High Speed Devices and Circuits

Prof. K. N. Bhat

Department of Electrical Engineering

Indian Institute of Technology, Madras

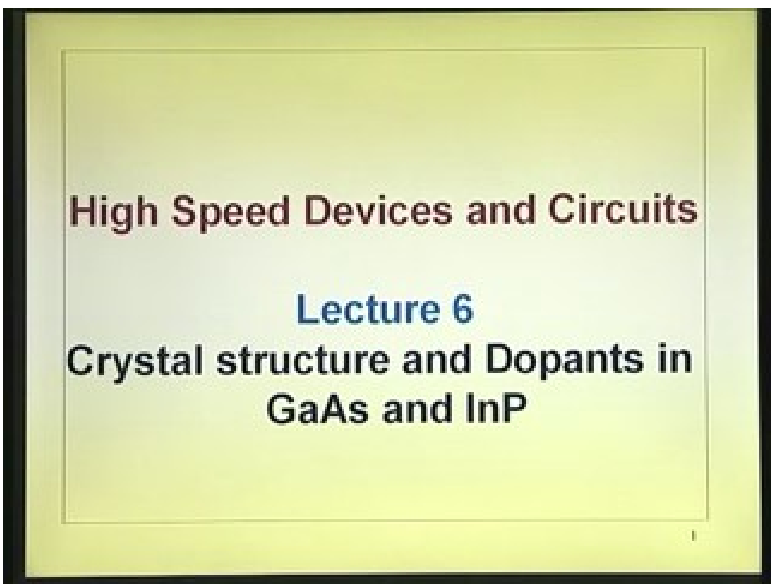
Lecture – 6

Crystal Structure in GaAs

In the last two lectures we have discussed and seen how powerful the compounds semi conductors can be. In fact, in that connection, we took a closer look at binary and ternary compounds. In ternary compounds, we have seen that we can combine different III – V semiconductors to achieve band gaps form one range to the other range

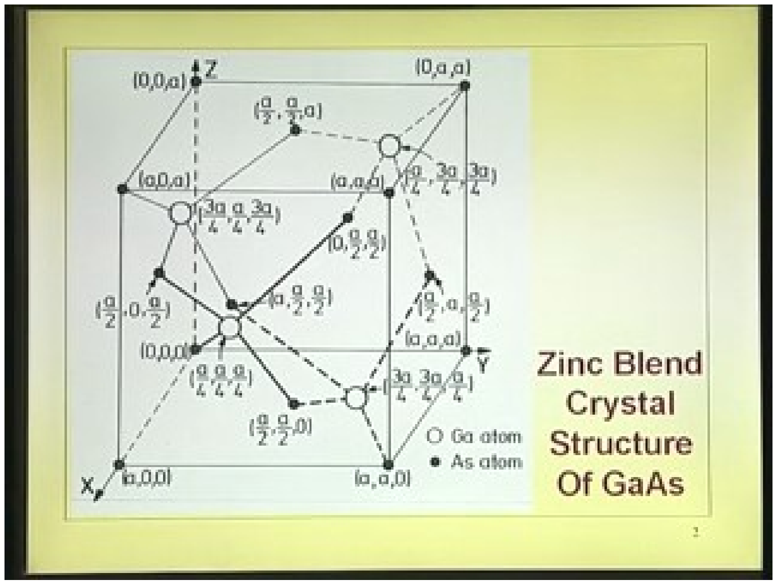
In fact, we can get direct band gap and indirect band gap. We can also make light emitting diodes; we can make detectors of the wavelength, which you look forward.

(Refer Slide Time: 02:04)



Now, today, we will further look into this device, that is, the material, especially gallium arsenide and indium phosphide, because we have seen that these are the two materials, which will be suitable for micro electronics. Of course, it can be in combination with other materials like aluminum arsenide, gallium phosphide, or indium arsenide; you can achieve with other applications which are up to electronic applications also. Now, let us just take a look at the crystal structure.

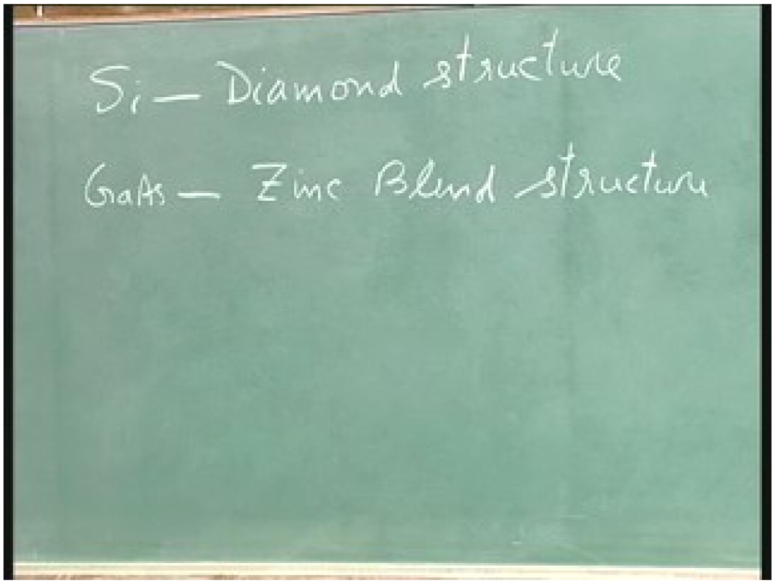
(Refer Slide Time: 02:40)



This structure is the cubic structure. In fact, when you say cubic structure, to recapitulate your memory, you can have a simple cubic structure. You can classify the cubic structures as simple cubic structures. If it is a simple cubic structure, in a crystal structure, what we are defining is a unit cell, which in this case, turns out to be cubic structure. This will be repeated in three dimensional x, y, and z directions. That is why we take a look at the single unit cell, because it will repeat itself in all directions.

Now, in general, this unit cell can be simple cubic. If it is simple cubic, it will have a cubical structure with atoms only in the corner of the cube. It can be face centered cubic, if there are atoms in all the eight corners plus atoms at the center of each face. That is, there are actually six faces; that is face centered cubic. We can also have body centered cubic, in a body centered cubic, there is an atom at the center of the cube. So, simple cube: face centered, body centered. Now, what we are taking a look at is, different from this. If you are talking of silicon structure, that is diamond structure.

(Refer Slide Time: 04:28)



A silicon structure is diamond and gallium arsenide is zinc blend structure. Basically, both are same structures. In fact, if you see this particular cube, if all the atoms here inside the cube, on the cube edges, everything, if all of them are silicon, then that is diamond structure. In the case of gallium arsenide, we can see this is the zinc blend structure. In the zinc blend structure, you can see all the black ones. They are the arsenic atoms and you can see four open circles, which are gallium atoms.

So, the structure is: on all the corners of the cube, you have arsenic atoms; on all the face centers, top face the x z plane center, the x y plane center, then this plane, which is y z plane parallel to y z axis, this is also center. So, on all these face centers, we have got arsenic atom. On all the edges of the cube, you have got arsenic atom. Now, in addition to that, you have got these four.

