Advance Power Electronics and Control
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Lecture - 03
Device Physics I

Welcome to our lectures on advance power electronics control. Today is our third lecture, we will continue with our device physics. That is the components we will discuss today is that SCS and power diode. So this will be actually all the devices that is going to be covered within subsequent two classes. That is basically you know from the 50 years rather we are using diode.

But we will see that this is power diode that power handling capability of this diode at least actually 1000 times higher or maybe 10 to the power 6 times higher. So this will be called a power diode. Thereafter, we will see that you know thyristors is a unique combination that is a 2 PN junction diode has been connected in series and it forms unique features and thus it will be a semi controlled device.

It turn on can be controlled but turn off cannot be controlled. Thereafter, bidirectional thyristors when you put actually two anti-parallel thyristors in a same package, essentially it becomes a TRIAC but power handling capability of the TRIAC essentially is very less and nowadays it is getting almost phased out with the advent of the matrix converter.

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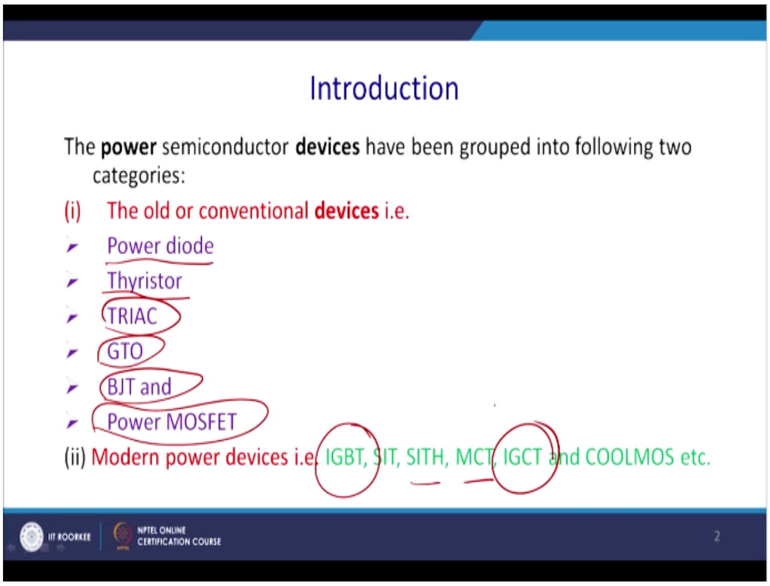

Thereafter, GTO since thyristor does not have a turn off capability, it require an external procedure to turn on that is called commutations and we can turn off a kind of thyristors with negative gate current so that will be GTO that will also be covered. Thereafter, BJT this is also power BJT because in analog electronics we have studied BJT but that power handling capability is quite low in watt.

It should be in a kilowatt or megawatt but it has shown a very little life span. Nowadays, it is not been used because of the high gate current requirement and instead of that we have a power MOSFET and also it has got a power handling in the range of the kilowatt level. So these are the conventional devices that we use. Apart from that, you know we have now few modern devices that is IGBT.

IGBT is discovered by one Indian (()) (02:50) so from there actually dimension of the power electronics changes because it combines the actual utility of the BJT and MOSFETs and it came out with a unique feature which has a low gate dissipation and high current handling capability. Thereafter, SIC, TH, MCT, IGCT is one of the advancement over the IGBT and thereafter COOLMOS, etc.

And we are also now actually reaching out for the silicon carbide-based devices or high bandwidth devices. Let us now talk about the power diode in details. So difference is that you know we have this power diode has to have a block, huge amount of voltages than the conventional diode which we have studied in the analog electronics. For this reason, you know you will find that n layer is stretched. It is not that only in PN junction you can find that -n and the +n.

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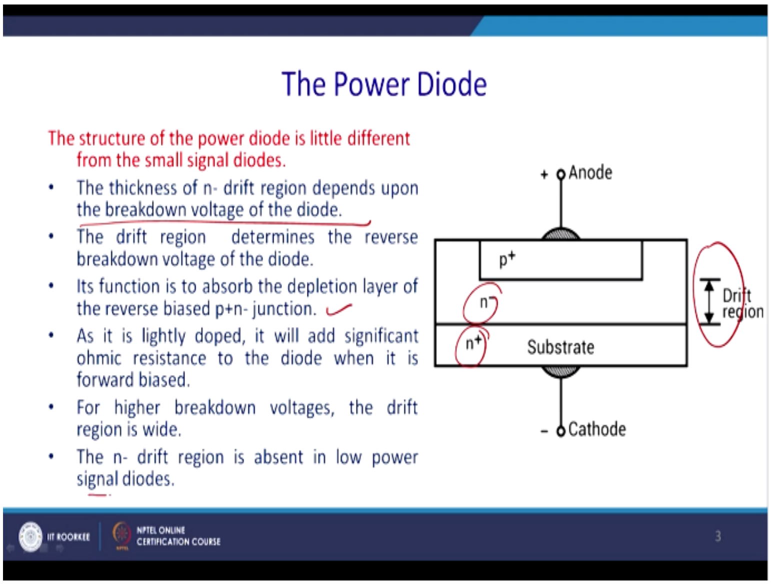

