Power Electronics with Wide Bandgap Devices
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Lecture-1
HEAT SINK - Continue

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Welcome to the course on Power Electronics with Wide Bandgap Devices. Today I will continue discussion about the Heat Sink. So, in the last lecture I have shown this particular circuit diagram. So, where this heat sink model is given.

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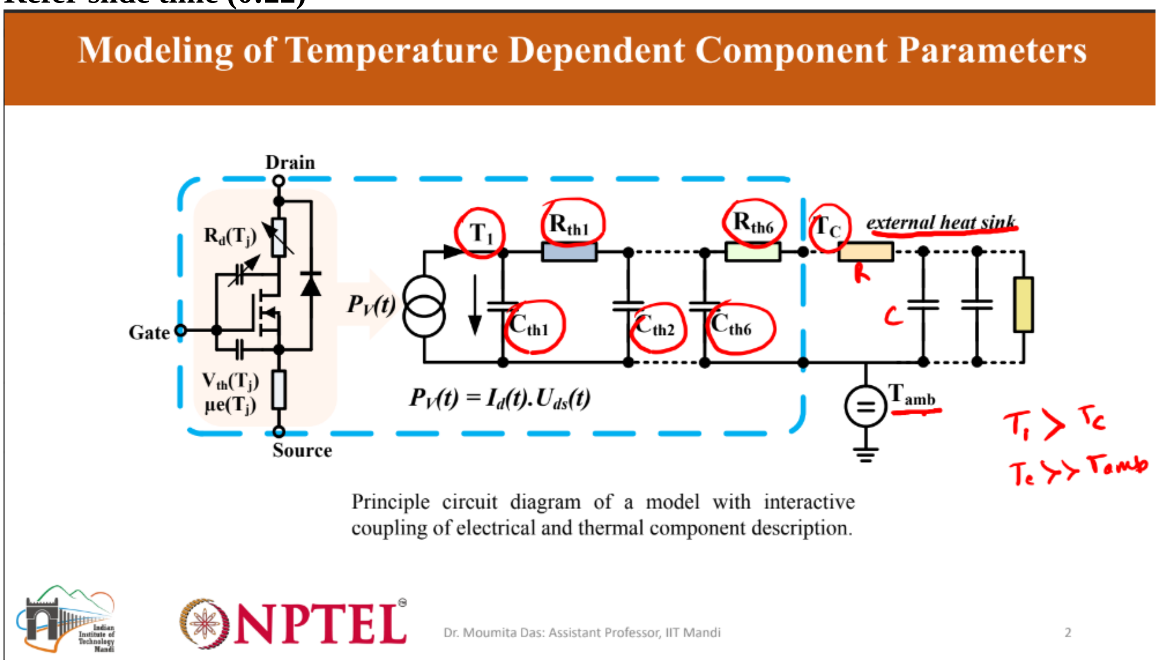

So, in this so the device is modeled using two different models I have discussed Cauer and Foster. So, this Cauer model is used here in order to design the device.

So, you can see here in the left side the design device is given. so this device is now modeled using different resistance and capacitances so now this different resistance and capacitances you can see here this rth1 cth1 like this rth6 cth6 so these are the different combinations of resistance and capacitances And from device what we can get? We can get the power loss component. So the power loss component which is given in terms of PV(t) so which is equal to ID(t) and UDS(t). So ID(t) is the drain current and UDS(t) It is the drain voltage.

So this power loss now it will pass through different combination of resistance and capacitances which is part of the device. So device is modeled in this particular way. Now Tc is the temperature which we can sense from the device which is basically the case temperature. Now this Tc we can actually connect to the external heat sink Now external heat sink again we can represent in terms of the resistance and capacitance Similar way as we can represent in terms of resistance and capacitance inside the device So basically the resistance these resistances and capacitances these are actually different resistance and capacitances of the device so this will dissipate some amount of heat which i have already discussed in the last lecture So this heat after dissipation whatever heat we can get so that is the case temperature But the junction temperature T1 it will be different than that of the case temperature Because case temperature will be lower than that of the junction temperature So that is why in order to find out what is the device junction temperature we need to have information about these different resistance and capacitances so that we can get actual temperature which device is actually facing in the junction. So, if that junction temperature we can actually use, then it is okay.

