Basic Building Blocks of Microwave Engineering
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Lecture - 19
Microwave Solid State Diode Oscillator and Amplifier

Welcome to the nineteenth lecture of this series of lecture on Basic Building Blocks of Microwave Engineering. Now, we have seen the microwave tubes and tube based amplifiers, now solid state devices also can make the oscillators and amplifiers. So, we will see a diode based oscillator very popular amongst microwave engineers.

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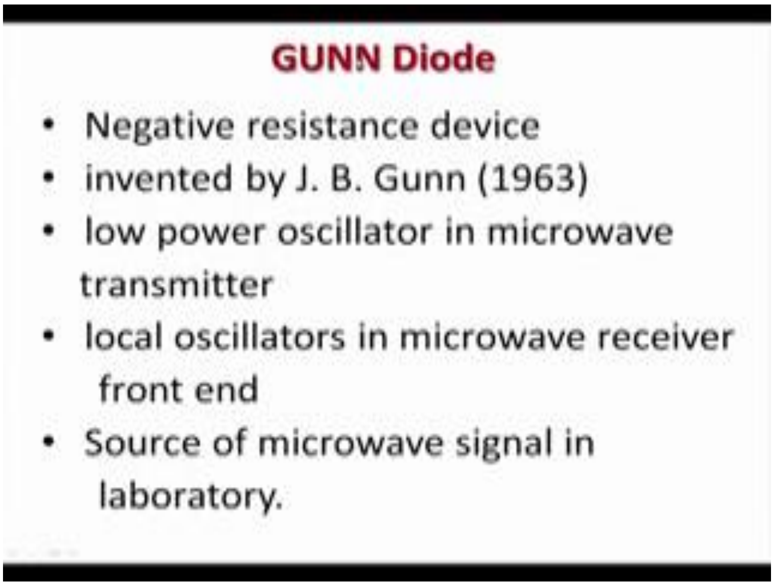

That is called GUNN diode, but remember the spelling GU double N, it is not GUN. It is a diode having negative resistance and was invented by J B Gunn in 1963 and thus the name GUNN diode. It is a low power oscillator in microwave transmitter, in local oscillators, in microwave receiver front ends all must invariably use this GUNN diode.

In our laboratory microwave signal, we can get from GUNN diode and nowadays you see the reflex lies on and that generally GUNN diode is much cheaper so, we use it only problem is its power is not much but most of the experiments can be done with this

GUNN diode and there are some experiments where we require high power particularly antenna experiments where we prefer to have a (Refer Time: 02:09) base source, but it is a very good source of microwave signal in laboratory.

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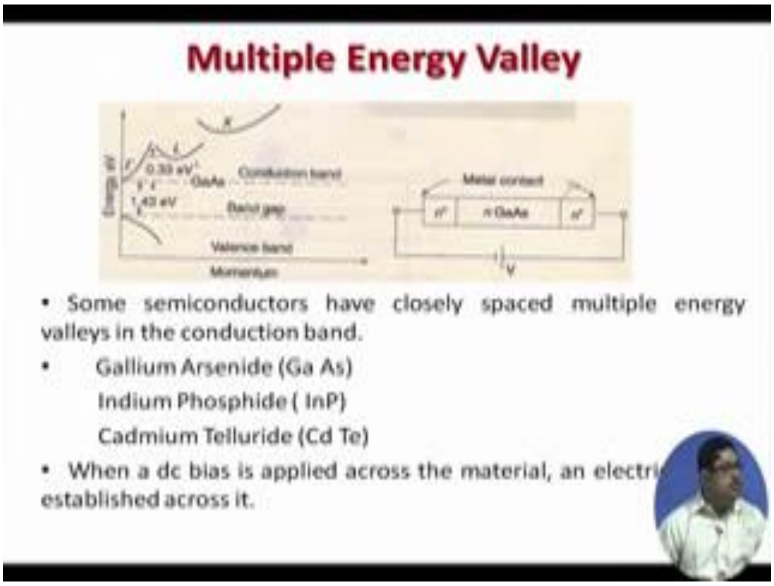

So, you look at the GUNN diode and if you look the energy versus momentum diagram of GUNN diode, actually some semiconductors and generally semi conductors have a valence band and conduction band and energy band diagram is to valleys which come together the conduction band lower part and valence band upper part which come together and that gap is called the energy gap, but some semi conductors like Gallium Arsenide Indium Phosphide and Cadmium Telluride these three in the conduction band they have closely spaced sub bands, closely spaced multiple energy valleys in the conduction band. So, you see here this is not in general we get only one, but here this in gallium arsenide we get these values for gallium arsenide.

So, the difference between these bands their energy is more, but you see that x axis is momentum and momentum of the electron if it is here then its velocity will be less and here also velocity will be less. So, when a dc bias is applied across the material, an electric field is established.

