Semiconductor Device Modeling
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Lecture - 45
DC Model of a Large Uniformly Doped Bulk MOSFET: Qualitative Theory

Let us continue our qualitative discussion of the DC model of a large uniformly doped bulk MOSFET. In the previous lecture, we have discussed the distributions of electrons, holes then the space-charge, the electric field and the potential as a function of the y direction.

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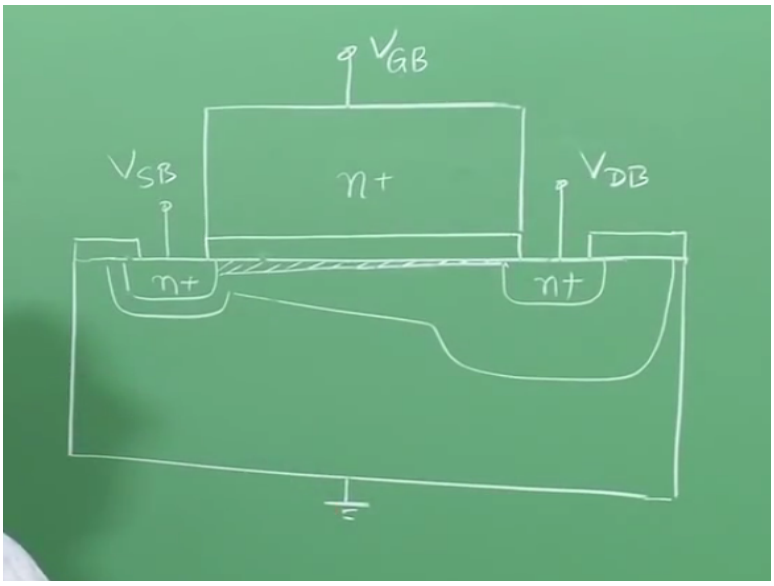

That is in terms of this diagram, the direction from the interface into the bulk okay. Now in this lecture, we continue this and move on to some other aspects of the spatial distributions of n, p, Jn, Jp, E, psi and energy bands.

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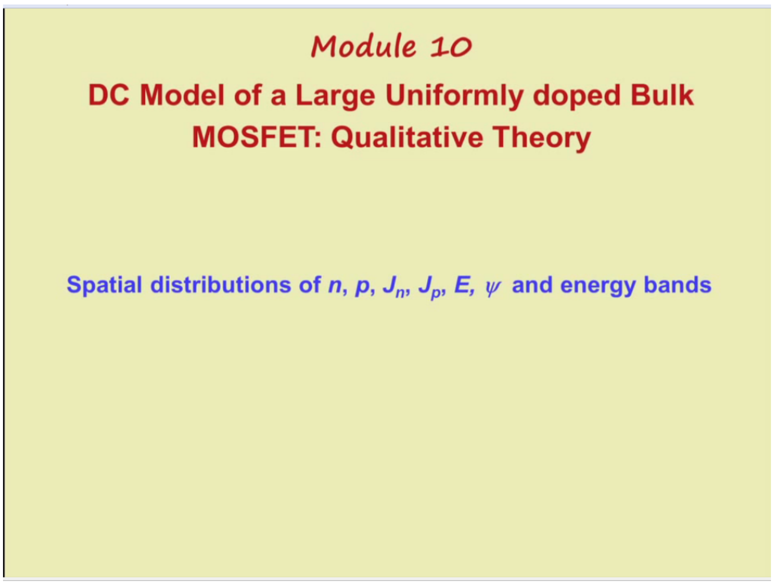

Module 10

DC Model of a Large Uniformly doped Bulk MOSFET: Qualitative Theory

Spatial distributions of n, p, J_n, J_p, E, ψ and energy bands

Specifically let us consider the plot of Jnx with y. Refer to the diagram here.

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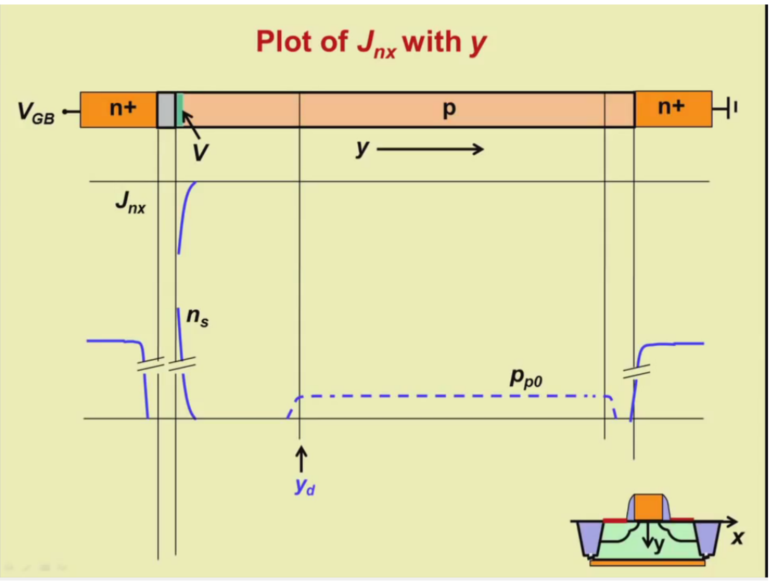

Plot of J_{nx} with y

Jnx is the x component of Jn, x component of electron density, x is the direction from source to drain as shown here and we want to plot this x component of electron density as a function of y. Now here is the section of the device rotated by 90 degrees so that the spatial axis is horizontal. So in this diagram, the x direction would be from this end to the other end so vertically upwards.

Now to plot the current density, we must look at the electron concentration and the distribution of the electron concentration is as follows. I am repeating a slide from the previous lecture. So this is a concentration of electrons in the inversion layer as a function of distance. Now the current can be because of drift or diffusion. The drift current would be proportional to the concentration of electrons shown here and the electric field in the x direction.

On the other hand, the diffusion current would be proportional to the gradient of electron concentration in the x direction. This means that like you have this kind of a distribution for n as a function of y for some x at another x you will have a similar distribution as a function of y, but the values of the electron concentrations would be different. Now it is easily observed that the gradient of the electron concentration itself is also dependent on the concentration shown here.

So if the concentration itself goes to 0 or very small values then the gradient of the electron concentration in the x direction that is this direction would also go to 0/the same distance or at the same location and therefore we can easily conclude that the Jnx, which depends on the electron concentration and its gradient in the x direction would both have qualitatively same shape as shown here for the electron distribution.

And this is what is shown here that as electron concentration falls to 0, the current density also falls to 0. The current density is shown in the negative axis because the current is from drain to source whereas the x direction is from source to drain. So we conclude that the current of electrons from source to drain would be very close to the interface. At the interface, the current density would be maximum and then it would decay rapidly and it would be restricted to the inversion layer.

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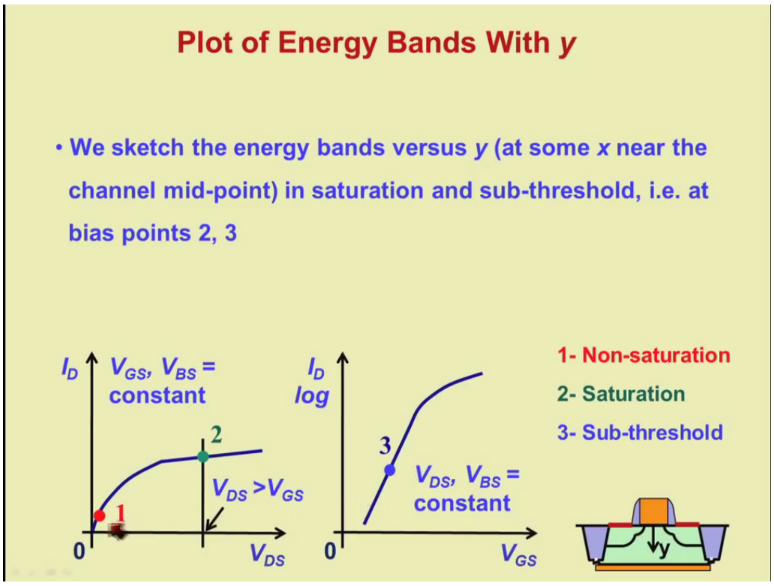

Plot of Energy Bands With *y*

- We sketch the energy bands versus *y* (at some *x* near the channel mid-point) in saturation and sub-threshold, i.e. at bias points 2, 3

1- Non-saturation

2- Saturation

3- Sub-threshold

Now let us move on to the plot of energy bands with y. Now here are the various bias points where we could draw the band picture. We sketch the energy bands versus y at some x near the channel mid-point in saturation and subthreshold. That is at bias points 2 and 3 that is this point and this point. I will be doing it for 2 and I will leave it as an exercise for you to do it at 3. You can also do it at 1.