Otherwise, we have to connect heat sink. Now, what is heat sink? So, external heat sink, it is shown here. This is also combination of, let us say this is R and this is C, combination of R and C. Now, we can have different types of heat sink which will give us different resistance and capacitance and based on that we can actually decide how much heat we can actually dissipate using this external heat sink Now this external heat sink also it is shown in different resistance capacitance combination and this T ambient you can see here this is the ambient temperature which will be the temperature of the device along with the heat sink after dissipating through different resistance and capacitances. This ambient temperature generally it is basically room temperature we need to consider.

so this temperature this is actually going to be the temperature after connecting the heat sink ok. So, this T1 and T ambient it is very different because T1 will be higher than that of the Tc whereas Tc will be much much higher than that of the T ambient ok. So, in order to maintain the ambient temperature to the device, wherever it is connected in PCB or in the module, then we have to connect external heat sink. Now, in order to make this equal, so basically we can, what we can ensure? We can ensure that the case temperature, it will be equal to the ambient temperature. So, we have to connect a heat sink so that it can take off the heat Whatever heat will be more than T ambient which is generated due to the power loss in the device.

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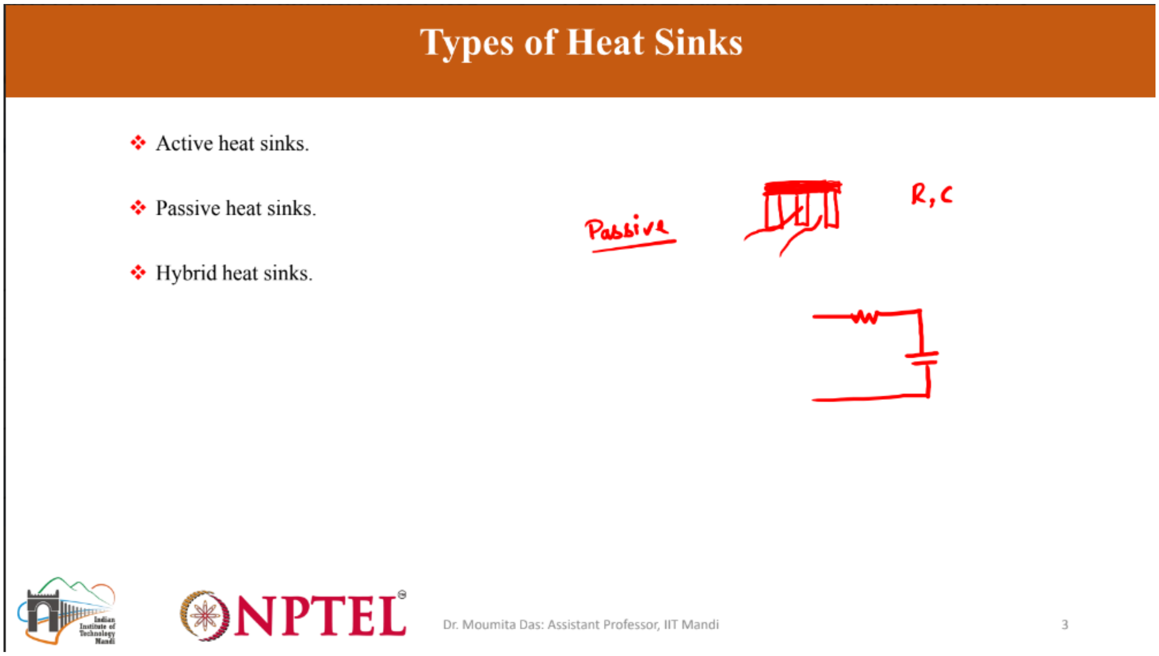

Okay, so now you can see there are different types of heat sink. Active heat sink, passive heat sink, hybrid heat sink. So, passive heat sink it is basically the fixed kind of device which you can see in the previous diagram. You can see the combination of resistance and capacitance. So you have probably seen so basically in the device so if I need to consider this passive heat sink so along with the device this heat sink will be fixed.

So generally you have probably seen the heat sink which is having different like thickness and then it is like having different air flow. They are like different types of air can flow in between. So now this thickness of different teeth and then the spaces in between which can be different for different types of the heat sink. But this comes under passive heat sink because this is fixed in nature. Once you select, so this will be fixed and it will have fixed type of resistance and capacitance.