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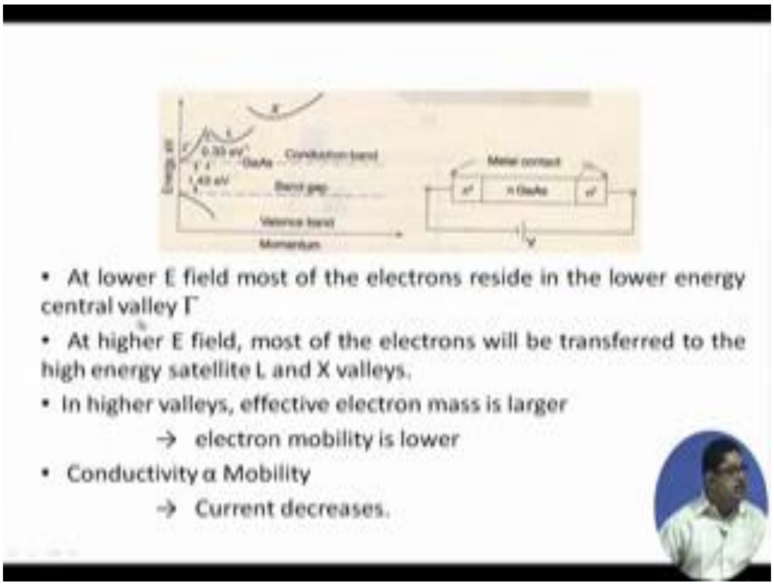

So, let us say this is the gallium arsenide thing and at lower E field most of the electrons because energy is small so you will decide in the lower valley gamma, but at higher E field as we give more electric field that means, if we go on increasing the bias the electrons will get energy from that bias and will transfer them to high energy satellite valleys like L and X.

Now, in higher valleys effective electron mass is higher and mass higher means they are obviously, from the momentum you have seen mass is higher. So, mass higher, now more mass electron has lower mobility and these bands the electrons mobility are less and if you go higher almost their immobile type of thing and we know this famous thing and science equation that conductivity is proportional to mobility.

We can say that if electron mobility is less, their conductivity is also less and if the conductivity is less then we can say the current will decrease.

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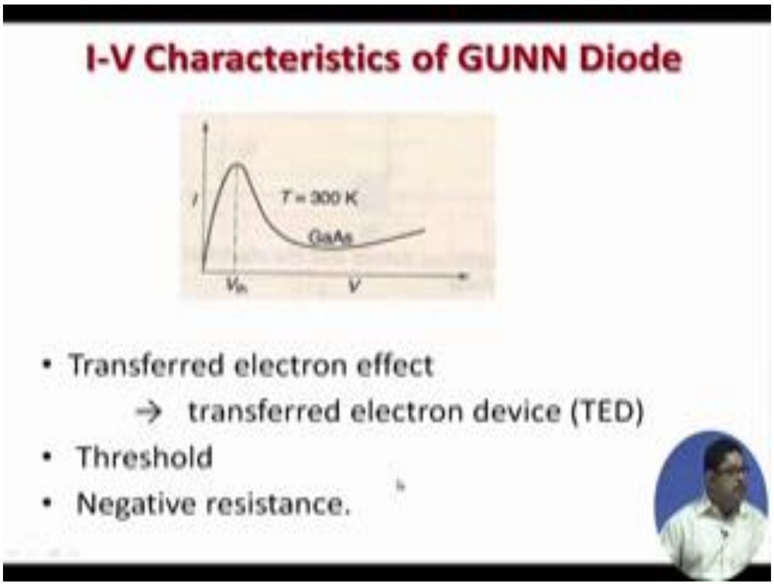

So, we can say that if we go on giving more bias voltage there is a threshold so, more voltage means more current that was ohm's law, but here you see you have a threshold actually that energy transfers that is taking place and transferred electron become predominant and then we get that as we are going on increasing V, it is no more ohm's law then it is basically an decrease in the current which gives rise to the negative electron. We are getting that above a threshold there is a negative resistance now GUNN in gallium arsenide and could make out that we can make a diode oscillator from these.

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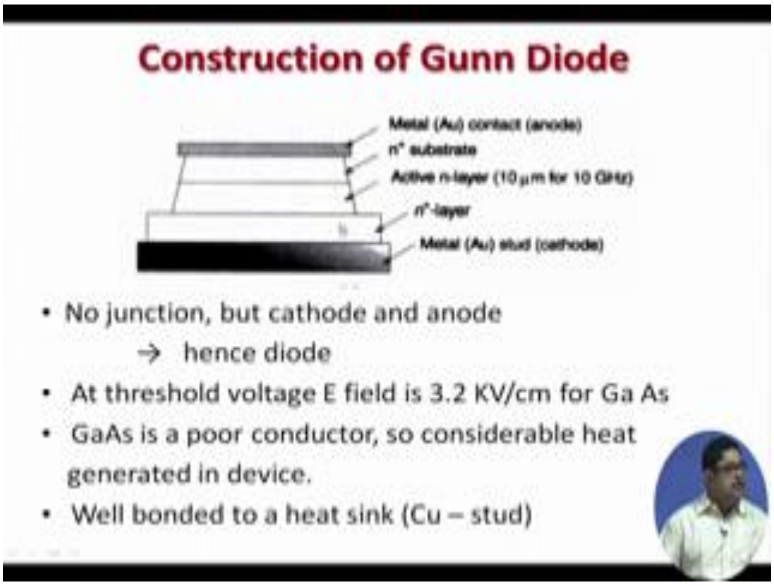

This is a construction of a GUNN diode and basically you do not have any junction sort of thing, you have a gallium arsenide crystal then you have n type these and only in the two sides you have two different higher doping n plus regions. So, whole thing you see same material, only doping level at the two ends for making electrons, they are making in different, but you are connecting when you are biasing, connecting positive part here connecting negative here. So, this will become cathode and this will become anode and that is why it is called a diode, otherwise GUNN diode is not a diode, it is a bulk semiconductor and there is no junction concept here, no junction but cathode and anode so, diode. At threshold voltage E field is 3.2 kilo volt per centimeter for gallium arsenide and for other two materials it is different.

