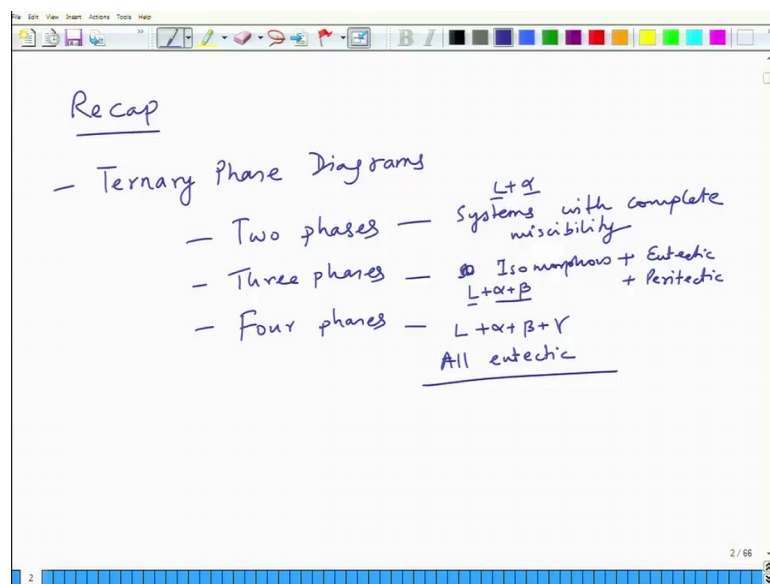


**Phase Equilibria in Materials (Nature and Properties of Materials - II)**  
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**Lecture - 39**  
**Application of Phase diagrams**

So welcome again to lecture number 39 in this course of Phase Equilibria. So, what will do is that will first recap the last topic basically not necessarily, not last lecture.

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So, in the last few lectures we discussed about ternary phase diagrams and we looked at various aspects of ternary phase diagrams as to how to analyze the composition, how did what is the tie line intermarry phase diagram, how do you apply leave a rule in ternary phase diagram. How did that our composition for example, when you have various lines in ternary phase diagram because, ternary phase diagram unlike binary phase diagram has 3 components as a result reading composition is rather tricky.

So, you have constant composition line lines which go from either apex to the base or they are lines within the phase diagram which could be parallel to one of the bases. So, and then we look at looked at various things that you can do it ternary phase diagram such as drawing a horizontal section which is isotherm basically or drawing a isopleth which is a vertical section, which is basically in the in the triangular prism you draw a vertical section. And look at the phase evolution as a function of temperature for given

ends of composition. And then we looked at few systems such as phase diagrams with two phases and then phase diagram with three phases and phase diagrams with four phases.

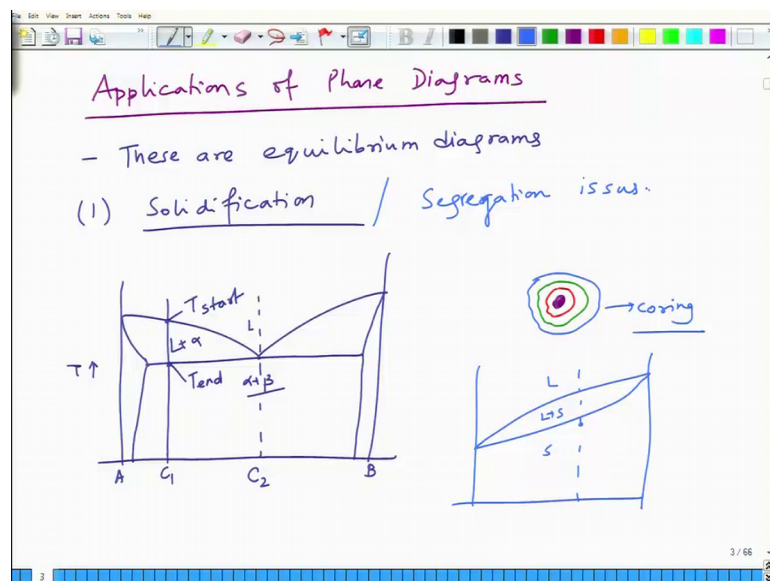
So, in the two phases you generally have systems with the complete solubility, complete you can say miscibility. And then we looked at systems with three phases such as it could be combination of you know isomorphous plus eutectic it could be combination of peritectic and so on and so forth.

