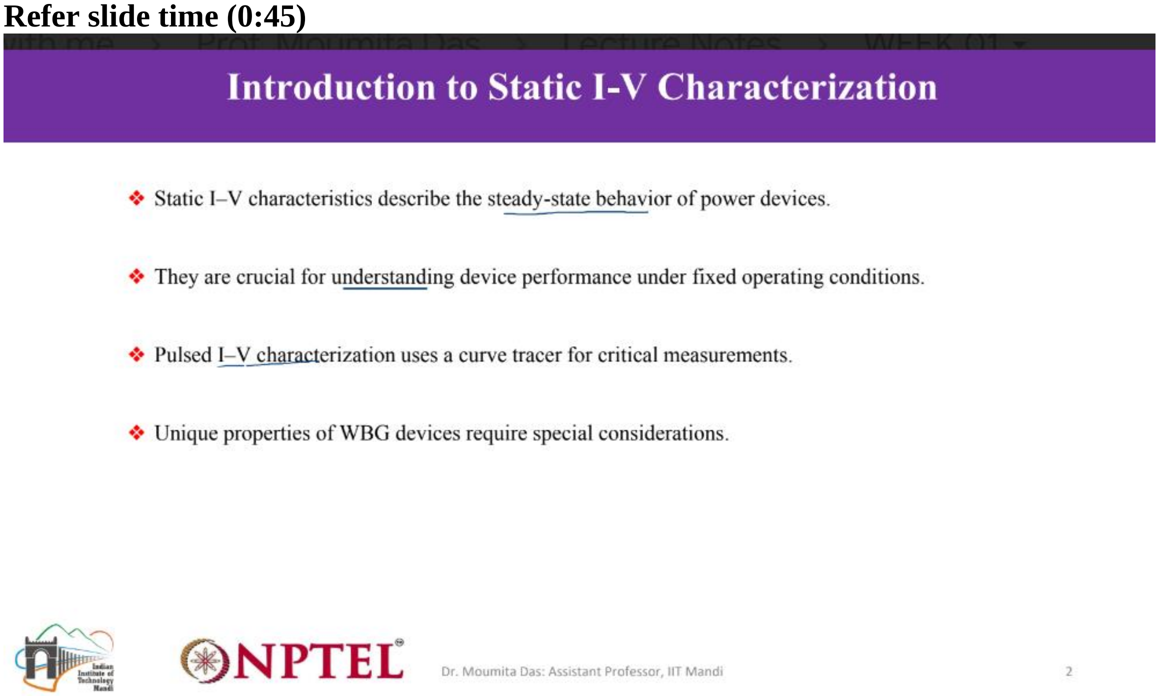
Power Electronics with Wide Bandgap Devices
Dr. Moumita das
School of Computing and Electrical Engineering
Indian Institute of Technology, Mandi

Lecture-3
STATIC CHARACTERIZATION OF POWER DEVICES

STATIC CHARACTERIZATION OF POWER DEVICES

Welcome to the course on power electronics with wide band gap devices. Today I am discuss about static characteristics of any power devices. So, static characteristic is important in order to find out maximum voltage, maximum current, on state resistance basically the static behavior of any particular devices. So, in this process we have to provide pulsed kind of signal in order to get the static characteristics.

Refer slide time (0:45)

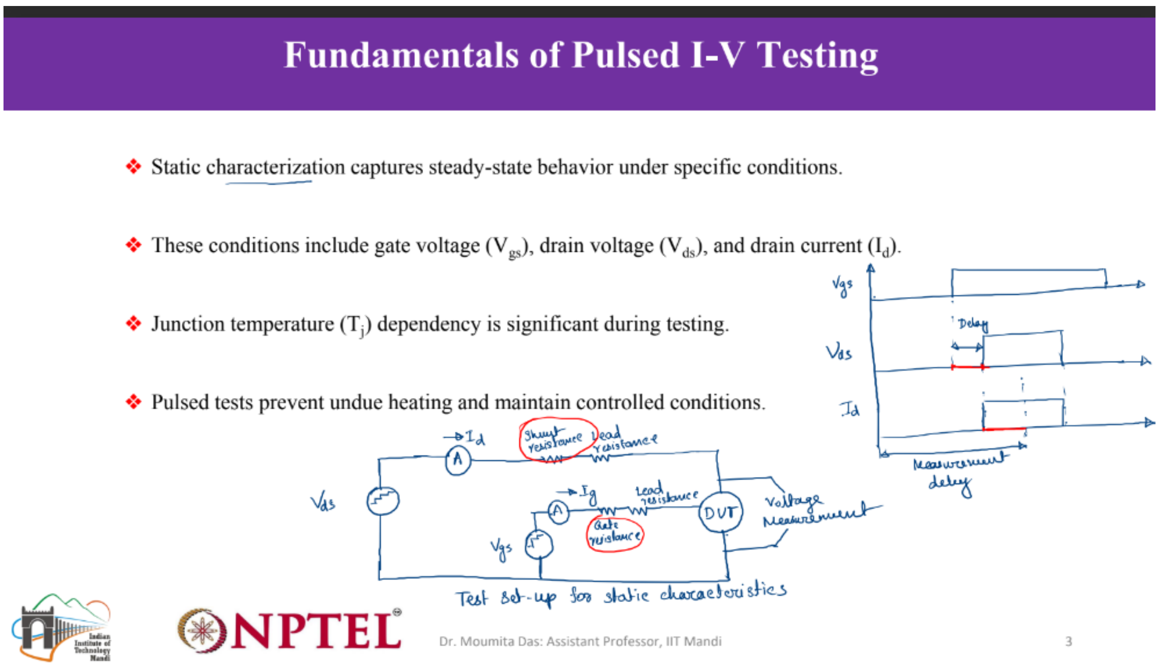


Basically, this static characteristics gives us I-V characteristics of the device. So, what are these I-V characteristics? So, basically it describes steady state behavior.

So, the first step to analyze any device is to find out the steady state behavior. So, how the device will perform in steady state. So that is why this is very important or this is the first step to understand any device and they are very crucial to understand the device performance for fixed operating condition. If the operating condition changes so obviously these characteristics will also change.

So, pulsed I-V characterization uses a curve tracer for critical measurement. So, generally for any device in order to find out I-V characteristics curve tracer is required. So, generally for silicon devices this curve tracers are well established kind of equipment which people use often to characterize silicon devices. But this WBG devices they are bit different in terms of size of the devices, their parasitic parameters, their slew rate all these things are much different from the silicon devices. so that is why in order to characterize the wbg devices special kind of attention is required so that is why i am going to discuss the static characterization in details and what are their requirements.

Refer slide time (2:20)



Fundamental of pulsed I-V testing so what is this pulse I-V testing so whenever we need to characterize any device for the steady state behavior so then the pulse kind of signal generally provided so for in the curve tracer this signal generally provided from the equipment itself so we just need to place the device under test in the equipment and it provides all the signals automatically and then it measures the signal output whatever is required for this characterization But if in case we have to provide this signal separately, then we should have clear understanding of this signal and where exactly we should be providing.

So, in order to provide this pulsed kind of signal, so if we do not have the curve tracer, if we have to use the component whichever is available in the lab and we have to make the setup using the component, so then the setup will look like So, it will have, it will need two different supplies. So, supplies we can get from the lab. So, the supply are basically gate to source voltage and the drain to source voltage. How this drain to source voltage and gate to source voltage looks like? So, basically we need to provide step kind of voltages. to both gate and the drain.

So this let's say this is the VDS we are providing. Now this will be connected to one current measurement port so which will measure the drain current, drain current id. This will be connected to one shunt resistance to limit the current and it will also have one lead resistance connected in series. So this is lead resistance of the device and this is shunt resistance to limit the current. Okay, now this will be connected to the device under test.

So, let's represent this as DUT. The full form of DUT is device under test. Now, this will be connected to the negative terminal of the source. Now, this device need to have also gate to source voltage and this gate to source voltage will also be step in nature. In order to provide different gate to source voltages, that is why we need to provide step kind of voltages.

So then accordingly we can get the characteristics. Let's say for VGS, in case of silicon carbide device, it is varying from 0 to 15 volts. Then the step voltage should be provided such that in each voltage level, let's say 0 volts, 5 volts, 10 volts, 15 volts, we can characterize the output. Now, this gate to source voltage is also connected to one current measurement port which measure the gate current and which is connected to gate resistance and then this is again connected to the lead resistance of the device and the negative terminal will be connected to this point. So, this is the VGS and this provides the gate current, this is the gate resistance, one is gate resistance.

one is lead resistance of the device. And here we can actually measure the voltage, voltage measurement of the device. It will give us actual drain to source voltage which is appearing across the device. Although we are providing drain to source voltage, but how it is appearing, so that we can get from this measurement. So this is the test setup for static characteristics.

So, if you have curve tracer which is easily accessible then use the curve tracer and if you can get it if you can get suitable curve tracer for wide band gap devices that is wonderful. Otherwise, you can actually use the same curve tracer which is used for silicon device and then modify it such that you can use it for wide band gap device. And in case if you do not have any curve tracer available to you then you can actually make your own setup. So, which looks like this and this you can use for characterization of the WBG devices or any devices you want to characterize. So, now here you can see how this pulse signal should be provided.

Now, this pulse signal should be such that The thing, this is the test setup. So, the pulse signal should look like, so it should have gate to source voltage provided. So, I am just showing you one signal. So, there can be multiple signal provided at multiple voltage level. To give you the example, so this should be, let us say this gate to source voltage we are providing like this.