You see this is a anode metal then n plus of sub state then active n layer and this is the actual bulk semi conductor, its thickness is 10 micro millimeter for a 10 gigahertz diode, n plus layer then there is again metal very thin silver but copper also used and cathode is here. Here metal contact now gallium arsenide is basically its conductivity is poor.

A lot of heat is generated in the device which defines it is a poor conductor of heat and that is why this metal contacts they should be put to a heat sink so that this heat can come out this device.

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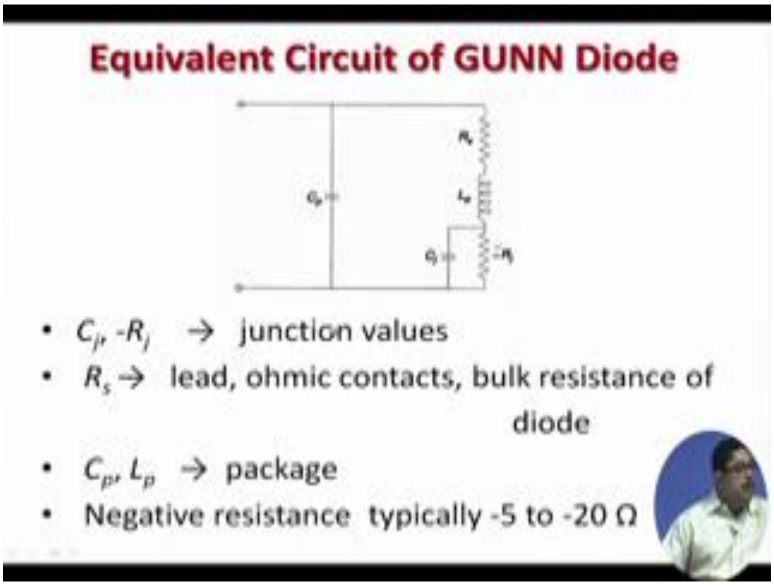

Equivalent circuit of a GUNN diode again you see the junction capacitance and resistance of diode and only change here is instead of Rj, it is a minus Rj because we have seen the negative resistance and there are the Rs n L p that thing and then Cp. So, Rs lead ohmic contacts, bulk resistance of diode and Cp and Lp at the package inductance and package reactance and negative resistance typically of the order of minus 5 to minus 20 ohm.

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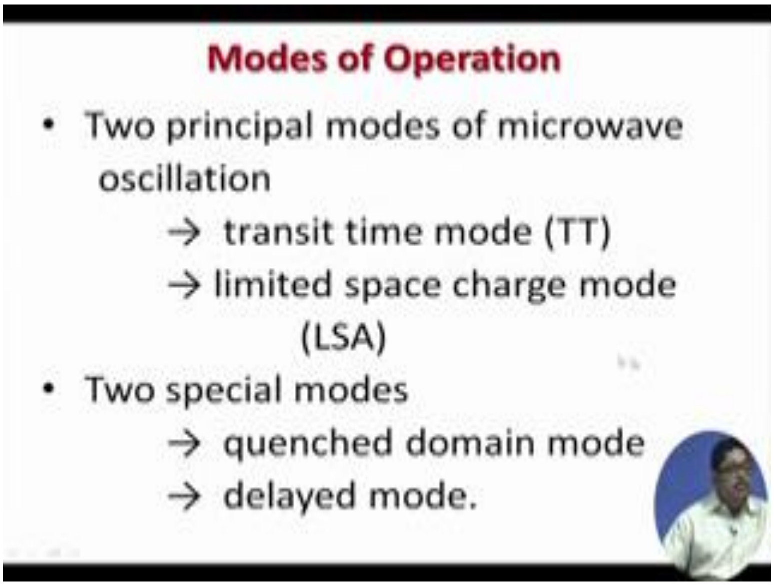

Now, let us understand the modes of operation of GUNN diode. There are two principal modes of microwave oscillation, one is called transit time mode or TT mode and the other is called limited space charge mode or LSA mode, but there are two special modes, generally these first two are the principal modes, but you can also operate it into other special modes, one is called quenched domain mode, another is delayed mode. So, there are four modes out of that two are principal and we will see all these modes.

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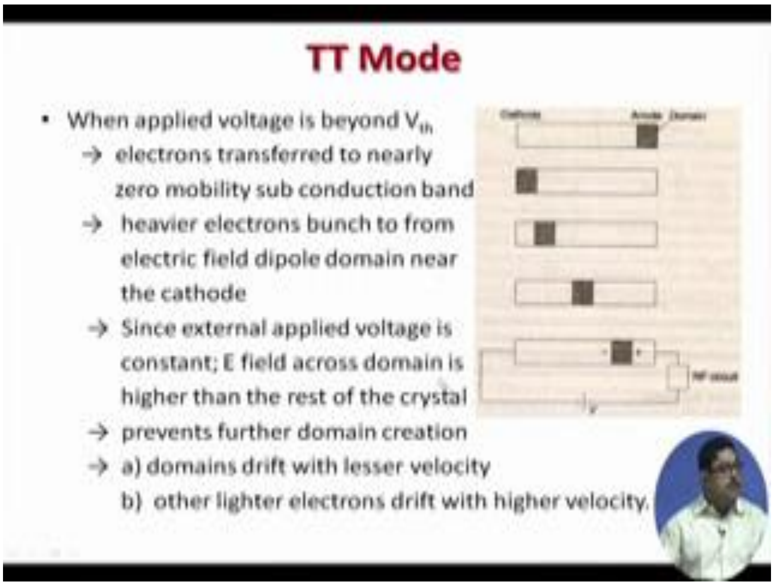

So, let us see the TT mode first. We have this semiconductor material and that is biased and then connected to an RF circuit. So, this is the GUNN diode, now this side is since negative so it is cathode and this side is anode. Now, when applied bias voltage is beyond the threshold voltage in the - i b curve and the electrons start getting transferred. So, electrons transferred to nearly 0 mobility sub conduction band.

