High Speed Devices and Circuits

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Lecture – 25

MESFET
Effects of Channel Length and Gate Length on IDS and g_m

We have been discussing the impact of velocity saturation on the drain current and the transconductance of the MESFET and what the conclusion was that as the channel length becomes smaller and smaller, ultimately it should become independent of channel length drain current and also the transconductance that was the conclusion. So now people will look at the experiments and the experimental results on the two types of devices I went to the fabrication technology of this simple process. So 1.2 micron channel length there is a gate length, please remember that the channel actually from here to here the gate control is only on the part of the channel, so we should learn to distinguish between the channel length and the gate length.

So, now you have got 1.2 microns channel length 0.2 micron channel length and remember the spacing between the gate edge at the source and the source that gap is kept in same both cases so that the series resistance between the source and the gate of the channel is same in both the devices because one does not have to worry whether that is playing a role otherwise that will effect. You will see when you go on to the next discussion, we will see that is one of the parameters which will affecting the performance without handle that minimize that gap, how much close you can minimize there is a different issue then. So, in these two devices, only difference is the channel length or the gate length. L is different in the two cases device 1 and device 2. Device 1 longer channel length, device 2 is shorter channel length

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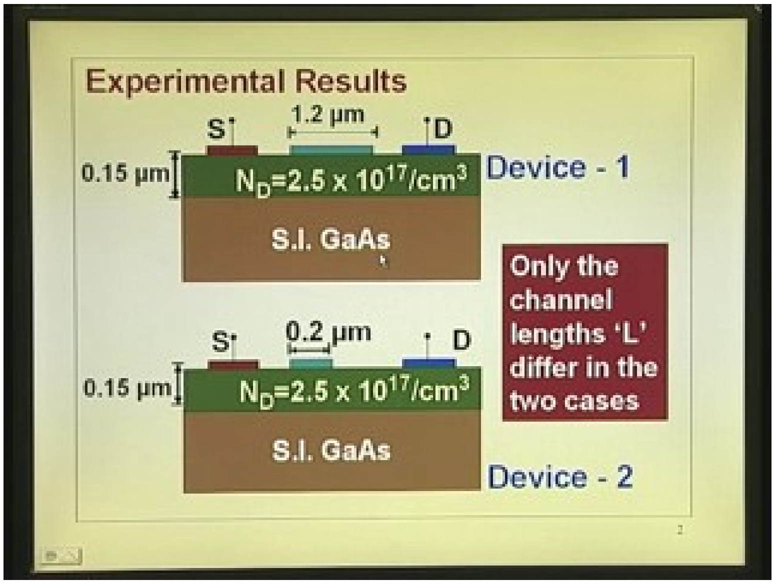

This pinch off voltage for both the devices from one dimensional analysis is given by this formula, standard formula qN_D a squared by twice epsilon r epsilon zero substituting for q N_D is 2.5 into 1 to the power 17 per centimeter cubed a is 0.15 microns squared of that divide by twice. In fact, 12.8 do not make difference for these values in to 8.854 into 10 to the power minus 14. I have put 12.9 here because some places they code 12.9 some place 12.8 so hardly affect this number that 3.9 volts pinch off voltage large pinch off voltage. Now for the channel length or gate length is equal to L1 equal to 1.2 microns L 1 into E of s is E of s is the saturation electric field taking it as about 3 into 10 to the power of 3 volts per centimeter. We get that as 0.36 and then the second case where it is 0.2 micron channel length that term out to be much smaller 0.06 for device-2.

As a result, this divided by V_{po} is alpha that is even smaller than that 0.36 divided by 3.9, so that is very much small compare to one in both the cases in both cases alpha is very much small compare to one that is the parameter which you have looked for to see whether it is long channel or short channel in long channel devices where the velocity saturation and pinch off coincide alpha is very much greater than one that is Shockley's theory matches the Shockley's theory o measurements on V_{GS} so what we expect from here from here what we expect is g_{m1} and g_{m2} the g_m for both the devices must be the same should not be a different across that should be independent of channel length and the drain current also must be independent of channel length but now you can see atleast g_m seems to be close to each other two is slightly more than g_m or by fact 1.1 the measured g_m at V_{GS} is equal to 0. Get source voltage is equal to 0, it holds well for other voltage also I have just taken the value which they coated for V_{GS} is equal to 0 and drain current its not just 1.1 it is three times it look something suspicious here

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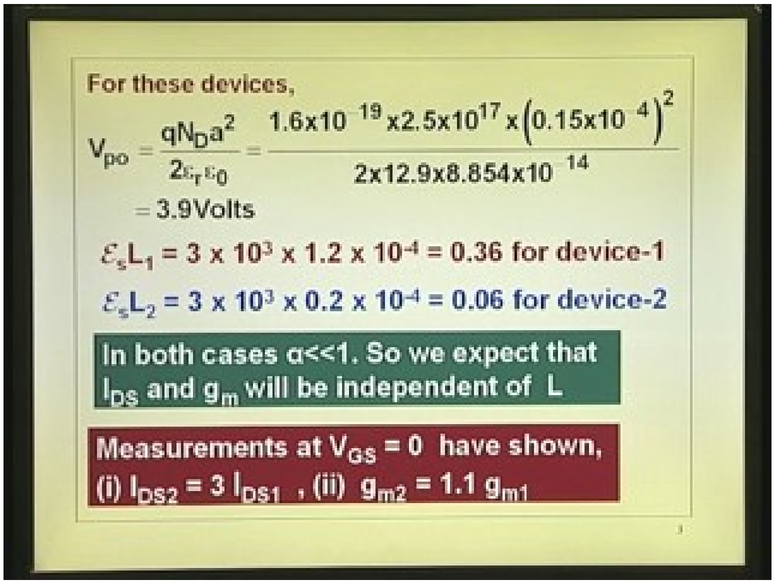

Where is the model different? What is the parameter which changes? Let us look at the formula that drain saturation current is given by one alpha is very much smaller than one this quantity the channel length does not come into picture. V_{GS} is equal to 0, plug in V_{GS} is equal to 0 in this equation, you will get that quantity all that type did was remove this term from there you will get minus V threshold squared that is equal to twice c of s W into V of s V threshold squared by V_{po}. Now what we recall is what is mean by threshold voltage is actually equal to build in potential minus V_{po} and V_{po} in this case is 3.9 volts and what will be V_{bi} less than 1 volt 0.9, 0.8 eight volts, so V threshold is almost equal to V_{po} not exactly equal if it takes at 3.9 and this is 0.9 I cannot neglect it but the threshold voltage mainly on depends upon V_{po} suppose V_{po} changes threshold voltage change just get a quick fuel of whole thing I just said V threshold equal to V_{po}

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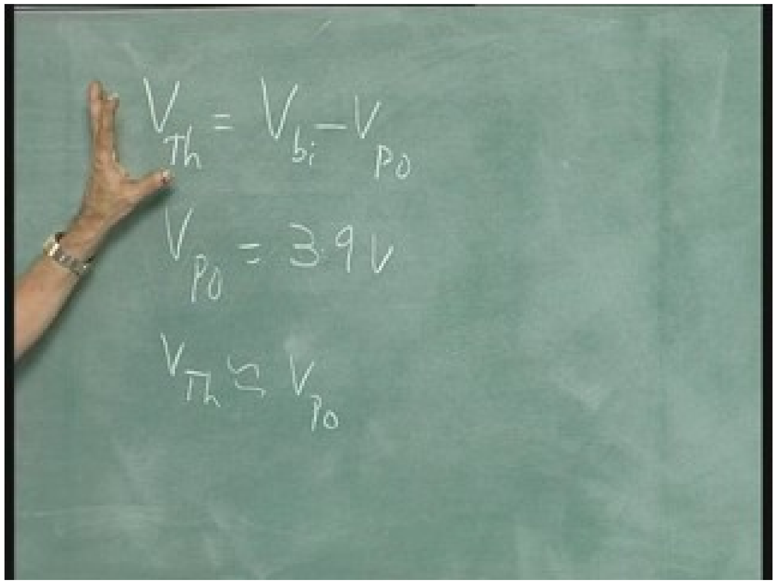

If you do that, now what happened? V_{po} is much larger than Vbi at least five times so these are number 3.9 and 0.8 volts approximately you get for Gallium Arsenide then threshold voltage approximate equal to V_{po}. Now what will happen to the drain saturation current we have to see the drain saturation current here becomes equal to V threshold is replaced by a V_{po} and V_{po} gets cancelled, square get cancelled and you get drain current is proportional V_{po} that there is no reason for to believe anything we change in as it terms g_m we differentiate that you get four times four times cs W Vs into this V_{GS} minus V_{Th} by V_{po} and that is twice V_{po} by V_{po2} has gone into that now V_{po} cancels.