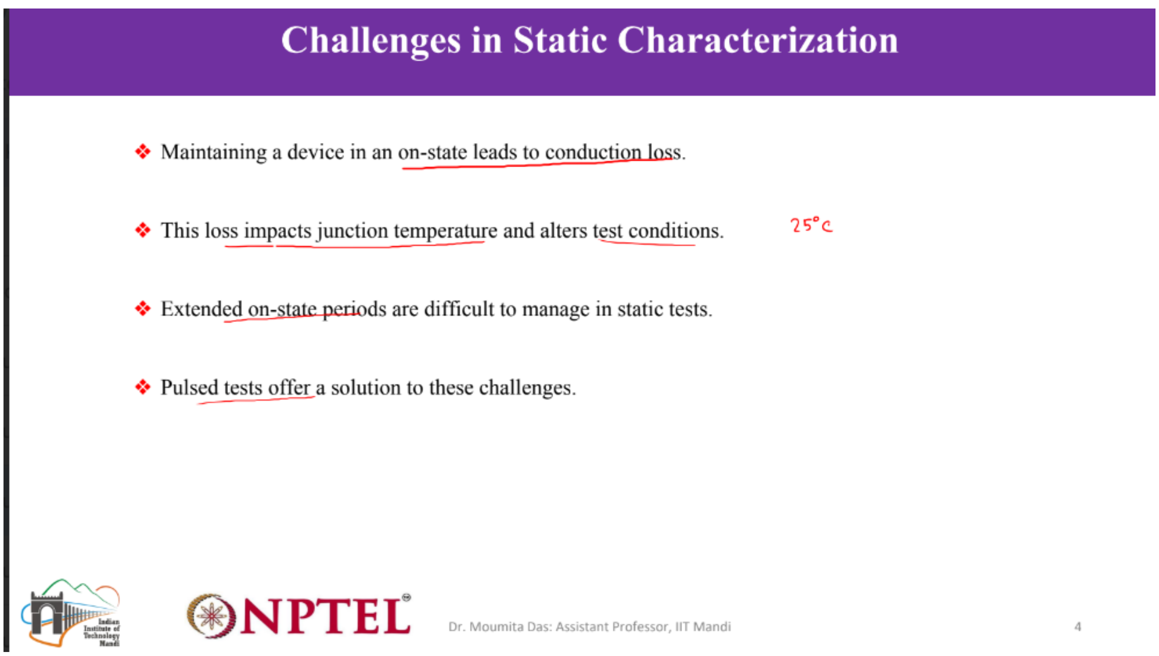
This is the gate to source voltage which is having pulse width like this. Now when we are providing gate to source voltage then after that after some delay point that drain to source voltage needs to be provided So, if there is any dynamic situation or the condition which arise after providing the gate to source, so that should reach to the steady state, then only the drain to source voltage need to be provided. So, this is the drain to source voltage and you can see here, so this is the delay between gate to source voltage and the drain to source voltage. Now once we are providing drain to source voltage so then there will be current flow from drain to source so that current I have also shown in this test setup. So, that is represented in terms of Id.

So, now let us say this Id we are getting like this. So, now the measurement point of the Id should be at the middle point. So, basically this is the delay for measurement of the drain current. So, let me just point out, so this delay is required for providing the drain current, so that if there is any situation which is required gate to, so that voltage across gate to source it should reach to the steady state value after let us say delay time, rise time anything. So, then this would first gate to source voltage should settle down and then drain to source voltage should be applied and once we are providing drain to source voltage immediately there will be drain current.

So, then we should be able to measure that drain current, but we are not measuring drain current at this particular point. We are measuring drain current after some time when it is reaching to the middle point because you know if there is any transient let's say overshoot undershoot anything any condition is occurring after providing the drain to source voltage then what we have to do we have to wait for some time so that device will reach to the steady state value once it is reaching to the steady state value then only we can actually characterize or measure this voltage across VDS and drain current. So, that we can get actual steady state value not the transient value. By default if we choose the initial point we may end up getting the transient values. So, that may not be the actual value which we are desiring.

So, that is why we have to wait for some time in order to measure that drain current. so now, this pulse width part is very important you know why because once we are providing this pulse width after let's say this delay time of the drain to source should be such that it generally like this should be provided based on the transient requirement like what when the device transient or the hard switching time will be over so that delay time should be that much and then this Id current when we are measuring that should not be like the pulse width for that also should not be very high because if we try to keep this pulse width very high so then what will happen this will end up increasing losses in the device because when the device is on although we are actually neglecting the switching losses but the conduction loss will increase and that will increase the heat generation in the device if heat is generated so then what will happen the device property will change if the device property changes then the static characteristics will also change that I will show you in characteristic curves how it will change so that is why it is very important to keep this pulse width in optimum condition so that we will not have the transient parameter but we should be able to get the value of the steady state condition. Then we can actually keep that much pulse width which will give us steady state value not more than that. Otherwise we will end up actually measuring the value which may not be the value in the original condition due to increase in the temperature.

Refer slide time (13:24)

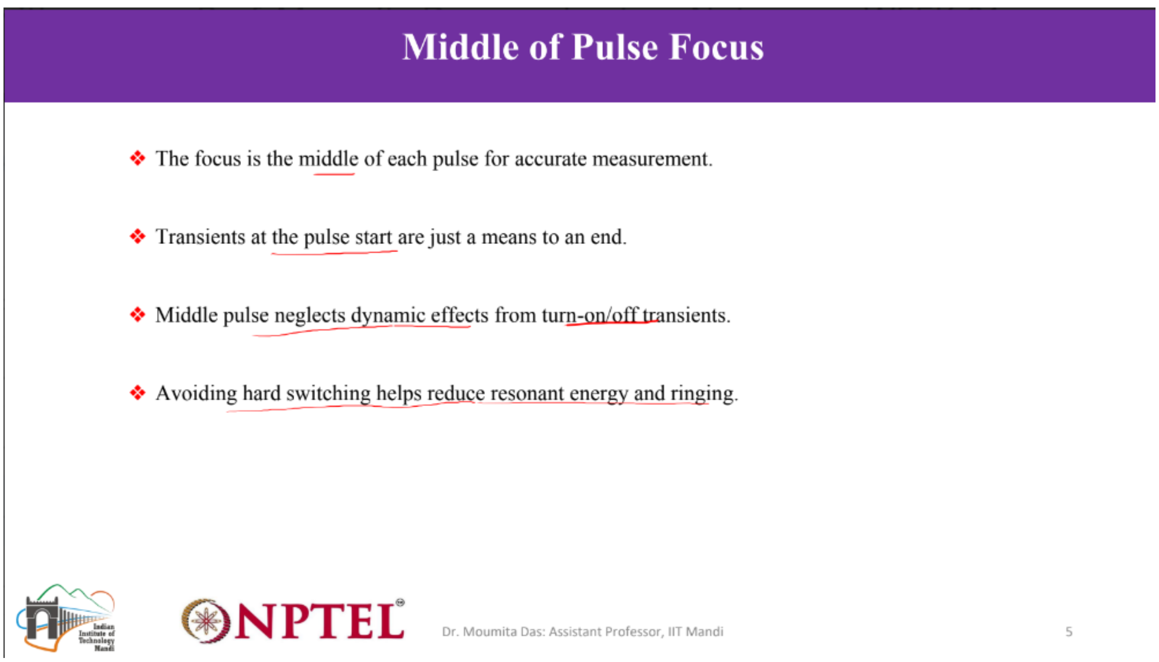


So, now this is as you have seen in the previous slide. So, this circuit looks very simple and also measurement looks simple and also the pulse we need to provide that is also only one pulse we are providing. So, that should not be very much complicated right, but there are challenges in characterization. So, what are the challenges? So, maintaining a device in an on state leads to conduction loss as I told you. So, basically we have to make sure that we are not increasing the conduction loss and that optimum point we have to select. So, that is one of the main challenges in static characterization.

And the obviously, this loss will impact the junction temperature and it will change the test condition. Let us say you are trying to achieve the condition at 25 degree Celsius. Let's say room temperature. Now, if the test condition changes, so then what will happen? This 25 degree Celsius can change to 50 degree or 100 degree Celsius. Then you will not get the actual value.

And third thing is that extended on-state period are difficult to manage in static test. So, this is also another challenge and then that is why the pulse test offer a solution of these challenges. So, that is why this pulse kind of signal we need to provide.

Refer slide time (14:51)

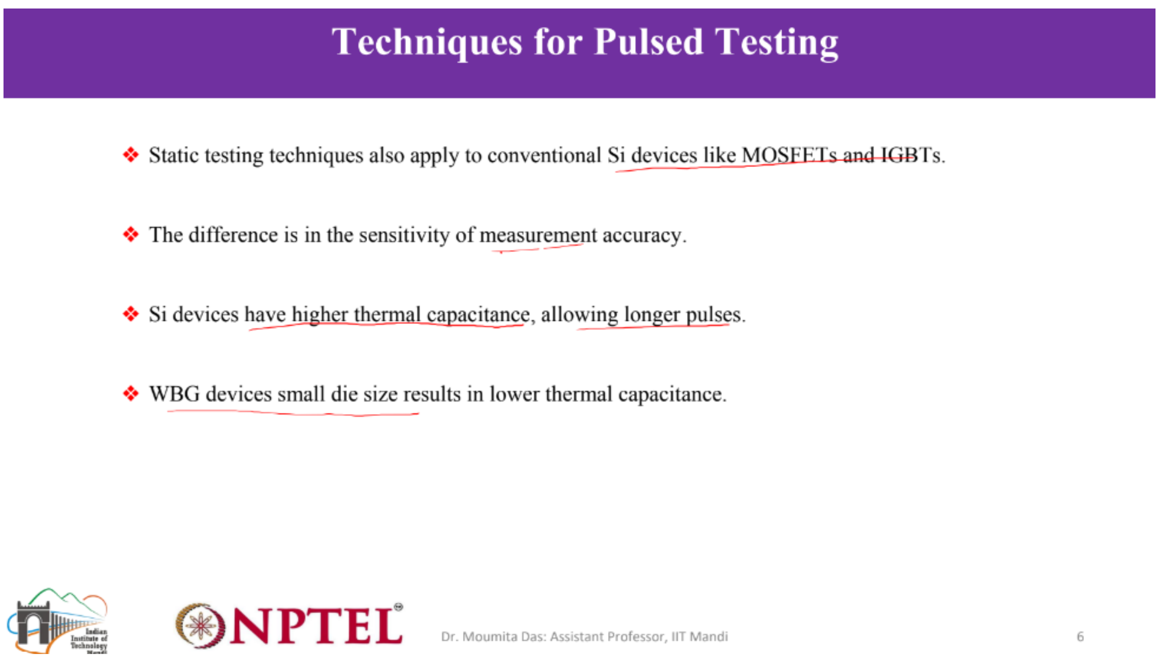


Now we have to focus in the middle part as I told you like after some delay time we can reach to the middle part of the current. So that part we need to focus in order to measure the actual static value.