Since, they are immobile so, the electrons which are coming from cathode now, they start coming in a group called domain. So, heavier electrons bunch to form electric field dipole domain near the cathode and near the cathode you see this black one, this is the domain.

So, like initially when the bias field is not there the domain was here that we will see later, but now there is a domain created and that domain is moving with a very small velocity field domain of the cathode since external applied voltage is constant. Now, this applied voltage is constant because beyond threshold we are trying to see what happened. E field across domain is higher than the rest of the crystal because here the E field will be higher because the total voltage is same. So, there are many electrons whose electric field is more than these. So, that electric field has that means that is opposing this B so that is creating which prevents further domain creation.

Now, the domain obviously has a drift. So, we have to stop t but there is some small velocity so, it is drifting with that lesser velocity and other lighter electrons drift with higher velocity and they are going.

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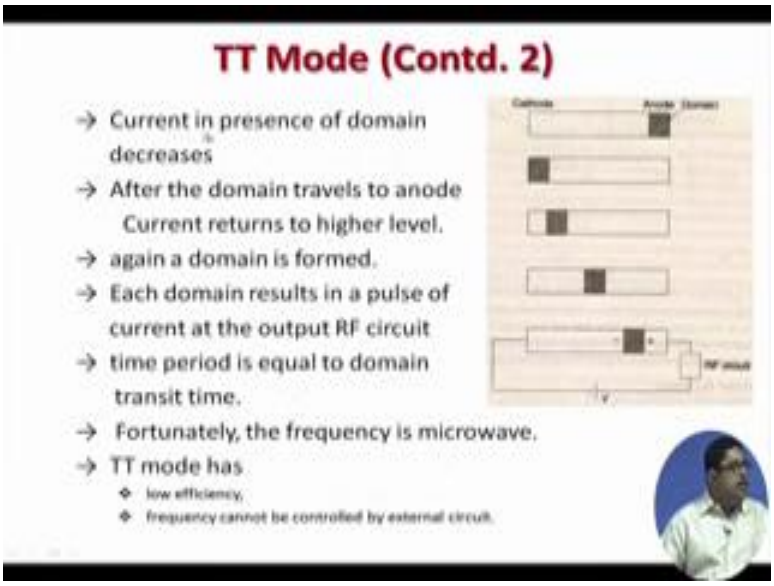

Now, current in presence of domain decreases because current means with velocity and if the velocity is less, the current is small and that we have already seen from the ib curve also. After the domain travels to anode then you see that to current returns to higher level because now the anode is here and whatever electrons again a domain will be formed here and that domain will start moving. So, each domain basically when it gets connected by anode, we can say that it creates a pulse of current at the output of circuit y when the anode is getting a suddenly you see a lot of current is there otherwise there the domain is taking quite long time to come. So, no current and then suddenly a huge current come.

So, RF circuit obviously, the other electron, they are few some current is there always, but this is a pulse type thing over that. So, you get pulsed signals and each domain results in a pulse of current at the output RF circuit, time period of that is equal to domain transit time and the domain from here to here whatever time it takes. We are fortunate that transit time of this GUNN diode for the domains that falls in microwave region that means, in the microwave frequency so one by that frequency and this transit time is fortunate and that is why we get microwave signal from this GUNN diode. So, TT mode has low efficiency as you are saying that you need to give the voltage and that much current you do not get and frequency cannot be controlled. So, there is no controlling mechanism in TT mode and you cannot control the output frequency, whatever the transit time of the domain by that only you can have this mode. So, this is the basic mode of GUNN diode.

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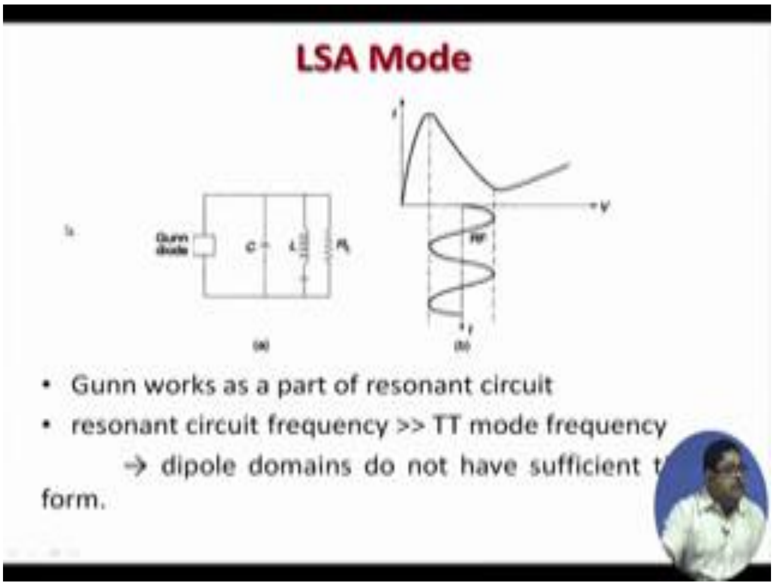

Now, what is a LSA mode, here we do some external thing, we connect that GUNN diode to a resonant circuit RL C. So, GUNN works as a part of resonant circuit. Now, resonant circuit frequency is much greater than TT mode frequency. So, whatever the GUNN diode was producing in TT mode, the RL C circuit the resonant frequency is much higher. So, the frequency of resonant circuit is much higher means time and only part of that domain transit time by that one signal is coming. The domains are not been able to form and do not have sufficient time to form because this frequency is much higher and because domains require from electrons to domain creation that take some time and by that time the whole thing is again repeating. So, domains do not get created in the LSA mode, limited space charge mode that is why they are called that.

