you talk about a module it is a Multi-Chip Module power electronic module: MCM we talked about this before right. It consists of multiple power devices transistors diodes etcetera operating in parallel to create a switch ok. So, I think the electrical engine is people electrical engineering backgrounds who probably know much more than me they will be able to appreciate this further better right. So, these have the highest power densities. So, most difficult to cool as well as losses ok.

The efficiency is about 95 to 98 percent alright. So, what I am trying to say the highest power sensors and probably this should be minimal losses 95 to 98 percent efficiency. So, the power dissipation levels can be from 500 to 5 kilowatts 500 watts to 5 kilowatts, compare that to some of the computing devices we are talking about. Single digit watts at most 100 watts and they can be designed for high temperature operation than the rest of the power electronic systems ok.

And these are some of the applications locomotive fraction ok, electric locomotives another one transportation technologies electric locomotives is very important. Avionics, hybrid vehicle power control, motor drives, wind or solar inverters ok; so, over here we see some of these power electronic modules.

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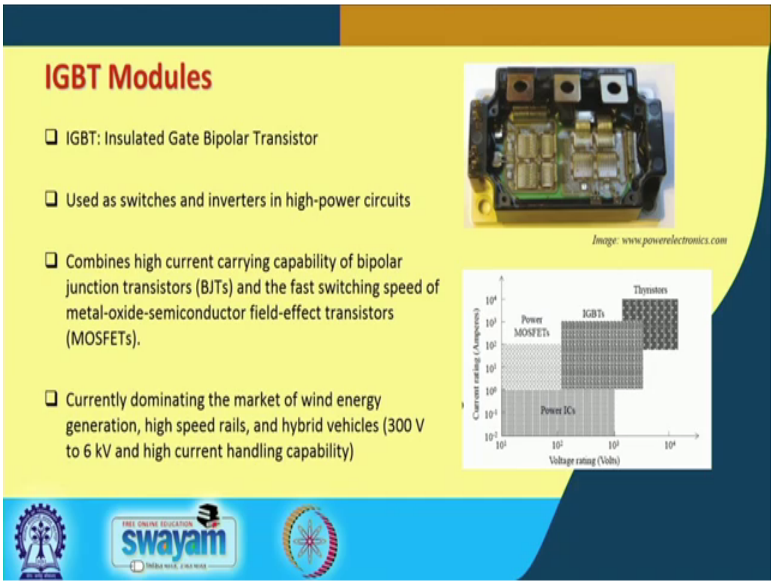

IGBT: Insulated Gate Bipolar Transistor that is what it stands for ok. So, it is used as switches and inverters in high power circuits. So, if you look at this plot at the bottom what you can see is the following; if you look at this current rating and this is the voltage rating. So, depending on where we are depending on the application that we are talking about you see that power IC is low power and voltage till a kilovolt you can use these. But however, as you go up you need either in voltage or current you need these other types of transistors.

MOSFETs stands for I think everybody with an electrical background will know and probably most other engineers will also know. MOSFET is Metal Oxide Semiconductor Field Effect Transistor, IGBT: Insulated Gate Bipolar Transistor by the way by when not asked so much, but maybe people who were like 5, 6, 5 to 7 years senior to us when they were studying electronics at that time it was BJT: Bipolar Junction Transistors today's almost not used; so very well used very rarely is primarily IGBTs or MOSFETs ok.

But BJTs had the characteristic of high current carrying capability and MOSFET on the other hand was very fast switching speeds right; IGBT kind of combines the best of both worlds alright. So, it is becoming very very important especially in wind energy generation high speed rails, hybrid vehicles very high current carrying capability you know the feature that was associated BJT along with high speeds and high voltage ratings. So, as you can see here high current high voltage this is where IGBT is fall. If you need to go further then you have to go for thyristors, power MOSFETs typically are higher current, but not so much of higher voltage ok. So, not so high power alright.

