# Properties of Materials (Nature and Properties of Materials: III)

**Professor Ashish Garg**
**Department of Material Science and Engineering**
**Indian Institute of Technology, Kanpur**

**Lecture 20 - Introduction to Slip**

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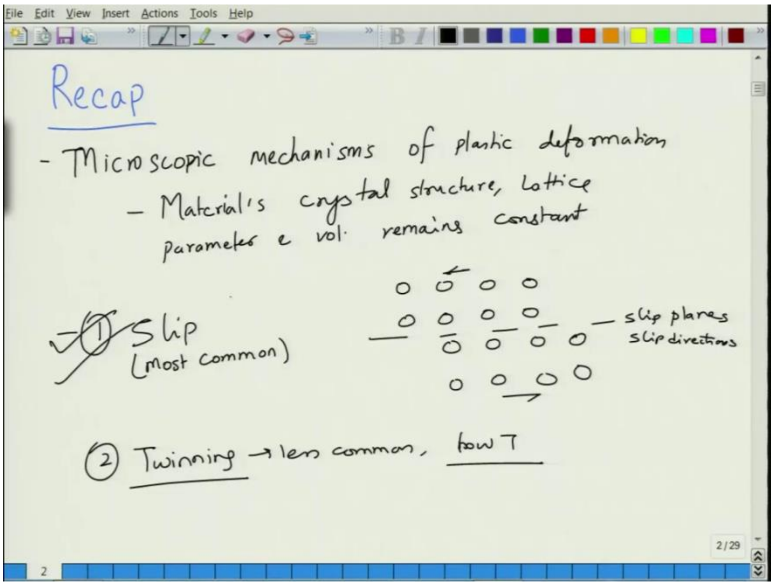


So, welcome again, to the new lecture on the course Properties of Materials. So, let us just briefly see what we did in the last lecture. So, in the last lecture, we saw introduction to microscopic mechanism of basically plastic deformation, we saw that if you do characterization of the materials after plastic deformation, one can see that material's crystal structure, lattice parameter and volume remains constant. So, this can be found out by detailed characterization.

Now, if that is true and what is that which leads to plastic deformation and it turns out that it is a phenomena called as so, microscopic phenomena, one is called as slip in which the plane of atoms in one part of the crystal slip against the other part of the crystal. So, across a plane called a slip plane leading to movement of atoms against each other. So, this is and this happens on certain planes called slip planes and it happens along certain directions, atomic directions called as slip directions. And we will see details of this in today's lecture.

And then second phenomena is less common, so this is the most common. Second is twinning, twin related deformation, which is basically formation of twins and deformation caused by it at, but generally this is less common and mostly it happens at low temperature when slip is not active or slip systems are not active. So, we will in this course, we will mostly discuss about the slip, we will not talk about the twins as such.

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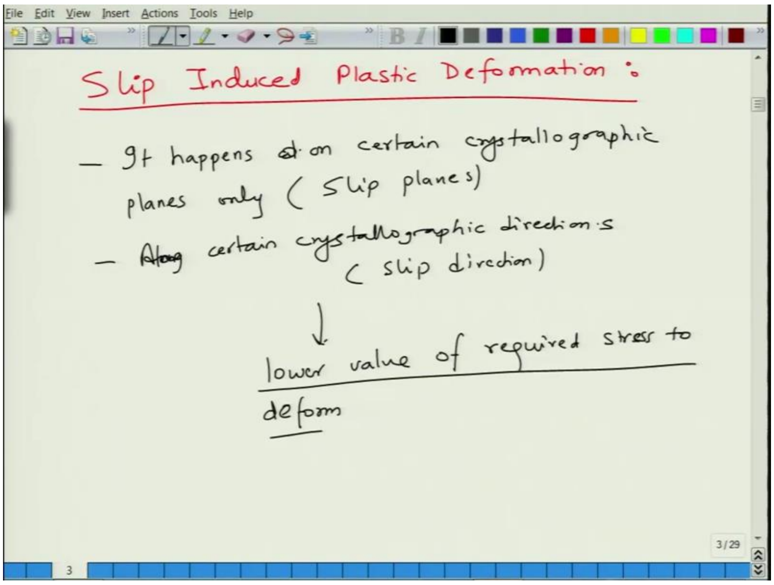