Then you have four phases. So, for example, you can have four phases could mean. So, this would be in basically liquid plus alpha, this would mean liquid plus alpha plus beta. So, liquid is the liquid phase so, L is the liquid phase, alpha is the solid phase.

In this case L is the liquid phase, alpha and beta the solid phases, four phases could mean L plus alpha plus beta and that could be present in a phase diagram such as all eutectic. So, these are the 3 kind of phase diagrams that we discussed. We did not go into details of many of these phase diagrams, but we basically looked at the phase evolution.

So, I recommended the book by you know West and Saunders, ternary phase diagrams in material science. I should read that book look at the problems in that book, it is a very nice book to read about ternary phase diagrams. So, what we will do in this lecture is we will basically look at the come to nearly the end of the course.

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We will see how one can use phase diagrams in various applications. So, applications of phase diagram ok. So, phase diagrams are useful for lot of purposes although they are thermodynamic. So, basically these are equilibrium diagrams, but they can be helpful in as and an equilibrium is seldom achieved in lot of processes. However, there is still very useful for determining a lot of things for example, first application of them lies in solidification.

So, when you have a phase diagram for example, like this then for a given composition you know at what composition the alloy will melt. So, for example, you know that for this composition the alloy will melt at this temperature. So, this will be the  $T$  start and this will be the  $T$  end. So, you know that solidification will process through 2 phase regime solid plus liquid regime. As a result you can determine to what temperature the alloy must be heated to for liquid to completely homogenize and then give rise to solidified product.

Similarly, you can find for this particular composition which is a eutectic composition, you can see that at this composition your melting point is there is only single melting point it does not go through a liquid plus solid zone. So, liquid directly transforms into eutectic alpha and beta. So, you know the eutectic temperatures if you know the phase diagrams. So, you can jump, you can design alloys and you can suit, you can choose suitable process protocols to melt the liquid and carry out the solidification processes.

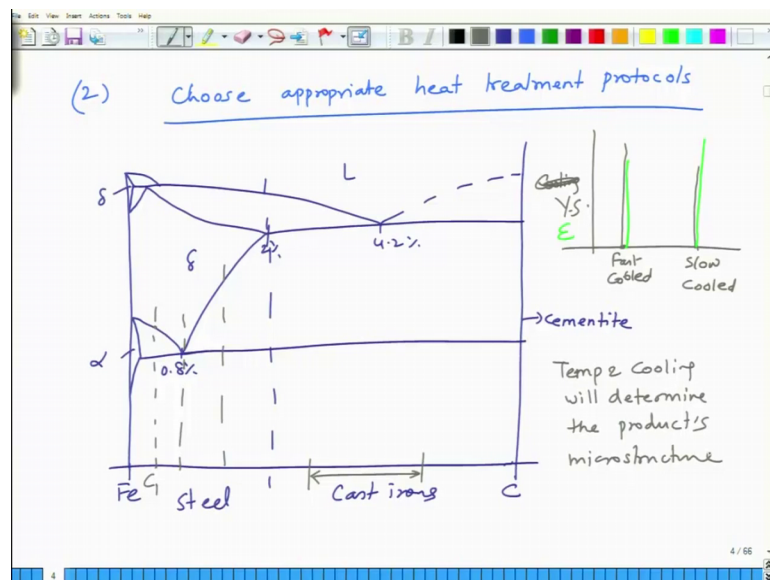
It is also important from the perspective of segregation. For example, in a lot of processes we have segregation and segregation happens as a result of non equilibrium cooling. So, in segregation as we have seen before you will have the core of different composition then you have another layer of different composition and next layer of different composition. And this is because the first solid is very different in composition as compared to the next solid and they do not have time to homogenize.

As a result the solidus or keep shifting and it keeps shifting it basically, it leads to micro structural variations within the solid itself. So, you have this kind of coring and this coring can be avoided by, a coring can be minimized by choosing appropriate temperatures to which the heat to which the solid must be heated or kept at. So, that compositional differences are minimized.