And for (()) (03:53) drift region and thus you know what we assume for the silicon diode that actually it will have a forward drop voltage of 0.7 volt, instead of that it will be higher because of this actually drift region is higher and that gives the actually higher reverse blocking capability but also it gives a higher conduction loss. So the thickness of the n-drift region depends on the reverse breakdown voltage of the diode.

So this drift region determines the reverse breakdown voltage of the diode. The function is to absorb the depletion layers, the reverse versus the PN junction and it is lightly doped it will add significant ohmic resistance for this I was telling that actually drop will be higher to the diode when it is forward biased. For higher breakdown voltage, the drift region will be wide so this region will be wider if required to have a higher reverse blocking voltage.

And n-drift region is absent for low signal diode which we have studied in analog electronics. Now this is the symbol of the diode. You are quite familiar from the analog electronics.

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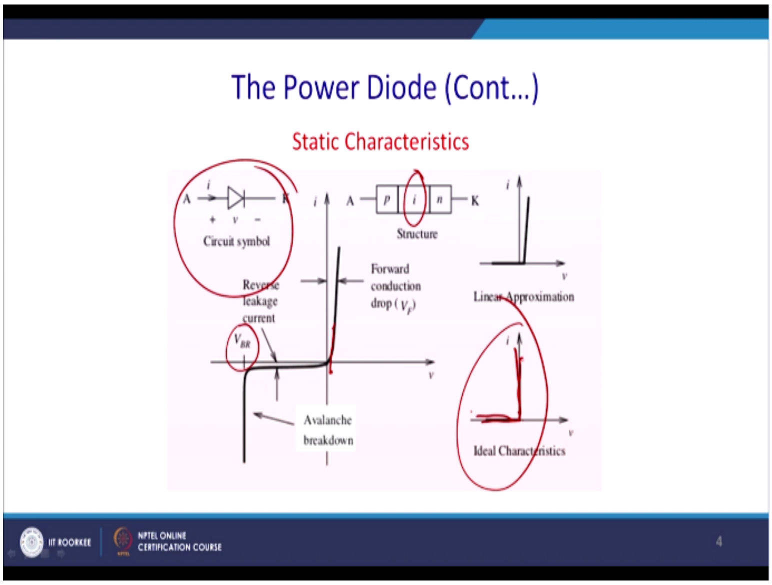

And you know this is the structures, this is a PN junction in between you have extra layer that is you might have seen, this is -drift region, -n layer has been put inside it to give you a reverse voltage blocking capability and this is basically the forward characteristics of the diode, it is same but this voltage may not be actually 0.7, it is generally higher depending on which amount of the blocking capability that diode have.

We refer to the data sheet then we will find out and this is basically the Avalanche breakdown and this VBR in this power diode we generally assume to be about more than 500 volt because it will be used for this power electronics purposes. So mostly in a rectifier cases, so actually for the 3 phase voltage which is required to be rectified so peak inverse voltage comings out to be around 600 volt for the 3 phase voltages.

So accordingly we require to choose the rating of the reverse effect breakdown voltage and this is actually the ideal characteristics of the switching characteristics. Diode essentially is an uncontrolled device, it has reverse blocking capability which has been shown by this line and it will conduct into the forward region, this is the mode of operation. It does not have forward blocking capability and the reverse current flow capability.

So it has a forward conduction capability and the reverse blocking capability. This is the characteristics of the diode. Anywhere you require this kind of characteristics; you can suitably place a diode instead of any control switches.