For example, this is not inside; this is on the front face. So, this gallium atom is located within the cube of this cell. All these four are within the cube, they are not body centered, and they are in the cube. They are in the location of them; you can see I have marked the coordinate here. This is the center of coordinates and from there, you move a by 4, a by 4 the x direction and y direction. Move up a by 4; if you have the corner there, a by 4 and a by 4 will be somewhere here, that is the atom. You can see similarly, there are other atoms which are with respect to the corner a by 4, a by 4, a by 4.

You do not have to memorize the structure. All that you have to remember is arsenic atoms on all the corners, arsenic atoms on all the face centers, and gallium atoms inside. There are four gallium atoms: Each one of them is located at a by 4, a by 4, a by 4 from that corner. What you do is, move exactly diagonally opposite there on the same plane. From that, a by 4, a by 4, a by 4 here; from here, it is a by 4, a by 4, a by 4 up. But, the coordinate turns out to be, with respect to that, 3a by 4, 3a by 4, a by 4. With respect to x y plane, it is a by 4 raised. So, these two atoms are raised from the x y plane.

If you take this as the ground plane, as the x y plane, then a by 4, a by 4 are on those two corners. Next two atoms, we can identify just move around like that to the opposite diagonal. So, as far as this diagonal on the x y plane is concerned, a by 4 move into the opposite diagonal here. Now, there are no atoms a by 4 for these two. You move to the top; from the top, a by 4, a by 4 downwards, from the top here a by 4, a by 4, a by 4 downwards. To see, if you imagine this womb, we can see that these two at the bottom a by 4, a by 4, a by 4 turn around to that. Then, go to the top plane, a up, come by a by 4, a by 4 down. Those are the atoms. That is the zinc blend structure.

The ones which are inside a by 4, a by 4 are gallium. If it is silicon diamond structure, all these atoms are silicon; structure is the same. Now, one more thing I want to point out here is, there is no sanctity about saying atoms in the cube are gallium and all on the surface are arsine. It can be the other way also. It all depends where you have taken the center of the coordinates. So, this keeps on shifting. You can draw the entire diagram just by shifting a by 4, a by 4, you will get all the gallium atoms on the cube surface, on the corners, and on the face center; all the arsenic atoms inside. That is the nice thing about it, because the structure is entirely repeating all over. So, what all shown here is the one which is inside. I have shifted up this coordinate to there. Immediately, the whole picture will be different. This will move to the corner, all this will move to the corner, and the face center gallium. So, please understand that there is no sanctity about just telling, it is always the arsenic atoms on the surface of the cube, gallium inside and the other way also.

I am repeating once again to make it clear. Now, we will also try to understand these pictures, if you are not familiar. For example, some of those planes, what arrangement of atoms are there in the planes, and all that. Now, if you take this gallium atom, that atom which is located from the origin at a by 4, a by 4, a by 4 up. Let us take a look at that. If you catch hold of one gallium atom, then the picture of the other things are same, if I move the center of coordinates.

Here, you can see these are the lines, which I have drawn the gallium has got. It has got five valence electrons. This is the difference between silicon and gallium arsenide. Silicon has got four valence electrons. Now, here, on an average, therefore, for gallium and arsenic, there are eight (11:00). So, this structure is also forming covalent bond. It also forms covalent bonds like silicon, but in addition to that, there may be slight ambiguity. This is because of slight negative charge. That we will discuss later.

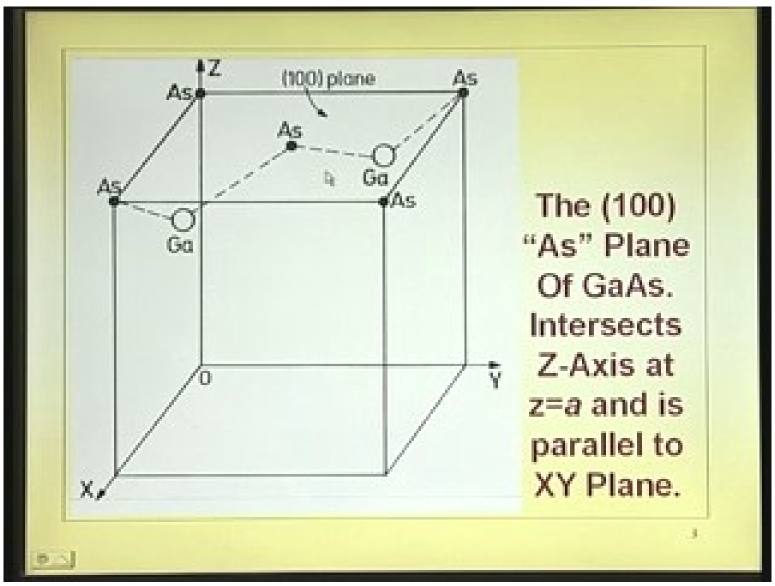
Now, we will see on an average, since there are four valence electrons, this gallium atom forms covalent bond with four neighbors. These four neighbors are arsenic. If you take arsenic atoms, the neighbors are gallium. So, this gallium atom, which is the neighbors, one is at the corner here. You can see this solid line drawn and the other one is here. We will go to this room and see that the structure will become clearer. That is this face. One is at the corner, the atom closest to that corner here. The neighbors are the ones right at the corner. Then, the other three are the ones which form the corner: that face, this face, and this face. So, that is why, if you go to this bottom face, you can see that is the center of the bottom face. If you go to the back side, if you see, that plane has got that is the center. x is 0, a by 2 is y, a by 2 is z. In fact, the coordinates are marked for you to make it easy to visualize.

Similarly, this one also so one, two, three, those are the planes. Those are the three planes which form that corner. So, the atom sitting in that corner forms bond with this atom here, a by 4. It also forms bond with those center atoms; that is the nearest neighbors. You can see any one of them for example here. That is coming from that corner down.

That you can see it forms bond with its nearest neighbors at corner. That corner is formed by the top plane and side two planes.

So, that forms bond with those atoms. This is at the back side, this is at the top, and this is at the side. Now, hereafter, you can sit down and visualize that. This is the zinc blend structure. Let us take a look at further. In fact, these will be lying on the main diagonal; these atoms when you go up from here to there. Let us take a look at what are the different planes.

