Phase Equilibria in Materials (Nature and Properties of Materials - II)
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Lecture – 21
Microstructure evolution in Cu-Ni binary system

So, welcome again to a new lecture, this is lecture number 21 of Phase Equilibria. So, we will just, we will first recap the last lectures content.

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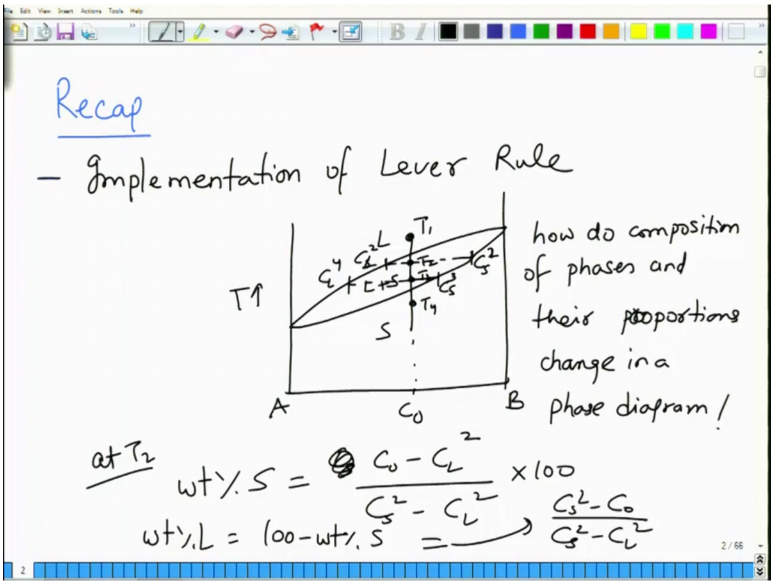

So, in the last lecture, we discussed about implementation of lever rule in a binary phase diagram. So, we considered a phase diagram like this. And in this diagram, we considered the formation of phases at various temperatures. And so, basically we looked at how do composition of phases and their proportions change in a phase diagram this is what we discussed.

So, we had alloy composition C naught and we looked at various temperatures T 1, T 2, T 3, T 4 and so on and so forth, it might not be in the same order, but roughly the trend that we looked at. And what we did was we basically looked at the composition. So, this point for example, a single phase region, its composition is C naught T 2 point at T 2, you have two phases liquid and solid. Liquid composition is given by this point, solid composition is given by this point. At T 3 liquid and solid again are in equilibrium, but liquid composition now given by this point solid composition is given by the point on the right. So, and at T 4, you have again single phase solid whose composition is same as C naught. So, this would be say, CS 2, CS C L 2, this would be CS 3, this would be CL 4 and the proportions would have varied according to the compositions.

So, the proportions of for example, in this case percentage solid weight percent solid would be for instance at T 2, it would have been CS 2 sorry, C naught minus CL 2 divided by CS 2 minus CL 2 in to 100. So, this would be the weight percent of solid and weight percent liquid would be 100 minus weight percent solid which would be equal to CS 2 minus C naught divided by CS 2 minus C L 2. And that is how you work out the composition and fraction of phase fractions of different phases in two phase equilibrium. Now let us move on with it and see what we want to achieve in this lecture.

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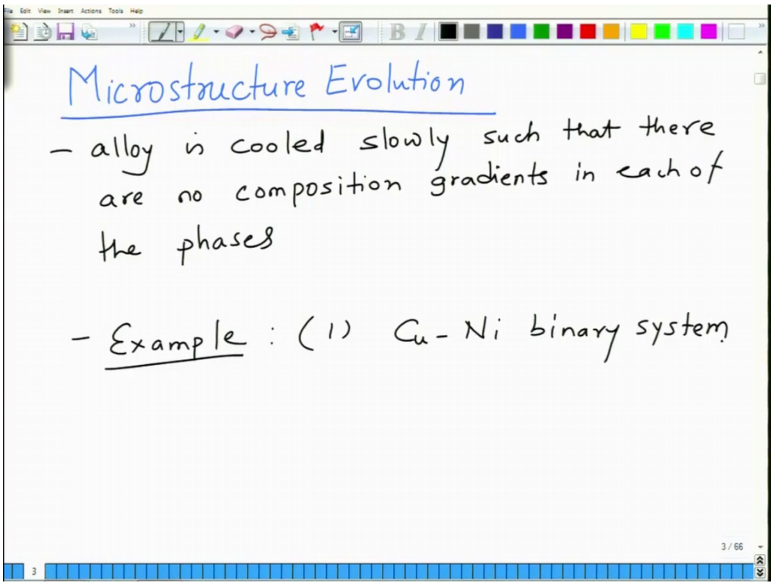

