Phase Diagrams in Material Science Engineering

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Lecture - 12
Solidification of Eutectic, Hypo-Eutectic and Hyper-Eutectic Alloys and their Morphologies I

Hello. So, we have discussed first in the eutectic phase diagram in the last lecture and we are going to continue the discussion. For further details I told you that there are three different types of eutectic phase diagrams which are normally used in the literature. The first one is this type.

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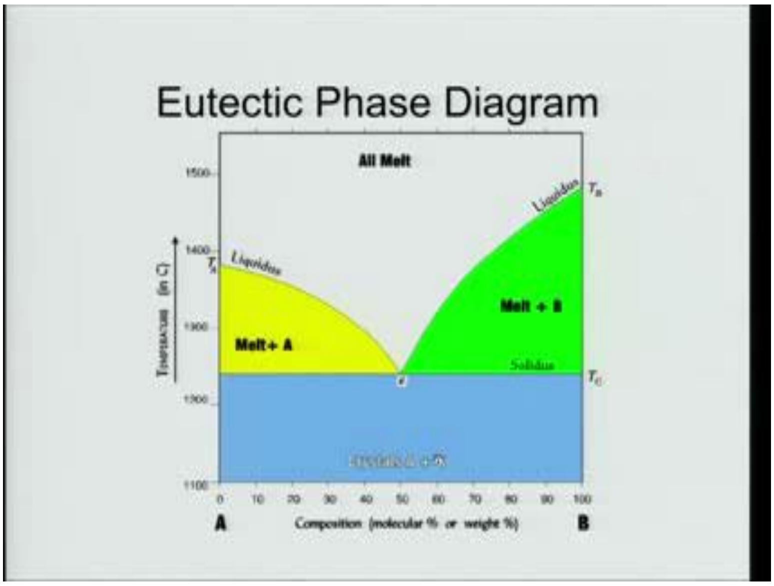

First one has very simple one in which we have the two liquidus surfaces coming and meeting at a point on the eutectic temperature line and that point is given by e here and on the left side, the region which is marked as yellow is consisting of liquid plus pure a. Pure a is the component on the right side, the green region consist of liquid plus pure b. That b is the second component and below the eutectic temperature which is given as t e that you have only a plus b as a solid. So, that means the eutectic reaction is given by liquid going to a plus b, choose a first type of phase diagram which we have discussed, second type of phase diagram is like this like a lead and tin in which we have the eutectic reaction at the temperature, eutectic temperature of 183 degree Celsius here for the related system, but also we have two n's.

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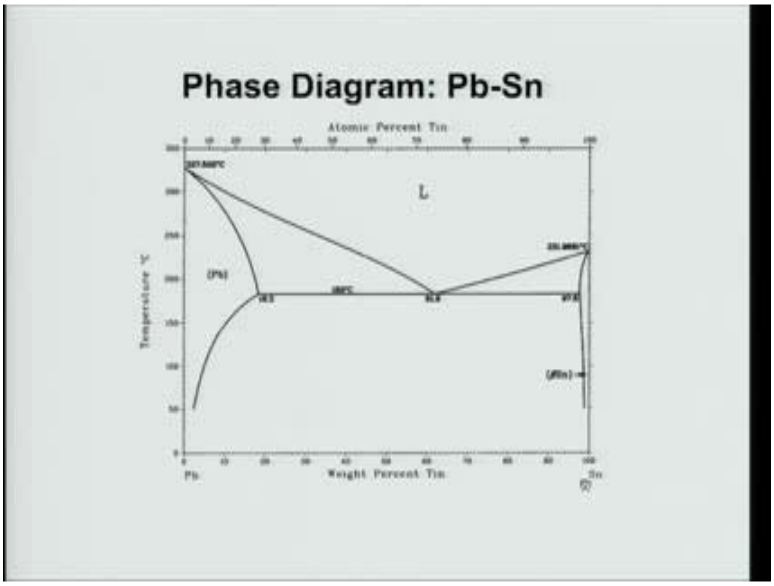

Now, the two ns means there ns of these two components are not as pure, but solutions of lead and you know tin is present on the left side and the right side, you have solution of tin in which lead is present. So, that means these are two are called terminal solid solutions in the literature terminals because the ends of the two components and that is why called terminal solid solutions and because of the presence of these two terminal solid solutions, they will take two reaction is little bit modified. Liquid goes to lead solid solution plus tin solid solution and this is the second diaphase diagram. Third diaphase diagram which we will discuss with a later part is known as aluminum silicon system which we will discuss later.

Now, let us move and show you, I will show you first some typical microstructure of the eutectic systems. Now, we will discuss how these microstructures actually formed because as you understand eutectic phase diagrams has the reaction even by liquid going to two solid phases. So, because of this simultaneous formation of two solid phases from the liquid, there are different types of microstructures which can form during solidification. So, therefore we have many choices or many rather not choices many different types of microstructure possible. So, I will start for the classical lead tin example because lead tin use a solder material still now for all electronic gadget. So, because of that lead tin is a classic system.