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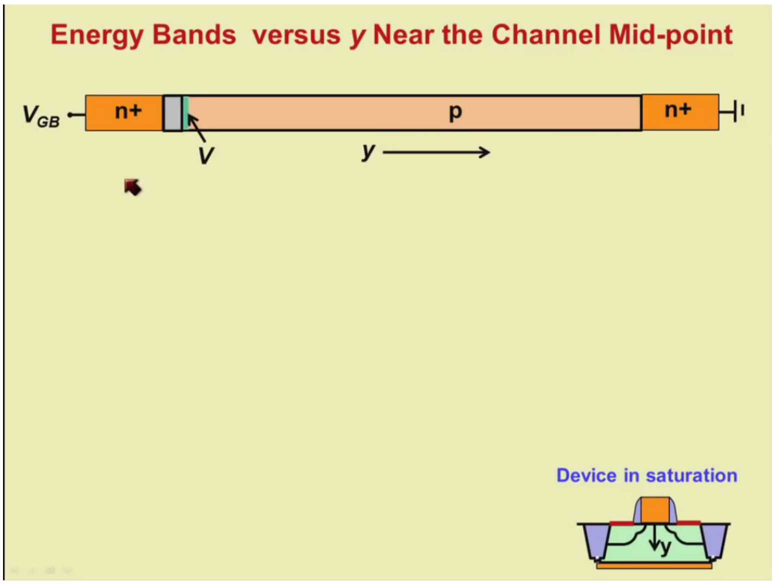

Energy Bands versus y Near the Channel Mid-point

Device in saturation

Let us consider the device in saturation. Now here is the section of the device that is relevant to us and here is the procedure for constructing an energy level versus y diagram.

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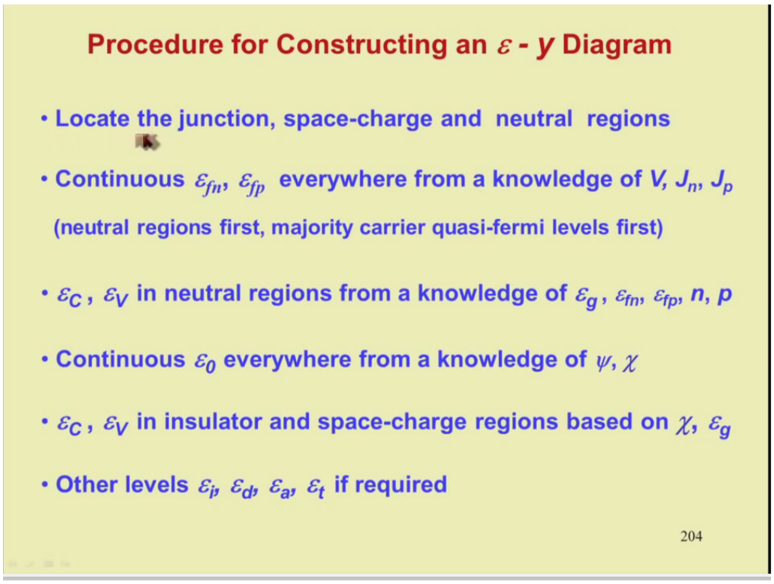

Procedure for Constructing an ε - y Diagram

- Locate the junction, space-charge and neutral regions
- Continuous ε_{fn}, ε_{fp} everywhere from a knowledge of V, J_n, J_p

  (neutral regions first, majority carrier quasi-fermi levels first)
- ε_C , ε_V in neutral regions from a knowledge of ε_g , ε_{fn}, ε_{fp}, n, p
- Continuous ε_0 everywhere from a knowledge of ψ, χ
- ε_C , ε_V in insulator and space-charge regions based on χ, ε_g
- Other levels ε_i, ε_d, ε_a, ε_t if required

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This procedure is repeated here from a previous module. You recall we have done a complete module on energy band diagrams and there we had listed out the sequence of steps in which any band diagram should be drawn. Now these are the steps. Let us look at the first step. We locate the junction, space-charge and neutral regions.

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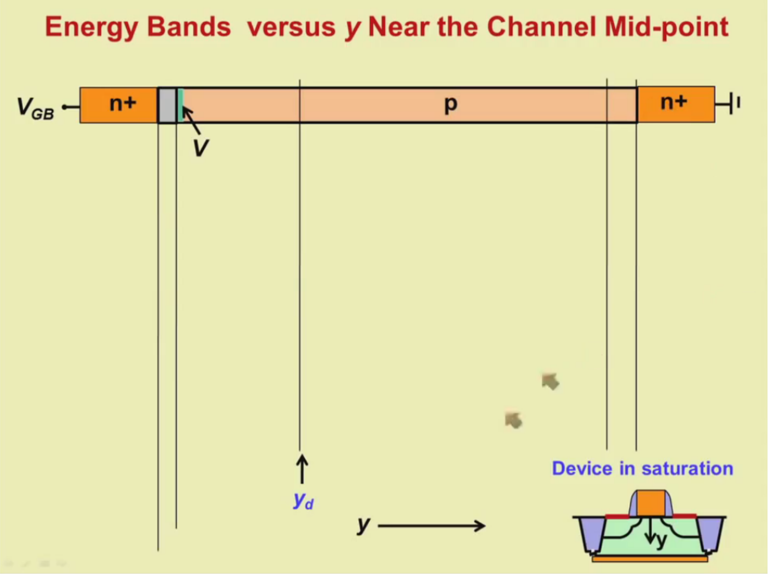

Energy Bands versus *y* Near the Channel Mid-point

Now let us do that junctions in this device structure are the n+ gate silicon dioxide insulator junction that is shown here. The silicon dioxide insulator substrate junction that is shown here. Then you have the substrate and substrate electrode junction that is shown here. Then you have the space-charge regions. This is one space-charge region, which is controlled by the gate and this is another space-charge region because of the substrate-substrate electrode junction.

Yd represents the edge of the depletion layer due to the space-charge layer control by the gate. The next step in this procedure is to draw Efn and Efp continuously everywhere from a knowledge of applied voltage across the junction V and current densities of electrons and holes. So you know that the gradient of Efn represents the current density Jn and the gradient of Efp represents the current density Jp.

Now whenever we have options we should first draw the Efn and Efp in neutral region and among or between Efn and Efp, we should first sketch the majority carrier quasi Fermi level. Now this order is dictated by the ease in which we can draw the Fermi levels so let us do that.

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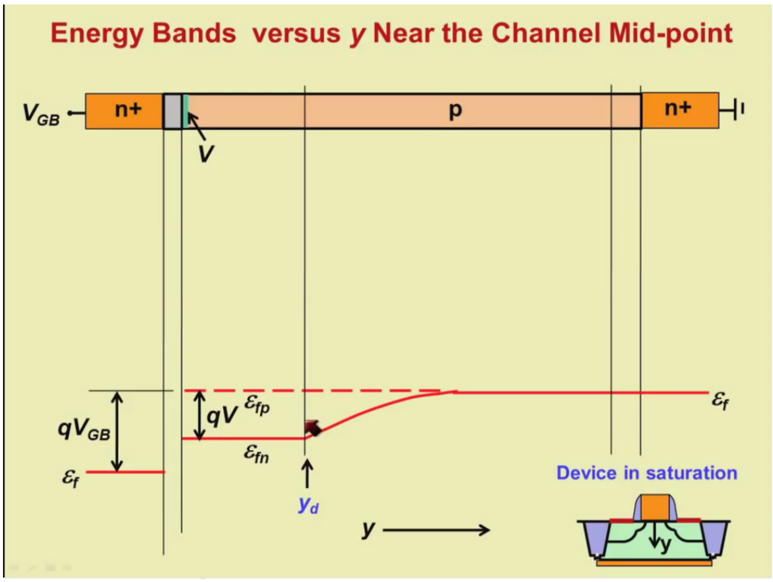

Second step, so here we have drawn the Fermi level across the substrate-substrate electrode junction. This is the easiest to do because as we have remarked earlier, there is no voltage drop across this junction because the voltage drop across this junction that is any part of the applied voltage, if it drops across this junction that would amount to a current flow across the junction and such a current flow is not possible because that current would have to flow through this insulator layer and this is not possible.

Thus this p n+ junction is in equilibrium and therefore we can easily draw a constant Ef across the junction. So Efn and Efp are both the same. Next, let us extend this Fermi level over the neutral region of the substrate until the depletion edge. Now while doing so we have shown it as a dash line because we want to first sketch the majority carrier Fermi level and that is Efp.

So the quasi Fermi level for holes will be shown with a dash line. Evidently, the quasi Fermi level for electrons in this region, which is next to the depletion edge, would not coincide with the quasi Fermi level for holes. This you can easily appreciate from your knowledge of a p-n junction. So when you have a biased p-n junction then in the neutral region near the depletion edge, the quasi Fermi levels split.

