Design of Power Electronic Converters
Professor Dr. Shabari Nath
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati
Lecture 11
Diode Datasheets

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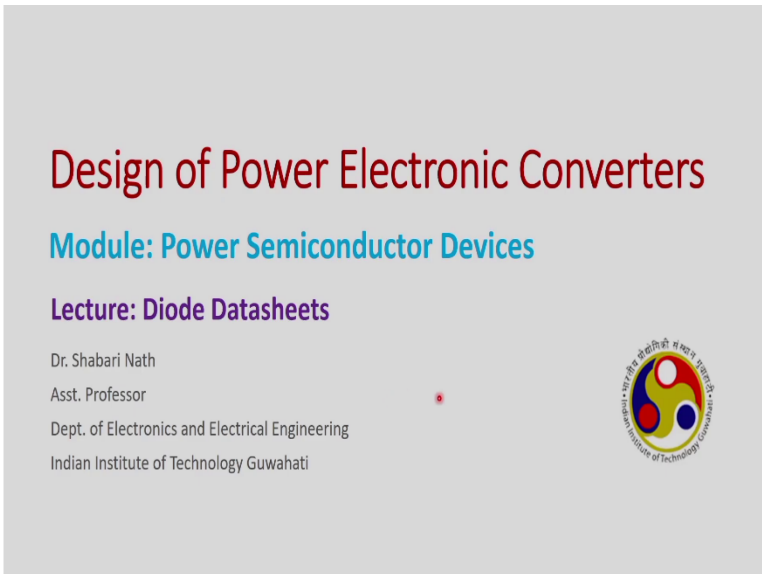

So, welcome back to the course on Design of Power Electronic Converters. And we were discussing the module power semiconductor devices and we had started with diodes. And there we saw the different types of diodes and also the vi characteristics and switching characteristics of the diodes.

Now, let us look into the terms, which are mostly given in data sheets. So, in this lecture, I will be telling you what are the important notations in data sheets, which you should be looking for while choosing your diode for your design.

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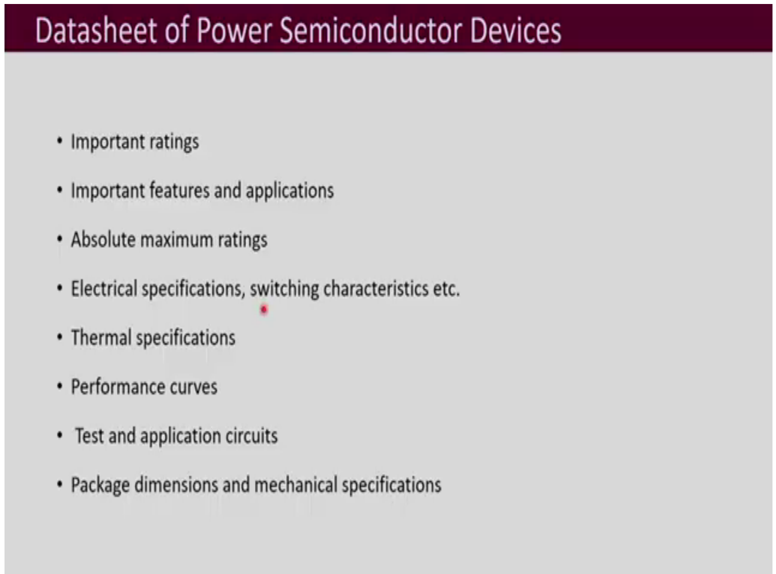

So, a data sheet of power semiconductor device usually has got the important ratings. And it will also contain the important features and applications. The device manufacturer generally will specify for which type of application the device has been designed. And what are the important features or the key features of that device.

Then the manufacturer will also provide the absolute maximum ratings for that device, every device can withstand below a particular level of different specifications of different parameters. So, those will be specified, the absolute maximum ratings. Then there will be electrical specifications related to switching characteristics or several other specifications.

Then there will be thermal specifications as well like what are the thermal resistances, different thermal resistances and curves related to that, they will be also provided by the manufacturer. Then there will be several performance curves, different types of performance curves may be provided by the manufacturer depending on the device and also depending on the applications for which the device is designed for.

