Solid State Devices
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Lecture - 3
Equilibrium and Carrier Concentration

Today we begin the first technical topic related directly to the course that is: Equilibrium Carrier Concentration.

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Solid State Devices

Lecture - 3

Equilibrium Carrier Concentration

Now before we begin our discussion on this topic let me summarize what we have done so far. So far we have seen how the devices can be classified in terms of the frequency or power of their operation. Then we have seen the objectives of this course. Specifically we have said the objective of this course is to relate terminal characteristics to the internal parameters with the help of simple equations based on a physical understanding of all the phenomena that are taking place within the device. Then we have seen the contents of the course in detail, this was the first lecture.

Then in the second lecture we have seen its uniqueness and how the technology of semiconductors has evolved. I suggest that you spend a lot of time thinking about the nature of technology and how this technology has evolved because that part even though it is just 1 hour it is as important as the remaining may be 37 hours of lecture. May be the nature of technology itself can be discussed in a separate course and some kind of comparison be done between semiconductor technology and other technologies. Now, coming to the topic Equilibrium Carrier Concentration let us see what exactly we are trying to achieve in the next four or five lectures on this topic.

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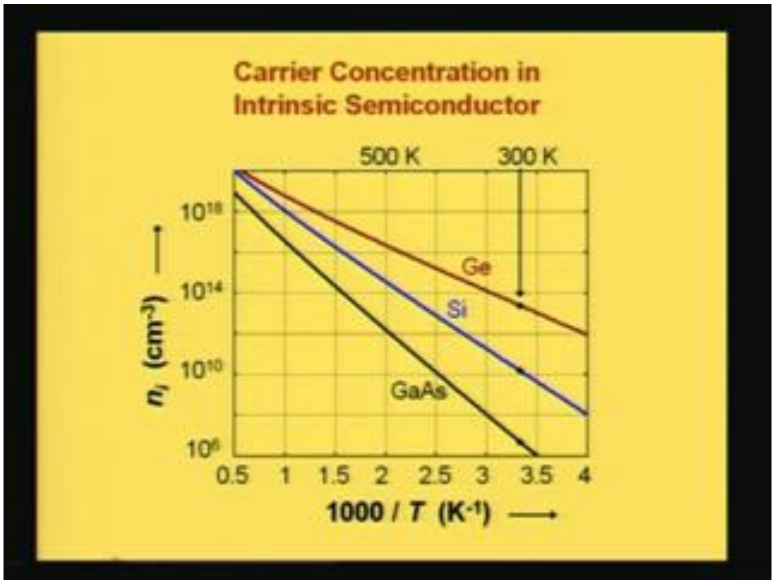

So the first thing is that we would like to derive a formula for explaining this particular behavior in an intrinsic or pure semiconductor. So what this graph shows is the carrier concentration as a function of temperature in a pure semiconductor. It is important to see the access on this graph. The Y axis, that is the concentration where “n_i” stands for the intrinsic concentration “i” is intrinsic. So the concentration axis is logarithmic and the X axis which has temperature is actually the reciprocal of temperature. So if you plot the concentration, the measured value of this particular parameter on a log scale as a function of the reciprocal of temperature, then you get a straight line. So, this obviously gives us a clue as to what kind of formula, what is the form of the equation for the concentration of function of temperature? Although we will have to determine what are the constants in this from a deeper understanding of the devices. You can also see that the concentration is different for silicon germanium, gallium arsenide etc and this difference is quite large. So we will have to find out what is the parameter associated with the material which is responsible for this difference.

Here we have also shown the room temperature point that is 300 K on this graph because the X axis is reciprocal we will have to convert this to the temperature and so you get a feel of the range of temperature covered here. So, here is the room temperature and on this side are the lower temperatures because it is the reciprocal of temperature on the X axis and this side is the higher temperatures, higher than room temperature. In a simply manner if you state, the concentrations seem to vary exponentially as a function of the reciprocal of temperature. That is the important information we get. Next, we will do a similar exercise for extrinsic semiconductors or doped semiconductors.

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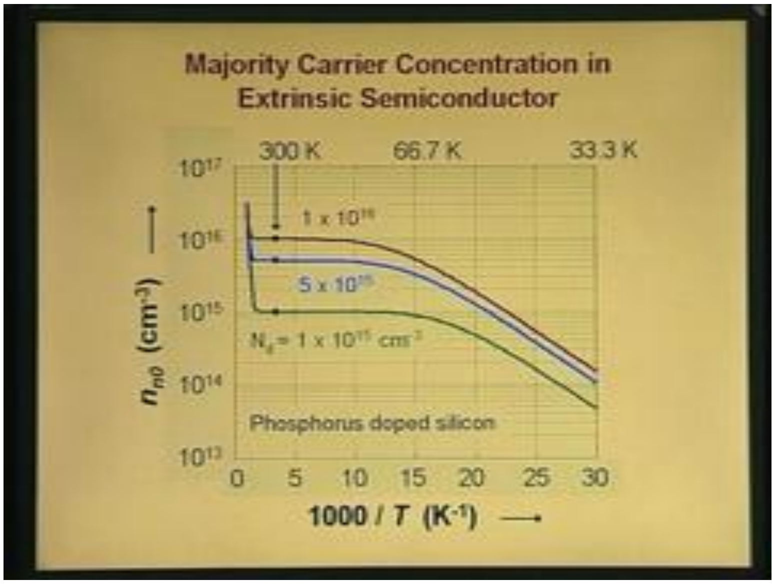

Majority Carrier Concentration in Extrinsic Semiconductor

Doped semiconductors have two types of concentration to be considered: majority and minority because the concentration of electrons and holes is not the same. In a pure semiconductor the electron concentration is same as the hole concentration. So the symbol $n_{i.,}$ in the previous slide represents electrons as well as holes, whereas in an extrinsic or doped semiconductor the electron and hole concentration in general is not the same. So you have the majority carrier concentration, that is the concentration of carriers which is in a majority, and you also have minority carrier concentration.

Again here we are plotting the majority carrier concentration in an n-type semiconductor. So, here in n_{n0} this n stands for electron concentration, n stands for the type of the semiconductor, that is an n-type semiconductor, and the 0 stands for the fact that the semiconductor is under equilibrium. This is an equilibrium concentration of electrons in an n-type semiconductor and this is also the majority carrier concentration because electrons are in a majority in an n-type semiconductor. So this concentration is plotted again on a log scale as a function of reciprocal of temperature on the x-axis.

You have an additional parameter as compared to the previous graph and that is the impurity concentration of the doping. So, whereas you had only one line for a material in the previous graph; here you have a number of lines, this is for silicon what we are plotting here. We have a number of lines each for a different doping. So here what is shown is doping level of 10 to the power 15, 1 into 10 to the power 15, 5 into 10 to the power 15 and 1 into 10 to the power 16. So doping is a parameter on which the concentration will depend. And room temperature is shown here, so the room temperature is close to the left end here in this particular graph. So the concentration has been shown for less than room temperature as well as for more than room temperature.

You find that there is a small region from this point here to somewhere here over which the concentration is constant as a function of temperature. This is the region in which the device is operating. This range over which the concentration is constant varies with the doping and this range is wider for higher doping levels. Generally this range is referred to as the extrinsic range, so we will have to explain this behavior: How do you get a constant concentration of majority carriers over a certain temperature range? How do you get straight lines when you plot log of concentration with reciprocal of temperature on the extremes of this range. So that is for low temperatures and for high temperatures here is what we would like to explain.