Okay. So, it is not variable. Once you are connecting to the system, so whatever resistance, so basically whatever resistance it will give equivalent resistance and the equivalent capacitance, it will be fixed. So, this is with respect to the passive heat sink. So this will be fixed in nature. So if the power dissipation is more or voltage and current all these parameters are changing and that is causing different power dissipation at different time or loading condition.

So then also it will be fixed and the heat dissipation will remain constant in this. Let's say heat dissipation in this particular kind of heat sink is 50 watts. So then the heat dissipation in low power loss also it will be same and high power loss also it will be same. So if there is a transient situation where very high power loss is happening in the device and we need to take off very high power so let's say around 100 watts within very short time so that kind this kind of heat sink will not allow us to do that so then what we can do we can look for other types of heat sink so this kind of heat sink along with some additional factor so then we can look for active kind of heat sink.

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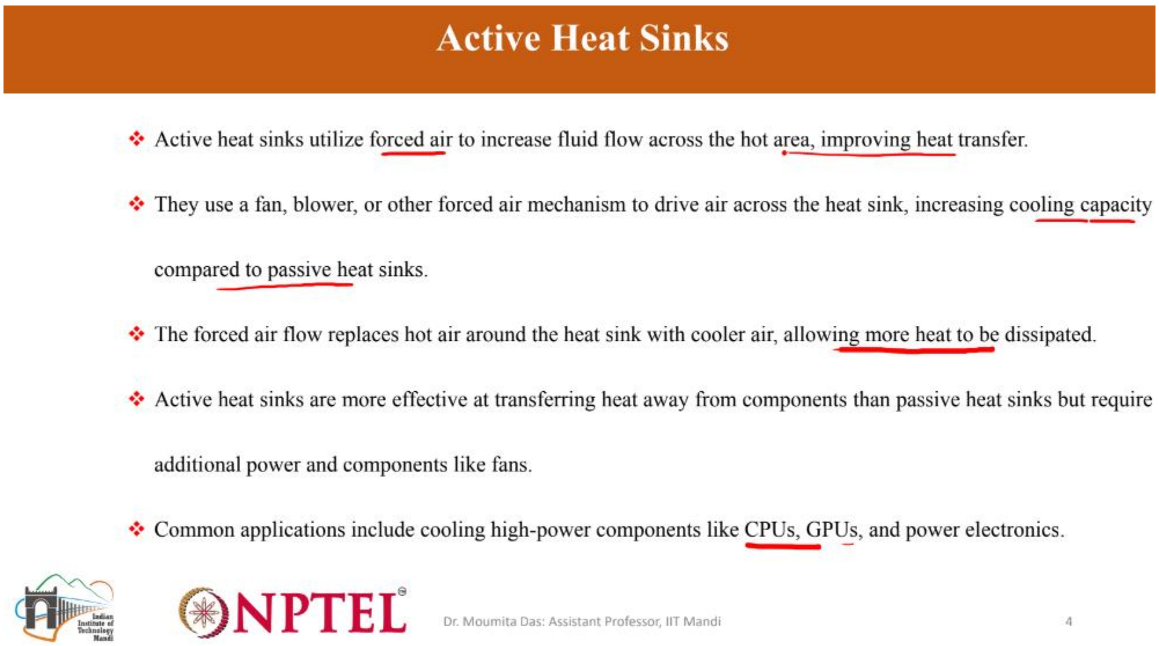

so what is active kind of heat sink so basically this active heat sink it utilizes some additional Factor so additional factor what it can be it can be it can actually utilize forced air So forced air how we can utilize so basically along with heat sink if we can connect lets a small fan So then what it can do it can actually force some air through the heat sink So that whatever gap is there in between different teeth. So then heat can actually be dissipated in this so basically it can take off the heat from the heat sink through the force air or to increase the fluid flow across the hot area improving the heat transfer so this is one of the ways and then they use a fan blower or other forced air mechanism to drive air across the heat sink increasing cooling capacity compared to the passive heat sink so the cooling capacity of active heat sink is more now this fan speed also can be variable so depending upon the type of heat dissipation or maybe like kind of heat dissipation we need to have we need to include in the system based on that we can actually change the fan speed So if heat dissipation is required more for some time so then fan speed can be more so that it can take off more heat If heat dissipation is less then fan speed can be less then less heat need to be dissipated Okay that way it can be regulated okay The forced air flow replaces hot air around the heat sink with cooled air allowing more heat to be dissipated okay now at this active heat sinks are more effective at transferring heat away from components that passive heat sinks required additional power components like fan okay common applications include cooling high power components like CPUs GPUs and power electronics in CPUs probably you have seen so there is already a fan which is connected along with the actual heatsink so this fan is always actually on so it is taking off heat from the CPUs okay through the heatsink so that way we can use active heat sink so active heat sink is much more efficient than that of the passive heat sink because you know it we have one active component along with the passive component okay .