Then there may be also some test circuits and application circuits and some other information related to the device that may be provided in the data sheet. And then finally the data sheet will also provide the packaging information of the device and the mechanical specifications, its dimensions, that information is also there in the data sheet. So, data sheet is a document, which is very important for choosing your correct device for your power electronic converter design.

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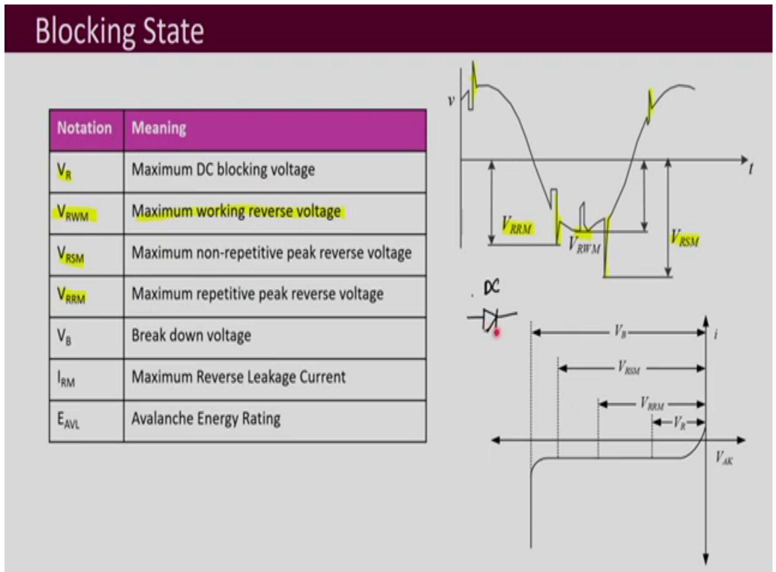

So, we will be now looking into what are the notations in the data sheets, which are important for diodes. So, blocking state of the diode, when we discussed vi characteristics, we just said that there will be a breakdown voltage, after which the diode basically is not able to do the reverse blocking. So, when you look into the data sheet, there you will not be seeing most of the time only one breakdown voltage, but several of the voltages associated with the reverse blocking state of the diode.

Now, what happens is that, what we usually think theoretically is that, that a very nice sinusoid is what the diode will be withstanding. But in actual practice that may not happen, it may have some glitches, some surges, some kind of transients that may be occurring in it, it may not be a very good sinusoid, that the diode has to block. In that case a few of the terms, that can be noted down are like this voltage, which is like the peak of the sinusoid, the negative peak of the sinusoid, which the diode is going to block every cycle without any transients or glitches or surges coming in.

So, that blocking voltage is denoted as V_{RWM}, the maximum working reverse voltage. It is working reverse voltage, that means this is the working reverse voltage that you expect theoretically to come out. And then there may be some surges, that may be coming up some glitches or transients that may be coming up, glitches in the sinusoidal waveforms.

So, those may be repetitive like this you can see here, there may be some power quality issue or some other problem and you can see repetitively there may be some glitches, that may be coming out which the diode has to withstand. So, that is V_{RRM}, it is a repetitive voltage, but the diode has to withstand it for a very, very small duration also. And it may not happen every cycle, some cycles it may be there after that it may disappear. So, this is called as the maximum repetitive peak reverse voltage V_{RRM}.

Then there may be surges, which may be peak reverse voltage, which may come once in a while. So that is V_{RSM}, maximum non-repetitive peak reverse voltage, which the diode will be able to block. And also, sometimes in datasheet you will see this maximum DC blocking voltage, that means if you apply continuous DC across this diode, then what is the voltage that the diode will be able to block?

Now, what is the difference here? If you see when you apply DC, it has to block that continuously, it is a DC, flat DC, that you are giving continuously it has to block. Whereas, when you see these sinusoidal voltages, this is something repetitively every cycle the diode will have to block, it is working voltage or it is the voltage that you expect. And there may be some repetitive surges or glitches that may be coming, transients which is for a very, very short time period it has to withstand, that is repetitive peak reverse voltage. And then there may be this kind of peaks which are non-repetitive.

So, the period for which the diode has to withstand those voltages are also relatively lesser. So, here this can be the relative magnitudes of these, this is in the reverse blocking state, DC blocking voltage, this magnitude can be somewhere here, then repetitive peak reverse voltage can be greater than that and non-repetitive peak reverse voltage can be even higher than that.