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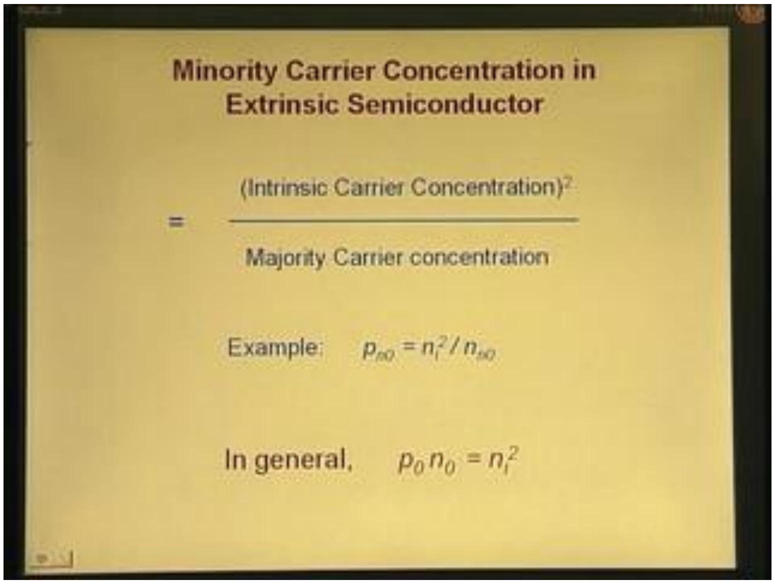

Minority Carrier Concentration in Extrinsic Semiconductor

$$= \frac{(\text{Intrinsic Carrier Concentration})^2}{\text{Majority Carrier concentration}}$$

Example: $p_{n0} = n_i^2 / n_{n0}$

In general, $p_0 n_0 = n_i^2$

Next we shall see the minority carrier concentration in an extrinsic semiconductor. The minority carrier concentration is given by the (intrinsic carrier concentration) whole square divided by majority carrier concentration. So the first slide that we showed was intrinsic concentration, the next slide was majority carrier concentration. So (intrinsic concentration) whole square divided by majority carrier concentration is equal to minority carrier concentration.

For example, in an n-type semiconductor the hole concentration is the minority concentration, $P_{n0,}$ P is the hole concentration, suffix n is the entire semiconductor, and the suffix 0 represents equilibrium. So equilibrium concentration of holes in an n-type semiconductor which is also the minority carrier concentration is given by n_i square divided by n_{n0}. In general, we will show that under equilibrium conditions the hole concentration n2 electron concentration, the product is equal to square of intrinsic concentration: $p_0 n_0$ is equal to n_i square.

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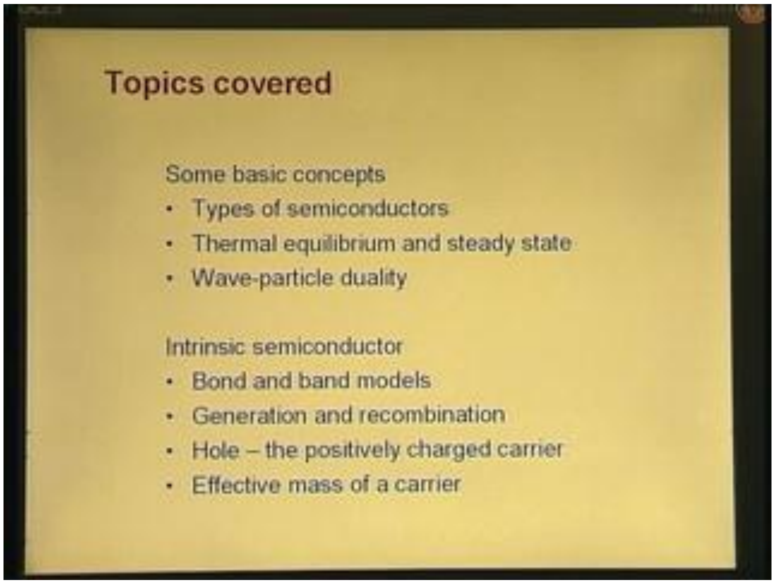

Topics covered

Some basic concepts
- Types of semiconductors
- Thermal equilibrium and steady state
- Wave-particle duality

Intrinsic semiconductor
- Bond and band models
- Generation and recombination
- Hole – the positively charged carrier
- Effective mass of a carrier

Now, to explain these things let us see the topics that we will cover. So first we will review some basic concepts such as types of semiconductors, the difference between thermal equilibrium condition and steady state, the wave particle duality. Then we will go to intrinsic semiconductor for which we will consider the bond and the band models, generation and recombination. We will see the concept of the hole that is the positively charged carrier, then the idea of an effective mass of a carrier.

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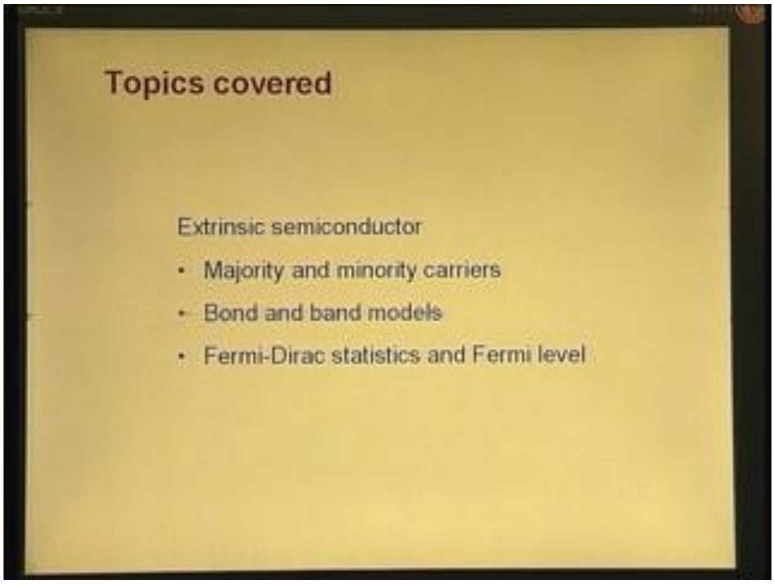

Topics covered

Extrinsic semiconductor
- Majority and minority carriers
- Bond and band models
- Fermi-Dirac statistics and Fermi level

Then we move on to the extrinsic semiconductor or dope semiconductor where we will discuss majority and minority carriers, the bond and band models of the extrinsic semiconductor, Fermi-Dirac statistics and Fermi-level. Let us begin with the first topic: the classification of semiconductors. It is important to state at the outset that we are considering concentration in the semiconductor bulk.

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Supposing this is the semiconductor block, this is the bulk, and this outline is the interface. Now a small region near the interface is to be excluded from the bulk because this region will be affected by the properties of the surface or the interface. It turns out that the interface is as important as the bulk. Very often when we draw a diagram like this we tend to concentrate on the bulk because the area is large, whereas it turns out that the interface is a very important part of the semiconductor. In fact the understanding of surface is still not clear. You have a journal devoted to just the Science of surfaces - that gives an idea of how complicated the surface is. Now, having said that we are talking about the semiconductor bulk and the concentration there let us see the types of semiconductors. One classification is simple and compound.