(Refer Slide Time: 13:53)



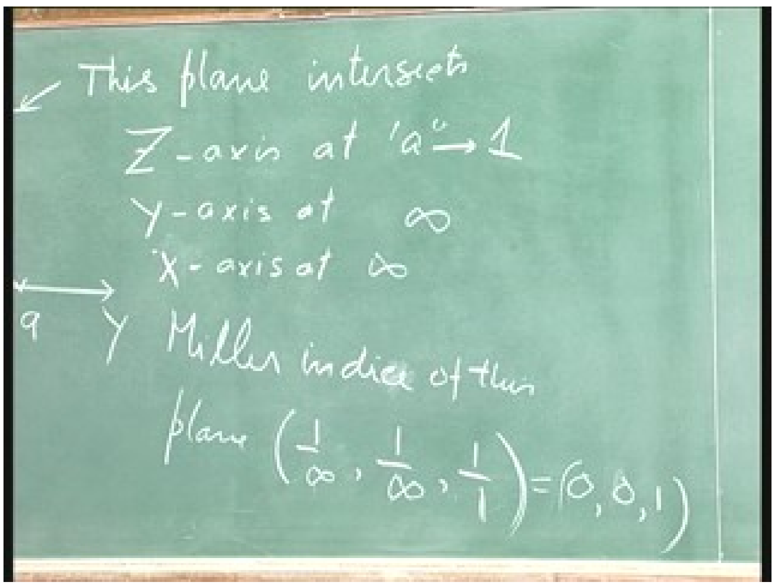
I just removed all other atoms form that cube. It is the same cube cleaned up everything. I have retained only the top surface. If you take the top surface that I have marked it as 1 0 0 plane. Strictly speaking, it is not 1 0 0 plane. For example, if I take x, y, and z, what we are taking is, this is a; that is a, that is a. If I draw a plane parallel to that, that is that plane, what we have put on the top. It intersects the z axis at a, or you call it as 1. Instead of putting a, you call it as one. That intersects the z axis.

This plane is something here. Just to go back to the discussion, this plane intersects z axis at a. We call it as 1, normalized with respect to time. y axis at infinity; x axis at infinity. So, the actual coordinates are one, infinity. Now, the miller indices, that is, you refer to that plane by what is known as the miller indices.

The miller indices of this plane is, x is one by infinity, y is one by infinity, z is one by one. So, this plane actually will be equal to 0 0 1. However, I have called this as 1.0 0 plane here

That is because you take any one of them, and the atom will remain the same thing. I can make this 1.0 0, if I shift the coordinates. So, what you do is, any one of these sides of the cube parallel to x plane, y plane, z plane, you call it as a family of 1.0 0 planes. So, these are the 1.0 0 planes. It can be 0 0 1; 1.0 0 or any combination of that; 0 1 0 depending upon which one you are looking at.

(Refer Slide Time: 17:39)



Now, I am sure that some of you have done this in years of course on technology. For those who did not have exposure or forgotten, I am just recapitulating this. Now, you can see here. The plane, if you take silicon structure, it is having silicon. Next plane, this gallium plane is at a distance equal to the distance between this plane and a plane crossing through that, which is equal to a by 4. This is because all the atoms are located at a by 4. If you take here, for example, that is a by 4 down, this is center, and that is a by two from top.

So, the distance between the planes there: 1 0 0 family is a by 4, a by 4, a by 4. Also, you can see their alternate layers, which are consisting of arsenic, gallium. You go back to that and see. Arsenic in that plane, gallium in that plane, arsenic in that plane, gallium in that plane, in fact, you have to sit back and visualize again. You have gallium, arsenic; gallium, arsenic; alternate planes, whether I go this way or that way. So, it is also ____________.

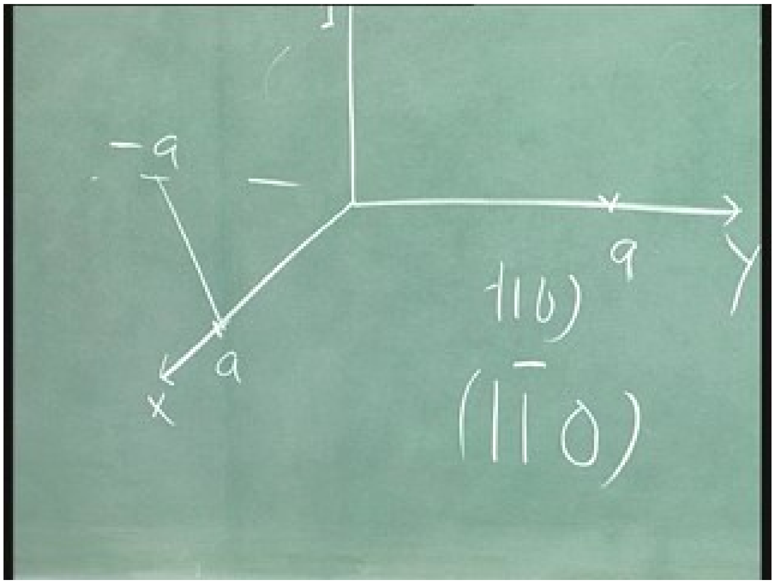
That is the difference between silicon and gallium arsenic. Silicon will have silicon, silicon, silicon, nothing else will be there. Now, let us take a look at this plane. You see another one deliberately going through this, because each one has some specific properties. This is because it is not silicon, silicon, silicon and it is arsenic gallium and silicon.

If you take a look at this, what you have marked here is, now I do not have to go to both. This particular plane intersects the x axis at a, y axis at a, and z axis at infinity. So, this is 1 1 0. Inverse of 1 is 1, and inverse of infinity is 0. This is 1 1 0 plane. This actually cuts or intersects the 1.0 0 plane.

The bottom is actually 1.0 0 plane. We are not really distinguishing between 0 1 0 and all the 1 0 0. You look at any one of those planes and the property will be same thing; because arrangement of atoms is same thing there. That is why we call it as family of 1.0 0. Similarly, you call it as 1 1 0.

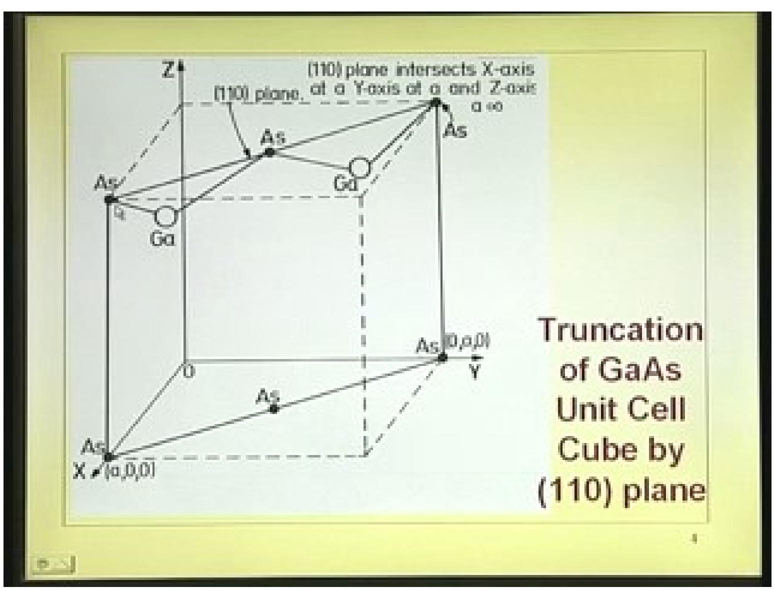
If I draw a plane perpendicular to that way, it will intersect the x axis at a, and y axis, if I go the other way, it will intersect at minus a. So, you do not call it as 1 minus 1, you call it as 1 1 bar 0. If it is like this, it is 1 1 0. If I have a plane going like that, minus a with respect to that coordinates, it is called 1 1 bar 0.

