**Semiconductor Device Modeling**
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**Lecture – 21**
**Characteristic Times and Lengths**

Today, we start a new module on characteristic times and lengths.

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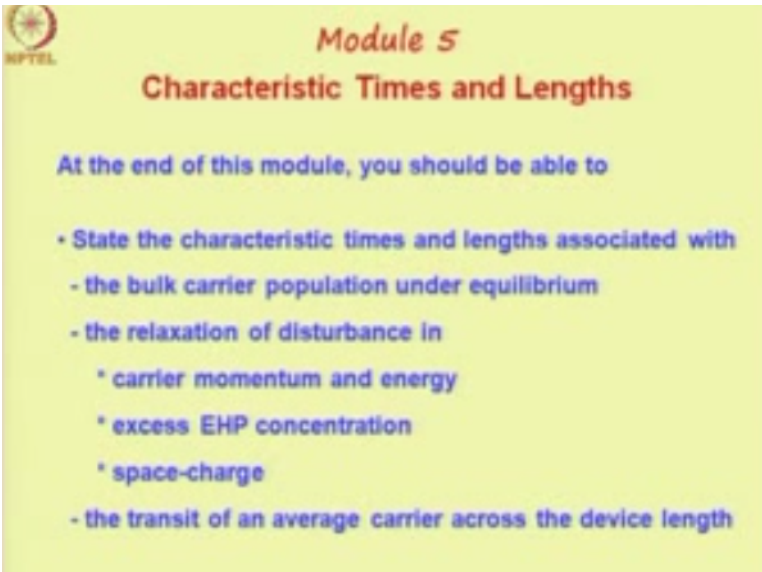


At the end of this module, you should be able to state the characteristic times and lengths associated with the following. The bulk carrier population under equilibrium. The bulk carrier population under equilibrium, the relaxation of disturbance in the following. First, the carrier momentum and energy, then the excess electron hole pair concentration and 3 the space charge. Then you should be able to state the characteristic time associated with the transit of an average carrier across the device length.

You should be able to state the conditions including those at the boundary and defining differential equation associated with each characteristic length and time. You should be able to state the order of magnitude of and factor governing the characteristic times and lengths. You should be able to state how the characteristic times and lengths are useful in qualitative description of device phenomena, simulation characterization of devices and validation of approximations.

You should be able to derive the defining equations associated with the various characteristic times and lengths.

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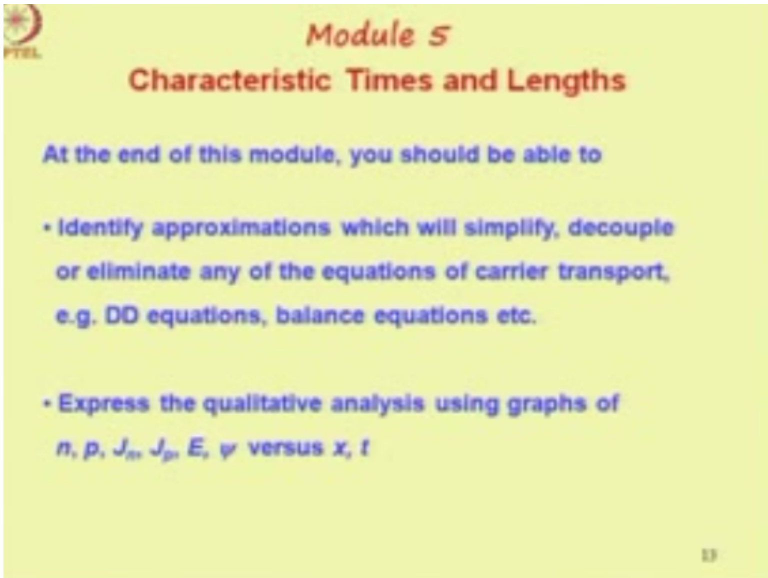


You should be able to identify approximation which will simplify decouple or eliminate any of the equations of carrier transport, such as drift diffusion equations, balance equations etc. and finally you should be able to express the qualitative analysis using graphs of electron concentration, hole concentration, electron current density, hole current density, electric field and potential versus distance and time.

Now we shell be using the 1-dimensional analysis therefore only x coordinate is indicated here for the distance. Now to began with let us see what is the motivation for the discussion of characteristic lengths and times. Now suppose someone asked you the size of this class room, you would probably tell the area in terms of square feet or square metres. You would not use a metric such as square centimeters.

Suppose someone ask you the distance between this class room and the market palace. You would say that the distance would be in order of say kilometers. On the other hand, if you are taking about the distance between various parts of galaxies. You can even use a metric such, as millions of kilometers, right. Now similarly about time, the duration of a lecture it is in minutes. The duration of end semester examination, you would answer the equations in terms of hours.

Duration of a semester it would be in weeks and so on. So, in other words you use different metrics of distance and time to describe different situations. So, your mind automatically changes the metric something like changing a gear when you accelerate a vehicle. Now similarly in the context of modeling of semiconductor devices, the characteristic lengths and times are very, very important. They give you an idea of what kind of approximations are possible in a given situation.

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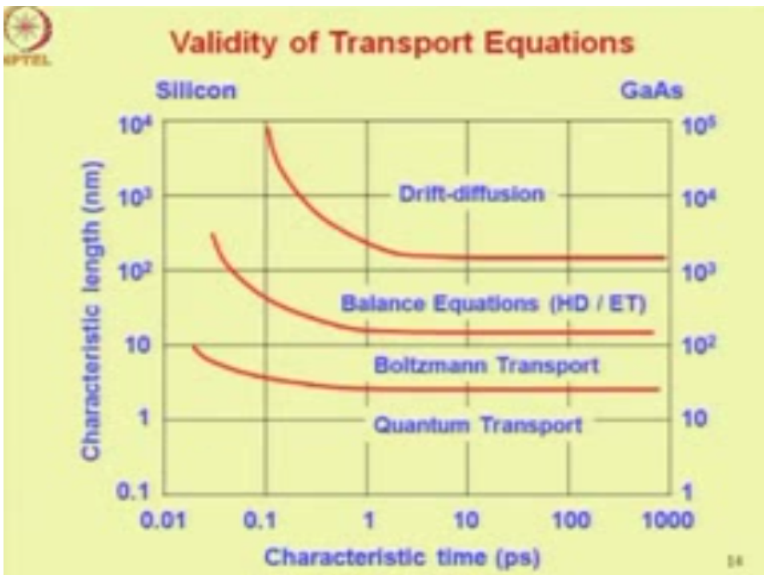


For example, look at this slide which was presented in the discussion of transport equation. So, the limitation of various transport models are indicated here and the red curves indicate the boundaries within which each of this method is valid or used. Now if you want to understand how these boundaries are arrived at, then discussion of characteristic length and time is very important.