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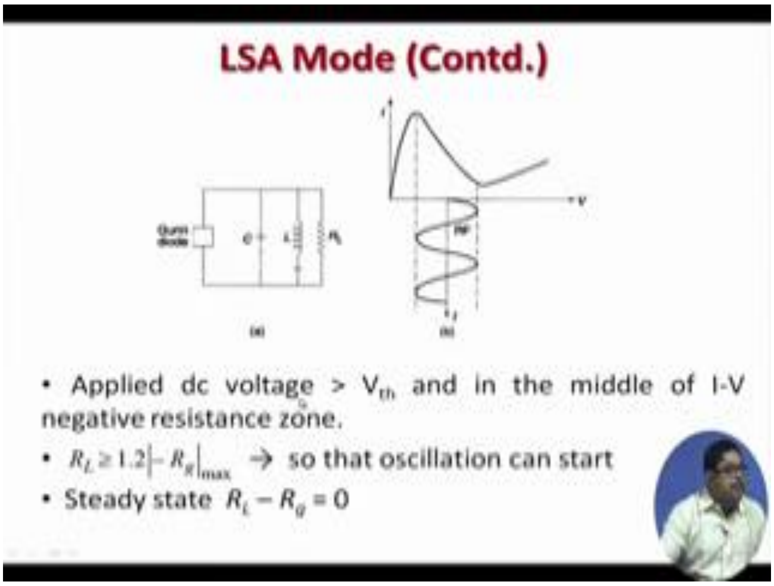

You are not applying the space to develop and applied dc voltage is greater than threshold and in the middle of I-V negative resistance zone. So, you see that the b is not BTH you are applying almost here BTI and Rl you are choosing so that oscillation can start steady state after a thing at steady state RL becomes equal to RG. So, a steady sustained oscillation takes place.

Now, peak to peak voltage of microwave oscillator is equal to voltage range of negative resistance curve because this to this voltage range of negative resistance curve which is equal to the peak to peak voltage of microwave oscillator and power efficiency is 20 percent, Output Power several Watts, Power decreases with frequency 1 watt at 10 gigahertz and if you want hundred gigahertz signal then several mega watt, but this a good mode of operation.

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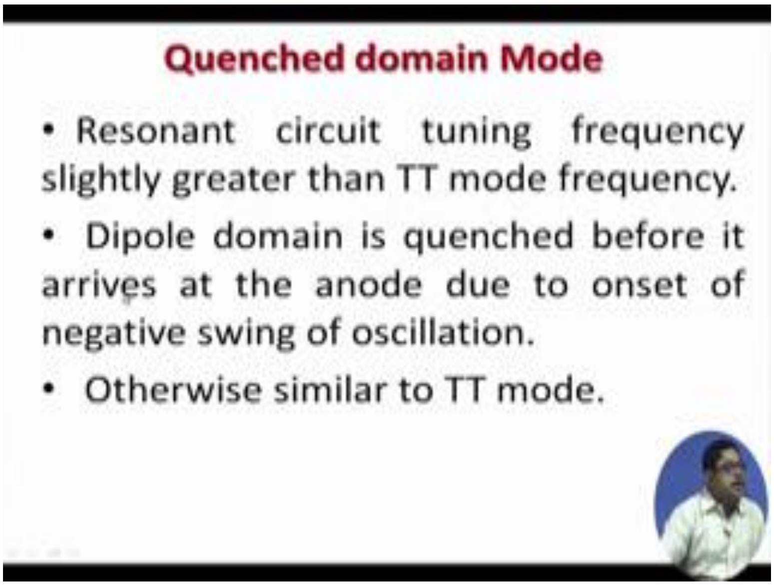

Now, quenched domain mode, Resonant circuit tuning frequency is slightly greater than TT mode. In LSA mode, it was much higher and here it is slightly higher than TT mode. So, dipole will be creating here, but dipole domain is quenched before it arrives at the anode because already when it is arriving, the resonant frequency is higher that is why already a negative swing has taken place. So, we say that the domain is quenched, but will have some TT mode some operations. So, there will be current, but it is a quenched domain.