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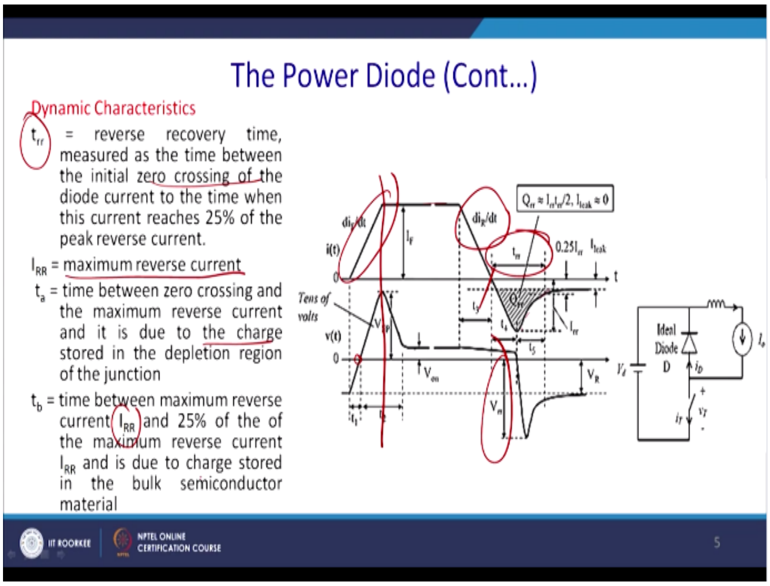

So let us see that you know we have a different kind of diode where we will find that it is a normal diode that will be used for the rectifier operation mainly. Most of the power actually from AC to DC you actually use rectifications but power qualities and issues still we use that and for this reason we have a different kind of diode and for this we require to understand actually dynamic characteristics of the diode.

So what happened when you apply a point of voltage builder, current also builds up and there is a rate of change of the forward voltage current and that will pick up. So in this region you can see that the voltage is also building up, current is also building up because it has got a junction capacitance, so current will also build up. So in this region you know actually diode will give you a voltage drop, power drop across this diode.

That is called the turn-on loss of the diode. Thereafter, what happen once it reaches through the voltage then voltage will fall and ultimately you know when voltage becomes zero to when voltage falls down to its actually forward blocking voltage let say 0.7 or 0.8 volt or more than that depending on the amount of the depletion layer, so this time is called t2. By the time you know actually, current will be actually to its saturated value or whatever the rated current it will flow.

And it will continue thereafter once you decided to actually take steps to reduce the voltage, then definitely actually you can find essentially here current become zero but even though the current becomes zero it does not have a reverse blocking capability because of the trap charge into the PN junction diode and you know since there is extra substrate present, it will take considerable more amount of time to actually drain out the charges from the trap region.

For this reason, you know actually you have to apply a reverse voltage; this is called reverse recovery voltage VRR. Then, actually this trap charges will come out gradually, ultimately current will flow in the negative direction for the short duration of the time and ultimately again it will go out and this time you know actually total time it is called the trr and it will have a leakage.

Thereafter, after trr leakage current will flow through it and leakage current should be actually one-fourth of this actually the maximum reverse current flows. So it should be around 25%. So this is the actually the characteristics of the diode. So let us get familiar with the few terms that is trr that is reverse recovery time measured at the time between the initial zero crossing of the diode current to the same time.

When this current reaches 20% of the peak reverse current and that is assumed to be basically the leakage current of the diode and IRR maximum reverse current that will be also specified on a data sheet, will show it and you know trr is a major fundamental parameter of the diode for different applications. If you are using a diode for SMPS kind of applications and which is for choosing frequency is very high and thus require very fast reverse or very small reverse recovery time.

So we have to choose a fast diode. Similarly, diode is using for rectification operation of the 50 Hertz or 60 Hertz supply. You can afford to take a slow device, slow diode or a snappy diode and if you require extremely fast devices almost zero on in level of the nanoseconds then Schottky diode will be preferred but of course higher will be the power of blocking capability.

So trap charge will be there and higher will be your value of the trr and also now your drop conduction drop will also increase if it has a higher PIV or peak inversion voltage and ta is a time between the zero crossing and the maximum reverse current and that is due to the charge stored in the depletion region of the junction and tb is the time is where actually the time reverses.

This is basically the two times ta and tb, so we have to find it out the maximum power reverse current trr is 25% of the maximum reverse current and IRR is due to the charge stored in depletion region or bulk semiconductor material.

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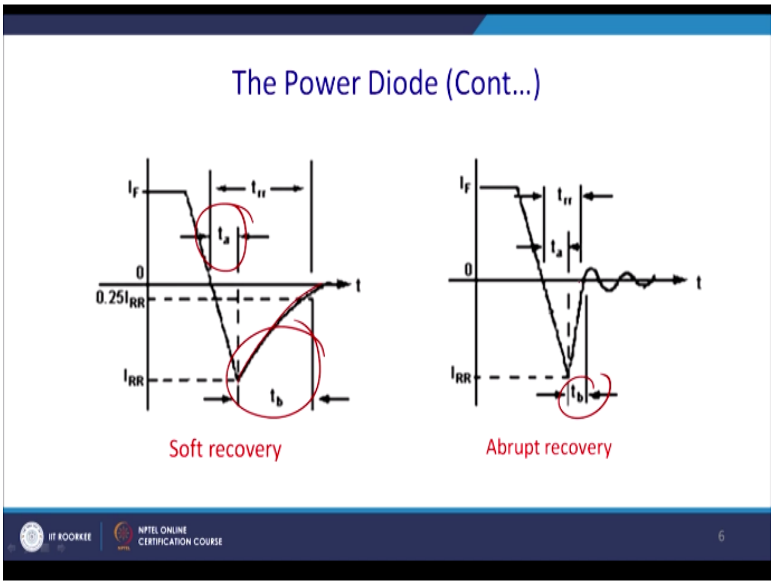