The transient and the pulse start are just a means to end up to certain point. So we have to let go that transient part and we have to reach to the middle part. So, after like few characterizations you will be able to understand when this middle part is coming. So, then you can choose the actual value. The middle pulse neglects the dynamic effect from the turn on and turn off transient.

So, this turn on and turn off transient we are not including in the static behavior. so here the main concern is the maximum voltage maximum current rating of the device what should be the on state resistance and what should be different current basically the leakage current of the gate leakage current of the drain or the current flowing through the gate so those current values will get okay avoiding hard switching helps reduce resonant energy and ringing so basically if we have hard switching so then that will cause some like resonating energy or the oscillation and it will take some time to reach the steady state value so that is why like if it is possible to avoid the hard switching by introducing soft switching or providing the pulses such that it will like automatically go to 0, the current will go to 0. So, then what will happen? Then this resonating energy will not be there, then what will happen? The oscillation at the beginning will be much less. So, then the reaching to the steady state situation will be much easier.

Refer slide time (16:41)

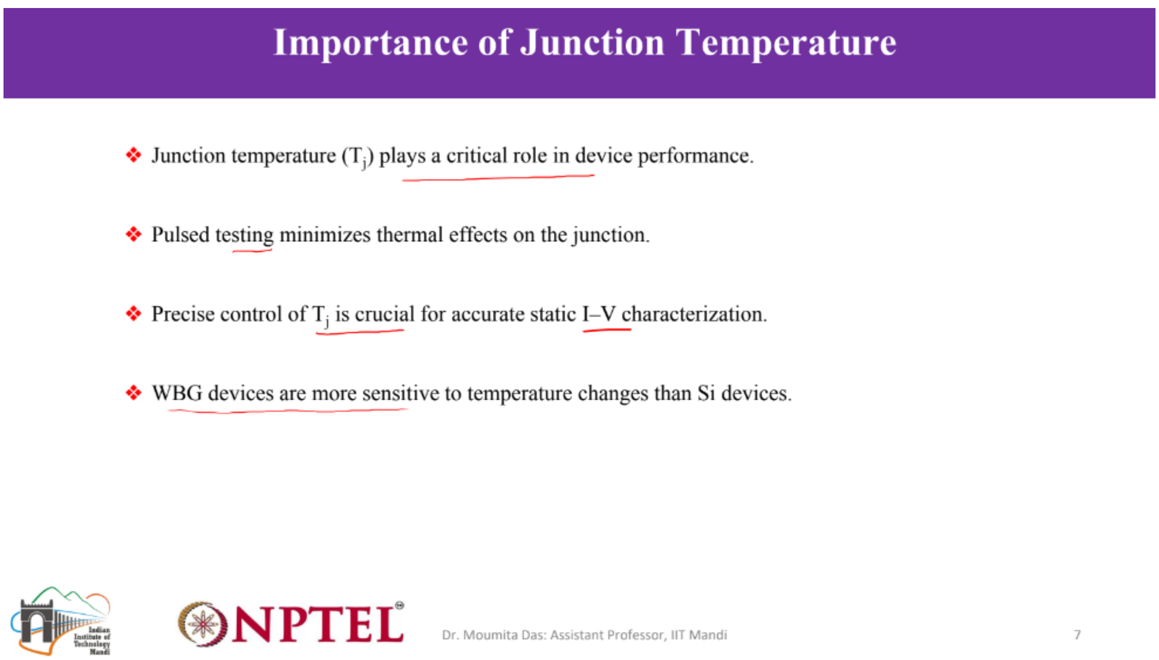


Now techniques to the pulse testing, so this is like it can be applied to any device. So pulse testing, any testing, so they are very, they are common. So either like static characteristics, dynamic characteristics, capacitive characteristics, any characteristics. So, the characteristic should be common like what are the things we need in the data sheet, but the method will change depending upon the device. So, if the device is very sensitive then we have to select a circuit or network which will not arise the additional parasitic parameter. So, that thing we need to look into, but the parameter which whatever is required in the data sheet, they are like constant for all kind of devices.

Let's say for silicon MOSFETs and IGBTs. So, whatever datas are available in the data sheet, it should be the same for any wide bandgap devices. The difference in the sensitivity and measurement accuracy makes the difference. silicon devices have higher thermal capacitor allowing longer pulses but you know the GaN silicon carbide especially GaN so it is having much lesser capacitance so that is why the pulse width required for the GaN device should not be as wider as the silicon device again the silicon carbide devices are having like capacitance level much lower than silicon but bit higher than that of the GaN So, then the pulse width also be different. So, that we need to find out like what should be the pulse width for different devices.

So, it should not be same for all the devices silicon, silicon carbide and GaN. So, and also like this small die size results in lower thermal capacitance. So, that is also another important point when we are going to characterize this wide band gap device.

Refer slide time (18:35)

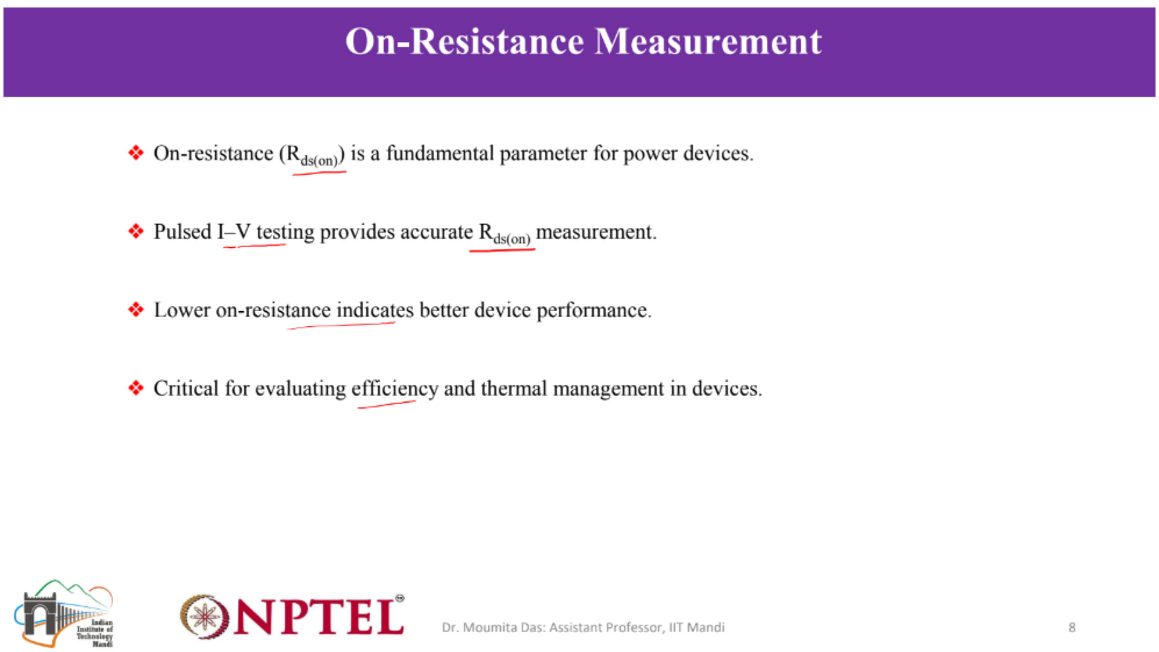


So, and we are talking about different parameter, but till now we have not discussed about the junction capacitance, but this is like one of the important parameter. So, this junction capacitance it plays very important role for characterizing any device.

So, this pulse testing it will affect as I told you it will affect the effect of this temperature in the device junction. So, that we can try we can assume that temperature will remain same as the beginning for characterization. now precise control is very important in order to characterize the device otherwise as i told you the the basically condition will alter whenever you see any data sheet so they are generally given like what is the voltage current level and or and additionally what is the junction temperature they have considered so generally in the data sheet so they take two different temperatures one is the room temperature another at a higher temperature let's say 100 degree celsius So, you can see the parameter values changes as it goes from room temperature to higher temperature. So, that is why they give two different temperature and if it is possible to characterize the device for like multiple temperature.