And then after that will be breakdown voltage, it is denoted as V_B. And there may be a small leakage current, that may be there through the device while the device is blocking, while the diode is blocking, that is maximum reverse leakage current I_{RM}, that also is given in the data sheet many times. Then sometimes in the data sheet, this specification is also given called as avalanche energy rating.

Now, what happens is that this diode not always, if you exceed the voltage ratings, immediately it will break down, it may not happen so it can withstand a certain amount of energy, which is called as avalanche energy. If it is the energy associated at that time and the current through it during the time is lesser than those avalanche ratings, then the diode may be able to still survive. So, those avalanche energy ratings are also many times specified in the data sheets.

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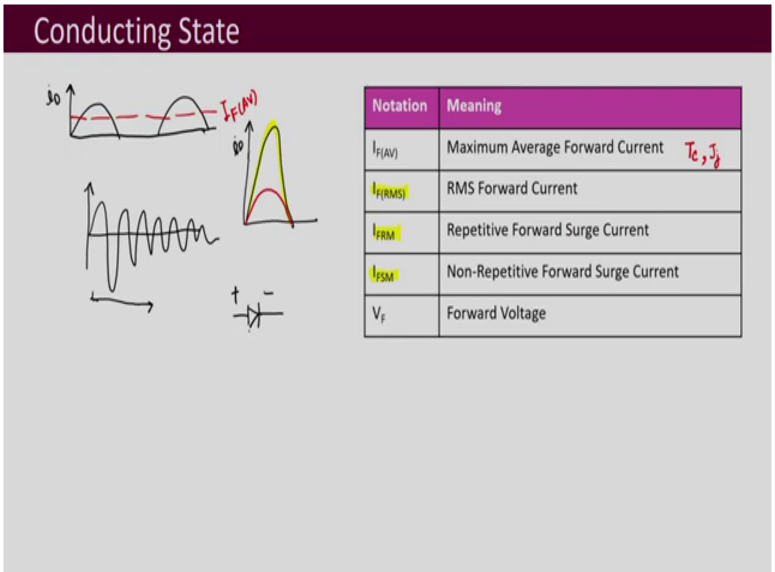

Notation	Meaning
$I_{F(AV)}$	Maximum Average Forward Current
$I_{F(RMS)}$	RMS Forward Current
I_{FRM}	Repetitive Forward Surge Current
I_{FSM}	Non-Repetitive Forward Surge Current
V_F	Forward Voltage

Then if we look into the specifications related to conducting state of the diode, first you will be mostly seeing maximum average forward current. Now, what is the specification there? Let us say you give these half sin waves to the diode, which the diode has to carry and this is the diode current i_D and if you do the average of this half sin wave, you find out the average, so that is $I_{F(AV)}$ is what is mentioned in the data sheet.

Now, usually it is provided with respect to a temperature. Case temperature or junction temperature, that may be provided with $I_{F(AV)}$. The average forward current, which the diode will be able to carry.

And then there are also specifications given for RMS forward current. Now, RMS forward current is usually associated with the thermal or the heating of the diode, so it is mostly physical limit, what this RMS forward current will be representing. And then if repetitive forward surge current I_{FRM}, these specifications are also given sometimes in the data sheets.

So, what it means is that, when you have let us say a rectifier application, so there may be these kinds of transients for few cycles. So, few power frequency cycles, the diode will be carrying current, which is much higher than normally what it is supposed to carry. Let us say the normally it is supposed to carry this much of forward current, but when some transient is going to come, then it has to carry this level of current, for few power frequency cycle, 50 Hz cycles or 60 Hz cycle, it will have to carry much higher levels of currents.

So, these are repetitive in nature and after that what is expected is that the diode will come back to its normal state of operation. So, the converter will resume its normal of steady state operation. So, that specification is given as repetitive forward such current I_{FRM}, because it is repetitive and it is a surge current, this will be much higher than normal average current rating of the diode. And the diode does not have to withstand for more duration, it is only for few cycles.

Then there may be situation, where there may be a fault, let us say if a short is happening, so at that time this duration may be much lesser than the duration of this repetitive surge current. So, for very small time the diode may be able to withstand even currents higher than this I_{FRM}. So, that is denoted by this I_{FSM}, non-repetitive forward surge current. And after withstanding this non-repetitive forward surge current, it is expected that the system is actually going to shut off or it is going to disconnect it from the supply. So, these are for much shorter duration, non-repetitive forward surge current.