So, in this lecture again, what we do is that, we will first look at the microstructure development in a binary phase diagram. And then we again get back to calculation of various phases and their fractions in a especially in a eutectic system back, because that is what is most interesting, very interesting.

So, first look at the micro structure evolution and the condition when we which we consider is that alloy is cooled slowly such that there are no composition gradients in each of the phases. So, basically what we are going to talk about is how equilibrium microstructure develops in a binary phase diagram. So, first let us consider the case of let us say the example that we choose initially is a copper nickel binary system.

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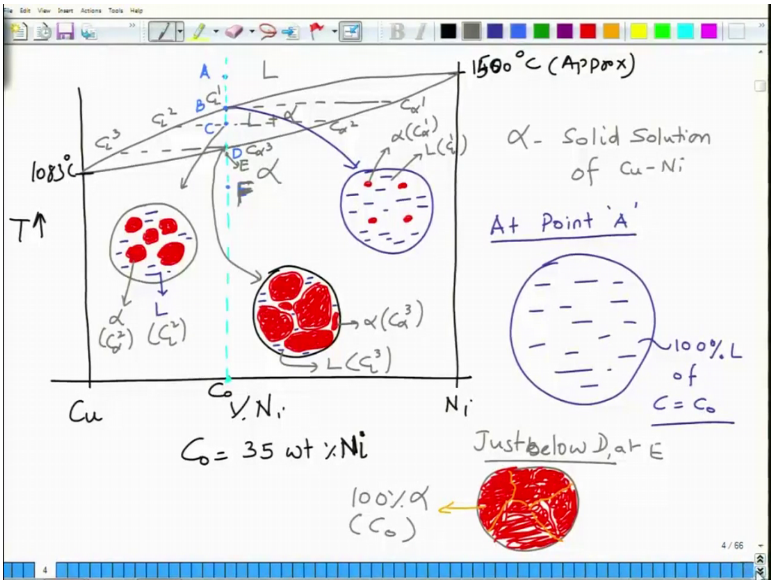

So, what we do first is? We first make a diagram. So, this is a copper nickel phase diagram, ok. In the copper nickel phase diagram at all of us know this is copper, this is nickel copper melting point is 1083 degree centigrade and nickel melting point is something like 1500 something. Let me just see how much is it? It is about, just one second, it is about 1450 degree centigrade roughly, it is not approximately, or maybe nearly 1500 degree centigrade. So, the phase diagram is so, let me just draw this a little further down.

So, they say this is 1083 degree centigrade, this is temperature this is percentage you can. So, the phase diagram would have, now behavior like that and about this point, you will have liquid plus solid and then you will have liquid plus alpha and then you will have alpha. So, alpha is basically the solid solution of copper, nickel, ok. It is basically substitution (Refer Time: 06:52) solution because copper and nickel are soluble in each other. Now let us look at the evolution of phases. So, let us first look at overall composition of about 35 percent nickel.

So, let us say we are at this point. So, if I draw a vertical line at this point, so, this is let us say so, we say that C naught is equal to, so, this is C naught and C naught is 35 weight percent nickel, ok. So, and we will look at the phase formation in such a manner. So, that we are at point A here, we are at point B here, we are at point C somewhere here and then we are at point D and then we are somewhere here point E right. So, that is how so, we will first look at what is the microstructure at point A. So, we can see that at point A, what you will have is you will have 100 percent liquid.

So, you can draw the phase diagram you can draw the microstructure. So, if you look at the, if you look at the system of this composition then you have liquid, 100 percent liquid of composition C is equal to C naught,. So, you have a 100 percent liquid of composition C is equal to C naught.

