Phase Transformation in Materials
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Lecture – 50
Introduction to Spinodal Decomposition

We are going to start a new topics today and that is on Spinodal decomposition; this topic is little new to you because normally Spinodal decomposition is not taught in many of the be take curriculum and across the country. So, I request you to be very attentive and listen the things very patiently; obviously, we cannot talk every details of this transformation, but I will try my best to put things together. So, that you understand what is it? It is a decomposition; so; that means, some phase transform to other phase or more than one phases.

So, present phase transform to more than 1 product phases. So, it is a decomposition just like if you take a material heated inside a furnace it can decompose into different phases similarly same thing happens or not that needs to be seen, but it is in decomposition in that way.

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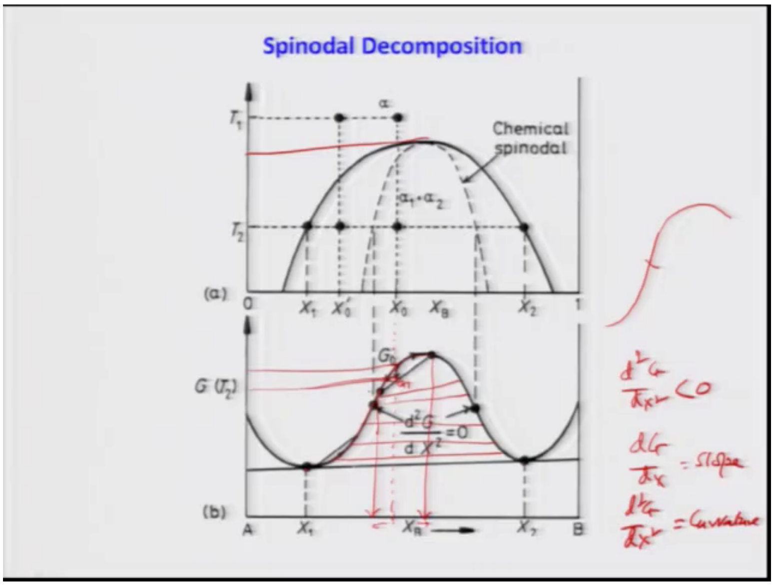

Spinodal Decomposition

Now, what kind of decomposition it is as you know this is observing very very peculiar phase diagrams the phase diagrams which shows the free energy versus composition diagram the one like shown here we have discussed the quasi chemical theory sometime back as a part of this course and in that quasi chemical theoretical approach I discussed that depending on the type of interaction between these solvent and solute atoms in an a solid solutions different kinds of free energy versus composition diagrams exist and the one which is very very distinct and different from the normal solid solutions is in which is the one in which the free energy verses composition diagram. So, say humph just like a road bumper. So, you can clearly see that free energy initially was like this then it decreases then his passes through minimum again increases reach a maximum value decreases again increases.

So, as you go from pure a to pure b ends only at the both ends the free energy decreasing initially as the composition of the solute increases as a composition of b increases the free energy is decreasing, but then there is a composition beyond which it start increasing and reaches a maximum value that is why I say it. So, say humph now once whenever you have such a kind of situation this happens only when the interaction between similar atoms are stronger than this similar atoms what does it mean in a solid solution suppose you have a and b type of atoms. So, there are three different types of interaction one can have interaction between a and a atoms b and b atoms and a and b atoms.

So, to first 2 interactions are similar type of patterns atomy interactions and the last one that is between a and b or b and a; they are similar this is this similar type of atomy interactions now if in a solid solutions the interaction between similar atoms are stronger than the dissimilar atoms. So, what will happen the solid solution will be not exactly solid solution by till even as a cluster of different similar atomic PCs a will you more preferred, then a b. similarly b; b is more preferred than b; a b. So, therefore, system will like to have more a and b; b bonds than a b bonds the analytically favorable such situation will gives rise to this kind of free energy curve which will come very clear later on.

Now, if you have a such a kind of free energy curve we can use this free energy composition diagrams to generate phase diagrams we know that normally we in the lectures we do other way we just show you free energy composition diagrams when you know the phase diagram, but normally free energy composition diagrams obtained at different temperatures can be utilized to generate the phase diagram. Now here the phase diagram is shown on the top.

So, let us first look at the solid line on the phase diagram. So, because of the presence of this kind of hump in the free energy composition diagram you can see that its shows a dome stable structure is less goes up and then goes down this dome repre structure now such a kind of phase diagram is a signature up what is known as spinodal decomposition let us explain in detail what actually happens given that do you know the phase diagram exists only I am asking you to concentrate on a solid line do not look into other parts now which will be coming slowly.

So, now suppose if I take an alloy composition alloy composition X 0 that is what is dotted line shown. So, at T 1; this composes alloy of this composition X 0 will be a complete random solid solution of alpha that is as shown there now as we cool down this solid solution alpha supposed to T 2; let us supposed to its quench instead of cooling because now you know what is quench we have discussed lot of about quenching martensites in steels. So, let us suppose I take this alloy quench from T 1 to T 2 correct as you see as T 2 that is what is written at this temperature alloy will be having a free energy given by G 0 here you see there because this is also composition x this composition x is. So, I can as a X 0 it will as a free energy up G 0; I can dotted line can be drawn and shown

So, now question is this at this temperature this solid solution is not stable why that is observable clearly from the free energy versus compression diagram why it is. So, it is very clear that even if there is a small fluctuations smallest possible fluctuation let us suppose a composition in this solid solution alpha at temperature T 2 these fluctuations can grow why.