So, for example, if you have a binary phase diagram like this. So, this is liquid, this is solid, this is liquid plus solid. So, you know that as you as you carry out the solidification the coring will occur, but then you also know once the coring has happened it is a fact. So, how do you what do you do to avoid it. So, you again reheat the material to a temperature which is slight which is just below the solidus temperature. So, that you have enough driving force or thermal energy for atoms to move and equilibrate.

As a result you can minimize the coring in the metallurgical systems in various alloys. So, it can help you to mitigate the problem, it can help you to understand solidification and it can also help you to mitigate the segregation issues. So, this is one application of phase diagrams that you will come across.

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Second application you can choose is appropriate heat treatment protocols and this is especially important from the perspective of as we saw in case of steel. So, if you look at the phase diagram of iron-carbon steel and cast iron both. So, this is iron carbon phase diagram. So, at low temperatures we have eutectic eutectoid reaction. So, you have this is the iron-carbon phase diagram. So, you have delta phase field, you have gamma phase field and you have alpha phase field and this is liquid and this is cementite.

Now, this phase diagram so, this is you have you have peritectic eutectic in eutectoid reaction by and large we are worried about. So, this is 2 percent point, this is 8 percent

point, 0.8 percent point, this is 4.2 percent point. So, compositions below are called as a steel and compositions above will be called as cast irons.

Now, the phase diagram helps in choosing heat treatment protocols in the sense that suppose you want to so, depending upon the. So, you know first of all you can determine that if you have a steel you going to change it is microstructure. Let us say you have this composition  $C_{\text{naught}}$  or  $C_1$  and if you wanted to change the microstructure homogenize you know to what which temperature you want to heat to.

So, you want to go above this temperature go to single phase austenitic region hold it for some time and then quality that slowly or fast either slow or fast depending upon what you want because, slow and fast cooling will determine the strength and ductility. And typically you will see that that strength and ductility so, cooling rate.

So, if you look at for example, if you compare 2 steels, one is fast cooled another is slow cooled and if you plot strength let us say yield strength. The fast cooled steel will have higher strength as compared to the slow cooled steel. So, this is yield strength and if you plot similarly ductility elongation; elongation of fast cooled steel will be little lower as compared to slow cooled steel.

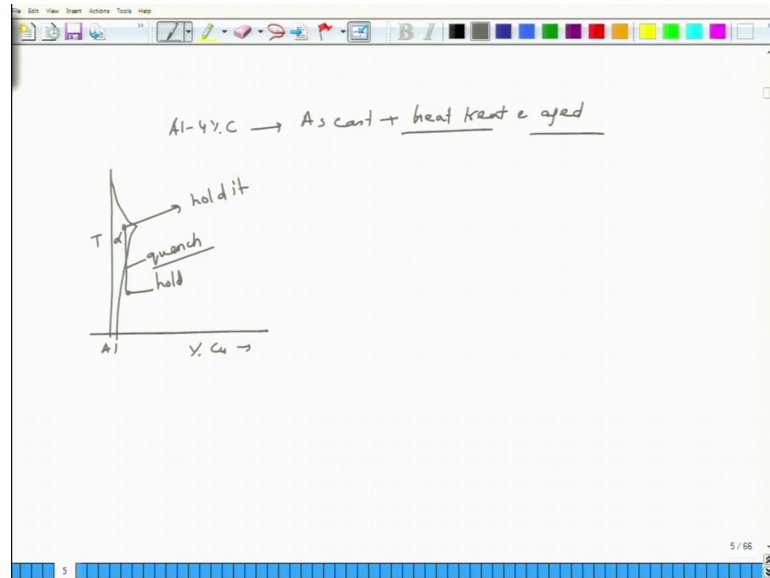
So, these are the things that you can do by choosing appropriate temperatures within the phase diagram. So, this is valid to all the 3 regimes hypo, hyper and eutectoid steels it is especially important in case of cast iron because in case of cast iron which are between typically 2 percent to 4, 4 point something percent. So, this is a commercial range of cast irons.