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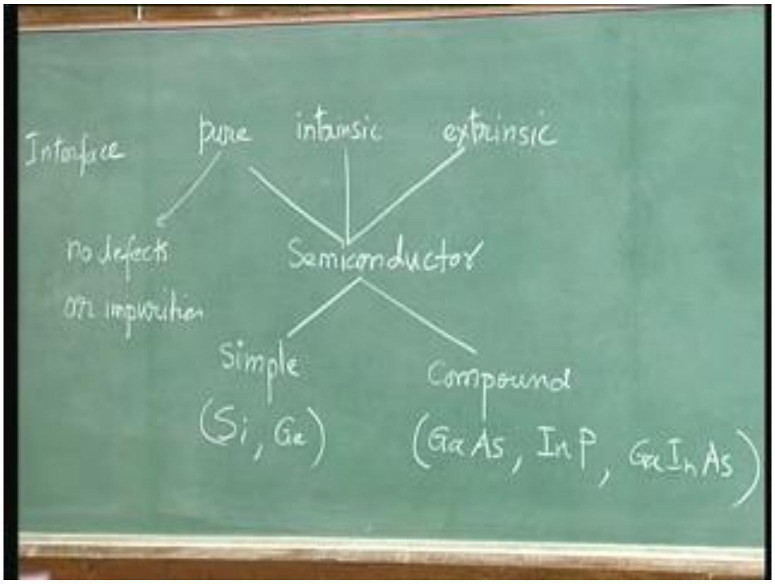

Example of simple semiconductor is silicon, germanium and so on. In these semiconductors you have just one type of atoms regularly repeated. On the other hand, in compound semiconductors you have atoms of more than one element constituting the semiconductor. Simple semiconductors are also called elemental semiconductors because you have only one element present. Examples of compound semiconductors are gallium arsenide, indium phosphate. You can also have more than two, for example gallium indium arsenide. You can even have four elements present. Another classification of semiconductors is pure, intrinsic and extrinsic semiconductor. A pure semiconductor is a semiconductor which has no impurities or no defects. That is, it is a perfect crystalline arrangement. In this material there is a regular arrangement of atoms. In this course, unless otherwise stated the element that we are going to consider is silicon.

Pure crystalline silicon would mean just regular arrangements of silicon atoms without any disruption. Now one must understand that this statement is valid only for bulk because even if you take pure silicon crystal, as you move to the interface there is a disruption in the periodic signal because you do not have any silicon atoms beyond the interface. Within the bulk this is valid. So when we are talking about pure semiconductor it strictly means that we are talking of this region where there no defects. A defect is a disruption in the regular arrangement, or no impurities; no atoms other than silicon present. Such a semiconductor is impossible to get. So the semiconductor materials which are used in semiconductor devices are 99.9999% pure, but still there is some impurity.

It is very difficult to make a very pure crystal. That is why we introduce a concept of the intrinsic semiconductor. The intrinsic semiconductor is one which may not be totally pure; there may be some defects, some small amount of impurities, but the concentration of electrons and holes in the semiconductor would be same as that in the pure semiconductor, this is possible when the effect of one type of impurity compensates the other impurities. Defects are present but they are compensating each other so that the concentration in the semiconductor remains the same as in a pure semiconductor. So this is an intrinsic semiconductor. Extrinsic semiconductor is anything that is not Intrinsic which means it is a semiconductor conductor with defects and impurities present and wherein the concentration of holes and electrons will not be the same under equilibrium conditions. So a doped semiconductor is definitely an extrinsic semiconductor unless the doping is of two types of impurities which are exactly compensating each other in which case it will become an intrinsic semiconductor.

Therefore pure semiconductor means no defects or impurities. Intrinsic semiconductors may contain defects and impurities but the concentration is same as that in pure semiconductors. Extrinsic: defects and impurities are present under equilibrium conditions electrons or hole concentrations are not the same. So, it is obvious that extrinsic semiconductor is more complex than the intrinsic. You need to proceed in a progressive fashion from simple to difficult and that is why we will first start with the intrinsic semiconductor and then go to the extrinsic semiconductor. Next let us discuss the idea of the thermal equilibrium or thermodynamic equilibrium.

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Many times the word thermodynamic is replaced by thermal equilibrium. If you go into the nitty gritty of the issue, thermodynamic is not exactly the same as thermal. But for our practical purposes we will assume that the two words are interchangeable.

What is the meaning of thermal equilibrium and why is this concept important in modeling or analysis of devices? It turns out that in Physics there is a general philosophy that is followed for modeling complex situations, and that is: you treat a complex situation as a small deviation from the idealized situation which can be treated mathematically. This is a very important idea commonly followed in Physics. A complex situation, let me introduce the word “real life” which can be approximated as a small deviation from convenient idealized condition which is amenable to mathematical treatment and one must always add the word “simple” here.

Actually this is not something unusual. For example, supposing you want to tell the location of some place to a person who does not know the place, very often you tell a landmark, when you say it is about so many meters or so many feet from this place, you tell a land mark. You do not tell the person how far is that place from where you are. This is the idea here. You are talking about a complex situation. Find out if there is an idealized situation that may not be a real situation, but one which is very near to that, and then if you have model for that ideal situation you can introduce a small disturbance and then try to model the complex situation.

Once you understand this philosophy then you will understand this idea of “thermal equilibrium”, it is a convenient idealized condition. It is not achievable in practice, but it is a convenient idealized situation. Many phenomena that we encounter can be modeled as small deviations from thermal equilibrium. That is why many times you will find the word “quasi equilibrium” attached to the device analysis or modeling. It is a quasi equilibrium model. What does it mean? It means you are treating it as a small deviation from equilibrium condition.

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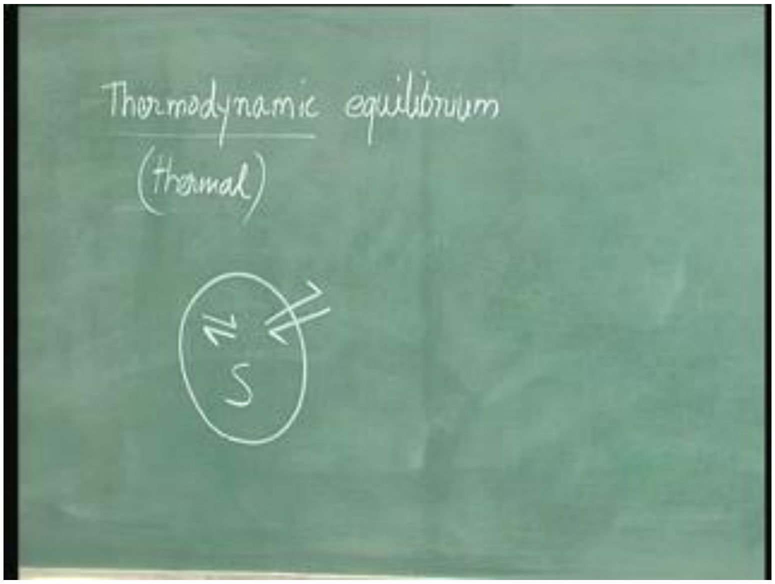

What is the definition of thermal equilibrium?
A piece of semiconductor is said to be in equilibrium with its environment. Whenever you talk of equilibrium you must talk of two entities, the equilibrium is between two entities. So it is understood when you say a semiconductor is in equilibrium (it is in equilibrium with its environment). The semiconductor is said to be in thermal equilibrium with its environment if for any process that may be going on between the semiconductor and the environment, there is an inverse process going on at the same rate. This also applies for processes within the semiconductor.

For any process that is going on or for every process that is going on, there is an inverse process going on at the same rate, this is a very simple statement of thermal equilibrium. It is also called the Principle of the Detailed Balance.