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so the another thing is that hybrid type of heat sink so in hybrid type of heat sink So here we have combination of both active and passive.

So active heatsink means like only active component will be there. Passive heatsink means only passive component will be there. In CPUs it is like hybrid combination. So basically it will have passive and active component both. Okay, so these two components are there.

So, then we can have a hybrid kind of heat sink. So, this heat sink obviously much more efficient than that of the passive or active heat sink because you know we have both the components and both will be equally utilized to take off the heat from the device.

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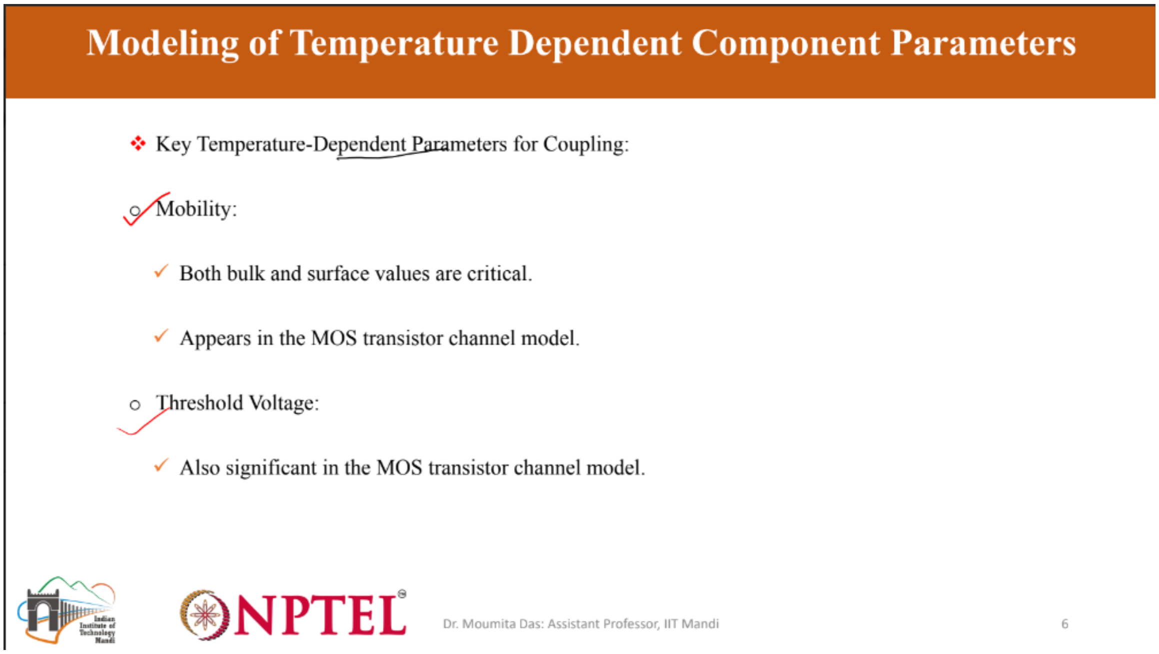

now this is the external thing but how we can know that what will be the heat generated in the device for that what we need to do we need to model temperature dependent component of the parameters which we have in the device so now generally in power electronics what happens either people focus on the converter or the control part But the thermal modeling part, it is generally overlooked. But it is very important part because you know thermal modeling can only give insight of the device how the temperature of different parameter, parasitic parameters are varying and what can cause the temperature in the device to increase or go beyond the limit which is given. Now this temperature dependent parameters if we have to consider them there are actually different parameters so first is that the mobility.

So, basically both bulk and surface values are critical. So, this appears in the MOS transistor channel model. So, this all these parameters are related to the device. So, we can just go through this different component and this the device modeling part is not included in this particular course so that can be covered in other course so right now i'll just give you the idea about what components are included in this temperature model second is the threshold voltage so this is important or significant for this mass transistor channel model because you know threshold voltage can also be variable with respect to the temperature so that is why we need to model the threshold voltage with respect to the temperature then the important thing comes with respect to drain resistance and the capacitance.