So, depending upon the cooling, depending on the temperature from which you cool and the rate at which you cool. So, temperature and cooling rate will determine the products microstructure. So, depending upon how from which temperature and how you will cool you can make a white cast iron or you can make a malleable cast iron, you can make a gray cast iron.

Of course, there are compositional fluctuations as well, but knowledge of these temperatures at which phases exist and whether you allow sufficient time or not you will come you will have cementite or graphite cast iron phase that will be quite critical from the perspective of engineering applications.

So, choice of appropriate heat treatment protocol is extremely important especially in case of steel.

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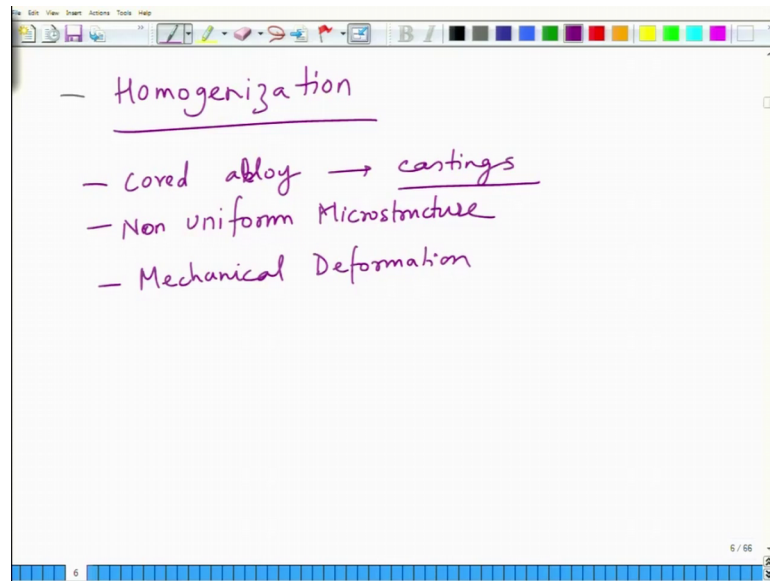


Similarly, in case of aluminium-copper, aluminium-copper has this kind of region at the on the low composition side. So, aluminium-copper alloys generally aluminium 4 percent copper alloys they are homogenized. So, they the as cast alloys are not very good so, they have to be as cast. So, after casting they have to be heat treated and then aged. So, this heat treatment temperature is decided by phase diagram.

So, you what you do is that you have as cast alloy of this composition you take it to single phase region this is alpha. So, this is alpha percentage copper, this is aluminium and you hold it at some time and then you cool it to low temperature not low enough, but please sufficiently high roughly about 150, 200 degree centigrade. And then you again hold it at this temperature.

So, this is quenching, quenching means fast cooling in water or let us say an oil then hold again. So, this gives rise to what we call as aged alloys aluminium copper alloys with Al 2 Cu precipitates which are hard and which are not big enough. So, that they give rise to high strength in aluminium copper alloys.

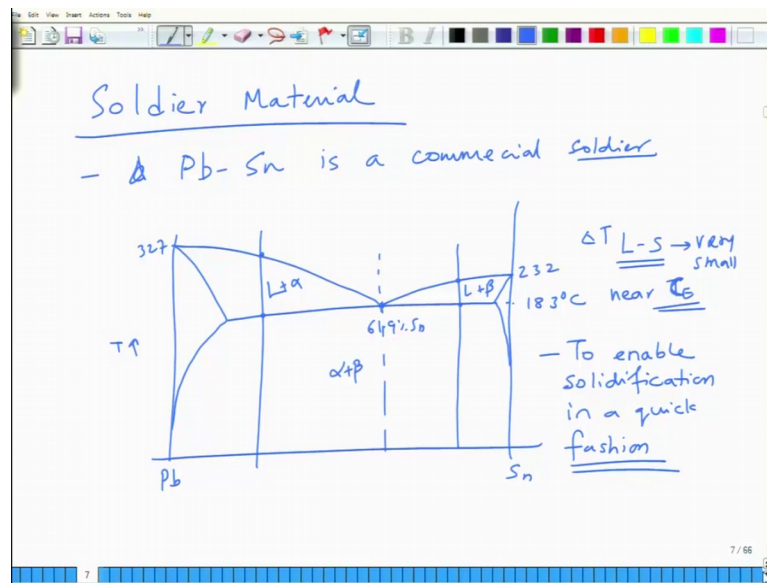
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So, this is another application that you will have in for phase diagrams. Third application which is normally it is homogenization. Now, homogenization is something which is done if you have a cored alloy. And this is especially in case of castings, the castings because the castings are made in moulds. The moulds do not offer uniform cooling in many cases as a result you have non uniform microstructure. So, you have cored alloy, you have non uniform microstructure.