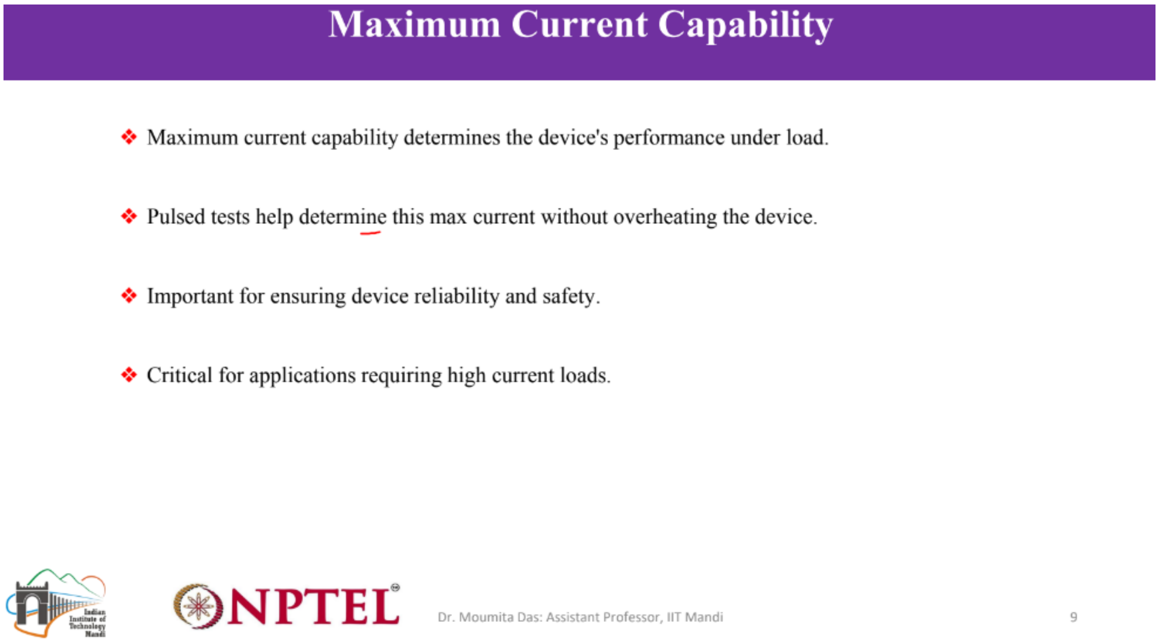
So, that is like much more advantageous. Then we can actually get the actual value depending on that particular temperature. So WBG devices are more sensitive to temperature changes than that of the silicon device. So this is like one another important point for WBG characterization. So this temperature we have to regulate properly so that we can get actual value in WBG devices.

Refer slide time (20:20)



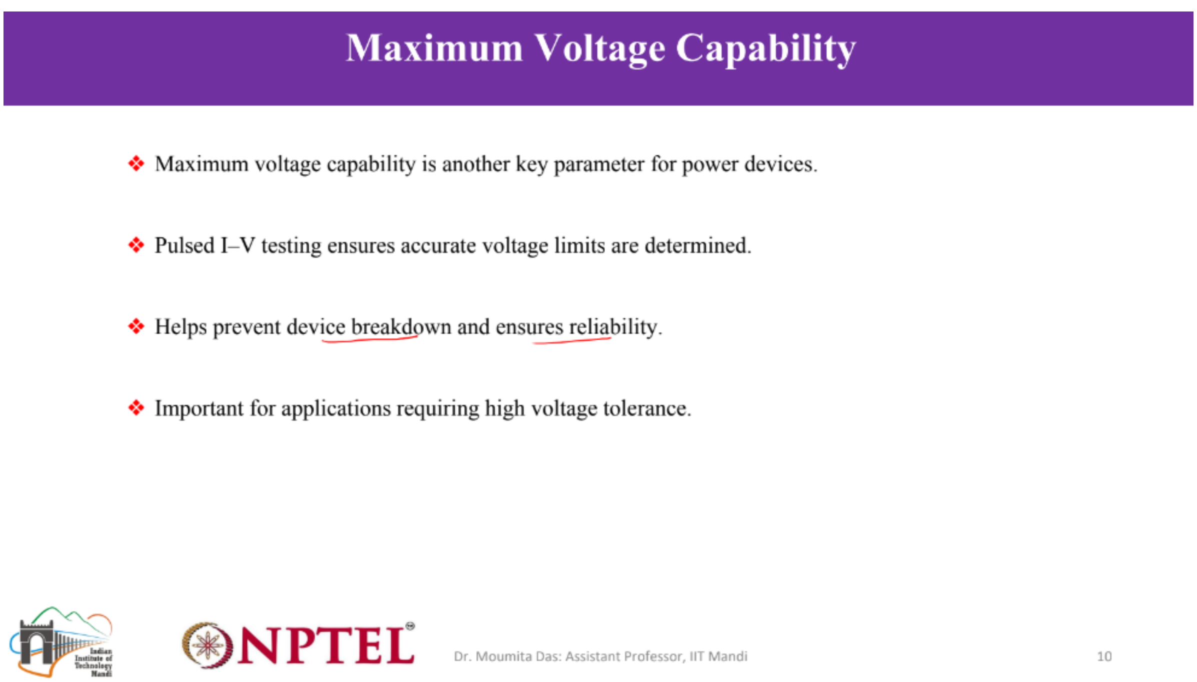
Now, so till now you have seen this different I-V and then junction temperature. Another important thing is the on-state resistance. Why it is important? So, this is required for finding out the conduction loss. This is one of the important parameter in any device. So, this pulse I-V testing provides accurate this on-state resistance measurement as well. The lower the on state resistance obviously it is like better for any device so the loss will be muchless. So this is like very critical to evaluate the device performance and the efficiency level of the device.

Refer slide time (20:20)



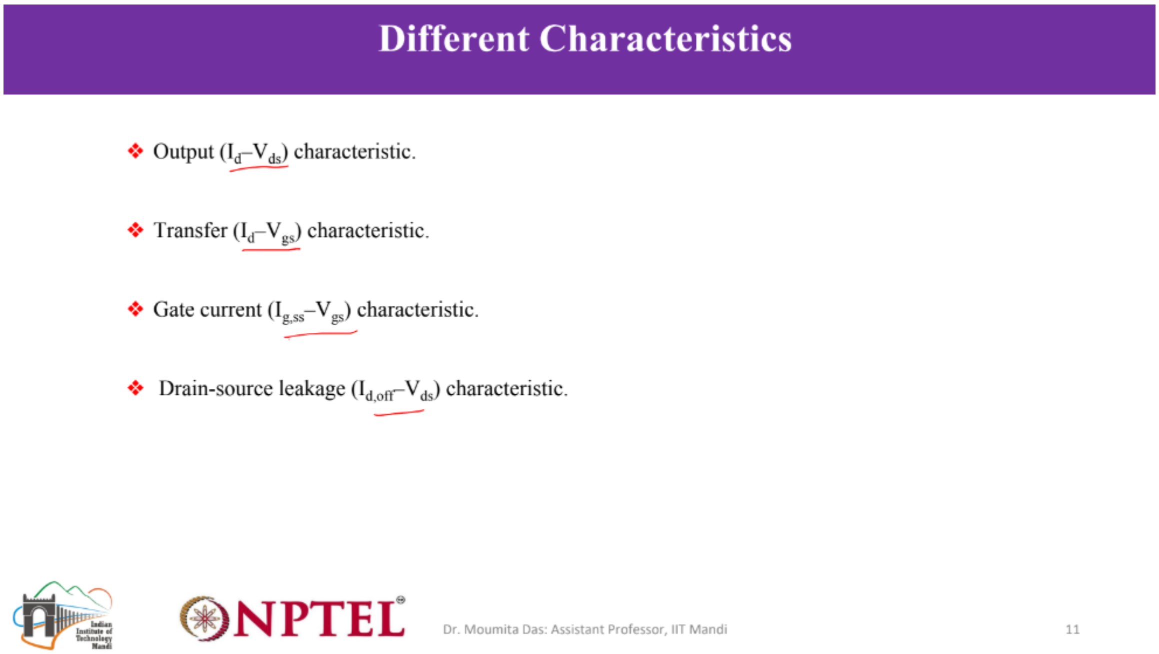
Then the maximum current capability. So the maximum current capability of the device is very important to find out the suitable device for any particular application. So pulse test also gives the maximum current which the device should be able to provide for reliable and safe operation. So this is also very important for any application.

Refer slide time (21:35)



So this decides like maximum current level for which the device can be applied okay and this now another thing is that the maximum voltage similarly the maximum voltage it so first thing we notice in the data sheet is the what is the voltage and current level so this also very important for to find out the breakdown voltage and ensure the reliability this is also like very important for particular application.

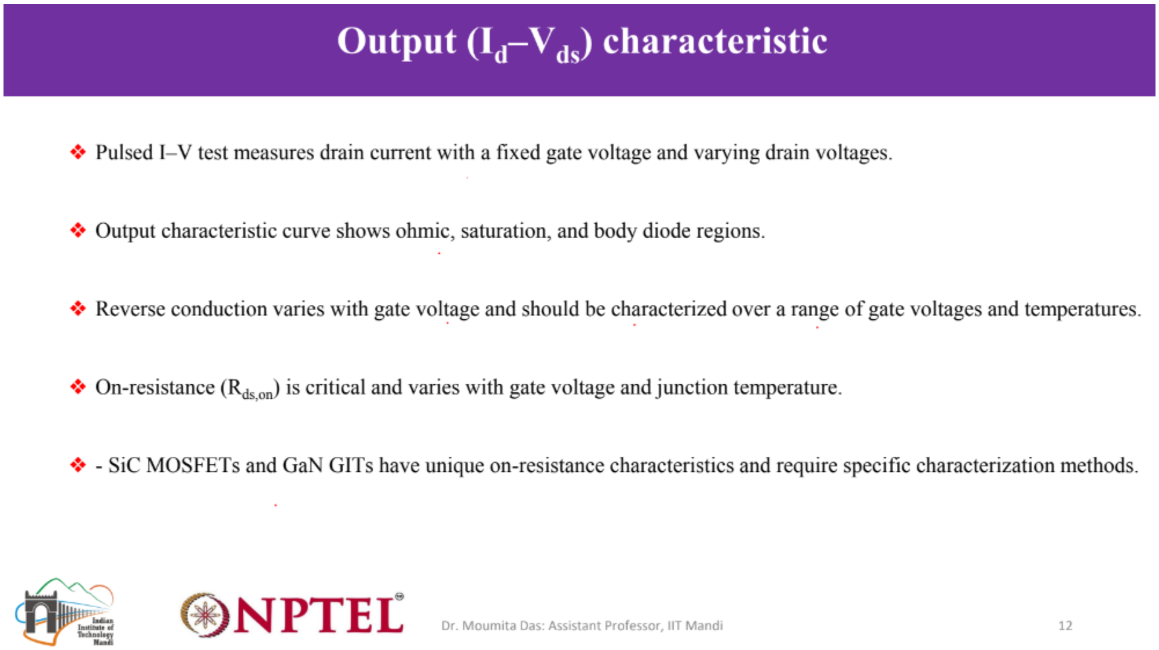
Refer slide time (21:55)



Now, in this static characteristics, what are the different parameter we can get? So, there are four different characteristics we can have using this method. So, first is the output characteristics which characterizes Id-Vds. Second is the transfer characteristics. So, this characterizes Id-Vgs.

