Fundamentals of Power Electronics

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Lecture – 09
Power Diodes

Hello and welcome back. Power devices are the power switches which we have considered or we have talked about when we first introduced the switching matrix to represent a power electronic circuit. We will start with power diode. The reason is that power diode is probably the most basic device out of all the power devices and if you understand the power diode, then it becomes easy to understand other more complicated power devices.

Now, one of the things that differentiate between what are called the power devices and the low power signal level devices such as diodes and transistors you know is the power level. So, here in power devices we are talking about very high power levels. Talking about power devices in general in the power electronic circuits we assume all the ideal properties of the power device.

For example, we assume large big down voltage; we assume fast turn on and turn off times; we talk about you know the low drop voltage drops and resistances across the device when it is conducting and we also talk about you know a capability to dissipate a large power by these devices. You will see that in due course when we do some analysis that these properties, they are actually having some sort of a trade off between each other.

So, basically there is no single device which will have all the properties and therefore, a person who is actually designing a power electronic systems and he is trying to use power devices he will have to use what is the best available device with all the best possible features. He will not get all the features and at the same time he may have therefore, more than one choice. So, it may not be a very unique device that he can use, but he can probably choose from given set of devices. Therefore, it is important that a design engineer he understands what exactly is the working principle or the power devices. What would be the meaning of a certain trade off?

Suppose and design engineer decides to compromise on the losses, in favour of getting high breakdown voltages then what is the price he will have to pay for that and how he will actually compensate in his design. So, all these things actually demand or in other words I should say that a good and optimum design, it demands that we know the working of various power devices and power diode it actually serves as a very good precursor to such a study, ok.

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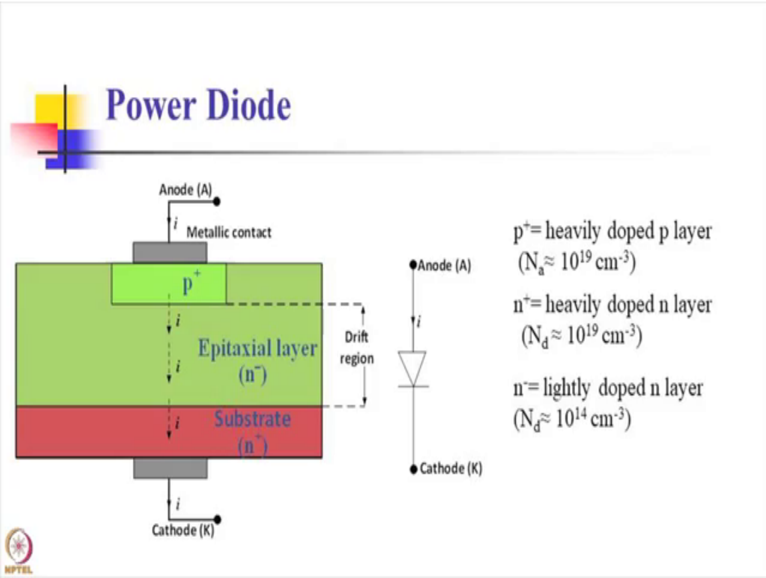

So, now let us just try to see what is the structure of a power diode and let us try to see how it is different from a low power signal level diode or we will just call them a signal diodes now. So, what you see right now is the structure of you know a power diode. The symbol of the power diode is also given on the right side ok. So, what you can see that just like the signal diodes you again see that there are two layers one of them is p the other is n. So, there are two p and n type materials which have been brought together, but now you also see a third layer which is sandwiched between the regular p and n layers and this is actually a lightly doped n layer that you see.

Now, the doping levels are actually you can see in this slide these are the typical highly doped and lightly doped you know concentrations which are given. So, we begin by an n-type substrate which is heavily doped with something like 10 raise to power 19 you know atoms donor atoms per centimetre cube on which is grown an epitaxial layer of a lightly doped n material. So, basically you have you know a much reduced concentration in this region of the donor atoms. It is only 10 raise to power 14 you know atoms per centimetre cube. Over this is grown a highly doped p layer. So, again if you see the concentration it is 10 raise to power 19 atoms acceptor atoms this time per unit you know per centimetre cube.

And, this p layer is connected to the anode which is serving as a anode of the device through a metallic contact and at the bottom you can see that, there is a metallic contact which is providing cathode connection to this device. The symbol of this diode is same as e low level low power level diode there is no difference, but I would like to mention two or three important differences between the signal diodes and the power diode that you can see on your slide right now.

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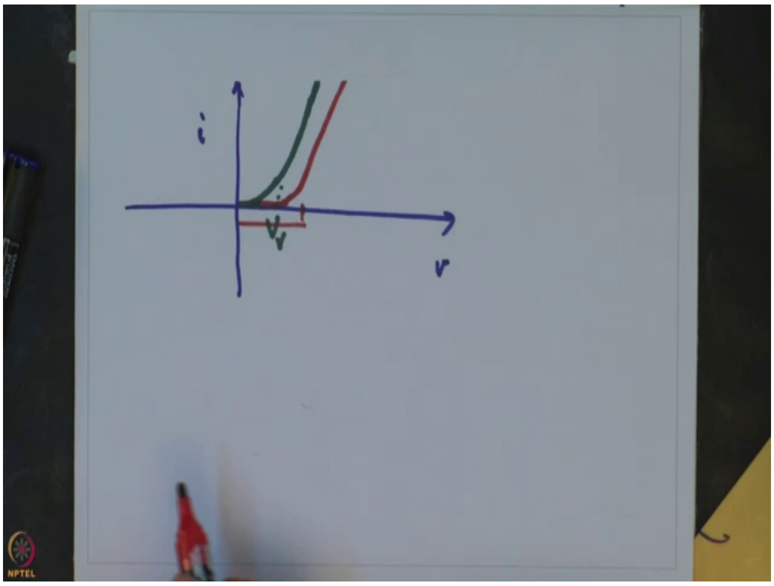

One of them is in their i v characteristics. So, one of the things that you will see is that if I draw the i v characteristic ok, of the two diodes and let us say I use a green pen to draw the characteristic i v characteristic of a signal diode. So, you can see that it actually is going to rise exponentially it drawn and there is what is called a cut in potential or contact potential and the device actually starts conducting only after that.

