Semiconductor Devices and Circuits
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Lecture – 35
MOSCAP: CV Characteristics – Continued

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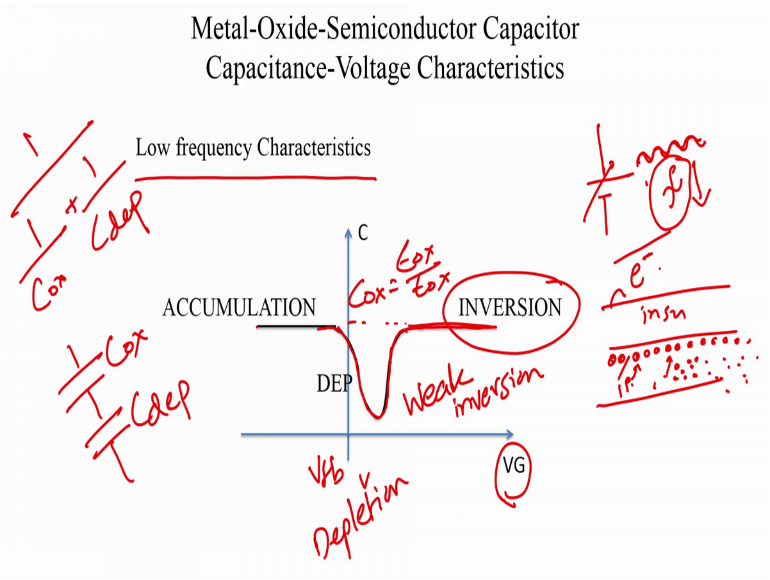

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

Low frequency Characteristics

So now let us divide the capacitance voltage characteristics into 3 parts, and we will just go one by one. So, first is something called the low frequency characteristics; what does this mean? This means that I am sweeping my VG very slowly. So, the DC voltage ok. So, let us say we change the DC voltage and then you do a measurement with an AC signal.

So, that VG is being changed very slowly and the AC signal being used to test the capacitance is also very low. The frequency is low. And what do you mean by it is low? It is low implies that the electrons in inversion we are only interested in version when we talk about the frequency in inversion there is enough time for the electrons to be thermally generated, and for them to appear at the interface in order to respond to the fluctuating AC signal.

So, you have an inversion layer. So, that is your insulator you have. Firstly, formed an inversion layer in inversion and the frequency is low enough that when this charge goes up thermally generated electrons can appear at the interface. So, the electrons are being are appearing and disappearing at a certain rate ok.

At the generation and recombination rates and the generation rate is fast enough for the electrons to respond to this low frequency AC signal. So, that is the low frequency characteristics. And based on our discussion earlier in accumulation mode if you were to plot the capacitance versus voltage the gate voltage and sweep the gate voltage.

So, let us say let us mark our V FB somewhere or easier to just mark VG minus V f b, but nevertheless. So, in accumulation mode you have holes of the interface the capacitance is equal to C ox which is epsilon ox by t ox, but the moment the VG starts going above V FB ok. So, let us say you start going above V FB ok.

The capacitor the MOS capacitance starts entering the depletion mode of operation. So, this is all the depletion mode and in depletion mode the C ox appears in series with the depletion capacitance. And therefore, the capacitance is now lower to capacitors and series the capacitance becomes the effective capacitance becomes this. And it becomes smaller than C ox and you will find that the capacitance voltage curve dips in the depletion mode, but then you will start reaching a point where E i starts going below E f and the electrons start appearing at the interface. So, soon once the electrons start appearing at the interface the electrons also contribute to the response. And you will find that you enter something called as the weak inversion mode ok

So, we have not discussed this mode in full detail, because for that we need to solve poisons equation accurately. So, you can; so you quickly go and get into inversion mode, where you have electrons a lot of electrons in the interface and the capacitance once again becomes C ox, because now the electrons can easily respond to this small low frequency electric AC voltage.

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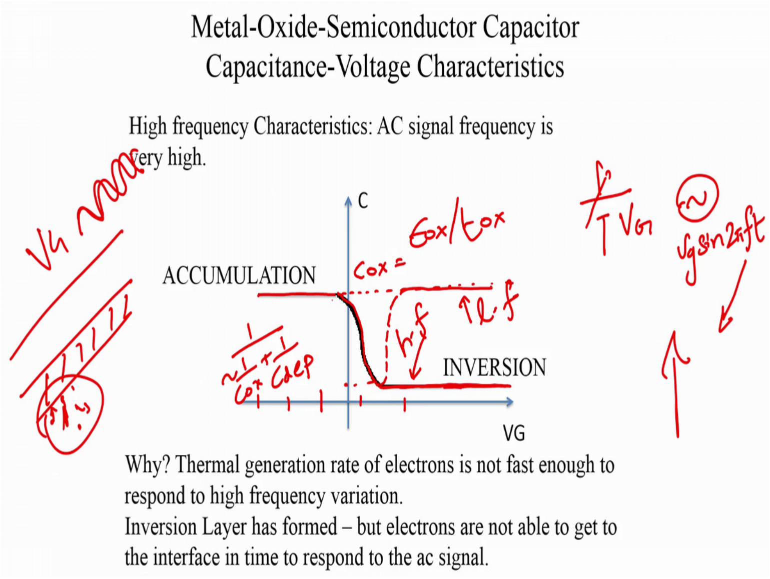

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

High frequency Characteristics: AC signal frequency is very high.