So you can see that in this graph actually the Y-axis is characteristic length and X-axis is characteristic time. So, towards end of this module, we will try to understand this graphs, which talks about validity range of various modules in terms of the various characteristics length and time that we shell discuss in the module.

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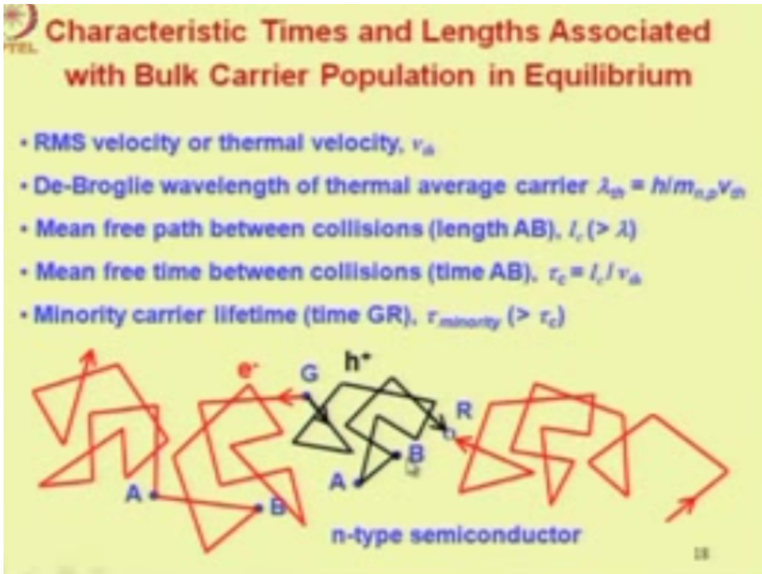


First let us look at characteristics time and length associated with bulk carrier population in equilibrium. The picture in equilibrium is sketched here. So, this an approximate picture where the scattering event is assumed to be instantaneous and localized. So, it is in terms of this picture that we shell define the various characteristic lengths and times. So, to began with, let us talk about the root means square or thermal velocity V thermal.

So, this is nothing to but average speed of the electron at any temperature. So, we have already discussed how this average is arrived at, so it is arrived at by squaring the speeds of each of the electrons then taking the mean and then taking the root. The De-Broglie wavelength of thermal average carrier. Now, an average carrier which has this velocity has a momentum given by effective mass multiplied by thermal velocity and therefore you can associate De-Broglie wavelength with this momentum given by this formula, lambda thermal, given by H/momentum.

As we will see this De-Broglie wavelength will enable us to decide weather the particular approximation of the electron or hole is valid in a situation or not. The mean free path between collisions is the average length AB, so, between 2 scattering events, so this length. On the other hand, the mean free time between collisions is the time required for the electron to traverse that average mean free path AB and this is given by tau c = the mean free path mean free length divided by the thermal speed.

The minority carrier lifetime that will time between generation and recombination. So, look at the event shown here, this point here shows electron hole pair generation. Electron is moving to the left and the hole is moving down. It undergoes various catering mechanisms and then finally it finds an electron to recombine with, so this is a recombination. For the time between this G and R is the lifetime. Since holes are minority carriers in n-type semiconductor.

This is minority carrier lifetime. Now evidentially this time will be more then the mean free time between the collisions because the carrier is encountering several collisions, several scattering events before it recombines after it is generated. Now similarly, there is also a majority carrier lifetime, however we normally do not discuss the majority carrier lifetime very much because in device phenomena it is a minority carrier lifetime that plays a role.

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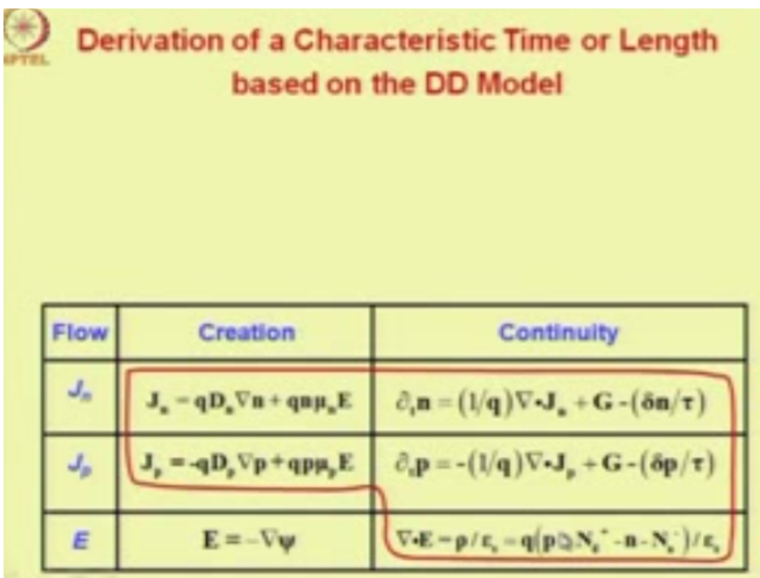


Let us make some comments about derivation of characteristics time or length based on the drift diffusion model. We will have to follow a few guidelines, some steps to do these derivations. So, this is our drift diffusion model. 5 of this equation have been grouped together. Now, this is because these 5 equations are all coupled to each other. You can see this very easily for example this Jn appears in the equation for continuity here of electrons.

And similarly Jp appears in the continuity equations for holes. The electron and hole concentration appear in the equation for Jn as well as in the Gauss' law and in the continuity equations. You can see the carrier concentrate appears here, so this is how one can see that the 5 equations here are coupled. This equation E = –grad psi stands out of this group because after you have solved for the electron concentrations hole concentration, the electron and the hole current densities and the electric field.

One can easily use this equation to get the potential drop. So, therefore in device analysis one uses these 5 equations and one works with these 5 equations and only after working with these 5 equations if necessary one use this equation. Now you would recall that we had said earlier that the 6 drift diffusion equations can be reduced to 3 equations, 3 coupled of equations in electron concentration, hole concentration and potential.

Now, this form in which you have 3 coupled equations is suitable for numerical simulation of devices. However, each of these equations in this 3 coupled equations is fairly lengthy. It contains many terms, you can see that very easily you would have done the assignment because when you take a derivation of Jn actually you have you to differentiate each of this terms with respect to X and further the diffusion coefficient and mobility will have to be assume to be constant.

