Basics of Materials Engineering
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Lecture – 11
Defects in Crystalline Materials -1
(Types of Crystalline Defects)

So far, we have looked at the crystalline structure of materials, how atoms are arranged in different crystalline lattices like FCC, BCC, HCP and so on. We have also discussed the methodology to describe crystallographic directions, planes, how to identify them, how to represent them using Miller indices, how one needs to take care of representing equivalent crystallographic directions in the case of HCP which requires you to use a 4 index notation as opposed to a 3 index notation usually used for cubic crystals, and so on.

The next important aspect that we need to look at, is the imperfections in solids or imperfections in materials. Here, we are only talking about materials in the solid state, and hence the topic is imperfections in solids.

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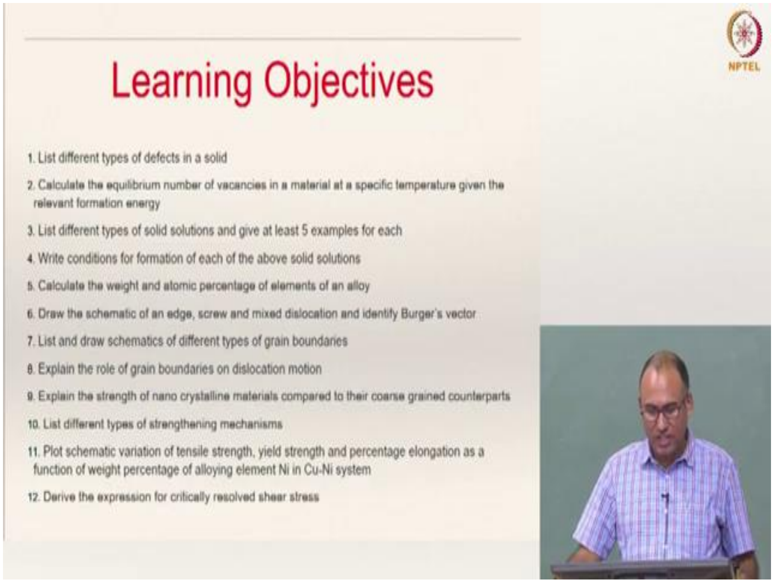

So, these are the learning objectives; you should be able to list different types of defects in a solid.

And then, we should be able to calculate the equilibrium number of vacancies or concentration of vacancies in a material at a specific temperature given the relevant vacancy formation energy; and list different types of solid solutions and give at least 5 examples for each of these types of solid solutions; and, write the conditions for formation of the solid solutions that were listed in point 3.

You should be able to calculate the weight and atomic percentages of elements in an alloy and you should be able to convert the composition from atom percentage to weight percentage; and, we should be able to draw the schematics of an edge, screw and mixed dislocations and identify something called Burger's vector.

List and draw schematics of different types of grain boundaries; explain the role of grain boundaries on dislocation motion; explain the strength of the nano crystalline materials compared to their coarse-grained counterparts; list different types of strengthening mechanisms; plot schematic variation of tensile strength, yield strength and percentage elongation as a function of weight percentage of alloying elements in copper-nickel system; derive the expression for critical resolved shear stress.

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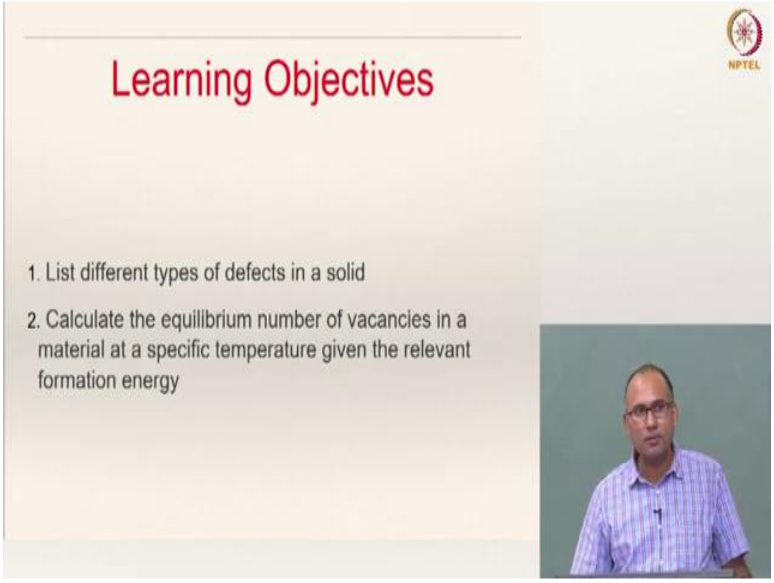

So, there are how many? Several learning objectives. So, this is a very important topic; this actually helps us understand the deformation mechanisms that we have discussed -- we will talk about in future -- in the last class, right? So, this topic lays the foundations for understanding the deformation mechanisms.