Now you can see the g_m is independent of V_{po} also at V_{GS} is equal to 0 that is the value that you have got but I_{DS} is proportional to V_{po} what we are trying to see is which have the parameter you could have changed this gives as a glue cs cannot change W cannot change V of s saturation velocity atleast as we understand it now, it cannot change so and here g_m none other terms can change may be Vs may be slightly changing for 0.1 times why it is we can see after wards but here if it changes 1.1 this also should have been 1.1 times I_{DS} one but V_{po} could that change, if that is changing then you can have ample reason to believe that I_{DS} could have changed without changing g_m

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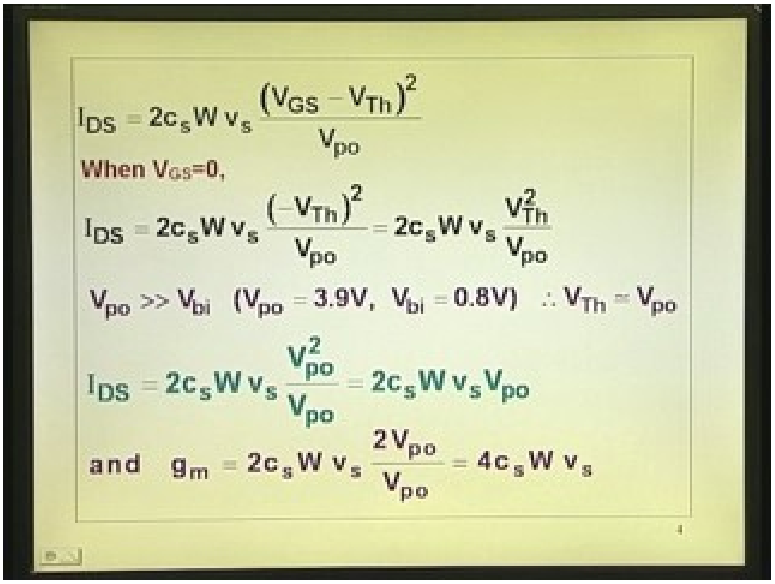

So that is what he said here g_m is practically constant it will change if its only if Vs changes so we take it as Vs is change by 1.1 factor but I_{DS} for go 1.1 times also by a factor by which V_{po} changes these two equations, so that to be increasing I_{DS} will be seen if V_{po} increases but it will not affect g_m.

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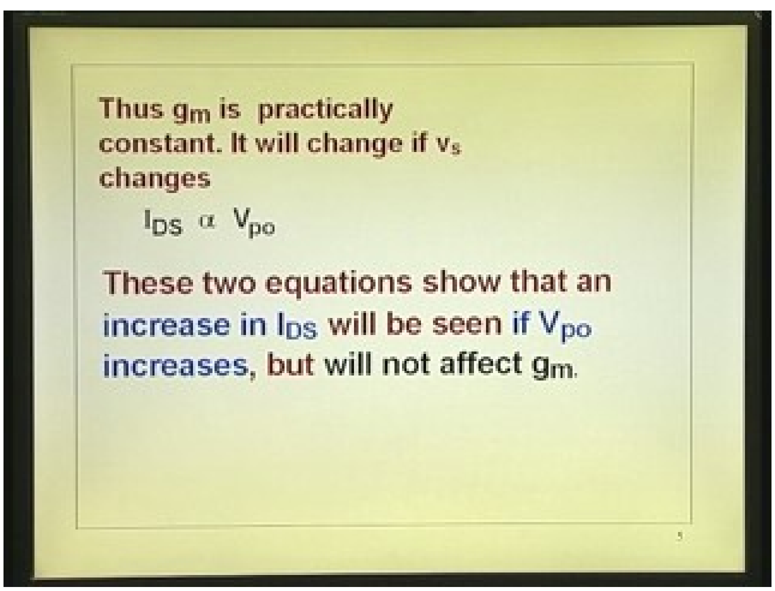

Because g_m is independent of V_{po} here, from this equation I just put all these what is seen in this equation I_{DS} zero can increase with the V_{po} g_m will be independent of V_{po} (Refer Slide Time: 08:05) Now let us see the effect of gate length on V_{po} that length will it effect to be 0 that let us see the whole problem is we believe very strongly on 1-D analysis we say that V_{po} is qN_D a squared by twice epsilon r epsilon zero that believes you take that entire thing is one dimensional. It is one dimensional keeps the depletion layer is parallel to the gate you can say it is 1-D, now let us see what happens in the two cases long 1.2 micron channel length 0.15 micron channel thickness

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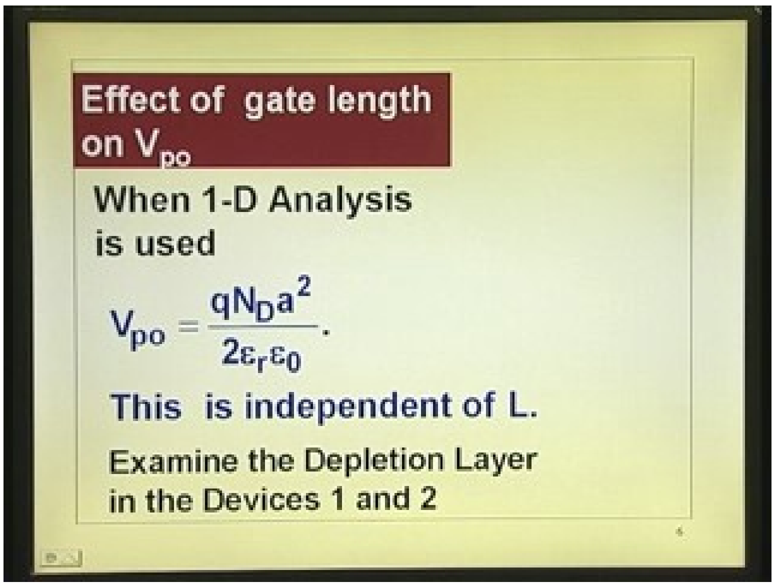

That is the situation this diagram ample illustrates that two devices for different as far as pinch off voltage is concerned. Let us see that this is the depletion layer drain voltage is equal to 0, so if the drain voltage is equal to 0 that is depletion layer keeps on moving down keeps on moving down from the region that is what have happened here it has kept on moving down then ultimately depleted fully. Let me just draw this diagram theoretically because I do not have animation here so let us animated on the board let us see what happens.

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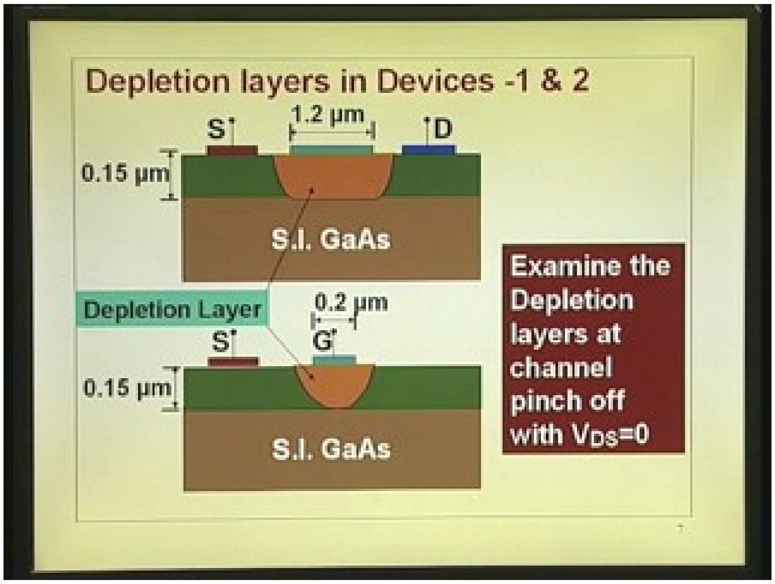

See what we are talking of is a situation where you have the semi insulating Gallium Arsenide and on the top of that I have got a 0.15 micron that is 0.15 thickness a now what we are talking of is you have a conduct output here you have a conduct here you have the gate region which is actually large compare to this thickness 1.2 micron. This is 0.15 micron I would have eight times longer compared to this. So now what we are doing is you are applying voltage here reverse voltage there so that I can just put it like this.

I apply V_{GS} I do not apply anything there when I apply this that depletion layer starts like this no drain voltage there is no reason to believe there is dropping in this direction its only one dimensional only and keep on increasing comes like that the one that shown in the slide is a situation where that comes light right upto this point and merge so the voltage at you must apply to the gate so that depletion layer has totally depleted this layer that is this situation that is what we put there whole thing is depletion layer because this channel length is large compare to thickness you have one dimensional effective over this portions the channel closes or pinches off when the depletion layer merges here and the depletion layer here is governed by one dimensional analyses because all the fields are vertical here but the depletion layer here is governed by the two dimensional analysis or a 1-D analyses with cylindrical shape for depletion layer um crowding will be there in this portion, so the depletion layer width here will not be same as this but channel pinches off the moment comes up to this so what we say is when the channel length for 1.2 microns I don't have no problem pinch off voltage is equal to 3.9 volts threshold voltage is 0.8 minus 3.9. Now let us see what would happen if I reduce the length if you reduce the length that is two dimensional region. Here, you have two dimensional region. I just bring it close here close to here 2.2 microns which is comparable to this.

