High Speed Devices and Circuits

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Lecture – 27

MESFET: Velocity Field Characteristics and Velocity Overshoot Effects

We have discussed in our last discussion the velocity field characteristics of gallium arsenide.

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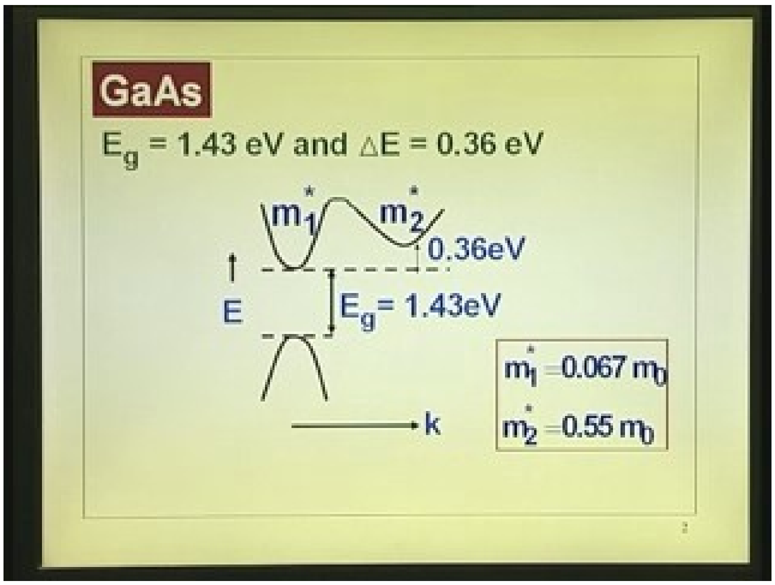

We have shown that the entire reason for that sort of velocity field characteristics is due to the scattering of electrons from this valley to that valley. As it gains energy from the electric field, those electrons become hot. That is, there are no longer in thermal equilibrium of silicon at that moment and then get transferred on to that. So, they will come into equilibrium after that point in the sense they have definitely higher energies. So, if you relax them they will come back to this point. That is what we have seen.

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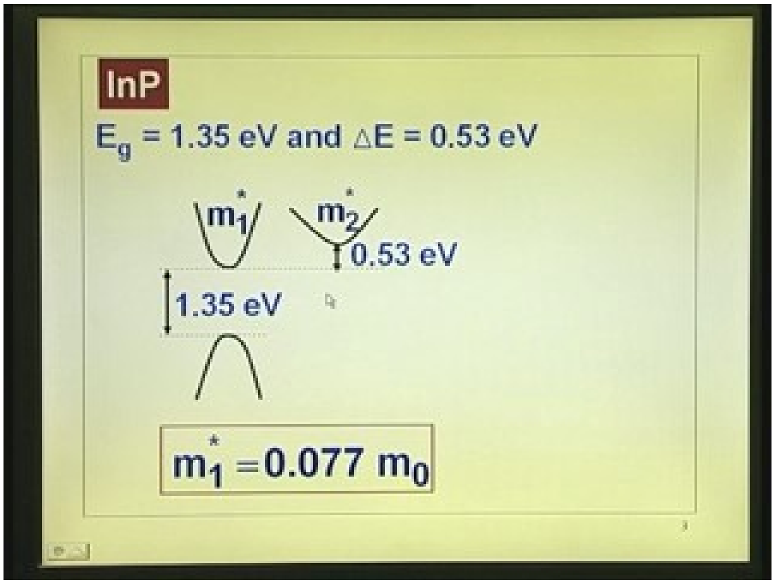

Also the other materials like indium phosphate, they have similar characteristics, because the energy band gap is 1.35 electron volts and this gap is 0.53. Now, this has some impact on the peek electric field and also the energy required transferring the electrons from here to here. They are more than that of gallium arsenide. Gallium arsenide required 0.36 electron volts. Now, this was more that means you could have higher fields.

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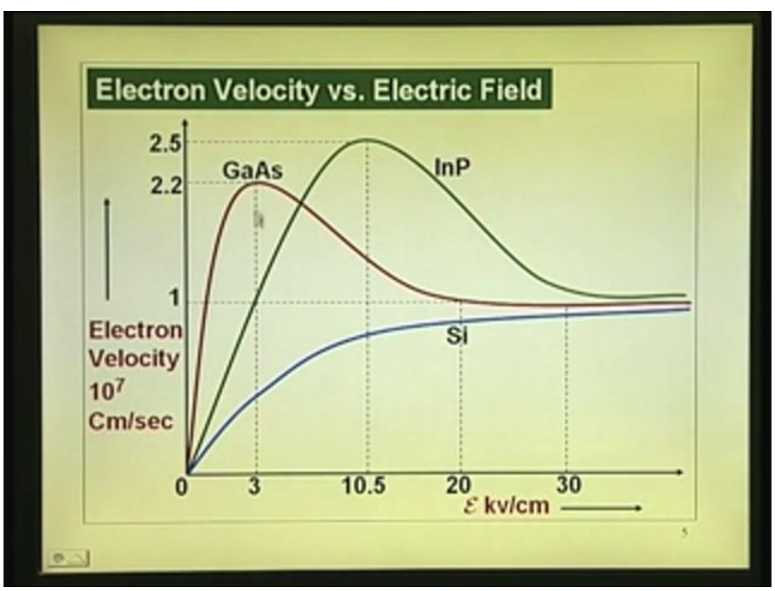

Now, so you just go back to this diagram now, so that it illustrates everything. The peek electric field at which the complete transfer of electrons from the lower valley to the satellite valley. That is over by starts the transfer of electrons really begins at 3KV per centimeter. This completes of course by the time you reach that point. The negative differential mobility, if you want to call, you can call, because I increase the electric field the velocity falls. So, the negative differential mobility region is this; that is due to the electrons getting transferred on to the upper valley. In the case of indium phosphate, the transfer takes place at about 10.5 kilo volts per centimeter. The reason at delta E is 0.53 electron volts and also since you subject it into higher energy, the peek velocity is more than that what you get in gallium arsenide. That is because it gets transferred much before that it can go to that velocity here you need higher energy; so higher velocity. As the result we have got 2.5 into 10 to the power of 7 centimeter per second that is the velocity.

Now, couple of things to note here, if you take a look at the silicon steady state velocity field characteristics, it never goes to the peek, whether it remains in the lower valley. This is we give enough time for the electrons to settle down to that particular energy. Now, if you take gallium arsenide, it goes through the peek and the velocity is in this range up to 20KV per centimeter or above than that of saturation velocity of silicon. Saturation velocity of electron in silicon is 10 to the power of 7; whereas, it is much more in this region. That is one thing to note. If you take indium phosphate, we can see it is from this point onwards right up to about 30 or more than 30 KV per centimeter the velocities are much higher. So you can expect that indium phosphate devices can be a potential contender for high speed devices but unfortunately the cost wise, silicon is the cheapest among; next is gallium arsenide and next is indium phosphate. Understanding of technology, silicon is best understood; next best understood gallium arsenide; the least understood is or more difficult process is indium phosphate.

So, you would not go to this, unless you really require that because this curve is quite a bit of purpose of high speed devices. It makes it easy to make devices with hydro junction etc., with gallium arsenide.

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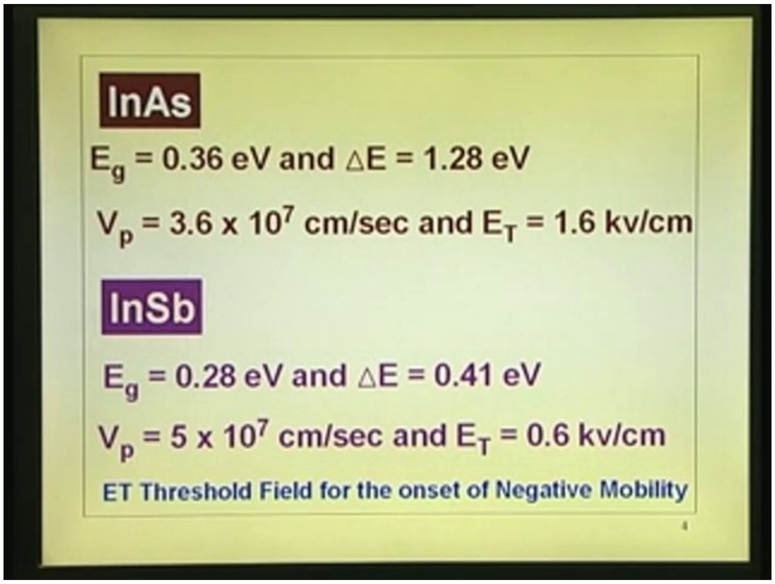

Now, you can just see some of the other material, just for sake of completion, I just project this. I am not plotting the electron velocity field characteristics. Indium arsenide if you take its direct band gap material 0.36 electron volts and delta E is 1.28 electron volts. Now, the peek field is actually higher in fact if you remember, the mobility of electrons in indium arsenide is much higher than that of gallium arsenide. So, it gets raised to that field quite quickly and it gets transferred much higher energy. This E_T is actually the peek electric field; you can call it as E_T or E_{peek}. Go back to this curve (Refer Slide Time: 06:20) if you take you can call this as E_{peek} and this as V_{peek}. Peek velocity electric field at which you get peek velocity Ep or you can call it as $E_{Transfer}$. Because that is the point at which the electrons begin to transfer to the upper valley. So, that is why we use it in a different ways. So, these are just information that I am providing they also under go this velocity overshoot or velocity peeking, because of the transfer of electrons from the lower valley to upper valley. Indium arsenide is much lower band gap delta E is 0.41 you have got much higher velocity is coming up. Mobility is very high here. This also is just information that I am providing you. But main material that we look forward is between these two (Refer Slide Time: 07:13) gallium arsenide and indium phosphate and between them also gallium arsenide.