You also use this in case of mechanical deformation that temperatures which we choose to mechanical deformation especially when you do hot processing. So, for castings non uniform microstructure for mechanical deformation to choose the appropriate processing temperature knowledge of phase diagram is necessary.

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Similarly, it has various other uses in choosing applications for example, soldiering material. We know that aluminium sorry let in alloy is a commercial solder soldering material right. The reason why knowledge of phase diagram makes it interesting is the core because this phase this alloy shows a eutectic at 61.9 tin. So, let me just draw the phase diagram of this alloy.

So, we have a phase diagram something like this write to this is Pb-Sn phase diagram and this is temperature led as a melting point of 327, tin has a melting point of 232, the eutectic occurs at 61.9 percent tin and the eutectic temperature is 183 degree centigrade so, we can see that.

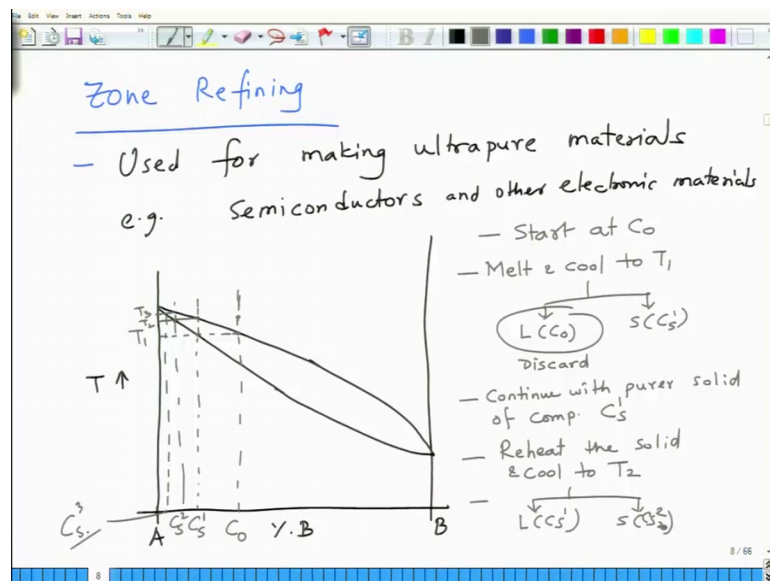
Now, a soldiering material that the reason you choose the phase diagram is important you do not want to choose as let tin alloy whose which melts and goes through. So, if you choose for example, this composition it will have a liquidus temperature, solidus temperature, it will have a range of solidification temperature. As a result now alloy will take long time to solidify.

Similarly, here if you start from here the solidification will end here. So, this liquid plus solid region should be avoided. As a result phase diagram when you look at the phase diagram it tells you that. If you are in the vicinity of eutectic composition then your liquid to solid difference is very small.



So,  $\Delta T$  is very small near T E C E. So, that is why your soldering alloys are typically of composition which are near eutectic compositions so, that they can solidify to enable solidification in a quick fashion. So, that the component that you want to attach in the semi in the chip is immediately is immediately stuck otherwise and the there is a great danger of the components to come out from the semiconductor circuitry and that would not be very good. So, as a result to enable solidification of soldier in a quick fashion so, that you can have immediate correction made and then another.

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Another application of this solidification phase diagram is found in phenomena called as zone refining.

Now, zone refining is generally a process which is used for used for making ultra pure materials. For example, in semiconductors and other electronic materials the electronic materials generally need to be very pure. So, what application is of course, semiconductor industry, but there are many other applications for making ultra pure materials.