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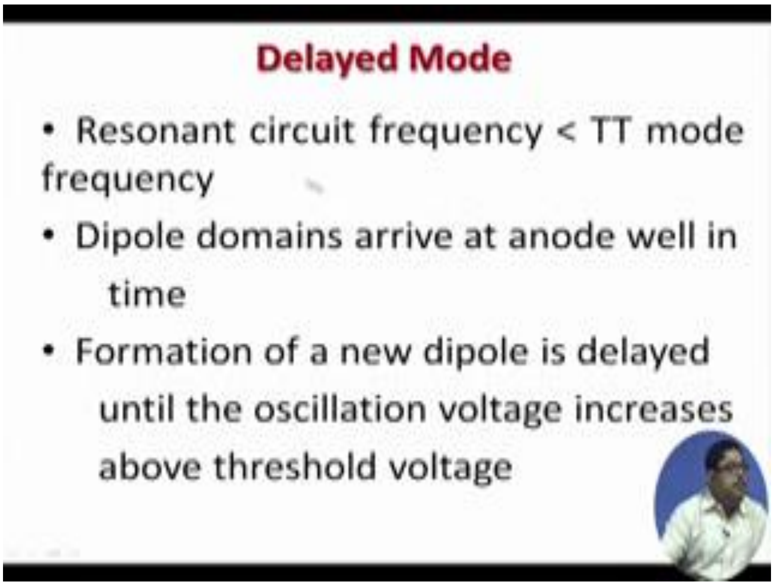

Then in delayed mode, Resonant circuit frequency less than TT mode and the other option that in quenched domain mode the resonant frequency is slightly higher than TT mode and here it is slightly lower.

So, dipole domains arrive at anode well in time then they will have to wait because formation of a new dipole is delayed until the oscillation voltage increases above threshold voltage. Here, the mode that will be slightly delayed because after creation of a domain and the domain is arriving getting a pulse, but then again sometime then the whole operation again is starting.

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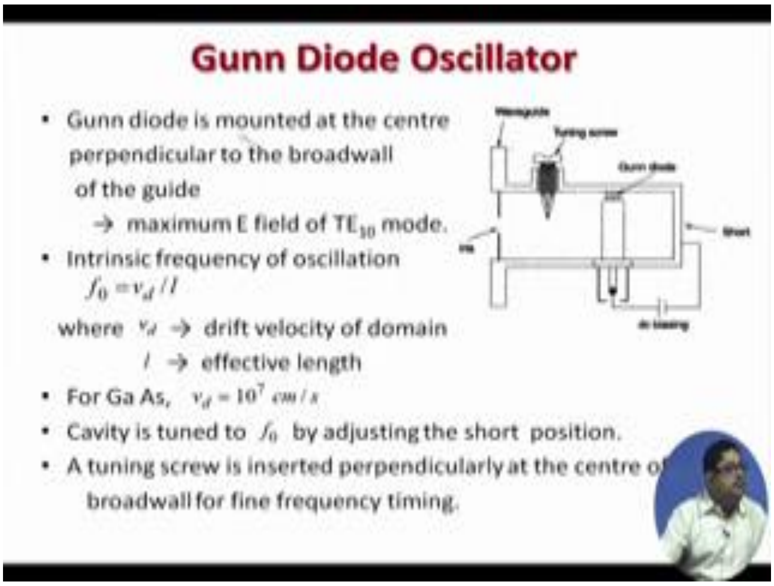

So, GUNN diode oscillator, generally this whole RLC circuit which is called GUNN diode oscillator and GUNN diode is mounted at the center you see this is the GUNN diode perpendicular to the broad wall of the guide. We have seen that what is the broad wall, so perpendicular to that of a rectangular guide, maximum E field of TEn mode is there where it is placed and intrinsic frequency of oscillation is vd by l, drift velocity of domain by effective length and this is intrinsic frequency or the TT mode of operation frequency. For gallium arsenide this vd drift velocity of domain is typically 10 to the power 7 centimeter per second and cavity is tuned to f naught by adjusting the short position. So, if you move that short you can make the cavity frequency and a tuning screw is inserted perpendicularly at center of the broad wall for again fine tuning.

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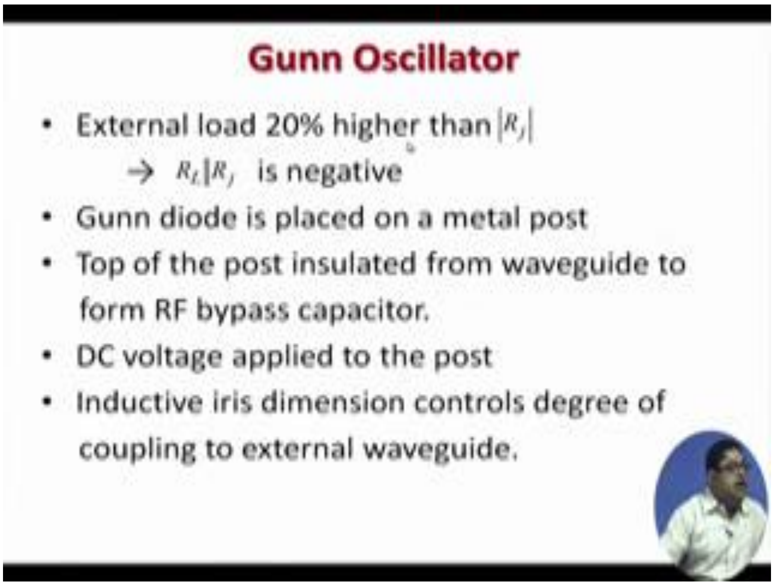

External load is 20 percent higher than Rj. This 20 percent is a good one because when the actual sustained oscillation is taking place this load is reduced because the Rj is a negative value. So, RL and Rj combination will be balancing. GUNN diode is placed on a metal post, top of the post as you have seen GUNN diode is, this is the post and post means that has some inductive value insulated from wave guide to form RF bypass capacitor.