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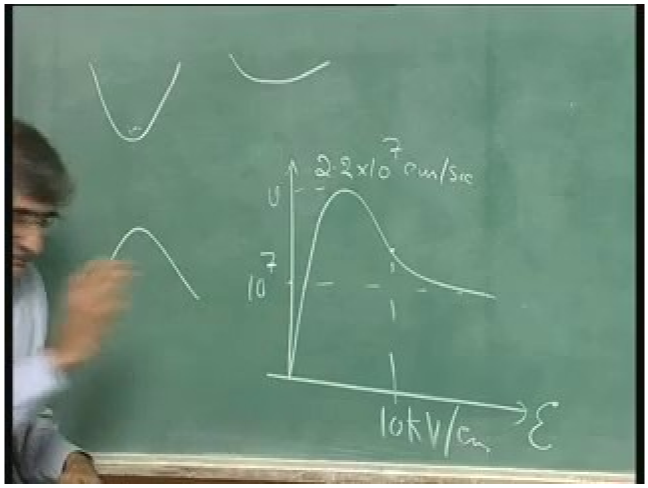

Now, couples of things, supposing you take the energy versus momentum, let us take gallium arsenide. Once you discussed that same thing holds good for indium phosphate also. Notice I am drawing it flat compare to this steeper, showing that effective mass is higher here 0.55 times m_0, 0.67 times m_0. So, when I hold, that is when the electrons are not hot that is the field is small, electrons remain here. Now, what we say is the velocity field characteristics go through a peek, reason being transfer by transfer from here to here.

Now, the plot that we have given there (Refer Slide Time: 08:20); the plot that is put in this case, let me just keep it here. So that we can just… it goes through thing like this and that is almost 1.0 into 10 to the power of 7 centimeter per second, why to do all these thing let me put it straight away 10 to the power 7; this is 2.2 times 10 to the power 7. This curve is derived or is achieved at steady state. We apply an electric field gives sufficient time the electrons can transfer from here to here. Now, you have electrons which are suddenly subjected to this field. That is the way you can understand very easily. This concept is slightly more over, but it is not very difficult. All that you have to visualize is it takes time for electrons to get transferred from here to here. If I apply an electric field give enough time, then it will get transfer to that. Now suppose I subject it to this field high field right away. For example, if I put 10KV per centimeter down here. What would happen? The electron which is present here immediately is subjected to that high field and it experiences the benefits of being here. What I imply is it experiences as smaller effective mass. So, it has got high mobility, but now the field that you get experience is very high.

If I am here it is a different issue the field is low, but if I apply high fields suddenly launched the electron into region where high fields are present, then it will actually get accelerated to very high velocities. V is equal to mu_n into E. mu_n is actually very high here. So, because mu_n is high and if electric field is also high it gets accelerated quite quickly with high velocities. Before it knows it has gone pass this energy. If you give time and slowly apply, it will get transfer into that. But now here itself it states it gets accelerated to high energy. There is a time gap between its acquiring high energy and the time between which it changes mobility momentum from here to here. There is a momentum change, so the entire difference you can move it as, to talk in more technical terms that, difference in the relaxation times for energy and momentum. It takes some time to acquire that energy. Once it acquires the energy it goes and settles to the momentum required to go transfer from here to here. There is a momentum difference after momentum is m into v half m is squared is energy. So has to require that energy once it goes to that energy you have got some momentum. So if you do not like to understand that way we can say that there is a finite time which lapses before the electron gets transferred from this valley to that valley. During that finite time it is moving at much higher velocity, so it goes into much higher velocity.

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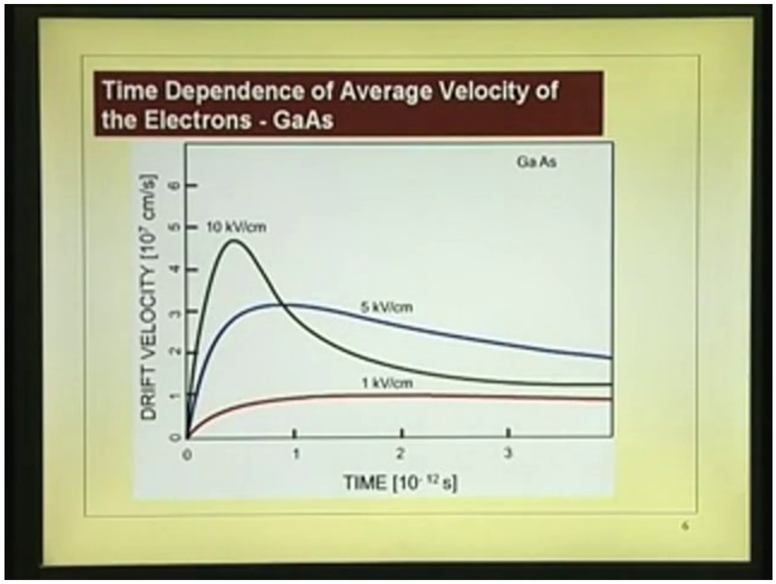

So, notice here this curve 10KV per centimeter applied. These curves are generated by simulation a technique called as Montour Carlo simulation, where actually you absorb the moment of each of those a group of electrons in individually, statistically. That is not bothered about how it is done but finally by that simulation they generated this velocity gets characteristic. The concept is because of this particular time lapsed that is during the transient time what is plotted here you can see is the velocities of an electron are sustained.

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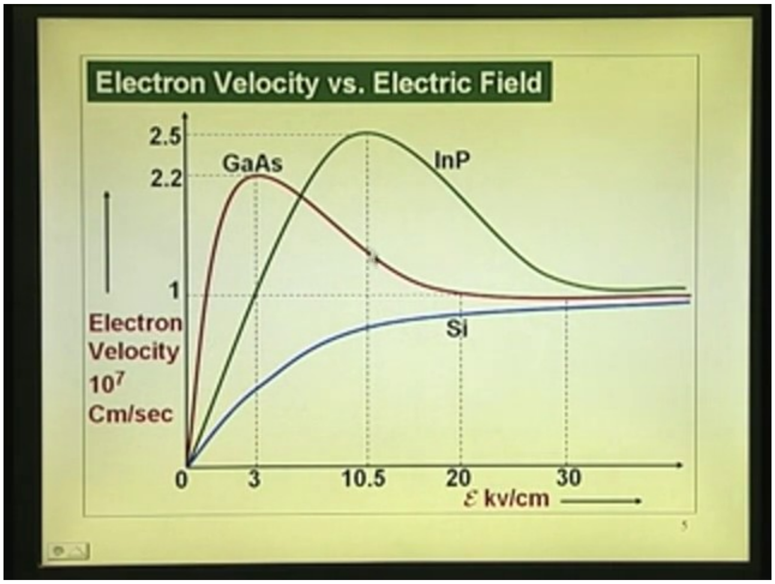

If you go back to the previous curve, velocity versus steady state field, so if I am biasing at 10KV per centimeter I am here. During the transient condition, if I apply suddenly a 10KV per centimeter, it will not go to this velocity. To go to this velocity it has go through this transient and go there. But because when you go through this transient here, just notice here, in this portion when you see this you are talking of low fields. Supposing when the electron is in the lower valley it experiences 10KV per centimeter, it will be right up there before it goes into this portion. So, there is a time which is elapsed before it acquires with goes from 0 velocities, this velocity to that velocity. That is what plotted there.

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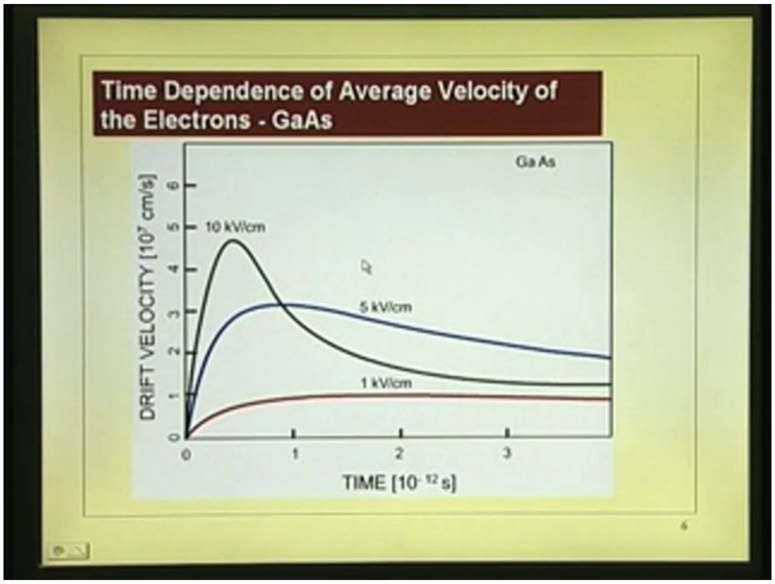

Ultimately, what will be the velocity? If you see the velocity versus time for that I will just explain one curve other rules are same thing. So, 10KV per centimeter to go through the peek even right up to about 5 centimeter, 5 into 10 to the power 7. I have to keep going back and forth from these curves if I go back. But here (Refer Slide Time: 14:49) 10KV is somewhere here because at 10KV is applied in this portion it goes like that and then comes back to this portion in a time frame. The velocity is much larger because v is equal to mu into E, E is much larger. So, ultimately, if you wait sufficiently long time what will be the velocity? That is 10KV by take 10KV per centimeter ultimately it has come to this. In other words what we are telling is the velocity of an electron versus time will not follow just like this go like that and come to that point and beyond that point constant.

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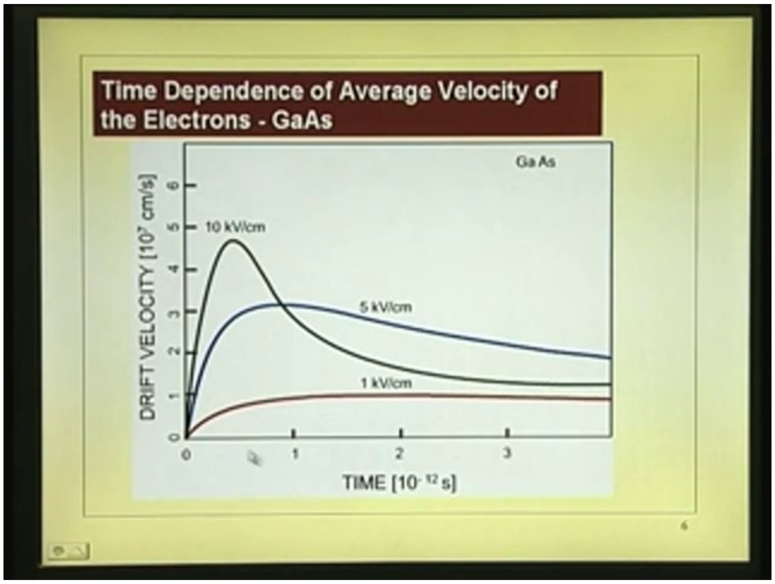

So, that is this curve. If I apply 1KV per centimeter what would happen? 1KV per centimeter you are here (Refer Slide Time: 15:53) it does not move from here to here. Only when you apply 3KV per centimeter and above it has a chance to go from here to here. So, 1KV per centimeter it is remain in this portion and it will just go in to that portion and settled down, then the time lapsed. There is a time gap by the time that acquired that energy. So, 1KV per centimeter if you take that is the curve. What is the difference between the two curves? In a low field there is a transient it takes about 10 to the power minus 12 seconds to reach that velocity, steady state velocity; whereas, if I apply 10KV per centimeter it takes more time of course, it goes through a velocity overshoot effect. So, you have got a velocity overshoot effects. This particular effect which is the transient effect is called the velocity overshoot effect.