So let us see, so this much is ta and this much is tb and if this recovery is this kind of thing, it takes actually considerable amount of time, then we call it is soft recovery and stress across this diode is less and diode will have a less conduction loss also, so but you will have a higher value of trr but if you want actually very fast recovery for high frequency applications then what happened you know tb is considerably low.

Ratio of ta and tb is basically one of the measurement of the diode's promptness but problem lies, there is a two problem if you require to have a fast higher recovery voltage, you cannot do anything, you require to choose this kind of diode. It will have a high EMI, EMC problem as well as you know actually cost of the diode definitely will be more. Apart from that actually the stress across this diode also will be higher.

So we have another diode that is called Schottky diode which has extremely low or almost zero turn off time. Reverse blocking capability is extremely low compared to the power diodes.

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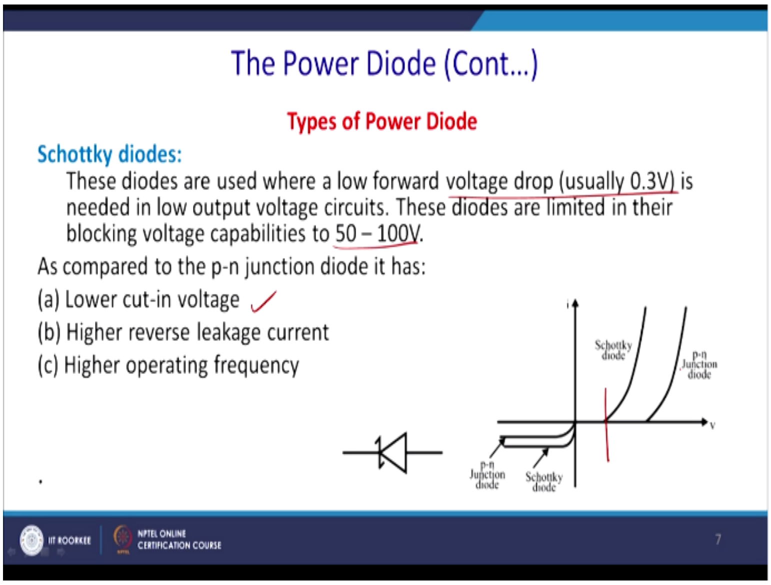

So these diodes are used where low forward voltage drop usually 0.3 volt is needed in low output voltage circuit. So these diodes are limited to their blocking capabilities of the voltage in the range of 50 to 100 volt whereas actually you will find that power diode can easily block 1000 volts. As compared to the PN junction diode, it has lower cut in a voltage, higher reverse leakage current that is we guess you know they will find that leakage current will be little higher and two times higher than the normal power diode of the same rating.

Higher operating frequency, you can operate for the SMPS and other applications. So this is one of the applications. So this is basically the PN junction diode and this is a Schottky diode and this drop will be instead of 0.7, it will be around 3 to 4 volt and PN junction will have a 0.7 volt and one of the advantages is that it has got a fastest recovery except SIC. So how you will categorize fast diode and the slow diode?

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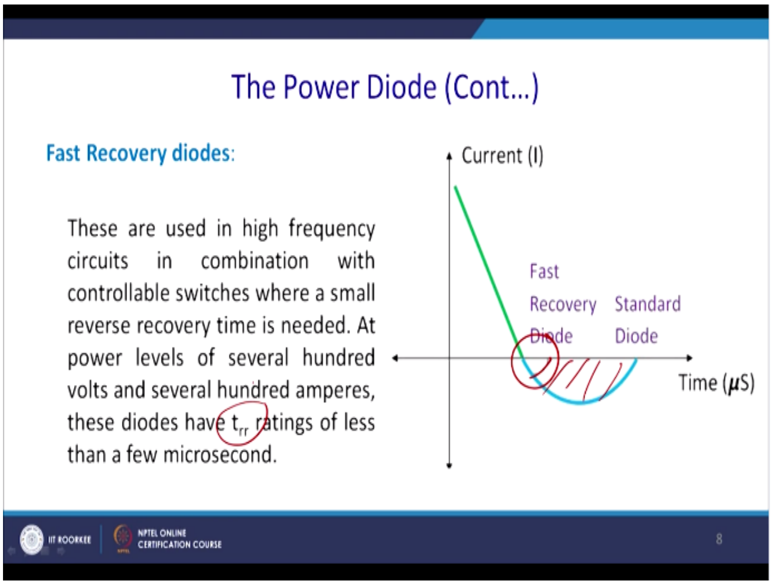