Now here this is the space-charge region corresponds to the inversion layer p substrate junction, which can be regarded as an n+ p junction, the inversion layer is n+ and the channel voltage V can be regarded as the reverse bias across the inversion layer p junction and therefore the Efn would not coincide with Efp. Now the Efp would be a constant line and it is easy to draw because the hole concentration would not be disturbed in spite of the bias.

This is the reverse bias and therefore the injection level has to be low and therefore the majority carrier concentration is not disturbed. Therefore, Efp remains a constant line okay, which is the same as under equilibrium and that is why in this entire neutral p region the Efp would be constant. Next, we sketch the Ef in the gate region. Once again here we have sketched the Ef in both the neutral as well as the space-charge region of the gate and we have shown it as a constant line because the n+ region here is under equilibrium.

No current flow can occur perpendicular to the silicon dioxide interface here and that is the reason why n+ region is in equilibrium. Therefore, we can draw the Ef as a constant line. Efn and Efp are the same. Now where do we draw this constant line? We know that there is an applied voltage VGB between this n+ region and the back n+ contact. Therefore, the Fermi level in the back n+ contact and the Fermi level in this n+ region would be separated by q times VGB.

This VGB is positive and therefore the Fermi level in the gate is below the Fermi level in the substrate electrode because this is energy band diagram and any movement upwards would amount to moving to more negative energies or more negative potentials and therefore a positive potential will be realized by moving downwards.

Next, we extend Efp in the space-charge region using the assumption of quasi equilibrium according to which in the space-charge region of a p-n junction, the hole current density rather will be approximately = 0. Note that in the space-charge region, you have a large gradient of holes and as well as a large electric field and therefore you have large drift and diffusion currents, which are however in opposition.

And the difference between the 2 currents okay is what results in the net current and this net current is what is represented by the gradient of the quasi Fermi level. So we are saying that individually the drift and diffusion are very high, but they are in opposition and the difference between them is very small. And that is what is implied by the statement that the gradient of Efp is very small or Efp is a constant line and therefore this is simply extended from the Efp outside the depletion region.

Next, we sketch Efn again as a constant line using the same quasi equilibrium approximation for electrons. The distance between Efn and Efp = the reverse bias across the junction that is q times V. So this channel voltage V is actually the reverse bias across the n+ inversion layer p substrate junction and since the inversion layer is positive with respect to substrate, the quasi Fermi level for electrons is below the quasi Fermi level for holes.

Now we connect the Efn from the depletion edge to the Efn deep inside the bulk as a continuous line. Now slope of this line represents the so called diffusion current of electrons, which is flowing okay because of the reverse bias across the inversion layer p substrate junction.

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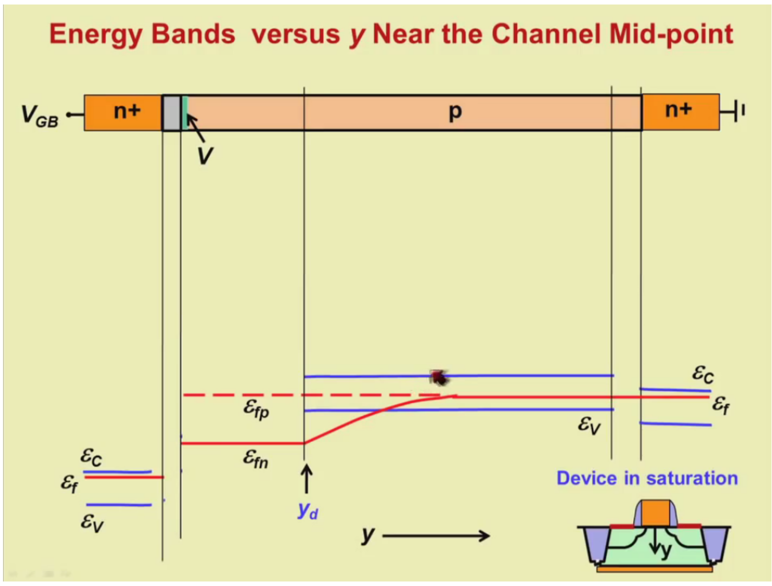

Energy Bands versus *y* Near the Channel Mid-point

Now let us clean up the slide and show other aspects. Referring to the procedure for constructing the E-y diagram, the third step is sketching of Ec and Ev in neutral regions from a knowledge of energy gap Efn, Efp and concentration of electrons and holes. Now that is what we do next. So we first locate the Ec in n+ region. The distance between Ec and Ef is given by the concentration of electrons in n+ region.

Then we sketch Ev below Ef in the p-type substrate. The difference between the Fermi level and the valence bandage in the p-type substrate is given by the hole concentration in the substrate. So we are sketching the Ev in the neutral region of the substrate. Then we sketch Ec in the neutral region of the gate okay. So Ec is little above Ef. In practice, for poly gates for heavily doped polysilicon gates, Ec and Ef are assumed to be coincident.

However, in our diagram we have shown a small difference between Ec and Ef both in the gate as well as here because we want to show the Ec and Ef clearly. Now using energy gap, we place the other level, we place the valence band edge in the substrate electrode and in the gate and we place the conduction bandage in the substrate in the neutral region of the substrate.

Now the 4th step is to sketch the continuous E naught everywhere from a knowledge of potential and electron affinity.

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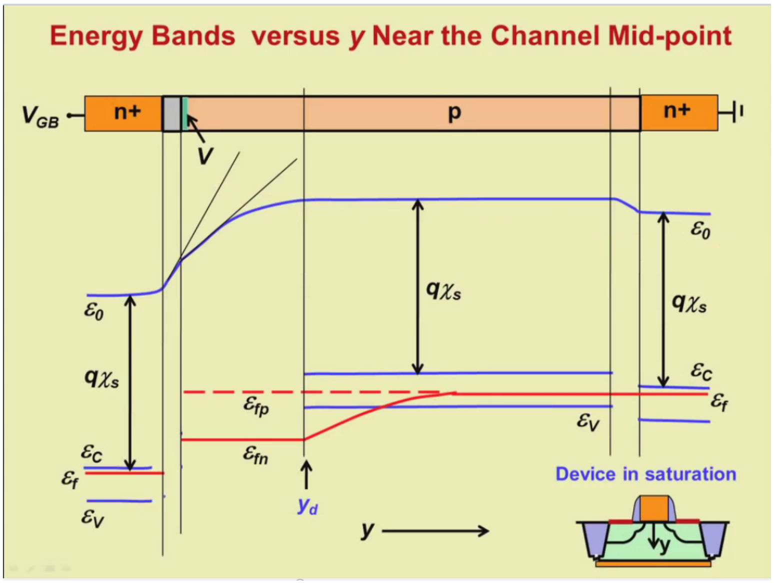

Energy Bands versus y Near the Channel Mid-point

So that is what we are doing here. So we place E naught in the neutral regions above Ec at a distance given by q times the electron affinity. So we have done that in all the neutral regions okay. Now after sketching the E naught in the neutral regions, we can now join these various E naught levels by continuous line as shown here. So we draw a continuous line for E naught in the space-charge region joining the various ends.

Now note that the slope of E naught is important and it represents the electric field. Therefore, for example if you take E naught at the silicon-silicon dioxide edge, in silicon dioxide region the variation of E naught has a constant slope because the electric field is constant. The gradient of E naught represents the electric field. In the substrate, at the interface, the electric field is different than the electric field in the oxide because of the directory constant differences between the oxide and the substrate.

And therefore you see the slope of E naught at the interface in substrate is different from the slope of E naught in the oxide. More specifically E naught in the oxide has a higher slope than the E naught at the interface in the substrate. In fact, the slope difference would be a factor of 3 because of the factor of 3 difference in the directory constant of silicon dioxide and silicon.

Now the next step is to sketch Ec and Ev in insulator and space-charge regions based on electron affinity and energy gap.