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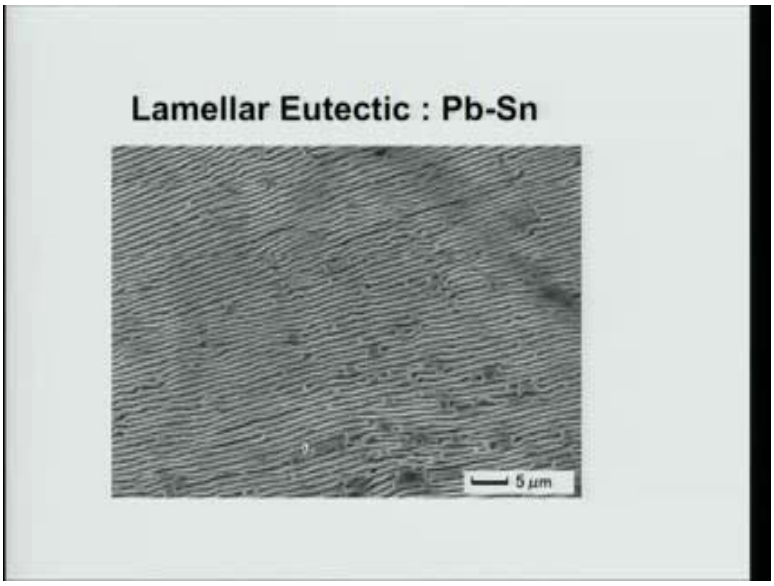

First microstructure which is showed you as a lamellar type for the lead tin eutectic system, you can see here that we have a white or gray rather gray and black, namely I could say this time lamella or lamely. Lamella is basically a singular in English and lamely is a plural in English. Lamely means many, lamella means 1.

So, you could see here for this gray region, I can point out here gray regions. They are basically tin and the other hand the black ones are basically lead, but they are in a lamellar morphology. What is the meaning of lamellar? It means they are slabs. They are actually slabs sitting on each other like this, one above the other. So, tin eventually they are slabs and when we cut and see another optical of microscope or scanning electron microscope, you see two dimensional sections and there it looks like a line or like a curve. So, here you can see continuous, you can see the curves going from one end to other end and this is the classical microstructure eutectic.

So, whenever you see such kind of microstructure features in any sample while examining, suppose in your lab by using optical microscope or SAM, you tell this is due to eutectic reaction whether eutectic reaction is given why liquid going to lead solid solution plus tin solid solution. Here tin is in beta phase. So now, one can actually see similar to this microstructure in you see complex simulations and you can see here three dimensionally, they look like a slab.

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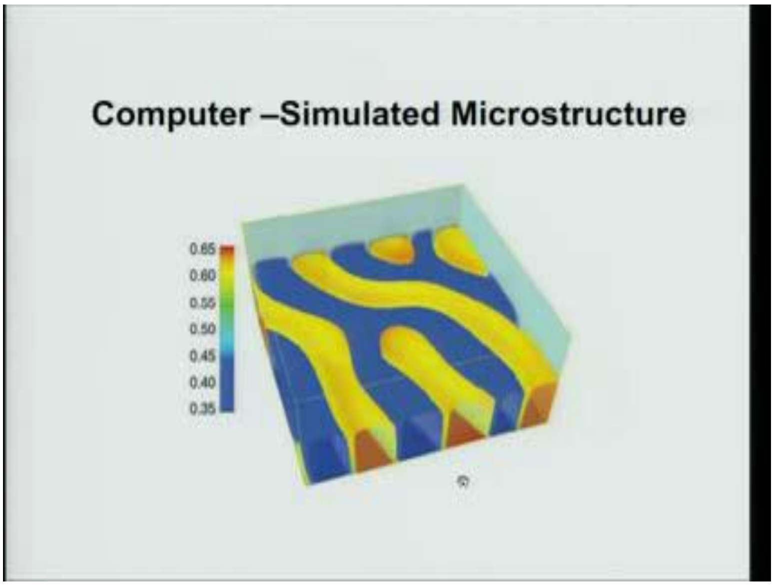

So, this is the green slab or the blue slab, this is the yellow slab. Sorry this is the blue; sorry this is the yellow slab. You can clearly see that they are actually looking like long slabs in three-dimensional and when you cut it using a two-dimensional section, they would look like a lamella.

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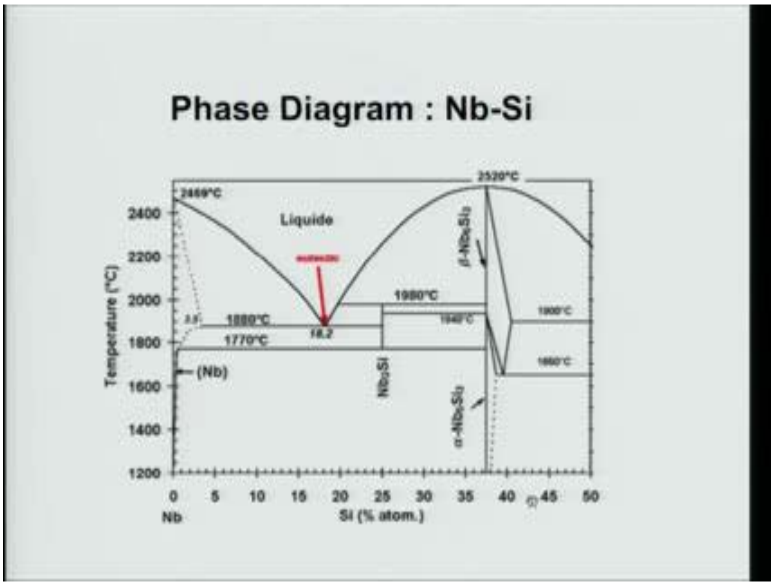