What you will find in the power diode; however, when you actually try to measure it is characteristics i versus v? You will find that first of all the value of this cutting potential is going to be 1 or 1.5 volts. So, this is going to be more; let us say I just kind of magnify and show you. So, the characteristic would be something like this, ok. So, what you see in this you know in this drawing is that the red colour characteristic or the power diode is more linear. Now, this linearity is coming because you have an n minus layer in this device which actually is obviously, having much less charge carriers and therefore, contributes to more voltage drops, ohmic drops which actually brings in this resistance type characteristic. So, that is why you see instead of an exponential in the green one, you see this linear curve in you know or linear plot in case of the power diode.

While looking at the i v characteristics of the diodes, it is important to note that even though the cut in potential or the threshold potential or the contact potential of the device may be given by you know a standard constant value as we discussed in lecture 8. The actual voltage drop across the device may be higher something like 1.5 volts or even 2 volts due to the ohmic property of the device. Hence it is important that we do not confuse the cut in potential or the contact potential values with the actual voltage drop across the device.

The other difference between the two is of course, the major difference as you already what have noticed that you have only p and n layer you know in a signal diode while here three layers you have an lightly load doped n layer, which is sandwiched between highly doped n and highly doped p layers. So, that is of course, another difference. The third difference point is that the doping levels in power diodes, they are higher both for p and n type they are higher than what you observe in case of signal diodes. So, these are some of the you know the differences between the two types of diodes, ok.

Now, why there is a need for n minus layer? Let us just study this part a little bit. Now, we have seen the forward bias and the reverse bias operation of the diode earlier and in principle it remains the same. The physics of the power diode operation remains the same, both in forward bias and in the reverse bias. So, there is no difference between a power diode working principal. However, let us see what happens because of the presence of this slightly doped n layer in between the p and the n layer, the main p and the n layers, ok.

So, in the last lecture that is lecture 8, we had obtained an expression for the breakdown voltage V BD which was given by if I remember correctly by equation 21. So, you may refer to your lecture 8 for this equation. Now, assuming let us say that we consider a special case now where we say that the p side, you know of the p-n junction is more heavily doped compared to the n side, ok. Now, which actually means that N a is much larger than N d.

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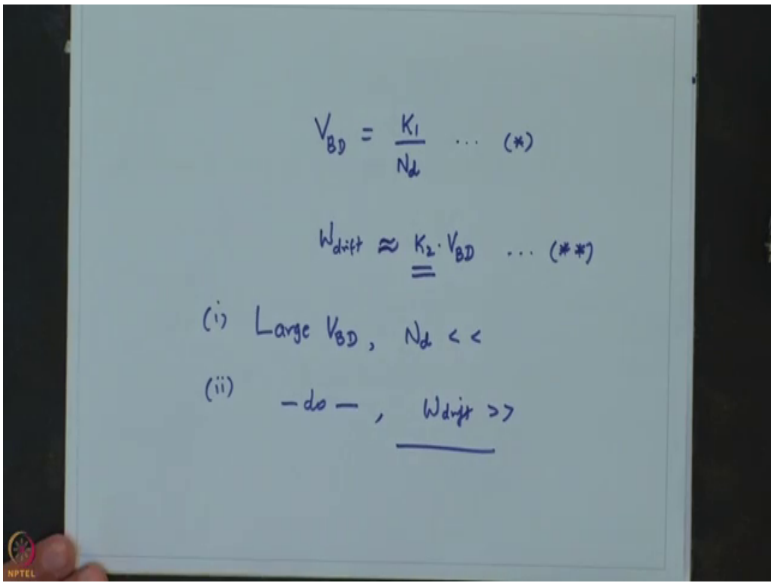

We can show that V BD will turn out to be some constant divided by N d; let us call this as an equation star. Now, similarly if you use equations 10, 11 and 13 from lecture a 8, and if you use the star equation that we just obtained we can also show very easily that the width of the drift region actually is about you can show approximately K 2 times V BD, where K 2 is basically a constant which will come by substituting the numerical values so, the various variables which are there in the equation, ok.

Now, let us call this as equation double star. Now, what are the conclusions that we can draw from these two equations star and double star, ok. So, one of them is a very important observation that shows that if you need a large voltage breakdown capability; so, large V BD if we need it means that the intensity of the donor atoms must be as small as possible as per the equation star, which means that we are saying that we need our n layer to be lightly doped.

And, the second observation we can say is that a large V BD will also require a large width of the depletion layer, ok. So, which means that my W drift should be large if we want to have a large V BD which basically this means that when well I will apply a large voltage I you know across my p-n junction, then my drift layer should be able to absorb the entire you know the depletion layer.

So, this is the major thing about the power diode basically the idea of using this n minus layer is to provide a high reverse voltage capability to this device and this you will see would be very apparent when we use applications such as rectifiers where you actually have large reverse voltages coming across these devices. So, you will see this happening even in the case of SCRs, the silicon controlled rectifiers and you will see that they also need a large negative voltage capability because of this.

The other devices that we will study in due course such as the MOSFETs, the IGBTs and the power BJTs they lack this particular feature they lack this capability of being able to withstand a large reverse voltage across them and we will find that because of this reason their application in you know processes like rectification is going to be limited.

Now, the question is that if power diode is able to withstand a large negative voltage reverse voltage across it, then and we are achieving it by actually inserting a lightly doped semiconductor layer n minus layer in it then obviously, you are having a region which is not having sufficient charge carriers.

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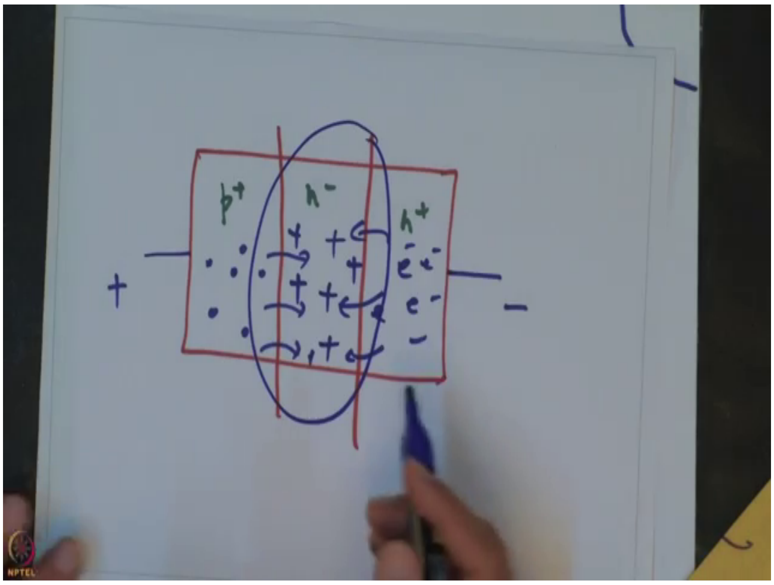

So, if I draw the situation let me say that this is the diode and let us just divide it into three regions p plus n plus and in between n minus and now, you have you know let me just use this blue pen now and now let us say we have the charge injection which is taking place. So, let us say we are trying to study the diode now during the forward conduction, ok, when it is conducting as the forward bias case that is a time when the current flows and that is the time and you expect the drops would take place what happens.