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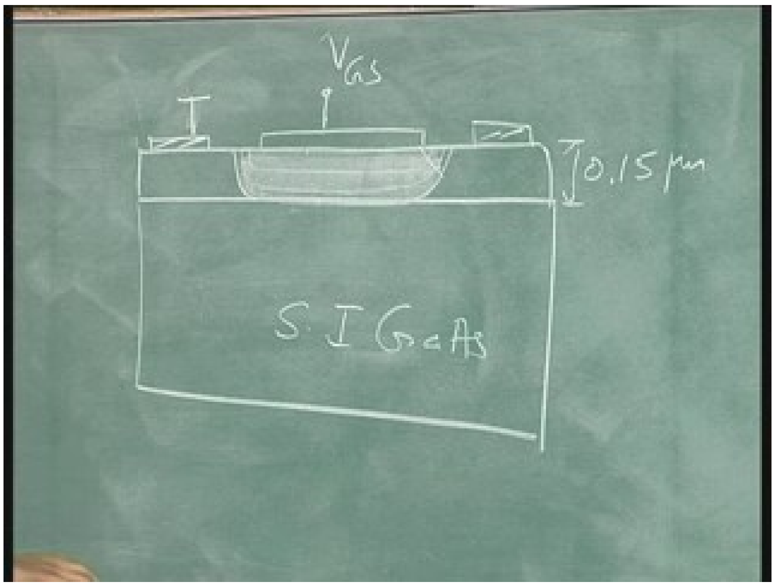

I can just draw that write here a simple change is there in the slide I remove this here make that this much what happens to the depletion layer width now that is not there the whole thing comes down infact I will make it more reasonable I am putting it like this I put it here small how will the depletion layer be this is not there entire thing is not there so it is coming down like this depletion layer actually does not have a plane parallel portion really both the cylindrical portions meet we will have a situation where it is like that instead of having to curved portion for the edges in as in the long channel device 1.5 micron is long for this case whether its long or short depends.

Now, we can see whether the length is long compare to this thickness in the first case the channel length is 1.2 microns that is large compare to 0.15 micron thickness now when you 0.2 micron that is comparable to that so you will have at depletion layer which is cylindrical right through now the question is when you decrease here let me draw it bit more clearly let us go like this the whole thing is cylindrical let us see that gets closer and closer to cylindrical when this becomes comparable to this we have a situation where that is comparable to this so here that depletion the pinch off voltage now will be larger than a pinch off voltage that goes to analyses

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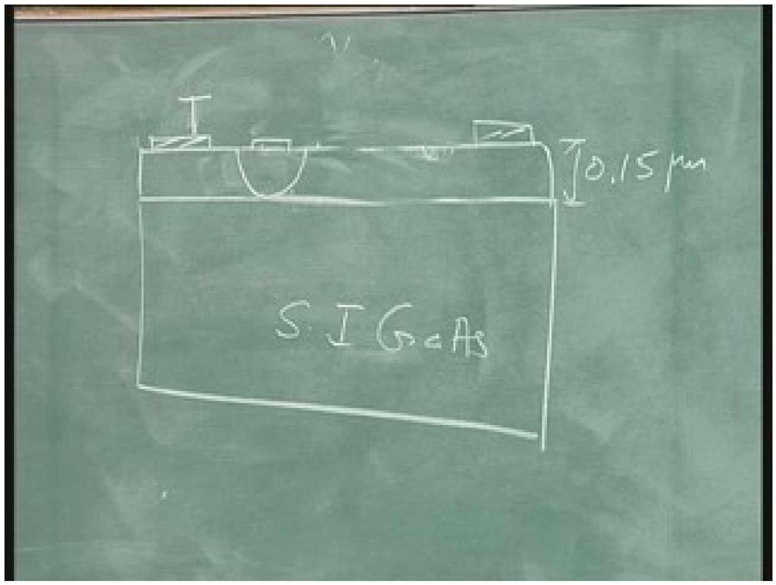

Let us take the example what I shown here is it is plain parallel here I can use V_{po} a squared by twice epsilon r epsilon zero let us here the voltage across the depletion layer by the time it touches or closer to the channel I see that right now we are telling that it is more in this case then that in the sense what we are telling is the V_{po} is more in the second case if that is more current will be more what about g_m because independent of V_{po} now let us take a look at it becomes easy to analyze this and visualize it if I take a cylindrical junction p plus n junction its all metal semi conductor conduct I will take p plus n junction

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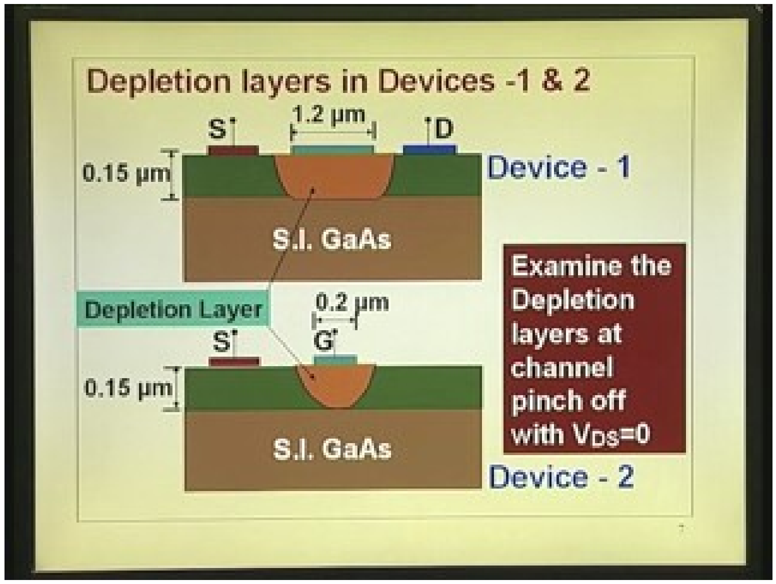

These all what we have discussed now just putting on the slide saying eight times larger so you get when the channel pinches off with V_{DS} is equal to 0 depletion layer has a plane parallel portion all that we have discussed on the with the reference with that diagram but then the channel pinches off in the plane parallel portion V_{po} is given by one dimensional analysis in the device one I just put this in the slide here saying when channel length is long pinch off voltage can be estimated by one dimensional analysis

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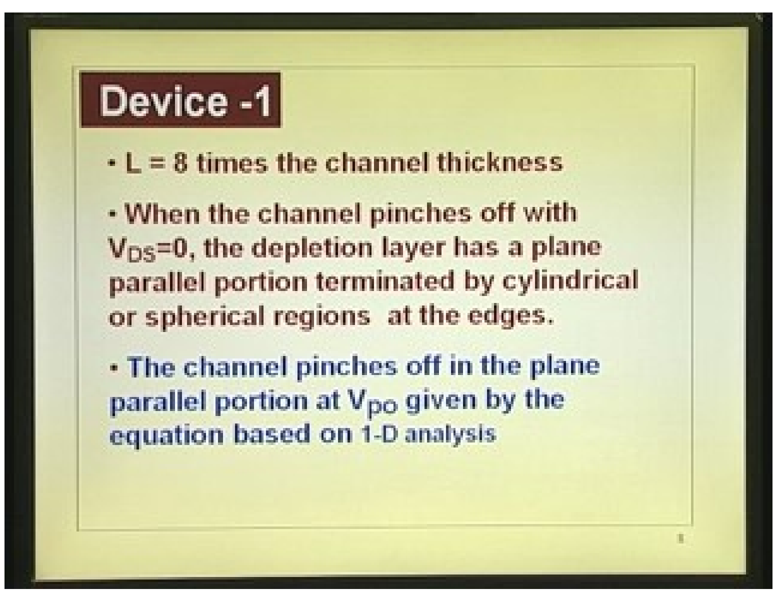

Because it is plain parallel but when a channel length is small as in the case of device two the plain parallel portion the plain parallel portion is absent in the depletion layer there is no plain parallel portion it is like that and the pinch off voltage is decided by the pinch off voltage of the cylindrical region it can be analyzed considering a cylindrical P plus N junction easily because here it might slightly involved we do not know what is the curvature etcetera but in P plus N junction exactly can estimate my purpose of using P plus N junction is to illustrate that the curved cylindrical portions are there pinch off voltage be larger than the plain parallel

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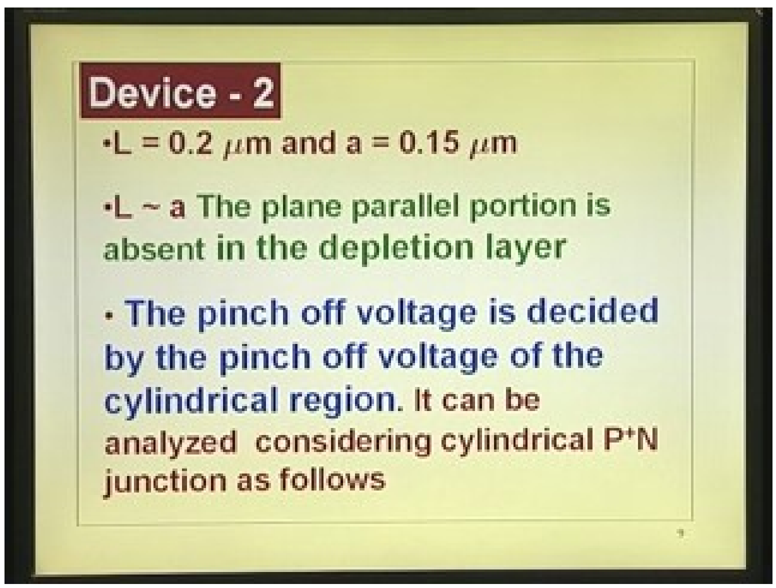

Some of you have taken devices of course would have exposed to this but some of you have not done did not have opportunity you can see this is the cylindrical junction P plus N junction instead of start here P plus N junction is there this is the depletion layer width. Now this is the depletion layer because this there is mu m cylindrical that is situation is put on board this situation where that is r_d and this is the junction P plus N junction.