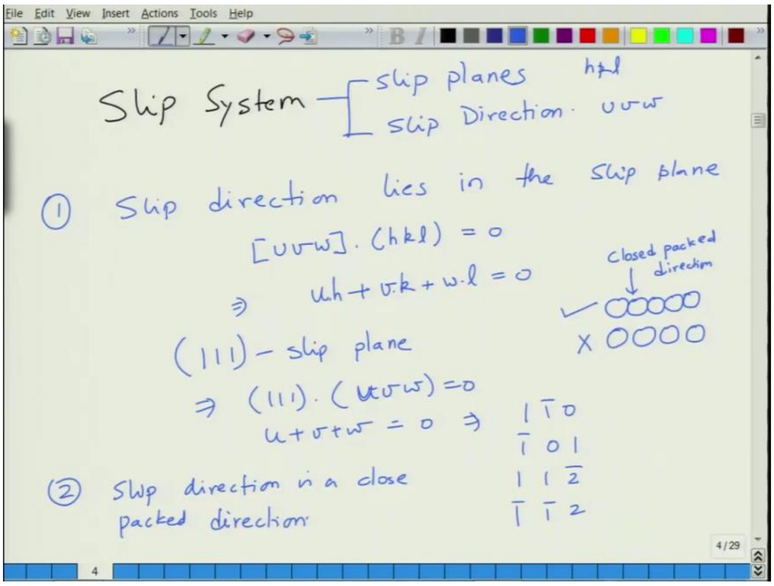


So, let us see what the slip is. What is slip induced plastic deformation? So, generally atomically speaking, slip happens on certain, it happens on certain crystallographic planes only and along certain crystallographic directions. So, this together so, these are called as slip planes and these are called as slip directions. And basically, it happens in this fashion because they lead to lower value of required stress to deform. There are theories behind this, microscopic theories, but essentially it is because of lower value of stress that is required to deform the material.

So, together they make what we call a slip system. So, a slip system contains slip planes and slip direction, okay. So, slip system is a combination of slip plane and slip directions. So, naturally the slip direction lies in the slip plane. I mean you cannot have one plane in another direction, the direction has to lie within the slip plane. So, this is first condition so, that means if slip direction is UVW and plane is HKL type then dot product of UVW to HKL is equal to 0, basically means u h plus v k plus w l is equal to 0.

So, if you have 111 plane as slip plane let us say then, then the only directions which on slip, which can give rise to slip are, so 111 will make dot product 0 UVW. So, essentially U plus V plus W has to be equal to 0. So, which means, it could be 1, bar 1 0 direction, it could be bar 1, 0 1 direction, it could be 1 1 bar 2 direction, bar 1 bar 1 2 direction and so on and so forth. So, what determines along these directions which will be the direction?

So, the next thing is slip direction is a closed packed direction. So, it is the direction along which atoms touch. So, you may have a direction in which atoms are touching each other. You may have a direction along which atoms are not touching each other. So, this is not the slip direction, this is a slip direction, which is the closed packed direction.

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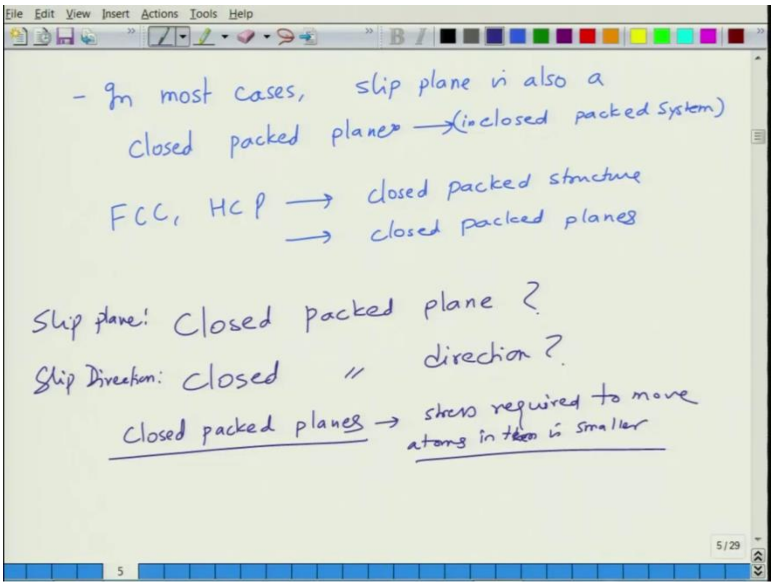


So, slip direction is a closed packed direction. In majority of the cases, slip plane is also a closed packed plane, but this is only possible for closed packed systems. Okay. So, if you look at systems like FCC or HCP, they have close packed, they are close packed structures and as a result, they have closed packed planes, okay.