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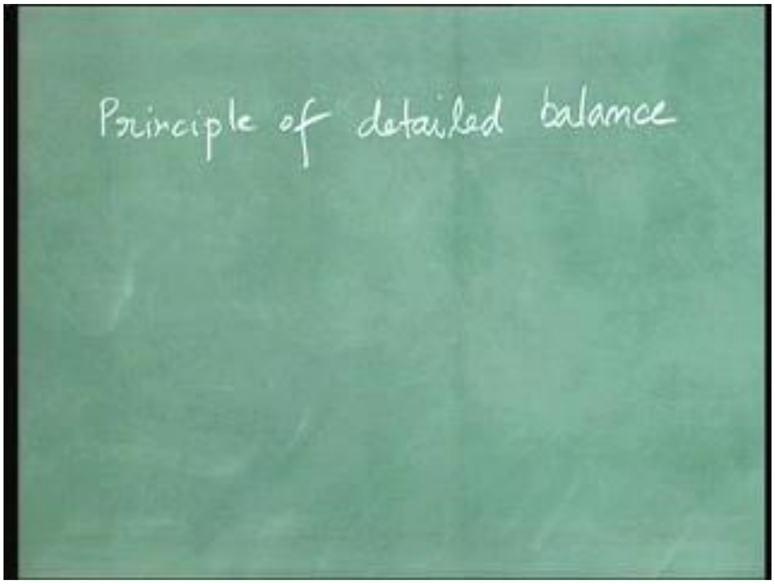

Principle of detailed balance

Both the words are important here detailed and balance. The word balance is indicated by these two pairs of arrows. For every process going on there is an inverse process going on at the same rate that is the Balance aspect. Now what is the meaning of the word Detailed Balance? The word Detailed Balance means that you look at the process as much as in detail as you want, and at every level of detail this balance will hold. This is rather a stringent condition. It means, for example, supposing there are 10 particles moving from 0.1 to 0.2 at a certain rate then exactly 10 particles of the same type will be moving from 0.2 to 0.1.

So if there are 10 electrons moving from 1 to 2 in a given time, in the same amount of time exactly 10 electrons will be moving from 2 to 1. Not only that, if all the 10 electrons are not of the same energy, 2 electrons have energy E_1, 3 electrons have energy E_2, and so on, there is a distribution of energy, the electrons are distributed over energy. Then exactly 2 electrons of energy E_1 will be moving from 2 to 1, exactly 3 electrons of energy E_2 will be moving from 2 to 1, this is the meaning of Detailed Balance. So you go on looking at the process in more and more detail; at every level of detail the balance is maintained, that is the meaning of the Detailed Balance. So the principle of Detailed Balance says that for every process there is an inverse process going on at the same rate. That is the meaning of thermal equilibrium.

Even though this statement is short and if you take the words literally it is not very difficult to understand, but its implications many times are not so clear. We can use a more practical definition which will be more verbose than this in which we will understand clearly and we state conditions 1, 2, and 3 you just say: Is condition 1 valid? Yes. Is condition 2 valid? Yes. Is condition 3 valid? Yes, then it is in thermal equilibrium. Such a definition of thermal equilibrium would be as follows:

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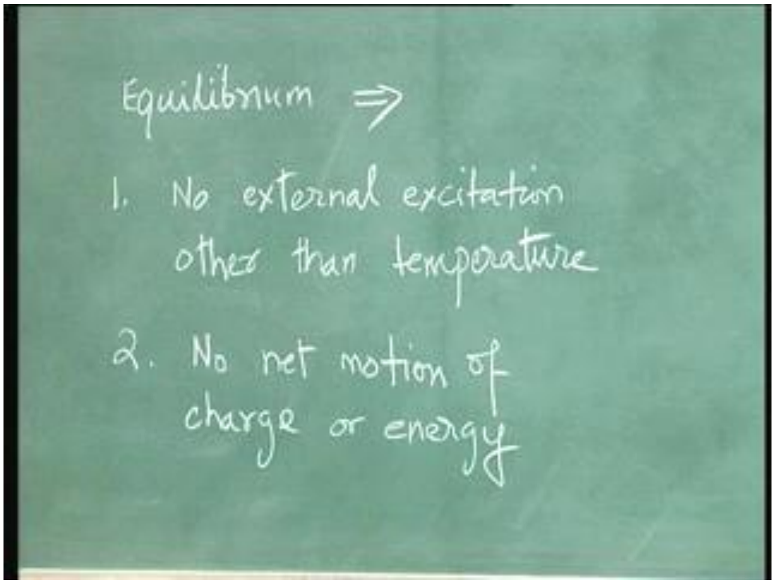

Equilibrium ⇒

1. No external excitation other than temperature
2. No net motion of charge or energy

Semiconductor is in thermal equilibrium if:

1) No external excitation other than temperature.
2) No net motion of charge or energy.

If these two conditions are valid then the semiconductor is in equilibrium. To understand this idea let us look at some simple examples of non equilibrium conditions. We must illustrate with examples, because as I said equilibrium is very difficult to achieve. Let us see what is meant by non equilibrium? Then, you can, by inference understand what equilibrium would mean.

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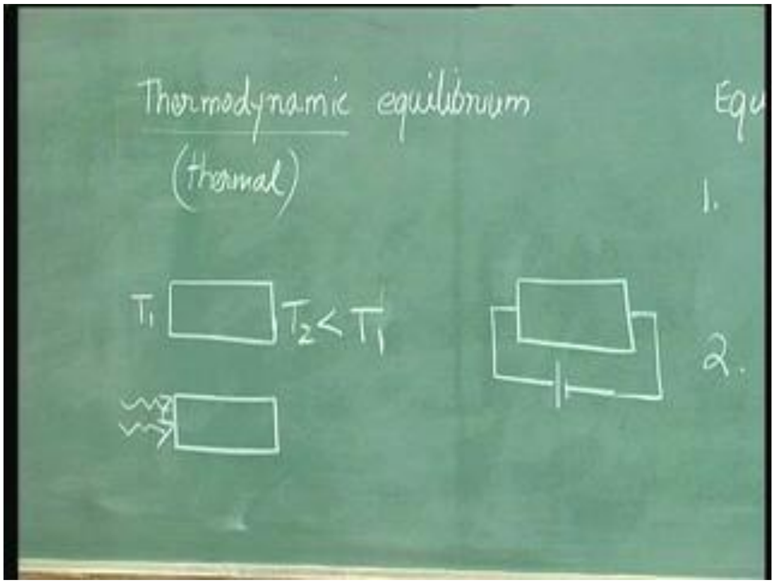

One example is suppose we have a semiconductor; at one end you have a temperature T_1, at the other end you have a temperature T_2. The first condition is satisfied here, there is no excitation other than temperature. However, if this temperature is more than this temperature then there is flow of heat from T_1, let us assume T_1 more than T_2, then there is a flow of heat from this end to the other end, that is flow of energy, and there is no inverse flow of energy to balance this. It is a one directed process from T_1 to T_2 so it is not under equilibrium.

Of course there can be motion of charge also but we need not go to another condition because if one condition is violated it is not under equilibrium. Let us take another example: Supposing you have light falling on a semiconductor, it may be falling on all sides or may be one side it does not matter. This semiconductor is not under equilibrium because you have light shining on the semiconductor, photons are being absorbed, and then that energy is being converted to another form of energy. There is no inverse process. It is not as though a semiconductor is giving out light. That is interesting, which means that if the semiconductor is visible it is not under equilibrium. So, the semiconductor should be under dark conditions. This is the implication of equilibrium.

Let us take another example which of course is straight forward. Supposing you have semiconductor and you apply electric field, so as current is flowing, now it is obviously not under equilibrium because the condition itself is not satisfied, there is excitation other than temperature. So, this is how you can find out whether the semiconductor is in equilibrium or not. A semiconductor will be in equilibrium if it is not visible, it is under dark conditions, and there is no excitation of electric field or any other such energy. These are examples of non equilibrium conditions.

Semiconductor devices are only useful under non equilibrium conditions; you cannot get anything out of a device if it is under equilibrium. So as we said in the beginning, thermal equilibrium is a convenient idealized situation because many practical situations can be treated as small deviations from this situation. In other words, many practical situations can be treated as quasi equilibrium situations. Let us understand why is it that many situations can be treated as quasi equilibrium situations? We will take an example take of a PN junction.