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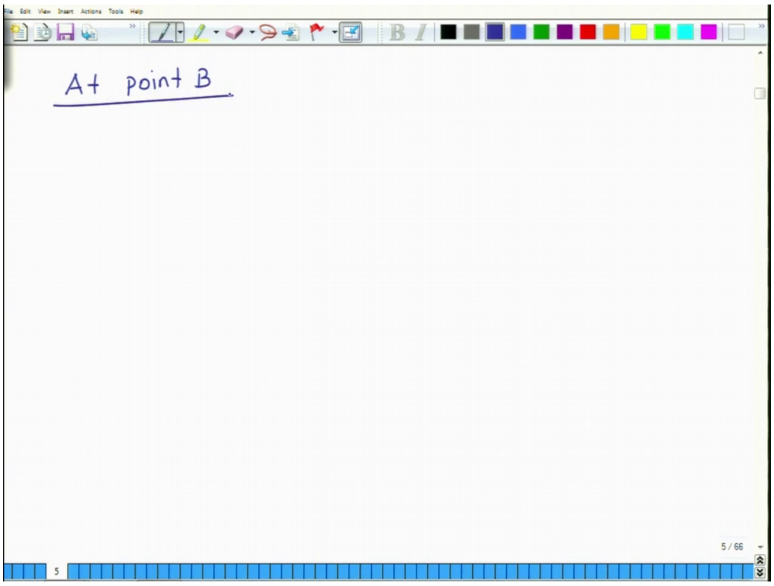

Now let us look at point B now. So, this is what, it will we also did in the last class. So, if you look at point B; point B will tell you so, this is at point A, point B will have some amount of alpha very tiny amount of alpha forming here and there. So, this is alpha let us say, but remaining is all liquid. So, this is newly formed alpha and this is all liquid and we can find out the composition of these two phases using tie line rule and the phase fractions using lever rule just like we did in the last class.

If you look at point C point, C will have this alpha would have grown and some more new alpha would have formed. So, basically what you will have is you will have bigger crystals of alpha. And the shape will depend upon various factors, but let us consider the shape will be a irregular, just it would have grown roughly equal in all the directions. So, sort of irregular shape so, this would be your microstructure at point C, this is alpha crystals which have grown bigger and some more have formed and your liquid phase has decreased in fraction as you can work out using lever rule. So, you have liquid phase, and the compositions etcetera you can draw by drawing a tie line which I have explained, how to do it in the last class and then we reach point D.

So, let us now look at point D, point D is the point which is just the solidus line. So, at point D, if you look at the microstructure, what you will have is you will have nearly everything is converted into alpha, you have very large grains of alpha. So, this is all alpha which has grown very big, let us say this is a more alpha here. So, you have lot of alpha so, this is alpha. And of course, you could determine the composition, the self are using tie line and then you have very little amount of liquid left here and there.

So, this is liquid. So, you have very little amount of liquid. So, liquid amount of liquid progressively decreases as it decreases the temperature, the alpha grows in size the composition of liquid becomes more and more rich in copper less in nickel. And the composition of solid becomes more and composition of solid also as compared to the first solid form comes closer to C naught which is the equilibrium concentration. So, this, this is let us say C alpha 1, this is C liquid 1, this is C alpha 2, this is C liquid 2, this is C alpha 3 and this is C liquid 3. So, this alpha would be C alpha 1 and this would be C liquid 1. At this point alpha would be C alpha 2 and liquid would be C liquid 2. At this point, it would be C alpha 3 and this would be C liquid 3.

So, liquid is getting, is getting smaller and smaller in proportion and it is, it is getting depleted in nickel gradually. The alpha also as compared to the alpha which formed right at the beginning has become depleted and nickel, but it is coming closer to C naught, ok. It is coming closer to the equilibrium concentration, because eventually when the whole solid forms everything should be equal to C naught. So, you have alpha approaching composition of alpha approaching C naught whereas, composition of liquid is getting reduced to very less nickel. And eventually at point E or even let us say at this point just below D, if you look at the comp, if you look at just below D, let us say just below D is the point which is E and we call this as F,. So, at E all of liquid would have changed into alpha. So, what you will have is something like this you would have.

So, these are grains of alpha which have merged into each other. Another grain of alpha which is merged into which is grown bigger and this is another grain of alpha which is grown. So, this is all alpha, I can go to grain boundary using another color. So, you will have grain boundaries something like that these are the different nuclei of alpha which have grown and impinged upon each other. So, what you have at this point is 100 percent alpha of composition C naught. So, this is how the microstructure in a binary isomorphous system would grow and you can determine the phase fractions and compositions using tie line and lever rules.