So the question is, why is that slip planes are usually close packed? Why is that so? Closed packed plane, why closed packed direction? Why? So, this is slip plane, this is slip direction and this is because the closed packed planes have stress required to move atoms in them is smaller. So let us see first, what closed packed. How do you work out? What is a closed packed plane? What is not a closed packed plane, before we come to this in a little bit more detail.

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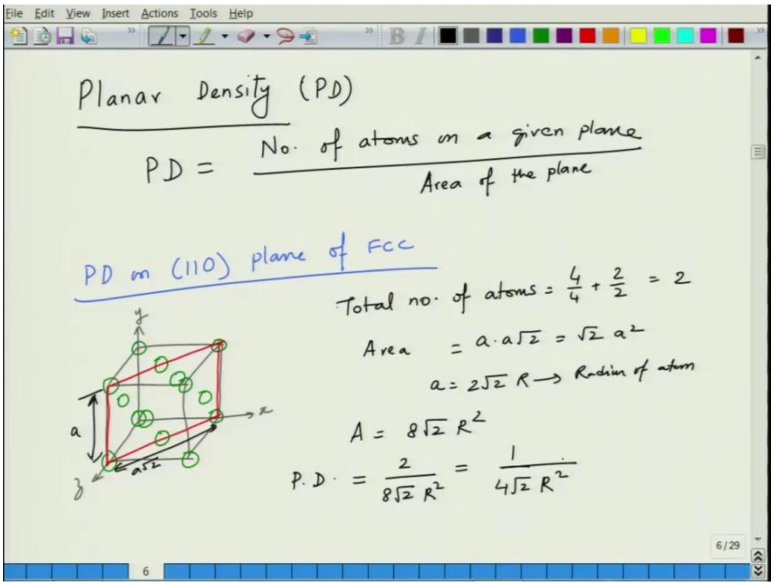


So let us first look at how we determine a plane is closed packed. So, let us say, we work out what we call as planar density in planes and crystals. So, basically planar density or we can say PD, PD is given as number of atoms on a given plane divided by area of the plane. So, basically number of atoms per unit area. So let us say we want to calculate PD on 110 plane of FCC crystal. So first, we do is that we make a let us say a cube, let us say these are the atoms that we have, so the 110 plane is the plane which is this plane. Alright.

So, how many are the number of atoms? So, in this plane, we can see the number of atoms are so this is one quarter, this is one quarter, this is half, this is half, this is half. So, these two are half, these two are one quarter, so total number of atoms is basically you can say 4 by 4 plus 2 by 2 this is 2, within this area. And what is the area? If the atomic radius is R, so you can see that this is basically you can say a, this is a root 2, so this is a into a root 2, which is root 2 a square and in FCC, we know that a is equal to 2 root 2R where R is the radius of atom, this will work out to be 8 into root 2 R square. So, the planar density can be 2 divided by 8 into square root 2 R square, this will be essentially 1 divided by 4 into root 2 R square. So, this is how you can find out the planar densities.

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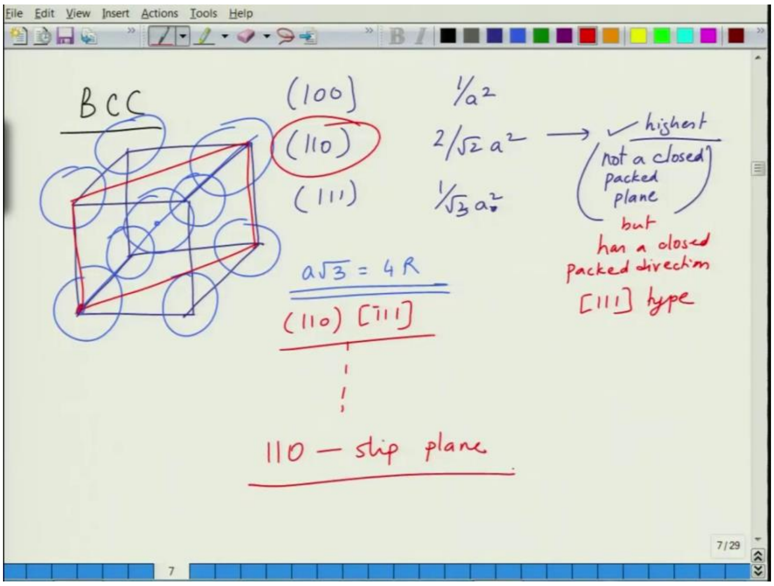