If we just go by what we have seen so far without applying any other explanation we will find that it turns out to be a device with a huge ohmic drop a very big ohmic drop and probably the device would be impractical for use, but a very good thing that happens in bipolar devices such as a power diode or the power bipolar junction transistor and even the insulated gate bipolar transistor that we will see later is what is called conductivity modulation, ok.

So, when you have your diode which is conduct which is actually connected in the forward bias; so, you can see the polarity of the external voltage source that is applied ok, now what will happen that holes will be injected from p region to n region during the forward bias, ok.

Now, because n region is not having enough electrons definitely not as many as the corresponding holes in the p region because that it is highly dome if the injection of holes from p region to n region or n minus region is large your electrons in the n minus region will not be able to neutralize the holes, and therefore, there would be an actual accumulation, at least temporarily of plus net plus space charge in this region in the n minus region.

Now, the moment there is a net space charge which is positive in this n minus region you have electrons you know which actually start jumping and going into this n minus region they all cross over. So, what happens basically is the net result of all this is that you are this particular region which was actually devoid of charge carriers because of which we were actually afraid or an anticipating that there would be a big ohmic drop is actually has become rich in the charge carriers.

Now, this phenomenon of injecting the holes from the p type to the n minus layer and injecting electrons from the n layer to the n minus layer we call this a phenomenon of double injection and it actually leads to increase in the conductivity, which is also called conductivity modulation. We will find that this is going to be the case with all the bipolar devices. In fact, all the bipolar devices will have this phenomenon and therefore, they are usually having much less on losses, on-time losses are much less in bipolar devices.

Let us try to see that, what exactly are the properties of diodes, when it is used in power electronic circuits because you know that the power electronic circuits require this power diode to actually go on and off. So, this is going to be working as a switch an uncontrolled switch in a power electronic circuit. So, it is important that we see the switching characteristics of a power diode when it is actually used in a power electronic circuit.

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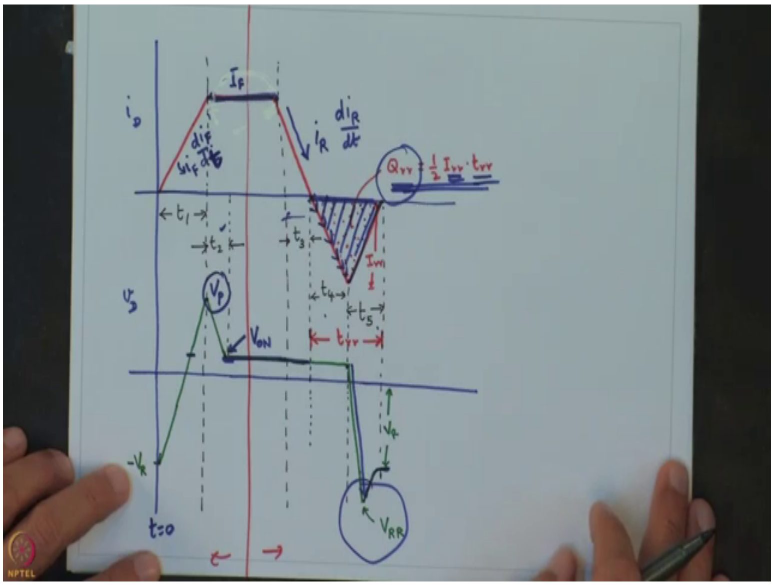

So, what I have done is that on this sheet I have just drawn the typical switching waveforms for the voltage and the current across a power diode. So, what we are doing is we are looking at both the turn on and turn off switchings of the diode. So, what you see on this side on the left side if I just draw this on the left side is a turn on and on the right side is the turn off switching of the diode.

During the turn on let us say that the reverse voltage across the diode just when we started to turn on the device just before that it was let us say minus V R and the current was obviously 0. So, the current starts rising from 0, and this is what this line shows here it goes up with a slope which is defined as di F by dt and would be actually determined by you know the external circuit elements which are there like the inductance ok. This could be the legitimate inductance or it could be these free inductance that might be present in the circuit.

Now, at the same time you know during this up slope of the current you have the excess carriers which are all getting accumulated in the lightly doped n minus layer. Now, what is happening to the voltage across the diode at that time the voltage is also rising, ok. It is rising starting from minus V R and it is going up.

Now, ordinarily we would have assumed that it would just go and get settled at you know at some value here which is the forward voltage drop, but you know there are a few issues one of them is that during this time which I have marked as t 1 during which the current through the diode is building up the excess charge carriers have still not built up completely. So, still there are there is a high resistance across the n minus layer or the drift layer of the device. So, that is one thing.

Secondly, there are stray inductances on a corner of the silicon wafer as well as the leads. So, this voltage what you see it actually tends to o shoot and it actually you can see that I have marked this as V P it actually reaches a value which is V P. Now, what happens at the interval after t 1? So, it is marked this as t 2, now what happens during the t 2 is that my current I the diode current has settled, ok.

It has settled to you know a constant value here. So, let us say this is the constant value I F. The excess carriers have now all built up. So, the losses or the voltage drops across the n minus layer have also reduced drastically, and they have actually because of the conductivity modulation that we have seen before you have very low drops there and that is the reason you find that the voltage across the diode you know it falls quickly from it is value of V P and it comes to it is on state value which is it is regular normal you know this it actually comes to the V ON value.

Now, this is where it continues as long as the diode is conducting the forward current I F which is shown here. Now, let us consider you know the turnoff switching of this diode , but before that I just want to say that this t 1 plus t 2 it actually represents you know the forward switching on of the diode or we can just call it as the forward recovery time as it is called by many authors. So, this is a forward recovery time which a diode needs to turn on.