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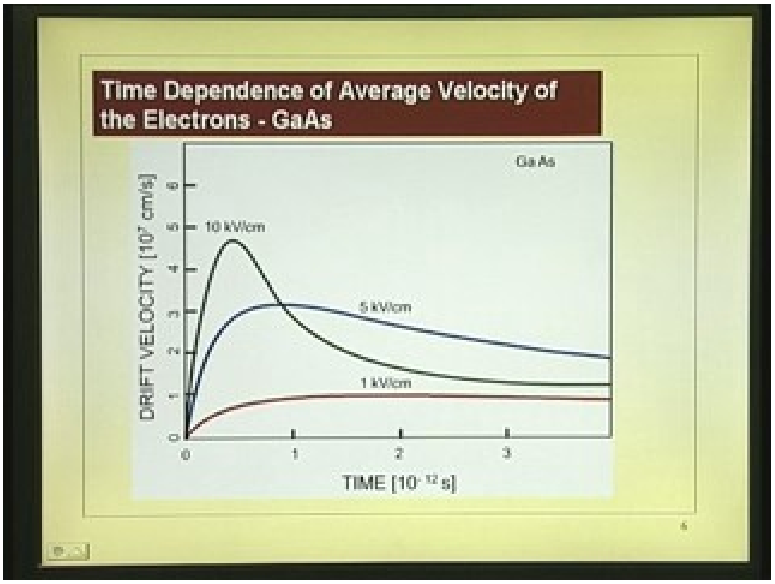

Then, you can see now if the electrons are launched into the channel where the fields are high, it is experienced velocities which are in excess of saturation velocity ultimately, you may have saturation velocity. But during the time this period it goes through that. Now, let us see what will happen with distance? After all, with time the electron gets accelerated with high velocities and when it gets accelerated it moves also. So, at the end of time here if I move at the end of 1 Pico seconds, it would have moved through some distance. I can plot the same velocity versus time curve as velocity versus distance. In fact, what you have to do is velocity into time you integrate, if I want to find out what is distance, up to this point integrate this curve you will get the distance. So, if I plot velocity versus distance I will have the same curve, same behavior. So what we are telling is, you take a channel, launch the electrons into the channel with high fields, it experiences that transient effect, where the velocity goes through a peek overshoot effect during certain time; during that time it has moved through this distance.

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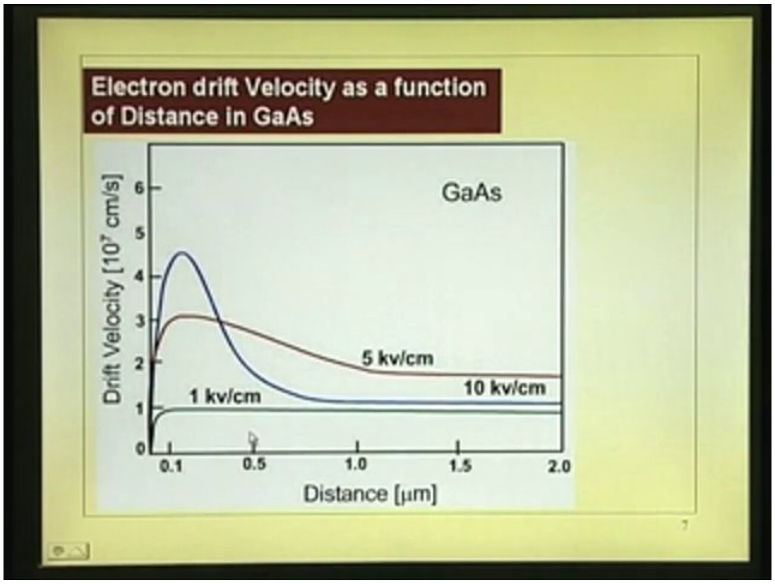

Now, let us take 10KV per centimeter you can see that goes to the peek, same peek value. But, x-axis distance because you multiply time into the velocity by about 0.5 microns, it has almost reached. In fact even write up to about 0.75 microns the velocity is much more than 10 to the power 7 per centimeter.

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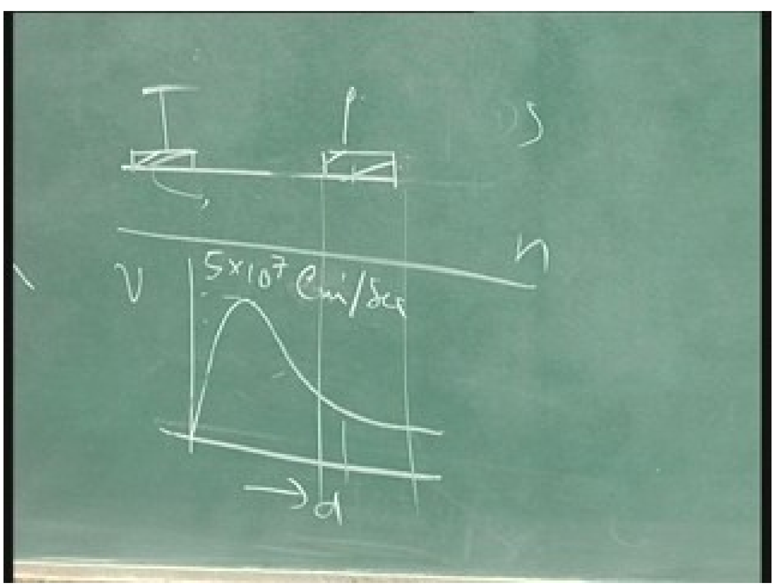

So, what we are telling now? What we are telling is if I have a channel and if I launch, I apply, I do not show the gate here right now. So launch electrons here. These electrons will move here, let us say this is high field these electrons will move here with velocity. What will be the velocity? Velocity versus distance, this is the channel. The gate is in between, let us not worry about that right now, because after all the field comes between these two. Go through like this. What we were concerned is if the field is high you end up with the velocity saturation that is steady state, but in the transient conditions if I may have even 5 into 10 to the power of 7 centimeter per second, that high. This distance could be as much as 0.5 microns; 0.5 and 0.7 microns. What are we telling? What you are telling is suppose I reduce this distance here; for this situation if I plotted here. The average velocity will be, take the total thing divide by distance – average. Suppose I move it here. Now you can see where the impact of this velocity overshoot effect is. Make the channel length shorter, this is exactly works out against the belief of people that short channel effect devices gallium arsenide will not give the benefit. Because they feared that the velocity saturation V_s is almost same as silicon gallium arsenide. So, when you go to short channel devices you will not have any benefit. But now you can see in the initial region of 0.5, 0.6 microns you will have a velocity is much higher than saturation velocity. Now, if I make the channel length shorter, that is, I put the contact instead of here I put it here. Which is about 0.6 microns or even 0.7 let us say, I put it somewhere here what happens? What is the average velocity right through a channel velocity is more than the velocity saturation you end up with devices which can give J is equal to qn into V. V is average is above that 10 to the power of 7. Two to three times or four times, the velocity of what you can get in saturation with silicon. This is the reason why you get transconductance is gallium arsenide which is much higher than that of silicon even when the devices or channel length are shorter. Now, only condition that we must have is where you get the gate control that is the point at which the electrons must be injected. After all you are able to control the current the real channel or the gate is the region. So you must launch electrons right into the mouth of this gate. The source ends of the gate with cold. So that from there it gets accelerated like that.

So, what we are telling now is, is that clear enough? So, you get velocity overshoot effect over a distance 0.5, 0.6 microns easily.

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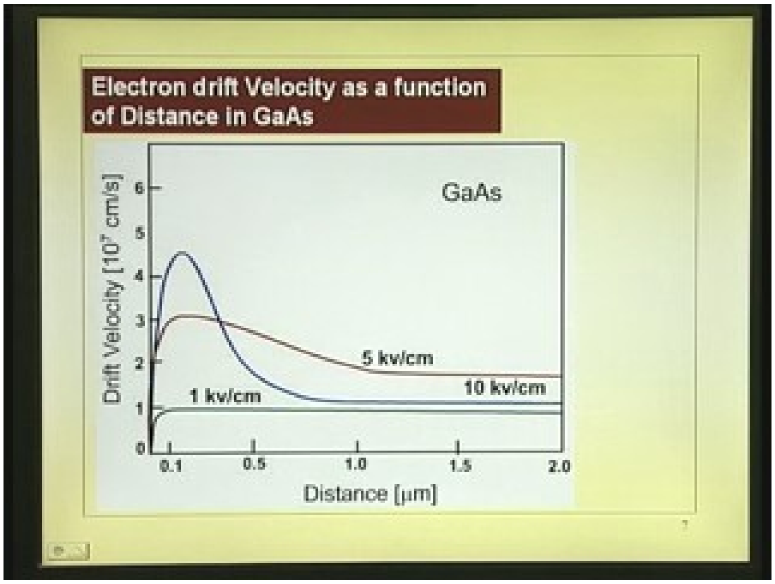

And you see more the field, more is the velocity here. Why? The electrons are in lower value they experienced hire field v is equal to mu into E; mu is high, that is why you get that. In fact, let me finish this thing because other one or two thing between silicon and indium phosphate I can just quickly go through because that is the same effect.

Now what we saw? The whole discussion came up, because we are trying to find out two devices in our last discussions we compare. In one device the n plus region comes right up to the gate, in other device the n plus region is not there, we were concerned about that.