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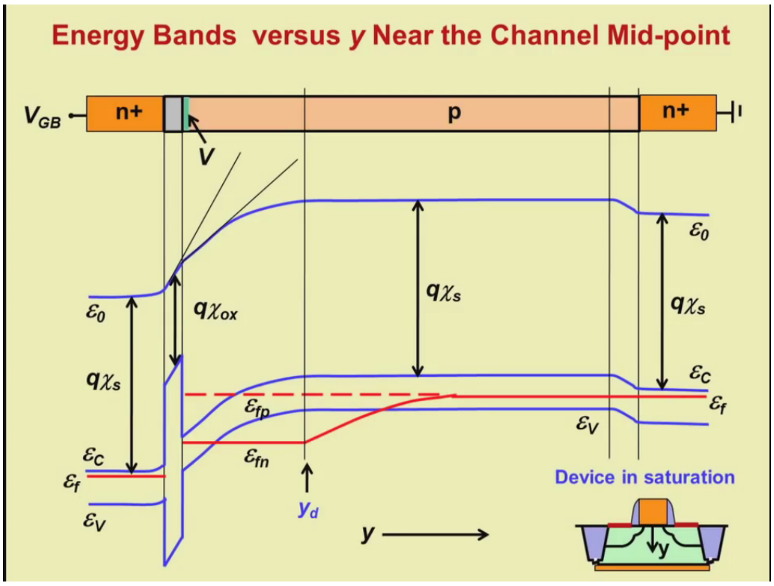
Energy Bands versus y Near the Channel Mid-point

So let us begin with the insulator, we place Ec at a distance q times the electron affinity of oxide below the E naught and we place Ev at a distance Eg below the Ec. Now we place Ec and Ev in the space-charge regions controlled by the gate. So both the space charge regions in the substrate as well as in the gate. Now this is done in a similar way as we have done for Ec and Ev in the oxide okay.

We are doing it from the knowledge of electron affinity so this Ec line here in the space-charge region would be q times chi s below the E naught line in the space-charge region. Similarly, for this Ec line and the Ev line here in the space-charge region would be energy gap below the Ec line and similarly here. Now let us repeat the same process for this space-charge layer.

Now we are not going to show any more levels such as a donor level or any trap level and so on. I leave that as an exercise to you.

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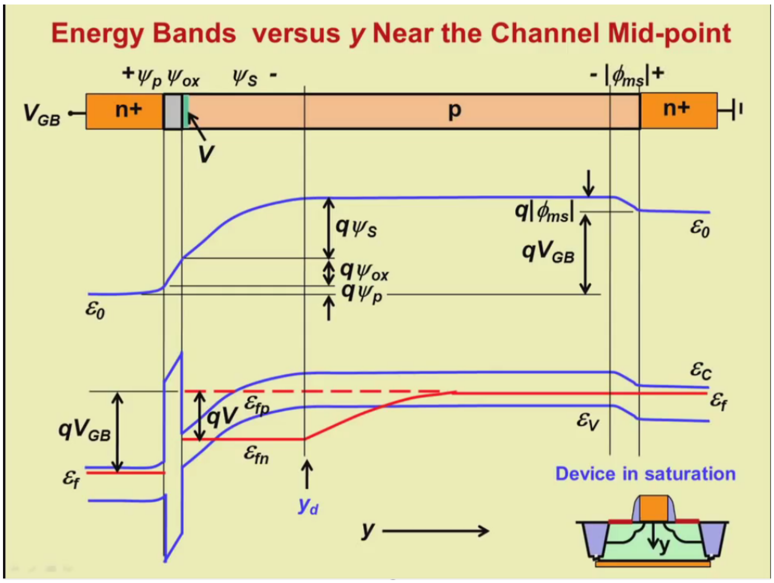

Energy Bands versus *y* Near the Channel Mid-point

Let us look at some further aspects of this energy band diagram. For that let us clean up and show only the energy levels. Let us show the voltage differences. Now q times VGB is a difference between the Fermi level here and this line which represents the Fermi level in the bulk electrode, the same qVGB also appears as the difference between the E naught levels in the substrate electrode and the E naught level in the gate.

As we have remarked earlier, the difference between the quasi Fermi level for holes and the quasi Fermi level for electrons in the space charge layer controlled by the gate = q times the channel voltage V, q times the potential drop across the poly, q times the potential drop across the oxide and q times the potential drop across the semiconductor okay or q times the surface potential.

Now these are all represented for the E naught variation from the gate into the bulk. Just for the information of the students, psi p, psi ox and psi s are the potential drops occurring in these regions of the device and this is the polarity, q times phi ms is actually the total variation of E naught across the space-charge region of the substrate-substrate electrode junction okay.

Now that is essentially the potential drop or the built-in potential drop okay across the substrate electrode substrate junction.

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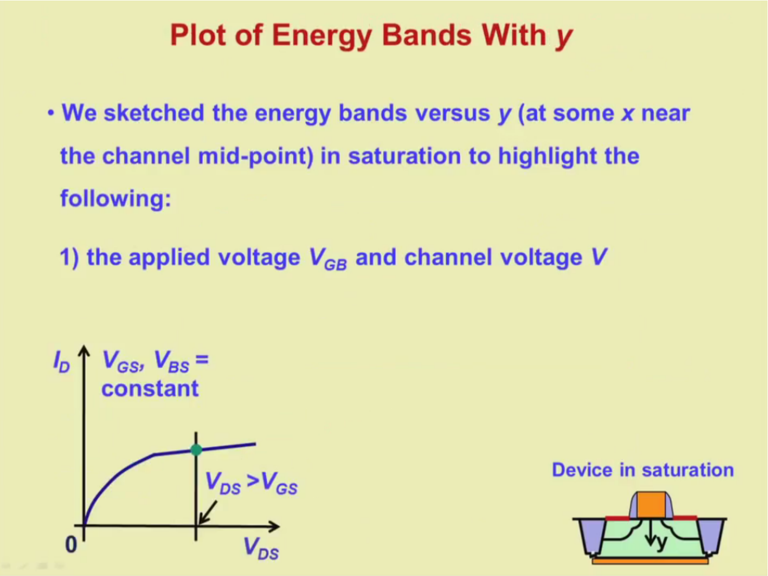

Plot of Energy Bands With y

- We sketched the energy bands versus y (at some x near the channel mid-point) in saturation to highlight the following:

1) the applied voltage V_{GB} and channel voltage V

Now let us summarize what have we achieved by drawing these band diagrams? We sketch the energy band versus y at some x near the channel mid-point in saturation to highlight the following. Now this is essentially the bias point at which we sketch the band diagram. The first point we highlighted was the applied voltage VGB and the channel voltage V. So go back and see this is applied voltage VGB and channel voltage V.

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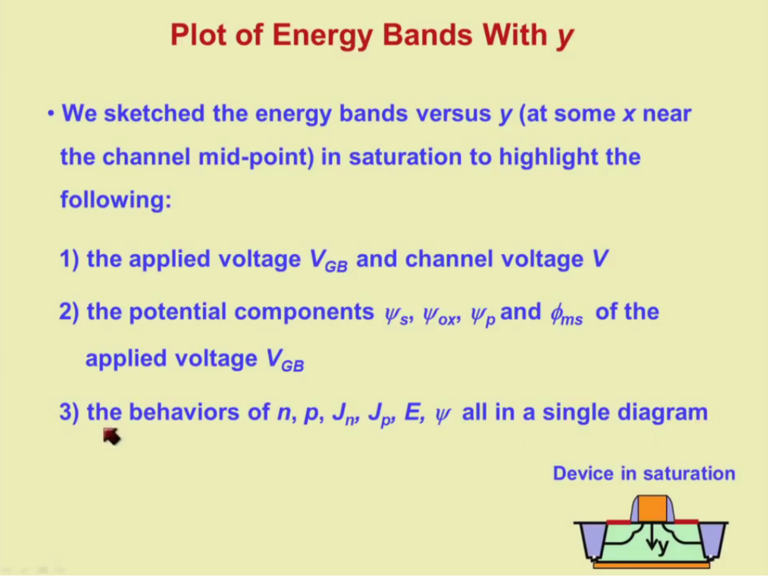

Plot of Energy Bands With y

- We sketched the energy bands versus y (at some x near the channel mid-point) in saturation to highlight the following:

1) the applied voltage V_{GB} and channel voltage V

2) the potential components ψ_s, ψ_{ox}, ψ_p and ϕ_{ms} of the applied voltage V_{GB}

3) the behaviors of n, p, J_n, J_p, E, ψ all in a single diagram

Then we wanted to show the potential component psi s, psi ox, psi p and phi ms of the applied voltage VGB. So psi p, psi ox and psi s and phi ms. So these components of the applied voltage VGB, which is the difference between E naught levels. So you see the various potential drops are shown on the variation of the E naught level okay whereas the applied voltages VGB and channel voltage V are shown as differences between quasi Fermi levels.

Finally, we wanted to show the behaviors of electron and hole concentrations, electron and hole current densities, electric field and psi all in a single diagram. So when you look at this energy band diagram, from this diagram you can conclude okay you can derive the information about electron concentration, hole concentration, electron current density, hole current density, electric field and psi. Now let us just explain how?