So fast recovery diode actually will go from this point to this point, so basically this is the region you know this is the current, if you integrate over time, this is the charge. Ultimately, your depletion region should hold very less amount of charge that is the only solution to provide a fast recovery and that is used for the high frequency application. So if you integrate over it though this gives you the charge.

So this is used for the high frequency circuit in a combination with the controllable switch by a small reverse recovery time is needed at power level of the several hundred volt and several hundred amperes of diodes, trr having times less than the microsecond. We shall see the dataset in a normal rectification operation, what kind of trr you will get it and another is that low frequency diode.

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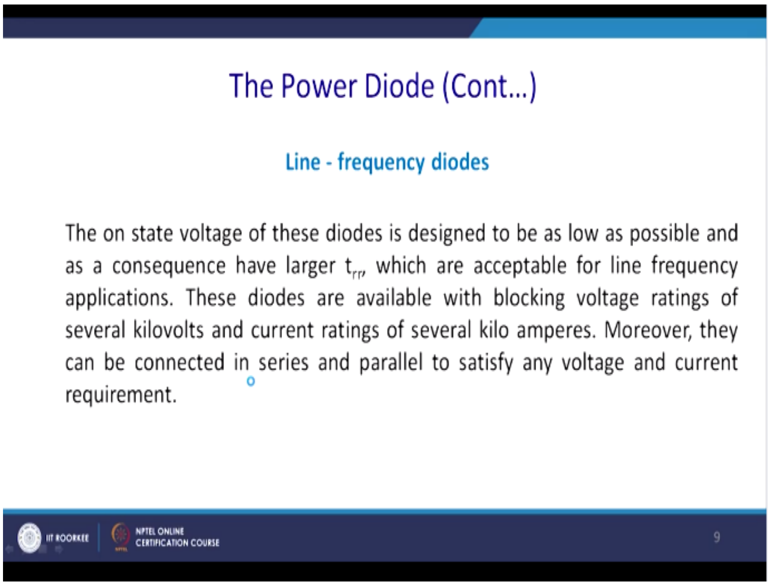

Low frequency diode is normally used for the rectifier operations and we want actually lower conduction loss because it can carry then higher current and drop will be lower but it will have a soft recovery or a slow recovery. So the on state voltage of the diode is designed to be low as possible as a consequence it has larger trr which are acceptable for the line frequency applications in 50 hertz or 60 hertz depending on the countries you are using.

These diodes are available with a blocking voltage of ratings of the several kilovolts and the current ratings of the several kilo amperes. Moreover, they can be connected in series and parallel to satisfy the voltage and the current requirement.

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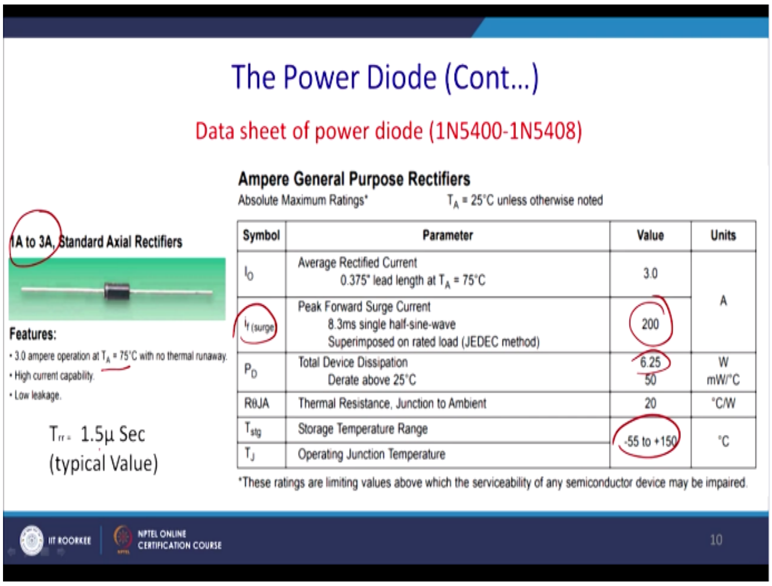

So this is the data sheets of one of the power diode in a nominal power rating not very high rating. So you can see that what are the parameter will be given, you know this is the current carrying capability of this diode is only 1 ampere to 3 ampere and at a temperature of the still 75 degree centigrade there is no thermal runaway or the thermal breakdown and one aspect is that surge current capability.