Now, coming to the switching off characteristics of the diode let us say that at the beginning of this interval t 3 which I have just marked here you know let us say the circuit conditions are now such that the diode is now about to start turning off. So, you can see that the current falls starts falling and let us say that the current now as the current is falling let us denote this current by i R and let us say that this load therefore, will be di R by dt. Again, it will be determined by the elements of the external circuit in which this diode is placed, ok.

Now, till the end of the t 3, the diode current continues to fall and it actually comes to 0, but unfortunately the excess carriers which have actually got built up during the turn on ok, they are still there and they are still not removed. So, what happens that the current continues to flow? So, you can see that the current actually reverses here after t 3 the current has reversed; it is now negative, ok.

And, you can see that this is all because of this stored charge that we have seen here and at a certain point, we find that this current reaches it is maximum which we are denoting as the reverse recovery current I rr and beyond that all the excess carriers are getting stripped off because of the reverse current now there are hardly any excess carriers left.

So, the diode you know it obviously, cannot meet the demands of some external inductances which might be there in the circuit and so, it actually quickly falls to 0 marking the end of this recovery time. So, I have just marked these intervals when the current became negative, and after losing all the excess charge carriers it has quickly dropped to 0 I have just marked them by interval t 4 and t 5.

Now, typically this t 4 plus t 5 this interval is actually referred to as a reverse recovery time and we denote this by t rr and this triangle of course, I have to say that this is just an approximation if this will actually have a very very complex waveform. So, this we have just shown as a triangle because it is enough for our understanding and analysis.

So, this triangle it actually this area it represents the extra charge that has got accumulated during the on condition of the diode which has now been swept out and the p-n junction of the diode has regained, it is capability you know to block you know the reverse voltage, ok. So, basically now we are back into the condition where the junction can now block any reverse voltage applied to it and hence we can actually reverse bias diode, ok.

Now, what I have written here is that how much is this charge we can approximately right by just taking the area of this triangle and we can just say Q rr is nothing, but half into I rr which is nothing as we have seen is the peak the peak reverse current I rr into t rr which is nothing, but the base of this triangle, ok. So, half into the peak current I rr into t rr that will give me the area which is nothing, but the excess charge carrier that has been removed during the turn off process before the diode is ready to take the next condition.

When the current is just falling during the interval t 3 there is hardly any impact on the voltage. So, the diode it continues to be in its normal on state because the current is still flowing, and it continues like that the junction of the diode is not yet reverse bias. In fact, the junctions must remain forward biased. So, that you know there is a possibility for the exist carriers to be swept across swept out.

Now, you know at the end of interval t 4 when the charge carriers have been swept off the diode junction it becomes reverse bias and when it gets reverse biased you can see that the voltage suddenly falls down, and again because of the stray inductances shows some over shoot we just call this peak value as V RR and after that it just goes back and it just stays put at the reverse voltage that has been applied to the diode to reverse bias it that completes this process of the switching off or turning off of the diode.

So, this interval t 4 plus t 5 this is called the reverse recovery time which is actually associated with the turning off of the diode now the forward recovery time when the diode is turning on is not really a very critical thing because we can see that this actually can take place very fast and it does not really you know have any delays as such associated with it, ok.

However, it is the reverse recovery time at you know when we diode is getting turned off that we are more interested because that is more critical because unless the store charges are actually removed or swept out, we cannot say that the diode has actually switched off and it has a direct bearing on the speed at which the diode can actually work, ok. So, what should be the frequency you know what is a frequency at which my circuit is operating, where I want to use a particular diode which; obviously, we determined by this reverse recovery time that a diode actually exhibits that we have just seen, ok.

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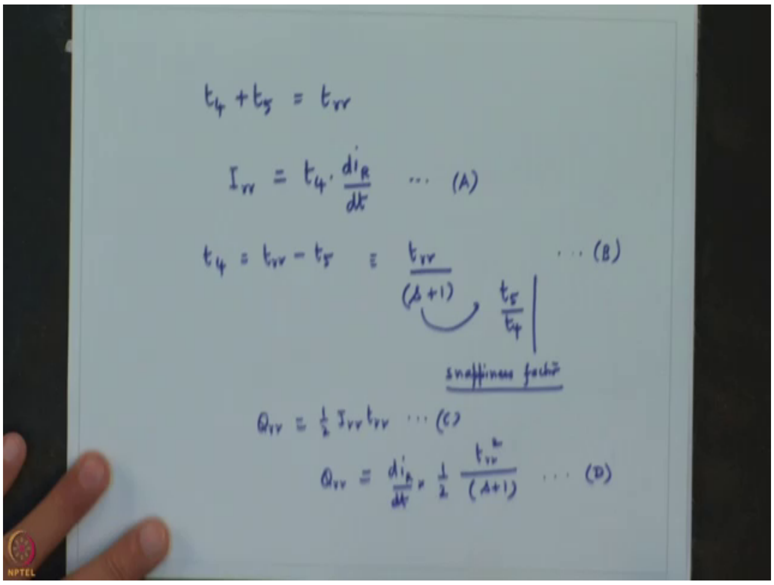

So, t 4 plus t 5 is what we denoted as the reverse recovery time, ok. Now, I can say that peak reverse recovery if you look at the diagram that I have shown before that the switching waveforms of the current and the voltage that I have shown before. So, if you look at the current waveform at the time of turn off, you can actually see that the I rr valued can actually be given by you know this term t 4 that interval time duration into the slope of the current at which the current was actually falling down. So, di R by dt. Remember iR is what we decided to denote the falling current the turning of diode current, ok. So, let me just say that this equation is A, ok.

Now, we know that t 4 is nothing, but t rr minus t 5 and I can then further with some manipulation I can say that this is nothing, but t rr divided by s plus 1; where s is nothing, but the ratio of the time t 5 to t 4, ok. So, this is that ratio. Now, often we denote this t 5 by t 4 the people who work with diodes they call this as a snappiness factor snappiness factor and usually t 5 is much less than t 4 and we say that the such a diode is a snappy diode, which can really turn off fast that is what it is, but if you want to have this t 5 to be comparable to t 4, then we got what are called non-snappy diodes and these are also called soft recovery diodes.