(Refer Slide Time: 21:00)



There is no sanctity in that, because property of that plane and that plane are the same thing. This is because of arrangement of atoms is the same thing. You can see here. The arrangement of atoms is actually top surface, arsenic, arsenic, arsenic. If you go diagonally down, you see those four atoms which are actually two atoms, which are a by 4, a by 4 down, a by 4, a by 4, a by 4.

(Refer Slide Time: 21:23)



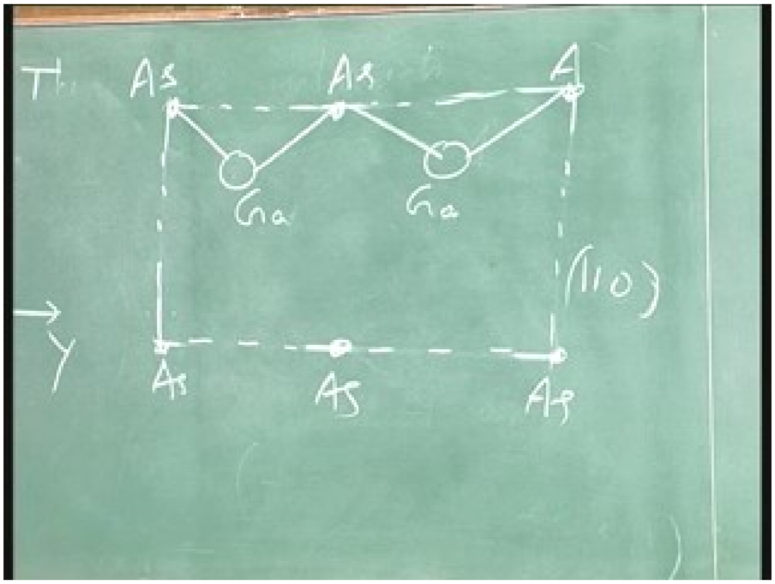
That is the atom and that atom forms bonds with the nearest neighbors. It is in the same plane as this. If you take a look at this particular plane, this atom lies on the diagonal. So, that is here. That forms bond with this and this. There are four bonds; other two bonds are: that atom form bond on this plane and also on that plane. We are not showing that, because we are seeing only that particular cut view of that particular plane.

What we are marking is, only this. Just to take a look at the atomic arrangement, what we are doing is like that. That is the 1 1 0 plane. Arsenic is there, arsenic is there, arsenic is there, that is, arsenic is here at the corner. Arsenic is here at this point in the bottom plane. Then, there is a gallium atom here. There is a gallium atom here. That is the atomic arrangement; number of atoms you can count there. So, this form of bond is here like this, bond here like this, bond here like this. In fact, I should not put this thing. This is only just, bond is only there. This is the boundary which I am marking.

I am drawing it by dotted line to distinguish the actual bond and this boundary. So, you have got the arsenic, arsenic, arsenic, and gallium. You have got the diagram there. So, we can see this particular structure has got certain peculiarities: the gallium atoms are there on the plane, this gallium atom belongs entirely to the gallium to the plane, and this arsenic atom belongs to this plane. It is also shared by the plane, which is continuous on the top. If you take this area here, contribution of this arsenic plane to this arsenic atom to this plane is half and this one is one fourth, so, one, two, three, four; 4 together is one contribution. This is half, this is half, and this together is one.

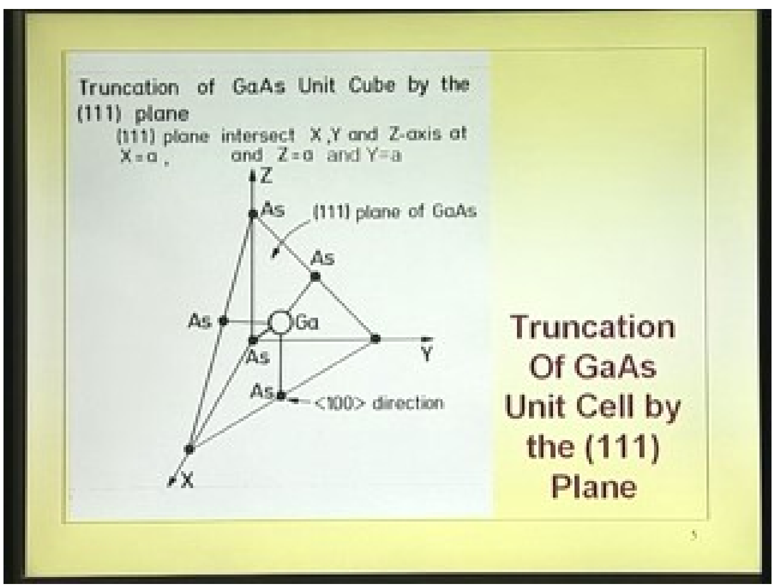
Actually, if you see this particular area, there are two gallium atoms, two arsenic atoms, so it is neutral. Hence, there is no problem. That is what I want to point out here. It is a neutral plane, even if there is some chance. In fact, gallium has got three and arsenic has got five electrons, there is some iconicity. The bonding is not perfectly neutral like in silicon. There is some shift of electrons towards arsenic. So, there will be gallium, which is plus charged; in fact, it is plus half. Arsenic will be minus half charge. So, the bonding between the two atoms not merely covalent bond, it is also ionic bond. There is slight force of attraction between them, plus and minus charge. If you take this smooth plane as it is, it is neutral.

(Refer Slide Time: 25:03)



There may be charge sharing between them. Now, let us take a look at it further. This gives further idea about the crystal structure.

(Refer Slide Time: 25:20)



For example, you remove this here. So, what we are trying to see now in that picture is, the one which intersects here, here, and here the plane, that is this plane. You have marked there. That is a, a, and a. So, this plane is actually, intersect is 1 1 1. Inverse of that also is 1. That is 1 1 1 plane. Now, when we say 1 1 1 plane, we mean the entire family. I can just go in this direction; I move here to minus a; I can have the plane going like that; I can have the plane going down like this; what will be that plane actually? That is x, that is 1, and this is minus 1 1 1 1 bar, but the arrangement of atoms is the same, this or that. I can go in that direction; I can put 1 1 bar 1. So, all of them are called by one family, 1 1 1, because the atomic arrangement is same thing. What is the atomic arrangement?