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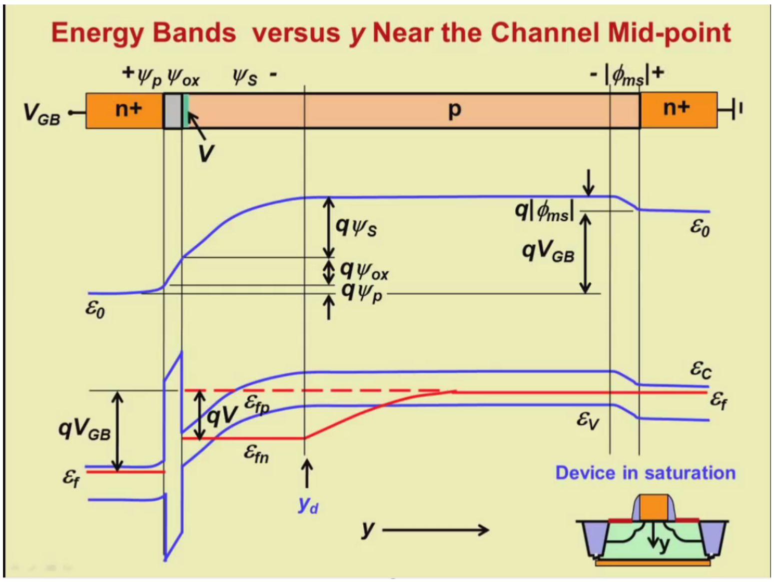

Energy Bands versus *y* Near the Channel Mid-point

Device in saturation

Now you know that the difference between Ec and Efn okay gives you the electron concentration at any point. Similarly, the difference between Efp and Ev gives you the hole concentration. The gradient of Efp gives you the hole current and the gradient of Efn gives you the electron current density right. Now the gradient of E naught gives you the electric field and similarly gradients of Ec and Ev also give you the electric field.

And the variation of E naught is actually nothing, but the variation of the potential. So this is how n, p, Jn, Jp, E and psi all are reflected at once okay in the energy band diagram.

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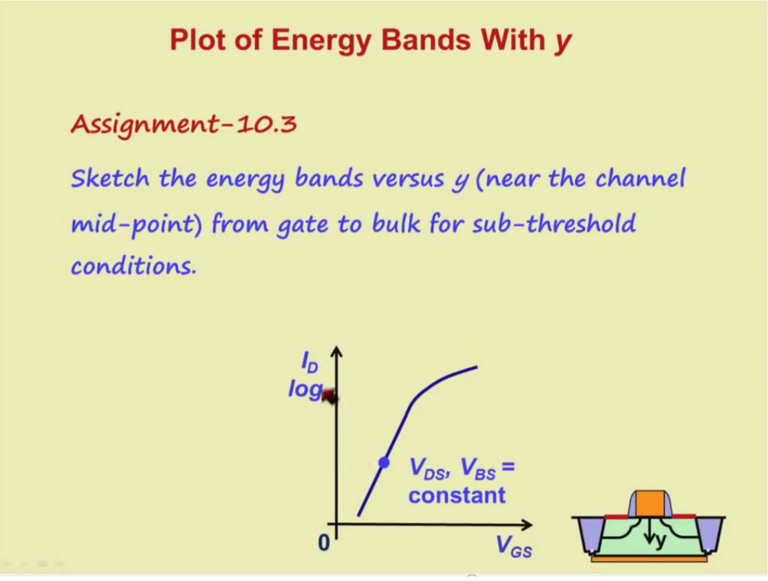

Plot of Energy Bands With y

Assignment-10.3

Sketch the energy bands versus y (near the channel mid-point) from gate to bulk for sub-threshold conditions.

Now here is an assignment for you. Sketch the energy bands versus y near the channel mid-point from gate to bulk for subthreshold conditions that is for this particular bias point shown on a log ID versus VGS graph.

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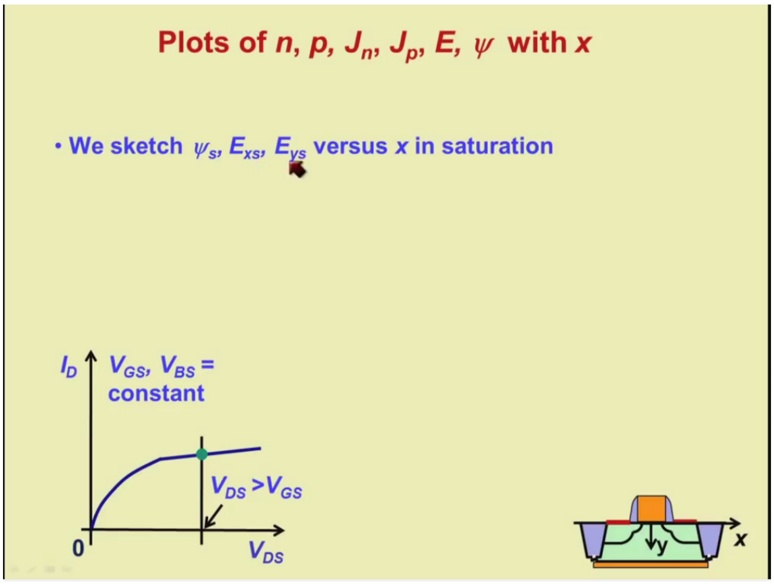

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation

Now let us turn our attention to plots of n, p, Jn, Jp, E and psi as a function of x. Now so far we were plotting quantities as a function of y that is from the interface into the bulk. Now let us plot along the interface from source to drain that is what we are doing now. Now we are not going to plot all of these quantities, we are going to plot some of these relevant quantities. I will leave it as an exercise to plot those quantities, which I am not going to do here on the slides.

First let us sketch psi s, Exs, Eys versus x in saturation that is at this bias point. Psi s is the potential of the silicon dioxide interface or surface, Exs is the x component of the electric field that is electric field directed along this x direction from drain to source or source to drain whichever way you look at it along the interface so s here means it is along the interface and similarly Eys is electric field in the y direction, but plotted along the interface in x direction.

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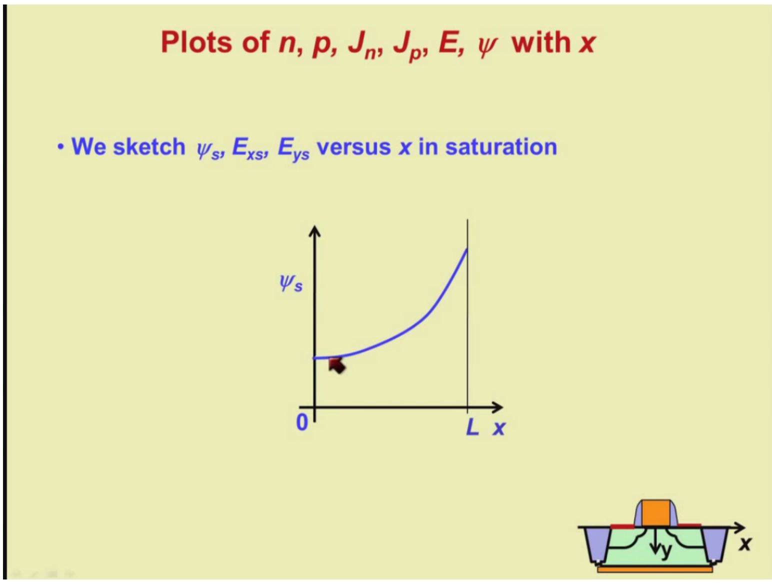

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation

Let us look at psi s as a function of x. This variation would look something like this. So 0 is the source and x=L is the drain. So from source to drain the surface potential goes on increasing progressively okay. The variation is slow towards the source, but rapid near the drain.

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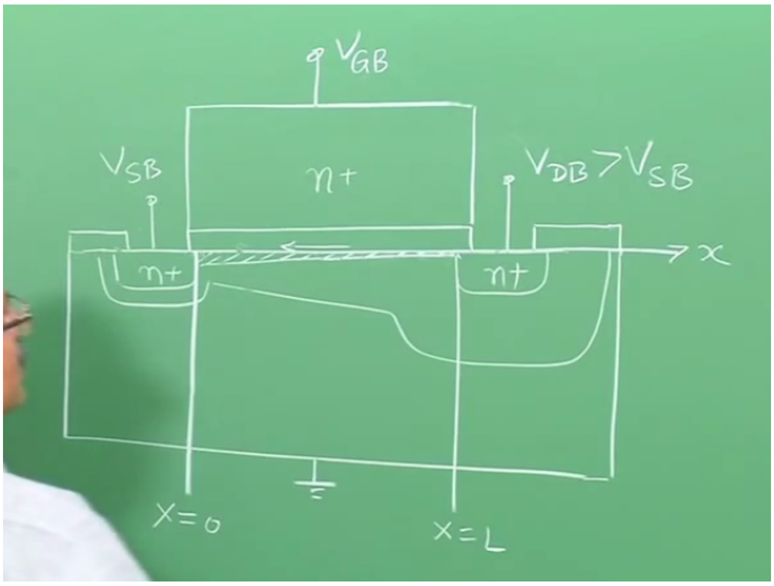

Now let us explain this with the help of this particular diagram. So psi s is the potential of this interface okay with respect to the bulk. Now if I take the source n that is this, so this is x=0 and this is the drain end, this is x=L. Now we are assuming strong inversion so the inversion charge concentration at the interface or the electron concentration at the interface may even be more than the doping in this heavily doped source okay.