And it turns out now if you do the maths, then for let us say for BCC if you take the primary planes, so let us say along 1 0 0, the planar density is 1 divided by A square. So let us say we write in terms of a.

So, I mean you can write this in terms of a as well. So in terms of a, it will be 2 divided by square root 2 a square or square root 2 divided by a square. So, this will be this and 1 1 0 will have a planar density of 2 divided by square root 2 a square and this long 1 1 1 it will be 1 by square root 3, a naught a square.

And out of these three you can see the maximum density plane is this is the highest density plane 1 1 0. But this is not a closed packed plane, but it has the highest density. Closed packed planes means the planes in which atoms touch each other, these are the closed packed planes. So, this is not a closed back plane, but it does have a closed packed direction. So, if you look at BCC crystal so you have an atom sitting here, you have another atom sitting here.

So, this atom, this atom and this atom they touch each other. So, you can say that a root 3 will be equal to 4 R, this is the relation. So, 1 1 0 this is so this 1 1 0 plane itself is not a closed packed plane, but it is the plane with highest density, all other planes are going to be smaller density, but it has a closed packed direction, but has a closed packed direction. And you can work this direction out, this direction from here to here is a 1 1 1 type direction.

So, basically, 1 1 0 plane will have 1 1 1 type of directions so of course, the dot product has to be 0. So, essentially, it could be bar 1 1 1 type of direction. So, there could be multiple combinations, so this will make a slip system in BCC. So, 1 1 0 plane is the highest density plane, so 1 1 0 is the slip plane.

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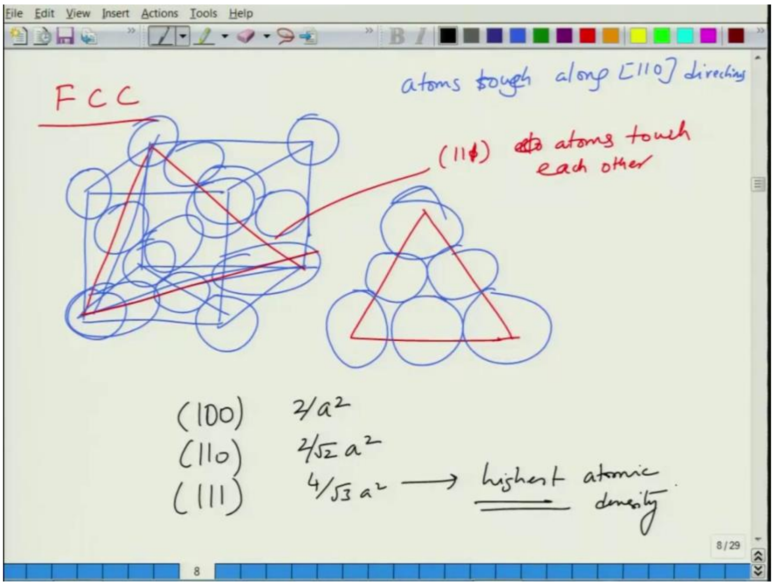


Coming to FCC, okay. So FCC is this where you have this atom, this atom, this atom, this atom, and this atom, okay. So, essentially you can say that the atoms touch along the faces. So, atoms touch along 1 1 0 directions and there is a plane which is this plane, which is 1 1 0, 1 1 1 sorry, which is the plane in which atoms touch each other. So, essentially, 1 1 1 plane will look something like this.

So let me see if I can draw it correctly, it is something like this, this will be the 1 1 1 plane. And if you now calculate the atomic density for different planes for 1 0 0, for 1 1 0, for 1 1 1, this will be 2 divided by a square, this will be 2 divided by root 2 a square, this will be 4 divided by root 3 a square. So, this has the highest atomic density and it is the closest packed plane. These are the, this is how you work out the planar density.