So, top of the post is insulated and there is an RF bypass capacitor also and dc voltage is applied to the post. DC voltage goes to here and the RF is choked, inductive iris dimension controls degree of coupling to external waveguide and see this is the iris. So, whatever this oscillator is producing, the external part iris means it is a capacitive thing and from there by capacitive coupling it is taking to the outside RF.

Now, GUNN diode oscillator is in laboratory instead of reflex diode, we have GUNN diode oscillator then this is producing microwave signal and that external load DC voltage.

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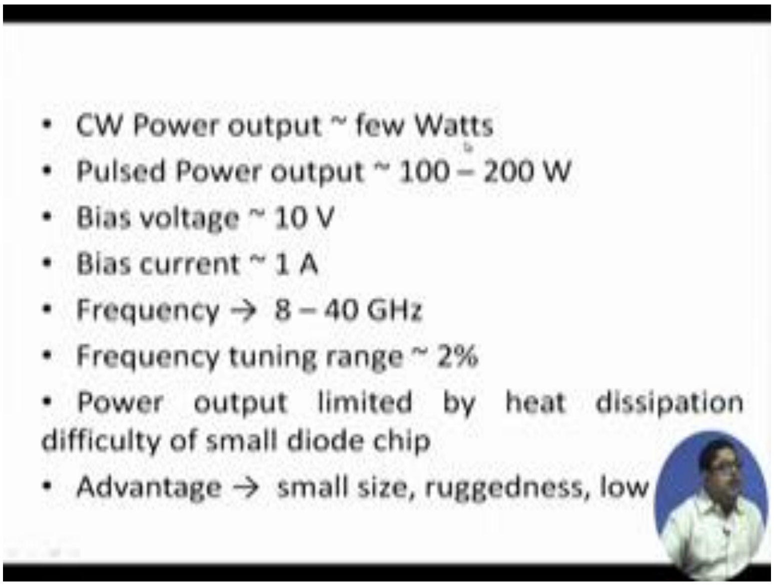

Output power is few watts you can get like klystron you can also have this GUNN diode power, pulse power output 100 to 200 watt pulse power you can get, bias voltage 10 volt, bias current 1 ampere. So, quite good you can by 10 volt supply in laboratory we can have that frequency 8 to 40 gigahertz and you can get frequency tuning and you can get electronic tuning two percent quite at gigahertz range 2 percent means suppose 10 gigahertz. So, you get 200 mega hertz and that is quite good. Power output limited by heat dissipation difficulty of small diode chip, gas is a poor conductor.

So, the power output, you cannot go on increasing the high power because heat dissipation is a problem in the gas etc and advantage is small sized, ruggedness, low cost.

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This is a typically GUNN diode oscillator. So, by moving this screw basically you can change the tuning that this is the tuning screw and this is the iris from where power is extracted and this side actually fits into the GUNN diode oscillator.

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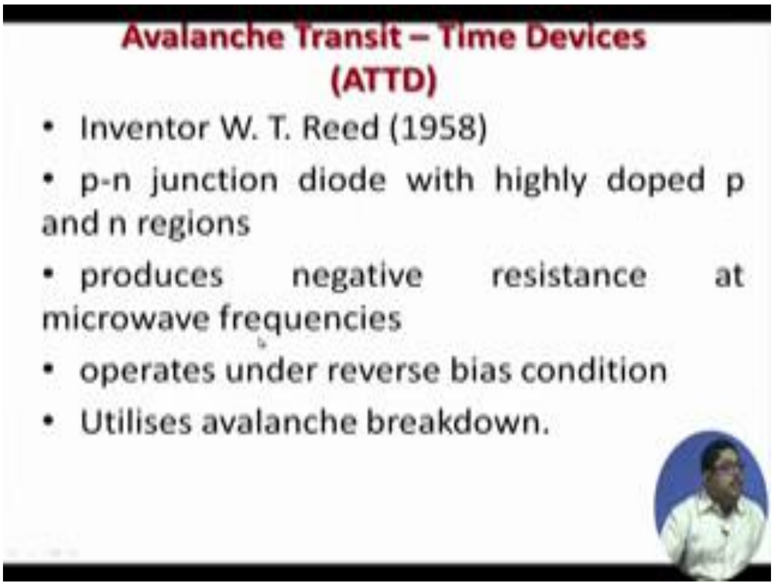

Now, we will see another diode, actually there is another effect Avalanche Transit-Time Devices and in GUNN we have seen the transfer electron type, but avalanche process which also gives a good transit time devices, these are called ATTD and they have three varieties, Inventor was W T Reed in 1950 almost the much 4 years before the GUNN invented that GUNN diode and these are p-n junction diode, these are junction diode with highly doped p and n regions. So, p-n junction diode with highly doped p and n region and these also produces negative resistance at microwave frequencies and this operates under reverse bias condition. So, it is a reverse bias diode and gives sufficient reverse bias so that, avalanche breakdown take place.