Otherwise each of the terms here will have to differentiated according to the product rule and you will get many terms in the equations. So this foam of equation, in the 3 coupled equations form, this is suitable for numerical simulation but not for analysis. For analytical approach, one uses the equations separately. So it is easier to use each of these 6 equation separately and analysis.

So, 6 simple equations are more suitable for analysis than 3 complicated equations. 3 complicated equations, however, are suitable for numerical simulation because there the computer can easily solve any complicated equation it is more important to reduce the number of coupled equations in computer simulation.

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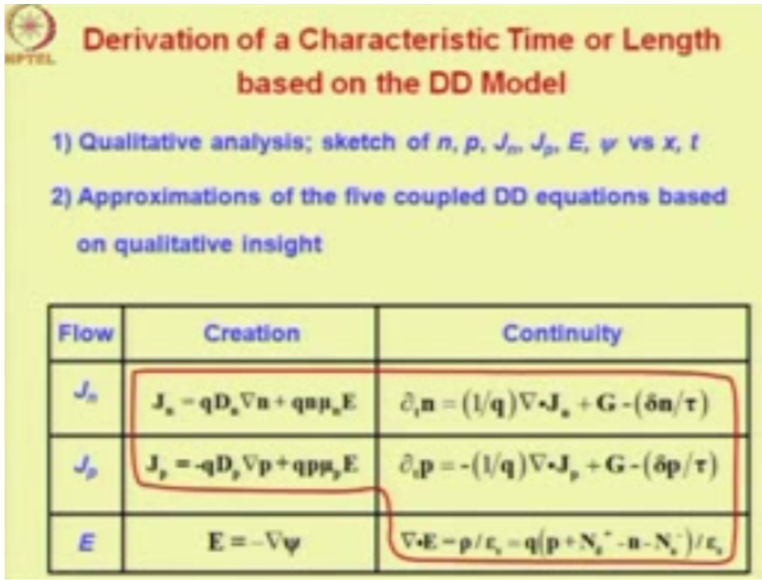


So the first step of derivation using this drift diffusion model would be a qualitative analysis and this will be reflected in the sketch of the electron concentration, hole concentration, electron current density, hole current density, electric field, potential versus X and T.

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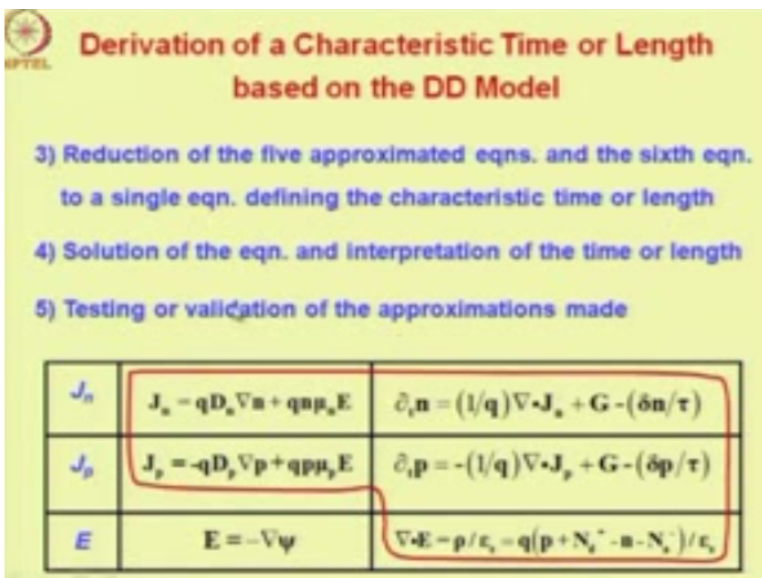


The next step would be approximations of the 5 coupled drift diffusion equations based on qualitative insight. So, the 5 equation are those within this boundary. The third step is reduction of the 5 approximated equations and the 6th equation to a single equation defining the characteristic time or length. So, the 6th equation is this equation here. The 4th step is solution of the equation and interpretation of the time or length.

And finally the fifth step is testing or validation of the approximation made. We shall we using these 5 steps to derive the characteristics time and length base on the drift diffusion model.

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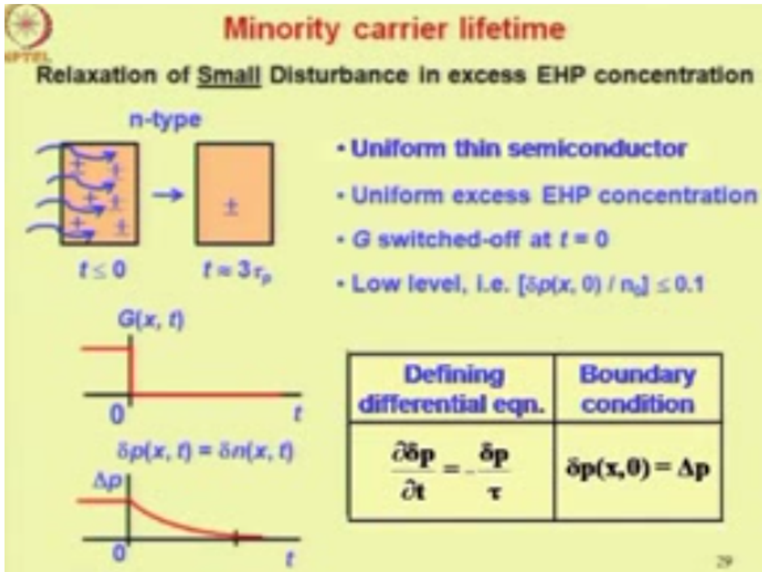


Let us take the first characteristic time that is the minority carrier lifetime. This time is related to relaxation of small disturbance in excess electron hole pair concentration. Let us consider a physical situation, suppose you have a semiconductor sample that is thin enough so that you are able to generate electron hole pairs, excess electron hole pairs uniformly throughout the device volume.

Let us say this is the situation for t <= 0. So you have created access electron hole pairs within a device volume and a t=0 you are switching of the source that is the life witch is creating electric hole pairs, then what is going to happen. So you will find that progressively electron and holes will recombine and the semiconductor will return to equilibrium. Now what is the time that it will take to do so.

So we shell show that this time assuming n type semiconductor, the time to return the equilibrium would be about 3 times the lifetime of holes or minority carrier lifetime. Thus, if you want to describe this relaxation of access carriers to equilibrium, then the characteristic time would be the minority carrier lifetime. Let us derive this characteristic time. Now first we should put down the condition of the situation.

So first you have uniform semiconductor then the excess electron hole pair concentration is uniform throughout the device value at all instance of time. The generation rate the excess generation rate G is switched off at t = 0 and finally we assume that the injection level is low. That is excess minority carrier concentration is less than 1/10th of the equilibrium majority carrier concentration.