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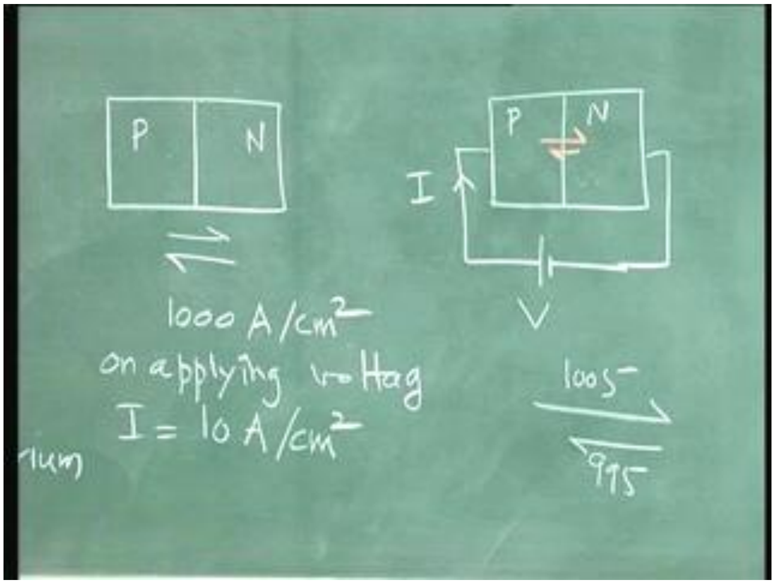

We have not done an analysis of PN junction. So you just accept as a piece of information. Across the PN junction you have very large current density even under equilibrium conditions, for electrons as well as holes. What is important is that current density in one direction is exactly balanced by current density in the other direction. In other words the thermal equilibrium is not a static equilibrium; it is a dynamic equilibrium. There is intense activity under thermal equilibrium. Only thing is the activity does not contribute anything in any one direction that is what is important. That is why we said “no net motion of charge or energy”, it does not say “no motion of charge or energy”; the word “net” is very important. So, it is a very dynamic situation in which there is intense activity but which is not in any one direction. This is the reason why this condition is a useful starting point because now if you add any other excitations then we can treat this condition as a small deviation from equilibrium conditions. So let us take this example: for a PN junction one can show if you take for electrons at the junction, there is a current of a 1000 A by cm square. So there is one tendency for electrons to go from P to N at the rate of 1000 A by cm square, and it is exactly balanced by another density tendency.

One tendency is a drift and another tendency is a diffusion, we will not get in to more details here, all that I want to point out is that is the current density under equilibrium conditions across the junction. But there is no net effect of this because the net current is

0. Obviously you cannot get a current out of a PN junction if it is under equilibrium. Now you will appreciate how a practical situation can be treated as a small deviation.

Let us take the current levels encountered in a diode under practical conditions; so here again I will not make a calculation, you can make a calculation, you can take a practical device, what is its area, what is its current level that you are going to have. Then you can find out the current divided by area as the current density. This will result in some kind of a number like this: 10 A by cm square, the practical current on applying voltage I is 10 Amp by cm square. So this is an equilibrium condition.

If I were to show after application of voltage, obviously this is valid only for some voltage that is applied. But I am just taking one practical example that is I. Now what has happened is obviously these are not matched. One tendency is slightly increased and other is slightly reduced or may be one is not affected the other is affected that is also possible. So, I am showing this arrow as a longer arrow, and I show this arrow as shorter, to show that an imbalance has been created there of 10 A by cm square.

Now how can I get 10 Amp from 1000 Amp? One way I can get is: 1000 becomes 995 in one direction and it becomes 1005 in the other direction. So, I can have may be 1005 in this direction, and 995 in other direction. The difference is going to give me 10 A by cm square. Now you can see that this is really a small deviation from equilibrium. 1005 is a very small deviation from equilibrium, 5 out of 1000 is a very small percentage change. This is why the thermal equilibrium condition is important. It is a dynamic condition, it is a condition of intense activity, and in practical conditions the deviation from equilibrium is very small. Let us distinguish the equilibrium condition from the steady state.

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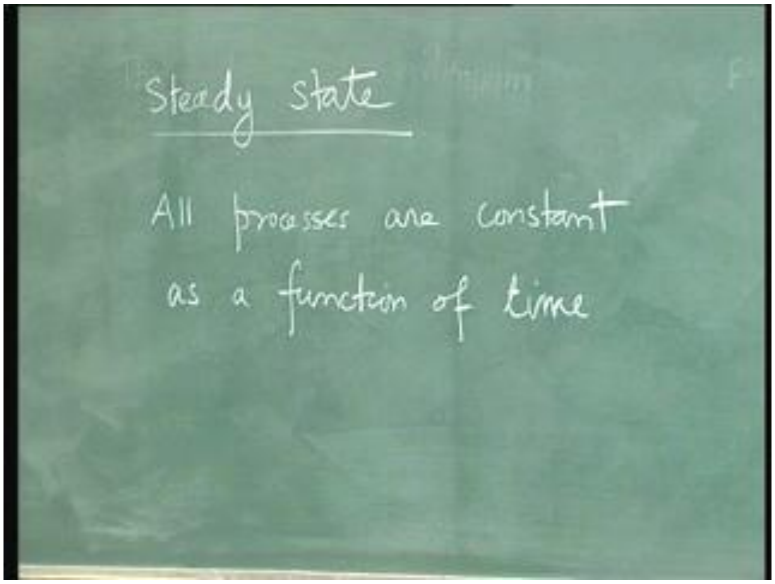

Steady state

All processes are constant as a function of time

Many times people confuse between equilibrium and steady state. So it is important to distinguish between the two. Steady state means all processes are constant at the function of time, it is not necessary that for every process there should be an inverse process, that is equilibrium. Steady state means all the processes are constant as a function of time. If you want to show the relationship between equilibrium and steady state it would be something like this, you can use the Venn diagram.

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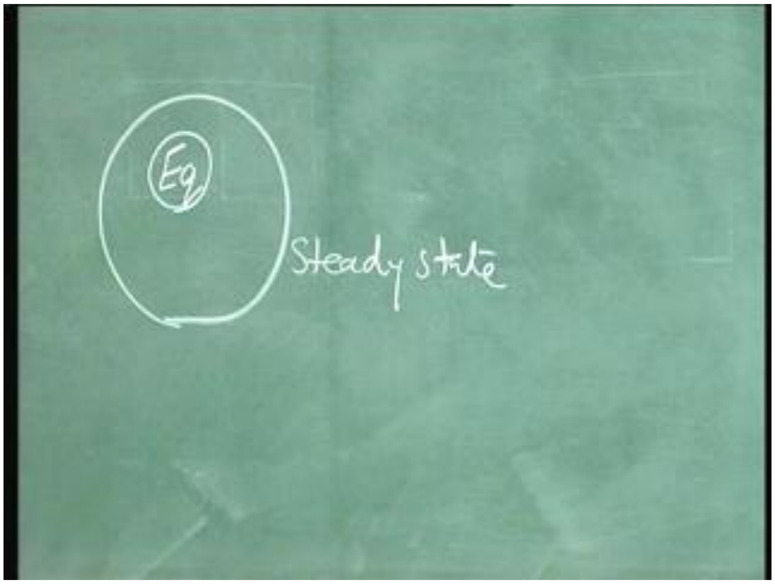

If this shows steady state, then that is equilibrium, so Eq stands for equilibrium. So if a semiconductor is in steady state, then is it under equilibrium. This clearly shows that if a semiconductor is in steady state, it need not necessarily be under equilibrium; but if a semiconductor is in equilibrium, it is definitely under steady state. The importance of steady state is similar to importance of equilibrium. Many dynamic conditions, that is, non steady state conditions, where parameters vary as the function of time can be treated as small deviations from steady state condition. That is why you will find for transient analysis they will attach a phrase called quasi steady state analysis, or quasi static analysis. Transient conditions can be approximated as quasi steady state or quasi static conditions. The word quasi always means “small deviation from”.