Now, let us look at another system which is little bit of complex, but do not bother now about reading the phase diagrams because the course is basically meant for phase diagram. So, right now we only look for the element surface diagram. You see this is the phase diagram between the niobium and silicon, but we are only showing only half of the phase diagram while silicon concentration varies from go to 50, another 50 percent or 50 to 100 percent. I am not showing it. So, reason is very simple. There is a eutectic reaction marked by this red arrow. You can see it is written in eutectic. This reaction takes place at very high temperature 180 degree Celsius and by the reaction you form solids as usual one is niobium solid solution n b solid solution. I said in solid solutions, the phase diagrams are marked by this pause brackets.

So, the moment you put fast bracket are in the n b, that means there is a solid solution between niobium and silicon or rather that means, silicon is inside niobium in the same crystal factor niobium. That is why it is called niobium solid solution just like a liquid solid solution by within solid state in liquid solid solutions. In liquid solutions, you are supposed take water and add sugar. So, water is solvent and sugar is the solute. Similarly here a solid solution niobium is a solvent, silicon is solid. Why niobium silicon is solid? Silicon passenger is very small. Maximum is about 3. 5 percentage.

So, this reaction will produce niobium solid solution plus nb3 sin b3, si is inter metallic phase. We will discuss that in our subsequent lectures inter metallic phase. Why this called inter metallic phase? Because it has two metals wherever it has one metal and one metalloid, but anyway does not matter as nb3 plus si, it is fix stoichiometric composition. So, eutectic reaction will give into these two phases together what kind of Mach search will produce. Forget about other parts with phase diagram. Do not concentrate even right now.

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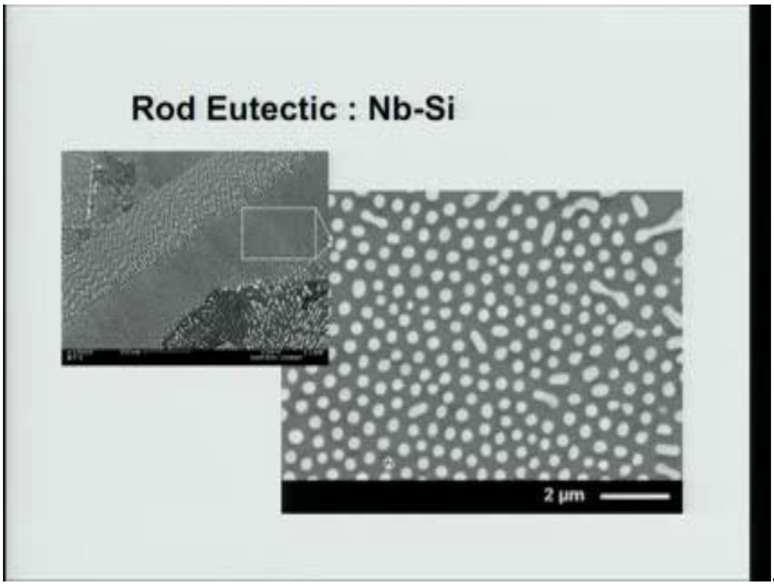

This will produce such a kind of mark structure you see here they look like a rod, exactly look like a rod. I will show you this exactly this is like a rod. So, they look like a thin dimensionally rod and they arrange in a very peculiar fashion. In some other cases, they arrange like a hexagonal manner. So, there is an arrangement possible and such kind of thing happens because of certain reasons. So, you have seen lamella microstructure lead tin and this is rod type of eutectic. So, why is such kind of change happens? We will discuss later, but first you absorb that there are variety of microstructure possible in the eutectic system.

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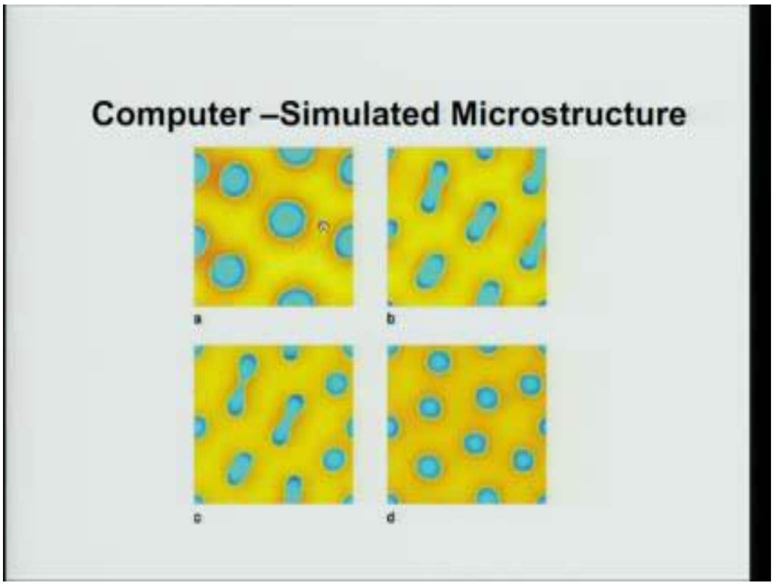

Now, you can always simulate a microstructure and you can see that these rods are possible to see in a microstructure.