Why? Thermal generation rate of electrons is not fast enough to respond to high frequency variation.
Inversion Layer has formed – but electrons are not able to get to the interface in time to respond to the ac signal.

Now, what about the high frequency characteristics ok. So, what is the experiment we are doing here? So, in this experiment you have 2 things to vary, you have VG and you have your e C signal we can pick your AC signal frequency. The VG is varying very slowly you set this you make a measurement then you set this and you make measurement you give the device enough times. So, the VG is varying very slowly ok.

So, let us say you are manually turning a knob, but this frequency the AC signal frequency has now become very very large, you have ramped up that AC signal frequency it is not low it is become very large and it is become. So, large that it is greater than the generation rate the thermal generation rate of the electrons. So, in this case what happens?

So, when the MOS is in accumulation mode the holes have to respond to this high frequency AC signal. And there are plenty of holes they are abundantly available and there is a band bending which encourages whole step here at the interface and the holes easily respond to this charge. So, the whole pub the accumulation mode capacitance will not change. It will be exactly like your low frequency capacitance curve and that will be your C ox which is epsilon ox by t ox. And then in depletion mode the depletion width starts increasing or decreasing in response to the applied AC field and that too can happen quite quickly it is.

But now when you hit the inversion mode the thermal generation rate of electrons is not fast enough for it to for the electrons to respond in time to the AC signal. So, the inversion layer is present ok. So, it is not that the inversion layer is not present the inversion layer is present because you have made the VG very positive. So, VG is large. So, you are first created the inversion layer no doubt the inversion layer is present.

But now to on top of that V, DC you have an AC signal and for that AC signal the electrons have to either more electrons have to come in or some of the electrons have to go away as. And when the signal goes up and down that is the response we are trying to measure that is the small signal capacitor. And this AC signal frequency is so, large that this response cannot happen this response is not seen the thermal generation rate is too slow to match that AC signal response.

So, although there is an inversion layer this fluctuation and electron charge or the electron concentration does not happen and therefore, the measurement device thinks that the MOS is still in depletion mode operation. You can continue increasing a V G, but it sees no response of the inversion charge no small signal response of the inversion charge. And therefore, the value remains pinned at this value here ok. And that value there is approximately your 1 by 1 plus C ox plus 1 by C depletion.

On the other hand in the low frequency characteristics the electrons thermally generated electrons could respond and we saw that the curve looked like that ok. That was the low frequency characteristics. And this is the high frequency characteristics of the of high frequency C V characteristics of the MOS capacitor

Now, we have one more case.

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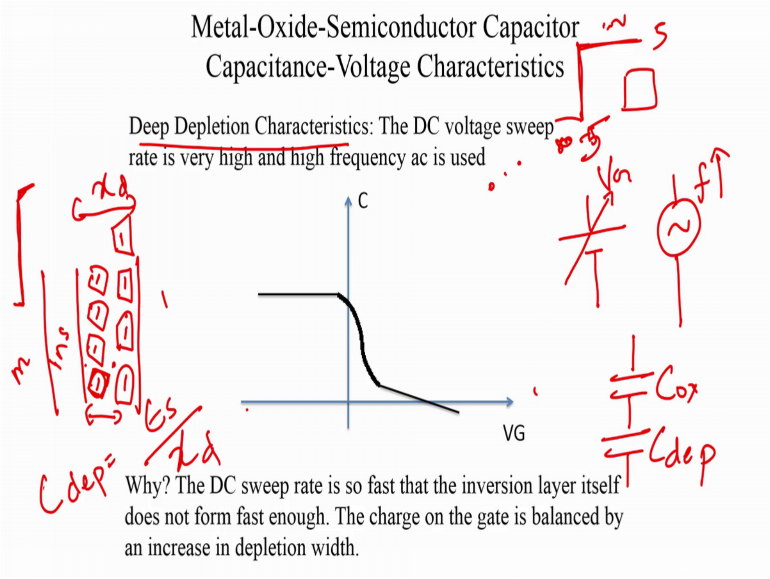

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

Deep Depletion Characteristics: The DC voltage sweep rate is very high and high frequency ac is used

Why? The DC sweep rate is so fast that the inversion layer itself does not form fast enough. The charge on the gate is balanced by an increase in depletion width.

And this case has got to do with the DC voltage and the AC voltage. So, we know not only use a very high frequency AC signal, but the rate at which we are sweeping the DC voltage is also very large ok. So, instead of you turning the knob very slowly imagine the MOS capacitor experiences a rapid pulse, let us say the VG went from 0 to whatever 10 volts and or you know minus 5 to 5 volts within a few picoseconds or a few nanoseconds a very sharp pulse appeared at the gate.

So, the DC voltage itself was very very varied very rapidly and the AC frequency is very large. So, what happens in this case? The holes will respond the depletion charge will also respond, but then since the voltage went up. So, quickly it was too quick for the electrons to even form an inversion layer ok.

So, you have your metal insulator semiconductor interface the DC voltage went up. So, rapidly that the thermally generated electrons are the thermal generation rate is too slow for it to even match the DC response. Therefore, an inversion layer never formed the electrons never got to the interface ok.