Now, one of the important things here is that we would like the current during t 5 not to fall very suddenly in certain cases because this might cause large voltage spikes to the other devices in the circuit, ok. So, if we I if somebody really analyzes the circuit as we will see later on in this course we will see that a very small time t 5 if the interval t 5 is very small we will find that the current would be so snappy it will be so fast that the di by dt will be very high and this will actually cause large voltages to appear across you know some other components and the devices in the circuit, which our circuit may not allow and that is why we might have to go for what are called soft recovery diodes, ok.

Now, using this expression that we just got if we just call this as B this relation is B, and we also know that Q rr the charge that got accumulated which has to be actually removed during t 4 plus t 5 interval is half I rr into t rr and let me just call this as equation C. Now, if I use the value of I rr from a from equation A and if I substitute this into C, I can say Q rr will actually turn out to be equal to d i r the slope into you know half of t rr square into s plus 1, this is a expression we will get and let me just call this as D forward later reference.

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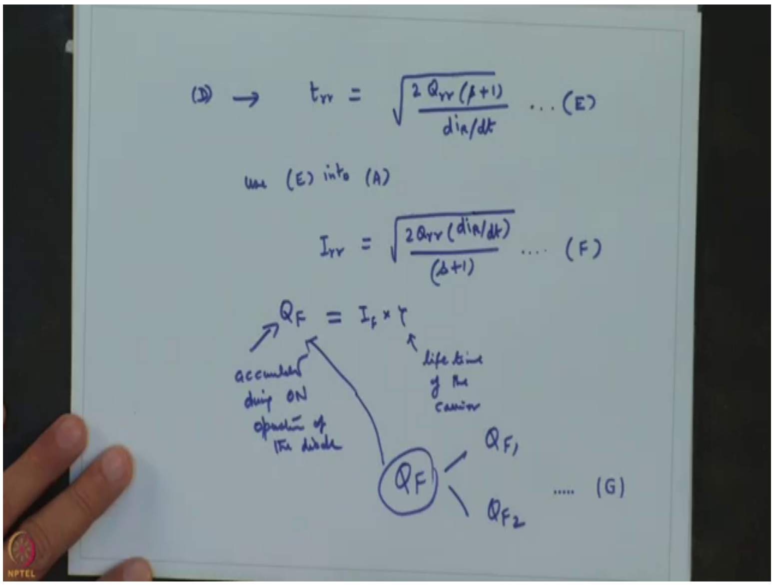

D can lead to you know this more comprehensive in expression for the diverse recovery time. So, t rr actually turns out to be you know the square root of 2 Q rr into s plus 1 and the denominator of this expression within the square root remains is actually d I R by dt and we just call this as expression E.

Now, if I use E in A use basically this expression that we have just obtained E in expression A then we can also get straight away I rr, the peak river reverse recovery current; we can get this equal to 2 times Q rr and into di R by dt whole divided by s plus

1 entire thing is the square root and let us call this as equation F, ok. Now, during the forward bias when the when we were looking at the on time characteristics of the diode, we find that when the current I F was is flowing in the diode you know, obviously, it has caused a lot of excess charges charge carriers to get accumulated you know in the device mainly they the drift drift region the drift layer.

Now, let us say that this charge which has got accumulated is Q F let us say this is the charge. So, this is the charge which has got accumulated during ON operation of the diode. So, this Q F we can show is also equal to nothing, but the forward current into you know tau, where tau is nothing, but the average lifetime of the carrier.

So, basically when a carrier is you know is there in a certain region how long it can survive before it recombines you know either with a hole or with an electron. So, this charge carrier if it is a hole how long it is before it recombines with an electron or if it is an electron how long it is before it actually recombines with a hole. So, this average time is actually considered to be their lifetime how much they can live in a particular region of a semiconductor. This is how it is defined is the most basic term, ok.

Now, so, basically what we are trying to say is if we know the lifetime tau and the forward current we know how much charge has been accumulated in the device, ok. Now, some charge when you are switching all the device some of this charge Q F, ok. So, this Q F actually has two parts; one of them is let us say Q F 1, which is actually cleared off you know by recombination, ok.

But, there is another component which is as we have seen the current actually reverses and that is what is clearing it. So, that it is basically getting cleared by the reverse current. So, that let us call as the component number 2. So, clearly both Q F 1 or Q F 2 are smaller than Q F individually.

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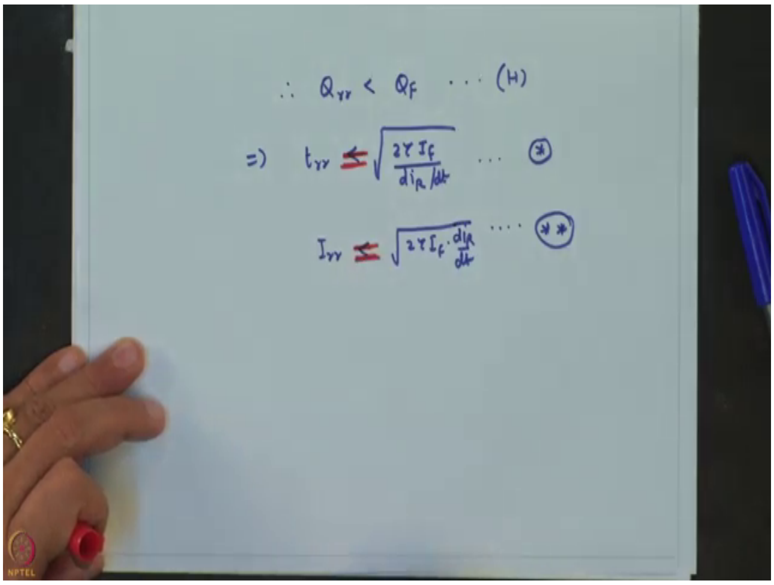

Therefore, from what I just discussed or I just explained I can say therefore, that the Q rr which is swept out or swept away where the reverse current is less than Q F, that is what we just concluded. Our Q F 2 part which I just explained is nothing, but Q rr in this case. So, that is less than this and let us call this as an expression H.

Now, once we know this I can say t rr is less than you know just using my expression E that we have obtained earlier I can say t rr is less than 2 tau I F divided by di R by dt and similarly, we can say I rr is less than 2 tau I F into di R by dt, ok. So, these are very nice and compact relations that we have got let us call them as star and double star; these two expressions. Now, this is an inequality, this is an expression which is an inequality expression both of them, but in the worst case I do not think that there is any confusion about this that we can just replace these signs less than signs or inequality sign by an equal to sign.