First let us see that suppose as I told you the free energy of the solid solution at temperature T 2 is G 0. Now if it decomposes into 2 phases of composition suppose one having composition given by these point other one is these point and we have shown there is a line joining these 2. So, therefore, the free energy of that solid solution G 0 can be reduced to G 1; here you can see here G 0 1 by decomposing into 2 solid solution this one and this one you may ask how say if I have 2 solid solutions one as a composition of this one and another one as a composition of G s 2 because of decomposition of the solid solution alpha into 2 different solid solutions composition of these and these.

Now, what will happen the average free energy value of these 2 phases is given by G 1 that must lie on this line that is obvious because average is whatever is nothing, but free energy of this multiplied by the mole fraction of that and free energy of these multiplied the mole fraction of that that is that is; what it is a one fraction of that rather mole or mole fraction.

So, this will lie on this line and this will be just below this because the composition of the solid solution initial solid solution was x 0, but if you look at carefully it can still decompose keep on decompose like this and 2 different solid solutions can be produced. So, what is the meaning of the decomposition; the decomposition will happen in such way; it will produce is phase which you reach in a produce another phase; it will reach in b that is what you see here this one; this one reach in a reach in b reaching more a reaching more b reaching more a reaching more in b slowly this will happen.

Now, this process will occur for any alloy compositions for any alloy compositions this process spontaneous process will occur with any alloy compositions for which this condition is satisfied what is that the double derivative of G with respect to the composition must be less than 0; that means, that equivalent to saying that this will happen till this inflection point on this curve what is an inflection point as you see here this one is one curve that one is another curve right you see I prepared draw it here this is one curve this is another curve part of the same curve, but this is concave this is convex.

So, there is a inflection point what is the inflection point inflection point is where the curvature is changing the curvature is always given by double derivative you know the slope is given by single derivative this one is slope and this one is tells you the curvature. So, as you see a curvature is changing from negative to positive I do not know that is anyway curvature is changing does not matter where the negative deposit, but this changing. So, when it changes form or changes a sign there must be 0 point it cannot go through directly from positive negative or negative positive, but that must be. So, that is why these points are shown as a double derivative to equal to 0.

So, this decomposition which is happening spontaneously leading to 2 phases a reach and b reach can easily happen without even percent decrease requirement of nucleation this is something which is not easy to understand this is a spontaneous process does not require a nucleation and so corresponding to these points we can draw another curve. So, that dotted curve which is shown here is known as chemical spinodal and; that means, any alloy composition within this range will undergo decomposition as I just now I told you spontaneously decompose into 2 different phases at temperatures below this that is what is known as spinodal decomposition I hope I am clear to you understandable to you also.

The whole process which I described you just now thermodynamically as well as using phase diagram is known as spinodal decomposition; remember, this is one of those processes very few where you do not need nucleation of the second phases apparent phases; the composition fluctuations whatever exists in the material grows spontaneously and this happens within the chemical spinodal decomposition.

So, now, question is that will it stop here decomposition? No, why because you see here still it can reduce the free energy till these 2 points reaches then all the free energy is increasing as you increase the composition. So, till this point here you see this 2 are till this points; the chemical decomposition will keep on happening. So, finally, any alloy will decompose into a and b these compositions given by X is E 1 and X a 2 at temperature T 2, but alloys whose compositions lie between you know chemical spinodal and this solid line here also between chemical spinodal and the solid line; they will undergo nucleation and growth this kind of decomposition happen, but it will happen via nucleation and growth.

So, any alloys outside this chemical spinodal small variation and compositions you will lead to increase in finance you and the alloy therefore, is metastable. So, in the finance system can only be lowered or decrease if a new nuclear of the new fridges formed with a small with a composition very different from the parent phase. Therefore, outside the spinodal composition; transformation must proceed by nucleation and growth and normal down will diffusion. Just now, I discussed you to down will diffusion will happen see why it is called a down will diffusion normally diffusion will happen down the compress conservation gradient.

So, therefore, in the alloys; so, that is what you seen in many of this process. So, there is a paralytic transformation or its some it is any other transformation which have seen why request diffusion precipitation also diffusion always happened down the constantly let us call downhill diffusion, but within this chemical spinodal diffusion happening our field why because the alloy is having this composition X 0 as you see here X 0 with certain amount of a certain amount of b, but a decomposition in such way that a regions become more a rich be regions become more be rich.

What does mean as it decomposes into these 2 all praises a the process of decomposition must be such that a will go to a b will go to b reached regions which is opposite right normally a reached regions a must diffuse from a reached regions to the b reached regions why because that is what the compositional gradient will decrease, but in this case, it is happening other way here a reach regions a will move more into a reach regions and b will move more into b reach region and that is what is known as our field diffusion. So, diffusion happening against the compositional gradient this is failed very widely accepted thing happens in the literature.

So, let me discuss some more stuff with you. So, again that diagram was taken from the book of porter and sterling this is taken from Jena and Chaturvedi similar things is to see here.

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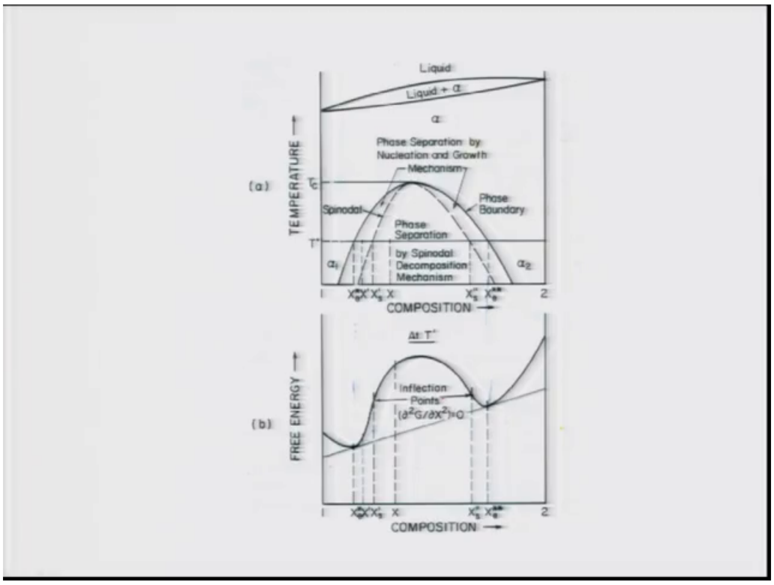