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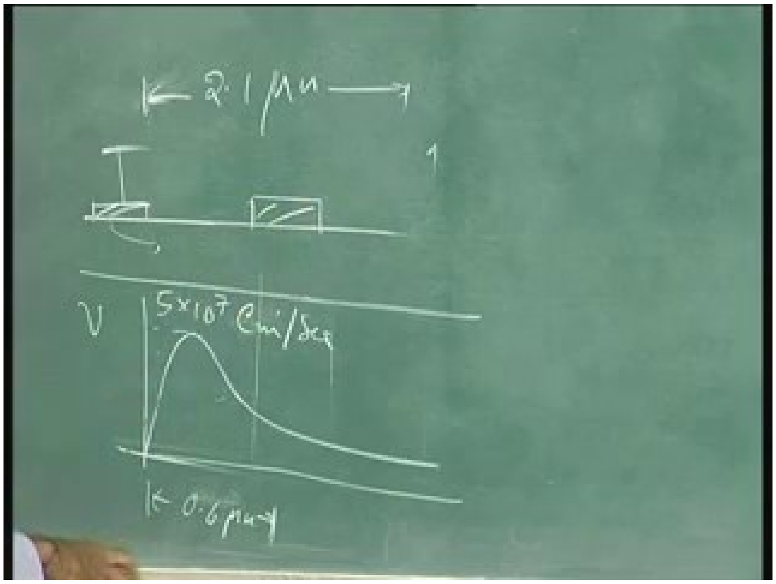

Let us take a look at this if this is understood. If I put this region large and if there are high fields present, which is very easy, two microns if you put, you can get high fields quite easily, throughout. So, if I apply voltage here I am putting the same curve. A situation where the drain contact is put here, then you gets a velocity like that. If the drain contact is far away this is where it launched. The electron goes through the transient sitting in the 0.7 microns rest of the 1.5 microns. Supposing this is 2. 1 micron, that is what we were talking of I think last time, 2. 1 micron if you have. If I apply voltage this is only about 0.7 microns if I take or 0.6, 0.7 microns that is about that. Beyond that point, the velocity is slower saturation that is like silicon. So, device with this long channel, long channel in the sense, source drain contact about 2. 1 microns undergoes that velocity overshoot effect initially and rest of the portion three fourth of that portion it is lower velocity. The average velocity is actually smaller compare to the situation where I put it here.

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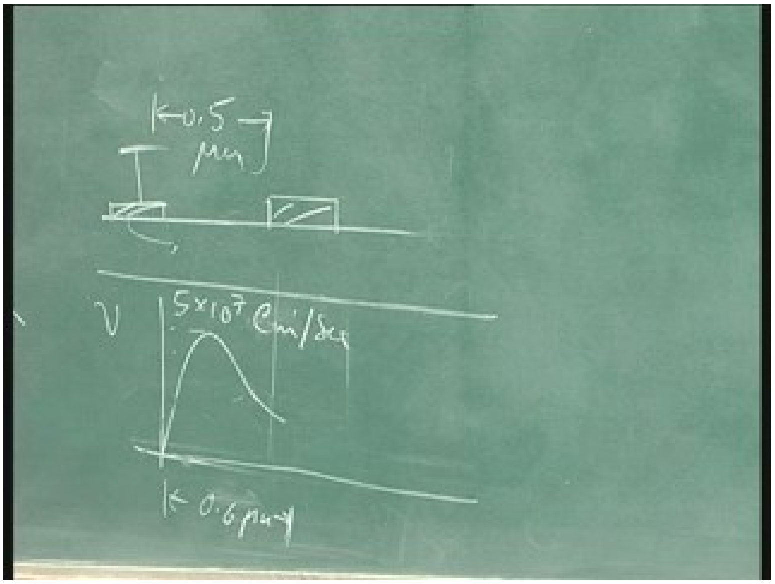

Before it has reached velocity come down to steady state it whole thing is transient condition itself. If I put the contact at 0.5 microns, within the 0.5 microns the velocity is high. So, you get actually we are operating the device in the region where this velocity transient effects are existing. It has not reached the steady state. Who cares whether the transient condition or steady state? All that you want is high velocity electrons. So, that is why in the two devices that we discussed when the n plus contact was… let us just put that down now.

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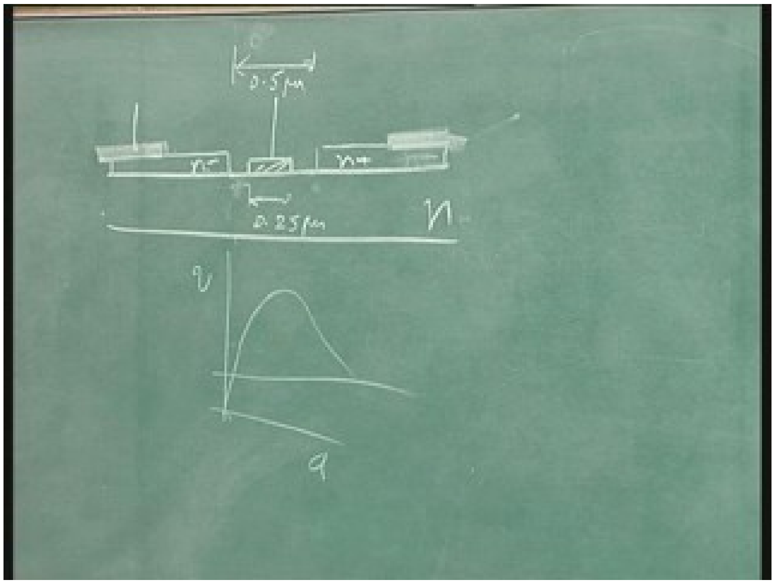

In one device, I just put only the n layer, in one device you had the n plus layer going all the way up to this point. Put the contacts here, of course you accelerate etc I am not showing that. I put the gate here. If you recall, let me draw the diagram right there itself. I just plotted like this. So, I put a gate here, this was 0.7 micron. Remember yesterday's or previous lecture this was 0.7 microns and of course it is not showing etching force and etc. Conceptually this was 0.75 micron, this was 0.25 microns; where are the electrons launched to the channel? This is the channel. Now, notice the difference between channel and the gate. Electrons are launched here and the distance here is 0.5 microns and this is 0.25 microns. What is these distance here? 0.5 minus 0.25 that is 0. 25 divide by 2, 0.125. That means, the electrons here velocity versus distance if I see, that is right up to this point and it is like that and that one is like this, overshoot effect. So the currents are higher transconductance is higher.

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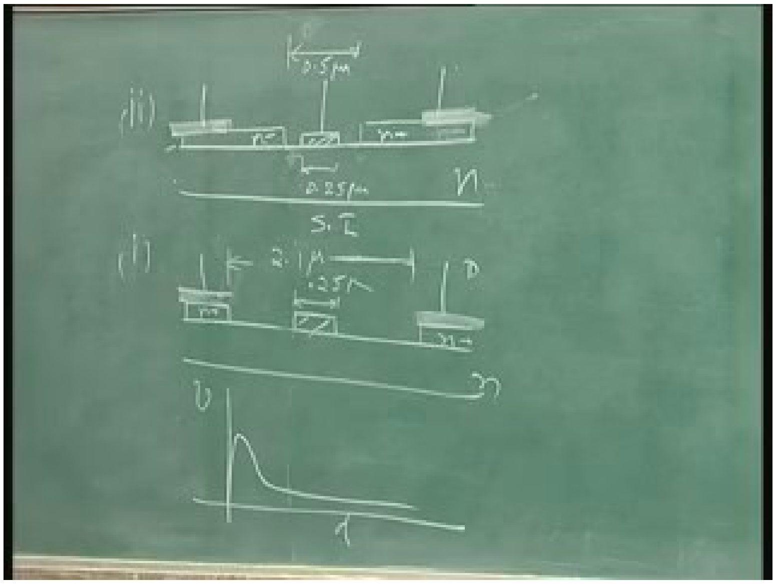

Now, the other case, second case, this is semi insulating, the second case this was number two in previous lecture. Number one was only this. If n to the power plus is present here; and we have the source and n to the power plus is present here and here is the contact drain and this is the n layer and the gate is present here. In fact, the gate is present exactly that point, same way, only difference is that n to the power plus layer is removed from here. Now what happens? This is 2.1 micron and this is 0.25 microns. So, 2.1 minus 0.25 that is the about 1.85 divide by 2. So, that is about closed to 1 micron.

So, we should plot velocity versus distance here, just I plot it here. Here, the electrons are launched is as good as metal put here, n plus layer. Here the electrons entered the channel right here. It is cold here it gets hotter and hotter as get moves inside. So this is about 1 micron so before that everything is over. It has experienced, it has enjoyed its overshoot effect right at the beginning by the time it has reached the gate it is velocity saturation. So, over the most of the region under the gate it is lower velocity. In fact we saw it was about 1.1 into 10 to the power 7 centimeter per second; whereas, in this case average velocity was close to 2 into 10 to the power 7 centimeter per second, 1.9 that is what we saw. So, you can see, this is the remarkable thing we saw.

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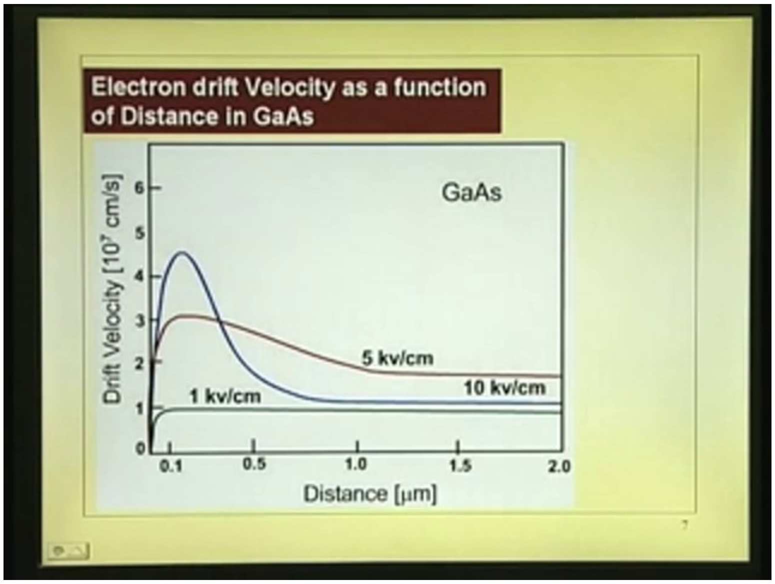

Now, what do we conclude from here? What we conclude is if I have to make a device with gallium arsenide, short channel device, you cannot make afford to make it like this. Absolutely no use, because the gm is small comparable to silicon. You have to have a device of like this. Best device that you can get would be this is (Refer Slide Time: 31:42) merging with that. Self aligned structures let us take a look at that. There are several other curves which are there in the slide, but I will not show it right now, since we are in this topic, let us get into this. We will get back to other things afterwards.