There is a another type of diode not a silicon p n junction diode it is a different type of a diode which is used extensively in power electronic applications and this is actually called a Schottky diode.

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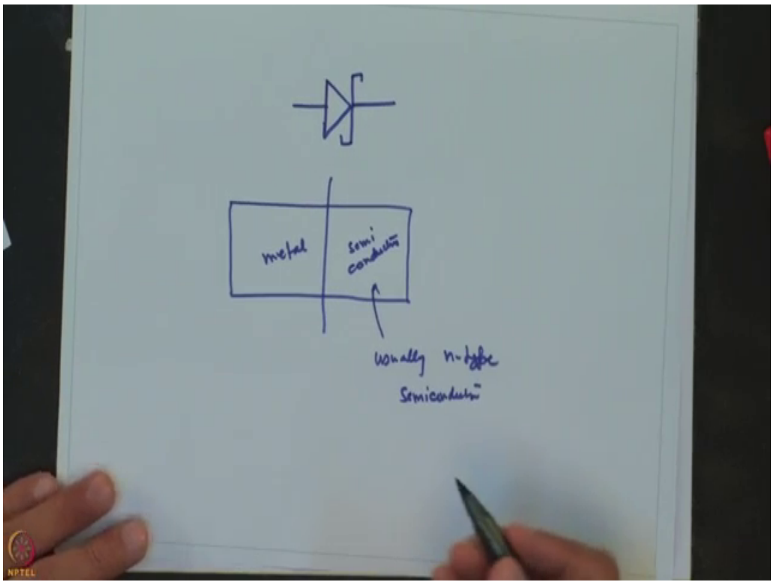

Now, a Schottky diode is actually represented by this symbol. This is a Schottky diode symbol and what it actually has is an interface of metal with semiconductor, ok. Now, usually both n or p type semiconductors can be used, but in practice it is the n type semiconductor usually it is the n type semiconductor which is preferred for this, and the metal which is usually used for this application for the Schottky application you know it actually could be molybdenum or it could be tungsten, but they have their own you know advantages and disadvantages. Schottky diode is actually a majority carrier device. It is not a minority carrier device like the bipolar power diode that we have considered so far a p n junction that we have considered so far it is actually a majority carrier device.

Now, when we talk about a majority carrier device that basically means that its mechanism is such that it does not really need to pile on you know or kind of accumulate the minority carriers you know on to the other side of the junction. Actually the flow of the current in this case is constituted by electrons which are actually generated through thermionic emission, ok.

So, both metals and the semiconductor they actually have this thermionic effect because of which the electrons are generated. One of the very big advantage of the Schottky diodes is that you know they actually incur very low forward voltage drop as a diode is conducting, ok.

The other advantage of course, is that because there is no accumulation of minority carriers there is no reverse recovery time problem here. So, these are really fast they switch really fast, but the Schottky diode has a reverse leakage current that is much higher than the silicon p n junction diode I want to actually show you some typical data sheets.

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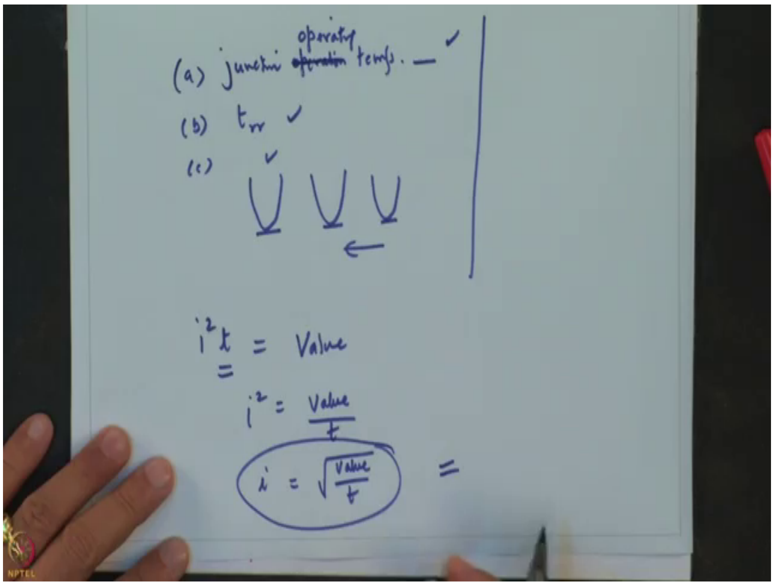

Now, for the power diodes you know typically we would be interested in looking at some of these parameters. One of them is the junction operation temperature. So, the specification what is the maximum junction time operation junction temperature or junction operating temperature. So, what is the maximum temperature allowed as per the datasheet. This is a very important parameter for the design; then what is the reverse recovery time t rr; then what is the repetitive peak reverse voltage.

So, for example, in rectifiers if you will see you have these reverse voltages which are going to come across the device when it is reverse biased, ok. So, what are these peak voltages which are repetitively coming and appearing across the device? This is again a very important parameter and it is also important to see what is the one time maximum reverse voltage that will appear across the device, then what is the peak forward search current in the forward direction, what is the maximum search current that is allowed? What is the average current with the device will allow the diode will allow to flow? What is the rms current that it will allow? What is the peak current that it will allow? So, all these are very important parameters that will somebody will typically look at when looking at the data sheets of the power diodes.

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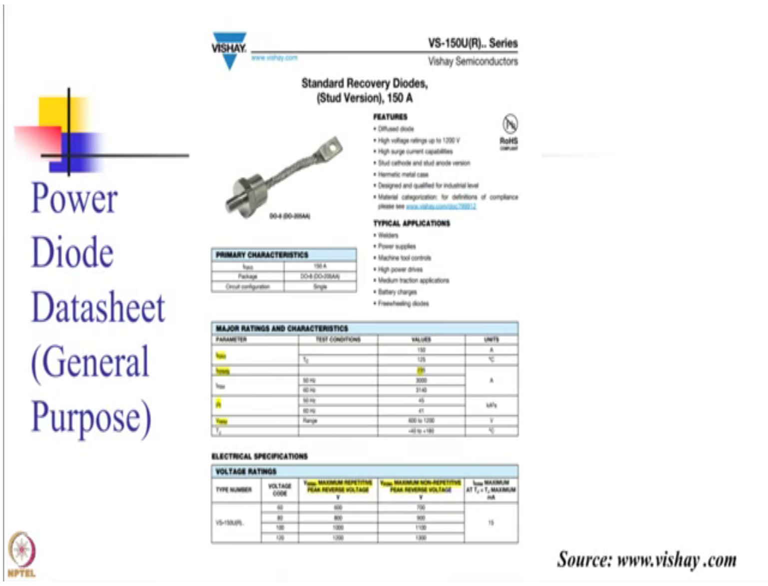

You can see there you know these parameters the you can see the forward average current the forward rms current and you can see that for this example which actually happens to be a 150 ampere stud type diode,. You can see all these values are given you can also see a very interesting thing here which is saying i squared t at 50 or 60 hertz. So, what is that you know that unit which is basically the kilo ampere square of seconds? What does it show? It basically means that we are trying to put a protective device we are trying to put some protection for the diode.