So, as you see here this is a complete phase diagram up the top portion. So, say I saw her first type phase diagram leaves the formation of dissolution is alpha at temperature above T c the alpha is stable, it is a random solid solutions temperature below T c in undergo spin orderly decompositions and everything is. So, near inside curve is known as chemical spinodal where that is where the transformation will happen via spontaneously composition no need of nucleation between the spinner the dotted line a dashed line that is what is chemical spinodal and these solid line the boundary of this spinaodal nucleation and growth can happen.

So, that is what is shown here phase separation by spinodal decomposition and here space separation by nucleation and growth be careful about this and we told you why does it happen as you grow past this inflection points the free energy and the free energy will you know decomposition is lead to increase in the free energy that is what is you see correct small varies in a compositional lead to increase in free energy as you go beyond these 2 points impression points.

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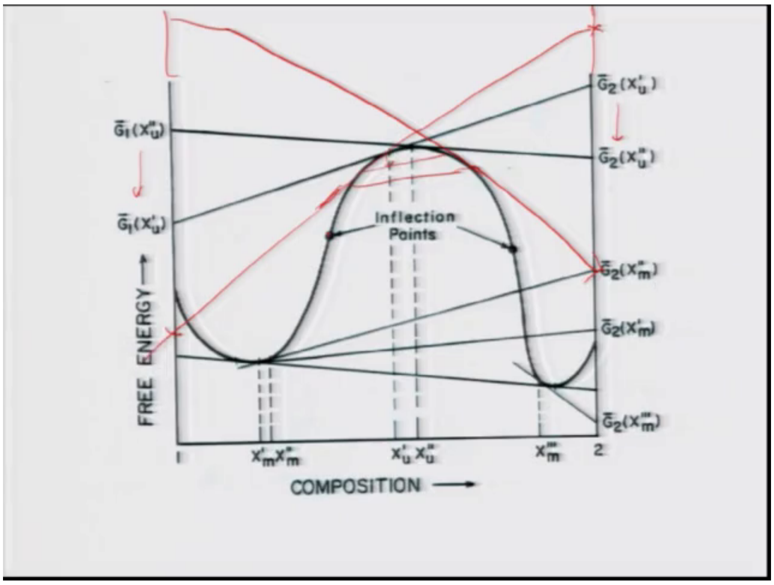

And that is why the only way it can it can reduce this free energy system by nucleation growth and this is the basically blown up view of that whole situation and little more aspects which needs discussion; as you see here, this is a free energy curve, it shows a hump with the 2 inflection points and I will just draw and then remove it show you how this inflection points develop see this is a curve with this kind of slope and this is a curve with this kind of slope.

So, and therefore, there is a change of curvature and this change of curvature is given by this spinodal d.

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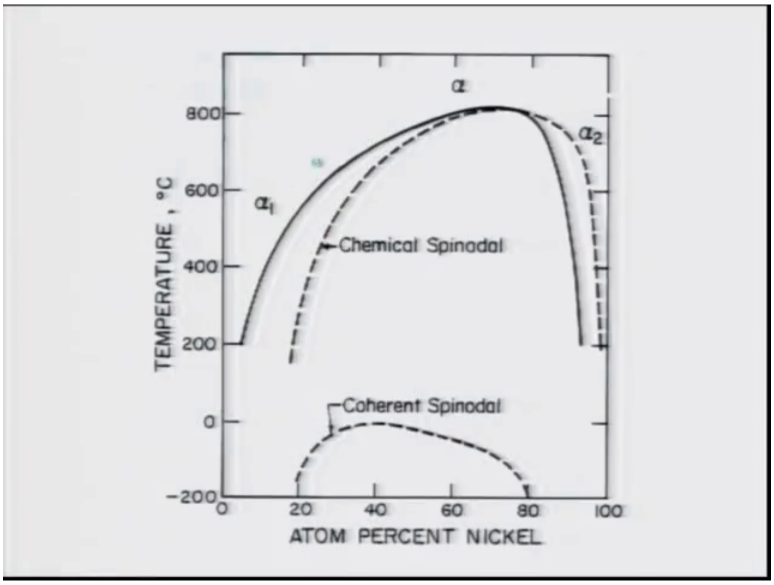

What is that one as inflation points? So, now, let us first explain in terms of the chemical potentials and I am going to show you 2 important points on this diagram let us first take this chemical potential here at the top of this tone; that means, let us suppose I draw a tangent to the curve and if I do a tangent to the curve for xu dot this is x u dot compositions I draw a tangent.

So, what will happen if x in the tangent what did he give; it will give the chemical potential that you know. So, a chemical potential means the G 1 bar and G 2 bar for component 1 and component 2 for a chemical composition for a composition of the alloy x u dot; this is taken lightly from the book of Jetton Jena Cheturvedi. So, I am not changed the symbol symbols a little bit around not simple one by the way, but it explains the things very nicely.

So, what will happen this is the chemical potential of component one chemical potential of component b correct. Now question is this why it will you know any kind of decomposition must lead to reduction of the chemical potential; right that you know because chemical potential must be equal, then only this will be the transformation will be same. So, as you clearly see for the composition x u double prime chemical potential of component 1 chemical component 2 is given by this.