Now excess minority carrier concentration would also be the same as excess majority carrier concentration in this case. So we can say the low level means the excess carrier concentration is less then 1/10th of the equilibrium majority carrier concentration. Now, this is the statement of small disturbance. So what do we mean by saying the disturbance is small, so this is the condition, So under this condition only the characteristic time that we derive will be valid.

Now, let us convert our preliminary understanding into graphs. So here the G is switched off, so this is what is the graph of generation rate as a function of X and T. So the generation rate is uniform throughout the volume that is our assumption and it is switched off t equal 0, the generation rate abruptly falls to 0. It really does not matter how the generation rate was varying for t les than 0, right, all that it matters to us is that this generation rate was switched off at t equal 0.

And therefore there was some excess carrier concentration and that excess carrier concentration is returning into equilibrium. So here we have plotted the excess hole concentration which is the same as excess electron concentration in this case. So the initial value of the excess hole concentration is denoted as capital delta into P where as the lower case delta is used for time varying excess carrier concentration.

Now we shell show that the defining differential equation would turn out to be a simple differential equation of this sort. So dou/dou t of delta p = minus of delta p/tau. Now we are talking in terms of minority carriers here, we can always write a similar equation for majority carriers by replacing delta p/delta n because here delta p = delta n. The boundary conditions to solve this defining deferential equation would be the excess carrier concentration at any X or t = 0 is delta P.

So for any X it is the same because the conditions are uniform.

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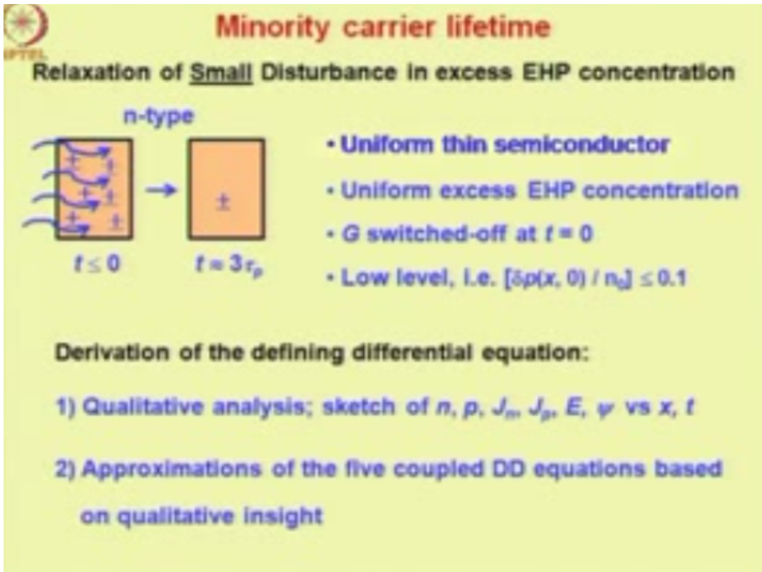


Now let us derive the defining deferential equation. So, the first step is qualitative sketch of these quantities n, p, jn ,jp, e ,and psi versus x and t.

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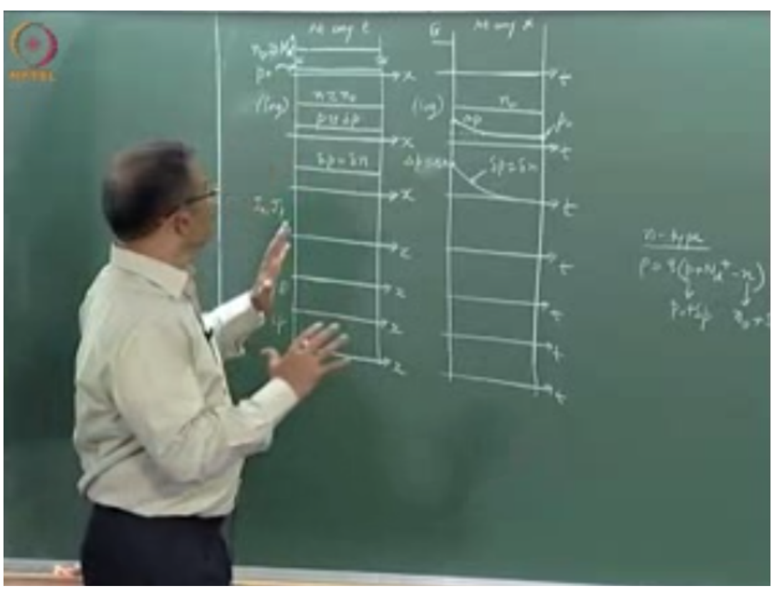

So, let us say here we are plotting as a function of x. So, this would be at any t, at any incident of time and will also plot as a function of time for any x, now first condition was semiconductor is uniform this means for example that the doping level is the same throughout the device volume. So this is shown here, so I can say n0 is Nd+ approximately because we can neglect the contribution of minority carriers here.

So equilibrium majority carrier concentration it is uniform. Now equilibrium hole concentration also would be uniform. So one can sketch that also. Now, if I want to show both equilibrium, majority and minority carrier concentration then I have you use a log scale. If, I use the linear scale then I should show a brake. So, this could be p0. Now another condition that is given to us is that the generation rate is suddenly switched off.

So this is the picture for g as a function of time. Now let us proceed further what happens to the electron concentration and hole concentration. So, since condition are uniform, the electron concentration is something like this and the hole concentration is also uniform. So, here let us use a log scale to show the both electron and hole concentrations. Now on a log scale because the injection level is low, I can say the n is approximately = n0.

So this line would be the same as the equilibrium condition line, on the other hand, p however will be greatly disturbed as compare to the equilibrium picture. So, in fact the p here would be approximately appears to delta p because the delta p would be much more then p0. So this is a log scale. Supposing, I sketch the excess carrier concentration as a function of x. That would be also be uniform throughout.

I can show this on linear scale and everywhere the excess hole concentration would be equal to excess electron concentration because condition are uniform. If you do this as a function of time, then the picture would be like this. The electron concentration would appear not to be changing on a log scale because injection level is low. So the majority carrier concentration would be shown just the same approximately.

The minority carrier concentration however will change from delta p to the equilibrium value. So, this is delta p and this is p0. This is on a log scale. If I sketch the excess carrier concentration that I can do in a linear scale so that is in fact shown by this difference here. The excess electron concentration is also the same however since it is a log scale, the majority carrier concentration does not appear to be disturbed very much that is why this look like almost constant line.