Now, i square t is given to you. So, some value is given to you let us say do we just call it value and it is also given to you that how much time you know a a certain current is allowed, ok. So, you can actually get from here i square to be equal to value divided by e and then you can just get the value of i by square root of this term. So, i is equal to square root of value over t, ok. Now, this will give you basically you know this is the limit that is given by the datasheet. So, if your current is going above this you know you must have a fuse in place that your device actually gets cut off from the supply so that it is same otherwise you might end up destroying the device.

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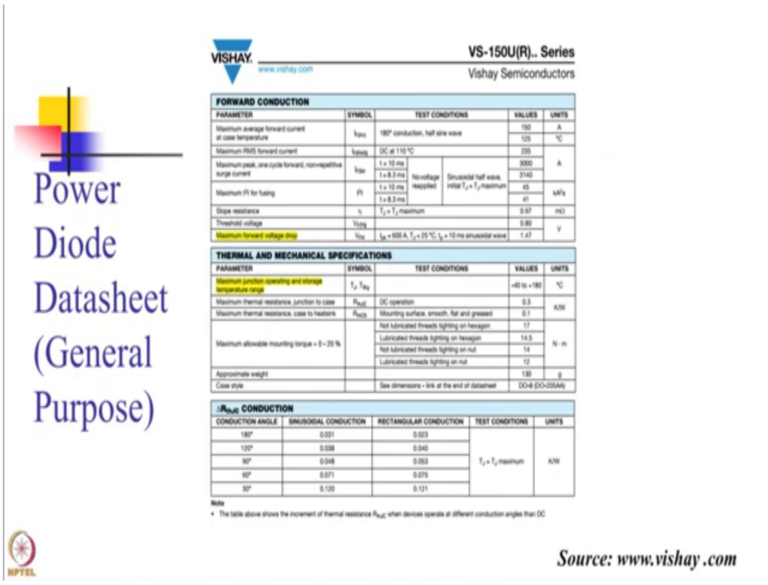

We can also see you know on this slide which is the second page of the datasheet of this particular diode the maximum forward voltage drop which actually is about 1.47 and you can see that all the other values are given at which this particular forward voltage drop will hold. So, it also gives a temperature of 25 degree centigrade it says that what is the peak current which is 600 mps and so on under those operating conditions it says that the voltage drop will be 1.47.

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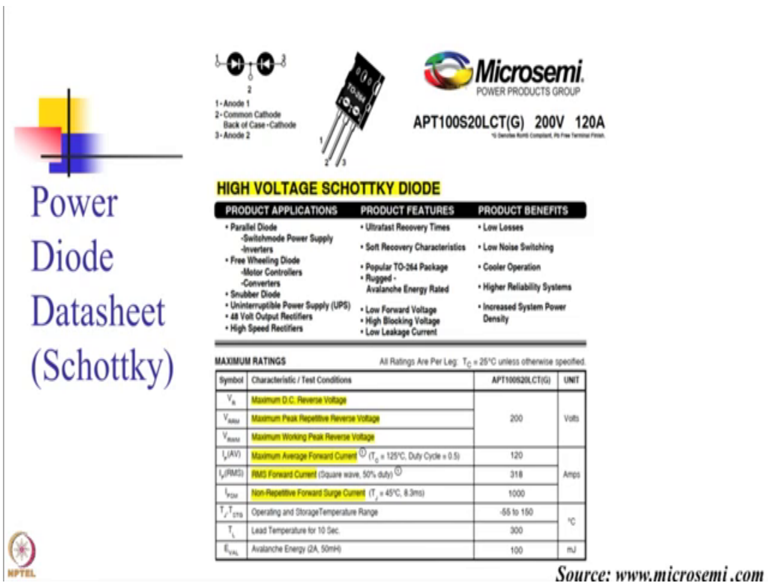

And here there is a datasheet that is of a Schottky diode basically they are calling it an ultra fast recovery time. So, basically you have the t rr to be extremely low in this diode. Schottky diodes as I told you are actually famous for being very fast with very low reverse recovery time. And, you can see the maximum peak repetitive voltage, and maximum working peak reverse voltage which is about 200 volts for this particular device, then you can see a forward current average which is I F average is given, then there is an rms value of the current is given which is allowed through this device.

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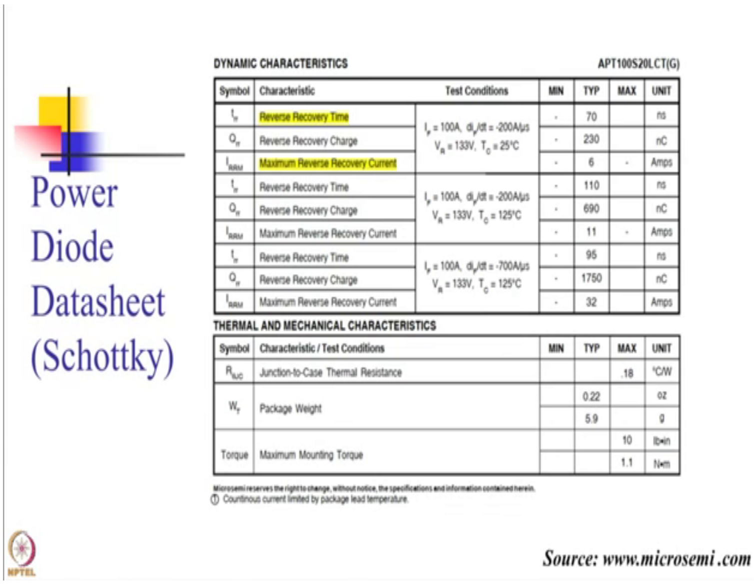