Then V_F, forward voltage, the maximum forward voltage. So, while the device is conducting V_F voltage appears across the diode and that is the maximum forward voltage drop that may be there and that also is given.

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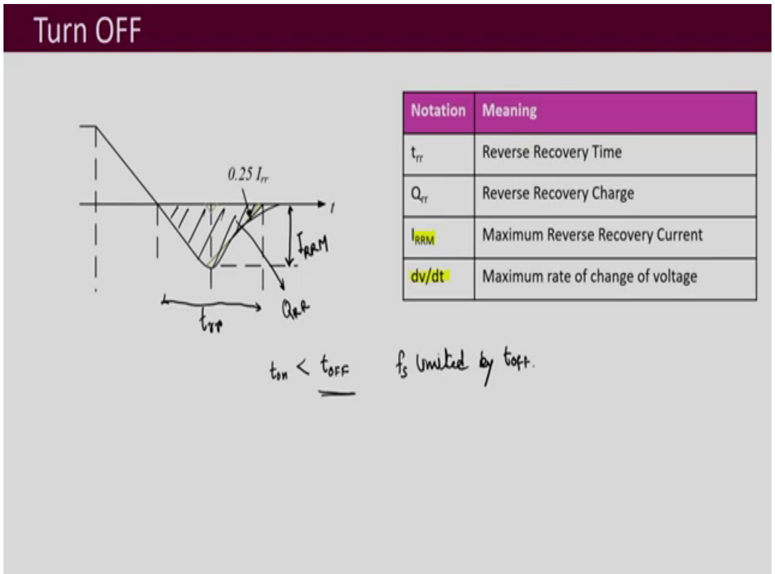

Then in the data sheet notations related to turn off of the diode are mostly specified. So, t_{rr} reverse recovery time, this we have already seen it. So, t_{rr} is reverse recovery time t_{rr}, that will be provided in the data sheet. And then whatever is the charge associated with this region, that is Q_{RR}, the reverse recovery charge, this also we have discussed, when we discussed the switching characteristics.

So, reverse recovery charge is usually also specified in the data sheets of fast recovery diodes. In rectifier diodes this may not be specified, because rectifier diodes are slow diodes and these turn on and turn off times are not of so much importance. Then this current that is associated with the reverse recovery process, the maximum reverse recovery current I_{RRM}, that also will be specified in the data sheet.

Then there is $\frac{dv}{dt}$ limit, that is the maximum rate of change of voltage across the diode, which the diode will be able to take or which is allowed, that also is sometimes provided in the data sheet. Some of the data sheets they give this $\frac{dv}{dt}$ limit.

Now, turn on times and forward recovery time, many of the data sheets they do not provide it usually. And the reason for it is that, we have seen before t_{on} time of diode is smaller than t_{off} time. So, the switching frequency of the diode is limited by this t_{off}, so f_s is limited by t_{off} and so that is why it is usually the t_{off} time when the reverse recovery time is provided. This Q_{RR} and I_{RRM}, they are more of a concern in many of applications of fast recovery diodes.

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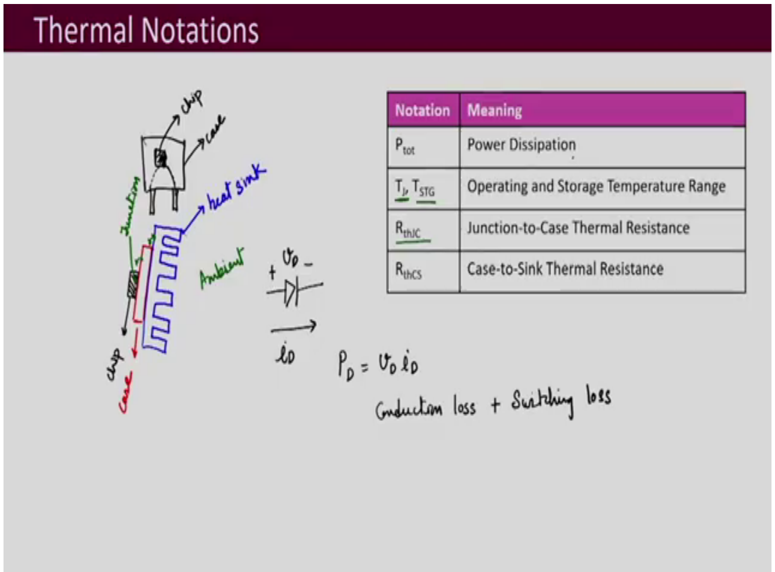