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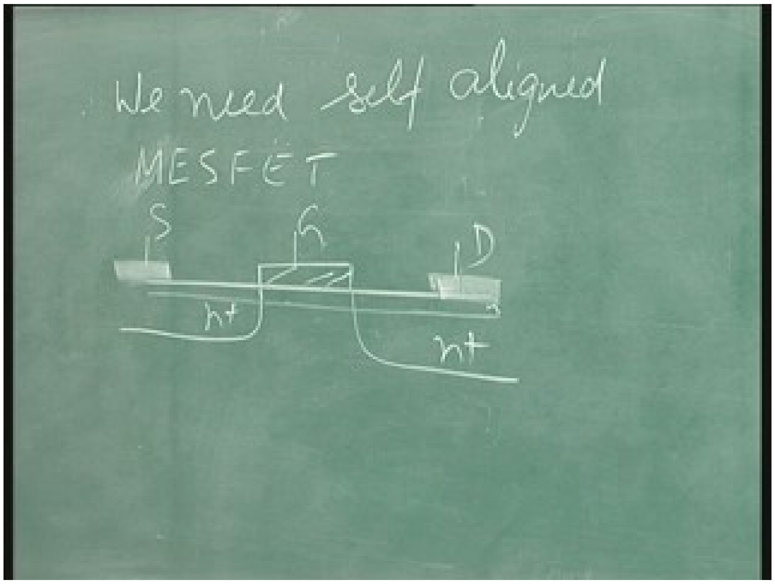

We need self aligned MESFET. What is the meaning of self aligned? You want it like this, rest that you can get will be: you have a n layer; have a gate here; this may be n layer and you must have n to the power plus layer like this, directly into this edge of the gate electrons are entering cold and their right through the high velocity, velocity overshoot effect. You can put your contact here that does not matter. The metal contact can be away. What is the problem with this? The problem is this is shorting with respect to that; it may not short but it may give a very leaky device and metal and n plus region. One, the break down voltage between the metal and this n to the power plus region is very low. You cannot afford to do that. So, people have been working on that… so this is the targeted thing, that is, the n plus region must be there below this, you cannot put the metal write into this point that is the hopeless situation. All that you can think of is bringing this layer as close as possible to this portion that involves lot of technology. One approach which people adopted is n plus layer you want it here, all that you do not want is over here you should not have n plus. So, people were very clever, what they did was buried that n plus layer little bit below.

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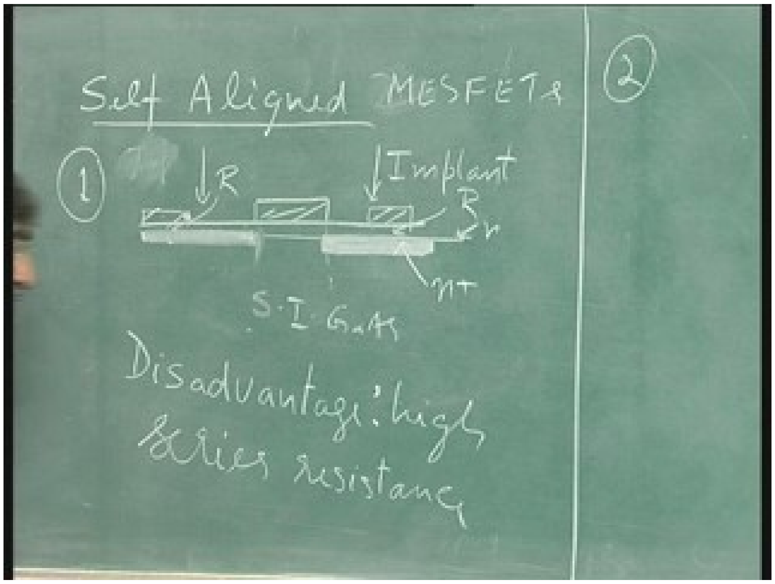

So one approach, self aligned structures, we will go through self align structure or MESFETs now. One of the efforts is… So, what we told just now is not possible. What they did was same thing they put, take semi insulating gallium arsenide and then implant channel. So you have got a channel region there. This can be pitation layer or people prefer that we implanted. Because with one device you can have tool equipment like an implantation system you will get everything. Implant that and then put your metal here, gate. Now, I am putting in slightly differently, if we put a nth implantation here, with this as a mask. So, that metal layer access we mask implant through that. But use higher energy, those implanted high dose will come here, the peak of that, if I plot. So for most of the implanted ions will come here, it is in contact with channel here. You put it here, this is n to the power plus. This is self aligned very much. So, that is very clever technique where you implant deeper buried n plus layer buried, in the sense it is below this surface. Then, now put a contact here, it worked out alright. But the problem is, this is in contact with that partially at least the resistance between this portion R, R between the contact and buried layer there is a high resistance path. Particularly, if you are using a light dose here and heavy dose here, if this region does not have many dope points so between the metal contact and buried layer there is high resistance path. So that whatever you gain you lose, in terms of power dissipation; in terms of gm, gm is, gm 0 divide by 1 plus gm into R that is the effective.

So now another technique that we use, we go one by one; before we go into those other whole lot of curves because we can even skip those things. Second approach… disadvantage: high series resistance, coming from this portion to an implantation deeper. You need n plus contact for reducing the resistance that is not present here, at least in this portion also. The partial contact will be there into the channel region.

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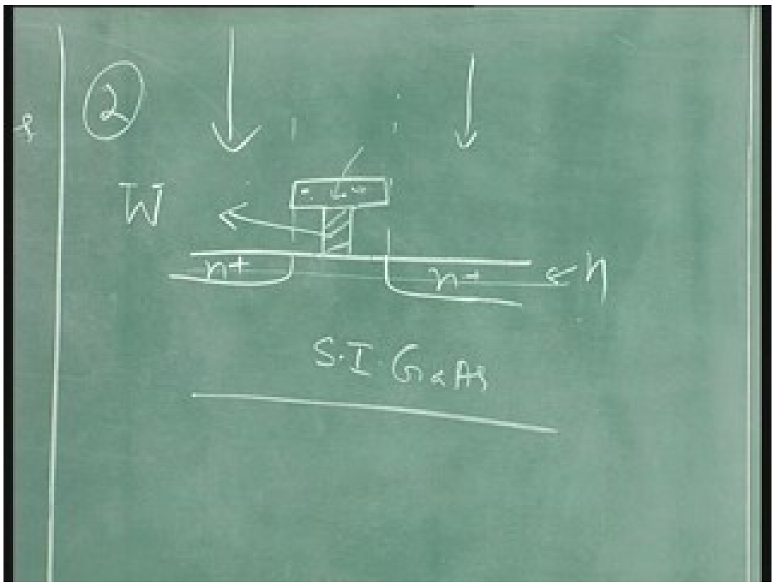

So, second approach is even more clover. It is like this. Take a semi insulating gallium arsenide, implant on to that and take a n layer. You get a n layer, now what you should do is the whole problem is if the n to the power plus layer is coming in contact with that. Realize a structure like this, a T gate. A gate looks like T. So this is actually one metal, this is the gate metal, which is tungsten. Because even there also some sort of problem is there. In the sense after the implantation, you know here just come back to this. After the implantation of this you must subject it to any link. If I use this gate as the mask for implantation, gate is in contact to the substrate. You must (40:23) as 700, 800 degree centigrade to recover the damage. You cannot afford to have a metal which is reactive the gallium arsenide. So you must put refractory metals here like tungsten as a metal gate. You could work out all right it serves the purpose, but problem here is, series resistance.

So what we do is, we go back to this type of structure and if I have a structure like this how do we do that? What we do is let us see supposing you realize this type of structure. You can use this as the tungsten; this is another material, this is a mask. Let us take this structure that is realizable. Then, what do you do? We Implant. An implant it is vertically going down. It is vertically going down therefore implantation takes place here, because this is shadowing that under that there will not be implantation exact put in that mask implant. This is self aligned. But where is the gate here, there is a gap between the gate and the drain contact you can make this as small as you like 0.4 micron, 0.2 microns you can make by adjusting this so. You can get close to the flick self aligned structures here only problem here is in fact people have made note that devices made some integrate circuits also, using this type of structure. Problem is, this has got to be tungsten W, W is tungsten titanium alloy. This quantity, this particular air on the top that can be a photo resist which does not get attach during fetching of this one.

So, how does it made? How does it make? Let us come back to the technology I suppose this point is clear enough if I can make a structure like this, T type of structure. I can use that as mask for implantation, ensure that n plus layer if not in contact to the gate. So actual gate is here and that is the gate length; that is the channel length. I can have this 0.5 microns or 0.25 microns and I can have it 0.1 micron, 0.1 microns there. Because that is depends on how much this other cut is.

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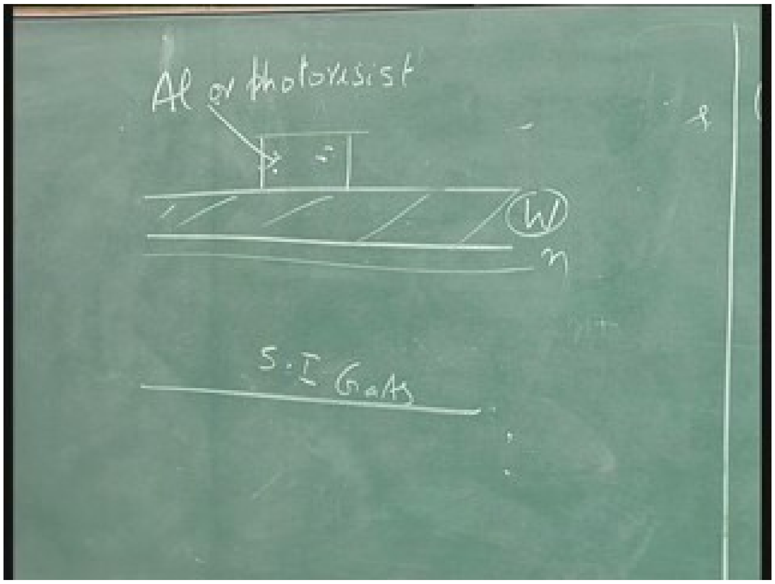

So, they make is semi insulating gallium arsenide just going through how they do that. Then you have got n layer put or implanted and then deposit tungsten all over. Then, this is tungsten, on the top of that put that second material, which can be photo resist or you can use aluminum metal because if you etch this quantity that extend should not attack. This one should not attract that. So, what you do is after this two layers output deposited you do lithography photo lithography, etch the portion. You have to draw one more diagram I am just doing it easily by rubbing it up so you remove that by photo lithography etch it. Now, put it in plasma etching system which will not etch this; it will etch this. In fact you can use CS4 oxygen this is like that. It will not attack this aluminum or photo resists; a photo resists which is resistant to do the etching. This will remain. It can be this is tungsten and this can be photo resist aluminum or photo resist. It is easier to photo resist because you can exponent. Now, subject it to reactive ion etching, which is not an anisotropic, but isotropic. In the sense, the etch vertically down it can etch laterally also. So it comes here and after that what happens? It will etch down then etch laterally. Because of isotropic etch we are not using an inisotropic etch.