So we are ignoring any small potential variations that may occur okay across this region because of the difference between the inversion layer, electron concentration and electron concentration in the source. So we will assume more or less both are at the same potential. Now psi s goes on increasing from source to drain this is evident because VDB is more than VSB.

So the psi s should increase. Now the psi s increases slowly near the source, but rapidly near the drain. Now this is evident from the fact that the inversion charge is very strong near the source, but weak near the drain because of which the electric field directed in this direction, now this is your x direction, now our electric field at this here it is like this okay, you also have an electric field in this direction, but we are concerned with the electric field in this direction because we are interested in the surface potential variation in this direction.

Now this electric field is high near the drain and low near the source because as we have remarked earlier the current has to remain constant from source to drain approximately constant at least there may be some contributions from thermal generation and so on which are small. If the same current has to be there, when the inversion charge is more as well as when the inversion charge is less.

Wherever the inversion charge is more the electric field in this direction should be small and wherever the inversion charge is less to get the same current I should have a higher electric field.

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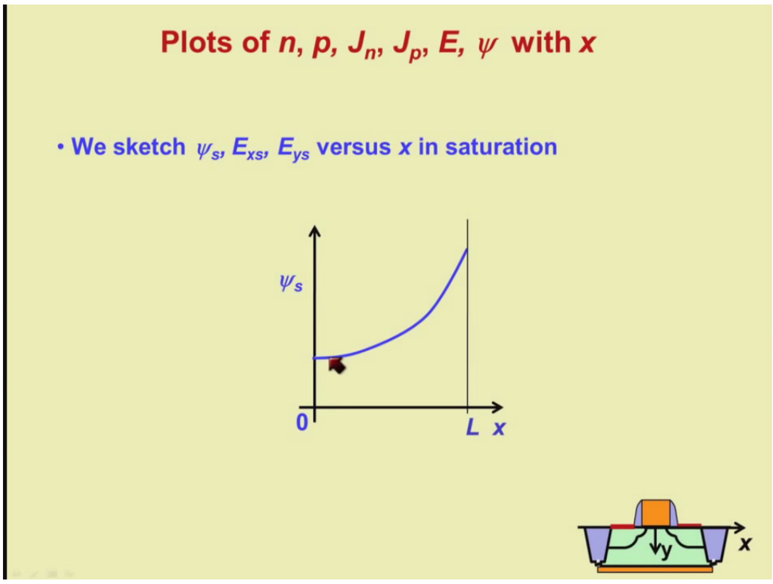

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation

Now that explains why the slope of psi s is small near the source end, but high near the drain end.

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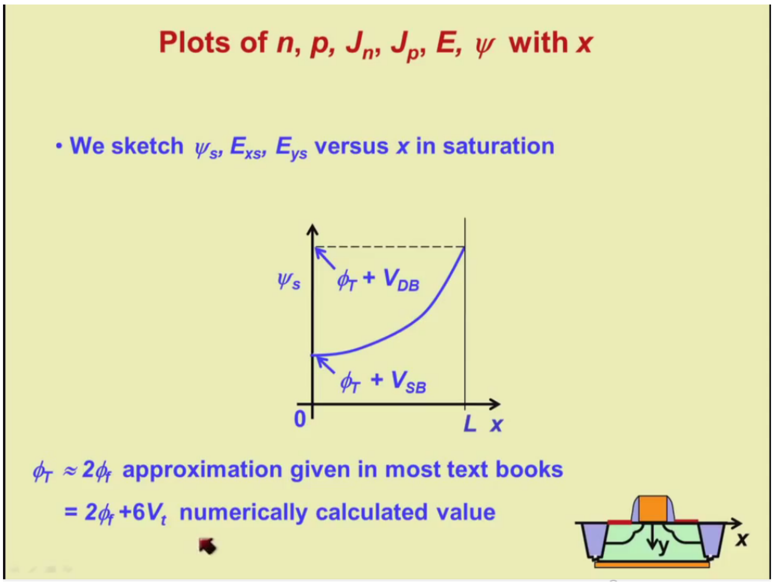

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation

$\phi_T \approx 2\phi_f$ approximation given in most text books

$= 2\phi_f + 6V_t$ numerically calculated value

The value of psi s at the source = phi T+VSB where phi T is normally 2 times phi F where phi F is the difference between the Fermi level and the intrinsic level in the substrate. So this approximation is normally given in most text books; however, when you do numerical calculations then the accurate value is twice phi F+6 times the thermal voltage. This we have explained in our discussion of the MOS capacitor.

At the drain end, the psi s = phi T+VDB. So source end is here and drain end is here.

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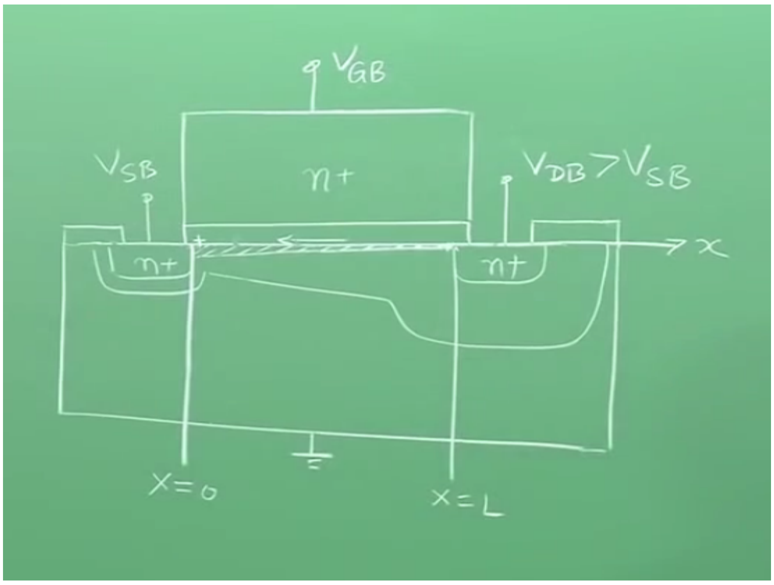

So we are saying that at this end the potential of this point with respect to bulk is VSB+phi T and at this end it is this VDB+phi T so this potential with respect to this.

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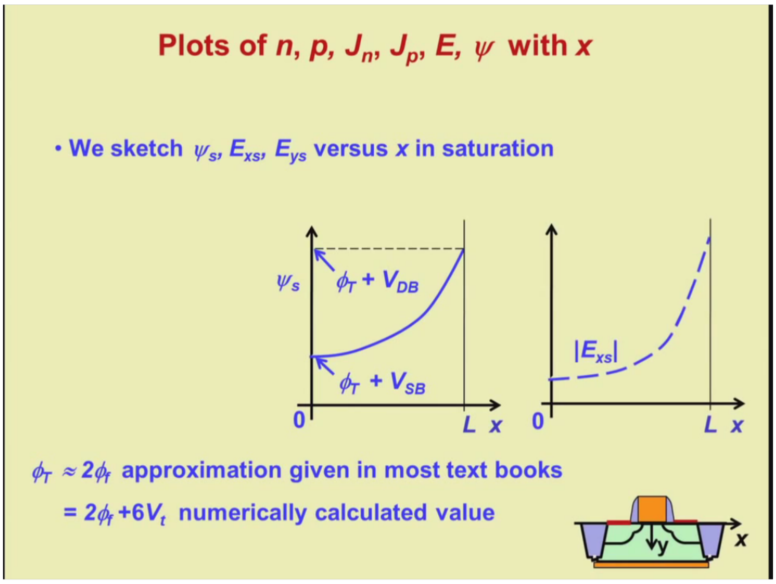

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation

$\phi_T \approx 2\phi_f$ approximation given in most text books

$= 2\phi_f + 6V_t$ numerically calculated value

So from psi s versus x we can easily plot Exs versus s. As we have already remarked, Exs is nothing but this electric field okay, this exaggerated electric field and at the interface. So this Exs is nothing but - dou psi s/dou x.