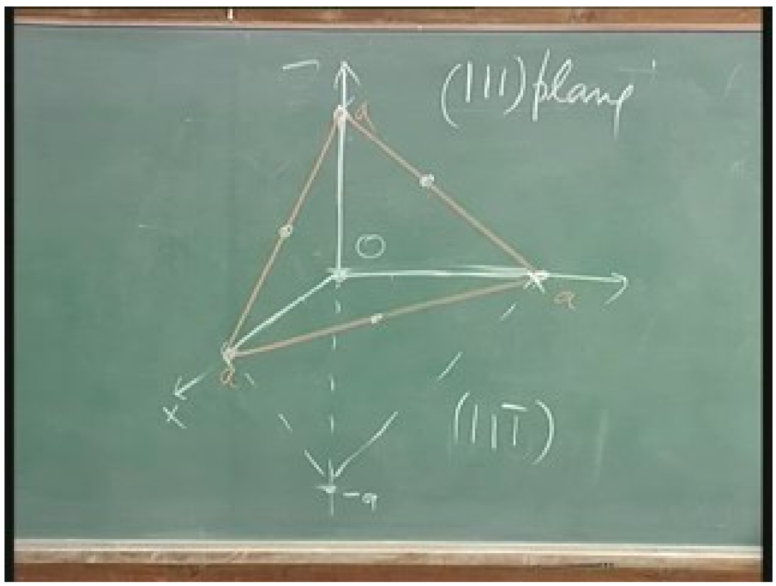
The atomic arrangement if you see, this is that plane. Now, what we would like to see is, go back to this original diagram. The 1 1 1 plane is drawn from there, along this diagonal here. So, along the diagonal in that plane, what are the atoms which are present? Arsenic, arsenic, this is inside, arsenic, arsenic. So, that is why, you have got here arsenic, arsenic, arsenic, and on this plane, you have got arsenic, arsenic, arsenic. So, that is what you can see here. Now, go back to this.

So, all the atoms you have marked now. That is, on this plane, the backside of that plane, there is one atom. Once again, that plane you have got three arsenic atoms, this plane you have got three arsenic atoms and on the backside, that one, it is coming, this is the center of that plane. So, through that, when it comes, you get this atom. They are all in one plane. That is what is marked here. So, on that plane, here on this triangle, you have got number of atoms. How many of them belong to that? That you can see. What is on an average? Now, you also see here at the corner, there is one. So, you have got this plane 1 1 1. That is totally arsenic; no gallium atom there.

You have got another plane, which passes through this. You can draw another plane parallel, that is 1 1 1. Whatever is parallel to this is, 1 1 1 family. So, I can draw parallel to that passing through this. That is 1 1 1. That is arsenic. In between these two, you have got a gallium plane, because this is a, this is a, but a by 4, a by 4, a by 4, you should take, there is a gallium atom. That is this atom. This atom is below the plane. So, if you stand on that plane and draw parallel lines, you will see that arsenic is there, gallium is there, and then arsenic is there. So, you can see the forces of attraction between these two planes will not merely be the covalent bonding, plus electrostatic force will be there, because this is totally arsenic.

Next plane is totally gallium. In fact, if you see carefully these planes, draw these lines if you carefully see, now this and this forms a tetrahedron. What you have is a structure something like this. That is the top; this one is coming like this. So, you have got all these atoms on the top of that corner and also of course here. Now, I just have to draw these atoms, because these are joined and it looks different.

(Refer Slide Time: 31:06)



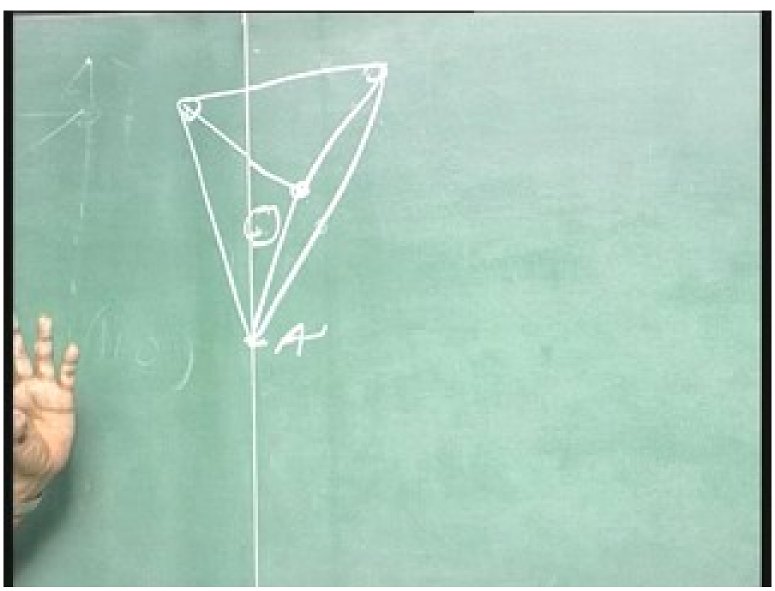
Join these atoms, these atoms, those atoms, and join them onto this. So, what I am trying to point out is, narrowing down to these; these are the four neighbors. See this gallium atom, that is not its neighbor; the one on that side, this one arsenic, this arsenic, this arsenic. So, these are the four neighbors for gallium atom and these lines, one, two, three, and four are the bonds. Do not worry about this particular line; I have drawn that to show the plane. In that plane, we have got these three atoms which are closest to this gallium atom. These three atoms are closer to the gallium atom and it forms bond with that.

This gallium atom forms bond with that one. So, when you draw a diagram in two dimensions, you see gallium surrounded by arsenic. I think I will put a slightly colored thing for that arsenic. I am deliberately putting that small, because tetrahedral radius of gallium is 1.26 angstroms. This is 1.18 angstroms smaller. Now, you have got arsenic here, arsenic here. This is 31, that is 33, but the tetrahedral radius of these are different: 1.18 and 1.26. This is arsenic; this is arsenic.

So, this is the one; these are the four neighbors. Let us go back to this, this gallium atom shifting here is bonding with that atom, that atom, that atom, and that atom and those atoms are in the plane, the corner one. This is at the corner one. So, these together form the tetrahedron. So, they say that the crystal structure is tetrahedron there. What you have gone is, you have gone into this cubic cell and picked out those neighbor fixed form with covalent form together. That is the tetrahedron structure. I do not know whether you are able to visualize from here to here, going into that, four in the side like this. Suppose you have a structure like this: those are the four at the top, then coming down like this, this is a corner, arsenic, arsenic, arsenic, arsenic.

Where is the gallium atom? Center of this thing, it is there. That is forming a bond with one, two, and three like that up and this one down. We have to be a bit involved, we have to actually visualize and see, but if you understand the position of the atoms, it is very easy to look into that one. So, you have a tetrahedral structure for gallium arsenide, silicon also. In silicon, all of them are silicon; this is also silicon.