We now plot for liner scale, so it would look something like this. So this is delta p and it will be = delta n. That is this point and this is. Next, we need to sketch jn and jp. So, like we are sketching n and p on the same graph, delta p and delta n on the same graph, w should try to sketch jn and jp on the same graph. So, now what would jn and jp depends on? If the carrier concentration are uniform throughout the volume you know that there is no diffusion current but jn and jp current contain drift current also.

Now how do you know whether there is drift current or not, you need to know whether there is an electric field. So as of now unless we know the electric field, we cannot plot jn and jp. So let us leave this for the present move to the electric field. Now how do you plot the electric field, the electric field can be plotted.

If you know the space charge and boundary conditions of the electric field. So what is the space charge. So, if I first try to sketch the space charge that can be done based on information about electrons and holes. So the space charge is q times p+nd+ -n for an type of semiconductor that is what, we are assuming. Now since delta p = delta n, therefore delta p will cancel delta n when I put here in this expression.

So, if I put p as p0+delta p and this n as n0+delta n, we know that p0+nd + -n0 is 0 because the semiconductor and equilibrium is space charge neutral and since delta p = delta n therefore even under non equilibrium conditions the space charge is 0. So, here, it is just a 0 line for the space charge. Now, the space charge is not there, you know the electric field should be constant by the Gauss's law.

But there is no electric field either at the left end or the right end. There are no surface charges nor have you applied an electric field, therefore the electric field is 0. So, since electric field is 0 you know that electrons and hole current are also 0. So, here all these lines will be just the X-axis. Psi, since there is no electric field, the potential is not changing, we can assume the potential to be 0 everywhere.

Now one can similarly plot this as a function of time it is a trivial exercise because all these are 0, so the corresponding graphs here would all be the 0 lines. So, now this is our qualitative analysis. We have understood what is happening to each of the quantities of the drift diffusion model namely the electron concentration, the hole concentration, the electron current density, hole current density, electric field and potential.

Now, we are not yet used the equations as such qualitatively reasoning, we have got this information. Now this background is very, very important to actually solve the equation. So, one should not rush into solving the equations, one must first do this exercise for every problem that you encounter and we shell we doing this for every device that we analyze, every situations that we analyze.

So, our next step would be approximation of the 5 coupled dif defision equations based on qualitative insight.

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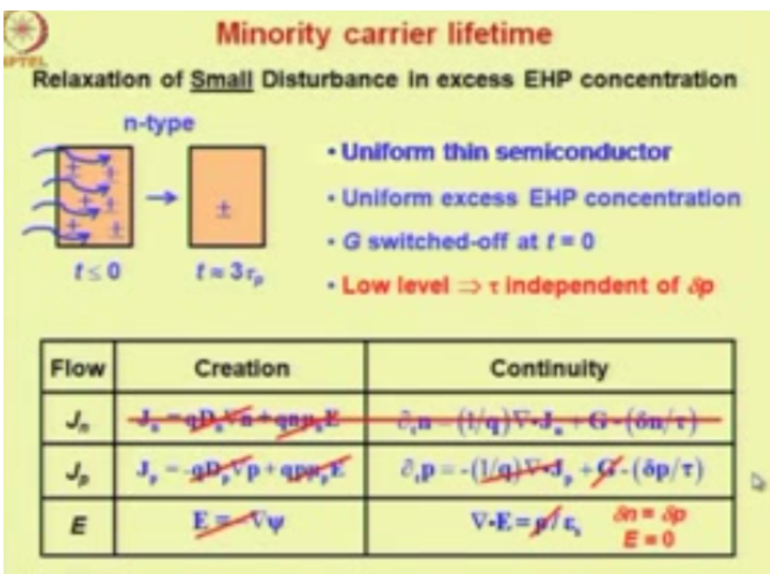


Now these are the 5 equations which are circled here under this, within this red curve. So, we bother about the approximations for these because these are coupled, we really have to decouple them, or simplfy them or eliminate some of them. Now, since the semiconductor is uniform and access carrier concentration also is uniform, space charge is zero. So, the space charge goes out of the picture Delta n = delta p.

This charge nutrality condition is a very, very useful condition as we shall see the great achivement, the great result that you get out of the charge nutrality condition is thatyou need to solve only one of the 2 equations, 2 pair of the equations. So, you need to solve the current density and the continuity equation for electron or for hole, this pair for holes. So, 2 equations are goinf out of the picture.

Now in this case we have removed the equations for the majority carrier. As we wil see often it wil turn out to be easier to solve the equations for minority carriers. So, if you have a choice of either solving the pair of equations for electrons, the current dencity continuity pair for electrons or for holes then you decide the type of the semi conductor and based on the type of semi conductor choose the pair for minority carriers.

This point will become clearer as we proceed further and consider other characteristic time such as for example the diffusion thing. Let us see what other approximations are allowed because of the charge nutrality condition. Since exccess electrons and holes are equal in concentration, the diffusion currents drop out. Since row is zero, we have shown that electric field is zero and therefore the drift terms dropout.

Since the hole current itself is zero, the divergence term of the continuite equation of interest drops out. Now, we are switched off the G okay and therefore for t greater than 0, this term does not enter into the picture. Now we have cancelled, removed this E = -grad psi because actually there is no electric field so we do not need this. This not really a consequence of the switching off of G, it is a consequence of the E becoming zero.

Now finally low level conditions. So, what implication does this have? So, it is because of low level conditions that the time constant tau entering in this term here is independent of the excess carrier concentration. So, you would recall from the discussion in the previous module about the life time that under low level conditions independent of the mechanism of recombinations whether it is Shockley-Read-Hall or thermal recombination or auger recombination or the radiative recombination.

Under low level conditions, the life time is constant, independent of excess carrier concentration. If the time constant is dependent on excess carrier concentration, then the differential equation would become a little bit more complex.