Now, so; that means, what chemical potential of one can be decreased this way chemical potential of 2 can be decreased this way correct so; that means, what; that means, that any other composition lying on the top of the dome; they can reduce the chemical potential where decompose into 2 phases this can go down or this can go you can reduce easily. So, you can see here if I draw a tangent here this will be you can see that this is the chemical potential here and this is if I draw a tangent here chemical potential will be like this; it is a chemical potential of component 1 chemical potential component 2 component 2 component 1. So, it is getting reduced right. So, in the reach region chemical potential of component 1 is very low b reached chemical potential component 2 is also low correct.

So, similarly if I do it at this minimum points here on this curve you can see our x prime m and x double prime m the chemical potential has sewn G 2 prime G 2 X 2 prime and x x prime double prime; it is very clear that this is the chemical potential can be reduce farther down as you go along this. So, that is the basic mode of transformations. Now before I go to the kinetics of these transformations let me just show you few of these important phase diagrams and micro structures in next 4-5 minutes this is I think phase diagram between nickel and cobalt as you see here there is a chemical potential here chemical spinodal here and this spinodal alpha is going to transform into alpha and alpha 2 and there is in coherent spinodal which will discuss later maybe next class. So, what is it, but that is how the phase diagram looks like ok.

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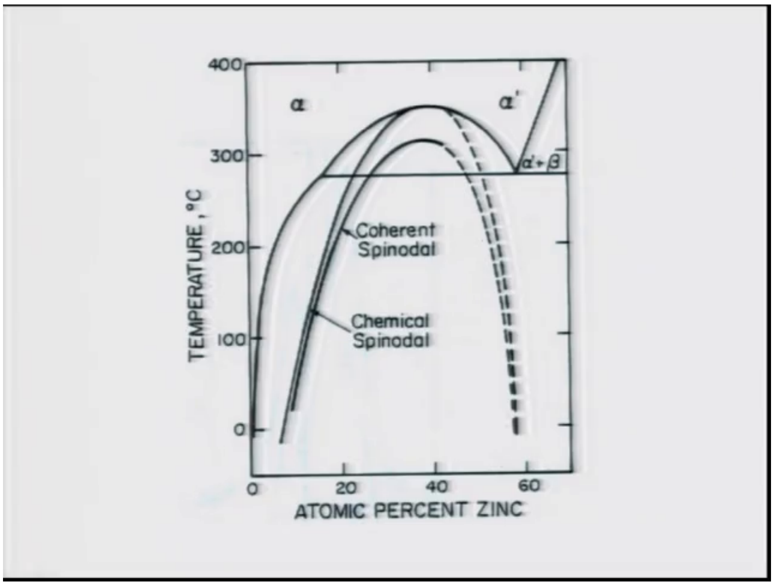

Now, here this is again I think this is zinc copper zinc probably up now aluminum zinc yes aluminum zinc as you see here again although the boundaries. So, there is a chemical potential and a coherent presence spinodal which will discuss later; what is coherent spinodal as the alpha can decompose into 2 phases came this spinodally.

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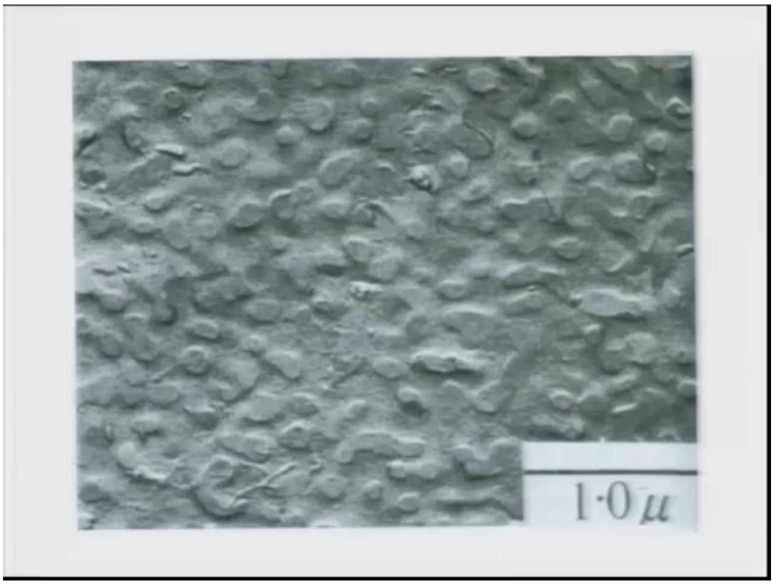

So, what are these pictures shows these pictures shows that if the chemical spinodal decomposed regions you see here how these 2 regions from one is this; other one is these one is these other one is these 2 compositions can easily form.