Surge current capability is quite high, it is as high as 200 ampere and you know there is power dissipation and you know this power dissipation can be as high as 6 watt, 6.25 watt and you know this is the thermal resistance and junctional operating point can be -55 to 150 degree centigrade. Another important data is given that value of the trr, I am coming to this little you can see that it is 1.5 microsecond.

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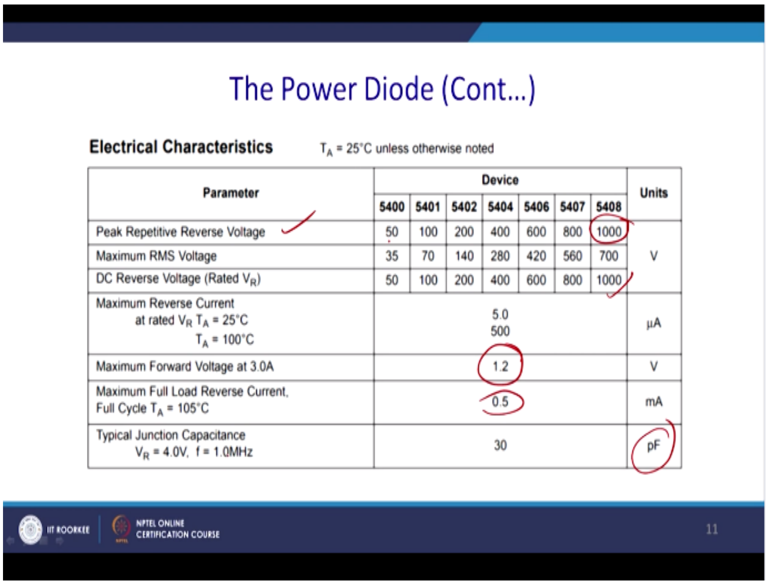

Parameter	Device							Units
	5400	5401	5402	5404	5406	5407	5408	
Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
Maximum RMS Voltage	35	70	140	280	420	560	700	V
DC Reverse Voltage (Rated V_R)	50	100	200	400	600	800	1000	V
Maximum Reverse Current at rated V_R T_A = 25°C / T_A = 100°C	5.0 / 500							µA
Maximum Forward Voltage at 3.0A	1.2							V
Maximum Full Load Reverse Current, Full Cycle T_A = 105°C	0.5							mA
Typical Junction Capacitance V_R = 4.0V, f = 1.0MHz	30							pF

And you know there is difference series depending on you can choose a different power rating, you can see that this is basically the peak repetitive voltage if you apply for the rectifier operation that is very important because you have a negative half cycle. So it can block, it can start from actually the 50 to 1000 you can choose any diode depending on its rating in between and so if you choose 5408, it has a blocking capability of the 1000 volt.

And maximum RMS rating will be 700 volt and reverse blocking capability will be same. The peak voltage, peak repetitive voltage that will be 1000 volt and you can have a maximum forward voltage at you can see that this is not actually 0.7 volt which you have assumed in the actually analog electronics or the linear electronics diode. It is basically 1.2 volts, so it gives you the considerable drop.

And we have a full leakage current of around 0.5 milliampere and you got a junctional capacitance in the range of the 30 picofarad at 1 megahertz.

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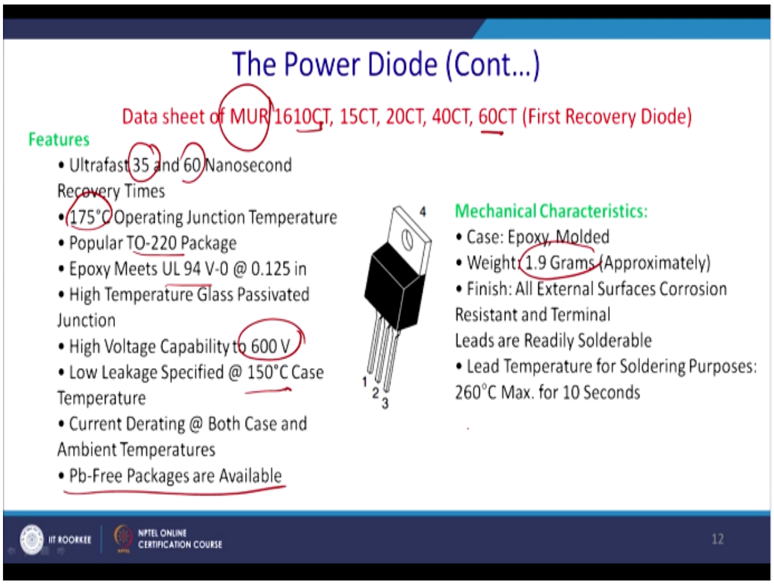