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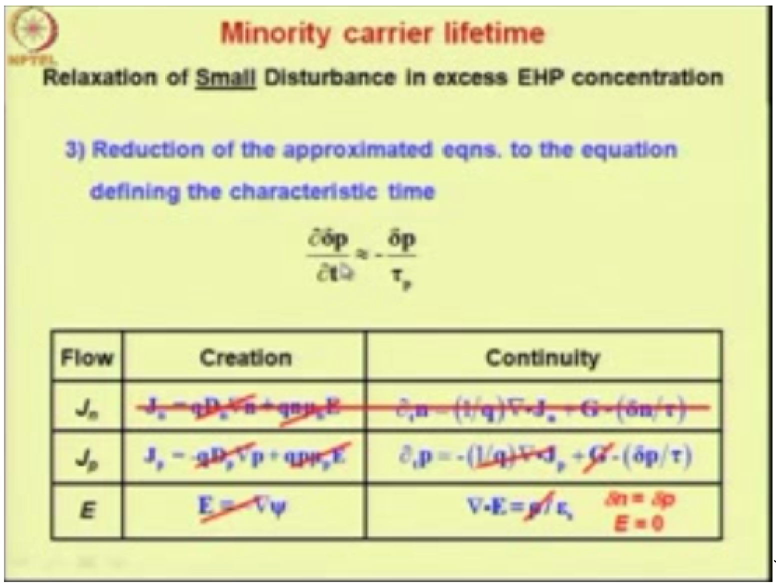

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The third step is reduction of the approximated equations to the equation defining the charectristic time. Now this is straight forward because all that you need to do is just pickup this continuity equation for holes. So, dou p/dou t = – delta/tau, so that is the equation. Now, here on the left hand side you have dou delta p/dou t instead of dou p/dou t. Because p = delta p+p0. And we know that dou/dou t of p0 is 0.

So therefore, dou/dou t of p is dou/dou t of delta p.

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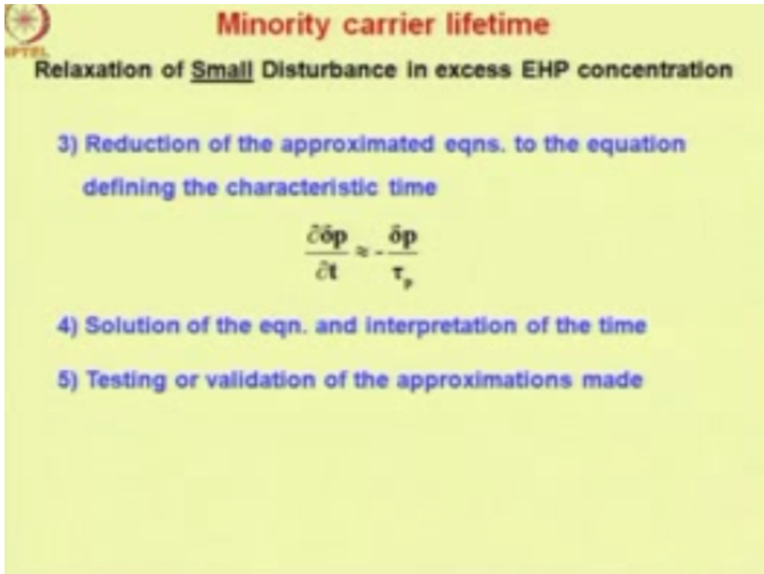


Next step is solition of the euation and the inerpretation of the times and finally fifth step is testing or validation of the approximation made. Now validation is not much not an isue for our situaton because whatever simplifications we have done are a cinsiquence of the conditions assumed for the situation. So, we have really not made any approximations that are likely to be incorrect or anything like that.

So, we straigtht away go the solution of the equation and the interpretation of the time.

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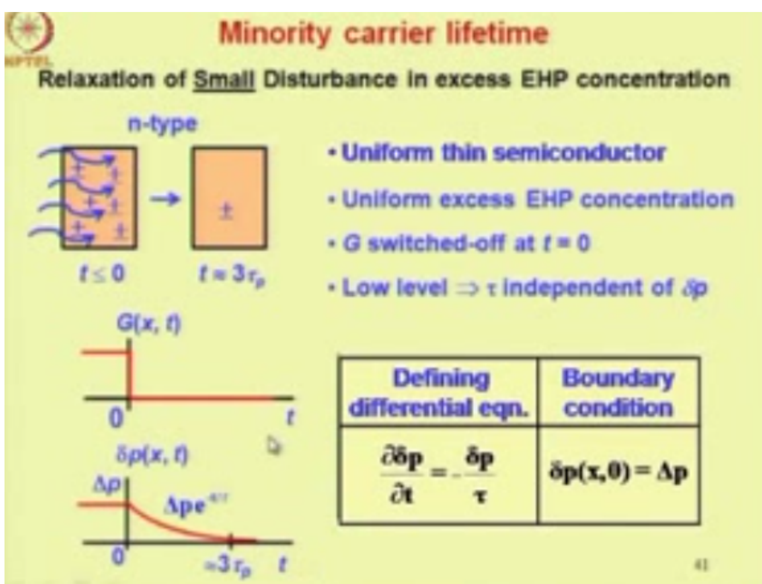

The solition of this equation is an exponential that is shown here and the carrier concentration decay is exponentially from the initial value to the equilibrium value. Now from the properties of the exponential, you know that the exponential can be assume to be almost died out, if the duration is 3 times the time constant that entered into the exponential. So this time constant tau is life time of holes tau p.

So, here the value would be less than 5% of the value here if you use the factor 3. Now that is the reason for using the factor 3, so, whenever you find that the disturbance has reduced to < 5% of it is initial value then you say the disturbence has almost died out.

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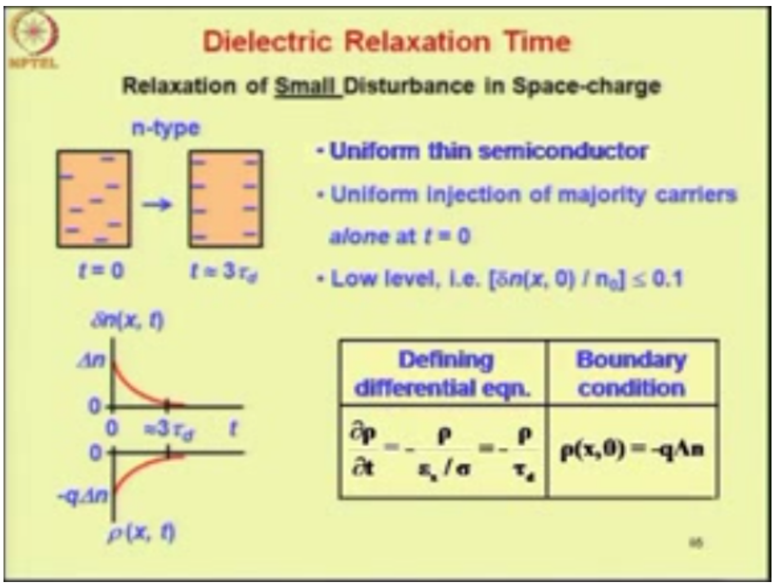


Now let us do a similar thing for another time constant that is the dielectric relaxation time. The dielectric relaxation time is assciated with relaxation of small disturbance in space charge. First letter is described the situation. So you have n type semi conductor in which you are injecting only one polarity of carriers, let us say we are injecting majority carriers. So we shall consider the injection of majority carrriers and minority carriers separate right.