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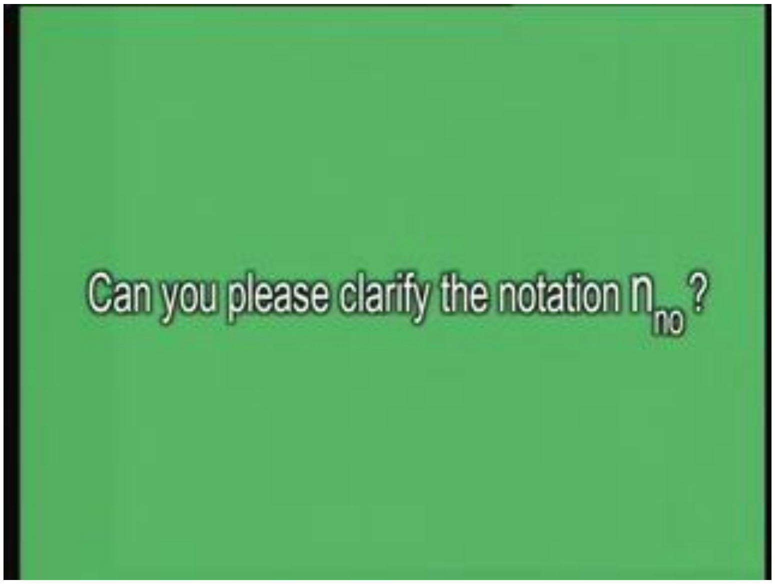

Can you please clarify the notation n_{no}?

Can you please clarify the notation $n_{n0?}$ Let us look at the slide.

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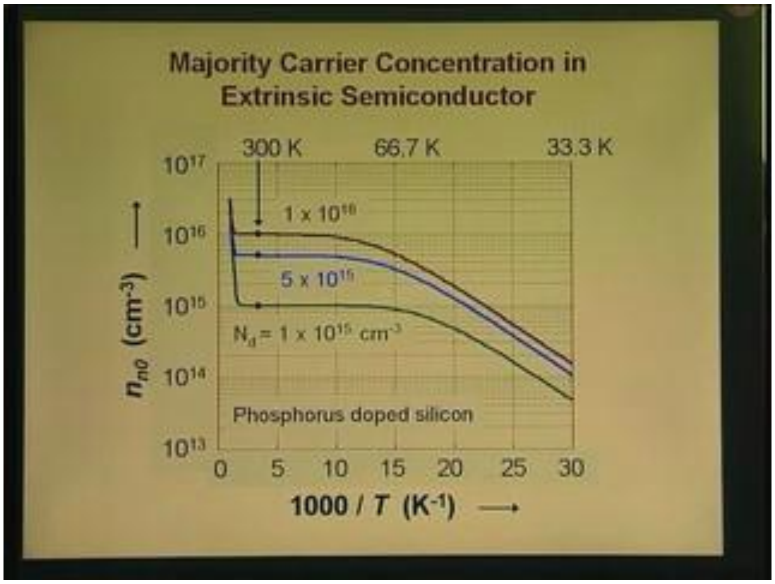

Majority Carrier Concentration in Extrinsic Semiconductor

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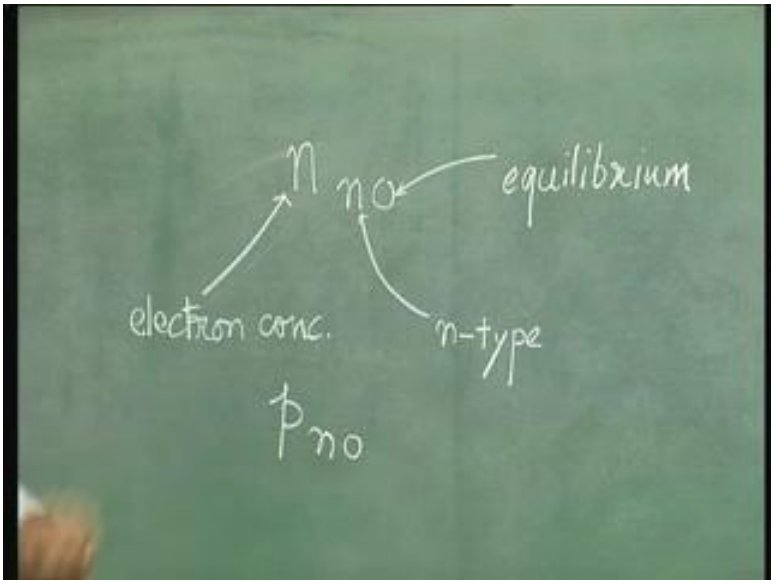

What is this n_{n0}?

In this notation this n stands for electron concentration, this suffix n stands for type of the semiconductor; that is n-type. As you know an n-type semiconductor is one in which electrons are in a majority. This suffix 0 stands for the fact that the semiconductor is under equilibrium, so n suffix n0 means the electron concentration in an n-type semiconductor under equilibrium conditions. So, as per this notation if I write p_{n0} that would imply the whole concentration in an n-type semiconductor under equilibrium.

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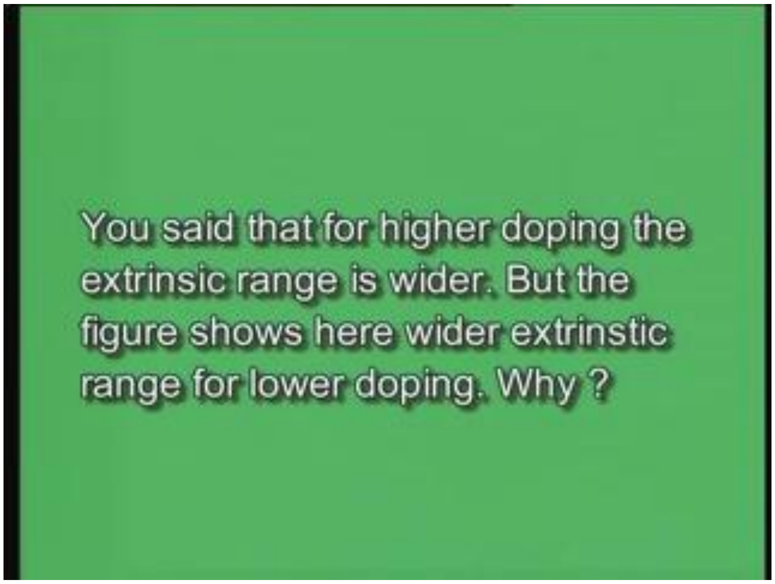

You said that for higher doping the extrinsic range is wider. But the figure shows here wider extrinstic range for lower doping. Why ?

Sir, I have a question regarding the majority carrier concentration versus temperature behavior. You said that for higher doping the extrinsic range is wider, but the figure shows here wider extrinsic range for lower doping. Why? Let us look at the slide again. This is a good question.

Let us look at the green line here it has a constant portion. This range of the constant portion for the green line appears to be wider than the constant portion of the red line, and also the constant portion of the blue line. So this gives an impression that for N_d is equal to 1(10 to the power 15) cm cube. The extrinsic range is wider than the extrinsic range of 5(10 to the power 15) cm cube and 1(10 to the power 16) cm cube. This is happening because there is some amount of distortion when you plot the concentration as the function of reciprocal of temperature rather than as a function of temperature. So let me explain this to you in detail.