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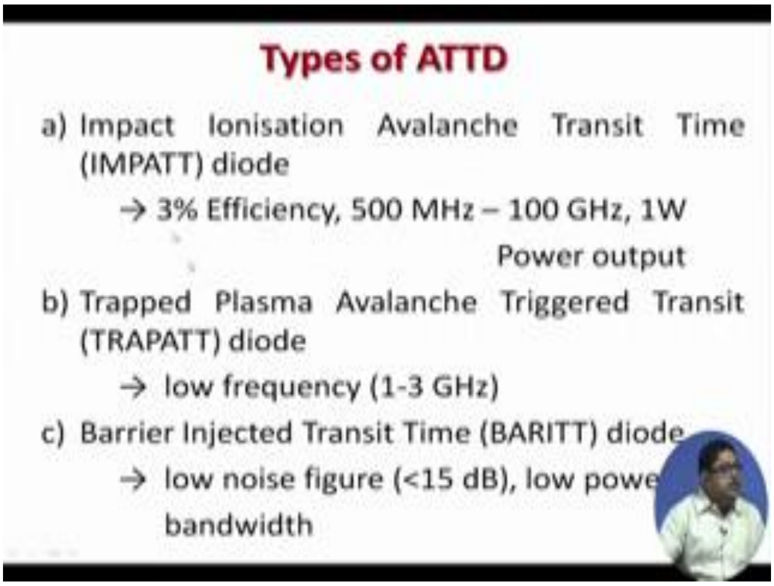

Now, there are three varieties of ATTD, one is called Impact Ionisation Avalanche Transit Time and this is having 3 percent efficiency up to 100 gigahertz 1 watt power output. So, quite good low frequency thing, Trapped Plasma Avalanche Triggered Transit TRAPATT diode, low frequency these are low frequency diode 1 to 3 gigahertz only and Barrier Injected Transit Time BARITT diode this has low noise figure less than 15 dB low power and low bandwidth.

Actually, this ATTDs, they are generally having high noise figure because these are avalanche process is lot of noise, but this barrier injected transit time this has low noise figure, but 15 dB is also not a very good noise figure, but in this family it is a good one.

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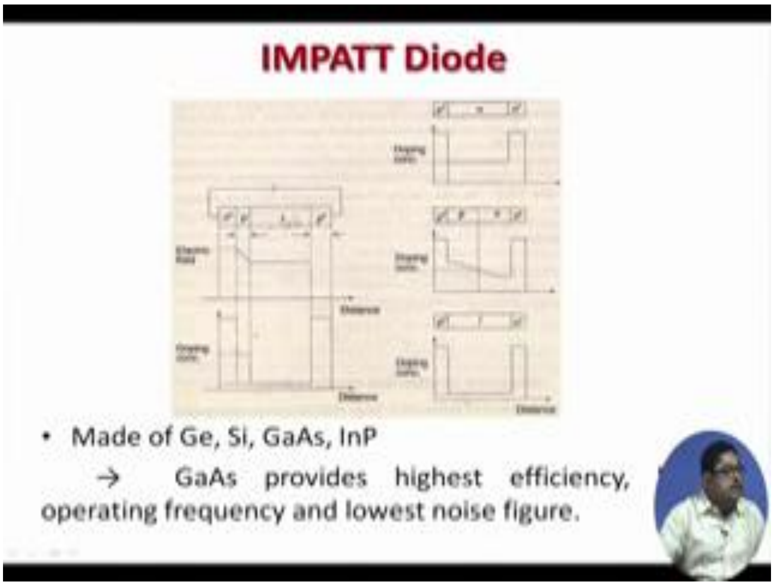

So, this is a thing that you see n plus p junction then there is an intrinsic junction p also you can have other varieties p plus etc, but there is p n junction. So, material you can have germanium, you can have silicon, you can have gas, you can have indium phosphite and now gas provides highest efficiency, highest operating frequency and lowest noise figure. So, IMPATT diode with gas is good.

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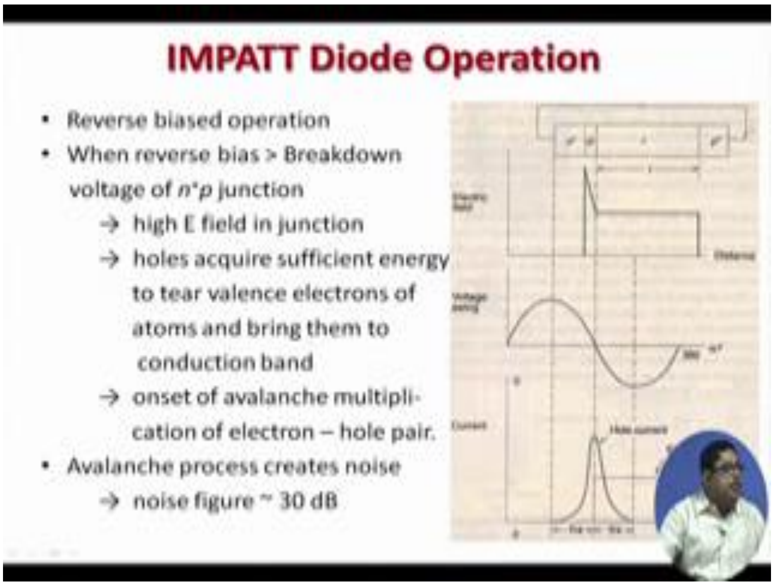

Now, its a reverse bias operation. So, you have a junction diode. When reverse bias is where greater than breakdown voltage of p n junction then high E field in junction as shown that electric field is high. With this high field, there is sufficient energy. So, holes in since we are describing with respect to these. So, holes acquire sufficient energy to tear valence electrons of atoms and bring them to conduction band and then this is greater.

Again these electrons with such high energy will collide with other atoms and they will take that avalanche process. So, on set of avalanche multiplication of electron hole pair, avalanche process creates noise and that is why you see noise figure of IMPATT diode is 30 dB. So, very noisy, but it is good if you want to have power you can also use impact diode.

Thank you