Now, another set of notations, which are given in the data sheets is related to thermal performance of the diode. So, to understand that you have to know that, usually in a semiconductor device there is a chip and that is actually the semiconductor device and then it is put inside a case and then there are usually pins, which bring out those terminals.

So, if we show it like this, this is the chip let us say and then there is this casing, so this is case and this is chip and then you will have a heat sink. So, this is heat sink, which will be there for cooling. Now, there will be thermal resistance corresponding to each of these joints. So, there is this thermal resistance corresponding to our junction to case. So, here what you have is, what is called as the junction and it is the junction temperature of the semiconductor device which is of a lot of importance, because if you exceed the junction temperature, then device may get damaged, it will get destroyed.

So, that is junction temperature T_J, which is provided in the data sheets and there may be a storage temperature range also that also may be given. And this junction to case thermal resistance is provided in the data sheet, that is the thermal resistance for the cooling. So, junction to case there is one thermal resistance. And then case to sink, there is another thermal resistance and sink to ambient, so this is your ambient. So, it also has a temperature, which you can also call as the room temperature, but ambient temperature may not be always the room temperature, it depends on what environment the converter is being operated.

So, the sink to ambient temperature is also there, thermal resistance is also there, sink to ambient thermal resistance, but that is more when you look into the heat sinks data sheet. So, in the device data sheet what you see is this case to sink thermal resistance will also be provided. And maximum power dissipation, that will be also provided. So, what it means is that, so if you have this diode, so this diode voltage drop is v_D and whatever the current flows through it is i_D. So, power dissipation,

$$P_D = v_D . i_D$$

And while the device is conducting, there will be conduction losses, because it is going to carry some huge amount of current and there is a forward voltage drop across it. So, there will be conduction loss and if you have let us say a fast diode, a fast recovery diode or a Schottky diode, then during turn on and turn off also there will be losses that will be happening. So, those are the switching losses.

So, what is the maximum power dissipation, that the diode can withstand, that will be most of the time provided in the data sheets. And what is the importance of it? Why it is related to thermal specifications? Because all these losses lead to heating and that heating increases the junction temperature and you have limits on junction temperature, you have to operate the diode below the maximum junction temperature for safe operation.

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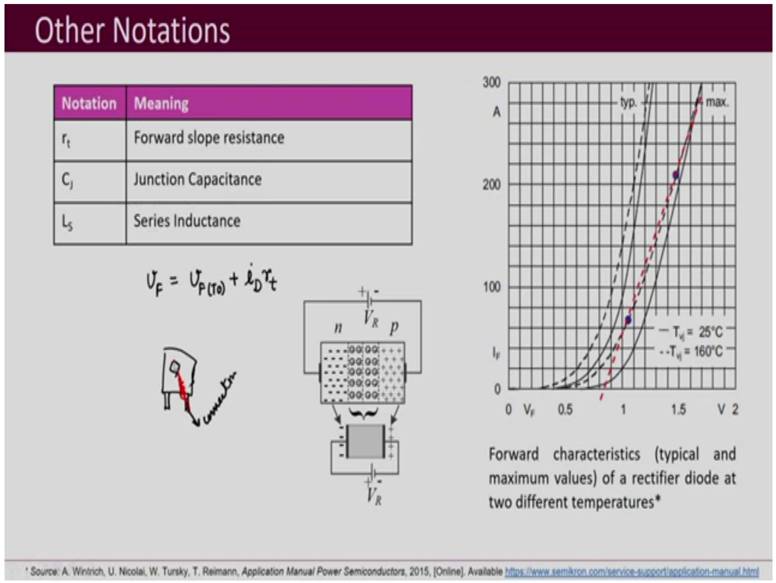

Then some other notations that are of importance in the data sheet is forward slope resistance, this we have discussed before when we discussed vi characteristics. So, this shows the vi characteristics, a typical vi characteristics of a diode and this is given for two different temperatures 25^0 C and 160^0 C. And so, this is the maximum that you can get and this is the typical vi curve that you will be getting.