Now what you are telling is we want to find out what is the voltage across the junction here when the depletion layer goes into that portion comparative to the voltage which estimate from the one dimensional analysis which is thickness equal to a. So let us apply Gauss law to unary r you can write Poisson equations cylindrical coordinate and solved or simple thing we apply Gauss law at r from the origin here this is r_j this is r_d r_j is junction depth so the difficulty in metal semiconductor you cant till how much is exactly the r_j is its related to probably it was thickness of the metal but not establish so much so now Gauss law is saturates d dot ds epsilon r epsilon zero into E of course now we are taking just totally a cylindrical junction going like that the curvature like this so it is independent of length it was depend upon the radius so filed is dependent only on the r it does not depend on length that is what so even though is two dimensional thing you meet it 1-D they are considering field dependent only on r but they effect of crowding will be seen here.

So this is left hand side is actually epsilon r epsilon zero into electric field at E of r that is the flex D into that r d theta that is the elemental length integrate from 0 to pi, you see the whole surface at r and I have put that r at r if I draw surface here that is infact we can integrate over the entire circle but we do not need to do that pi 0 to pi r d theta is this area. So, it is d dot ds that is equal to whatever charge is present beyond that r see if I have a surface and field lines are crossing that surface that total number of field lines are crossing the surface from here or from that side whatever total number of field lines are crossing is equal to total charge beyond that divided that epsilon r epsilon zero so or total flux is equal to total charge there so we are calculated total flux crossing that that is equal to total charge total charge is per centimeter cubed is ND what you are doing is r d theta into dr is an elementary volume

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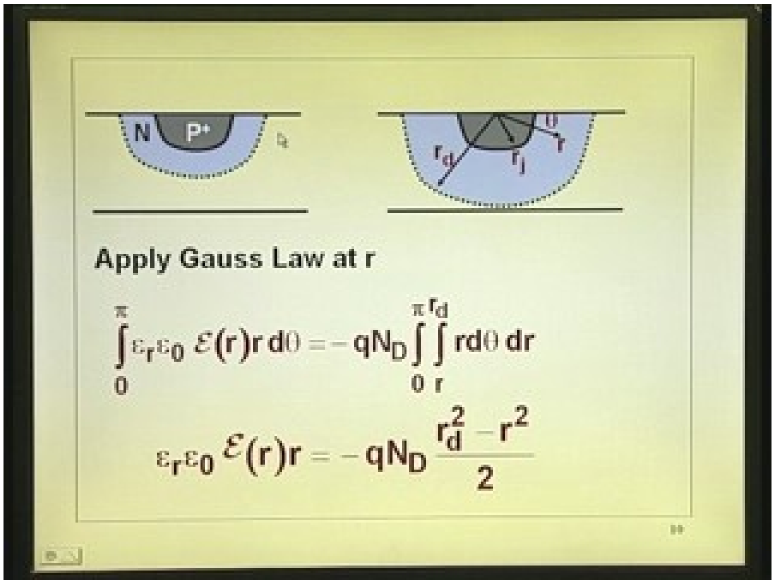

What we are doing now is we have a junction like that I am sorry we have a junction like that at depletion layer of width is equal to r_d and you have a junction r_j on r_j is present and we are finding out the field length this diagram is not so good but still the idea is you have a at r you are finding out estimate in the field along the surface so what you do is you take a small element here at an angle d theta that is r d theta that is the length if this integrate it from zero to pi you get the entire r d theta over the surface of course the field lines are crossing this r electric field into r d theta r d theta integrate over that total surface that is left hand side into epsilon r epsilon zero of course and the field lines are crossing here this surface where to the terminate that is the volume what you are finding out is now total number of charges beyond this point up to r_d.

All those cross this line so total number of field lines which are charges are present here is equal to what you do is take r d theta take a small volume r d theta into dr r d theta into dr may be I think I should not make it rough they are like this which we have like that or d theta or d theta into dr r d theta dr that is the area length I have not taking because I am taking unity length see the whole thing is cylinder of length L so that is why the length does not come into picture that is why the surface area also I am finding only this integrating only into pi multiplying it by one otherwise you have to have two integral double integral on left hand side volume integral on right hand side its only two integral on right hand side because length part you have taken as one so all that you do to how much is this area here or d theta integrated from r to r_d and theta integrate it on all over that is what to do so if you understand that simple Gauss law saying finding out what is the field line crossing this into epsilon r epsilon zero total field length crossing that that is left hand side of an integral

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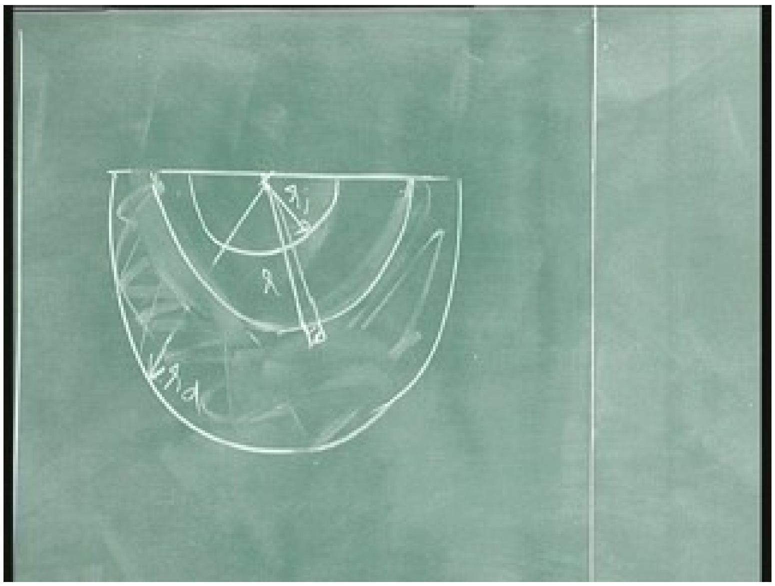

On the right hand side total number of charges present in this side that we found out by r_d theta into ND into p integral 0 to pi and r varying from r to r_d I hope its clear enough its simple Gauss law so when you do that and you would be wondering what happened to the length that is one you have taken as length which is going one centimeter or unity length so when you integrate that pi 0 to pi here incase of pi 0 to pi here gives pi get cancelled so you have virtually envelop writing this as left hand side there is two integral for r so you get this as um right hand side is qN_D the minus indicates that minus indicates that the field lines are in that direction and E of r you have assumed as in this direction that is the meaning of that physically when you wrote the equation you wrote E of r is in that direction but actually field lines are because donor of this side that is the minus sign there now integrating this has gone pi gone so integrate in this r_d squared minus r squared by 2.

Next, once you do that the concept is clear um you have to do integration and find the voltage what we are trying to find out is what is the voltage across this junction when the depletion layer reaches this edge which is totally cylindrical (Refer Slide Time: 19:30) but you are try to do is this is the m layer this is the semi insulating what is the voltage across the junction V_{po}.

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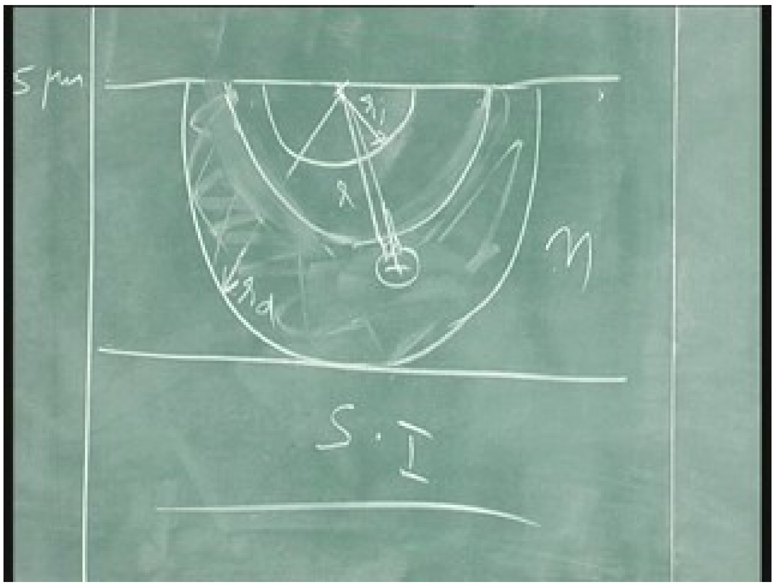

So you get this particular term I rewrite it once again here epsilon r epsilon zero into r is qN_D r_d squared minus r squared by 2, so electric field is equal to now you can see electric field variation different from that often dimensional case it is proportional to r_d squared minus r squared by r so as you go to closer and closer to a junction the field becomes much more in the case of 1-D analysis the field lines are linearly falling here it is a hyperbolic practically once you move away from the junction it is r_d squared by r only that is its hyperbolic that means what you are telling is there is lot of crowding taking place just at the junction and from it quickly decades down so lets integrate to find a voltage there is integrate this term to find the voltage (Refer Slide Time: 27:50) how do you integrate it integrate this electric field term you want to find what is the total voltage across the junction is integrate it from r_j to r_d total voltage drooping for depletion layer its star from r_j that is that so when you integrate you get that now what our job now is to find out how much is this compare to that V_{po} that usually calculate for that we should take some numbers. Let us see, now let me just write down that.