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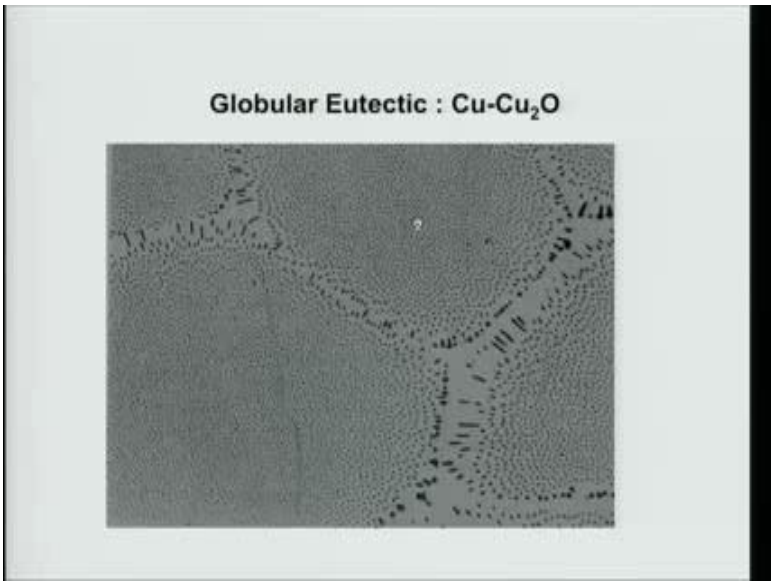

There is another type of microstructure known as globular eutectic. What is that? It is normally found between cu and cu2o. If you have a copper melt and if you have sufficient amount of oxygen present in during certification, then such a kind of things forms here c u o is basically looking like continuous gray color stuff.

You see gray color stuff continuous, but these black dots are actually globules as cu2o if they see they are formed as a gray in structure. I have shown you in earlier, this is gray in of one grain, this is another grain. I am sorry this is another grain like that. So, they are actually looking like a globule; not like a rod. They are looking like a globule. Difference between globule and rod is that rod is a continuous long object and globule is a simple small object. It is like a one round separate object. So, that is what is the globule. So, this is a globular of eutectic.

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Another interesting terms eutectic forms and spiral that is found in magnesium and zinc system and this eutectic is between magnesium solid solution and Mg-Zn2, right. You can see here they are like a spiral very fascinating microstructure. One phase is spiraling continuously. Why does it happen is basically very not difficult to understand is I will explain in detail. If you have two phases going side by side suppose and their thermal expansion coefficients have quite a lot different. So, the moment you cool it down from high temperature and low temperature, then only you can find this microstructure by eutectic reaction.

So, the moment you cool it down from high temperature, because of thermal contraction the contraction of those two phase will be different because alpha thermal expansion coefficient is different. So, because of that bend is like a bimetallic steep. If you heat a bimetallic steep, the one which is high thermal expansion coefficient will expand faster than the other and it will then the whole thing will bend. These exactly happen here. So, once you cool it down; one guy is basically shortening faster than the other guy because of the different thermal expansion coefficient and this leads to spiral formation. Those have done engineering mechanic course, they know that this spiral is on you can see here one spiral, sorry one spiral, one spiral there, another one there, another one there, and many and each of them actually forms a grain. This is a beauty of these eutectic systems. You have kind of different type microstructures.

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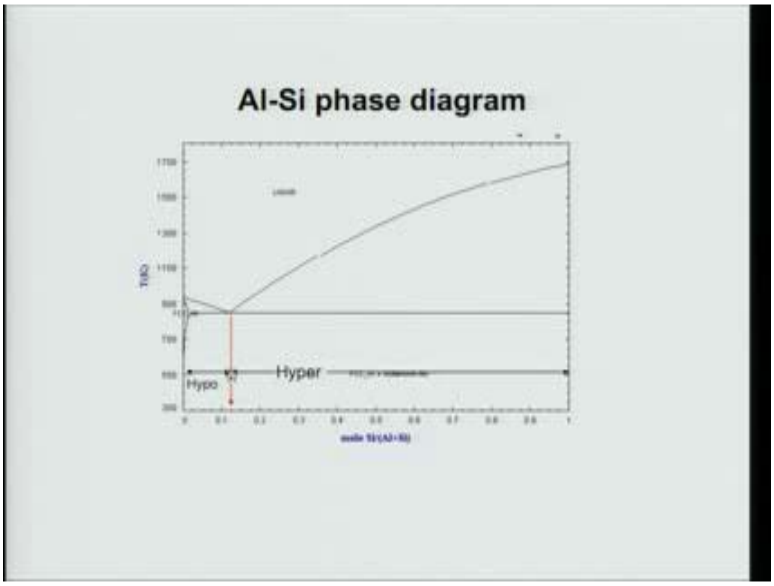

Now I discuss a third type of eutectic systems first and then, I will discuss the microstructure. The first eutectic system I showed you that no terminal solid solution, second one I showed for lead tin, there are two terminal solid solutions and third one I will show you for aluminum silicon system. See this is the phase diagram of aluminum silicon system and this is the pure aluminum and this is the pure silicon end silicon concentration lying from 0 to 1. This is fraction and that is why 0 to 1. That means0 percentage to 100 percentage eutectic reaction is here shown by a red arrow and you see eutectic is between alpha aluminum and pure silicon.