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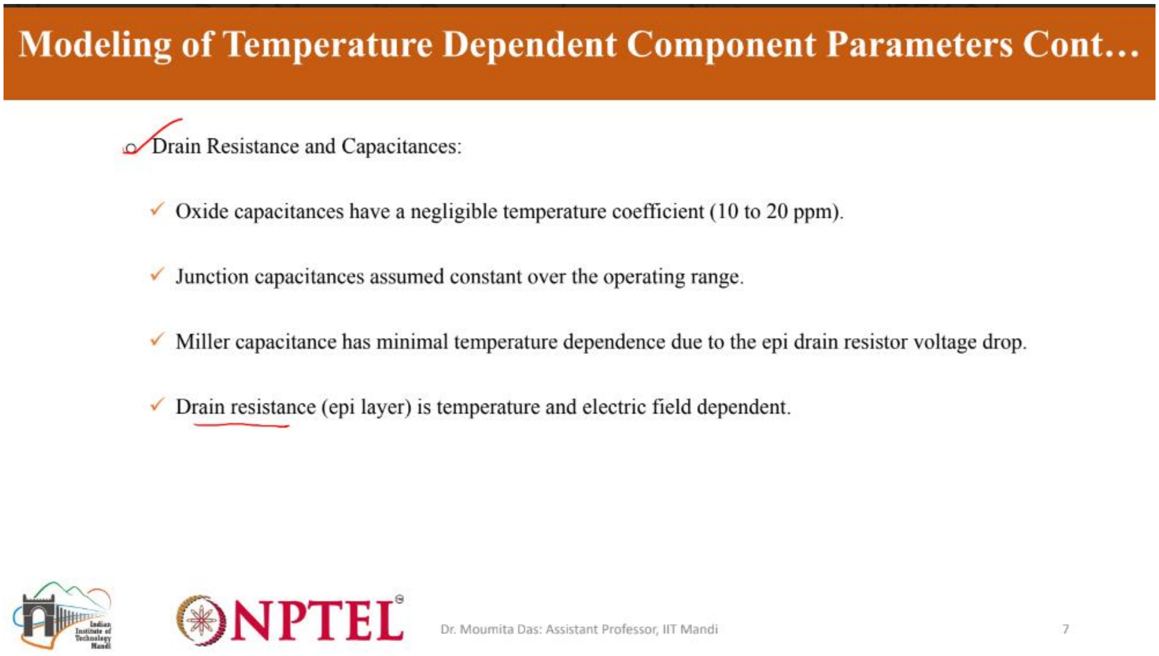

now this resistance and capacitance generally we consider it is fixed kind of device but These are not fixed, these are also temperature dependent. So, with respect to temperature, the values of the drain resistance and capacitances are also variable.

So, these oxide capacitances have a negligible temperature coefficient, okay, but the junction capacitance is constant over the operating temperature range. The Miller capacitance has minimal temperature dependence due to the drain resistor voltage drop. the drain resistance is temperature and electric field dependent so this drain resistance mostly gets affected by the temperature but the capacitances they do get affected but the variation is not that much.