In this class we will try to achieve these two learning objectives: list different types of defects in a solid; and, we should be able to calculate the equilibrium concentration of vacancies in a material at a specific temperature, by knowing the vacancy formation energy of that particular material.

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Are you familiar with any perfect crystal? Unfortunately, there is no such thing called perfect. Perfect crystals do not exist. So, in some sense, philosophically if you want to say, materials and human society are alike; they both work despite having defects. And several times it is actually desirable not to have perfection. We may think that perfection is always good, but sometimes imperfection is sought after.

We will particularly in mechanical engineering applications, the defects are very important for us to actually make several things. How do you make a sheet metal? You must have studied in your manufacturing technology or manufacturing processes course or you are going to study, ok? How do you make a sheet metal?

We run the iron billet or aluminium sheet metal between 2 rollers and then, it becomes a sheet. A solid block can be made into a sheet. The reason why you are able to make that into a sheet is because, you can impart plastic deformation in the material.

Imagine if the material is brittle; that means, it will simply break. You will not be able to impart such huge amount of plastic deformation; and if not for defects, you will not be able to impart plastic deformations. Plastic deformation is actually the motion of a particular kind of defects in material called dislocations.

In that sense, several engineering components can actually be made because of the presence of defects. So, many times perfection is not sought after. They actually lead to many good things; best example is semiconductors, right? Semiconductors work because of doping; because of adding impurity elements. So, we are adding some defect to the material intentionally, to get something very nice out of it.

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Most of the metals that we are familiar with are alloys; that means, you do not have pure material, it is impure; it is not only one element. For instance, steel is an alloy of?

Student: Iron.

Iron and?

Student: Carbon.

Carbon primarily, and there are going to be other elements too. But it is not purely iron, right? If it is purely iron, you probably will not get the properties that you are actually enjoying with steel. Alloying is something that you are actually making a pure material like iron as an impure material by adding other elements, but getting good things out of it; similarly, semiconductors.

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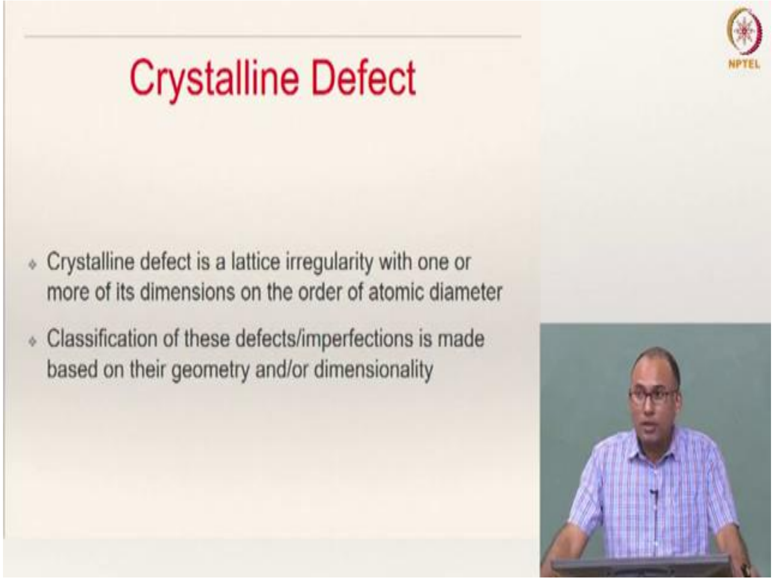

Now, we need to define what do we mean by a crystalline defect? So, a crystalline defect is a lattice irregularity with one or more of its dimensions on the order of atomic diameter. It is a lattice regularity.

How do you classify these defects? So, that means there is some irregularity in the lattice structure that we have discussed in the previous chapter or previous module. The defects can be classified based on their geometry or their dimensionality.

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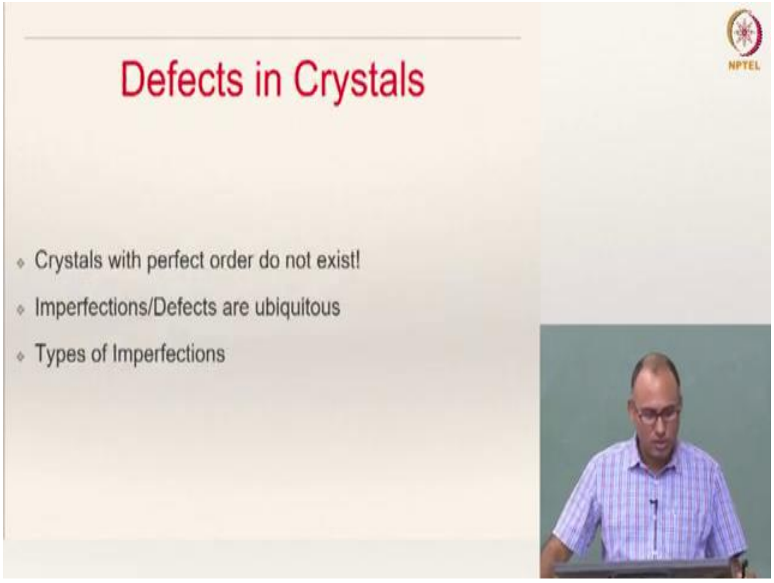