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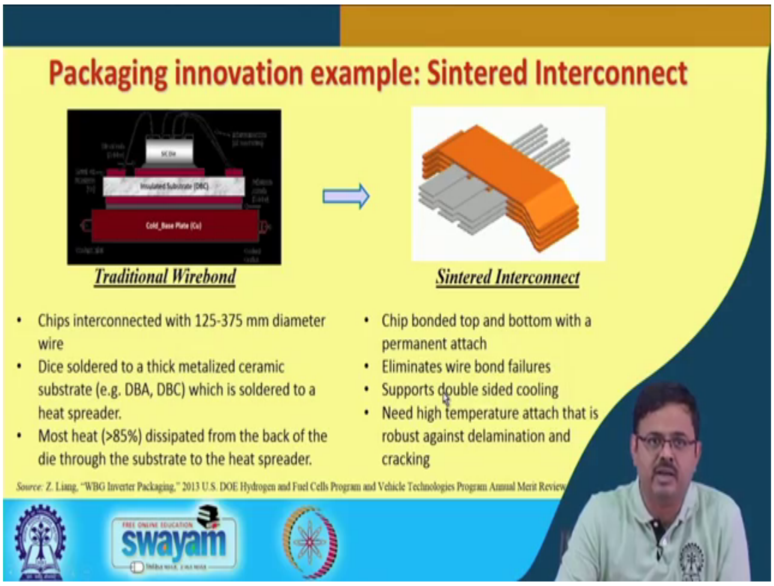

Ok So, power electronics is a different ballgame and so therefore, it has its own unique challenges for packaging. So, I am giving just an example this is a packaging innovation example for interconnects. So, you go from traditional wire bond to something called sintered interconnect because, here we are talking about we have already studied wire bond, wire bonding schemes. Sintered interconnect what happens is you can see these are more permanent type of attacks, the chip is bonded both in top and bottom with a permanent attach and you see this interconnections coming out these are not thin wires ok.

So, it eliminates the wire bond failures and it also supposed double sided cooling because you have this metallic surfaces both at the top and the bottom ok. You want to know more you can read this WBG into inverter packaging, I have listed the source over here. If you can get hold of this paper you can know more about this.

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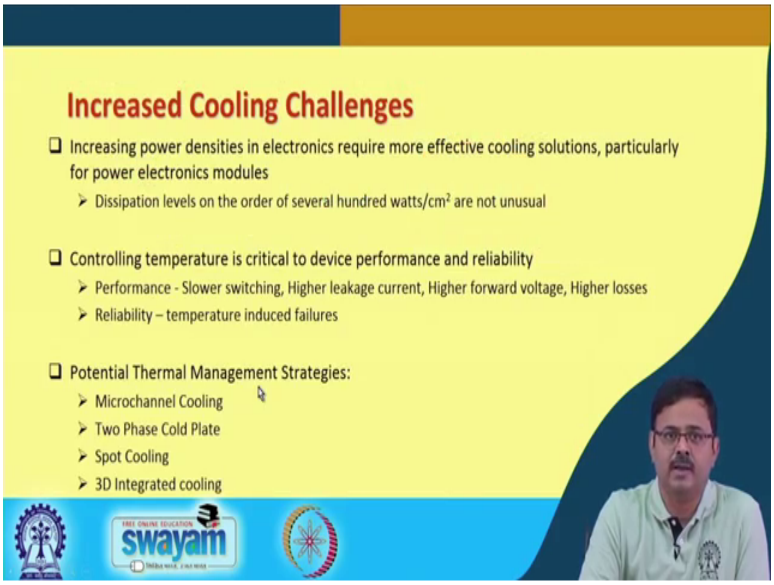

The other thing is about increased cooling challenges because, dissipations is of the order of several hundred watts per centimetre squared. It is no longer 30 watts per centimetre square, 50 watts per centimetre square with which itself we were struggling. So, many a times you know air cooling in that small area is no longer enough; you have to you have to resort to either very very large heat sinks or you have to go for remote cooling where, you use water or liquid to cool for the first level of cooling at that site and then cool that water using a radiator somewhere else ok. Because, a controlling the temperature is critical to its performance and reliability; we know that I do not think we need to talk about any further.

Performance: if you do not control the performance, if you do not control the temperature it will be slower switching, higher leakage current, higher losses and reliability of course, temperature induced failures we have all seen how important that is. So, potential thermal management strategies these are some of the things that are being researched currently; micro channel cooling. So, micro channel remember these are very small channels embedded inside typically embedded inside the device itself whether its silicon whether its gallium nitride silicon carbide. So, remember we were talking about Nusselt number and Nusselt number for laminar flow if you go back you will see it is a constant for flow through a channel; for laminar flow through internal laminar flow through a channel.

A Nusselt number is h d which is the hydraulic diameter h times hydraulic diameter over the conductivity of the fluid. So, now if you go to micro channels which is very small channels what happens the hydraulic diameter goes down, but Nusselt number is constant. Therefore, heat transfer coefficient has to go up because h d by k is constant. So, for micro channels you get very high heat transfer coefficients and heat transfer rates, but as I said nothing comes for free.