So, that means there is a solid solution field here at the aluminum end, but there is no solid solution field in the silicon end silicon end makes the pure. It does not have aluminum cannot get into silicon to form a solid solution here on the silicon end, but silicon can easily get inside aluminum and form a solid solution and that is known as alpha aluminum because aluminum has structure. So, that is why this is called alpha. Alpha is a first Greek letter. So, phase diagram starts with that. So, that is why alpha aluminum or you can write them aluminum within first brackets and then is solid solution. So, you can clearly see there is a eutectic reaction here, so this is the third type where there is only one end in a solid solution and other end does not have anything.

What kind of (Refer Time: 12:38) will form? Let us first tell you this is the very important alloy system for all car engines. All the car engine blocks actually use aluminum. Alloy contains this aluminum silicon because aluminum silicon is very easy to caste and high strength aluminum alloy. That is why it is used what is the microstructure is very different from the all the other alloys.

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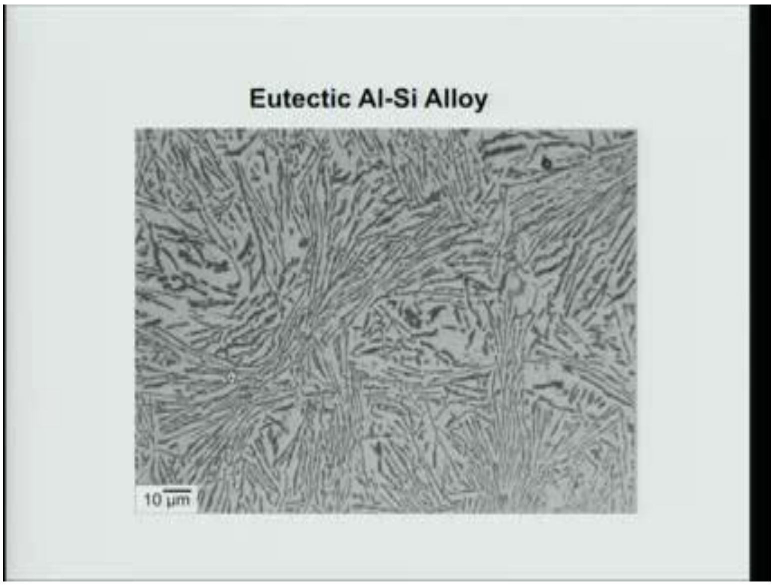

You have seen here black and white gray color things, gray color thing which is continuous is aluminum, alpha aluminum solid solution whatever you define and these black things whatever see here long needle like structure is basically silicon. They are five as such actually they are like exactly and they grow in this very different kinds of directions and I will you know silicon is a metalloid. That is a problem. That is why growth of silicon has problems and there are many issues, many researches going on in the world.

I am now going to discuss how to do that aluminum silicon is very interesting alloy system. Now, I also go back to the phase diagram. I told you eutectic composition is going by this red arrow. Any composition below or is less than that is called hypo eutectic and above is called hyper-eutectic. Remember hyper-eutectic alloys will contain silicon as a primary phase which I will discuss and tell you why hypo alloy will contain primary aluminum. So, hyper ones will have because primary aluminum is ductile on there and primary silicon is very brittle. You can take a silicon piece and just put it like this and drop. It will break into sudden two pieces. Silicon is so brittle, but aluminum is so ductile and that is why hyper aluminum hypo eutectic aluminum silicon alloys are used extensible in the engine blocks or aluminum in the cars.

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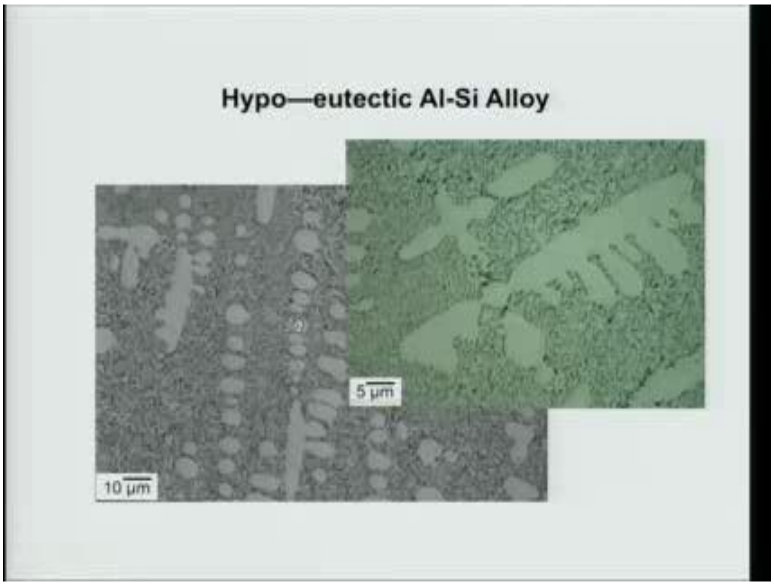

So, you will have this aluminum and rights and in between will have eutectic. You can clearly see aluminum and rights and this it did not right means two like structures is there look like a tree, as a trunk. You can see this is one trunk, another secondary trunks we have third side trunks also possible.