The question is how do you make ultra poor materials? Because, everything that is available in nature is impure. So, for example, you have a material phase diagram like this. So, let us say you have A, B and this A, B have a phase diagram which is something like this. So, I will just draw a part of the phase diagram ok. So, this is temperature and this is percentage B ok. So, let us say if you go like this ok.

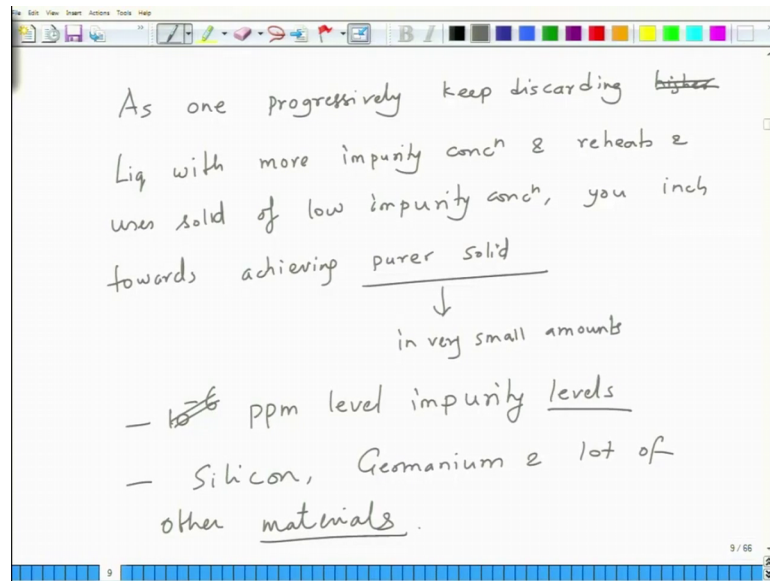
So, now let us say you want to make pure A. So, A and B you have an alloy whose composition is like this. So, this is  $C_0$  that you begin with. So, if this is your alloy composition. So, you start at  $C_0$  and you start at  $C_0$  you know that alloy contains  $C_0$  not percentage of B it is not very pure. So, what do you do? You can heat it to a temperature high enough. So, you heat it to a temperature let us say this temperature and then you slowly cool down to this temperature which is let us say  $T_1$ .

So, what you do is that you melt and cool to  $T_1$  when you cool to  $T_1$  what you have is you have you form a solid the first solid that forms will have a composition  $C_{s1}$  let us say ok. So, the first solid that forms is. So, melt to cool to  $T_1$ . So, what you will have is you will have liquid of composition  $C_0$  and solid of composition  $C_{s1}$ .

So, what you do, you see that you form a solid which is purer than the liquid. So, what you do with at this point is you discard the liquid and continue with purer solid that is of composition  $C_{s1}$ . So, then again you reheat it. So, when you reheat it and then again you cool it back you come to temperature  $T_2$ . When you cool to temperature  $T_2$  again you form a solid and liquid which gives rise to. So, liquid of composition  $C_{s1}$  and solid of composition  $C_{s2}$  and you have solid of composition  $C_{s2}$ .

So, if you have such a scenario what do you do? So, if you keep repeatedly, if you keep discarding the liquid which is more impure and if you keep heating and cooling and reusing the next solid forms you keep on moving to the left of this diagram. So, again when you discard the solid liquid of composition  $C_{s1}$  and retain the solid of composition  $C_{s2}$ , you again reheat it and again you go to this temperature let us say  $T_3$ . So, this is  $T_2$ , this is  $T_3$  again at that point you will have liquid of composition  $C_{s2}$  and solid of composition in this case for example,  $C_{s3}$ . So, this is  $C_{s3}$  for instance.