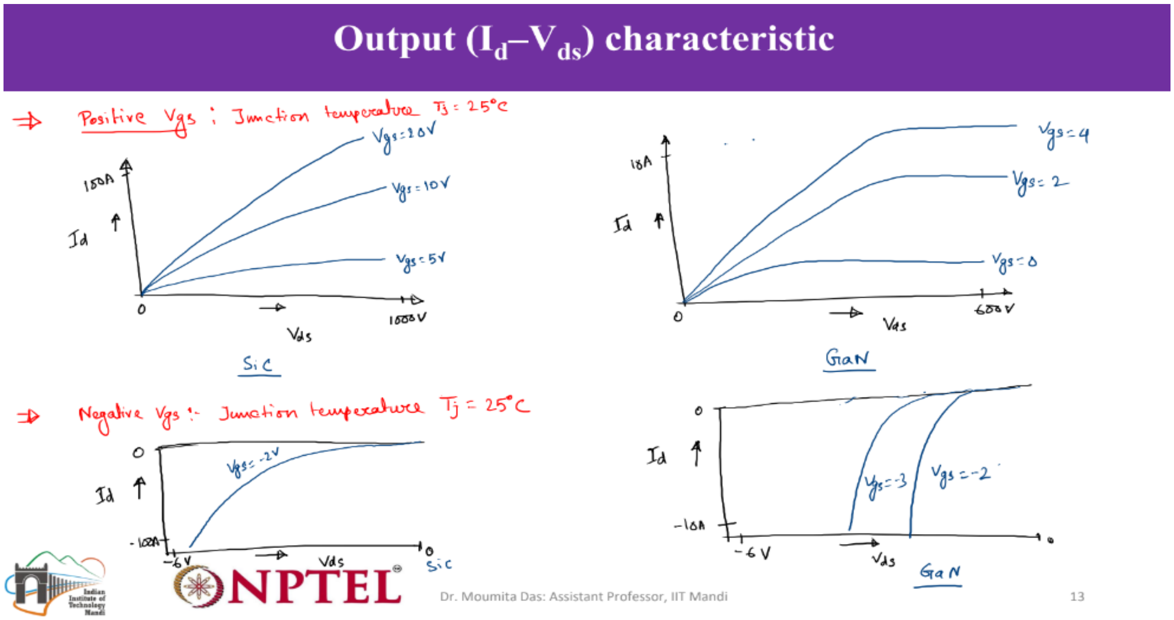
And third is the gate current characteristics. So, what is the value of gate current with respect to different voltage at gate to source that characteristic and then fourth is the drain to source leakage characteristics.

Refer slide time (22:35)



So, this first characteristic is the Id versus Vds. So, drain current with fixed gate voltage and varying drain to source voltage we can characterize by this method. So, output characteristics, curve source, ohmic saturation and body diode region. So, reverse conduction varies with the gate voltage should be characterized over a range of gate voltage and temperature. And on-state resistance also we can measure from this particular characteristics. Silicon carbide MOSFETs and GaN have unique on-state characteristics and require specific characterization method. So, these are the different things which we can achieve in this particular characteristics.

Refer slide time (23:29)



So, let us see how this characteristics looks like. So, when we are saying output characteristics basically Id versus Vds.

So, then as I told you in the previous slide the gate to source voltage is kept constant right. So, let us say first. So, this first one characterize this Id and Vds with respect to different gate to source voltage. So, let us consider positive Vgs we are considering in this case. So, now how this characteristics looks like? As I told you we are characterizing the device basically we are measuring the drain current with respect to so it is positive it is increasing in the positive direction.

So, with respect to different voltage level Vds okay so Vds will increase from 0 to let's say maximum for 1000 volts and drain current will increase let's say 0 to 100 amperes so this is increasing like this this is increasing like this now The important thing is that Vgs need to be constant. Now Vgs if it is constant so then let's say the characteristics looks like this. So Vgs is constant. So this is let's say Vgs equals to 5 volts.

Now this if I consider for silicon carbide device. Now, silicon carbide device we can have maximum gate to source voltage 20 volts. So, then if we try to increase this Vgs, so then what will happen? This current will also increase. So, let us say this is with respect to Vgs equals to 10 volts and then again it will increase with respect to let us say 20 volts. So, this is how the characteristics will vary.

So, you can see here, so Vds as for any particular Vgs. if we keep it either 5 volts or 10 volts so then as the drain to source voltage is increasing how the current curve looks like that we can plot in this in this case very important thing is that junction temperature is constant so in this particular this positive vgs we are keeping here the important thing is that junction temperature, junction temperature Tj constant. Let us say Tj equals to 25 degree Celsius. That is constant. That we are not varying and we have to regulate that.

That is also very important. If we are not varied that does not mean that we cannot we should not check that what is the junction temperature. We always have to maintain at 25 degree Celsius. Otherwise these characteristics will change. Now this is with respect to silicon carbide device. Now similarly we can also plot the For GaN device, it is also the similar thing.

So, ID we can plot here in the Y axis and Vds it is in the X axis. So, similarly for Id let us say for drain current it is 10 ampere maximum and Vds let us say it is around 600 volts. It is increasing like this. Now, gate to source voltage for GaN it is different.

So, then Vgs will also be different. So, let us say after this, this is reaching to steady state and then this is here Vgs equals to 0. Similarly, we can provide Vgs, let us say it is equal to 2, Vgs equal to 2. Now, it is equals to 4. So, this we can actually try to, so you can see here, so 10 ampere will be corresponding to 4.

So, like this we can actually plot different devices. So, this is with respect to GaN. Now, you know that this gate to source voltage, here it is shown only positive. In case of silicon carbide and GaN it is advisable to provide lower voltage in gate to source as negative means in case of silicon it is like 0 to 15 means the voltage remains in the positive side but in case of GaN and silicon carbide the voltage ranges can vary let's say from minus 4 to 15 volts or minus 2 to plus 4 volts like this so this is this characteristics with respect to positive but if we provide negative gate voltage, then how the characteristics will look like. So, let us see that. So, here also, here we are providing negative Vgs and junction temperature we are keeping constant.

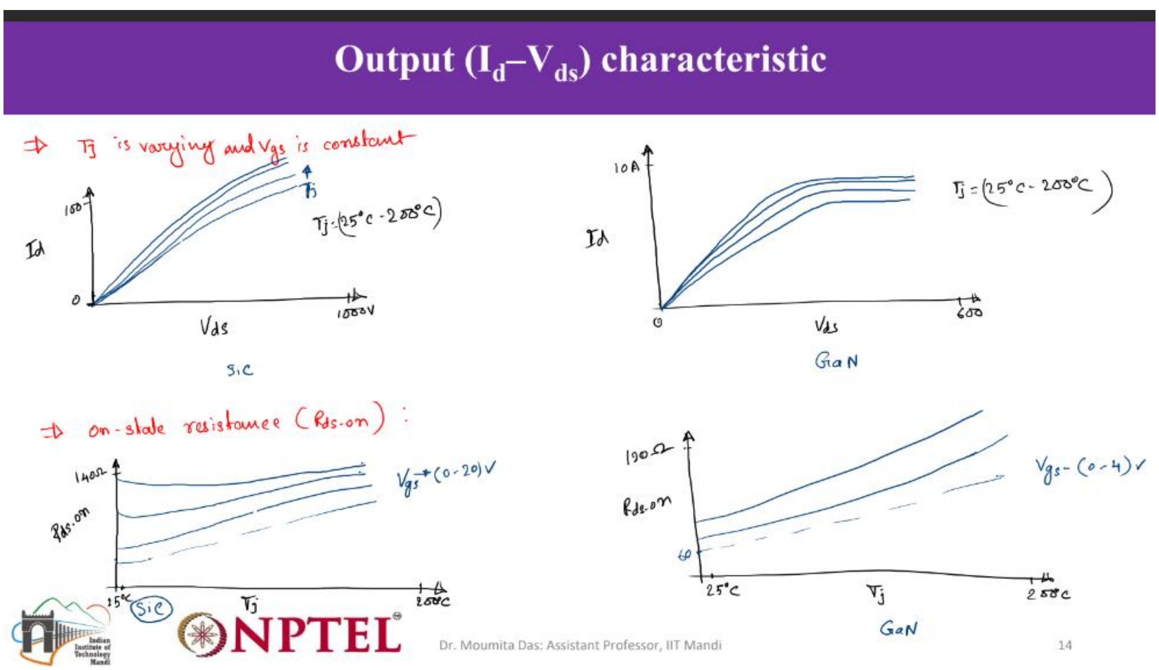
Temperature Tj , Tj just a minute. Tj equals to 25 degree Celsius as the previous one. Here we are actually considering negative voltage. So, then negative voltage if we are considering So, then Id should be negative and Vds also should be negative. Now, Vds let's say it is varying from Vds it is varying Vds here it is varying from 0 to maximum of let's say minus 6 volts and Vgs we are varying.

So, Vgs if we have to provide certain voltage. So, let us say we start from 0 and then we go to the negative voltage level. So, then the current level also will vary 0 to let us say minus 100. This is with respect to Id. So, Id is increasing like minus 100 to 0 and Vds is increasing minus 6 to 0 volts. So, Vgs if we consider some voltage level, let us say Vgs equals to initially it is providing, we are providing Vgs equals to minus 2 volts.