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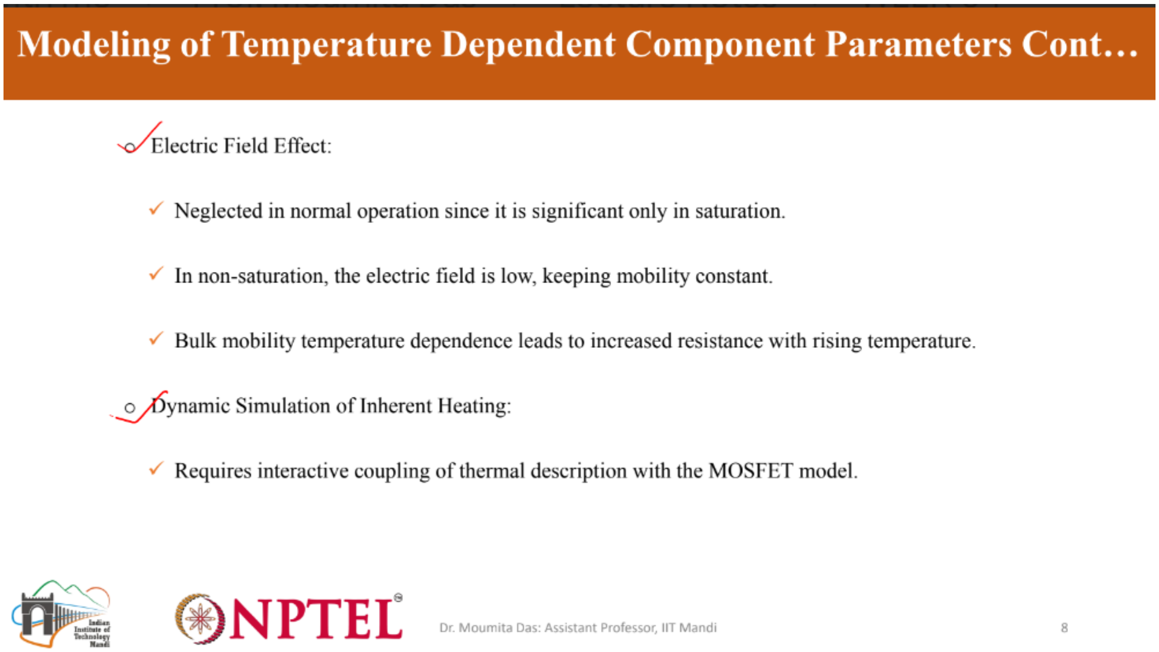

Now there are actually effect due to the electric field. So electric field effect if you see they neglected in normal operation since it is having significant only in the saturation. In non-saturation the electric field is low and keeping mobility constant.

Now bulk mobility temperature dependence leads to increased resistance with rising temperature. So this electric field is going to affect the mobility. Now dynamic simulation of inherent heating. It requires interactive coupling of the thermal description with the MOSFET model.

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Modeling of Temperature Dependent Component Parameters Cont…

- Instantaneous Power Dissipation:
  - Determined by the product of current (I_d) and voltage (U_{ds}).
  - Proportional current is fed into the thermal equivalent network.
- Junction Temperature Node (T_j):
  - Provides momentary junction temperature.
  - Interacts with temperature-dependent parameters of the MOSFET.

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Now the thing which... are of our interest that is instantaneous power dissipation so the instantaneous power dissipation how much it is happening the previous thing it mostly comes in the device part so that need to be covered in separate course. So, but the in this particular course what we can find out the power dissipation. So, this is determined by the current and the voltage. So, Id and Uds. So, this current dissipation whenever we have at least we get the maximum power dissipation and from there we can get what will be the temperature in that device junction.

This proportional current is fed into the thermal equivalent network. So, this current whatever we get, so that can be feed into the thermal equivalent network to find out what will be the temperature rise. Now, junction temperature. load. It provides momentary junction temperature and interacts with temperature dependent parameter of the MOSFET.

So, once we have this power losses and from there we can get the proportional current and which give us the junction temperature. And this junction temperature, it provides momentary junction temperature. So, once the current is increasing for transient So, then it will give the momentary junction temperature which will be during that particular time. So, during the transient time if there is a high power loss, so that will give us high junction temperature for very short time.

Okay. sometimes it happens that this temperature whenever it is arising if it is within the specified time range then the device survives otherwise generally this kind of temperature can destroy the device so that is why it is important to find out that how much maximum temperature we can allow in the device accordingly we need to design the heat sink so that the temperature can be taken off from the device okay.

So now all this heat sink you know about so that already are in use for silicon devices means active heat sink passive heat sink hybrid type of heat sink it is there available in all the consumer electronics and in laptop also like you can see in the CPUs or computer CPUs laptop or computer CPUs so you can see this kind of heat sinks are there so if you try to open that and see that heat sink what kind of heat sinks are there you will be able to see different types of heat sinks available okay now these are there for silicon devices what about wide band gap devices so where we need to change for wide band gap devices so generally all the kind of heatsinks which are available so they are generally used for silicon devices but for wide band gap devices the situation is bit different so that is why due to the their property and everything as you already know what are the differences so then we have to look for alternate solution what can be the alternate solution so can we really use this heat sink or we have to look for other solution so basically wide band gap device is there the temperature variation So, it is actually much different than that of the silicon devices because their operation at high frequency and also this kind of devices are like much more compact than the silicon devices. So, that is why the type of heat sinks need to be used for this kind of devices must be much more compact than that of the passive heat sink which are available. So this kind of compact heat sink which should be much more efficient to take off the heat So that kind of heat sink we need to look for So the both active and passive that actually takes like quite large amount of space In the in the system.