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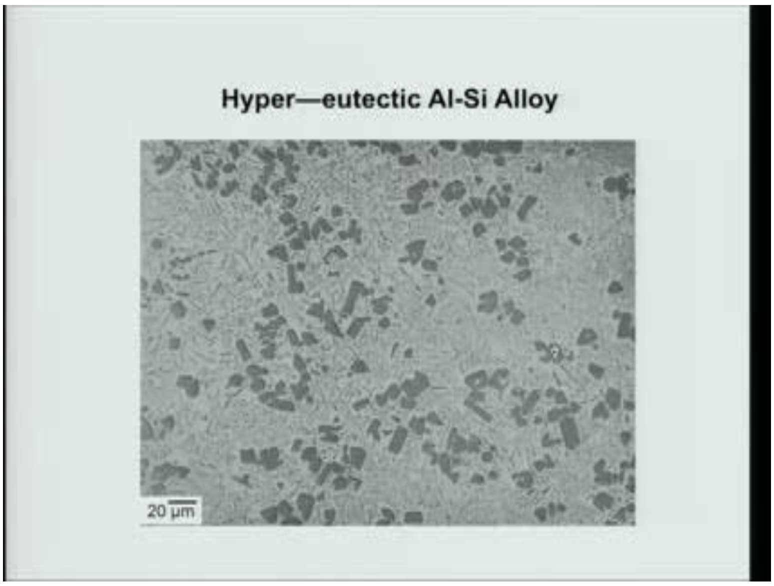

Then you have eutectic in between. So, I will again come back. Another one is hypo eutectic alloy. You will have silicon. No dendroid silicon has a piece. You can see here silicon hesitated silicon crystals around and the eutectic and these silicon crystals are brittle there. So, hyper-eutectic aluminum silicon alloys rarely used in the applications.

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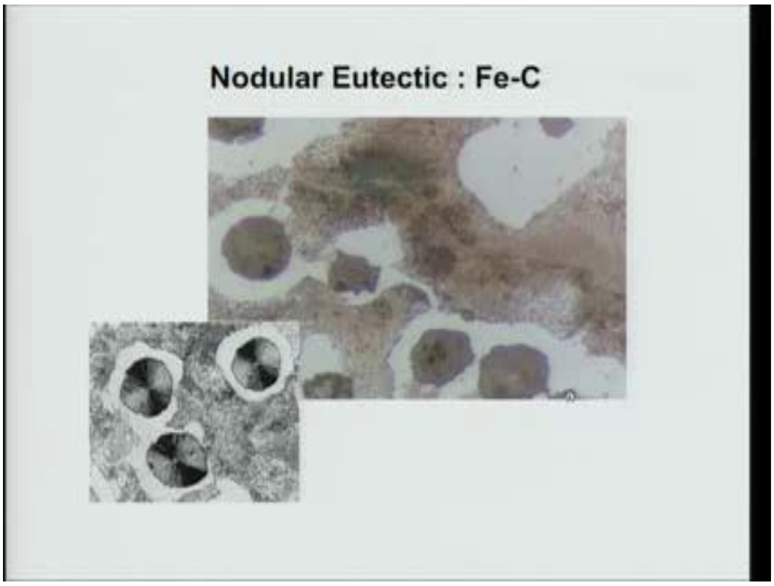

Another classic example of eutectic alloys, irons, carbon or rather cast iron, all are pure. We are in the industry they know the cast iron is the most important material for automobile industries. It has lines see as in automobile industry. So, cast iron has a eutectic phase diagram and eutectic is between gamma iron and carbon or graphite. So, you can see here this is the graphite nodules. They are like the nodule.

Nodule means you see nodule like picture and they are gamma iron around it. You can clearly see that and these things which you see here this is a transfer product of gamma iron to per light. Let us not bother right now. This is not due to eutectic reaction, but this is due to eutectic reaction which we will discuss in detailed manner when you discuss eutectic quite. So, eutectic reaction is between liquid going to gamma iron plus graphite and graphite gammas are nodule gamma iron is looking like a white thing.

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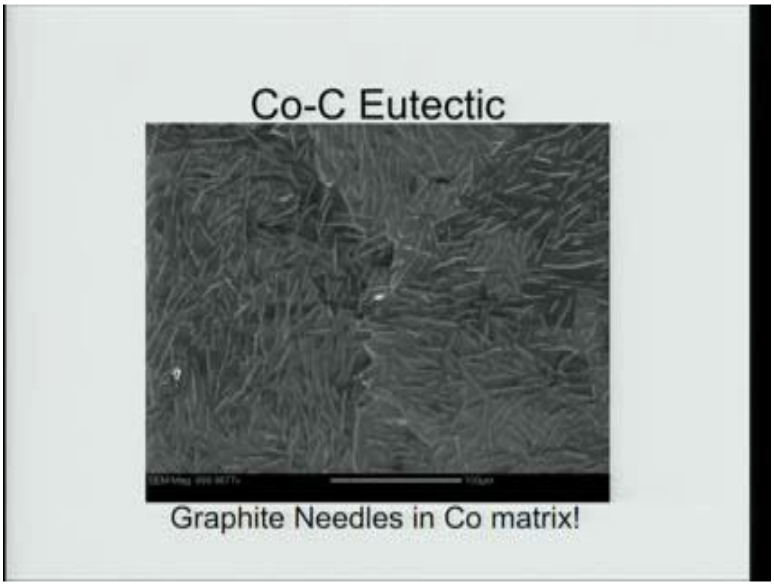

Now, there is another eutectic which is copper eutectic. We see here, here also the carbon copper co by matrix carbon eutectics. Carbon is coming as a graphite needles here and co by matrix is a continuous gray matrix. So, I have written graphite needles in a co by matrix very important material because of strength.