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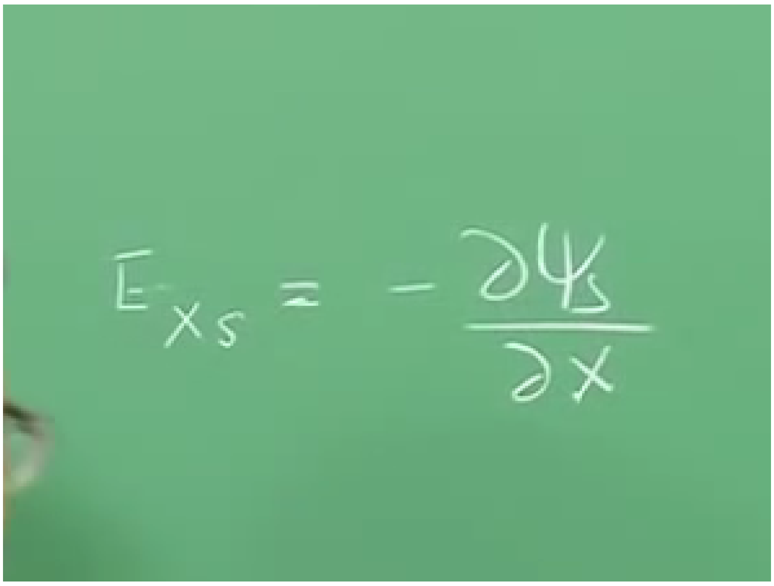

$$E_{xs} = -\frac{\partial \psi_s}{\partial x}$$

And since the Exs is directed from drain to source, it is negative and that is why we are plotting the modulus here. So this curve is nothing, but the slope of this curve.

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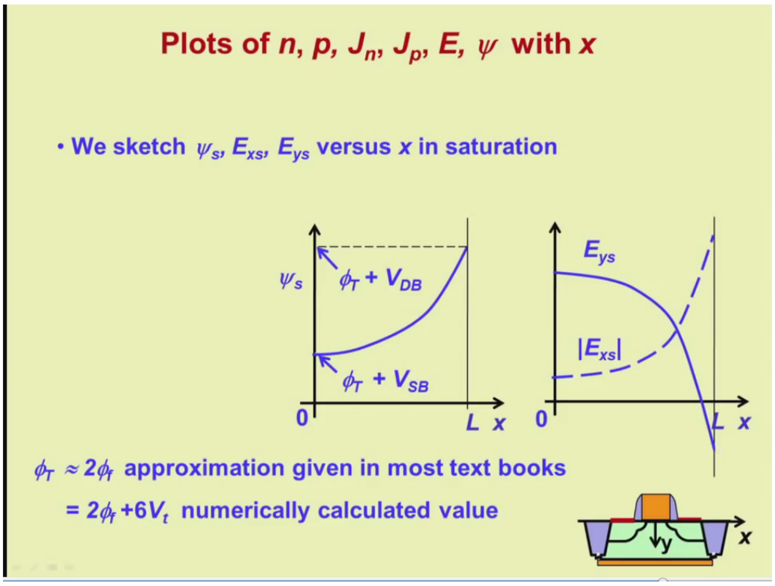

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation

$\phi_T \approx 2\phi_f$ approximation given in most text books

$= 2\phi_f + 6V_t$ numerically calculated value

Let us turn our attention to the y component of the electric field. Now here is a plot of Eys as a function of x. You see the Eys is crossing the 0 line and becoming negative for x=L.

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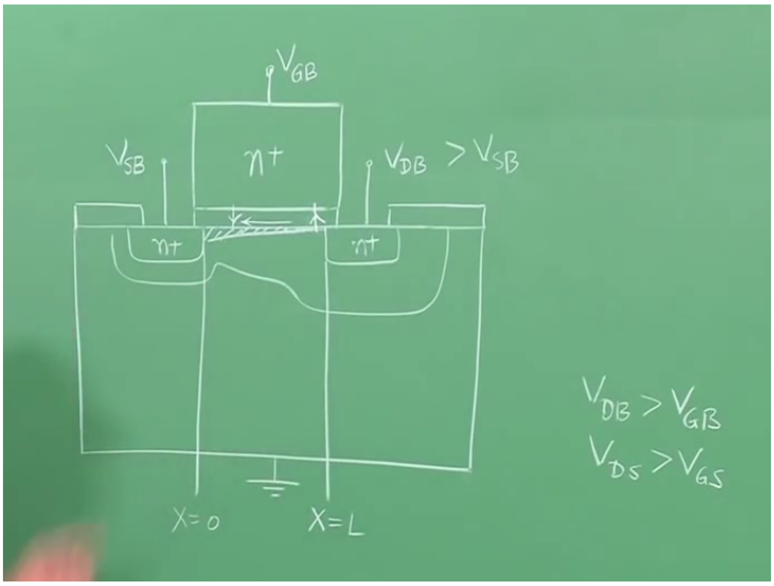

Now this is because you recall we were considering a bias condition in which the VDB is > VGB, which is same as say VDS is > VGS. Now for this bias condition, we have sketched the equi-potential lines, field lines and so on right in one of the earlier modules and you recall when VDB is > VGB, near the drain end the field is directed from substrate to gate.

Whereas over most of the channel length near the source the field is directed from gate to substrate. At some point, the field reverses direction okay. Now let us explain the shape of the Eys versus x curve. The Eys is high near the source and it progressively goes on decreasing. Why is it so?

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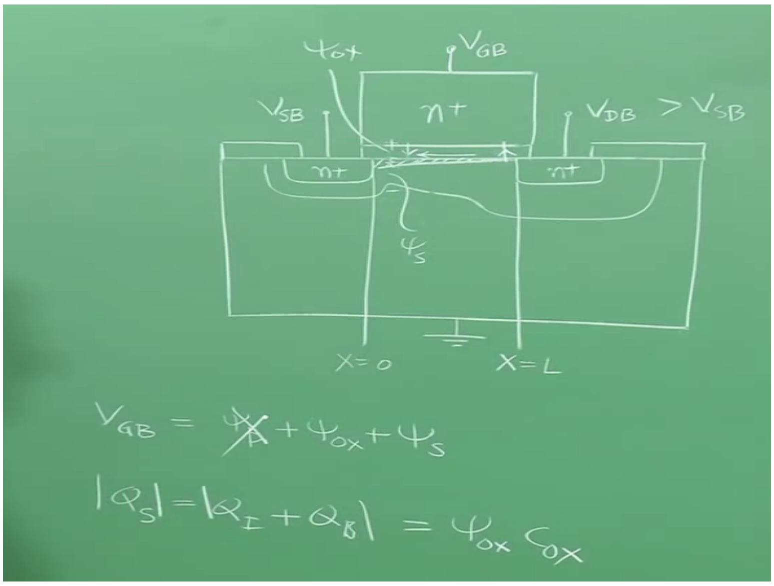

Now look at this diagram and this is your Eys that is the Ey at the surface or interface. Now you know that the applied gate to bulk voltage falls partly across the polysilicon, partly across the oxide, and remaining across the depletion layer in the substrate. So we can write this as VGB=psi p+psi ox+psi s, where this is psi ox and this is psi s. Now let us ignore the psi p that is the potential drop in the poly.

Now VGB is constant from source to drain, but what happens to psi s. So you see the psi s is going on increasing from source to drain. Consequently, psi ox goes on decreasing from source to drain so this potential drop decreases from source to drain. Now the total charge in silicon that is inversion charge + depletion charge should decrease from source to drain because the psi ox is decreasing from source to drain.

So total charge in semiconductor if you represent it as Qs which is sum of QI the inversion charge and the depletion charge that is this charge and this depletion charge. Then the magnitude of this depends on psi ox. So this is = psi ox into c ox. This is by the parallel plate capacitor law. Now since psi ox decreases from source to drain, the Qs decreases from source to drain.

Now if Qs decreases from source to drain then by Gauss's law, the y component of the electric field which terminates on this charge, which is actually the Eys, that Eys should decrease from source to drain. Now note that we have to argue in terms of psi ox because if you take the inversion charge and depletion charge individually, inversion charge goes on decreasing from source to drain, but the depletion charge increases from source to drain.

So purely from this knowledge of variation of QI and QB we cannot conclude about Qs because this is decreasing from source to drain, this is increasing so we cannot talk about the sum right unless we talk in terms of psi ox. Now the next point of interest is the fact that the variation in Eys is slow near the source and it is rapid near the drain.

Now this is because of the same reason because of which the x component of the electric field that is the field directed from drain to source increases rapidly near the drain right and the variation in this field is slow near the source. So the conditions in the channel change rapidly near the drain right, but they vary rather slowly near the source.