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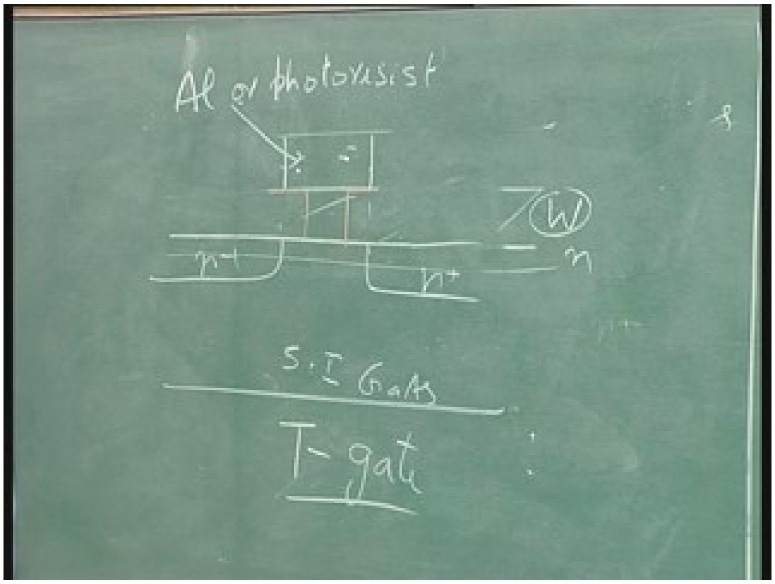

Isotropic etch is very much down and laterally also. So, when you do that you remove all this now, you have got the structure that you wanted. So a T gate (45:59). Only problem that you have here is, the use of tungsten refractory metal you need that, because after you do this implantation on to this portion, n plus you have to subject it to anile at about 700 to 800 degree centigrade. To recover the damages which have been produced to push that open atoms into (46:37) lattice side all that you have to do.

So, people just were looking into other methods of obtaining self aligned structures. The key thing here is to realize the structure like this, but the dope metal put the metal at the end aligned with respect to that, that is called… that technology I will discuss right now. Because the entire focus now is to obtain self aligned structure.

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We have discussed two types: one of them have the problem of highly series resistance and both of them have the problem of put using refractory metal. So now, the method that is quite popular has been popular is, but bit more complicated technology involved technology is saint. Self aligned implantation for n plus layer technology, saint. I do not know who invented that word, in the sense comes nicely so it is the same saint technology that we are going to discuss now I will go through the ppt very quickly so that you can just see one of the other.

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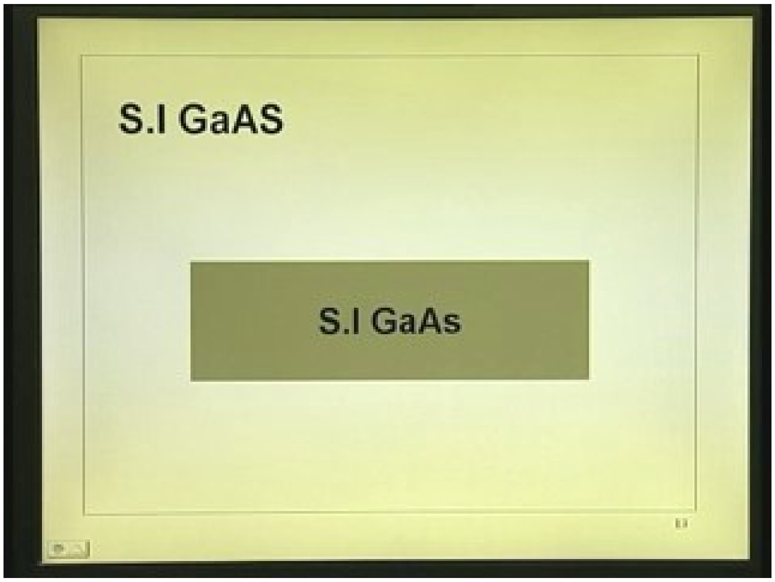

Starting material means see the whole thing is like this, you take the structure like this which can be used for implantation. So, whole effort is to get a structure like this without metal with photo resist, so semi insulating gallium arsenide.

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Spin photo resist is on the top of that. Do lithography.

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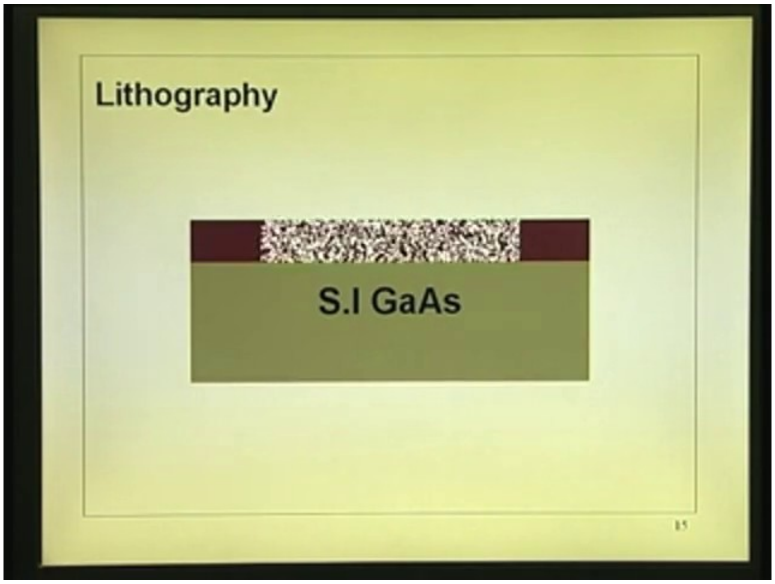

Remove the photo resist from there. So all that is I can put one diagram like this, but thin photo resist open the windows like this. Use this as for implanting, after all you need to realize the channel region semi insulating is not contacting, you must have n layer.

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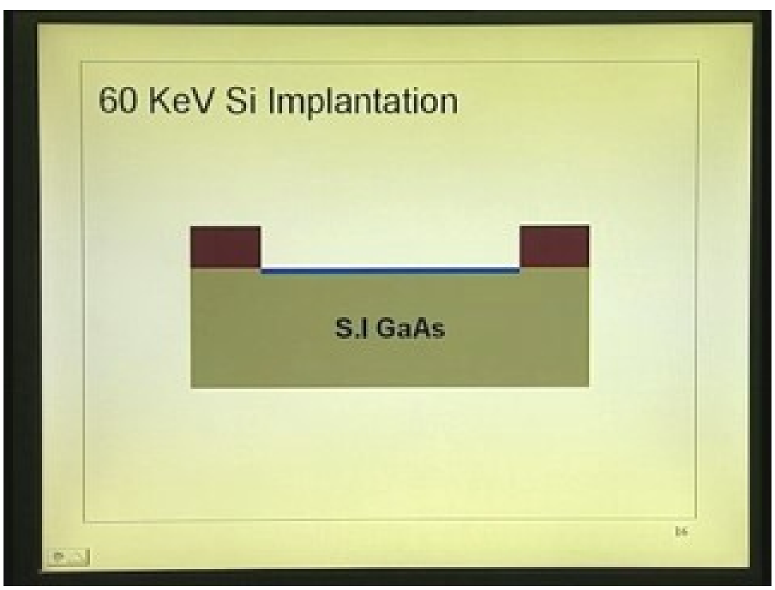

60 KeVs silicon implantation is 10 to the power 11 or 10 to the power 12. So you get that layer there. That is the channel region which will be formed.

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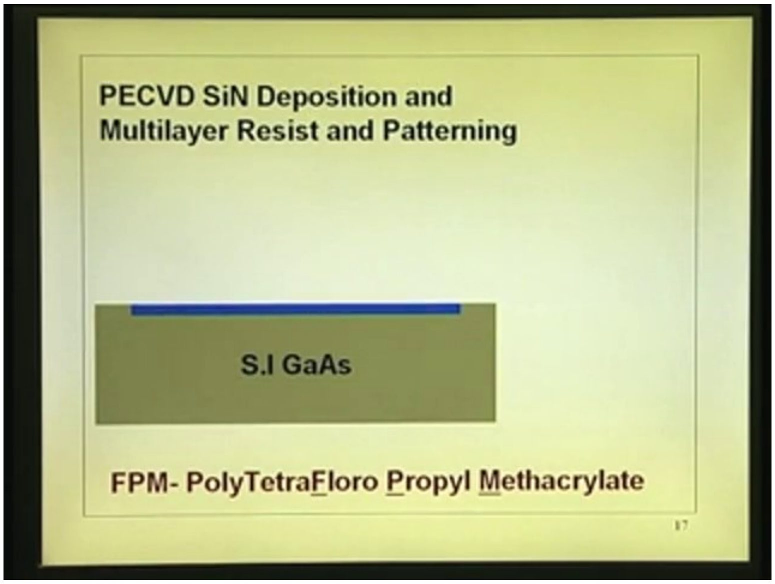

Then an implanted layer and then multilayer resist is put, silicon nitride layer is deposited. Because after all after implantation you need to finally lean and when you lean you must have a cap. Why do you need a cap? To cover this arsenide, to prevent the loss of arsenide, on the top of this is try layer in the technique, second layer is actually the photo resist which is called Floro Propyl Methacrylate very easily you can dissolve it acetone. Put another layer which is silicon dioxide each one is used as a mask for next layer.