First, let us discuss the case in which we inject majority carriers. We will also assume that the majority carriers that are injected are uniformed throuthout the volume. So in this case for n type semi conductor you have injected electrons. Now what is going to happen, so as shown here the volume concentration of the excess electrons will decay to 0. So, what is going to happen is the electrons are going to all move to the surface.

Now since this is the 1-diamentional situation, we are assuming, the electrons move to either the right surface or the left surface, right, you are not shown any electron on this horizontal surfaces because our situation is 1-diamentional. If it is 3 dimensional volume, then you must consider the mobile carriers to move to the surface of the 3 dimensional volume that is what will happen. Now we need to explain why does this happen, how does this happen?

And we need to get an equation for this return of space charge to nutrality condition. So please note space charge here is 0 but surface charge is not 0. So essentially what is happening is the space charge which was present at t = 0 is converting itself to surface charge. So the situation here is that semi conductor is uniformed and the injection of majority carriers is also uniformed and only majority carriers are injected, there are no minority carrier injected here.

So this is not like electron hole pair injection, right, it is only electron injection and also the excess electron concentration is small so that low level conditions prevail. So in terms of graphs what we shall observe is the excess electron concentration decays to 0, the volume concentration, decays to 0, it is converting into surface concentration but volume concentration goes to 0. In a time that is about 3 times the time constant namely the dielectric relaxation time or the space charge decay is to 0, in the same time.

Now we will show that the defining differential equation would be of the similar form to that we just discussed. Namely, it will be a first order differential equation in time. So, this would be given by dou rho/dou t, here rho is the space charge = minus of rho / the dielectric relaxation time which is given by epsilon s that is the dielectric, the permitivity of the semi conductor divided by the conductivity of the semi conductor.

So, we will have to show this, the boundry conditions in this case are the space charge for all x is the same because it is uniform condition at t = 0 it is = -q times the excess electron concentration that is injected. Now let us explain how this decay will happen?

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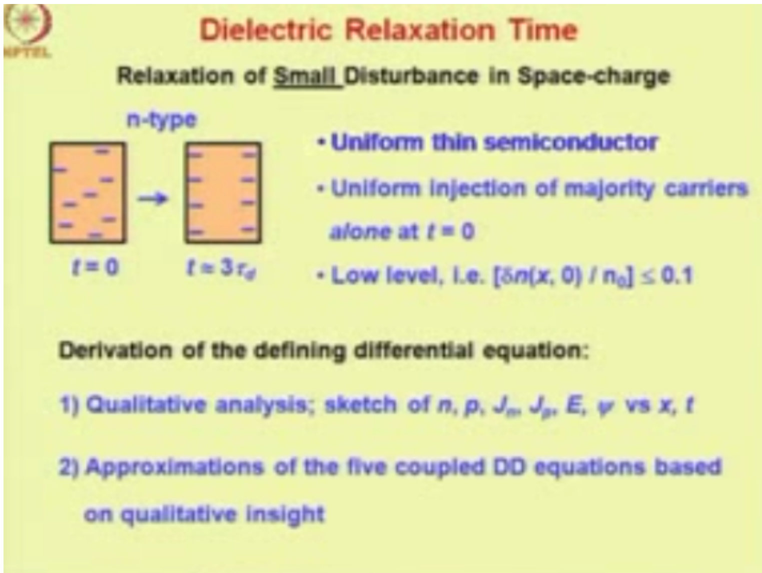


So again to drive the defining differential equation, we will first do a qualitative analysis and sketch these quantities as a function of X and T.

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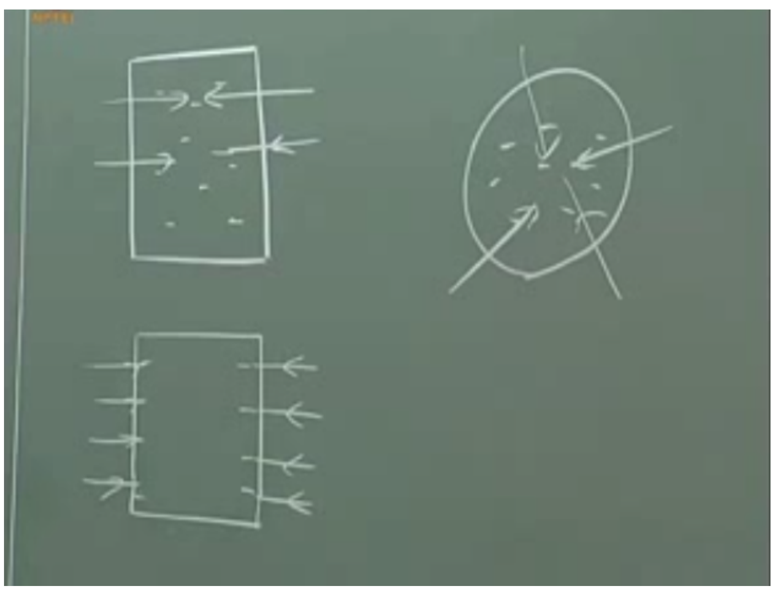

So, as soon as we inject electrons like this and electric field is going to be set up. So, from the source from where these electrons came an electric field would come and each of this electrons would terminate in electric field line in this manner. So, if it is a volume then the electric field would be something like this, okay terminating on each of this charges. So, we will look at our one diamentional equation.

Now, what is the consequence of this electric field coming here and terminating on the charge now since this charge that we have injected is mobile, it will move in this direction. So, the electric field that has been created as the consequence of the space charge itself will try to drive the electrons, either to this side or to this side. Now this is the reason why ultimately the process stops only when the electrons move to the surface besause there after the picture would be something like this.

So, the electrons cannot move out of the surface and they will be held to the surface by the electric field. Okay and now the process will stop. So that is how the space charge gets neutralized and converts into a surface charge. Now, let us look at things in detail and plot the various things the way we did earlier for the case of minority carrier lifetime. So, we are going to follow the similar approach.

So, here again we have a uniformly doped semi conductor, so your doping is uniformed okay.