So, how is the positive charge on the metal plate compensated? Now it has to be compensated by the depletion charge, because there is no inversion charge anymore. The generation rate is too small. So, you have the depletion width here normally when the DC rate was slow beyond this width the inversion layer would have formed and after that should have been the electrons that were responding to the applied gate voltage.

But now, the electrons have not formed and therefore, the only way the excess charge in the gate is compensated is by increasing the depletion width. So, the depletion width continues to increase like as though it is still in depletion mode. And therefore, the depletion capacitance becomes smaller and smaller, because x d is increasing say the depletion capacitance is what it is epsilon s by x d so that becomes smaller and smaller, because the x d keeps increasing.

And therefore, the series combination of C ox and C depletion also become smaller. And smaller and therefore, the curve looks like this ok. So, it is those drawn in a very non artistic manner it is not really accurate, but it portrays the message. The curve looks like that ok. The capacitance keeps going keeps heading low it does not, it does not flatten because there is no electrons present.

So, to summarize these 3 characteristics: so what is the difference between high frequency and deep depletion?

So, this character is called the deep depletion characteristics ok. I have no I do not know whether I mentioned that and what is the difference between high frequency and deep depletion. In high frequency that DC voltage is varied very slowly, but the AC signal has got a high frequency. In deep depletion not only does the AC signal have high frequency, but the DC voltage is also varied very rapidly ok. So, that is the deep depletion characteristics.

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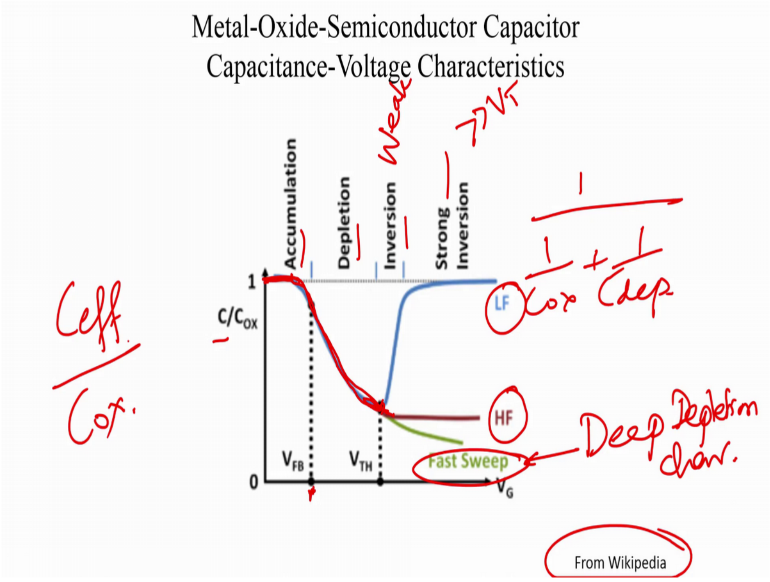

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

From Wikipedia

So to summarize all these 3, I have taken this nice picture from an online source and what we are plotting here is C by the C is the effective capacitance of your MOS capacitor C by C ox. So, first is the low frequency. So, we have the low frequency characteristics the high frequency characteristics and the fast sweep or the deep depletion characteristics.

So, the low frequency characteristics you have the 3 different regions of operation you have the accumulation the depletion the inversion the weak inversion what we have been calling as the weak inversion; and the strong inversion which means, which is well above threshold voltage. We have still not discussed this portion very clearly because we have not solved Poisson's equation accurately.

So, in accumulation mode do you have C effective being equal to C ox or C by C ox is one because it is holes appearing at the interface and then in depletion mode you have the series combination of C ox and C depletion and the capacitance goes down. So, this happens after V is equal to V FB.

Now, once you hit threshold voltage the device approach is strong inversion. And you have electrons at the interface and they can easily respond to the low frequency signal and you have your low frequency characteristics. And then in the case of the high frequency characteristics these 2 regions are the same the accumulation mode and the depletion mode is the same. But the electrons can now no longer respond to the small signal capacitance cannot reflect the response of the electrons to the high frequency AC signal, because the thermal generation rate is too low to match the high frequency signal.

And therefore, the capacitance appears to be flat it appears to be the same as the capacitance at over here which is basically the series combination of your depletion capacitance and oxide capacitance. And finally, we have the deep depletion characteristics where the DC voltage was itself varied very fast and the inversion layer itself did not formed.

And therefore, the only way to compensate for the charge and the gate was by increasing the depletion width and then you have characteristics that reflect the deep depletion behavior of the MOS capacitor. So, this is the qualitative understanding. So, what we are going to do now is very quickly quantify these results.