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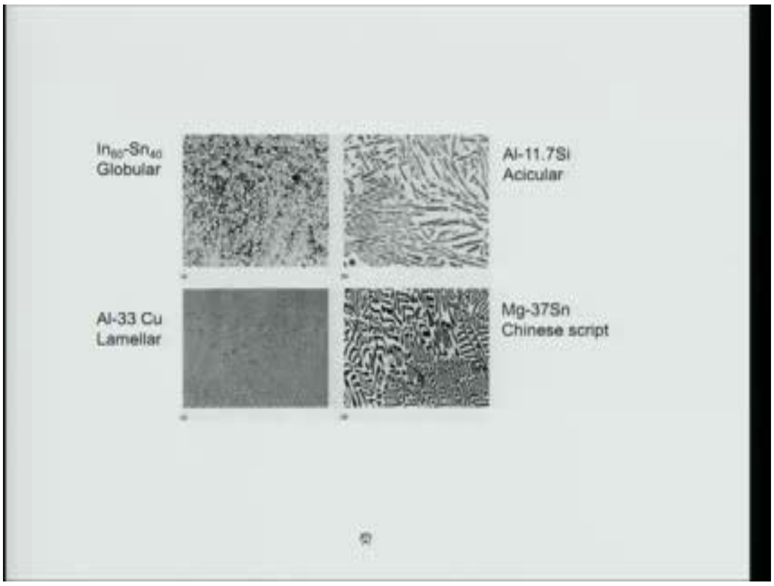

Then, you have many irons. I do not want to talk about much. So, in a nutshell these are the four different eutectics. I am showing you together. One is indium steel globular eutectic aluminum silicon known as acicular of highest eutectics. You can see here I have discussed and then there is a lamellar again aluminum copper lead tin also lamellar and there is another type between magnesium tin is Chinese script type. Chinese script types are very difficult to understand. They look like a tree, it looks like many things. So, any kind of structure which forms like that kind of which is called Chinese script microstructure, this is very literature correct. So, I am not going back in to phase diagram. So, let me just now discuss what happens in hypo and hyper-eutectic. Let me just go back yes.

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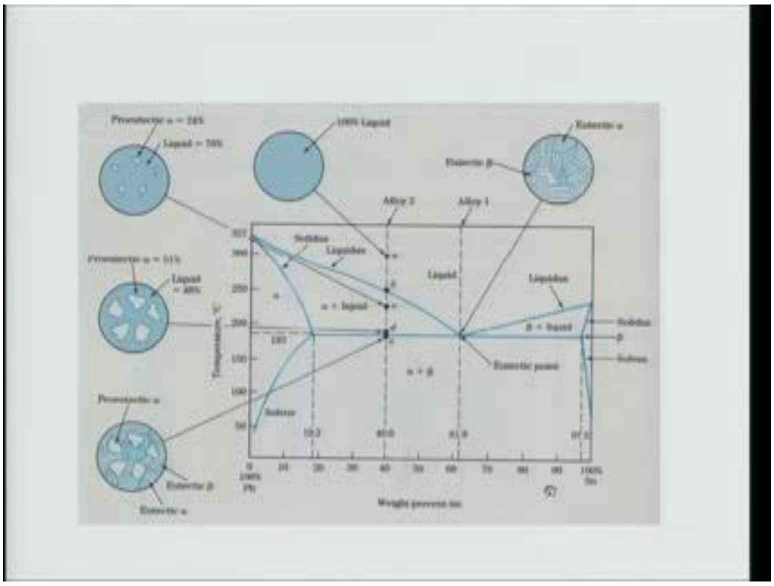

So, I told you in the last class, I am going to discuss three alloys solidification and I tell you what actually happens. So, let me first tell you that there are three alloys means one is eutectic alloys, other one is the hypo eutectic alloy and third is the hyper-eutectic alloy for a phase diagram which looks like a most common one, where you have two terminal solid solution like a lead. So, let us now go back to board and discuss that.

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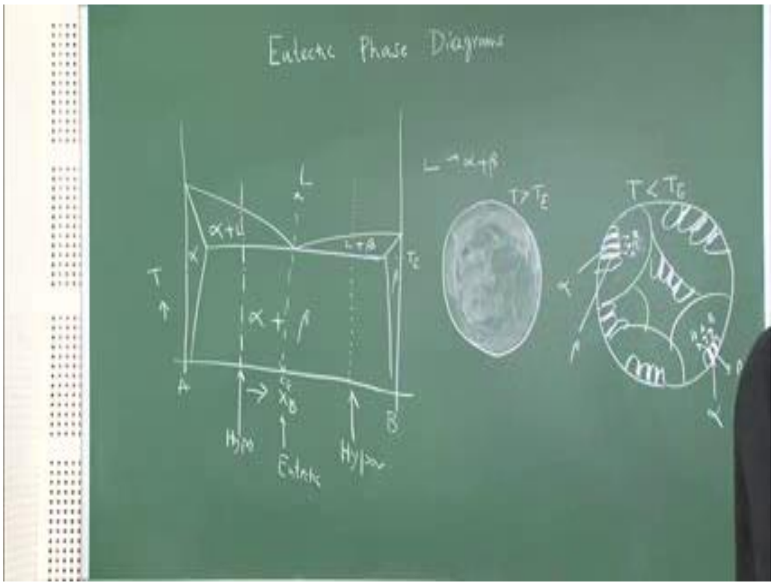