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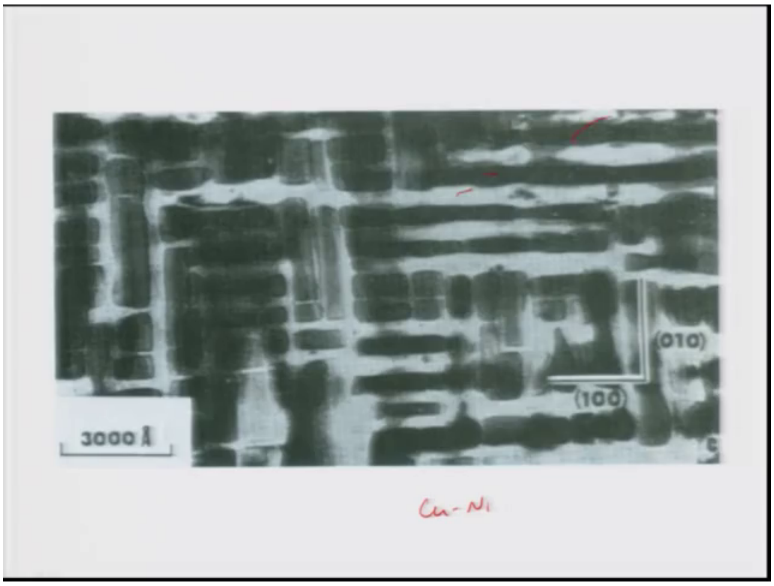

Some of the microstructure which you were able to see this is also another one is basically shows the chemical the spinodal of the decomposition of the 2 phases; 1 is white color, 1 is a black color dark field image take tons electron microscopy this is a copper nickel alloy copper nickel it must be and it shows that there is a compositional you know variations across 1 O O directions this is 1 O O, this is 0 1 O. So, basically; that means, that another both directions the spinodal decompositions that the fluctuations waves are the decomposed zones actually created you can see the fluctuation website this is like this you can draw that increase here in the middle decrease here in the middle; that means, if you drop our white page this will be opposite black page which I have drawn.

So, in the both sides both direction it exists many cases many of the alices add in silicon it sources various fine scales spinodal decomposition still tracks chart. So, this is how the microstructure looks like these are the small domains of composition fluctuations and these domains can then further grow and it become rich bigger.

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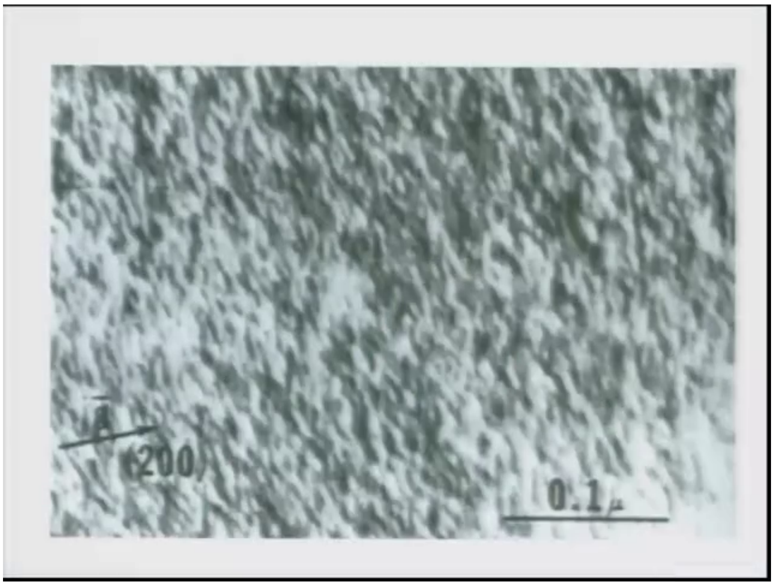

So, in a schematically we can actually show the next slide will be showing you that this is yeah.

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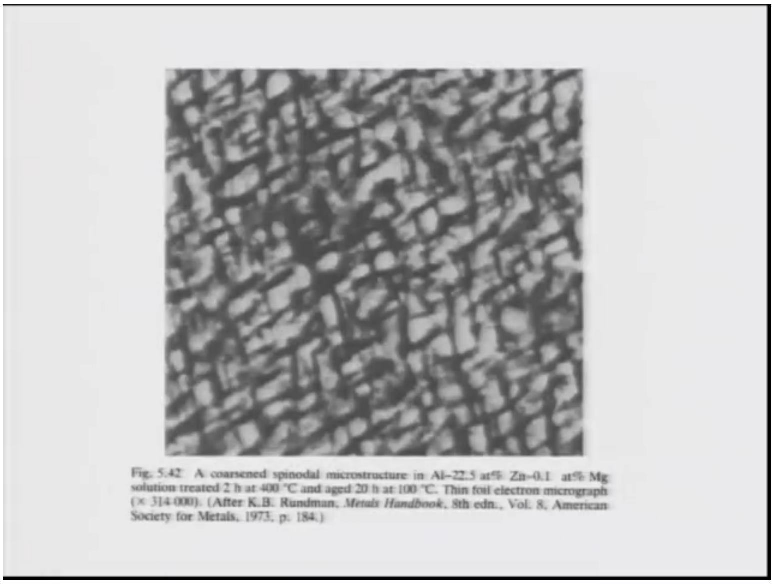

Fig. 5.42 A coarsened spinodal microstructure in Al–22.5 at% Zn–0.1 at% Mg solution treated 2 h at 400 °C and aged 20 h at 100 °C. Thin foil electron micrograph (× 314 000). (After K.B. Rundman, *Metals Handbook*, 8th edn., Vol. 8, American Society for Metals, 1973, p. 184.)

This another one is aluminum zinc magnesium alive this is been heat treated at 400 degree Celsius and aging for 20 hours for the solution treated at 2 hours per on degree and then followed by aging at 100 degree per 20 hours and see here that decomposed parts decompositions you can see that along this direction along this direction both at present.

So, there is some crystallographic orientation of these decomposed zones.