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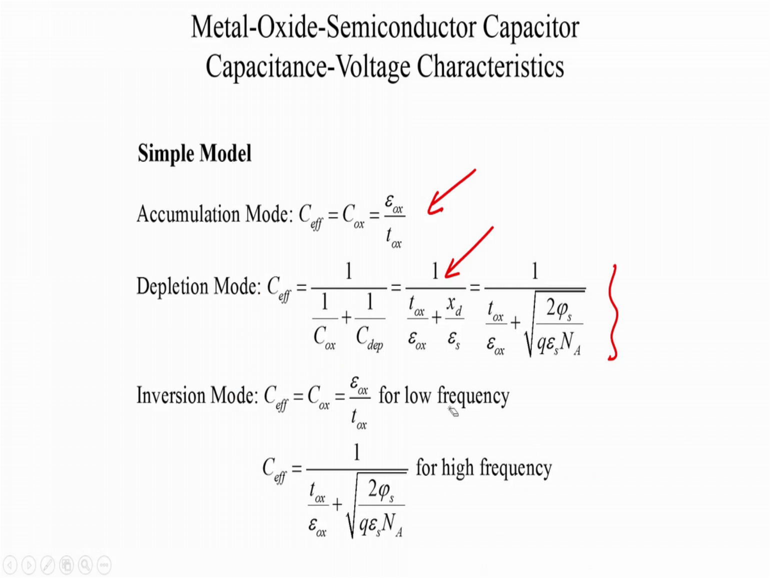

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

Simple Model

Accumulation Mode: $C_{eff} = C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$

Depletion Mode: $C_{eff} = \frac{1}{\frac{1}{C_{ox}} + \frac{1}{C_{dep}}} = \frac{1}{\frac{t_{ox}}{\varepsilon_{ox}} + \frac{x_d}{\varepsilon_s}} = \frac{1}{\frac{t_{ox}}{\varepsilon_{ox}} + \sqrt{\frac{2\varphi_s}{q\varepsilon_s N_A}}}$

Inversion Mode: $C_{eff} = C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$ for low frequency

$C_{eff} = \frac{1}{\frac{t_{ox}}{\varepsilon_{ox}} + \sqrt{\frac{2\varphi_s}{q\varepsilon_s N_A}}}$ for high frequency

So, a very simple model what is the model for accumulation mode the capacitance is simply C ox in depletion mode this is our capacitance it is a series combination of C ox and C depletion. And C depletion is epsilon s by x d and we know what x d is in terms of the surface potential. So, these are, I am not going to go we are not going to spend too much of time in these relations this is. So, that is the depletion mode capacitance.

And for inversion mode you should know whether you are in low frequency or high frequency. And low frequency it is going to be C ox and in high frequency is going to take the same value as the depletion mode capacitance ok. The only thing is you need to be use the same capacitance at different VG values all the VG values.

So, this is a simple model. In order to get a more accurate model you need to solve Poisson's equation more accurately ok.

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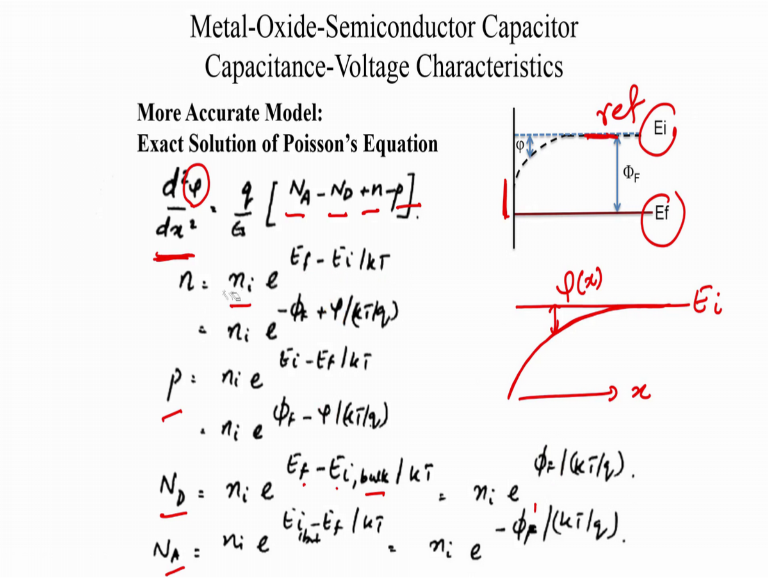

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

More Accurate Model:
Exact Solution of Poisson's Equation

$$\frac{d^2\varphi}{dx^2} = \frac{q}{\epsilon_s}\left[N_A - N_D + n - p\right]$$

$$n = n_i e^{E_f - E_i/kT}$$
$$= n_i e^{-\phi_F + \varphi/(kT/q)}$$
$$p = n_i e^{E_i - E_f/kT}$$
$$= n_i e^{\phi_F - \varphi/(kT/q)}$$
$$N_D = n_i e^{E_f - E_{i,bulk}/kT} = n_i e^{\phi_F/(kT/q)}.$$
$$N_A = n_i e^{E_{i,bulk} - E_f/kT} = n_i e^{-\phi_F/(kT/q)}.$$

So, the very general Poisson’s equation is simply this it is d square psi by d square phi by d x square is q by epsilon into any acceptor ions donor ions, electrons, and holes you cannot get more general than this for a for our case. And the way we are going to define the potential what is this phi.

The way we are going to define the potential is this is E i that is E f and that is the band bending this is the reference potential. And the way we have defined phi is it is this potential ok. So, it is basically phi is a function of x. So, if that is the bulk that is the flat band and during band bending the E i bent this way. So, that becomes phi of x. As x varies your phi varies and what is E f minus E i E f minus E i is an indicator of what n is n is n i times e to the power E f minus E i by k t and E f minus E i can be written in terms of phi.

Similarly, p can be written in terms of phi N D is nothing but E f minus E i in the bulk ok. So, that can be written in terms of phi f and N A can be written in terms of phi f ok. So, you define all these 4 variables N A N D n p and n and p, in terms of phi n phi f ok. So, these things should be quite clear because we have already discussed such a case in the case of metal semiconductor junctions.