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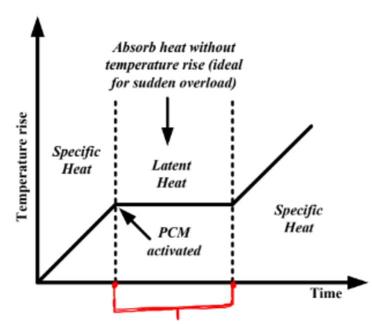
Phase Change Material (PCM)

- PCM absorbs heat during phase transition (solid to liquid) while maintaining constant temperature.
- PCM heat sinks effectively manage thermal stress during transient overloads in WBG devices.
- Proper selection of PCM volume is crucial for optimizing performance.



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So that is why we can look for alternate solution that alternate solution can be Using the phase change material. So what is the phase change material? So basically this phase change material it is Some material which has the property to absorb heat during the phase transition.

So you can see here this phase transition so basically here whenever that phase transition is happening so then what will happen let's say this solid to liquid it is going to solid to liquid or liquid to gas so in that kind of condition so the heat which will be dissipated that will be constant so you can see here absorb heat without temperature rise so in this particular region basically heat dissipation heat rise in the device or the system it will be constant if we have so like if we have a heat sink which has the phase change material so then what will happen during this particular time the heat dissipation remain constant or heat generation in that particular heat sink will remain constant although the with respect to the time so basically heat dissipation so the power dissipation is increasing but heat generation is not increasing so that is the property of the phase change material so we can use this kind of material along with the heat sink so basically whatever heat sink we have so generally how the heat sink looks like so basically you can see any heat sink so basically if you try to represent it in the simpler form so it will be having some teeth okay so now this will be connected to the device now this is with respect to the passive heat sink in active heat sink so what will happen so there will be fan In hybrid heat sink it will be combination of fan plus passive heat sink Now in PCM what will be there? So this kind of heat sink It will have some portion of So, basically let's say so like if the size of this particular heat sink is such that we can actually replace one third of this particular heat sink size using phase change material. So, this is our passive heat sink and this particular solid portion we can actually connect phase change material. So, this is how it can look like. so now we can have like quite significant portion of using phase change material or maybe small portion so that is depending upon like kind of heat we want to dissipate and now due to this phase change material this small amount of phase change material the overall properties of the heat sink will change so you can see here so this is the property which we are including along with the Passive heat sink. Okay, this PCM heat sinks effectively manage thermal stress during the transient overload in the wide band gap devices so during transient overload so that is for very short time So as I have already told in the previous slide So that in the transient time also temperature will rise for very short time So in that time if we have this PCM material then PCM will get activated and it will keep the device within this particular region for very short time the temperature of the device can increase but due to this PCM gets activated so the overall temperature remain constant for that particular duration so that it can actually maintain the device temperature within a suitable limit okay so this is very useful for wide bandgap type of devices because you know there is like high frequency operation and it can happen that during transient time or the switching time so there can be transient over overload stress or maybe thermal stress can be there in the device so that can be taken up by using the PCM based heatsink So proper selection of PCM volume is crucial for optimizing the performance because we can have because you can see here this is the solid portion so there has to be enough space so that heat can be dissipated so if there is a fan along with this overall heat sink so like heat sink which is based on PCM so if we have a fan so there should be space to take off the heat So basically air can flow through that spaces So if we have the complete solid block So then there will not be any space to take off the heat By forcing the air through that particular heat sink If we have these different spaces So, then only the air can be forced.

But if it is completely solid then air cannot be forced. So, that is why we have to see that how much space, how much of this particular passive heat sink we can actually replace by using PCM. So, you can either replace one third, two third or complete. heat sink by PCM obviously that will give us the property of PCM but there will not be enough space to take off the heat by forcing the air through the heat sink okay so that is why it is very much important to select the volume of the heat sink which we are going to replace using the PCM okay that's all for today thank you so more about this i am going to discuss in the next lecture.