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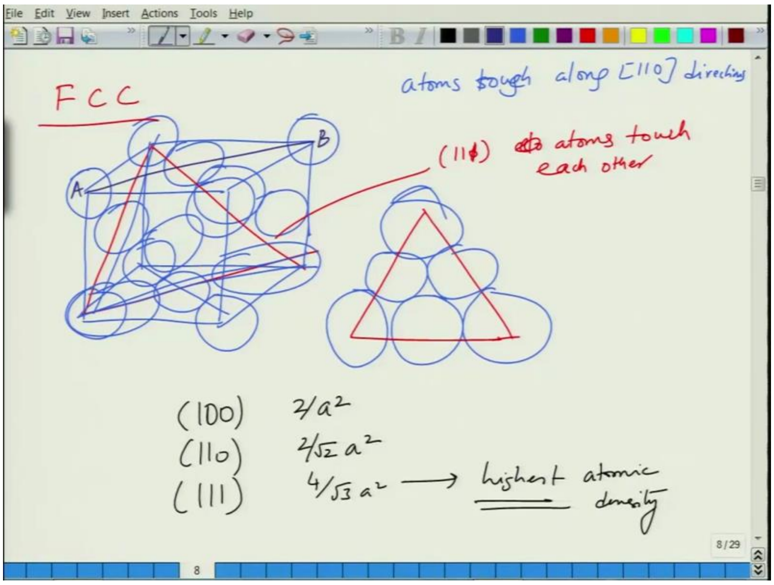


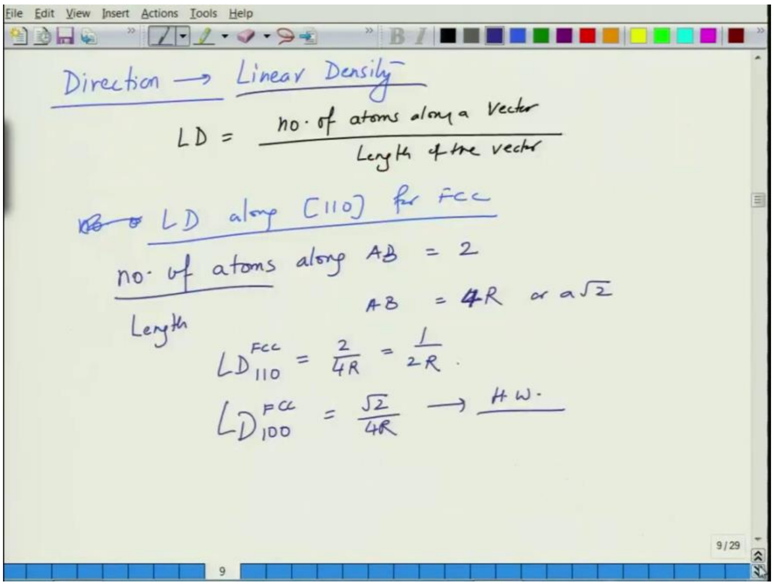


For a direction you can work out, you can work out linear density. So, let us say you have a FCC, again, you go to FCC, so linear density you can define as number of atoms along a vector divided by length. So, basically, number of atoms per unit length. So let us say we want to calculate numbers, so we want to calculate LD along 1 1 0 for FCC. So, for FCC, we know that number of atoms….So if you go to previous picture, this is the direction 1 1 0. So if you take along this AB, so along AB number of atoms is equal to, you can say 2. And length, along length of AB is equal to 4R or a root 2, okay.

So, LD along 1 1 0 for FCC will be equal to, for FCC will be equal to 2 divided by 4R or 1 divided by 2R. And you can also show LD along 1 0 0 and 1 0 0 will be square root 2 divided by 4R. I will leave it to you as a homework. So, it turns out that basically, the, you can find out using linear density what is the direction, what is the density of atoms along particular vector and you can find out the planar density.