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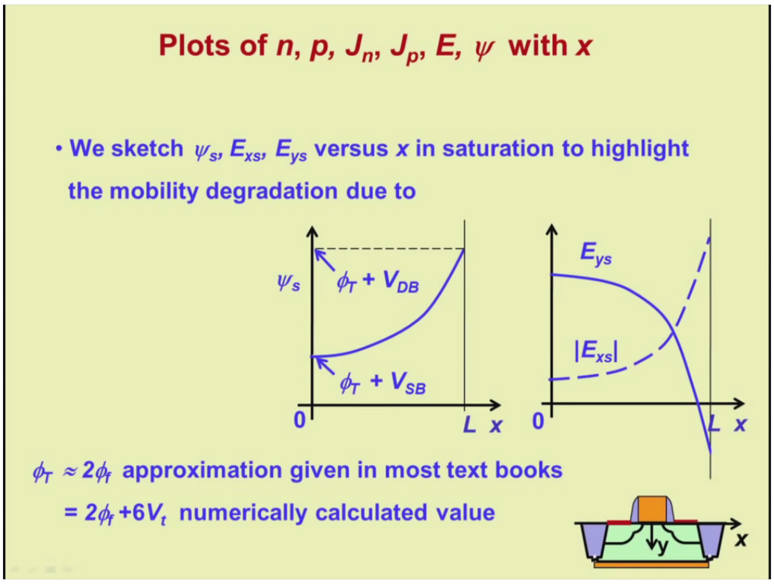

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation to highlight the mobility degradation due to

$\phi_T \approx 2\phi_f$ approximation given in most text books

$= 2\phi_f + 6V_t$ numerically calculated value

Now let us see what can we do with this information? So we have sketched psi s, Exs, Eys versus x in saturation to highlight the mobility degradation because of the following factors. So what we are saying is from this information regarding the variation of the y and x component of the electric field, we conclude something very important regarding how the mobility varies along the channel.

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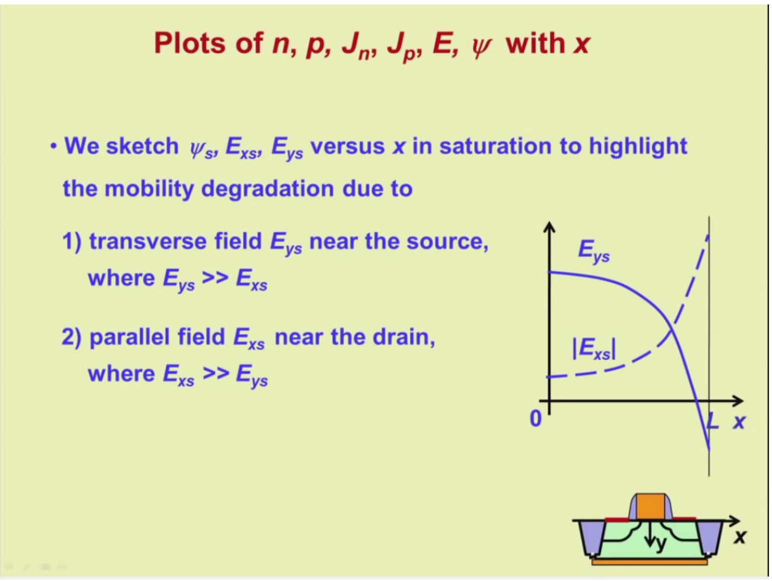

Plots of n, p, J_n, J_p, E, ψ with x

- We sketch ψ_s, E_{xs}, E_{ys} versus x in saturation to highlight the mobility degradation due to

1) transverse field E_{ys} near the source, where $E_{ys} >> E_{xs}$

2) parallel field E_{xs} near the drain, where $E_{xs} >> E_{ys}$

The first point is the mobility degrades due to transverse field Eys near the source where Eys is much greater than Exs. So here you can see near the source Eys is much more than Exs and therefore mobility degradation near the source would be because of Eys that is it is because of the vertical field or the transverse field. On the other hand, the mobility degradation is due to parallel field Exs near the drain.

So when I come near the drain, the Exs is much, much larger than the Eys. So near the drain the mobility degradation would be due to parallel electric field, electric field parallel to the interface okay and that is what causes the velocity saturation effects.

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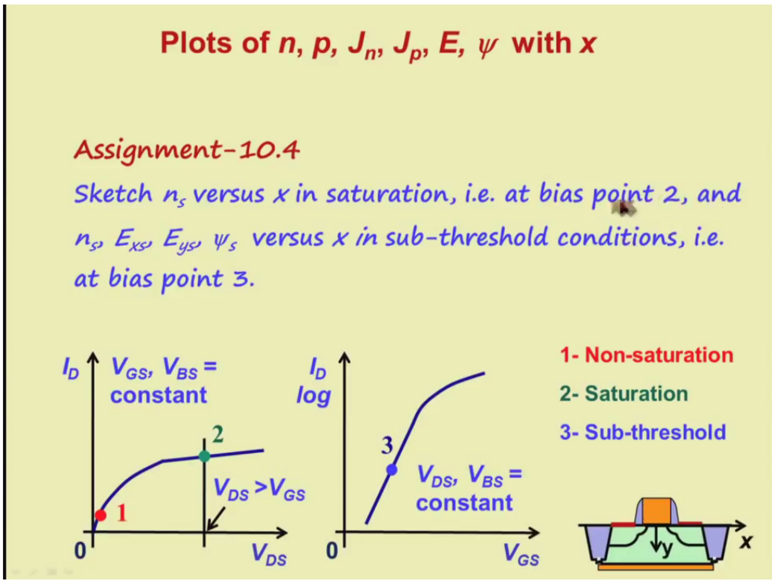

Plots of n, p, J_n, J_p, E, ψ with x

Assignment-10.4

Sketch n_s versus x in saturation, i.e. at bias point 2, and n_s, E_{xs}, E_{ys}, ψ_s versus x in sub-threshold conditions, i.e. at bias point 3.

1- Non-saturation

2- Saturation

3- Sub-threshold

Now here is an assignment for you. Sketch ns versus x in saturation that is at bias point 2, that is this point and ns, Exs, Eys and psi s versus x in subthreshold conditions that is at bias point 3. So at bias point 2 that is in saturation we have sketched Exs, Eys and psi s and therefore you are asked to sketch ns alone whereas for subthreshold conditions you sketch all these quantities.

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Summary of the Lecture

With that we have come to the end of the lecture and so let us make a summary of the important points. Now in this lecture first we sketched the electron current density directed from drain to source in the y direction and showed that this current density is restricted to the inversion layer thickness. In other words, the current in a MOSFET is restricted to the inversion layer thickness. Next, we drew the energy band diagram in y direction near the channel mid-point.

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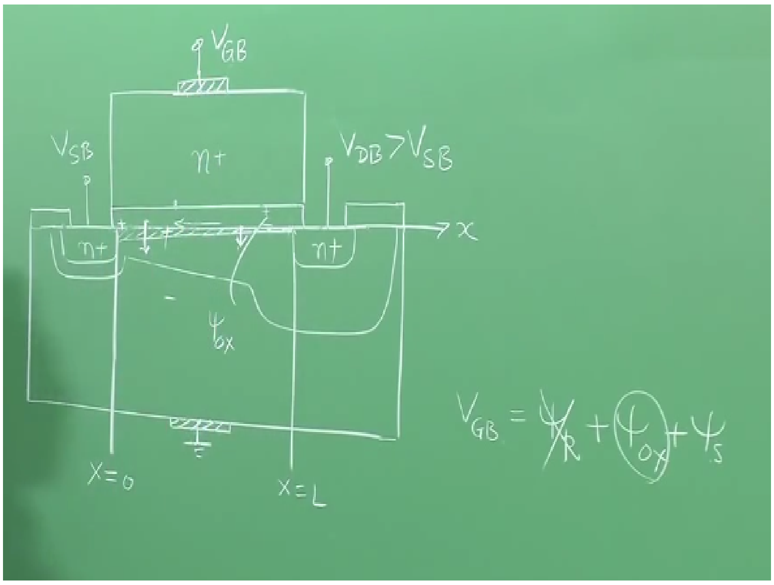

Now while drawing the energy band diagram, we made the important point that the material associated with the electrode connected to the substrate and electrode connected to the gate that has to be taken into account while drawing the energy band diagram in the y direction and therefore whenever you draw energy band diagram in the y direction, you must explicitly show the gate electrode and the substrate electrode.

For simplicity, we assume that the gate electrode had the same material as n+ gate and the substrate electrode was of the same material as the gate electrode and therefor that was also n+. The band diagram was used to highlight the applied gate voltage VGB, the channel voltage V and the potential drops psi p, psi ox and psi s across poly, oxide and the substrate as well as the built-in potential or work function difference phi ms.

Another thing we achieved by drawing the energy band diagram is that from the energy band diagram, we are able to show the variation of all important quantities namely n, p, Jn, Jp, E and psi. Then finally we sketched the potential variation at the interface from source to drain that is psi s and the electric field components directed parallel to the interface at the interface that is Exs and the electric field component directed perpendicular to the interface Ey at the interface.

The variation of these quantities as a function of distance from source to drain. The field components were sketched to highlight the causes of mobility degradation and we remarked that near the source the mobility degradation occurs due to transverse electric field that is electric field from gate to bulk whereas the mobility degradation in the channel near the drain occurs because of the parallel electric field that is electric field along the silicon-silicon dioxide interface. We shall continue this discussion in the next class.