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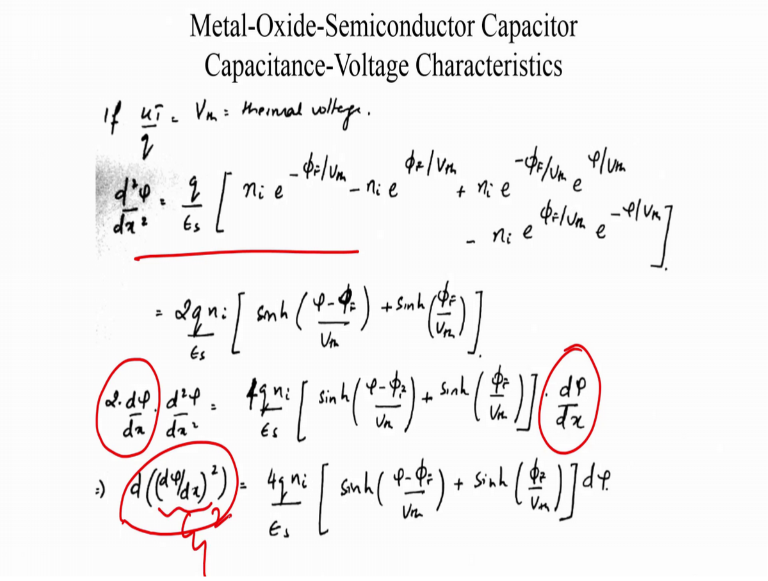

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

If $\frac{kT}{q} = V_{th}$ = thermal voltage.

$$\underline{\frac{d^2\varphi}{dx^2} = \frac{q}{\epsilon_s}\Big[\, n_i e^{-\phi_F/V_{th}}} - n_i e^{\phi_F/V_{th}} + n_i e^{-\phi_F/V_{th}} e^{\varphi/V_{th}} - n_i e^{\phi_F/V_{th}} e^{-\varphi/V_{th}} \Big].$$

$$= \frac{2qn_i}{\epsilon_s}\left[\sinh\left(\frac{\varphi-\phi_F}{V_{th}}\right) + \sinh\left(\frac{\phi_F}{V_{th}}\right)\right].$$

$$\boxed{2.\frac{d\varphi}{dx}}.\frac{d^2\varphi}{dx^2} = \frac{4qn_i}{\epsilon_s}\left[\sinh\left(\frac{\varphi-\phi_F}{V_{th}}\right) + \sinh\left(\frac{\phi_F}{V_{th}}\right)\right].\boxed{\frac{d\varphi}{dx}}$$

$$\Rightarrow \underbrace{\boxed{d\left(\left(d\varphi/dx\right)^2\right)}}_{\mathcal{E}} = \frac{4qn_i}{\epsilon_s}\left[\sinh\left(\frac{\varphi-\phi_F}{V_{th}}\right) + \sinh\left(\frac{\phi_F}{V_{th}}\right)\right]d\varphi$$

And you solve this differential equation ok, and how do you solve this. So, this becomes your differential equation how do you solve this differential equation. You multiply both sides by 2 d phi by d x and the left hand side simply becomes this term here ok.

And what is this there is nothing but the electric field squared. And you solve this differential equation.

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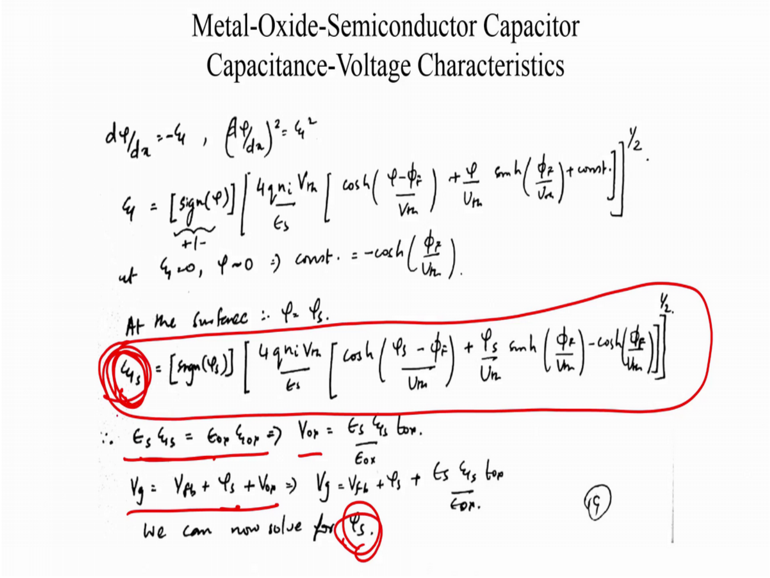

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

$d\varphi/dx = -\mathcal{E}$, $(d\varphi/dx)^2 = \mathcal{E}^2$

$$\mathcal{E} = \underbrace{[\mathrm{sign}(\varphi)]}_{+/-}\left[\frac{4qn_iV_{th}}{\epsilon_s}\left[\cosh\left(\frac{\varphi-\phi_F}{V_{th}}\right) + \frac{\varphi}{V_{th}}\sinh\left(\frac{\phi_F}{V_{th}}\right) + \text{const.}\right]\right]^{1/2}.$$

at $\mathcal{E} \sim 0$, $\varphi \sim 0 \Rightarrow$ const. $= -\cosh\left(\frac{\phi_F}{V_{th}}\right)$.