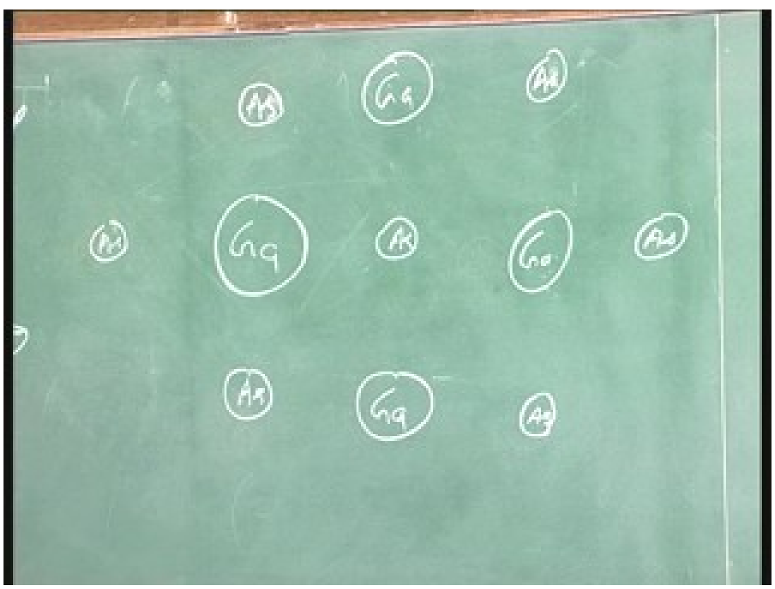
(Refer Slide Time: 34:28)



That is where it is. They say that it is sitting in the centre of the tetrahedron, one silicon atom. Here, a gallium atom is sitting at the centre, which is not necessarily the gallium atom is sitting at the centre of the tetrahedron. It can be arsenic with four around them. Take a look at this now. The two dimensional picture we can draw it like this. You can draw it closer, so that, I can cover more number of atoms. Let me draw arsenic, arsenic, arsenic. We move down now.

On this side, we will have gallium. Gallium is surrounded by four arsenic atoms in this picture. If I move, again, you will see gallium. Gallium, arsenic, gallium, and here, this gallium has four neighbors, which are arsenic. This arsenic has four neighbors, which is gallium. So, that is the complete picture. This gallium has four neighbors, which is arsenic. That is a two dimensional picture and that is simple to see. In fact, if you see the three dimensional picture, if you go anywhere and you pick up, you will see them like that. So, this is arsenic and this is also arsenic. I can go on arsenic, arsenic.

(Refer Slide Time: 36:29)



If you want slight difference in color, you can put that. So, I make it visible, that it is arsenic here, arsenic here, arsenic here. I can keep on expanding and put gallium here, put gallium here, and so on.

(Refer Slide Time: 37:02)

I can spend the whole hour doing that. The idea is that, you have got gallium atom, surrounded by arsenic atom and arsenic atom surrounded by gallium atom. That is the whole idea, whereas in silicon, you draw the same structure, everywhere silicon. Now, you can see that bonds are like that. You put two to show that it is on an average two and silicon, you put two like that. So, total eight electrons and these are the electrons which you represent are found upon. Now, arsenic is 75. Therefore, one of the electrons will be displaced partially towards that. So, it will be having electronegativity; negative charge on arsenic and positive charge on gallium. That is the reason why, when you go down like this, from this 1 1 1 plane, you go down not a by 2 or so; it is some root 3 by 2, root 3 and 1 is to root 3. That should go diagonally.

So, it should go down into this plane. That plane has got all gallium atoms, which has got plus half charge and next one has got negative charge. So, you can see the planes are holding each other with that attractive force, whereas if you take 1 1 0 plane, there is no additional binding force. It is only the covalent bond, there is no additional charge. This is one different set; you remember that it has some effect. It has got a very effect on etching, cleaving of gallium arsenide. For example, if you take silicon, if you just break it, what is the cleavage plane? It is 1 1 1 plane.

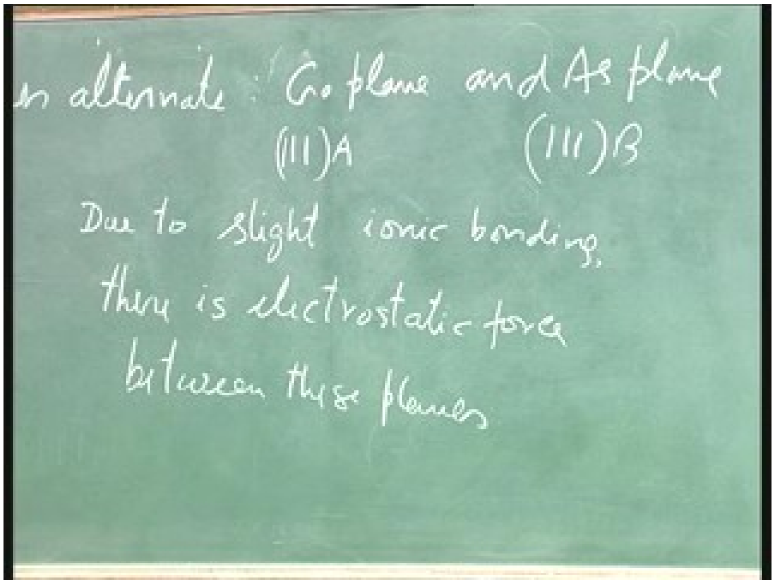
That is mainly because there is no other binding force there and it is only covalent bond. It is 1 1 1 plane, because along the 1 1 1 plane, binding is good. This is because they are densely packed. Number of atoms along the 1 1 1 plane is more. So, it is densely packed. That is why 1 1 1 plane when you cleave, it does not break along across that, it is parallel to that coming off. That plane as it is, it is bound together. If you take gallium arsenide, the cleavage plane can you take a guess? If you take 1 0 0 plane, you have gallium arsenic, gallium arsenic. That means, there is force of attraction between the two in addition to the initial bond. If you take 1 1 1, gallium arsenic, gallium arsenic; again, that force of attraction, electrostatic force is there. It becomes difficult to cleave.

If you take 1 1 0, we saw totally number of arsenic atoms equal to number of gallium atoms in that plane. We saw the number of atoms counted together, you see six here, but contribution is only two and gallium atoms two. If you take the entire plane, number of gallium atoms is equal to number of arsenic atoms and charge is neutral. Between the planes, there is no electrostatic force of attraction. It is only covalent bond. So, it becomes easy to cleave in that plane. Between the planes, binding is not so hard. So, we are able to cleave it. Now, let us just write down some of the facts.

1 1 1 plane alternate; this is very important, where they make use of this property for some technology. Alternate gallium plane and arsenic plane, this is true, whether you talk of gallium arsenide, gallium phosphide, or gallium nitrate. So, to keep it general, they will call it as 1 1 1 A plane, 1 1 1 B plane, B referring to fifth group, A referring to third group. So, A plane, B plane; 1 1 1 A plane is gallium, 1 1 1 B plane is arsenic.