On the reciprocal of temperature axis higher and higher temperatures tend to get compressed more and more. For example, here, this temperature corresponds to about 600k whereas the 0 of this reciprocal of temperature axis corresponds to infinite temperature. So 600k to infinite temperatures is compressed in this small region. That is why you are not able to see the difference between the temperatures, this corner of this green curve and the temperature corresponding to this corner of the red curve, whereas there is a significant difference in these two temperatures.

On the other hand you are able to see the temperature difference between this point which is one end of the flat portion of the curve and this point which is also the end of the flat portion of the green curve. So at this point the temperature difference between this point and this point is very visible; this is because these are lower temperatures on the reciprocal of temperature axis their difference is enhanced as compared to the high temperatures and that is why you feel that the higher doping levels have lower extrinsic range than lower doping levels.

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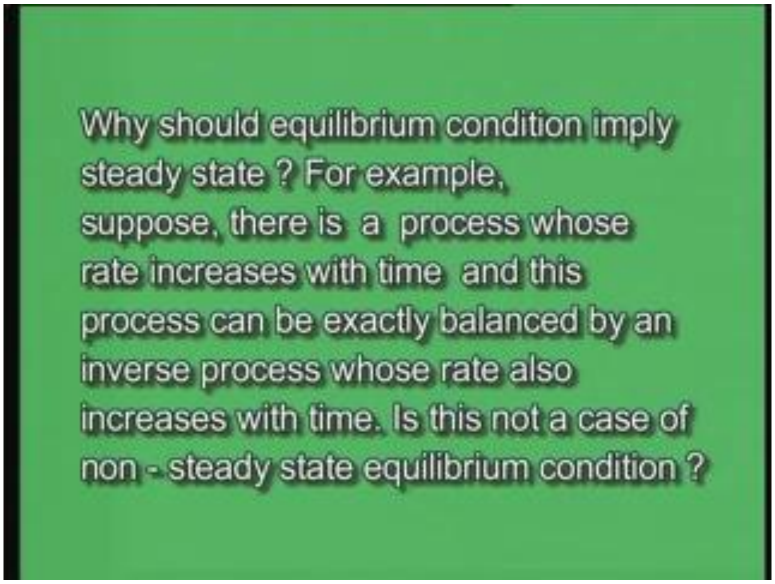

Why should equilibrium condition imply steady state ? For example, suppose, there is a process whose rate increases with time and this process can be exactly balanced by an inverse process whose rate also increases with time. Is this not a case of non - steady state equilibrium condition ?

Why should equilibrium condition imply steady state?
For example, there is a process whose rate increases with time and this process can be exactly balanced by an inverse process whose rate also increases with time.

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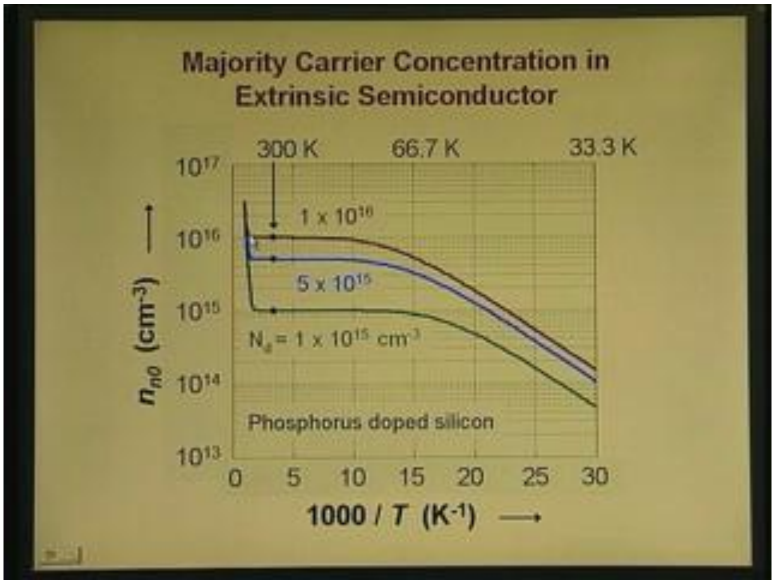

Majority Carrier Concentration in Extrinsic Semiconductor

Is this not a case of non steady state equilibrium condition?
Let me explain to you with an example.

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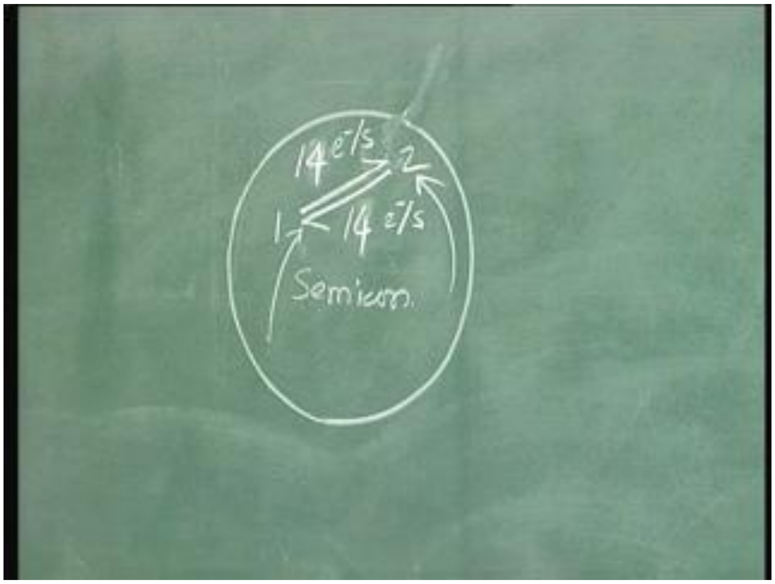

Let us say this is a semiconductor and in this between some two points there is a process of electron transferred from one point to another point in this direction at some rate say 10 electrons per second, and you have an exactly inverse process going on in between same points, and you have a reverse transfer of 10 electrons per second.

Now what you are saying is, if as a function of time the rate goes on increasing, that is, may be after a minute or so, this 10 becomes 12, and this 10 here reverse process also becomes 12, and then may be after another minute it becomes 14, and this also becomes 14, then is it not a case of equilibrium? What you are saying is that it is not a case of steady state because the processor is not a constant as the function of time. This process is increasing from 10 electrons per second to 14 electrons per second.

Now the catch here is that, we have said in the definition of equilibrium that for every process there should be an inverse process going on at the same rate. Now if the rate of electron transfer is from 0.1 to 0.2 is increasing from 10 to 14 then it means that the number of electrons in this region is increasing from 10 to 14. More electrons are coming in from somewhere else because otherwise the electrons involved in this exchange cannot go on increasing.

So, the number of electrons is going on increasing as the function of time within this region. Some how more electrons are coming in from somewhere, maybe from outside, or maybe from inside the semiconductor from some other place electrons are coming to this point as well as to the other point. Now there is no reverse process for this particular process. So there is a net movement of electrons from this point to 0.1 and some other point to 0.2, and there is no corresponding inverse process so that is why this is not a case of equilibrium.