Similarly, if we provide Vgs equals to minus 4 volts, similarly we can get sets of characteristics. This is with respect to the silicon carbide device. Now if we consider the GaN device we will also get similar kind of behavior. Now GaN device if we try to plot so then what will happen. So similarly we can get like Vds it is like starting from 0 here Vds and it is going to maximum.

not maximum minimum minus 6 volts so in this direction it is increasing and current it is like id so current level it is starting from 0 here and in this direction it is actually decreasing to minus 10 ampere so this direction it is increasing so now if i try to plot the characteristics by changing the gate to source voltage so with respect to different gate to source voltage the characteristics will be like this so it will go like this okay as the as the gate to source voltage will change so it will change like this so Vgs will be let's say Vgs will be equals to let us say here it is equals to minus 2, here it is equals to Vgs equals to minus 3. So, like this it can actually go to left side. So, in this case it is actually going from like 0 to minus 2 in this case of silicon and this is with respect to the GaN device. So, this is how the characteristics will look like for positive and the negative gate voltage.

Refer slide time (33:08)



Now, In these two conditions temperature was constant parameter. But for any application temperature may not be constant all time actually it is not constant all the time. Temperature will also vary and also we can have a condition or we can actually if we certain application we need to see the characteristics of the device. at different temperature level then we have to see the data sheet where that different temperature related characteristics is provided. If certain sets of characteristics is provided from there we can actually get the required value at least we can have the idea how the characteristics or how the values will change. So, that is why now it is important to see how the characteristics will be for different temperature.

now, I told you the circuit which you can actually develop in order to characterize the device. But if you have to provide the temperature, then what you have to do? You have to either use oven or the hot plate to provide the required temperature. oven or hot plate if you provide the temperature, if you set the temperature it will give that temperature characteristics, okay. So, that you need to use if you want to get temperature related characteristics, okay.

So, now let us consider this case. So, in this case temperature Tj is varying Vgs is constant. So, we get Id versus Vds characteristics. So, now how this characteristic will look like? We consider Vgs is constant and positive. In this case Vgs is positive. So, now Id as it is varying let us say 0 to 100 similar device we are considering as the previous one.

This V also varying 1000 volts Vds. Now let's say conditions we are considering Tj where it is varying from 25 degree Celsius to 200 degree Celsius. So we can have sets of characteristics. Means one at 25 degree Celsius, another at 50 degree Celsius, another 75, then 100. Like this we can actually get the characteristics till 200.

So how it will look like? So then the characteristics will look like. So basically it will have this kind of characteristics. So then it will not vary much. Means Like this it will look like.

So as the temperature is increasing Tj. So this different values will change. Definitely change. Current and voltage values will change. But the variation will not be as much as it is with respect to Vgs.

So this is with respect to silicon carbide. And this one let's say with respect to GaN. So, we are taking the same device, same GaN device, let us say 0 to 600 volts Vds and here it is varying 0 to 10 ampere Id and considering the same junction temperature condition that is Tj varies from 25 degree Celsius to 200 degree Celsius. Okay. So then how it will vary? So it will vary similarly like the previous case but the variation will have slight change. Not much change will be there.

So with respect to temperature different characteristics we will get. Okay. Now this is Tj is varying and then you are getting different characteristics of GaN and silicon carbide. this is with respect to GaN device. Now we have the characteristics of the device basically Id and Vds with respect to different temperature and different gate to source voltage condition. how to find out on state resistance because on state resistance will also come from this to this experiment this different parameters only so then if we try to find out on state resistance let's say on, Rds-on so then how we can get So this Rds-on means it is having the information of Id and Vds.

So this we can actually plot. And this will change with respect to temperature. Then junction temperature with respect to that only we have to plot. So this is 0 and this is junction temperature let's say maximum 200 that is what we have considered. And this Rds-on let's say for silicon carbide it is varying. 0 to 140 ohm so then how this is looks like so another important parameter here will come gate to source voltage if gate to source voltage we are varying from 0 to let's say 20 volts positive voltage we are considering here negative voltage we are not considering in this case 0 to 20 volts So then the characteristics will look like, so basically as the temperature will change, so then different characteristics will be like this.

So, like this the resistances will change. So, in steady state, so basically after reaching certain temperature the resistance will be constant. Initially if we are considering 25 degree Celsius probably in that time the resistance will be much higher. As the temperature is increasing resistance will go to the steady state value. It may be more or it may be less depending upon the gate voltage condition.

So, this is with respect to the silicon carbide device. This is for silicon carbide. And when we are considering the GaN device, so again the same parameter we are considering Tj equals to 0 to 200 volts, sorry not 200 volts, 200 degree Celsius and here Rds-on also we are getting. So, in case of GaN this Rds will be much higher. lower so basically here instead of considering zero we can consider 25 degree celsius because you know when we are considering this temperature so the minimum temperature we can get room temperature here now this is let's say 120 ohm So, constant resistance in this GaN it is considered lower than that of the silicon.

So, here it is starting from let us say 60. So, then the characteristics will look like this. So, one thing you can see from here at least. So, here also Vgs is varying. Vgs is varying from 0 to 4 volts, positive volts. So you can see as the temperature is increasing in case of GaN So the on state resistance is increasing.

In case of silicon carbide it is not like that. It is very different. So that is why this information we can get only if we characterize this. Otherwise we get the constant value. In the data sheet generally what they do they give one value and also the electrical specification for that particular value is given. But if we want to select different specification that we cannot get if we don't have this kind of characteristics. So that is why this kind of characteristic is very important.

Refer slide time (42:35)

Transfer (I_d–V_{gs}) characteristic

- The drain voltage must be high enough to keep the device in the saturation region throughout the gate voltage range.

  $V_{ds} > V_{gs(max)} - V_{th}$

- Effective drain voltage should be chosen from the saturation region of the output characteristic.
- The transfer characteristic should exclude the ohmic portion and focus on the cutoff and saturation regions.
- Three key parameters identified from the curve: forward transconductance (g_m), threshold voltage, and Miller voltage.
- These parameters are essential for modeling device behavior and dynamic characterization.

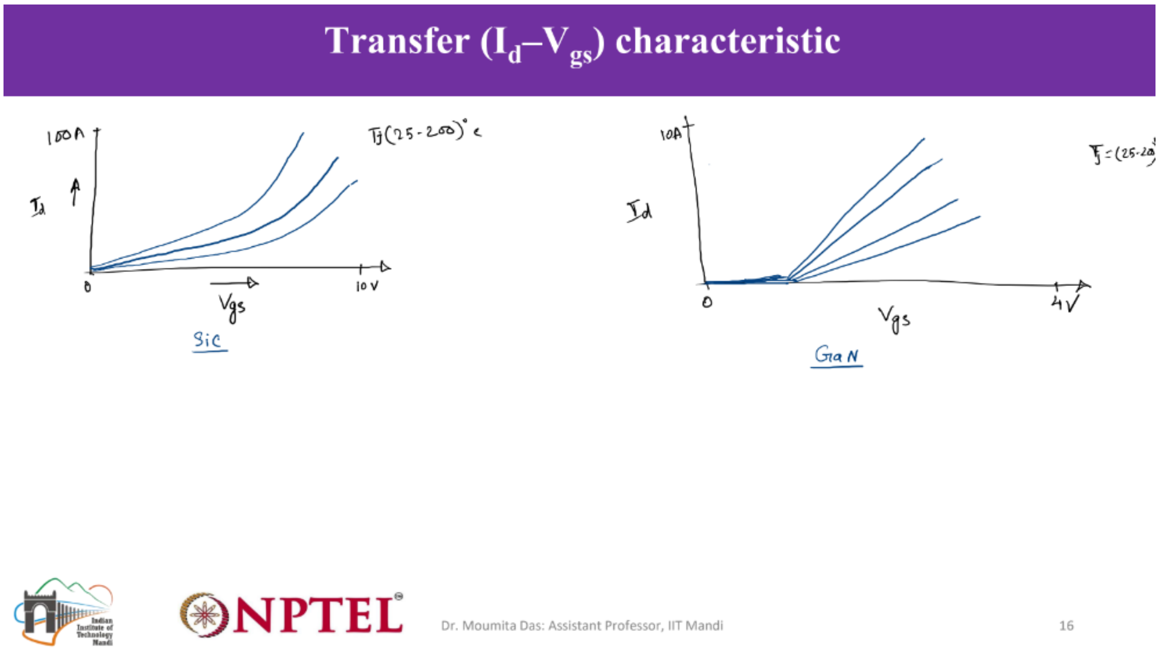
NPTEL Dr. Moumita Das: Assistant Professor, IIT Mandi 15

So, now the second characteristic is the transfer characteristic. So, what we get in transfer characteristics? We get Id-Vgs. curve so why it is required so the drain voltage must be high enough to keep this device in the saturation region throughout the gate voltage range so in this case we have to choose a condition so where the drain to source voltage we have to apply because in this case we will be varying vgs and we will be actually measuring id And here we can consider different temperature. But what should be the value of Vds? So, the for that what we have to consider? We have to consider a condition where Vds just a minute.

So, I should use different color so that it will be visible. So, Vds should be greater than Vgs max minus Vth threshold voltage of the gate. So, this is the voltage we have to consider for this characteristic. The effective gate voltage should be chosen from the saturation region of the output characteristic. The transfer characteristic should exclude the ohmic portion and focus on the cutoff and the saturation region. Three key parameters identified from the curve, so that is the forward transconduction, transconductance, threshold voltage and the miller voltage.

So, this parameter is very very important for designing gate driver for the device. So, that is why this parameter we will get from this transfer characteristics and this comes under static characteristic. These parameters are essential modeling of the device behavior and the dynamic characterization. we can design the gate driver from this characteristic and also this is important for dynamic characterization. So, that is why the static characteristics should come first. Once we have this information from the static characteristics, then only we can go for the dynamic characterization.