Now, let us look at the fair, look at the formation of alloy in a now what will happen when the alloy is, now in reality we are doing this experiment. So, if you do this experiment, if you do it slowly enough, you will get what I have shown you, shown you here, but in very rarely in practice the cooling is slow enough to give you a perfectly homogeneous alpha phase and perfectly homogeneous liquid phase.

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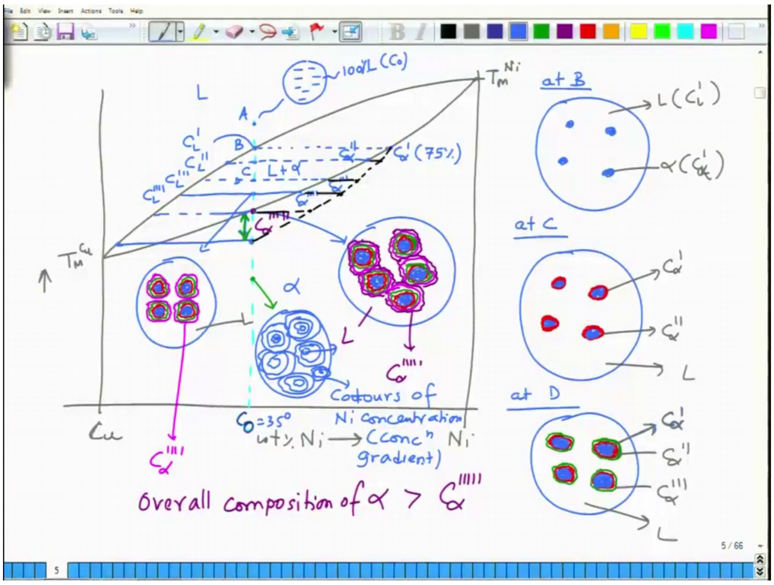

So, what will happen there is if I rub this point? What will happen there is if you now make a phase diagram of imperfect cooling of a system? So, this is copper, this is nickel. So, this is Tm nickel, this is Tm copper, and this is weight percent. Now what will happen in reality is if you now consider, let us say I have a composition, this composition C naught.

Now, what will happen in reality is you start cooling when you come to. So, you come from point A and point A will have a microstructure which is 100 percent liquid of composition C naught, ok. When you come to this point, let us say first point, when you come to first point at this point which is point B, you have liquid of composition CL 1 forming and solid of composition C alpha 1. So, this is liquid plus alpha, liquid and this is fine. So, your first solid forming of composition alpha prime, let us say this is nearly I do not know, we are starting at 35 percent. So, this is nearly let me see, let us say about 75 percent. Now what will happen at this point? If I look at the microstructure at B, you have tiny crystals of alpha formed.

So, this is and the remaining is all liquid. So, so you have liquid of composition CL 1 and alpha of composition CL C alpha 1. Now what will happen is that when you go down to point, let us say this point, now point C, this is point C, at this point ideally you should have all the solid of composition, this is C alpha double prime. Just and this should be the liquid of CL, CL double prime, but what happens in reality is that the first solid which had formed was this.

Now, the next solid which is going to form around these already formed nuclei is this layer sorry and, ok. So, the next solid will form around this, ok. So, what will happen now is now ideally whole of this solid would have been of same composition, but in reality the diffusion or the movement. So, basically overall composition should have been C alpha double prime, but what has happened is in the first alpha which formed was of composition C alpha prime.

The next alpha which is formed is C alpha double prime, because C alpha prime was unable to redistribute the nickel atoms to the next forming solid, because of lack of time, because you know movement of atoms in solids require times because solids are diffusivity of solid. As you will see the as you will see from the fundamentals of diffusion, diffusion is nothing about movement of species and movement of species or atoms or molecules in liquid phase as faster as compared to solid phase. In solid phase, the diffusion or movement of atoms is very fast, it would be quite fast at high temperature, but at relatively lower temperatures it is, it is lower than definitely in liquid.