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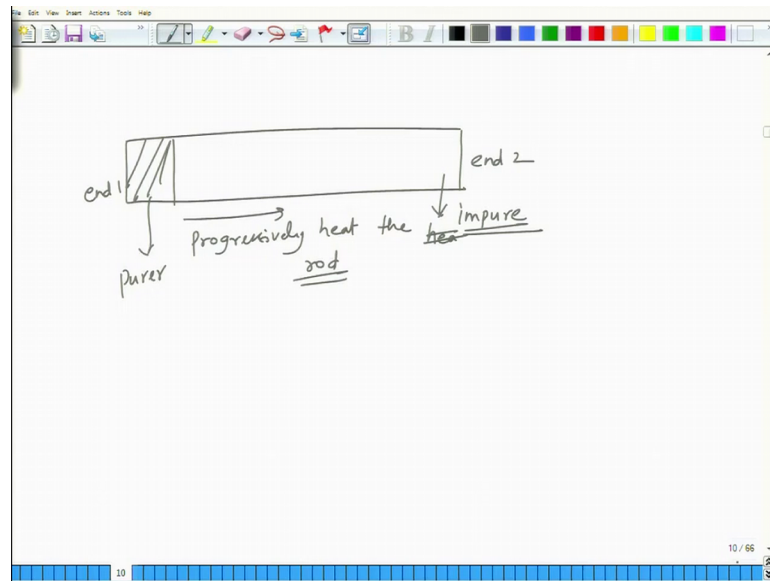
As you keep doing it, as you progressively keeps discarding higher liquid of more impurity concentration and reheats and uses solid of low impurity concentration. You inch towards achieving pure purer solid.

So, eventually you will spend a lot of liquid which is basically wasted which of course, can be reused it is not wasted as such. But, you eventually reach you eventually achieve purer solid in very small amounts. This is of course, a thermally very taxing process, you waste a lot of heat. It is a use of high temperatures you waste a lot of material.

And it is a time taking process, it does not happen all of a sudden, you have to allow the equilibrium to achieve and then hold it for some time before you will carry out the solidification then you watch out very carefully so, that the solid formed is very little in the amount. So, that solid is very pure as compared to liquid and then you remove that solid throw with a liquid and then again you heat that solid, again you extract the purer solid and again through with the liquid and this process keeps going on. And you form a very pure solid in very small amount.

So, this way one can reach concentrations of so, one can achieve p p m level impurity levels. So, this is for example, important in silicon, germanium and lot of other materials. So, zone refining is one very important application of phase diagrams, this is used typically for making semiconductor.

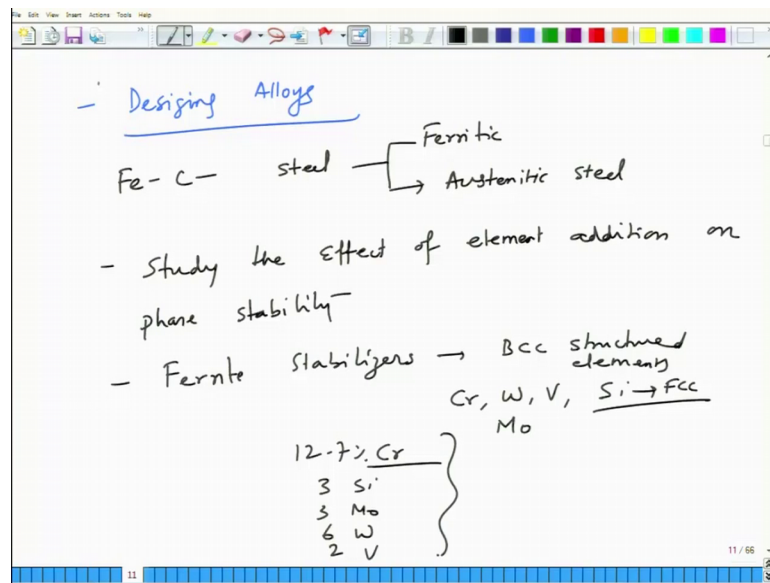
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Similarly, another application another method in which you do zone refining is you take a rod and then you progressively start. So, this is  $n_1$ , this is  $n_2$  and you progressively heat the rod. So, the end at which you start you make it end up making purer as compared to rest of the rod.

So, solute keeps shifting to the right as a result you end up making this end very pure. So, this could have a purer side and this could end up being a impure side. And this is as a result of partitioning of solute as a function of time and progressive heating and cooling cycles. And again in about 10 cycles, 10-15 cycles you can bring the concentration down about a ppm or so, again a very useful process.