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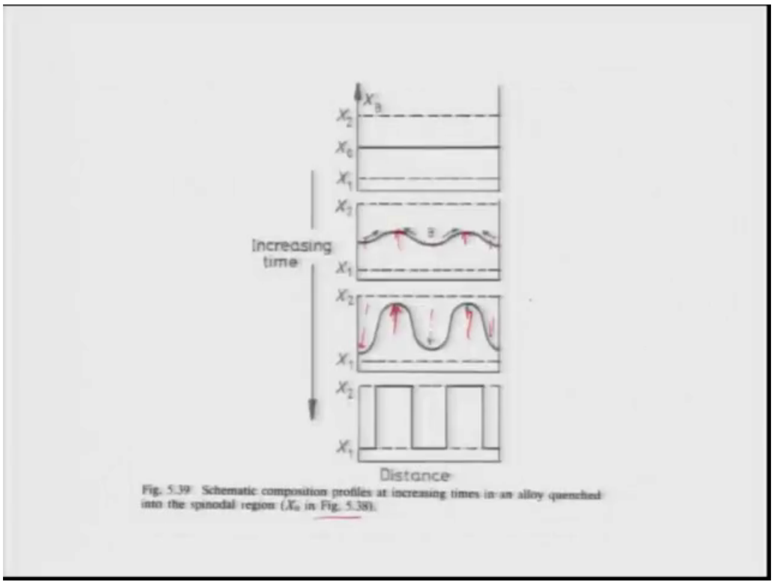

Fig. 5.39 Schematic composition profiles at increasing times in an alloy quenched into the spinodal region (X_0 in Fig. 5.38).

This is what exactly happens as you as you talk of the decompositions. So, suppose I have a alloy with a composition X 0. So, and then it is within the chemical spect neural chemicals spinodal regime. So, that put any small fluctuations with there will spontaneously develop as you see here these fluctuations are slowly developing. So, these decisions becoming be is diffusing out. So, decisions becoming a reach this is also a reach this is also a reach and these regions are actually b reach.

So, now slowly as you know slowly these regions are actually becoming bigger. So, b reach regions are becoming bigger similarly a b regions are also becoming bigger these are the b reach regions and these are the reach region. So, I am drawing by dotted line this is also dotted and this is continuous and finally, final microstructure will have completely decomposed per regions of a and b reach you consider X 2 and X 2 1; correct that is this; the composition zones of that. So, this is directly taken form that first one; I showed you let me go back this one; X 2, then x 1; you can see here this is directly done that. So, if you do that it is this will kind of things will form.

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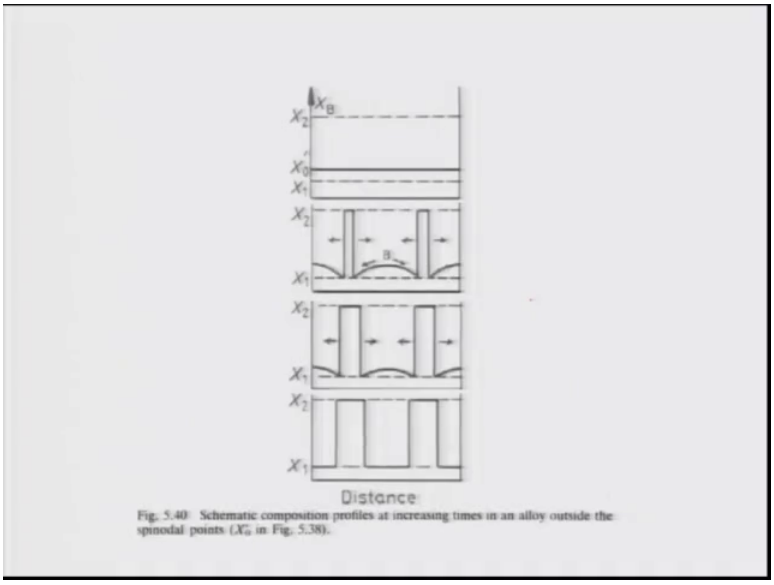

Fig. 5.40 Schematic composition profiles at increasing times in an alloy outside the spinodal points (X''_0 in Fig. 5.38).

So, now; so, this is the increasing time as a time increase this one will happen. So, that is basically what is meaning of spinodal decomposition that is the way we can actually explain; how spinodal decomposition occurs; how it happens. So, let us now discuss about the transformation rate and details of many of these things now as you know this is a diffusional formation very evident why because the atoms of A and atoms of B; B actually diffusing for me solid solution 2 different parent phase product phases one is a reach and P reach its evident. So, therefore, rate of the spinodal decomposition depends on the inter diffusion coefficient.

What is inter diffusion coefficient we know the diffusion coefficient of the individual components A and B in alpha phase the inter depletion means a diffusing from alpha to a decisions. So, that diffusional process occurring through a boundary correct we will see what is at boundaries in a once time and when it goes happens to a boundary. So, that is what we call inter diffusion from one phase to other phase the diffusion coefficient of that process is known as in the diffusion coefficient

So, now question is that within this chemic chemical spinodal d happens to be frankly speaking although it is not poss faceable and physical negative in the diffusion coefficient it because it is up yield diffusion so; that means, d has to be negative now compositional fluctuations will grow and it grows as a function of time as I shown you in the last part of the last lecture.