DYNAMIC CHARACTERISTICS — APT100S20LCT(G)

Symbol	Characteristic	Test Conditions	MIN	TYP	MAX	UNIT
t_{rr}	Reverse Recovery Time	I_F = 100A, di_F/dt = -200A/µs, V_R = 133V, T_C = 25°C	-	70		ns
Q_{rr}	Reverse Recovery Charge		-	230		nC
I_{RRM}	Maximum Reverse Recovery Current		-	6	-	Amps
t_{rr}	Reverse Recovery Time	I_F = 100A, di_F/dt = -200A/µs, V_R = 133V, T_C = 125°C	-	110		ns
Q_{rr}	Reverse Recovery Charge		-	690		nC
I_{RRM}	Maximum Reverse Recovery Current		-	11	-	Amps
t_{rr}	Reverse Recovery Time	I_F = 100A, di_F/dt = -700A/µs, V_R = 133V, T_C = 125°C	-	95		ns
Q_{rr}	Reverse Recovery Charge		-	1750		nC
I_{RRM}	Maximum Reverse Recovery Current		-	32		Amps

THERMAL AND MECHANICAL CHARACTERISTICS

Symbol	Characteristic / Test Conditions	MIN	TYP	MAX	UNIT
$R_{θJC}$	Junction-to-Case Thermal Resistance			.18	°C/W
W_T	Package Weight		0.22		oz
			5.9		g
Torque	Maximum Mounting Torque			10	lb•in
				1.1	N•m

Microsemi reserves the right to change, without notice, the specifications and information contained herein.
① Countinous current limited by package lead temperature.

Source: www.microsemi.com

And, on this sheet you can see what is the reverse recovery time, you know something that we really talked about so extensively some time back. So, it clearly says that you know this particular Schottky diode is having a t rr reverse recovery time of 17 nanoseconds when a forward current of 100 amperes is maintained and there is you know di F by dt, the rate at which the current is varying is also given as some minus 200 ampere for microseconds look at the really fast slope there, and the reverse voltage maximum is 133 volts which is allowed and even the temperature is given as 25 degree centigrade.

So, under these conditions it is given that what would be the reverse recovery time of this device and if you see the third row, it also gives the maximum reverse recovery current, the I rr value that we have involved in our analysis.

Now, based on the ongoing discussion that we are having about the speed at which the diodes can switch and you know about their maximum voltage capacities and so on, it is customary to actually classify or categorize the diodes into three types.

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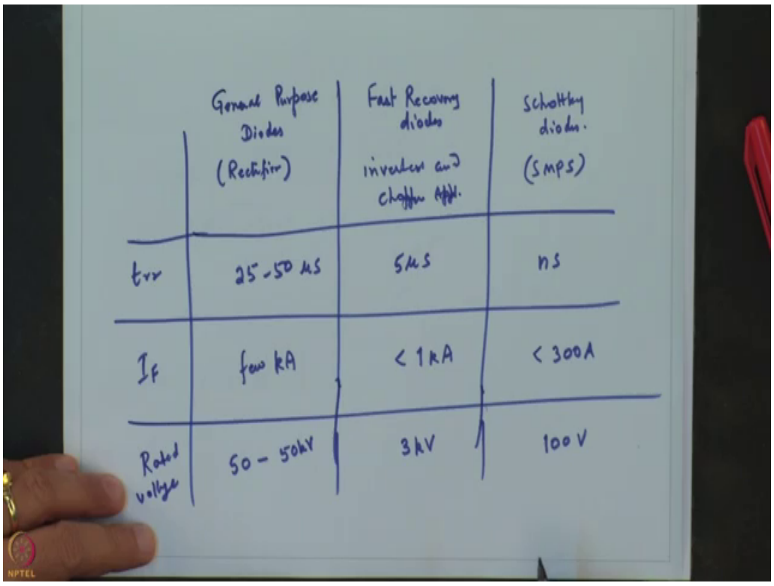

These are actually the general purpose diodes which are typically used for rectifier applications 50 hertz, 60 hertz rectifier applications. So, here the speed of switching is not really important. So, these diodes can be slow. The other type of the diode is what is called the fast recovery diodes, ok, now, these are the diodes which we want to switch fast and therefore, we expect their t rr to be very low or extremely low.

These are the ones which are typically used for inverters and you know our DC to DC converters or chopper applications and the third one are the Schottky diodes. They can switch really fast as you know the switching times are typically nanoseconds and they are used in switch mode power supplies.

The problem is that because we are not able to go to high power the Schottky diodes they have certain limitations with the voltage you know the maximum voltage that they can go to they are not really available for use in other applications like inverters and choppers, ok. So, schottky diodes the third type, I can just say that it is mostly the switch mode power supplies of you know the appropriate power levels where it is used.

Now, I will just write down some typical numbers here, ok. So, I will I can say that the t rr if I just say this parameter and compare these three. So, for t rr I will say that you know the general purpose diodes would have something like 25 to something like 50 microseconds. The fast recovery diodes would have typically 5 microsecond of you know t rr reverse recovery time, while the Schottky diodes would have in nanoseconds. So, we just saw when Schottky diode which had something like 70 nanoseconds is the reverse recovery time, ok.

The other parameter the important parameter that we know is a forward current which can be carried by the diode and for the general purpose rectifier the forward current rating typically is you know up to a few kilo amperes. It is really huge ok, thousands of amperes can carry for fast recovery diodes typically it is less than 1 kA 1000 amperes typically less than that there is also pretty large. But, you know they are of course, not having the same capacity as the general purpose diodes, and the Schottky diodes will typically have less than 300 amperes as their rating allowed rating, alright.

About the rated voltage that these diodes these three types of diodes can take the rated voltage you know the general purpose diodes typically 50 to you know 50 kV 50 volts to fifty kilo volts. So, huge voltage they can take the fast recovery diodes can take something like 3 kV up to 3 kilo volt and you know the Schottky diodes as I said before they are capable of only up to about 100 volts. Now, there might be diodes which are now coming Schottky diodes where people are actually are able to sustain higher voltages.

With these words I end this session and in the next one we will actually start with a new device, new power device and we will see what other benefits we can read from using those devices that we follow.

Thank you very much for your attention.