At the surface $\therefore \varphi = \varphi_s$.

$$\boxed{\mathcal{E}_s = [\mathrm{sign}(\varphi_s)]\left[\frac{4qn_iV_{th}}{\epsilon_s}\left[\cosh\left(\frac{\varphi_s-\phi_F}{V_{th}}\right) + \frac{\varphi_s}{V_{th}}\sinh\left(\frac{\phi_F}{V_{th}}\right) - \cosh\left(\frac{\phi_F}{V_{th}}\right)\right]\right]^{1/2}.}$$

$\therefore$ $\underline{\epsilon_s\mathcal{E}_s = \epsilon_{ox}\mathcal{E}_{ox}} \Rightarrow \underline{V_{ox}} = \frac{\epsilon_s\mathcal{E}_s t_{ox}}{\epsilon_{ox}}$.

$\underline{V_g = V_{fb} + \varphi_s + V_{ox}} \Rightarrow V_g = V_{fb} + \varphi_s + \frac{\epsilon_s\mathcal{E}_s t_{ox}}{\epsilon_{ox}}$.

We can now solve for $\boxed{\varphi_s}$.

You will end up with the electric field you will end up with an expression for the electric field ok. So, I have just written out the solution for your reference this part of it is neither for any test and it, but although it is quite important, because it gives you the exact solution.

So, that is the electric field and in some sense this is the low frequency electric field and why is it a low frequency, because we have assumed electrons are present at the interface. So, this is all this is not the deep depletion case. It is definitely either low frequency or high frequency characteristics, but the electrons are present at the interface the inversion layer is formed ok. And then you use this condition ok. So, this is the electric field at what gate voltage is this electric field present you need to calculate what phi s is and you use these 2 conditions to calculate to solve for phi s.

So, you know phi s and therefore, you know the electric field. So, this is the exact solution to Poisson’s equation.

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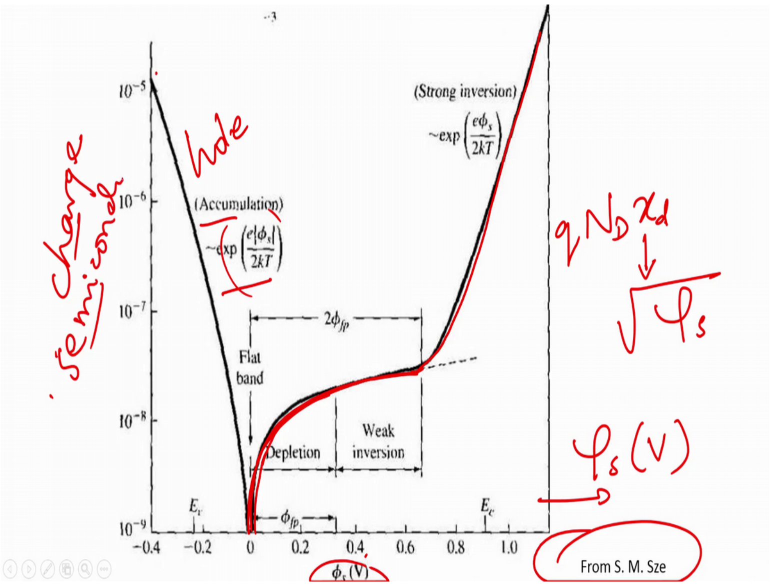

From S. M. Sze

And that solution can also give you a indicator as to what the charge is at the interface, the charge concentration at the interface. So, this plot is borrowed from the textbook of S M sze and what you are seeing here is essentially what happens when you start varying phi s ok. So, do not worry about too many details of this plot, but this probably this label has gone away from your screen. So, this x axis is phi s phi s is being varied ok.

So, initially you are in accumulation mode. And you find that the hole concentration is basically this is the hole concentration. So, you are in accumulation mode and you have holes that are varying as exponential of phi s. And then you enter depletion and your carrier and your charge in the semiconductor is basically the depletion charge and how does the charge vary it is q and q ND into x d and how does x d vary with phi s.

It varies as the square root of phi s and that is what is being reflected in these characteristics here. So, you see a square root of phi s dependence. And then finally, you hit inversion wherein the electrons start appearing at the interface and you have an exponential increase with respect to phi s. So, it is a nice summary of all the charges in the semiconductor I should say semiconductor rather than the interface.

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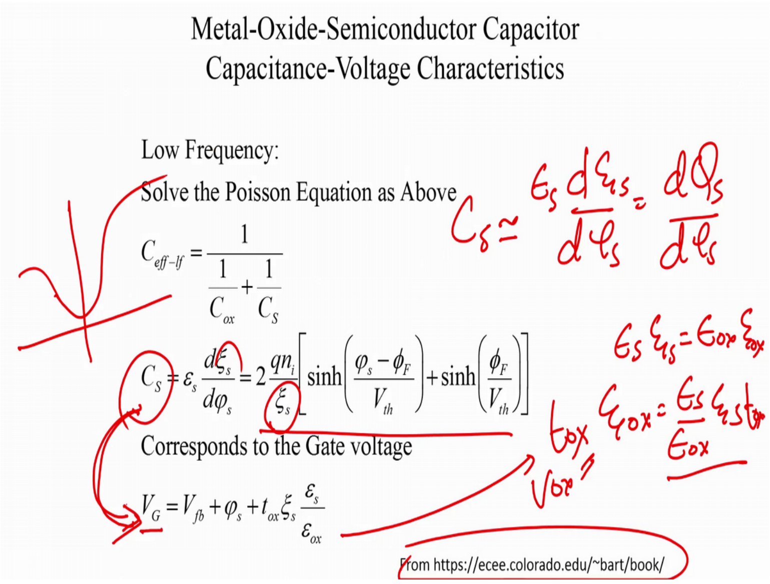