So, what happens is that, if this alpha which is formed earlier is unable to release, it is solute to the newly formed alpha at lower temperature. What will have, you will have compositional difference or inner alpha which has formed earlier will be of composition C alpha prime and the outer alpha which is formed on the outer periphery, we will be of composition C alpha double prime. So, this would be the outer alpha. When you come to now point D, let us say at point D, again the newly alpha formed is of composition C alpha triple 3 prime and you have C alpha.

So, again at point D what will happen is that at D what will happen is that within this microstructure of course, this 1 alpha would have grown. So, I am just drawing it very schematically. So, this is the first alpha which formed at T 1, do not worry about the sizes, these are just schematic diagrams. So, this is alpha which is formed first, this is the alpha which formed which was added to previously formed alpha at T 2. And the next one which will form, will have, which will form at T 3 will have, I will be something like that. What you will now have is you will have this of composition C alpha prime, this of composition C alpha double prime and this of composition C alpha triple prime.

So, as you keep doing it, when you go to point 4 and this is because of relatively slower solid state diffusion of atoms than in liquid state. So, it is a similar cone, you can argue that similar composition gradient can also exist in liquid, but liquid is the redistribution of solute is faster and liquid as compared to that and solid as a result the liquid is fairly homogeneous as compared to solid.

Now, when you come to next point, at this particular point then the composition should have been C alpha 4 prime and this is C liquid 4 prime. So, when you come to point E so, point E, I can draw here let us say if not there. So, at point E, you will have so, initial alpha followed by the alpha which is formed at T 2, followed by alpha which is formed at T 3 followed by now the alpha that will form at T 4. So, this would be C alpha 4 and then you will have liquid. So, remaining so, you will have liquid, you will have liquid in all of them and the amount of liquid will reduce as you. So, now, when you come at come to this point when the solidification is nearly complete, when the solidification is nearly complete at this point, your microstructure will be. So, again sorry that blue one goes first.

So, the blue one, this is the blue one. So, then comes the red one and then comes the green one, then comes the magenta one and then can stall it say the purple one, the final one and so on and so forth. So, you will have now final one C alpha and this is liquid. So, what you see is that now ideally you should have gone along this line the overall whole solid would have been at C alpha prime, C alpha double prime, C alpha triple prime, C alpha 4 prime and C alpha phi prime, but in reality what has happened is that you have formed solid gradually and the first formed solid has a higher composition as compared to the last formed solid. As a result the overall composition of the solid so, overall composition of alpha is greater than C alpha phi prime. So, the one which is formed here is of this composition. So, ideally this last solid should have composition like this, but in reality you have composition starting from C alpha double prime ending at C alpha phi prime. As a result, the overall composition would be the sort of average of this two, so the solid composition will now vary in this fashion.

If you look at the solid composition the solid composition will vary as, as this dotted line because the overall composition of solid is higher. So, solid composition will be shifted here, here, here. So, this is now the overall composition. And as a result what happen what happens is that in a binary phase diagram by diagram the solidus line is shifted downwards. As a result you will still have some liquid left at this point. So, the last liquid to solidify will not be at this temperature, the last liquid to solidify will be at this temperature, because the solid composition has changed. As a result the liquid is also getting more and more depleted in solute, because the solid compositions more than what it should have been at equilibrium so liquid has gotten depleted and this solid has shifted further downwards.

So, because of this the, the last liquid to freeze would be at this point. So, you will have some solid and this will be the last liquid to freeze. So, this is the extra degree of cooling that one needs to provide, because of inhomogeneous compositions, because of non uniform cooling, because the solidus line has shifted from here from there to here. This is the shift of solidus line that you will obtain. And as a result you will have liquid present in the microstructure not until that not until this point, but until this point.

So, this produces a microstructure which is very homogeneous and that is why one needs to carry out heat treatments etcetera to further home realize the micro structures. So; obviously, at this point what you will obtain, at this point is a microstructure which is so, which is basically microstructure with composition variances.

So, you will have rings of different contours of different compositions I am not using different colors now. So, this is how the composition will vary inside the solid. So, these will be the contours of nickel concentrations or you can say this will be the concentration gradient, concentration gradient. What we have done in this lecture is we have looked at the microstructure evolution in the binary system, copper nickel system in under both equilibrium non equilibrium condition. We will further dwell on this in the next lecture, before we study the solidification in a eutectic system.

Thank you very much.