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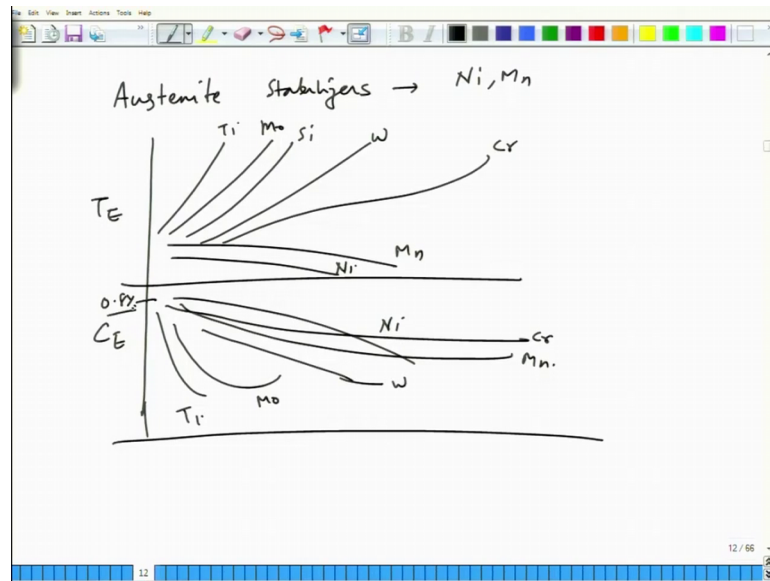
And then finally, one can use phase diagrams for designing alloys. For example, in case of iron-carbon, iron-carbon we know is the steel. But, there are couple of steels which are available in practice for example, you have ferritic steels, you have austenitic steels austenitic steels. For example, have better properties as compared to ferritic steels in terms of mechanical properties especially the impact toughness and because ferrite because F C C phase the steel has very good low temperature strength.

So, you can look at the effect of elements of so what you do is that you study the effect of element addition on phase stability. So, as we saw briefly in the last class you have in case of steel you have ferrite stabilizers. Ferrite stabilizers are typically B C C structured elements with the exception of silicon.

So, you have chromium, you have tungsten, you have vanadium, you have silicon. Silicon is F C C, but not B C C silicon is F C C, these elements are ferrite stabilizers. So, when you add them to steel similarly you can have molybdenum as well here.

So, critical time amount of silicon so, you if you add 12.7 percent chromium. You will have ferrite stability, if you had 3 percent silicon or 3 percent M o, 6 percent tungsten or 2 percent vanadium. So, all these are critical numbers which basically allow ferrite to become stable and. So, austenite basically vanishes it becomes enclosed in a loop.

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Similarly, you have austenite stabilizers and they are such as mainly nickel and manganese and both nickel and manganese provide stability to austenite.

So, if you so, that basically it suppresses the eutectoid temperature. So, if I plot the effect of these elements on eutectoid temperature. So, if so, for example, titanium, molybdenum, silicon, tungsten, chromium; so, this is chromium this is tungsten, this is silicon, this is molybdenum, titanium, they all increase that eutectoid temperature which means they make ferrite more stable.

If you look at manganese and nickel; manganese, nickel they decrease the eutectoid temperature which means they make the austenite region more stable. Similarly, eutectoid composition as generally decreasing with decreases with element addition, nickel decreases the eutectoid temperature. This is for example, chromium you have similarly manganese and then you have titanium, you have molybdenum and you have tungsten and so on and so forth.

So, most of the elements that decrease the eutectoid composition from 0.8 to lower so, this is 0.8 percent and they decrease the eutectoid composition and depending upon the nature of the element they decrease or increase the eutectoid temperature.

So, these are certain applications of phase diagrams in determining solidification, it determine in controlling segregation, in determining from the heat treatment protocols,

homogenization temperatures and in carrying out zone refining, as well as in looking at the effect of various elements on stabilized you know phases. So, this is what so, phase diagrams are very versatile, one needs to study them in detail. So, we have discussed quaternary and binary phase diagrams and in the next lecture what we will do is that we just review the course once before we finish this course.

Thank you very much.