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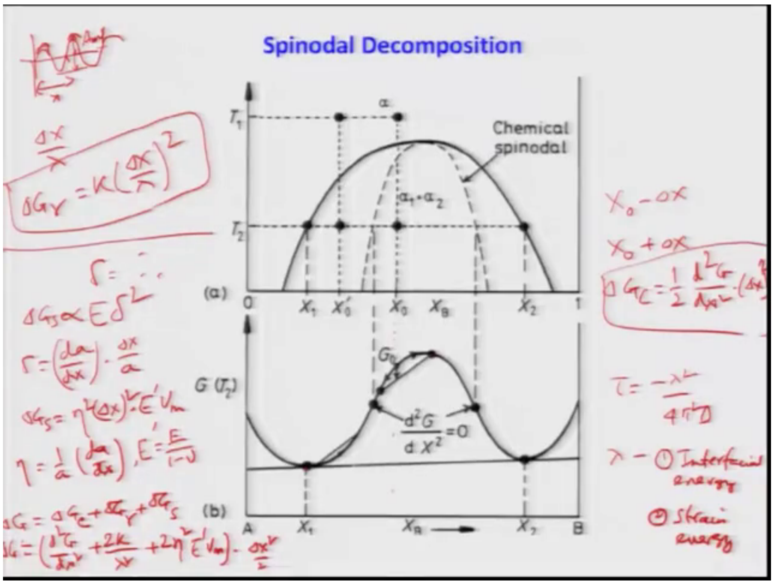

Spinodal Decomposition

And it seems the time scale is basically can be given lambda that the tau is basically equal to minus lambda square divided by 4 pi squared d here lambda is the wavelength of fluctuations remember I draw some at the end of the lecture, I showed you some picture where I draw some profile just like a sinusoidal sign way profile. So, if I have compositional fluctuations let me you show you that other this will not understand what is lambda the one I draw see I draw like this. So, you can see here it is like that this is for the white face correct. So, let me draw it here it grows right. So, the therefore, the wavelength of fluctuation is wavelength of the sinusoidal wave correct that is the wavelength and that is nothing, but lambda.

So, therefore tau timescale depends on wavelength square divided by 4 pi square d by d is the inter diffusion coefficient. So, as d becomes negative tau become positive because lambda square is positive pi square is always positive the d has to be negative. So, therefore, this is a time scale now rate of transformation therefore, is very high can be made very high by making a lambda where is small because; that means, tau can be weights very small by making a lambda small, but can you make lambda very small no lambda actually is cannot be made by small because lambda the wavelength of fluctuation can depends on many things that is what is our more the intention of discussions.

So, because there will be some minimum lambda below which you cannot reduce it further first panel decompression before we go into all this thing let us discuss how lambda is determine, but I do not think I can do to show you today’s lecture. In this lecture; how the lambda is determined, but I will tell you the process as you know if a homogeneous you know to do that we need to know the factors which actually determines these lambda. So, our basic purpose because as you said the kinetic depends on this tau; tau is the what is called this basically characteristic time constant and thus characteristic time constant tells you how fast the things will happen or how slow things will happen and this tau although; I am not showing the derivation mathematically has been shown it depends on wavelength of fluctuation lambda and the inter diffusion coefficient.

So, we must discuss these 2 things apparently, but as you know the lambda is basically square. So, therefore, by changing lambda we can change this tau very much by reducing lambda basically lambda actually depends on the wavelength fluctuation depends on in practice 2 important factors; first one is known as interfacial energy effects second one is known as the shear enrage effects. So, what are these? So, lambda actually depends on interspatial energy effect and stain energy. So, please do not ask me you do not know what is interspatial and instant energy things because we have been do discussing these things for many many transformation different types of transformations.

So, as you know in this picture, it is very clear that is suppose, if I take homogeneous alloy of alpha at temperature T 1 quench it to T 2, right that is what we have done in the first case and decomposes into 2 regimes 2 phases 1 that is compositions given by you know X 0 minus delta x other one is X 0 plus delta x delta x is the small fluctuation, right; in that in the case what is the chemical free energy chemical free energy means the free energy because of these chemic transformation when there is nothing else is present. So, chemical free energy is change rather chemical free energy change is given by delta G c you always write is given by half del double derivative of G respect to x square that is the curvature term multiplied by composition fluctuation square that is what it is; it has been shown the chemical free energy is given by this term.

So, now we know that if I have a solid solution homogeneous I quench into a lower temperature composition fluctuation develops and this composition fluctuation leads to change in free energy equal to half delta G star delta delta d squared G b divided by d j x square multiplied by delta x square correct now so; however, these 2 regions you know very small composition fluctuations are present delta x they are will be kind of a finely dispersed and let us suppose their coherent similar crystal structure their coherent with each other, but whatever situation because they are 2 different regions one having X 0 minus delta x other than a makes X 0 plus delta x.

This will lead to a interfacial energy effects because there is interface all the initial at the beginning of disparity decomposition the interface is diffuse you cannot really define because composition fluctuations are very small, but as the compo decomposition moves on the composition fluctuations become sharp and this leads to or rather a sharper I could say and this leads to interpersonal energy, right because we have a reach and b reach region as the time goes on the a reach b reach regions becomes very settle and clear. So, there is a composition deference; am I right.

So, now this leads to some effective interfacial energy contribution on the system because there is a sub boundary which is becoming sharper the magnitude of this energy is basically depends on the compositional gradient yes obvious because compositional gradient or compositional differences are become a slowly shuttle and because of that the interfacial becoming clearer. So, therefore, magnitude of these interfacial energy will depend on the gradient compressional gradient and that is why many people call this compo interfacial energy as a gradient energy the literature you will see people write it as a gradient energy correct and is very clear the gradient energy depends on compositional gradient how we can determine.

Let us assume you have a sinusoidal wave we have already assumed in cube when we talked about tau. So, sinusoidal wave will have a wavelength lambda and amplitude also a given by delta x delta x is what is the compositional fluctuation. So, if I have wavelength of wave given by lambda and amplitude of the wave and no I hope you know what is amplitude of all this wavelength if I draw a sinusoidal wave sin 0 is 0 here then it is just like this right slow. So, amplitude is given by these one right or rather one can do this way this is the amplitude and wavelength this you know that from here to there correct this is the lambda correct.