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

Low Frequency:
Solve the Poisson Equation as Above

$$C_{eff-lf} = \frac{1}{\frac{1}{C_{ox}} + \frac{1}{C_S}}$$

$$C_S = \varepsilon_s \frac{d\xi_s}{d\varphi_s} = 2\frac{qn_i}{\xi_s}\left[\sinh\left(\frac{\varphi_s - \phi_F}{V_{th}}\right) + \sinh\left(\frac{\phi_F}{V_{th}}\right)\right]$$

Corresponds to the Gate voltage

$$V_G = V_{fb} + \varphi_s + t_{ox}\xi_s\frac{\varepsilon_s}{\varepsilon_{ox}}$$

From https://ecee.colorado.edu/~bart/book/

$$C_s \simeq \epsilon_s \frac{d\xi_s}{d\varphi_s} = \frac{dQ_s}{d\varphi_s}$$

$$\epsilon_s \xi_s = \epsilon_{ox} \xi_{ox}$$

$$\xi_{ox} = \frac{\epsilon_s}{\epsilon_{ox}} \xi_s t_{ox}$$

t_{ox}

V_{ox}?

So now we can solve for the exact capacitance voltage characteristics ok. So, these equations are borrowed from this source; so what is our low frequency characteristics in depletion? It is 1 by 1 plus C ox plus 1 by C s and not in d depletion. In fact, this is in general case because we will you can solve it for all voltages.

So, in general this is the capacitance and I have replaced C depletion with C s because it is a general expression. So, it is AC semiconductor and what is C s? It is simply the derivative of the displacement to the electric field. So, it is epsilon s electric field by d phi s. That is basically your d Q s by d phi s right. So, that is your C s.

And since you have already solved for the electric field in Poisson's equation, we have solved for the electric field. We take the derivative with respect to phi s ok. And you end up with this expression here it is all again got the electric field term there. So, that is your C s. And this is the value of C s that corresponds to this value of gate voltage.

So, phi s you know at the electric field, and you have this term here and what is this; what is this particular term it is representing your V ox right. It is since your epsilon s in the electric field in the semiconductor is equal to epsilon ox and the electric field in the oxide your epsilon oxide is written as epsilon s by epsilon ox into epsilon s and epsilon ox into t ox is basically your V ox. And therefore, this term represents V ox ok. So, that is V ox.

So, you have VG that corresponds to this. So, this C s this capacitance corresponds to this VG. So, using different values of phi s you can plot your C V characteristics in a very accurate manner, you end up with the low frequency characteristics.

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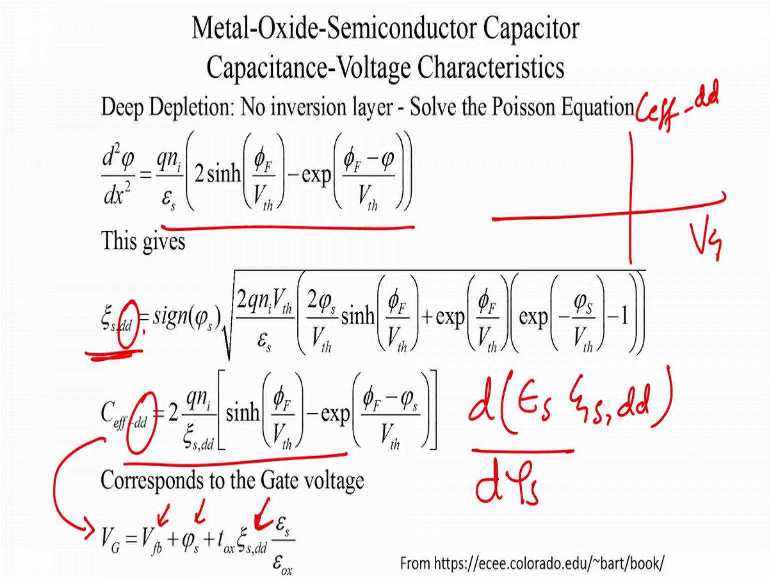

Metal-Oxide-Semiconductor Capacitor

Capacitance-Voltage Characteristics

Deep Depletion: No inversion layer - Solve the Poisson Equation

C_{eff}-dd

$$\frac{d^2\varphi}{dx^2}=\frac{qn_i}{\varepsilon_s}\left(2\sinh\left(\frac{\phi_F}{V_{th}}\right)-\exp\left(\frac{\phi_F-\varphi}{V_{th}}\right)\right)$$