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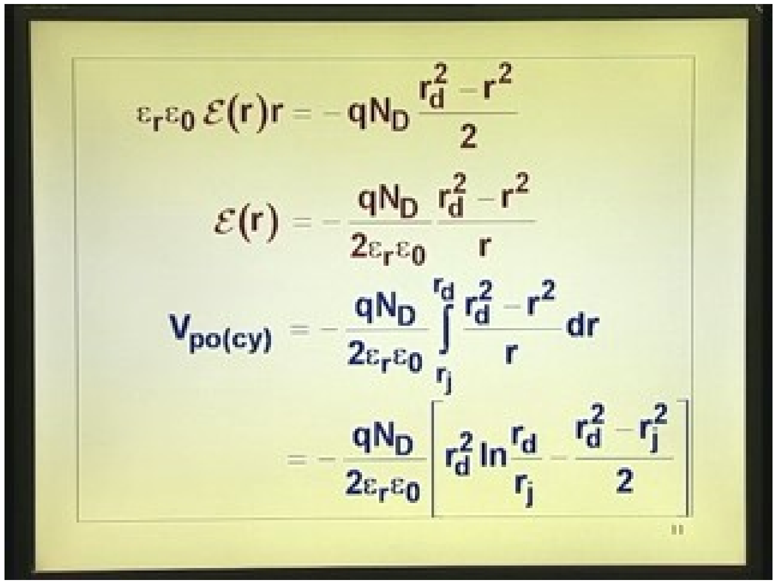

Let me just write down that so that we have it all the time V_{po} is equal to q N_D in fact it is not V_{po} it is V_{po} cylindrical is equal to q N_D amplitude twice epsilon r epsilon zero into r_d squared logarithm of r_d by r_j minus r_d squared minus r_j squared by two now V_{po} for the plain parallel case if there is no curvature junction then we saw it is equal to qN_D a squared divided by twice epsilon r epsilon zero I wrote on that so that you can see now what is the ratio of this thing for comparable for such particular numbers

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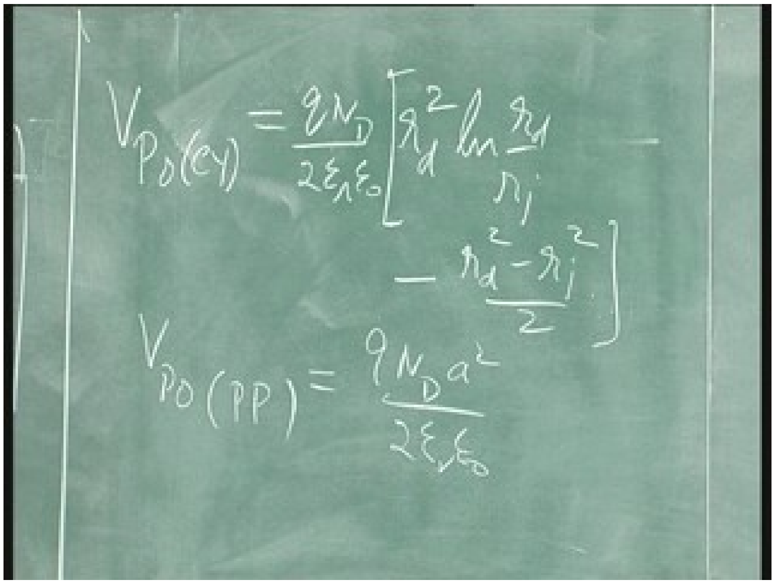

When you have this particular junction like this metal semiconductor it is a equivalent to the very small junction r_j very y small you can make this r_j very small there. Let us just take a look at to the terms now this on the board you have written now to this is that quantity and that is the qN_D a. I remove the minus sign because magnitude you are comparing ratio of V_{po} cylindrical by V_{po} plain parallel means its completely one dimensional analysis that is actually all that you do is this quantity qN_D twice epsilon r epsilon zero into a squared or plain parallel case instead of a squared you have this term so in divide V_{po} cylindrical by V_{po} plain parallel this term cancels and you have got a squared in the denominator (Refer Slide Time: 29:20) that is what you have got so whatever V_{po} was there divided by squared r_d squared by a squared ln r_d by r_j minus r_d by a whole squared that quantity does not mean anything. Right now we cannot say whether V_{po} is larger or smaller put numbers (Refer Slide Time: 16:57) if r_d is equal to a that is the situation where the junction becomes very small there merge almost with respect to that and r_d is equal to a that r_d is equal to a that is the channel thickness that we talk of usually and r_d by r_j is equal to thirty so what we are telling is if your a is 0.15 microns r_j is 0.15 by thirty may be corresponding to thickness of the metal equivalent of r_j so then we have substituting in this case r_d by a is almost equal to one logarithm of r_d by r_j is about 3 point logarithm of 30 minus this is 1.5 that goes off so its actually 3.4 minus 0.5 this is 2.9 so what you are said now. From this analysis is if r_j is small and if the whole thing is cylindrical then pinch off voltage n the cylindrical portion or cylindrical junction depletion layer will be much larger than that of I took this number that is z is 2.9 it looks as if mu m up but these are the numbers which are very closed to the reality so V_{po} is the cylindrical case 3.9 larger than 2.9 almost three times that of V_{po} is plain parallel case what are all we doing why did we do the whole analysis we found that the ID saturation in the device where the channel length is 0.2 micron is about three times larger than the ID saturation in the case of 1.2 micron

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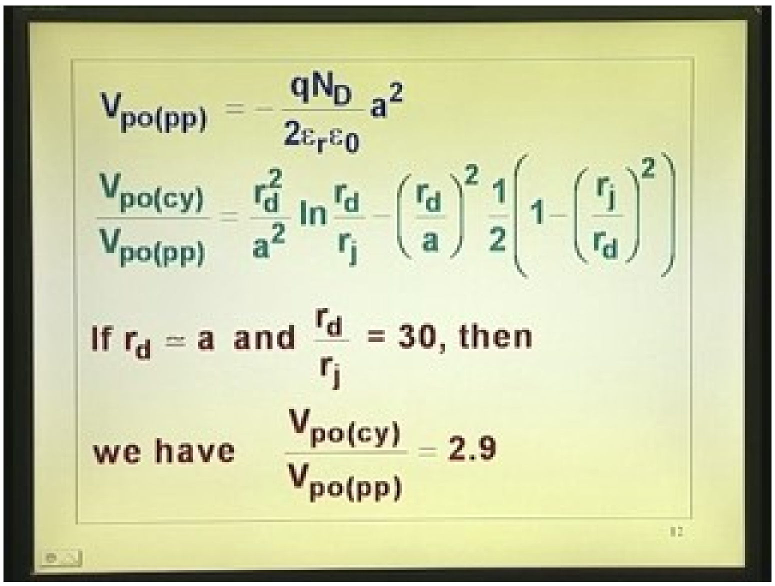

So now what you also found is the pinch off voltage in this case the voltage require for depletion layer width is equal to a that is the V_{po} is cylindrical is about almost about three times compare to the pinch off voltage that we require for this case, for that case where that is long and you have a plain parallel portion this is the case cylindrical case other case is I think I out it here other case is like this so in this case that is 1-D that will be 3.9 volts this will be 3.9 multiplied over by three that is what you have arrived particularly when the junction depth is small.

In this case junction depth you cannot talk junction depth may be this thickness s equivalent of junction depth that is why I took it as about thirty times smaller than this very small does not increase exactly match with the junction depth closed to that number you have the crowding here would depend upon how much the thickness also is so what we finally agree is that the pinch off voltage in this case in three times almost or larger compare to that now you make a device both cases the velocity saturation take place when you take drain voltage but in this case current is when velocity saturation takes place if the pinch off voltage is large compare to threshold voltage Vbi as in this case threshold voltage becomes almost equal to V pinch off voltage in that case the drain current becomes proportional to we just now saw pinch off voltage and transconductance independent of that so transconductance should be the same for in both cases but the drain current will be larger in this case because pinch off voltage larger because it is proportional to be threshold voltage proportional to be V threshold or V_{po} square by V_{po} that is V_p (Refer Slide Time: 16:57) so that is pinch that the pinch off voltage of spherical or cylindrical junctions that junction can be spherical or cylindrical if it is spherical you can see by we call it will be the worse pinch off voltage even be higher the crowding will be much more will be 2 to 3 times that of plain parallel pinch off voltage this is plain you have I_{DS} in device two where the gate length is smaller.

So now how will you keep suppose see now they are n a dilemma supposing I want to I do not want the threshold voltage to be different I want to have a channel length which is 1.2 I want to have a channel length this is the gate length which is 0.2 micron I do not want the currents are g_m to be different how will you do that prevent the two dimensional effect or cylindrical portion. How do you do that? The whole problem came because in this case and this case what are the difference thickness is small compare to the length you have got one dimensional portion.