Crystals with perfect order do not exist. Even if you want to, they do not exist; we will see in a moment why they do not exist. Imperfections or defects are there everywhere. What are these different types of imperfections or crystalline defects?

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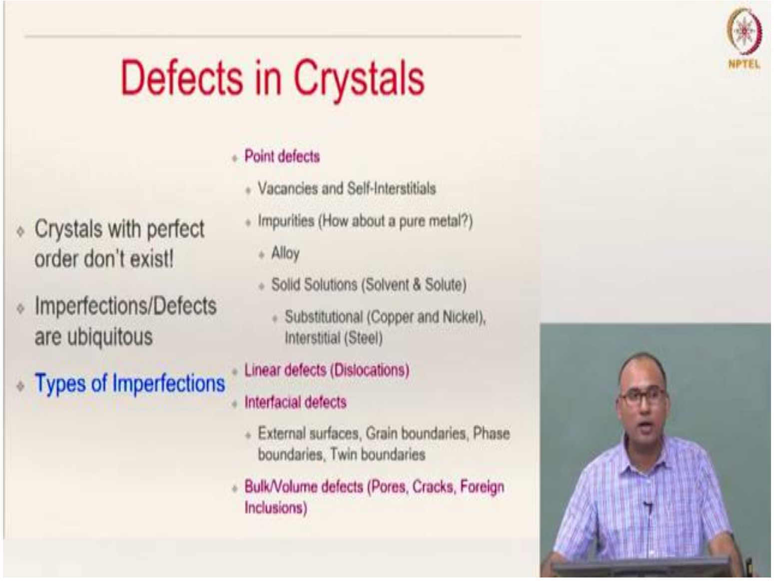

The first kind of defects are called point defects. So, zeroth order dimensionality, right? What are these point defects? For instance, if we have a crystalline lattice; if we have a vacancy or self-interstitial, that is one kind of a defect. Vacancy means, you need to have an atom there, but you do not have one; that means, lattice site which should have been occupied by an atom or a molecule is not occupied by that motif.

Basically, you have a lattice site, but you do not have a motif. Every other place you have motif, but on that one particular place you do not have the motif. Then, it is a vacancy. And the motif has specific position to sit in i.e., the lattice sites. But if the motif goes and sits in some other position which is not its lattice site, where it is not supposed to be sitting, that is also another kind of defects.

So, that is going and sitting in a place where it should not be. All of you have here lattice sites, and you are all different motifs for this class room. You are not expected to sit between the benches. If somebody comes and sits in between the benches then, he or she becomes the point defect for this nicely ordered class, right? So, that is what you mean by point defects.

You can also have impurities which means, normally you have a crystalline lattice such as iron, and then another impurity comes and sits in the crystal lattice, and that is what makes it an alloy; and you have these kinds of materials called solid solutions which we will discuss towards the end of this course.

And then, the next level of defects are line defects. So, according to dimensionality the first one is zeroth order and the second one is first order, second order and third order. So, that means, point defects, line defects next will be area or surface defects and then will be volume defects.

0 dimensional, 1 dimensional, 2 dimensional and 3 dimensional. So, the line defects or linear defects are also called dislocations, that is what we will look at in detail in this course. And, then you have interfacial defects or 2 dimensional defects or surface defects, right? So, they have 2-dimensional description; so, they are external surfaces, grain boundaries in a polycrystalline material.

Grain boundaries are sort of defects; and we will see what are phase boundaries and twin boundaries. And, then you have bulk or volume defects which means, you have a crystalline material from the bottom up and if you make your actual structure, normally you would expect your atoms to be filling the entire space and sometimes in your material you may find some voids, pores.

It is a 3-dimensional defect, where the material is not present for some reason; due to some reason during the processing of the material this pore comes in. So, this is a 3-dimensional defect; similarly, cracks and foreign inclusions which are not supposed to be there in the material.

So, these are all the different kinds of defects that you have in a material: point defects, line defects; interfacial or 2-dimensional surface defects and volume defects.

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As we have discussed, imperfection is something that is not necessarily a bad thing. Several times, we actually tend to get attracted to imperfections, even in society and even with people. So, do not worry if you have an imperfection, probably that is an attractive imperfection.