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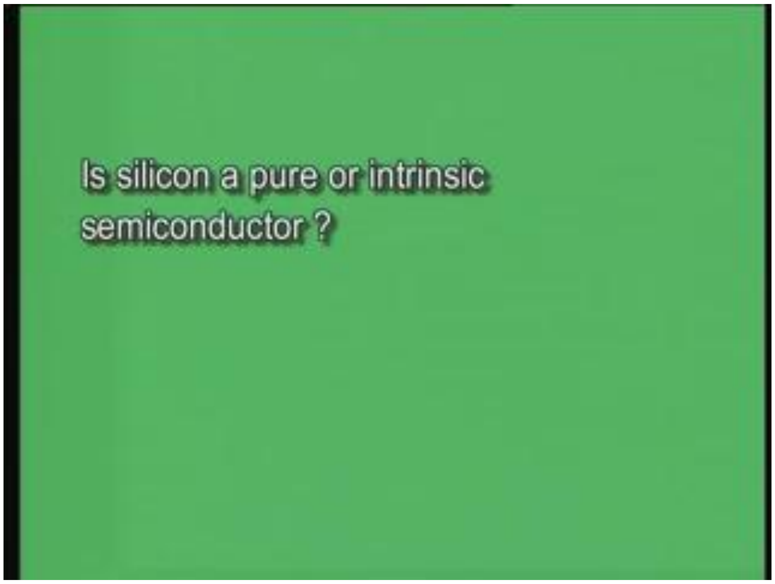

Is silicon a pure or intrinsic semiconductor ?

Is silicon a pure or intrinsic semiconductor? Let us look at the classification of semiconductors once more.

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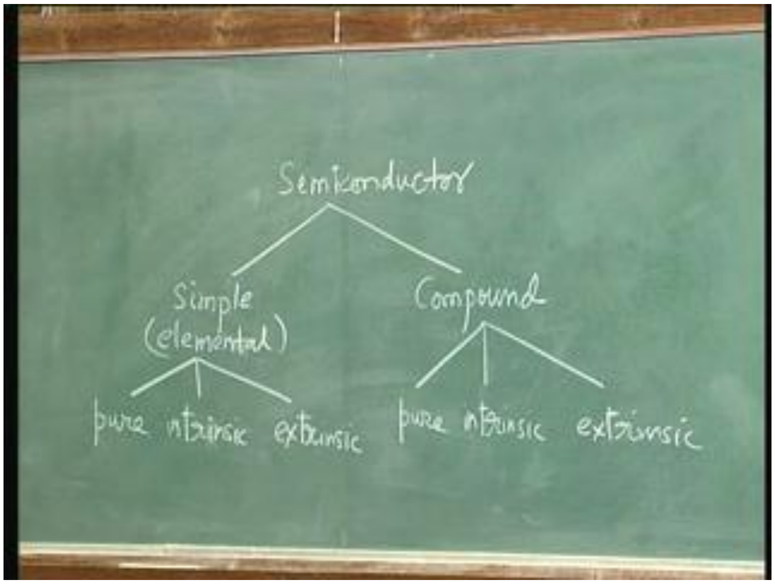

We can divide the semiconductor types into simple and compound. Simple semiconductor is also an elemental semiconductor. An example of simple semiconductor is silicon. An example of compound semiconductor is gallium arsenide; a simple semiconductor can be either pure, or it could be intrinsic, or it could be extrinsic. Similarly, the compound semiconductor also can be either pure, or intrinsic, or extrinsic. So a semiconductor is either simple or compound. A simple semiconductor can have any of these three types and a compound semiconductor can also have any of these three types. So the question that whether silicon can be either pure, or it can be intrinsic semiconductor does not make sense. That is, a silicon can be either pure or it can be intrinsic or it could be extrinsic.

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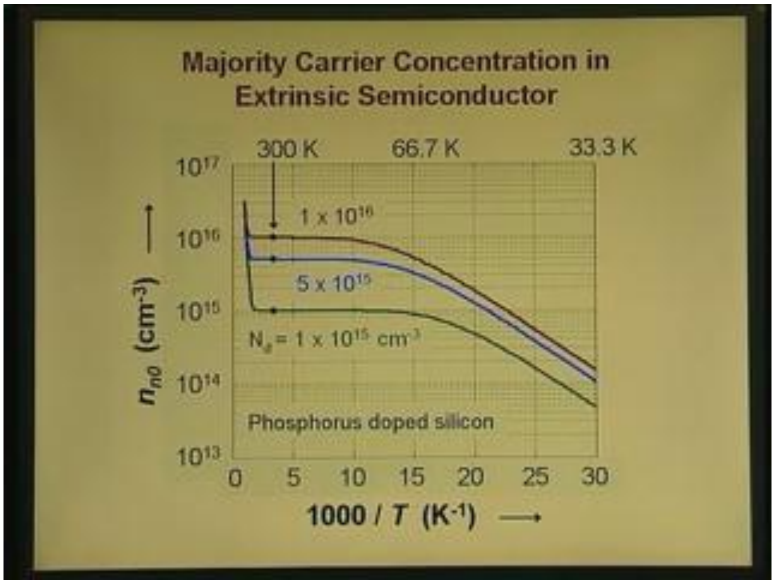

Majority Carrier Concentration in Extrinsic Semiconductor

If there are no more questions, before winding this lecture I would like to come back to this particular slide of majority carrier concentration in extrinsic semiconductor, related to which a student had a question: About why the extrinsic range is smaller for higher doping levels as drawn in the diagram, whereas in practice the extrinsic rate should be larger for high doping levels.

One point I like to discuss is, if because of choice of a reciprocal of temperature axis here, a wider extrinsic range appears as a smaller extrinsic range, and if such distortions are taking place then why should we choose a reciprocal of temperature axis at all? This is a very relevant question. This has to do with how experimented data needs to be plotted in order to confirm a model. If you plot this same graph using a linear temperature axis instead of the reciprocal temperature axis, then these two ends, that is, this portion of the graph and this portion of the graph would not be linear but they would be non linear.

There are some advantages in getting straight line portions in a graph because then the data and the model can be very easily checked. This particular aspect is very important in checking of the models. We normally like to plot the data in such a way that its various regions would be straight line or close to a straight line because it is very easy to fit a straight line to a set of points. So, from the point of view of checking experimental data whether it fits into a model, it is good to plot, then choose an axis in such a way that you get straight lines. But you must be aware of the distortion that may take place and therefore you must also know how the same data looks when you choose linear axis for both the variables.

I will discuss this particular point in detail when I take up the model corresponding to majority carrier concentration in extrinsic semiconductor as a function of temperature and majority carrier concentration in extrinsic semiconductor as a function of temperature. So we write down the equations and then it will become clear why we choose a logarithmic scale for concentration and a reciprocal of temperature scale on the x axis.

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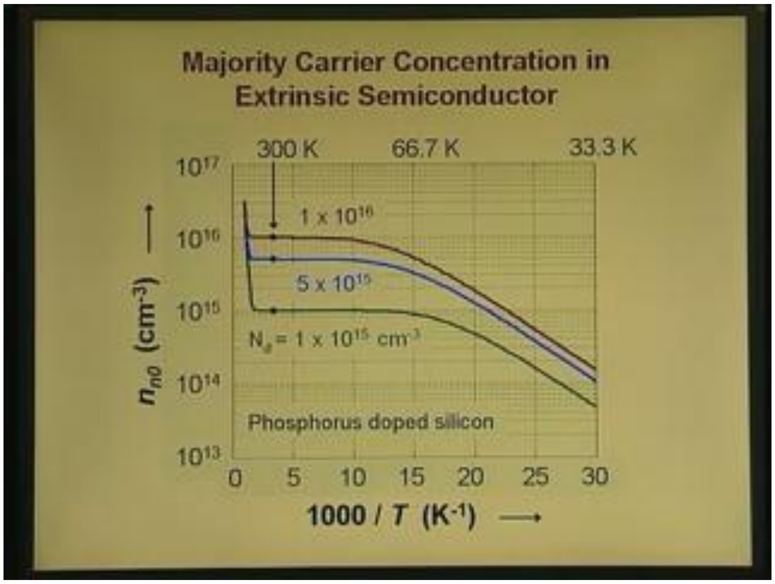

Majority Carrier Concentration in Extrinsic Semiconductor