You reduce the size of the channels you get more heat transfer per unit area, you get more heat transfer coefficient. But, you get very high pressure drop as well right we have seen that large fins facing to smaller fins facing is force conversion, we are talking about heat sink and fan the operating point was shifting to the left because the system pressure drop was steeper or higher.

So, for a given pumping power if we are talking about micro channel with a liquid for a given pumping power we are going to get less flow through micro channels compared to larger channels alright. But, micro channel cooling especially embedded micro channel cooling is one two phase cold plate is no longer water coming and water go, but I need to use the high heat transfer coefficients for two phase flow when it is boiling.

Spot cooling I was saying in the last slide right or two so, slides before you may have an area where there is an increased power density; I need to cool that targeted cooling of that spot. And 3D integrated cooling, multiple layers of maybe channels cooling channels inside the same die stack. If you are going for 3D, it is also true for 3D packaging when we talked about 3D packaging before you can have multiple cooling channels through each of them, because you may not have a lot of real estate you may have to work go up vertically.

So, you go so, 3D integrated cooling for example, you go one way you turn around and come back the other way through two layers of channels ok. So, these are some of the examples of current trends in research on thermal management.

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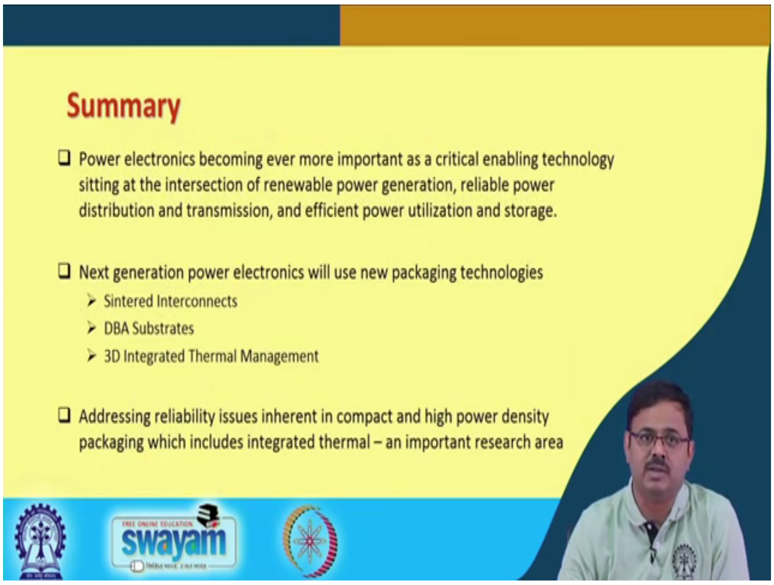

So, summarizing it power electronics is becoming very very important as a critical enabling technology and sitting at the intersection of renewal power generation, renewal power distribution and transmission and efficient power utilization and storage everything depends on power electronics.

And, with the thrust current thrust on energy especially renewable energy sources power electronics is only going to go more and more important; the growth of or the importance of power electronics is only going to grow with time ok. The next generation power electronics will use new packaging technologies, we already saw sintered interconnects as an example, 3D integrated thermal management, we talked about briefly DBA substrates. So, these are different types of substrates ok.

No longer FR 4, but some new ones newer materials newer characteristics newer properties and finally last, but not the least what we were discussing till the previous lecture reliability. See these are all new technologies we are coming up with, but do they perform reliability over reliably over time. Reliability issues inherent in compact and high power density packaging including thermal it is an important research area ok. So, that was just to give you a brief half an hour summary of something which is probably one of the hottest topics in electronics industry today which is power electronics ok. It is growing is growing at a rapid rate both in size and its importance ok.

So, this is an area also that many if you want to get into research in this in this field of electronic packaging power electronics probably today that is the area to get into. We have several groups over here at IIT Kharagpur who are who are working on not; so, much on packaging, but power electronic devices circuits.

And, it is important that as these electrical engineers innovate to come up with newer devices, newer modules the packaging engineers which involve experts from different fields come together and work together to develop commensurate packaging technologies that can enable these newer designs, these newer product designs as well as enable its performance its rather its reliable performance over its entire lifetime alright.

So, thank you very much and when we come back in the next lecture we will look at some other maybe a couple other important topics of current relevance ok.

Thank you very much.