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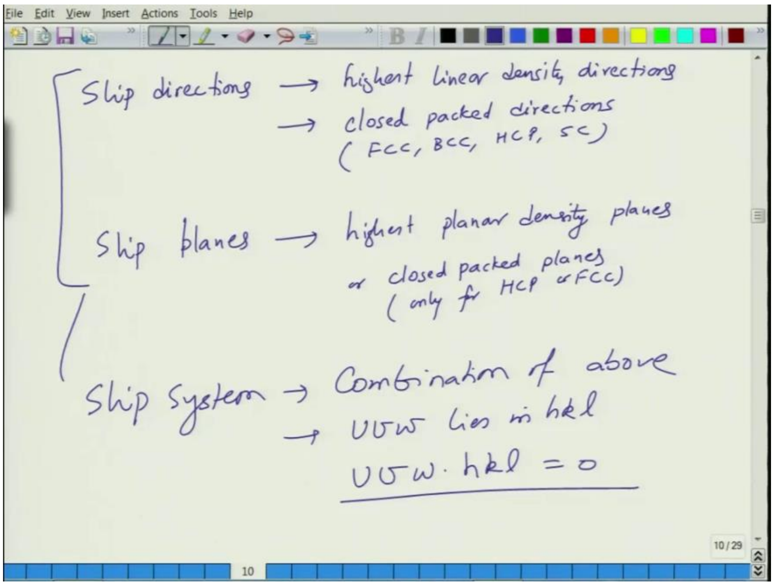


So, essentially slip takes place on the planes along the directions along which linear density is the highest, so slip directions are highest linear density directions. So, they happen to be closed packed directions. So if you look at the cases of FCC, BCC, HCP, simple cubic these are all, they will have closed packed directions atoms assuming that touching a sphere model. And then slip planes are highest planar density planes and or we can say closed packed planes.

Closed packed planes are not present in all the crystal systems. So, only for HCP or FCC because that is where you form closed packed planes. For BCC and HCP, for BCC and simple cubic, we are looking at planes, which have highest crystal density. So, essentially, these are slip plans. The combination of two as we said is slip system, but the condition that uvw lies in hkl. So, uvw dot hkl is equal to 0. And this is what the definition of slip system is.

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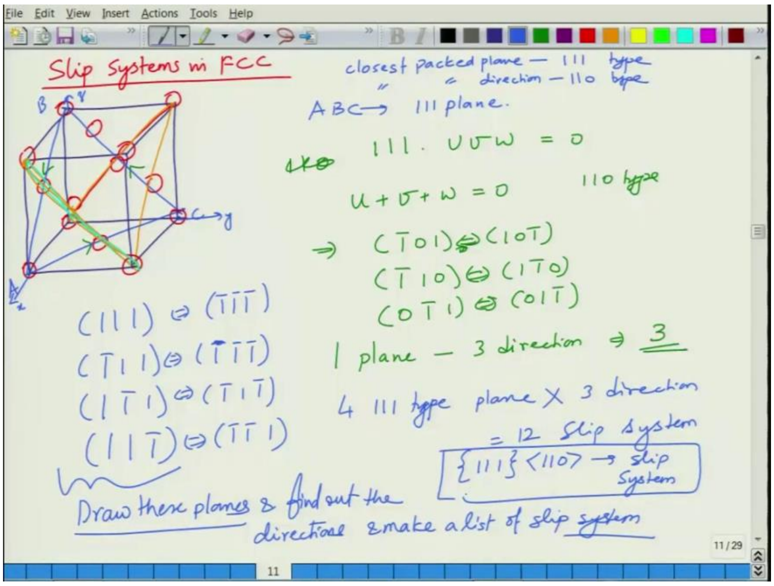


So, now let us see, we work out the slip system for FCC. So, slip systems in FCC. So we have atoms, we do not make touching atoms, just for the sake of clarity. Okay. Now, we know that highest density plane is this plane, so this ABC is the 1 1 1 plane. How many 1 1 0 type of directions lie in this? So it turns out we saw that for FCC closest packed plane is 1 1 1 type and closest packed direction from the calculations is 1 1 0 type, okay. So, let us find out different combinations.

So, we can see that in this 1 1 1 plane, if this is x, this is y, this is z, in this plane there are three 1 1 0 directions; one is this, second is that, third is this. What are these directions? So 1 1 0, 1 1 1 so basically you can say 1 1 1 dot uvw is equal to 0, so you can say that u plus v plus w is equal to 0. And we know that these directions are only of 1 1 0 type. So ignoring all other combinations it will lead to bar 1 0 1, 1 0 bar 1 which are identical, just oppose it bar 1 1 0 or 1 bar 1 0 and then 0 bar 1 1, 0 1 bar 1.