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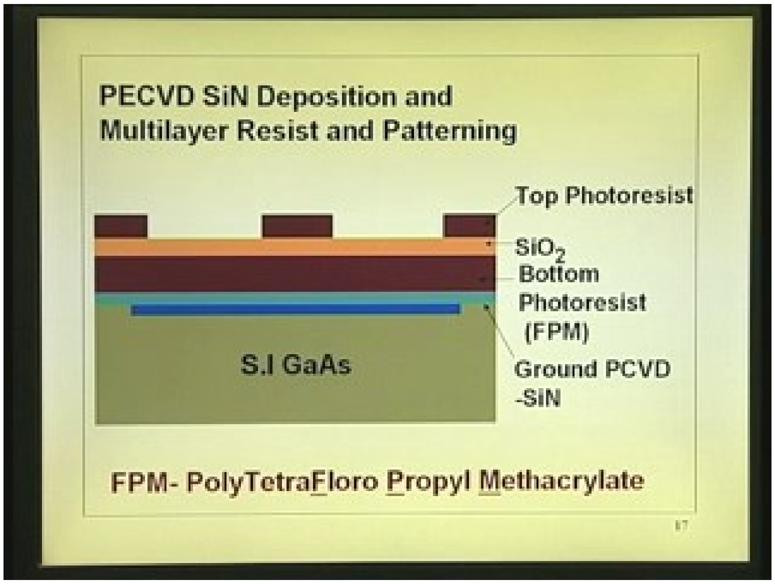

Another photo resist layer there, you can have bottom photo resist silicon dioxide then photo resist, flattering that, open the window there. Now, you can see you are getting an equivalent of that T gate portion now, the center. Etch top photo resist I already shown you masked, developed.

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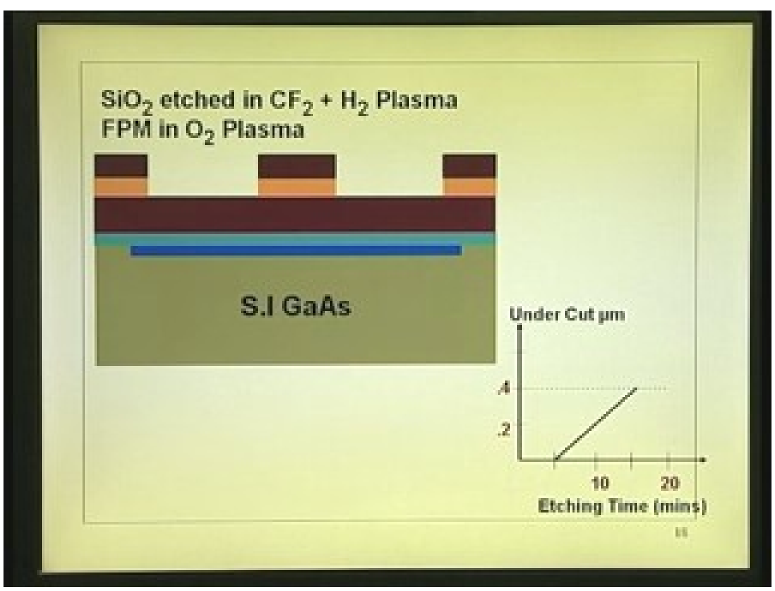

Then etch this particular layer silicon dioxide using a plasma of CF_2 and H_2 plasma we etch this. This particular top layer is acting as a mask for etching this one, it is protecting that. Now, this is photo resist; this is photo resist. Without this layer you cannot do the etching. So use this silicon dioxide as mask when you etch this one.

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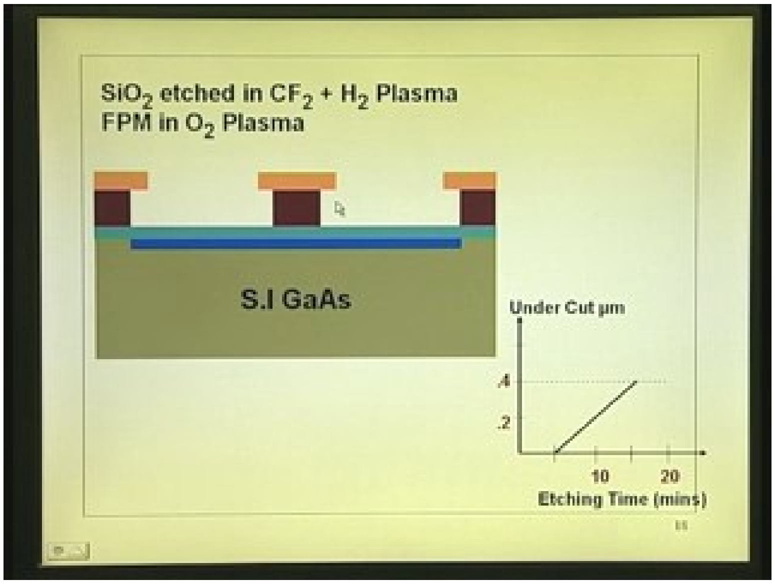

That photo resist goes off when you put in etch end. Now, use this, (Refer Slide Time: 50:46) go back to this, use this as mask keep on etching in oxygen plasma, over etch it you get the T structure. Not in metal, silicon dioxide and photo resist. How much under cut is there? Precisely you can control by timing. This under cut, (Refer Slide Time: 51:07) that under cut. Here what we shown is a metal. That will decide how much is the gap between a n to the power plus layer and the gate. So you can precisely control the undercut in fact I shown you a graph here which shows the etching time the minute versus undercut. I can put 10 minutes you get about 0.2 microns under cut. This is under cut, which will decide the distance between the gate and the drain.

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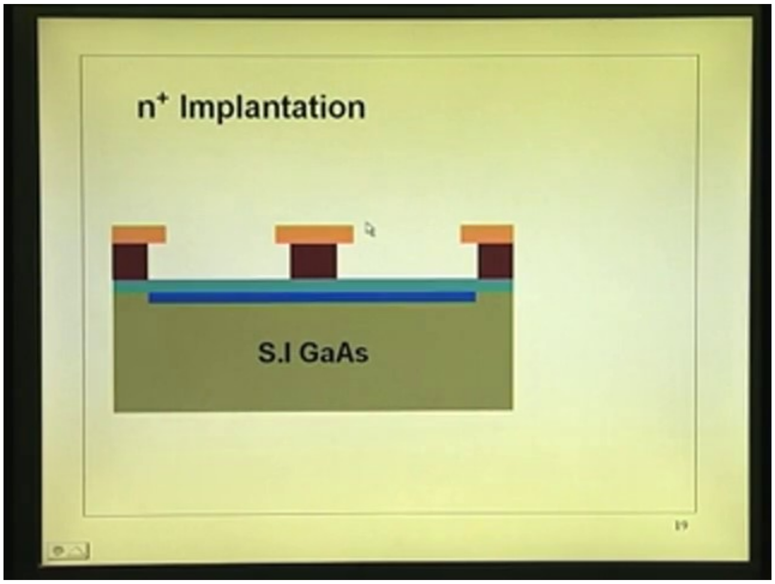

Now, go back to this curve is very helpful. This is the one through which implant here in the metal; whereas, here in this particular case what we are doing is we implant using this mask. See the implantation coming through. Wherever silicon oxide is there, implantation does not take place, that is n to the power plus. So this is the channel which has a low dose of 10 to the power of 11 or 10 to the power 12. This is 10 to the power 13 per centimeter per dose. A very heavy dose of 200 per KV, so that is go deeper. Then, so you have got now a channel region, if I can put the metal here there is a gap this much, which corresponds this under cut. That under cut can be precisely controlled by etching time.

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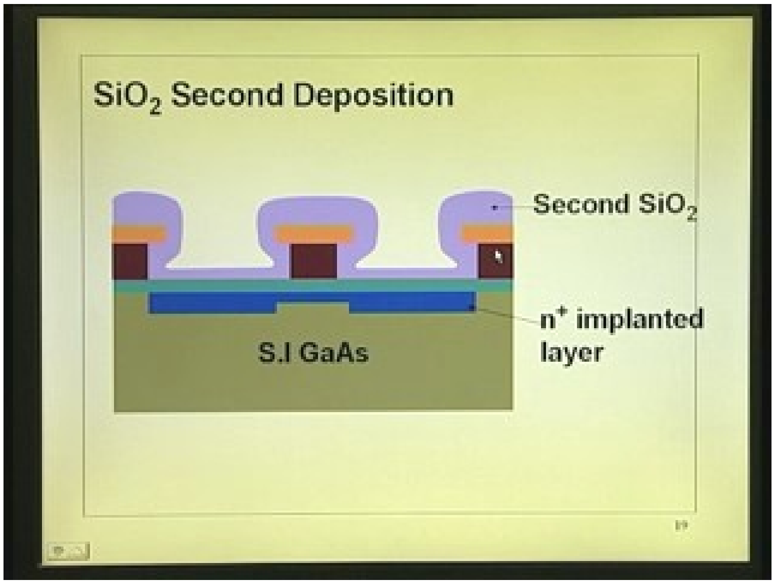

This n to the power plus implanted layer, now just notice what you do is deposit another layer of silicon dioxide; you can do that at low temperature, plasma deposition. 200 degree centigrade you can deposit using this silicon dioxide. That is how it comes. See, I deposit every where it is conformal deposition so it takes the shape of that. That is the oxide that we deposit. That is the second SiO_2 layer.

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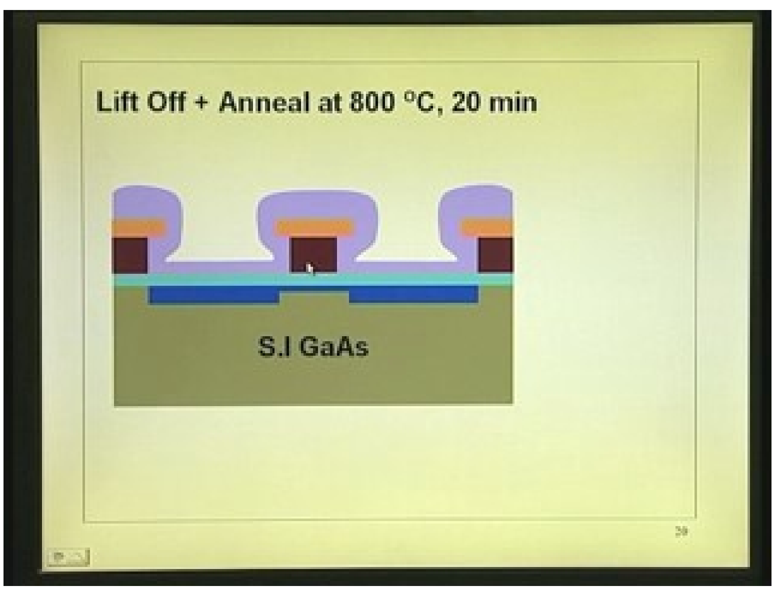

The key thing is I just put it in a solution which dissolves the photo resist. That is, this is the photo resist; this is SiO_2. I put it in solution which dissolves that, what will happen? Whatever is above that will go, that is left off.