This gives

V_g

$$\xi_{s,dd}=sign(\varphi_s)\sqrt{\frac{2qn_iV_{th}}{\varepsilon_s}\left(\frac{2\varphi_s}{V_{th}}\sinh\left(\frac{\phi_F}{V_{th}}\right)+\exp\left(\frac{\phi_F}{V_{th}}\right)\left(\exp\left(-\frac{\varphi_S}{V_{th}}\right)-1\right)\right)}$$

$$C_{eff,dd}=2\frac{qn_i}{\xi_{s,dd}}\left[\sinh\left(\frac{\phi_F}{V_{th}}\right)-\exp\left(\frac{\phi_F-\varphi_s}{V_{th}}\right)\right]$$

$$\frac{d(\epsilon_s\xi_{s,dd})}{d\varphi_s}$$

Corresponds to the Gate voltage

$$V_G=V_{fb}+\varphi_s+t_{ox}\xi_{s,dd}\frac{\varepsilon_s}{\varepsilon_{ox}}$$

From https://ecee.colorado.edu/~bart/book/

For high frequency characteristics what you do before, we go to high frequency for deep depletion what do we do. For deep depletion this Poisson equation is not correct because in deep depletion there is no formation of an inversion layer.

So, we solve a different Poisson equation. For deep depletion we solved this Poisson equation which does not take into account the inversion layer and this will give you a different electric field. So, that is the electric field I put a subscript of deep depletion there. And that in turn will give you a different capacitance value. It is once again the deep depletion capacitance is epsilon s electric field deep depletion d of this by d phi s. So, that is the capacitance.

So, that will give you a different capacitance, but this capacitance corresponds to this particular voltage. It is V FB phi s t ox into the electric field you use here is the deep depletion electric field. So, that is the difference ok. And if you plot this C, C effective deep depletion versus VG you will get the deep depletion characteristics of your capacitance voltage characteristics.

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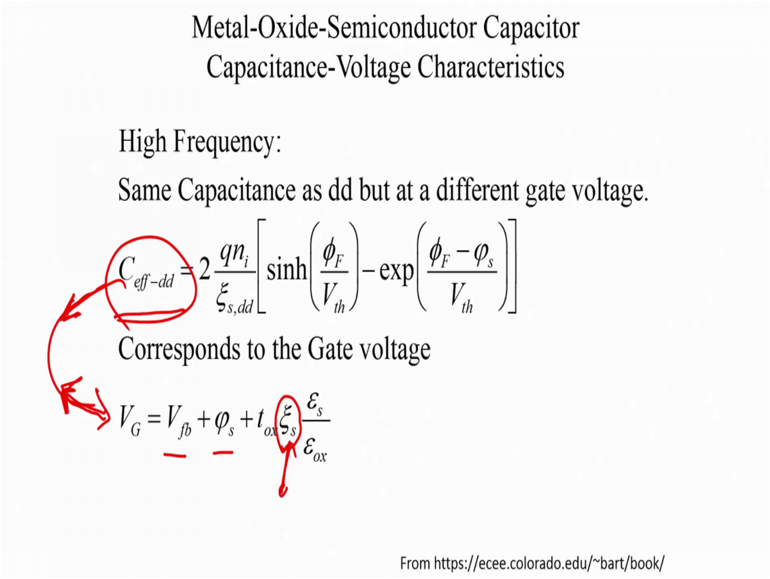

Metal-Oxide-Semiconductor Capacitor
Capacitance-Voltage Characteristics

High Frequency:
Same Capacitance as dd but at a different gate voltage.

$$C_{eff-dd} = 2\frac{qn_i}{\xi_{s,dd}}\left[\sinh\left(\frac{\phi_F}{V_{th}}\right) - \exp\left(\frac{\phi_F-\varphi_s}{V_{th}}\right)\right]$$

Corresponds to the Gate voltage

$$V_G = V_{fb} + \varphi_s + t_{ox}\xi_s\frac{\varepsilon_s}{\varepsilon_{ox}}$$

From https://ecee.colorado.edu/~bart/book/

And how do we get high frequency for high frequency what you do is you use the same capacitance as the deep depletion ok. Because it tells you that the electrons are not present in the AC response, but for the DC part, because the DC is still varying very slowly you make this electric capacitance correspond to a different gate voltage, and what is the gate voltage you make it correspond to the low frequency gate voltage which is V FB plus phi s plus you are using the low frequency electric field ok. So, I hope that is clear.

So, just to summarize, for this is for low frequency you have C s corresponding to this gate voltage where this is the low frequency electric field obtained from this Poisson equation. For deep depletion we solve a new Poisson equation which is permits the inversion layer. And you find the new electric field you find a new capacitance and that capacitance corresponds to this gate voltage which uses the deep depletion electric fields not the low frequency electric field.

So, both the capacitance and the electric field correspond to deep depletion, but for high frequency you use the deep depletion capacitance, but you use the make it correspond to the low frequency gate voltage, which is obtained from the first Poisson equation. The one we solved here. So of course, these are details that are not a part of your course, but nevertheless I felt it is important to mention ok.

With this we come to a conclusion we conclude our MOS capacitors ok. We have looked at the structure of the MOS capacitor the operation. We defined terms like the gate voltage the flat band voltage the threshold voltage. You know what is accumulation mode depletion mode and inversion mode. You know how the capacitance voltage characteristic of the MOS capacitor varies in low frequency high frequency and in deep depletion region. You know simple model as well as the detailed model for the capacitance voltage characteristics ok.

So with that, we conclude the MOS capacitor discussions on the MOS capacitor.