Refer slide time (44:48)



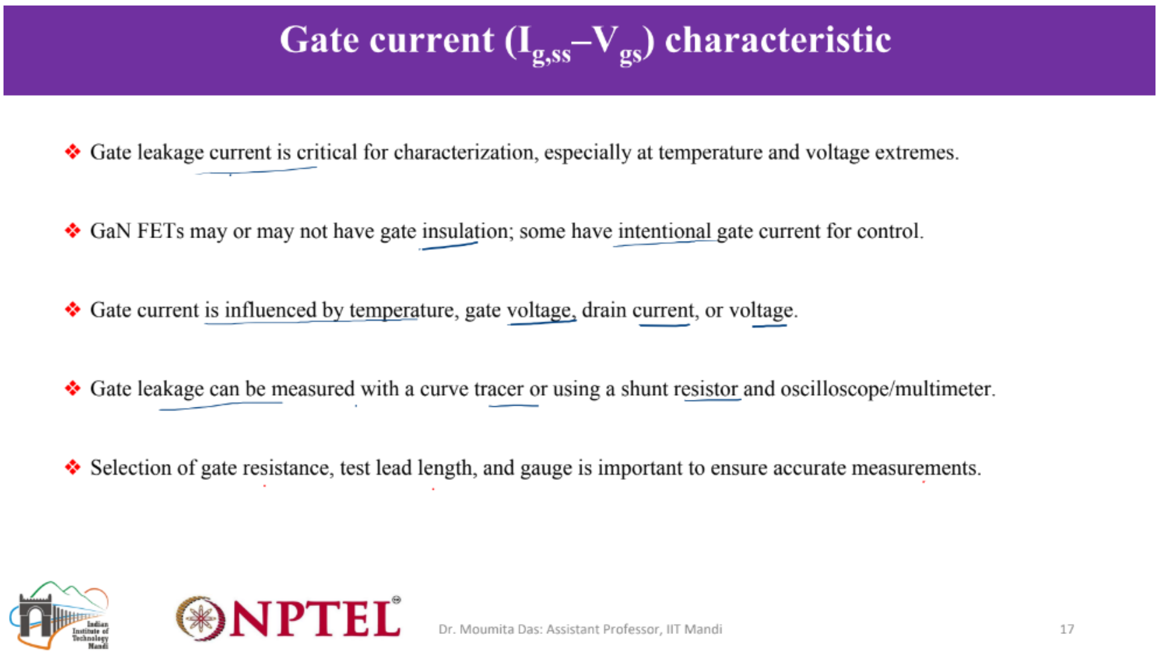
So, now let us see how this characteristic looks like. So, we are considering this condition. So, here we If we want to characterize this silicon carbide device first, so the silicon carbide device the Vgs is varying say let's say 0 to 10 volts and now Id is varying 0 to let's say 100 ampere. Here then for different temperature we can consider junction temperature of the device. Let's say 25 to 200.

This condition we have used for the junction temperature. Then the characteristics will vary like this. like this the drain current will vary with respect to the gate to source voltage for silicon carbide device. The Vds already I mentioned how much should be the Vds so that Vds we have to consider. Now for GaN device. We can choose the same device as the previous one.

So, the GaN device Vgs obviously it will be much less than that of the silicon carbide device. So, 0 to 4 volts and obviously drain current will also be less. Let's say 0 to 10 ampere. So, then as the temperature is varying Tj similarly it is varying from 25 to 200 degree Celsius. So, then the characteristics will vary like this.

It will be constant for some time, then it will increase like this. Similarly, it will be constant for this time and then it will increase like this, then this, like this it will change. So, these are the different characteristics of the GaN device. So, what are the things you will get? Miller voltage, threshold voltage and then transconductance. So, these are the parameters you will get from these characteristics.

Refer slide time (47:25)

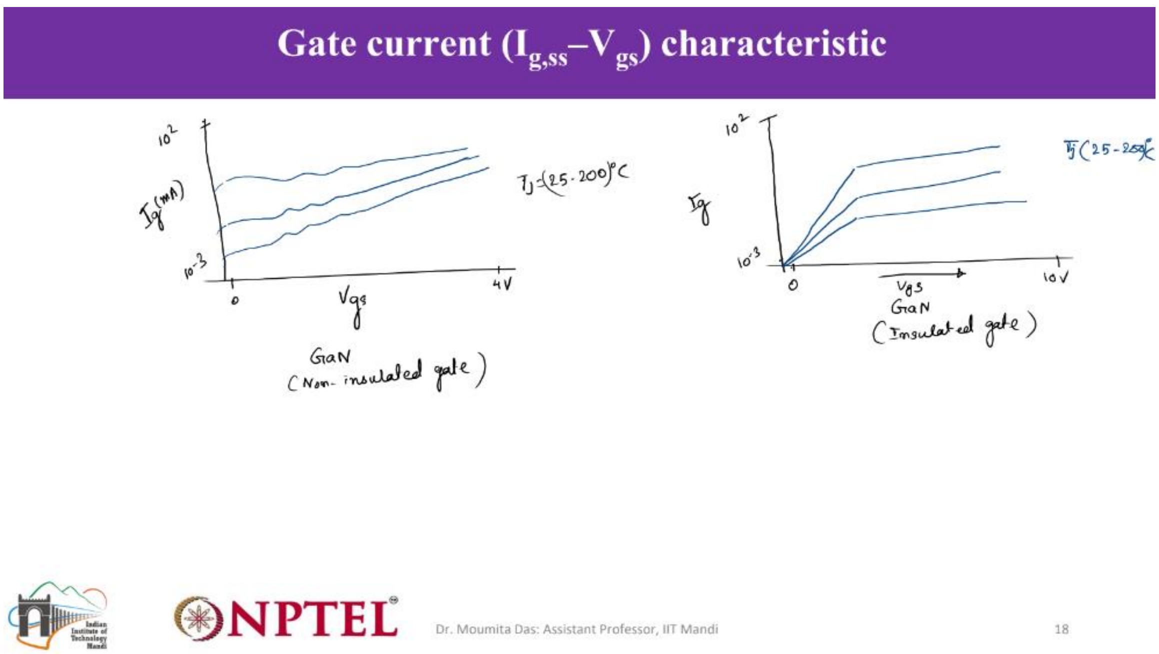


Now, we have another important characteristics that is gate current. So, what should be the value of gate current with respect to Vgs? As we are varying Vgs, the gate current should also be variable. How it should look like? This we can actually get from this characteristic. So, the gate leakage current this is very critical for characterization specially at temperature and voltage extreme points.

So, how much it will change so that we need to know. The GaN FET may or may not have gate insulation. Sometimes we have insulated gate or like non-insulated gate in case of GaN and some have intentional gate current for control. The gate current is influenced by temperature, gate voltage, drain current and voltage. gate leakage current can be measured with a curve tracer or using a shunt resistor so in the previous slide so if you remember i have a shown one resistance so this, before this actually you can see i'm just going back to show you this resistance so you can see here this shunt resistance so this shunt resistance is used here.

So, this can be used to measure the gate current. So, this is shunt resistance with respect to Vds. So, here the gate resistance is placed. So, this will give us Ig. So, basically this Id leakage current of the drain it can be measured by this shunt resistance and the gate current can be measured by this gate resistance. So, this is what this same setup we can use for this characterization as well okay so now selection of the gate resistance test lead length and gauge is very important in order to ensure the actual measurement.

Refer slide time (49:18)



So now how this characteristics looks like so in order to draw this characteristic so this is with respect to the Vgs so we are considering non-insulated gate for GaN device.

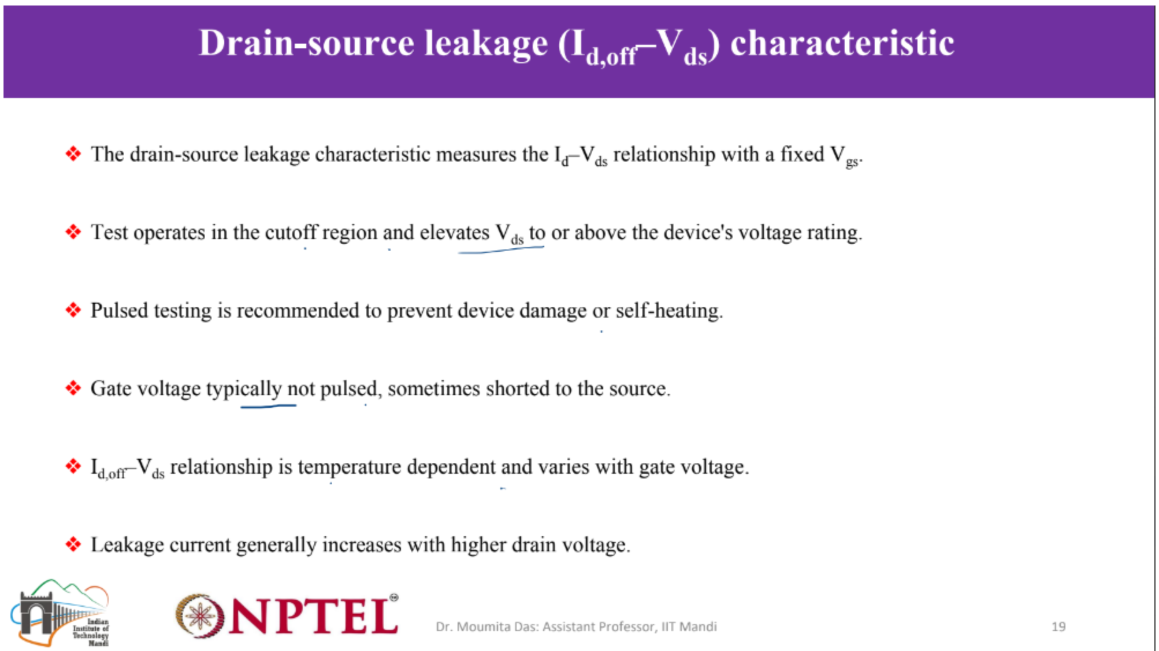
So, GaN device we are measuring. So, this is non-insulated gate. So, then Ig we can measure here. So, it will be in milliampere. And it is varying let's say from minus 10 to the power minus 3. So here it is varying from 0 to let's say 4 volts. 10 to the power minus 3 to 10 to the power 2 milliampere.