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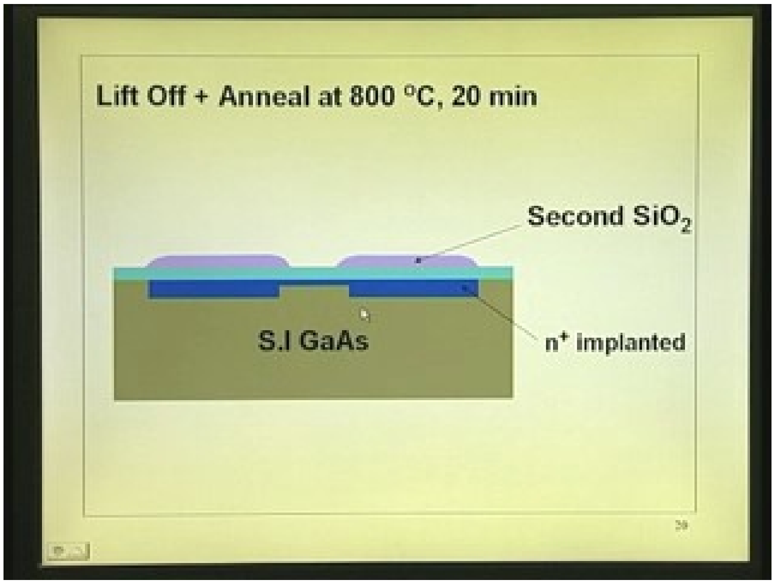

Whatever was there over this region (Refer Slide Time: 53:41) it is dissolved now in acetone, whatever is above that including that oxide goes off. Now, you have got defined n to the power plus region channel and you have got an opening here which is smaller than that. That is all those description.

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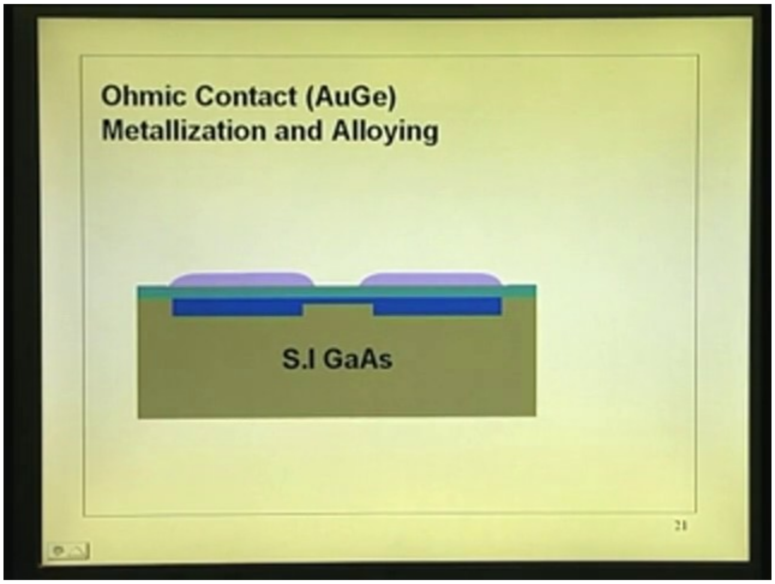

Make Ohmic contact, you want to form the gate contact finally without subjecting to any heat treatment. So make the Ohmic contact.

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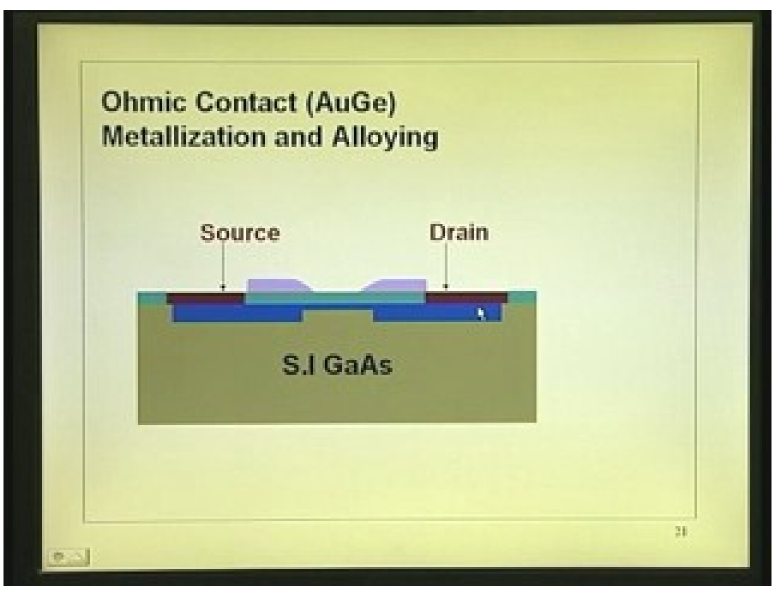

You can see the source drain contact is put there. Now what you want to do is put a metal contact here so all this by lithography, source drain contact cold germanium. Now, notice here.

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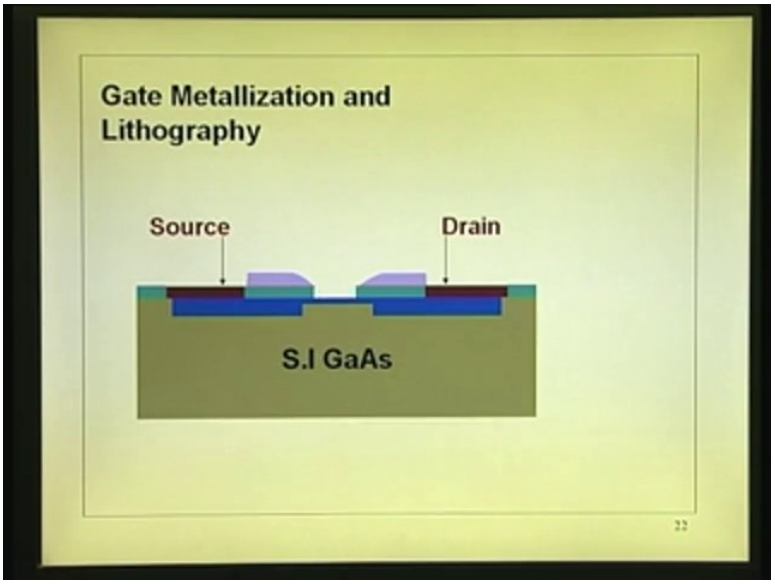

By lithography, you can precisely lift this portion because there is no oxide there. It is a very thin layer just about 1000 armstrong or less. So, you can etch it even a dip etching will do, but you can put photo resist remove that portion. Now you can see, you can do lift off technique again for realizing metal semiconductor contact only here.

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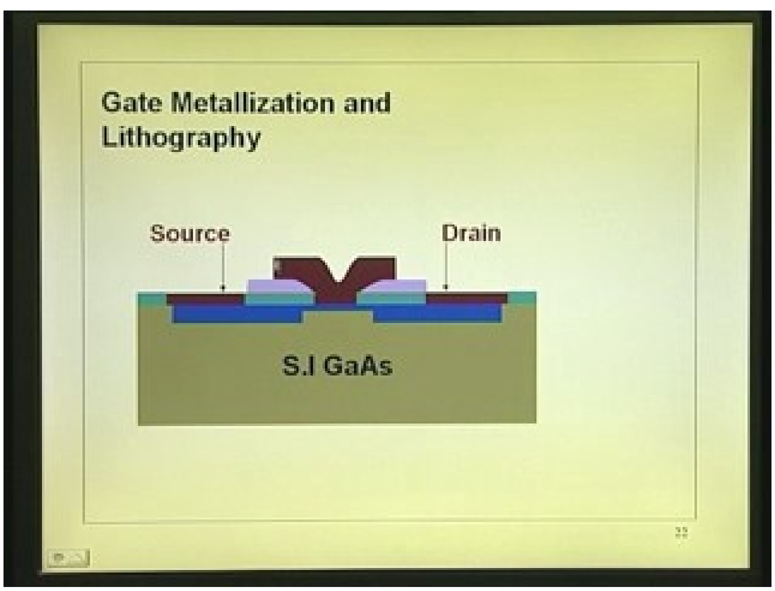

In the sense, put photo resist every where only in this portion so if I keep photo resist everywhere except this portion I put it in acetone, the photo resist from everywhere with the metal lifted off you will left to this.

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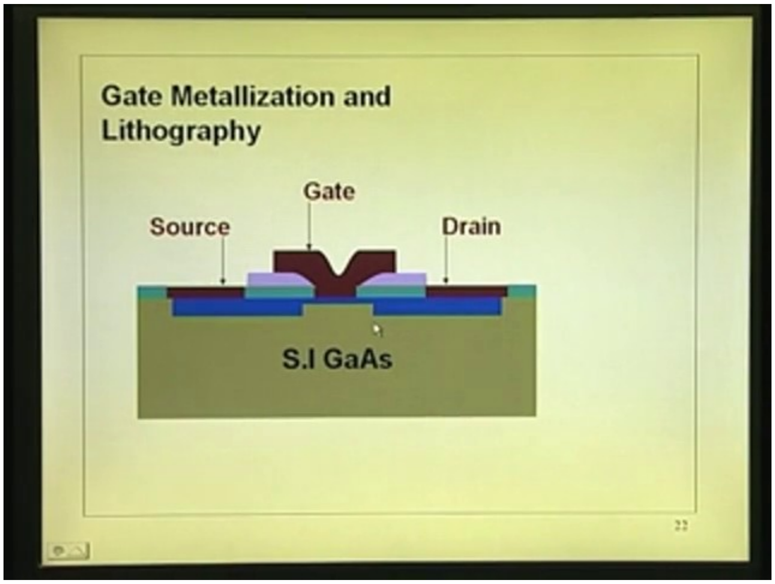

So, the key thing here is, after this step; realize metal in that portion now you can see we have got MESFET, which is self aligned with the distance between this gate and this portion realized by that T that you have got. So this is self aligned structure what you can get. With that, this is the very popular technique, saint. Some slight modification has come. The entire effort has been to achieve a gap between the gate and this n to the power plus layer, controlled gap which can be done with this self aligned implantation technique. I think the characteristic of this field we can discuss next time.