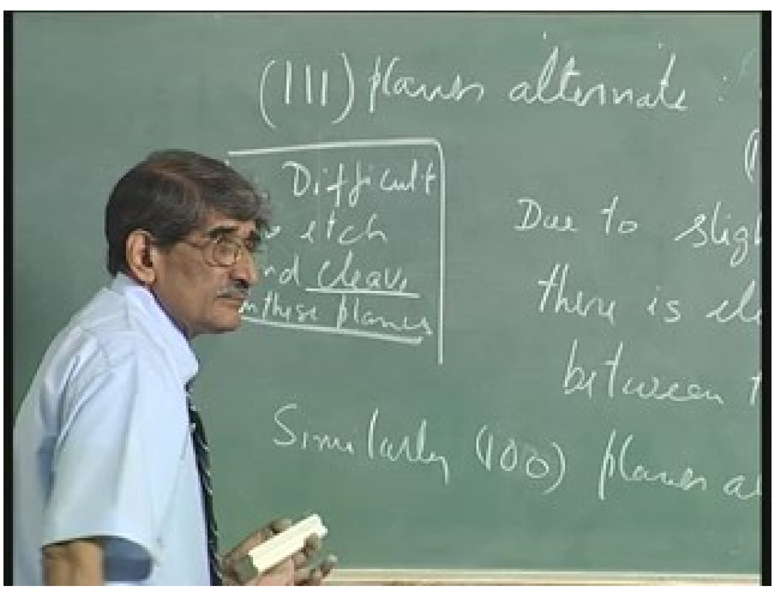
So, there is force of attraction due to the slight ionic bonding. There is electrostatic force between these planes. What I have said, I have put it in black and white or black and green.

(Refer Slide Time: 42:58)



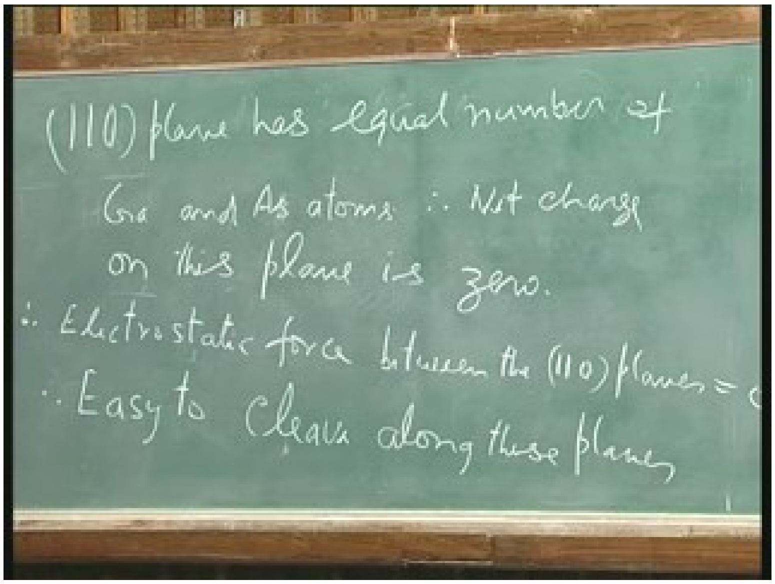
Now, if you take 1 1 0 also; similarly, 1 0 0 planes also have net charge. Hence, net force of electrostatic attraction. So, it becomes difficult to cleave those planes. This makes this property difficult to etch and cleave in these planes. There of course are other corollaries to this. In general, that is the case particularly true for the cleavage.

(Refer Slide Time: 44:37)



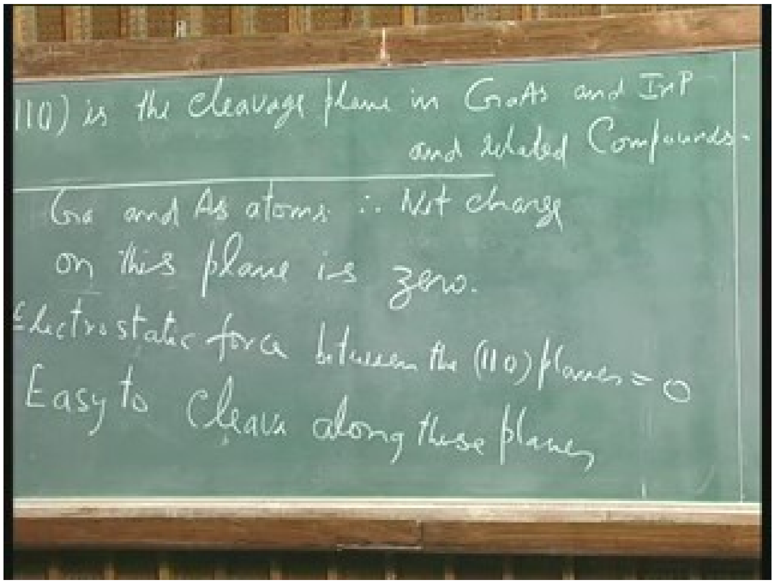
Let us take a look at the other plane, which have been staying all the time. You take a look at 1 1 0 plane, which has equal number of gallium and arsenic atoms. Therefore, net charge on this plane is 0. Therefore, electrostatic force between the planes in 1 1 0 planes is 0.

(Refer Slide Time: 46:48)



Therefore, it is easy to cleave along these planes. That is the key thing; but, they say whether it is gallium arsenide or indium phosphide, the cleavage plane is 1 1 0. So, 1 1 0 is the cleavage plane in gallium arsenide, indium phosphide, and related compounds. _______________ gallium helium arsenide that has a cleavage plane, which is equal to 1 1 0.

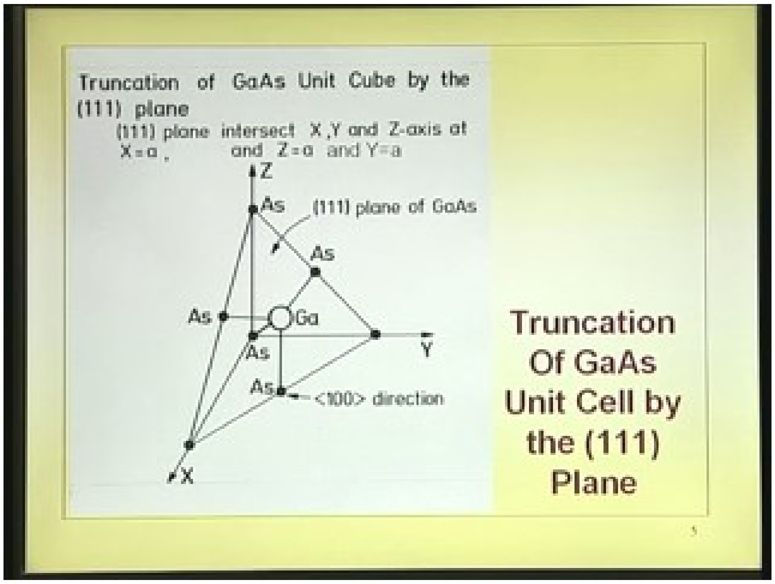
(Refer Slide Time: 48:23)



This is what I want you to try at home yourself. The entire idea of taking a look at the crystal structure is to understand some of the properties which are relevant to technology. What is relevant to technology is, if I scribe and cleave in silicon, if you cleave along 1 1 1 plane; how do you cleave? Just draw a line scribe to depth of about one-tenth of the thickness of the wafer. In that, apply a little bit of force and just cleave along that plane. That is what is meant by that cleavage plane. You just drop it, it will cut into pieces. If you take 1 0 0 wafer, you will be having that type of shape, corresponding to those. For example, triangle or the edges will be 1 1 1 planes.