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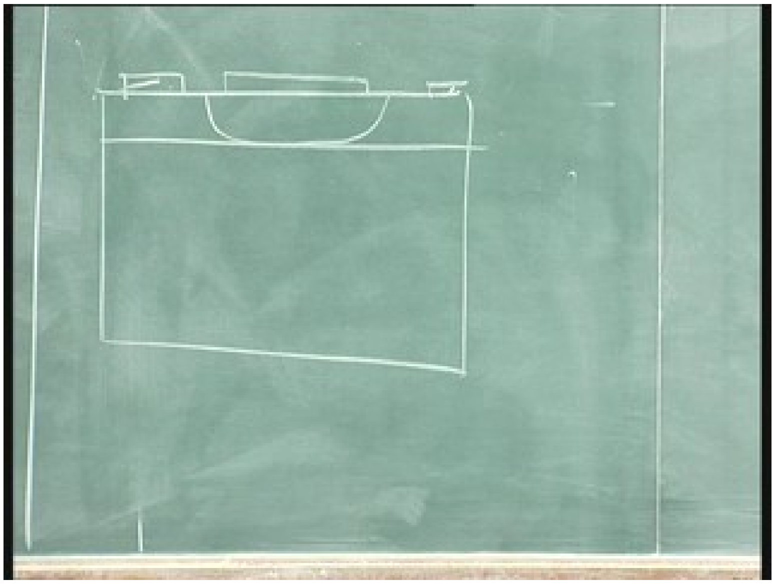

Here plain parallel portion here is small compare to thickness if you want reduce length it must be accompanied by reduction in thickness, let us do that here suppose I reduce it here to that I have reduced that I have reduced this now what will happen will be this is some values there is some parallel portions here but now we will say this will be independent of pinch off voltage It will be pinch off voltage be same in the both cases but your threshold voltage is different. Now, what you have to do is you have to reduce it thickness the pinch off will be voltage weakly by one dimensional equation, let me correct it here thickness is E 0.15. (Refer Slide Time: 38:09)

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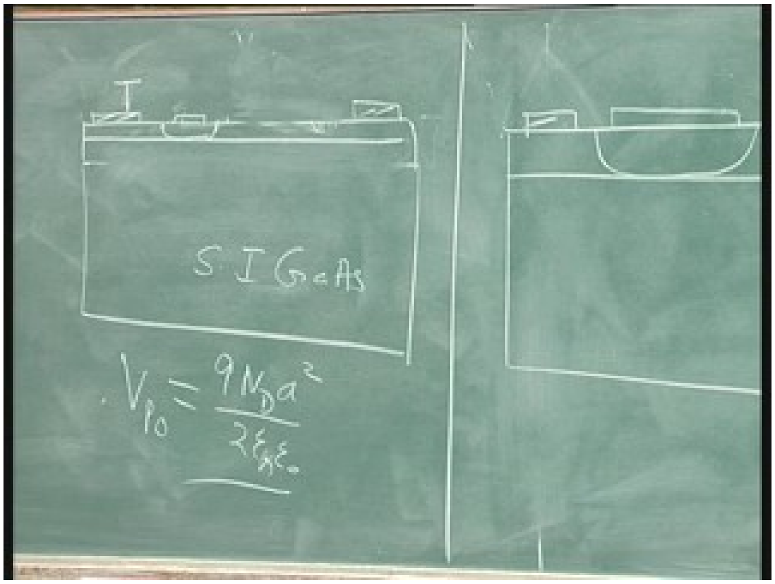

Here you must reduce the thickness. If you just reduce the thickness what happen to pinch off voltage a squared see it is not enough if you get the one dimensional thing if you want to make a threshold voltage same epsilon r epsilon zero what we saw is if I just reduce the channel length blindly pinch off voltage is going to change that we have a conjure currents and threshold voltage also threshold voltage also would be different because it is Vbi minus V_{po} now in this case if I reduce the thickness you avoid that problem but then you have another problem here also that is the same formula I have reduced thickness compare to that so V_{po} will be smaller that the previous case mu m smaller the current what should we do you want to keep the same V_{po} when you reduce a you should be accompanied by increasing the ND doping this is exactly what we do in the case of MOSFET.

In the MOSFET when we reduce the oxide thickness you increase the doping concentration always saying scaling loss out good here you can see these belong to the same family the MOSFET and MESFET it is an O and E is different it makes lot of differences for the device operation principle so if you reduce this you must increase that so that is kept seen so these one should remember in mind so what you are telling is you can still get the one dimensional analysis holding good and you can keep the V_{po}s same you can maintain all performances same still you have the velocity saturation effect is it all right. Now, let us see further see what we have seen in these two devices is what we have seen here is compare to the other device is we have reduced the gate length what we have been done for this channel length this is the channel length we just remove that now once again draw it make it clear bigger that is the source that is the drain so what we have seen is the situation where what happens this is n source drain gate if I reduce this I am holding it like this reduce that what happens you have seen if you saw that the whole thing there is an effect of pinch off voltage change but you can compensate by doing this thickness change but now question is what would happen if I change this channel length itself this is actually a channel this is a gate length

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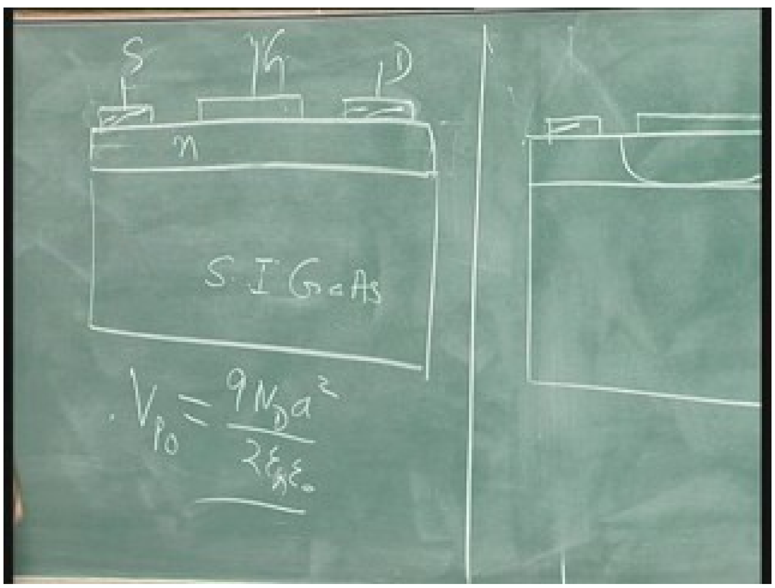

What is the difference between the channel length and gate length? Channel is a region between the source and drain gate is a region part of the channel where there is gate control the channel thickness is controlled by the applied voltage so now what we saw first was if I just reduce the gate length what happens? In fact once you have velocity saturation you do not expect anything but whatever changes you get because pinch off voltage change otherwise you will not get any change in the current or the transconductance. So what people have concluded from here is do not waste your money and Gallium Arsenide do not waste your money on Gallium Arsenide because once you go to a channel length which is even one micron beyond that point you may get benefit in the current by because of the pinch off voltage but transconductance is not changing what you look for its not just that current increase transconductance for higher speed because charging ability comes from delta ID by delta Vg that should be large you do not get the benefit effect because whole thing is saturated velocity saturation silicon one is 10 to the power 7 centimeter per second velocity saturation Gallium Arsenide almost same so what is the use of going in for Gallium Arsenide so these are the people who were shooting you know directing their gun towards the Gallium Arsenide people and they were silicon people understandable because that was understanding that was available because silicon is cheaper material why should spend your money on a costly material they answered provided by some of the people on Gallium Arsenide based devices was another experiment whole thing evaluation of the technology to and supporting and against that came up in hard way these are all 1980s and 1990s that is the period when thing we were fighting out. In fact I have seen articles written saying no more Gallium Arsenide require do not need Gallium Arsenide that is in 1980s silicon give everything true it can be quite a bit but in some cases where you need performance should be really go that question is still answering take a look at this the previous experiment conclusion was you do not get a benefit in transconductance you do not need. Now let us see this is one this experiment is you can see this is these are the two metal regions you have to very carefully understanding these are the metal regions Ohmic conduct and this region is the channel

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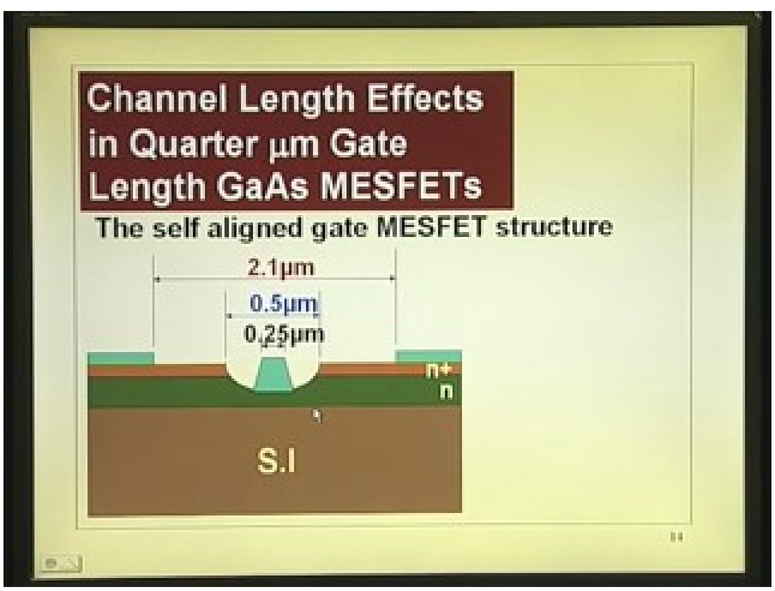

See what they did was lets me just put that things what they did was took semi insulating Gallium Arsenide on that a grew n type layer and on the top over there that is like a flicker on the top of that grew n plus layer n plus and n once you doping is heavy its aspects metal. So, now then what they did is they removed from portion of it like that mu m remove that portion because after all to make a short key and need n layer you cant make a short key n plus because its numeric. So on the top over that we put this metal that is the gate now we put a source conduct here metal conduct here this distance is .1 micro meter and this distance is 0.5 micro meter and this distance 0.25 but all that is available in the slide that I am going to show now, so they did that now what is the channel length what is the gate length tell me gate length is 0.25 micron the gate control is channel length is that 0.2 microns because even though you put the conduct here for the drain n plus region comes right upto this point this as good as extending the metal so channel length is 0.5 microns gate length is 0.25.