So now let us see a fast diode okay. Generally, two anti-parallel diodes are connected in series so forth this is and we have this kind of terminal. So you can have a 4 terminal, so generally these diodes will have a series of MUR 16 thereafter some numbers, 10 is actually will have a lower blocking capability and 60 will have a higher blocking capability. So ultrafast diode, you have seen that you know in previous diode has a trr or reverse recovery time in 1.5 or 1500 nanosecond, here it will have only 35 to 60 nanosecond.

Thus, it is a fast diode or fast recovery diode and find its application in SMPS or the any application where high frequency demands. It has got a huge operating point; it can operate as high as 175 degree centigrade. Popular package is this one and it meets actuals this is the UL standard, UL actually the standard is used for the European Union for anyone is exporting in a European Union, it has to meet this security standard of UL94.

Higher temperature glass passivated junction, for this it can operate at 175 degree centigrade and high voltage capability, it can block as high voltage as 600 volt, leakage has been specified even as high temperature 150 degree centigrade. Current derating both the cases of the ambient temperature has been specified and one aspect is that now one of the standard requirements of any modern country is that it should have a lead-free package.

You would also have a lead-free package for the environmental issues and weight is just you can see that around 2 grams, quite light and all external surfaces corrosion free and lead temperature of the soldering purpose and temperature while soldering can go to the actually 260 degree centigrade for the period of 10 seconds. No harm will be done on the diode.

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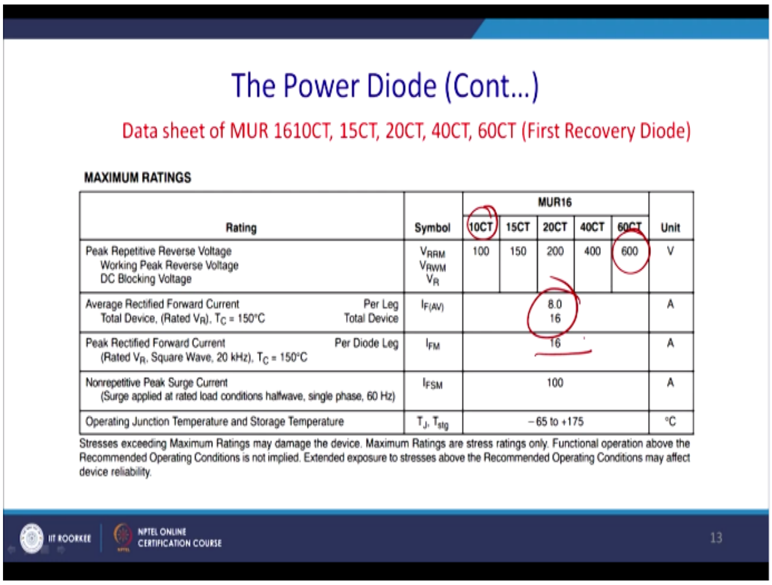

So these are the few features I was talking about, as this number goes you know you can see that power blocking capability increases. See that we had a blocking capability of the 1000 volts but anyway since it has a very fast recovery; it has only a power blocking capability of only 600 volt. So for this reason while choosing a diode, you require to understand it. What is another advantage of it?

It can handle huge current; you know it can handle 8 ampere of current or 16 ampere of current. Now the peak forward current is basically the 16 ampere and negative repetitive peak surge current can be as high as 100 ampere, it was same there but operating range is quite high, it is -65 to 175 degree centigrade. So it is a quite suitable for high frequency application.

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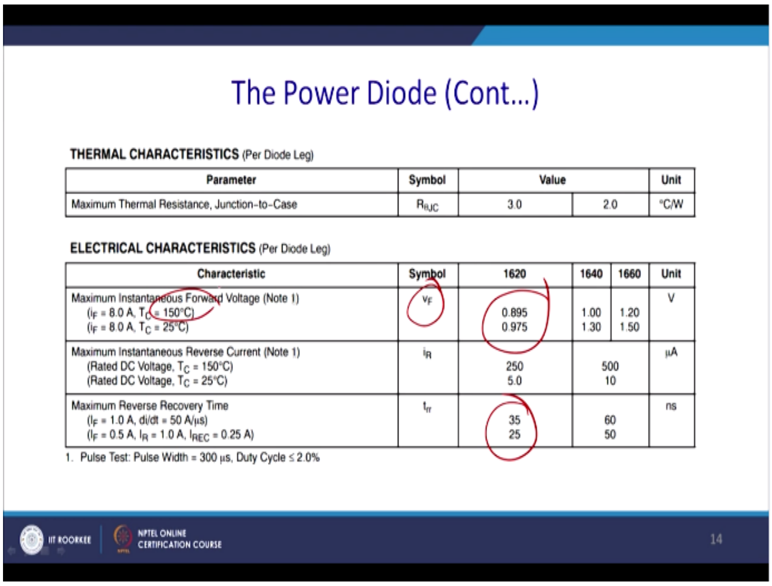