So if the temperature, junction temperature is varying from 25 to 200 degree Celsius. So how it will vary? It will vary like this. initially some oscillation will be there. So, then it will reach to the steady state value with respect to different temperature. This is for non-insulated gate. Now, if I consider insulated gate, so then the voltage for the GaN device only the insulated gate if I consider So the voltage we can have higher range.

Let's say 0 to 10 volts Vgs. And then similarly this is varying 10 to the power minus 3 milliampere to 10 to the power 2 milliampere.

This is Ig. Okay. So then this will vary like this with respect to different temperature. so it will vary like. So, here junction temperature similarly it is varying from 25 to 200 degree Celsius. This is with respect to gate current.

Refer slide time (51:35)



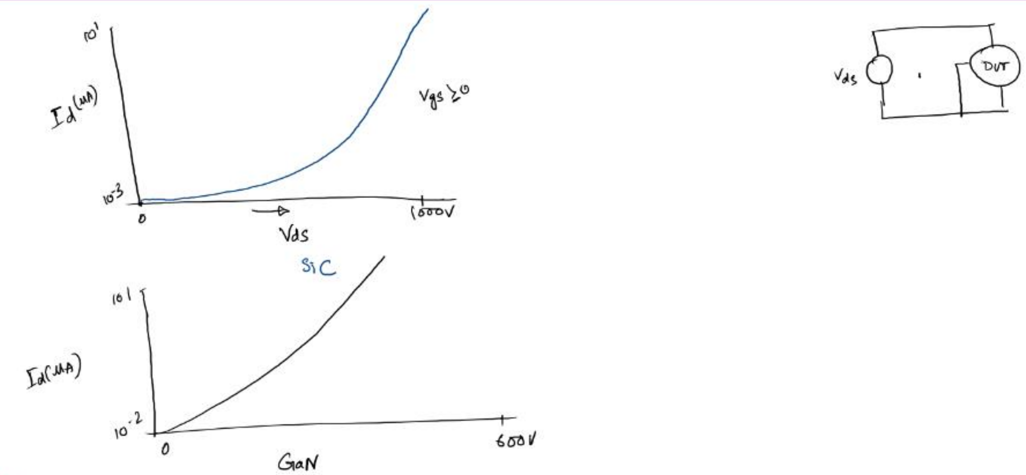
Now, another or the last characteristic which we can achieve from the static characteristics that is drain source leakage current characteristics. So, this drain to source leakage current measure the Id-Vds relationship with a fixed Vgs.

The test operates in the cutoff region and elevates Vds to above the device's voltage rating. Pulse testing is recommended to prevent the device damage or self-hitting as it is the requirement for static characterization. Gate voltage typically not pulse sometimes sorted to the source. So, the idea of Vds relationship is temperature dependent and varies with gate voltage. And leakage current generally increases with higher drain voltage.

Okay, so then, so these characteristics, so basically if I have to show you the characteristics, so let me draw in the next slide.

Refer slide time (52:30)

Drain-source leakage ($I_{d,off}$–V_{ds}) characteristic



NPTEL Dr. Moumita Das: Assistant Professor, IIT Mandi 20

So, here this drain characteristics as I told you. So, it is Vds will be varying. So, that depends upon the device rating let us say 0 to 1000 volts for the silicon carbide device same device we are using here. So, this is increasing here. and then we have to consider one Vgs so like Vgs should be constant in this case so the let's let me consider any value of Vgs any positive value of Vgs greater than zero and then id it will vary so here in this case Id will be micro ampere so it is micro ampere so the leakage current will be in micro ampere so this will vary let's say 10 to the power minus 3 to 10 to the power 1 micro ampere so this characteristics as the drain voltage is varying if we haven't provided in gate voltage since we are provide not we are not providing the gate voltage so gate terminal we can actually short it means the drain to source voltage we are providing here Vds here with after this like this device under test we are providing drain to source voltage device under test DUT So, then what we can do? We are not providing gate to source voltage.

So, gate to source voltage we can provide constant or we can just short the gate terminal. Either Vgs should be equal to should be greater than equal to 0. We can provide 0 voltage also. How we can provide this 0 voltage? If we short this.

Okay, we are not providing any voltage. So, then we can achieve this leakage current characteristics. So, how it will look like? It will look like this. As the voltage is increasing, the leakage current value will increase.

Okay, it will start from micro ampere. So, that is very less. This is for silicon carbide device. And similarly for GaN device also you will get similar type of characteristics. It will also look the similarly. So basically 0 to 600 volts if I consider for GaN.

And this will also be in the micro ampere range. So it is let us say minus 10 to the power 2 to 10 to the power 1. So it will be slightly different will be there. So it will be like this. This is for GaN. So, this is how we can actually you can get drain to source leakage current and how it will vary with respect to different voltages.

Refer slide time (55:10)

Drain-source leakage ($I_{d,off}$–V_{ds}) characteristic Cont…

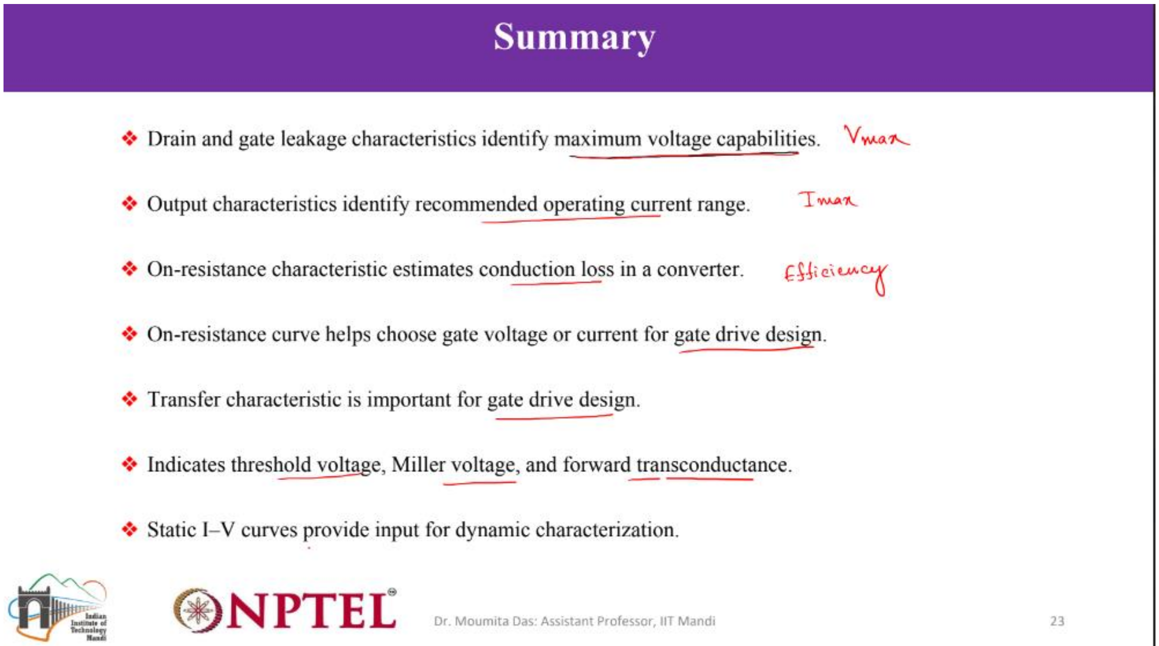
- The characteristic shape differs between GaN FETs and MOSFETs.
- Breakdown voltage is extracted by setting a current threshold.
- GaN FETs do not have a clear breakdown voltage due to lack of avalanche breakdown.
- Manufacturer guidelines should be followed to avoid gradual dielectric breakdown in GaN FETs.
- Pulse settings should balance accuracy and device protection to prevent self-heating or damage.

Indian Institute of Technology Mandi NPTEL Dr. Moumita Das: Assistant Professor, IIT Mandi 21

So, these are the different characteristics you can see. Just a minute. This is repeat slide. Okay. So, now you know. So, this characteristic step different for GaN FET and MOSFET. Breakdown voltage is extracted by setting a current threshold. GaN FET do not have a clear breakdown voltage due to lack of avalanche breakdown. Manufacturer guidelines should be followed to avoid gradual dielectric breakdown in GaN device.

The pulse setting should be balanced accuracy and device protection to prevent the cell fitting and the damage for this particular characteristic.

Refer slide time (55:50)



so okay so these are the different characteristics you can get from the static characteristics so ultimately what we achieve so we we know different things we have different characteristics we know the procedure for static characteristics we know the basic things that will be achieving voltage current and the drain to source resistance so why we need this so basically Drain and gate leakage characteristics identify maximum voltage capabilities of the device. So, this is the first thing we notice in the data sheet. Maximum voltage, how much it is? Vmax or Vbreakdown voltage.

Output characteristics identify recommended operating current. So, Imax or Irated current. On-state resistance characteristics estimate the conduction loss. conduction loss, so it gives us like what should be the loss during the conduction. So, this is required for efficiency calculation. And on state resistance curve helps to choose gate voltage current for gate driver design as well.

This is very important because otherwise I mean like this dynamic characterization we would be able to do using this gate driver. Transfer characteristics is important also to design the gate driver. This also indicates threshold voltage, miller voltage, forward transconductance. Static I-V curves provide input for dynamic characterization. So, this parameter we get first and then we go for dynamic characterization. This is the reference for this particular lecture. Thank you.