So, if I know this too, then we can calculate the gain energy term is very clear the gradient compositional gradient maximum compositional gradient is delta x by lambda that is obvious the gain energy term many times has written as delta gamma. So, delta G gamma is equal to constant k multiplied by delta x pi lambda whole square because that is the maximum possible gradient energy has to be scaled with square of that remember delta x as composition unit lambda has also is basically distance. So, that is why it actually comes k is a proportionally constants it depends on depends on the bond energies of the like and the unlike atoms.

Now, let me also tell you what is the origin of these this gradient energy in a solid solution which random then; that means, what probability of bonds between a and b is same as a and a and b and b correct, but when you talk about spinodal decomposition the probability of clustering of these atoms as more than random right; that means, a atoms like to be remain with a nearby b atoms would like to remain linear by b they do not want to be mixed together a b bonds are less likely if such is the situation a solid solution at the energy of the atoms like atom pairs is less than the energy of the unlike atom pairs. So, origin of this gradient energy is nothing, but increased number of unlike atom pattern with pair.

Initially composition fluctuation is small. So, therefore, unlike atoms are more than the like atoms as a completion fluctuation of wave length increases sorry the amplitude increases like bottoms like bonds are more than unlike bonds. So, that is actually happens at the end reason for this kind of gradient energy term is these unlike bonds presents in the solid solutions because energy of the like atom pairs less than the unlike atom pairs therefore, the origin of these gradient energy is nothing, but the increased number of unlike nearest neighbors in the solid solution containing compositional gradients compared to the homogenous solid solution.

So; that means, we know the chemical energy chemical free energy we know the gradient energy or the or the interfacial energy now we also need to know the energy of the strain energy term correct. So, what does all depends energy terms. So, therefore, this is my second equation this is my first equation what all these gradient energy this strain energy term depends on well size of the atoms that make up the solid solutions will not be same right because you see we have seen aluminum zinc copper nickel sizes are not same there are different distinct difference; difference may be small, but there are . So, therefore, the generation of this compositional difference a gradient will lead to a coherent system.

Now, it is a new term what is coherent system well it means that the misfit between a reach region and the b reach region misfit means what misfit means the atomic sizes are not same between a and b so; that means, the a reach region you have more a then a b, but the misfit does exist b atoms are there it is not there no b atoms. So, misfit that the difference between the size is difference between a and b; what is that is what is a misfit actual. So, that would this misfit between a reach and b reach regions suppose it is it is delta and delta is again difference of atomic sizes you can always define atomic diameter of a suppose atomic diameter a; if I write down d of a minus d of b divided by d of a yeah what is this what is misfit.

So, misfit is basically leads to what is known as this kind of the; depends in the atomic sizes. Now let me the explain further now if I know the misfit between a reach and b reach regions then I can calculate the strain energy strain energy is proportional to E delta square, but E is the elastic or young modulus basically at delta is your misfit between a and b these regions.

Now, how do you calculate delta delta is nothing, but this very simple da by dx what is a a is lattice parameter x is the composition multiplied by delta x by a a is the lattice parameter. So, a simple; that means, what if I do simple maths delta; Gs is nothing, but a constant term or basically eta square delta G x square multiplied by E dot pm where eta is nothing, but 1 by a and da by dx, right that is what is my eta and delta x square multiplied E dot and E dot basically sorry E prime basically E divided by 1 minus nu a nu is a Poisson ratio.

So, as you see here I can easily get these terms I should know the change of the lattice plane respect to composition, then only I can get eta and it goes into eta square. So, therefore, this is very important parameter and that is what the reason for your strain energy. So, as you know these are the three different components of the energy part. So, delta G total free energy change is nothing, but delta G c plus delta G gamma plus delta G s right and this can be easily written as double derivative you can see here double derivative of G respect to x square plus twice k by lambda square plus twice eta square because there is a half term that is what twice is coming into picture G c has a half that is what 2 is coming into picture the eta square E prime V m multiplied by delta x square by 2 correct because 2 has come out. So, 2 has to be going there that is a double double 2 k by lambda square to eta square.

This is my total free energy change correct. So, that is how actually you can calculate total free energy change of this spinodal decomposition now we can use this expression and I will not do it. Today I will do it in the next class to calculate what will be the optimum lambda and how things can be changed, but let me just tell you again I spent couple of minutes on that.

So, it is spinodal decomposition there are three important parts to free energy change one the chemical free energy change second the grain energy or the interpersonally G term third the strain energy term. So, what is chemical free energy term? So, if I have a homogeneous solution alpha of a composition given by X 0 and then it undergo decomposition leading to formation of 2 product phases with the composition X 0 minus delta x and X 0 plus delta x the chemical free energy is given by half double derivative G respect x square multiplied by the chemical composition square.

So, that is; obviously, that is because this is calculated from the free energy. So, therefore, double derivative comes in the picture now the gain energy is basically because of the gradient compressional gradient developed due to decomposition basically a reason is that there are; then a bond energies of the similar bonds similar atoms are less than the dissimilar. So, there for it does a dissimilar bonds there is in gradient and that is gradient is depends on the wavelength depends on the comfort the amplitude of the wave amplitude of the fluctuation. So, therefore, is b equal to k multiplied by a delta x by lambda whole square and the third time is the strain energy term it is mainly because of the change of lattice parameter with respect to the chemical composition.

So, you have a reach b reach regions there is a difference from the lattice parameter that is lead to misfit; misfit is leading to the chemical at the at strain energy and these equal to delta omega sorry eta squared delta x square E prime pm E is b primed this nothing, but E by 1 minus nu and then we can get these whole things. So, which I will stop here in the next lecture, we are going to discuss; how we can use this equation to explain the optimum value of lambda or rather we can calculate; what is the minimum value of lambda and then we can discuss some other parts of the phase transformation.