So, basically, you can see that one plane can contain three directions. So, basically, you can have a total of three slip possibilities. Slip can occur along three different directions so these are three slip systems. So, likewise, in FCC crystal you may have multiple 1 1 1 plane, so this is one 1 1 1 plane, the second 1 1 1 plane is this. So let us use different colour, this is another 1 1 1 plane, you can have one more plane that is, let us say this. Okay, you connect this, this and that. Let me use different colour maybe 1, 2 and 3, and the fourth one could be, so, you have, so let us write the combinations.

So, you have 1 1 1, you have bar 1 1 1, you have 1 bar 1 1 and you have 1 1 bar 1. You can write other combinations as well. So, essentially, for this bar 1 1 1 will be 1 bar 1 1, for this it would be bar 1 bar 1 1. So these are opposite planes basically, you can say. And for this, it would be bar 1, bar 1, bar 1. So we have multiple eight possibilities because you have eight vertices, but four of them are, two of them are equivalent. So, as a result, you will have total of four planes.

So, four 1 1 1 type planes. I will leave it to you as a homework, draw these planes and find out the directions and make a list of slip systems. So, four 1 1 1 type plane into three direction in each plane this gives you 12 slip systems. So, in a general sense, you can say you have 1 1 1 plane as slip plane, direction is 1 1 0 this is slip system. Of course, you have to choose combination for which direction lies within the plane that is the dot product of the two is equal to 0, that is what you have to do.

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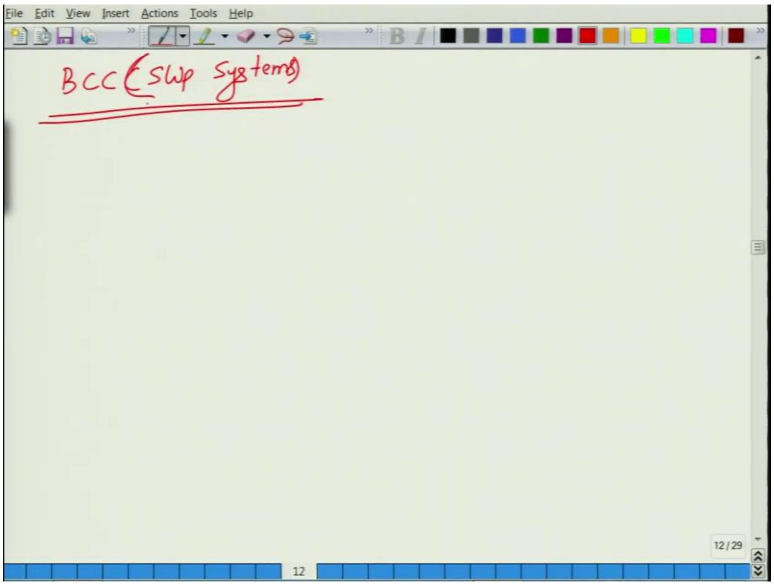


So, similarly, you can do this work for BCC as well. So, we do not have time for that today, we will do that in the next class. I will leave it to you to do some homework in this direction before we take up this in the next class. So, what we have done in this lecture is basically, we have looked at, we have invoked the concept of slip systems.

So, slip system, a slip system consists of two entities; one is slip plane and the slip direction. Slip plane is the plane on which the planar density is highest. In case of closed packed system it is the closed packed plane. So, for FCC it is 1 1 1 type of plane, for HCP it is 0 0 1 type of plane, but BCC and simple cubic structures do not have a closed packed plane, so in that case, the highest density plane is a slip plane.

And the closed packed, and the slip directions are directions which are closed packed directions or directions with highest linear density. So, in all these systems we have directions which are closed packed that is along which the atoms touch each other. So, for one FCC the direction is 1 1 0; for BCC the direction is 1 1 1 type, for simple cubic it will be 1 0 0 type of direction and for HCP, it would be one of those in plane directions of 1 0 0 or 0 1 kind of directions. So, we will do some more analysis on the slip systems in the next class to find out BCC and HCP slip systems before we move on further. So, thank you very much.