If I take a 1 0 0 wafer, let us ---- one or two things related to that, because we cannot get into new topic. But, at least, this has a profound influence on technology. So, let us take a look at that. I have many more properties relating to doping, and so on. We can see it frequently in the next lecture, but some of the things related to this, I will try to discuss. If I take a 1 0 0 plane, x, y, and z, 1 0 0 wafer, what is the plane? x y plane or parallel to x y plane or strictly speaking, we will say it is parallel to any one of those x y or y z or z x. Now, I just take this. If I take the 1 0 0 wafer, the surface is parallel to this. Now, where will the 1 1 1 plane be? We will see that.

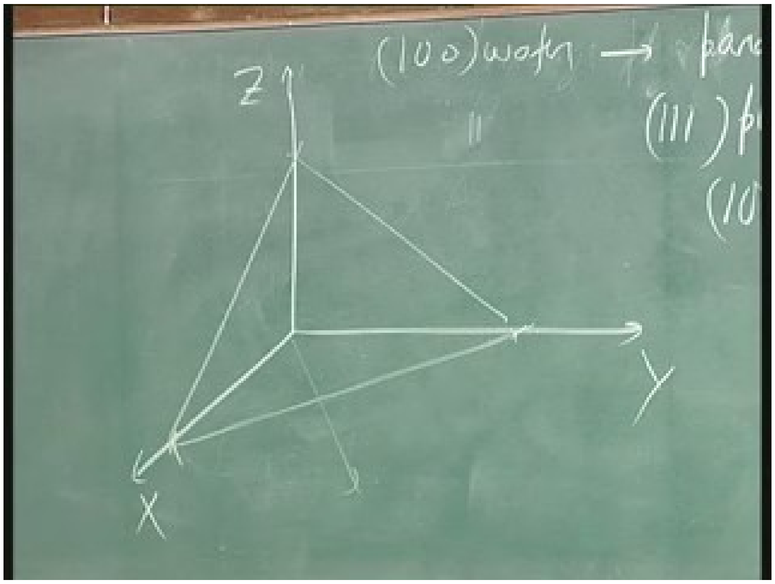
(Refer Slide Time: 50:54)



1 1 1 plane is at an angle of "54.7" degrees. That is, 1 1 1 plane intersects 1 0 0 plane at 54.7 degrees and it intersects it here. That is for 1 1 0 direction. It is 1 1 0, because a line drawn perpendicular to that is 1 1 0. So, it is 1 1 0 direction in the plane. So, it intersects there. If I just draw a line here parallel to that, if silicon, it will cleave along that plane. It is making an angle of 54.7 degrees. So, if you see the wafers, when you scribe them into individual chips, which are 1 millimeter by 1 millimeter, you see the edge of the silicon that will be at an angle.

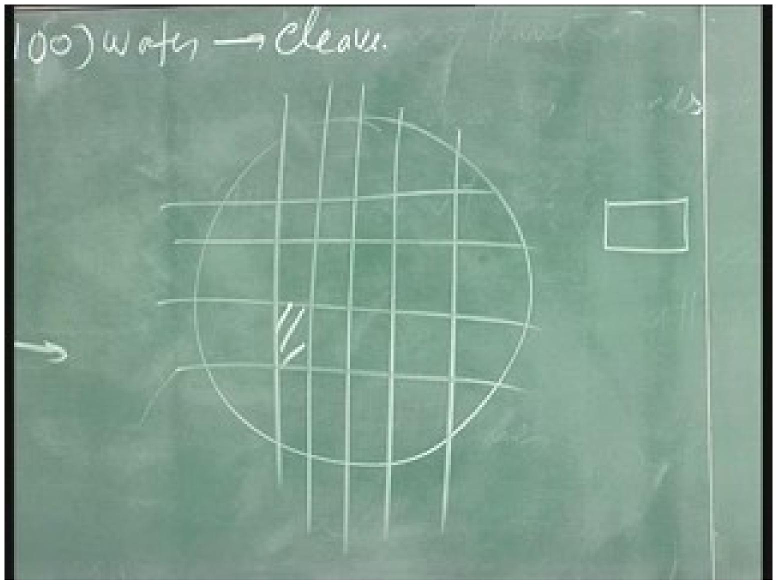
It can be like this or like that, because after all there are planes like this, are also going down. So, depending upon which way force has come, you see it is going like this or like that. What will happen in the case of gallium arsenide, indium phosphide, and so on?

(Refer Slide Time: 52:19)



If I take 1 0 0 wafer, if I cleave it, what happens? Cleavage plane is 1 1 0; if I cleave it, this is the 1 0 0 plane. 1 1 0 plane is a cleavage plane. That is perpendicular to that. What is the impact of that on the chip or the device? Let us draw that. See, if I take gallium arsenide 1 0 0 wafer, and then cleave, you get a plane which is like that. I draw a line, I take a wafer, and scribe like this; each one is a chip in the scribe _________. In the case of a silicon device, this is the one which you take out; that will be like that on the top. However, if you see the edge, it will be cleaved, whereas if you take gallium arsenide and if you cleave like that along this, the chip will actually be like this.

(Refer Slide Time: 54:11)



The chip will be like this, perfect cube or it is not a cube; it is a square with vertical faces. There is no shape like this. Now, you may ask, what do we get? Why should I worry about that being vertical? In micro-electronics, you may not worry; because in micro-electronics, all that happens is here. But, when you go to make a laser, you want that plane to be where that light is coming out. That should be polished and be vertical.

If you want to make lasers, this cleavage plane which is being perpendicular to 1 0 0 helps you. In fact, we can have those surfaces which are shining and which is giving the laser in that plane. So, for making laser diodes, this property is very useful. The property that 1 1 0 is perpendicular to 1 0 0 plane, I can scribe along the 1 1 0 direction like that. Both are perpendicular: 1 1 0 and 1 1 bar 0 on the x y plane. Both you call it as 1 1 0 direction; 1 1 0 direction; 1 1 0 direction.

If you call 1 1 0, that may be 1 1 bar 0; they are perpendicular. So, there the planes are vertical. That is the key advantage of having this material for this application. Now, more or less, we just have completed about the crystal structure and its importance cleavage plane, and so on. Also, we discussed about its profound effect on the chip size, chip surface, and its usefulness from electronic devices. Also, the atom being 1 0 0 1 1 we discussed. This particular thing is also the other property, which we have seen already. That is, silicon is indirect band gap; gallium arsenide is direct band gap.

I think, next class onwards, we will start discussing about the dopants of gallium arsenide and indium phosphide. Whatever we talked about gallium arsenide holds good for indium phosphide or for any other III - V compound semiconductor. So, we will discuss about those aspects in the next lecture.