And as I have told you before also, you can approximate it with a line with a slope and whatever is the slope that is forward slope resistance. So, that also is sometimes provided in the data sheets. And what is its importance? Why do we need it? So, the forward voltage V_F is V_F threshold, you can call it as $V_{F(To)}$ plus whatever the current that the diode is carrying, if we call it as i_D, the diode current multiplied by r_t, because what is the forward voltage drop across the diode, that depends on how much current the diode is carrying.

$$V_F = V_{F(To)} + i_D r_t$$

And there is a maximum forward voltage drop specification that is given in the data sheet. But when you want to calculate the conduction loss, you want to know what the forward voltage drop is corresponding to how much current is flowing in diode. So, this can be used for calculation of the forward voltage drop and then you can also use it for conduction loss calculations.

Then there is another term, which is junction capacitance, this may be specified in some of the data sheets of diodes. So, this is the structure of the diode and when you apply reverse voltage across it, let us say, V_R is the reverse voltage applied. So, this depletion region, this starts to increase, its length increases and this n and p, they act as electrodes and then there is a material over here, which acts as a dielectric material.

So, basically you can observe it like two electrodes with positives and negative voltage, and then a dielectric medium in between them. So, that is like a formation of a capacitor, so that is junction capacitance associated with this depletion region.

Now, what is its importance? This we will understand it later on in the course, but know that this junction capacitance is also specified in the data sheet. Then series inductance as I told you that there is a chip, then there is a casing and then there are those connectors, through which the legs come out and finally through which we are going to connect to PCB or bus bar. So, then there is an inductance, that is associated.

So, what we want to say is that, here is chip of the diode, then there is a case and then there is this leg and you are actually making the connection over here. So, from this to this over here, there is some inductance. So, that is the series inductance that also is many times specified in the data sheets.

And there may be many more other specifications in a data sheet and most of them are self explanatory. So, you can go through the data sheets and look into it and different terms will be specified in some you will find some of the notations, in some you will be finding some other notations. So, it all depends on what type of diode it is and what application for which it is intended.

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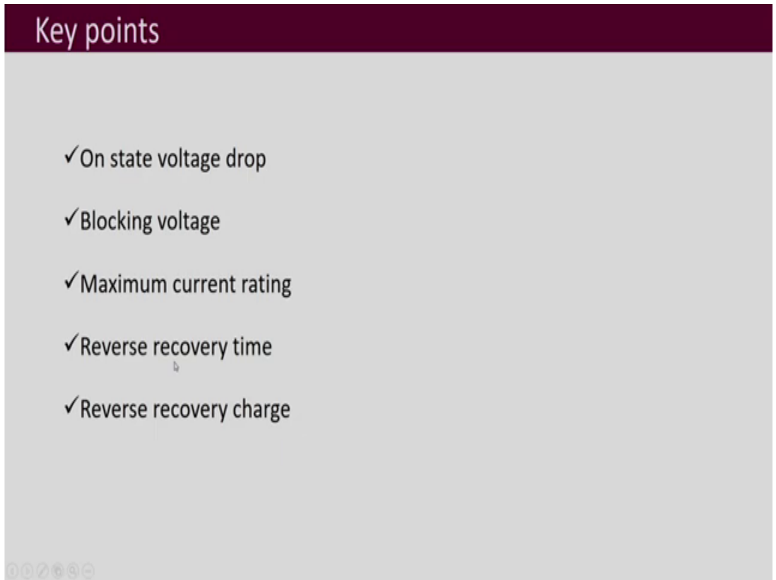

So, what are the key points of this lecture? The key specifications for a diode are forward voltage drop, the on-state voltage drop of the device, then the blocking voltage of the diode and the maximum current rating. Now this usually in the data sheets, they will be providing somewhere close to 25^0 C and also at higher temperatures. So, that also you should be looking for while seeing the maximum current rating.

Then if you are choosing a fast recovery diode or a Schottky diode, then you should also look for reverse recovery time and reverse recovery charge. So, these are the key specifications of a diode that you should be looking for in the data sheets. Thank you.