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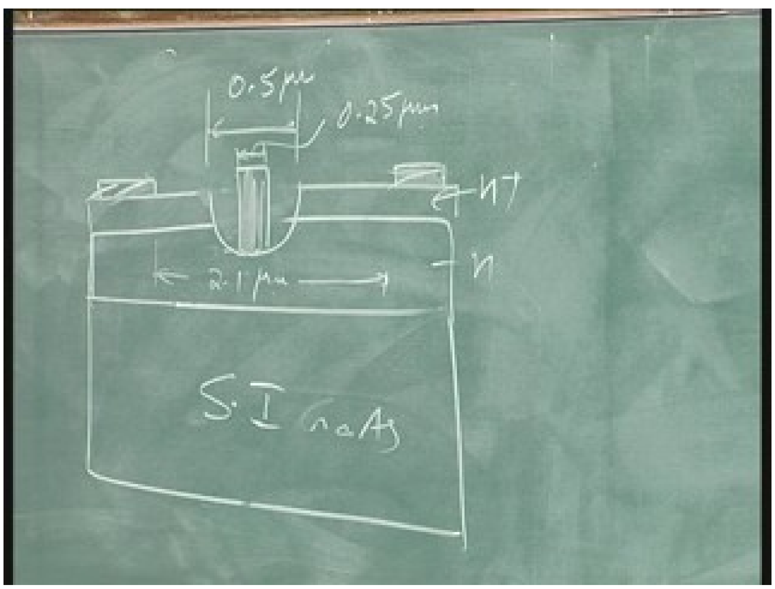

In another experiment what they did was they removed this metal n plus 1 near at here diagram if I remove this n plus I just from back to this if I remove this like this if I keep it like this what is the channel length there is no n plus layer that is the channel 2.1 micron and gate length is that one, so two devices are made one device with the n plus layer going up to this point channel length 0.5 micron another device with the n plus layer removed without n plus layer channel length is long gate length is kept same

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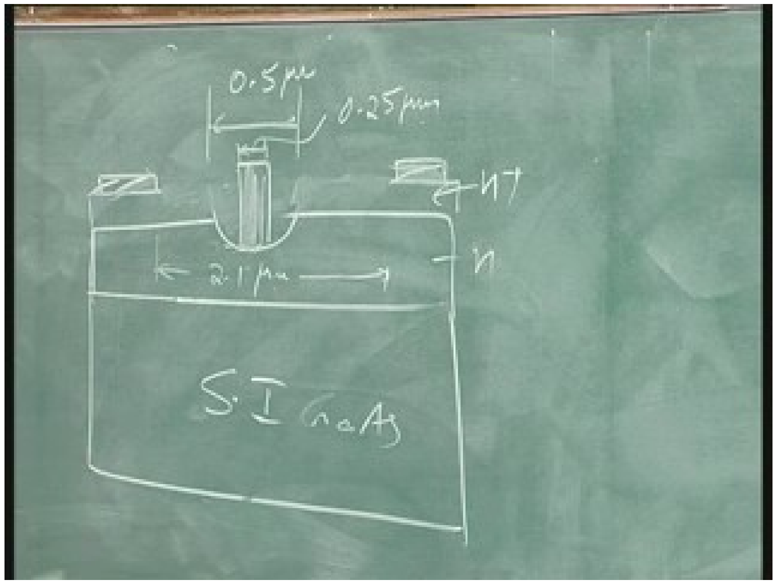

So this actually serves a purpose the gate length is same thing you do not have to worry about pinch off voltage threshold voltage changing it is the same all that you have done is the channel length is changed that is the conduct brought in closer and closer in one case mu m let us see quickly the result we can go through that these are all numbers this n plus layer is 10 to the power 18 into 1.8 that is quite very tope this n layer is 2.5 into 10 to the power 17 per centimeter cubed thickness of that a. Now you notice here this total thickness is 0.2 microns that is that it was h down by about 0.1 micron so thickness of the channel is actually 0.2 micron minus 0.1 micron that is what we put here that is 0.1 micron where is thin layer its not only the reduce a channel length thickness is also reduced clever V_{po} is 1.7 volts for that doping etc., 1-D analysis so at least the 0.1 and 0.25. At least the channel length is 2.5 times larger than thickness so still one dimensional analysis holds good for pinch off threshold voltage is 0.9 because I take Vbi is 0.8 minus 1.7.

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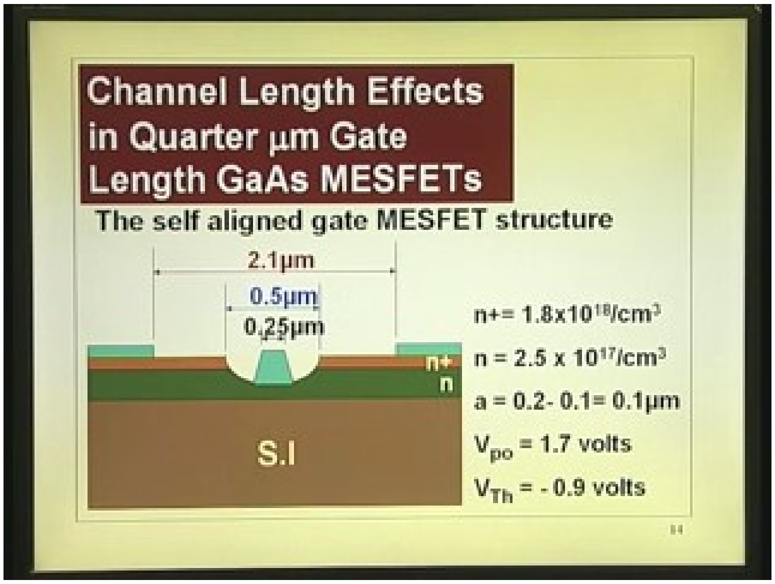

Now, case 1, n plus layer is edged this is the case 1, channel length is 2.1 micron gate length is 0.5 micron. Case 2, n plus layer is retained channel length is 0.5 micron gate length is 0.25 micron

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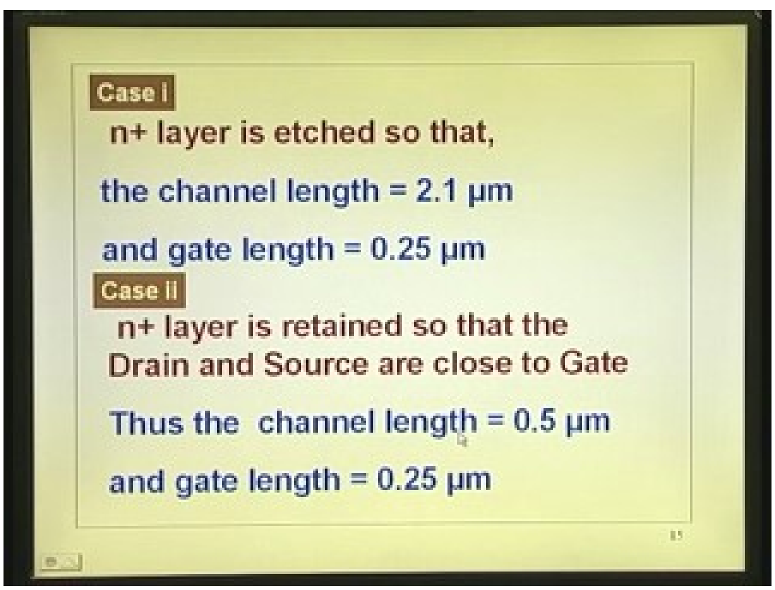

All the device both the devices are same only difference is the channel length one of them has 2.1 micron other one is 0.5 microns. (Refer Slide Time: 48:00)

So, what they did was device channel structure now this one without n plus layer between the metal conducts gate length in both case is 0.25 channel length is 2.1 in the case where n plus layer is not present 0.5 micron in the case where n plus layer going through that means the transconductance because that is the point that first think we are making transconductance is getting improvement on 215 milli ampere per volt per milli meter for this device on other 125 milli ampere volt per milli meter