So, I will first draw this phase diagram which looks like this. Let me just make it bigger between component a and b. I am not using any name of elements, only component a and b and one thing I want to stress upon that you must know this is the way to be done a and b x b. Please do not forget that whenever you draw a diagram. Now, I draw the phase diagram. This looks like this is a primary phase field of a solid solution on the b side and this is the eutectic reaction. So, this is Alpha. I told you that any phase diagram will start with a first Greek alphabet alpha and then you go on beta gamma delta.

This is also beta and eutectic reaction is liquid going to alpha plus beta which is happening at this temperature, at this composition c e. So, this is Alpha plus beta and obviously, between these two totally alpha plus liquid, these totally liquid plus beta are simple. So, I am going to discuss with you these alloy first. I put a dotted line and then, this one I put another dot in different kind of dotted line. This is hypo and this one I put it like this way hyper, this item hypo eutectic alloy, this item as hyper-eutectic alloy and this as a term of a, this one as a term as a eutectic alloy.

So, the better to start with eutectic alloy you know like a lead tin picture I have shown you, if I start with a eutectic alloy system here and what will happen. I cool it down completely. Liquid will remain present even above the eutectic temperature t because you can see here this is a completely a liquid phase. So, liquid will remain all the below the utility temperature. Liquid will react and form two solid phases simultaneously how does it come.

Let us consider this picture. I draw this is at temperature above eutectic temperature t e. I have completely liquid in the sample because I am above the eutectic temperature. Nothing has happened in the liquid correct. So, now I just show the temperature just slightly below the eutectic temperature. What will happen if I draw the temperature slightly below the temperature? You provide a force for formation of the solid phase because here are below the eutectic temperature and that means, nucleation of both the solid phases are possible alpha and beta.

Let us suppose alpha nucleus being one other things, alpha nucleus here like a dot and this is my alpha beta can also nuclear does not matter. I will tell you why for suppose for the understanding, let us say for the suppose understanding that alpha nucleus. So, as you see here alpha is reaching a, but very poor content of b can you see here alpha is near a end is pure a, but it contains very little amount of b. So, if it has to go into the liquid, suppose it goes into the liquid like this, it will reject all b because it needs a to go and need more a less b. So, it rejects all b in the liquid. So, b will come out in front of the alpha as it becomes bigger as it becomes bigger and bigger, it will become it will reject b. So, as if it rejects b, what will happen is the region is nearby in front and also side will have b, lot of b, plenty of b. B is a second component.

Plenty of b will present and because of that, these two phases because they are large content of b and beta contains c amount of b, very large content of b because beta remains in the b end or rather near the p or b. So, beta has more b less a. So, because of that if the concentration of b increase in the both side, beta will nucleate after certain time and beta will form like a again I draw like this. So, as you see on the both side of alpha, I have drawn two lamely of beta, right.

So, as you know for both of beta you need more b growth of beta growth of this. This is beta. So, for growth of b you need more b. So, if you need more b; that means, what all a and b is rejected in front of in by beta, all a will come out. This is small. All a will come out in front of beta or side of beta. As a come out, a will be concentrating here more and as a is concentrate increase, then alpha is then when a is very large content on both side. This is for the alpha to nucleate and go on both sides. So, like that again beta will form and that is the way you form a lamella. This is the way we will form a lamella structure. You can see here lamella structure same way I want to see for lead tin. Similarly here one of the lamella will form alpha beta. This will grow and the, similarly another one there, another one there and another one there. So, then each one will merge and form the whole microstructure.

Now, suppose I tell you beta nucleus, suppose instead of alpha here, beta nucleus and grow if beta nucleus and go it will require more b because it requires more b, it will reject a in front of it and also in sides of it and because of a concentration increases in both side, in front of it that will lead to very easy nucleation of alpha because alpha is reaching a. So, as a rejected more in the liquid on the both sides, a concentration will increase surround it and a concentration will reach very high value alpha which contains most of a will nucleate and grow like this and when as a grows, sorry as alpha grow, this is beta and this is alpha. As alpha grows, it will reject b. This alpha is basically pure a, almost like a pure a.

Very little amount of b is present. Alpha is at a be solid solution. So, because of that b will be rejected. As the b rejected, b concentration will increase in both sides and this will lead to formation of beta and so on. So, it does not matter whether you nucleate alpha beta at the beginning. What matters most is that you form a lamella structure. So, this is what will happen in all the cases. I am not drawing it, but this also happen in all the cases. All the one alpha beta, beta alpha like that and will form the whole microstructure.

In the next class, I will discuss about these two hypo and hyper-eutectic cases. Let us finish this one. We will discuss in the next class.