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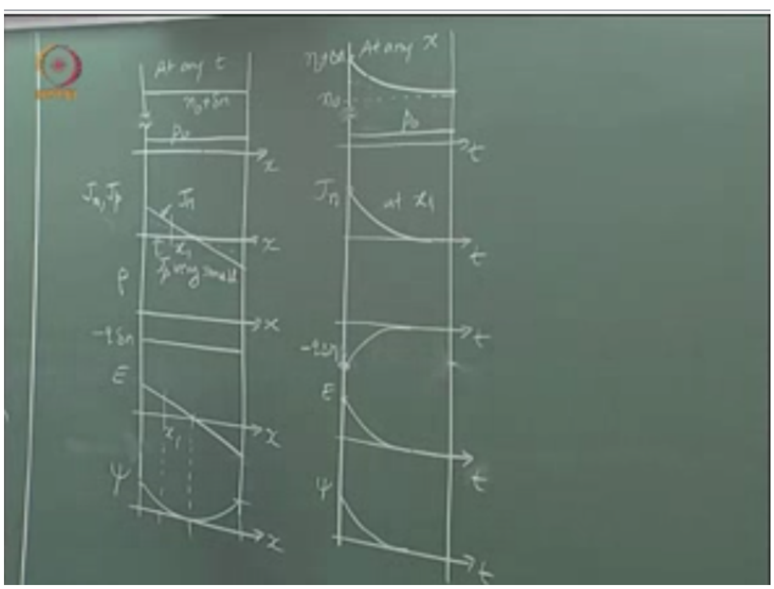

So this is at any T at the function of X and this is at any X as a function of T. So let us start with the electrons and hole concentration. So, the electron concentration, now we will use a linear because otherwise we will not be able to show any variation of majority carrier concentration at all, we are assuming low injection level. Whereas, actually we have injected majority carrier right and it is their variations we want to see.

So, I am going to use a linier scale and I am going to show a cut, so at any t your electron concentration would be something like this, n0+delta n, but since we have not injected any holes, the hole concenration would be just p0. So, this is n and p as a function of X. Now, what about n and p as a function of time at any X. So, let us talk about since the carrier concentration is uniform at any X, we will see the same picture.

So, the electron concentration is converting itself into surface charge and the volume concentration is dying out. So, it would be like this. So, this is n0+delta n in this point, this is n0. P0, however, p no change because we are not injecting any holes. Now note that this electric field will act on the holes also. So, when the electric field is moving the mobile electrons to the surface, will they not act on the holes? yes they will act on the holes also.

However, the disturbance of the holes would be really very small. So, it is going to be the mostly the electrons that are going to be effected by the field because they are in very high concentration and the drift current you know that is causing the volume concentration of electrons to move to the surface will be several orders of magnitude more then the drift current of holes because holes are minority carries.

So we really do not bother about the change in the hole concentration. Now, jn and jp, as the function of X. Again, if you want to know jn and jp, I should know the electric field. The carrier concentration is uniformed throughout the volume therefore there is no diffussion current. So there is drift current, because there is an electric field but what is the variation of the electric field unless we know that we cannot plot. So let us move to the electric field.

Now for doing the electric field as the function of X, we need to know the space charge, dou versus verses X. Now the space charge at any X is uniform and it is given by -q times excess electron concentration. So, the space charge uniform and negitive and therefore the electric field picture as a function of X. If you have uniform space charge, de x dx according to Gauss law constant. So, either the field picture will be linearly varying this or like this.

Now which is the correct one, well you look at the picture here, you can see that towards the rigth surface the field is inside, so this means the field is in the negative X direction here, at this surface. And at this surface it is in the positive x direction. So, the picture would be some thing like this. So, this is E verses X, linearly varying. Now because E is varying like this, the current because of this also will have similar variation.

So, this is supposed jn, jp would really cannot show on the same scale because hole concentration is out of some magnitude less than electron concentration. So, really jp is negligible. So, we cannot show jp, so we will just say JP very small. And finally, if you want to sketch the potential based on this, so as you move in this direction your electric field, if it is from left to right, your potential decreases right.

And then this electric field is from right to left as you move against this it increases. So therefore your potential picture would be something like this. So, that is your picture for electron current, hole current, electric field and potential right. So, what is happening at any t your current is like this it is zereo at the centre and here it is positive and here it is negative because you see the electrons are movimgf to the left because of the field therefore the current is to the right.

And here the electrons are moving to the right therefore the current is to the left, that is what it shows. So at the centre you have almost no current but the current increases as you move away from the centre. So, what is going to happen is as a function of time this current is going to drop like this. So this line is going to change like that. So at any other time if I want to draw this line it would be something like this and ultimately it will become flat.

Let us complete quickly the picture as a function of time. So since the current will you propotional to the carrier concentration and electric field okay at any X you have some electric field here. Now electric field is also dropping. Carrier concentration also is dropping, so the current jn would be something like this, as a function of time. JP we really do not show because it is really very very small. If you want to plot the electric field that would also fall at any X.

So let us say if I take the X here, we are taking an X somewhere here, similarly this electron current has been shown to be positive which means the X is somewhere here. If you take X here, the electron current would be negative. So let us say this is the place X 1. So this is at X1 and similarly this electric field is as a function of T. Space charge, it is actually of our interest. Space charge is however is negative everywhere.

So let us move this line up and space charge would decay like this, should be on the negative side. So this -q delta n, that is this value. This electric field if you want to convert, if you write in terms of this, it would be dependent on this multiplied by the volume and then divide by the epsilon S. As the function of time, the potential again at any X, so the region becomes neutral and the potential inside the regions falls. So this is psi as a function of time.

Now the next step to do would be to approximate the 5 coupled drift diffusion equations based on qualitative insight. Since we have come towards the end of the lecture, we will postpone this discussion to the next class and we will summerise what we have achived in this lecture. So in this lecture we began a discussion of the characteristics lengths and times. These are very useful matrix while analysing situations related to semi conductor devices.

They allow us to decide what kind of approximation will hold in which situation. We discuss the characteristics lengths and times associated with carriers in random thermal motion under equilibrium. Then, we outlined a procedure for deriving the characteristics lengths and times based on the drift diffusion model. Where, in we said first we should do the qualitative analysis and express it terms of graphs of n, p, jn, jp, e and psi as a function of X and t.

Then, we should use this qualitative insight to approximate the equations to decide what equations can be eliminated and which terms can be simplified. In particular, we saw that if you can make the cause in neutrality or charge neutrality assumption then you need to solve only one pair of equations current density continuity equations. Either that of electrons or that of holes. So one pair of equations is eliminated by the charge neutrality condition.

Then, we solve or reduce the approximated equations to a single defining equation for the charactristics lengths and time. We applied this procedure to derive the charactristics time associated with decay of excess electron hole pairs to equilibrium in a uniformed semi conductor and then we began a discussion of the decay of excess charge or space charge to charge neutrality condition tight.

And specifically, we considered the instence of space charge neutralization to charge neutrality condition when you inject excess majority carriers into a semi conductor samples. So we will complete this discussion of the decay of space charge when you inject majority carriers and we will repeat a similar exercise for minority carrier injections also. This we will do in the next class.