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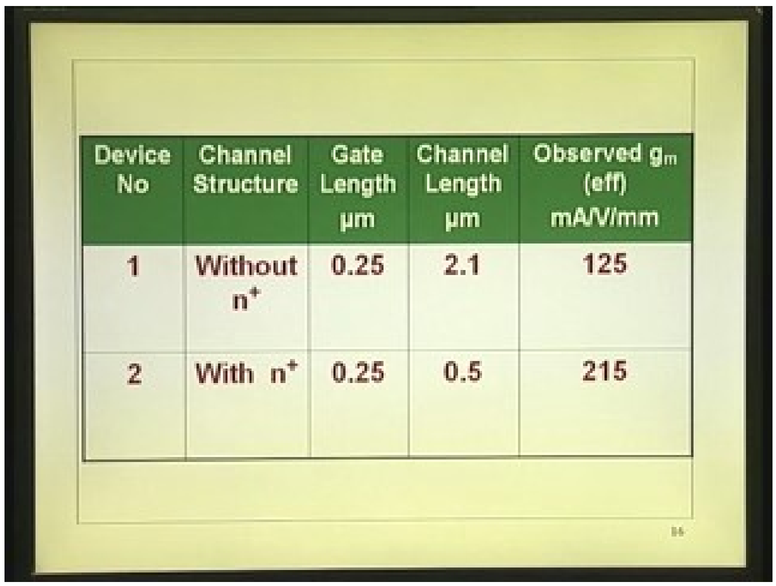

Device No	Channel Structure	Gate Length μm	Channel Length μm	Observed g_m (eff) mA/V/mm
1	Without n^+	0.25	2.1	125
2	With n^+	0.25	0.5	215

The non Gallium Arsenide guy is jumped up and said what is the hell this actually pertain quantity that you get here get better because from here to here if the n plus layer is absent there will be a series resistance if the n plus layer is present here current comes flow like that upto that point the series resistance in the case where n plus layer is present will be less if the series resistance is less when the remove that you automatically get the transconductance (Refer Slide Time: 48:00) So non Gallium Arsenide person told your device is like that but then fortunately you can measure very easily what is the resistance between the this portion and this portion how do you do that apply a small voltage between the two there is a drop here due to current flow measure the voltage drop divide by this current gives the resistance here very simple so they measured the resistance (Refer Slide Time: 48:00).

I just go back to that the resistance infact this is only to show how the g_m would vary I will come back to this after seeing this the device one the series resistances are 1.1 Ohms where the n plus layer was absent the device two where the n plus layer was present if you have the n plus layer coming all the way upto this evident the resistance is current will flow from here right upto that point if it is not there it will go through this higher resistance region so device two where n plus region is present is 0.5 Ohms 0.56 Ohms device one where the n plus layer is not present is 1.1 so though you are right the series resistance is less in the device where n plus layer is present so you can expect better transconductance now correct it for that let us see what is the intrinsic transconductance is when you correct it that becomes see what was earlier it was 125 and 215 (Refer Slide Time: 50:35) Now intrinsically is smaller on that intrinsically more than that that is 145 and 245, so that is finalize everybody

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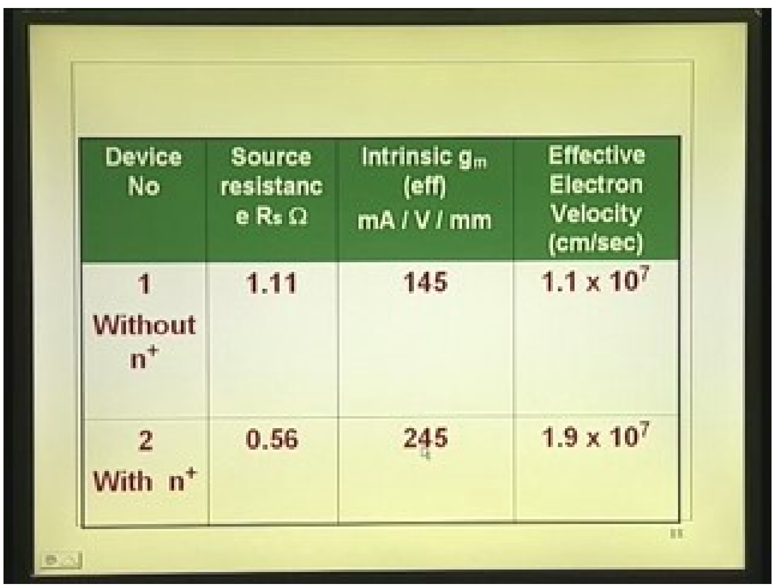

Device No	Source resistanc e Rs Ω	Intrinsic g_m (eff) mA / V / mm	Effective Electron Velocity (cm/sec)
1 Without n^+	1.11	145	1.1×10^7
2 With n^+	0.56	245	1.9×10^7

In the sense the transconductance I hope you understand what is the meaning of intrinsic transconductance is transconductance of device removing the effect of that transconductance only due to this portion just only that portion if you take what is the transconductance that is in the case when n plus layer is not present where n plus layer is present it is 245 milli ampere volts per centimeter millimeter whereas in this layer is absent it is 145 so what it tells us is the presence of n plus layer some how has enhanced the performance not due to this resistance and what people made out now is you know what is conclude from here is the velocity of electrons when the n plus layer comes up to this point is effective velocity in the channel is higher there is only that can talk off

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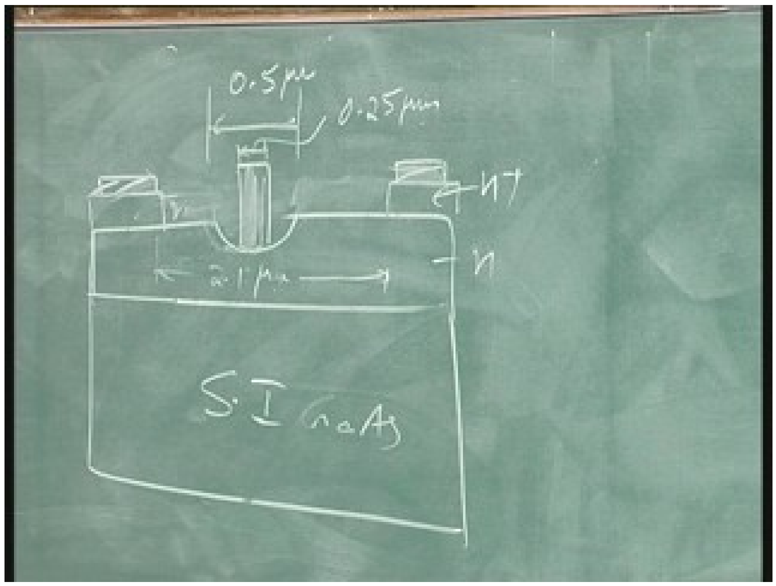

The velocity of electron is higher if the n plus layer is put here that is the average velocity within under the channel doubt it saturates but now what we are telling is effective saturation velocity is higher when n plus layer is present compare to the one where n plus layer is not present that is settle the whole issue why should be have we have to see now why should that n plus layer putting that increase the velocity infact what happens is when n plus layer is present you are launching the electrons directly into the channel from the n plus layer whereas in the previous case electrons are not launched directly to the channel there some where else by the time they reached that channel they already reached the velocity saturation some of those effects are profound effects which are seen in the case of Gallium Arsenide all three pi components mu m.

So, now there is only just the final and mu m nothing there is g_{m2} by g_{m1} is proportional velocities virtual velocities there is a formula for g_m nothing is changing V_{po} is not changing because get length is same so Vs may be different the velocity is when substitute there you calculate velocities in the case of second case it turns out to be 1.9 into 10 to the power 7 compare to 1.71 into 10 to the power 7 in the first case

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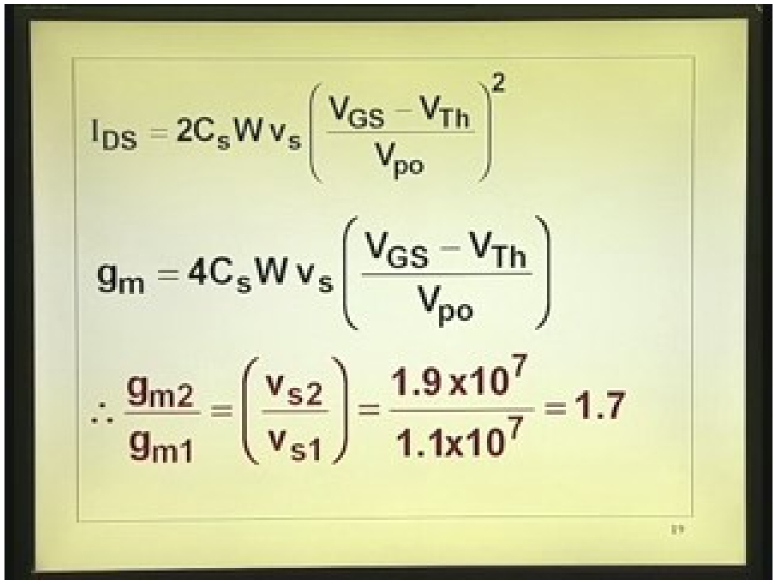

So you have got ratio of that, so what you have say is there is the saturation velocity self or the average velocity across the channel itself gets effected when the channel length is changed keep the gate length same so the moral of the stories keep the gate length small but have the n plus layer is going close to that point that means you must have self alloying structures like in the case of MOSFET you cannot have the n plus layer coming right up to this point then what will happen it is short n plus layer is short he much have some gap all those things are coming to picture people have just later on realized in technology that you must go into self alloying structures Gallium Arsenide devices came into existence the IC's performs much better will see more about this in the next lecture