And apart from that you know actually we have actually other data's that is that is what the important thing is that trr value is 35 or 25 nanoseconds depending on the forward current and if it is 1 ampere current is flowing and di/dt is 50 ampere per microsecond then actually you will have only 35 microsecond. If it is 0.5, then it will have actually 25 nanoseconds and data's are almost same for other values.

So these are basically the forward conduction voltage drop, you can see, it is just little above 0.7 volt. So thus it is an excellent diode, it is 0.895 and 0.975 for different junctional temperature, higher junctional temperature will give you lower conduction loss that is the advantage of it and this is basically the characteristics of this diode. Now we shall get ventured into a controlled device.

But first we will go to the semi controlled device. Problem of diode is that it can block reverse voltage and allow current to flow in forward conduction mode but it is quite necessary for different application we required to have forward voltage carrying capability and thus is necessitate or it is a controlled though it is semi controlled because you cannot stop that switch but you can on it. So for this reason, actually one device was discovered 60 years ago in 1956.

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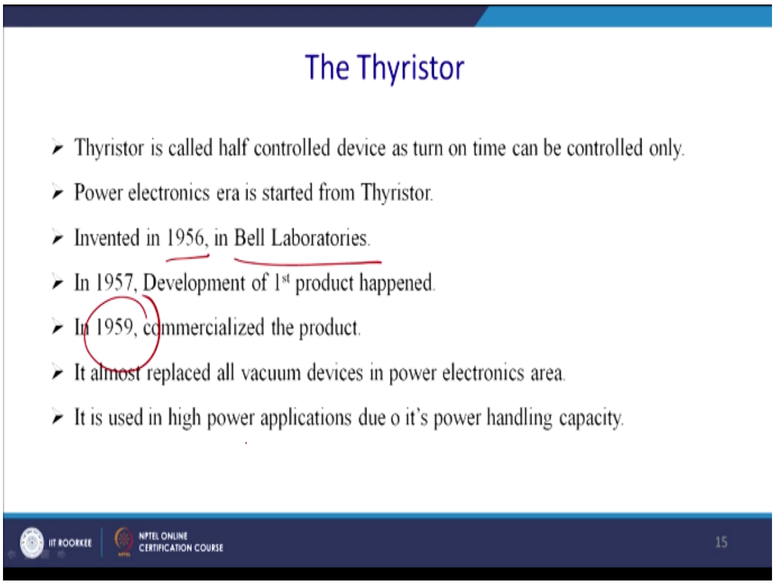

So the thyristors is called half controlled device and as turn on time can be controlled only. So you can control when to turn it on and it has got a forward blocking voltage capability and we can say that power electronics era started with the invention of the thyristor. Thus, we get into the venture into the power electronics when thyristors becomes fully functional and we can play around thyristors in those days.

And there is many research because turning on can be controlled, turn off cannot be controlled so how to turn off, so that was the main research in actually 60s. Thereafter, once we come out with the different technique of turn off, then it has been applied to the different topology apart from the controlled rectification operations and that was a domain of 70s. Thereafter, full controlled device due to the Baliga and all IGBT came and thus different application we do not use thyristors anymore.

And GTO came but still considering the power handling capability, no one cannot breach the capability of the thyristors. Thyristors has got highest power handling capability as far as current and voltage is concerned and also the less loss compared to the turn-on and turn-on loss compared to any other devices as concerned. So these are the few information we shall take it away.

It was the same lab where transistors were discovered. It was invented in 1956 in Bell Laboratories and first came into the production after a year in 1957, so it is almost 60 years and later after one year later the commercially it is available and it basically replaced all the vacuum power devices. We had a thermionic emission-based control rectification and that was removed and we came into the era of this power electronics from that point.

And it is used in high-power application due to its high power handling capability. We shall continue with the thyristors in our next class. Thank you for your kind attentions. We shall discuss thyristors in thorough and its characteristics and its applications, thereafter we will switch over to the GTO and other devices. Thank you so much for your attention.