A Brief Introduction to Micro Sensors

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Lecture - 11
Si Crystal Structure

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So, in this module, we will see that how micro fabrication processes are done for the MEMS sensor. So, till now, in we have already learnt that what are MEMS, how what are their like graph working principle and also like, how different mechanical and electrical parts work and how they are coupled together right.

Now, we will see that how these sensors are made, like, which is the most important part of this course. So, let us start with micro fabrication for MEMS.

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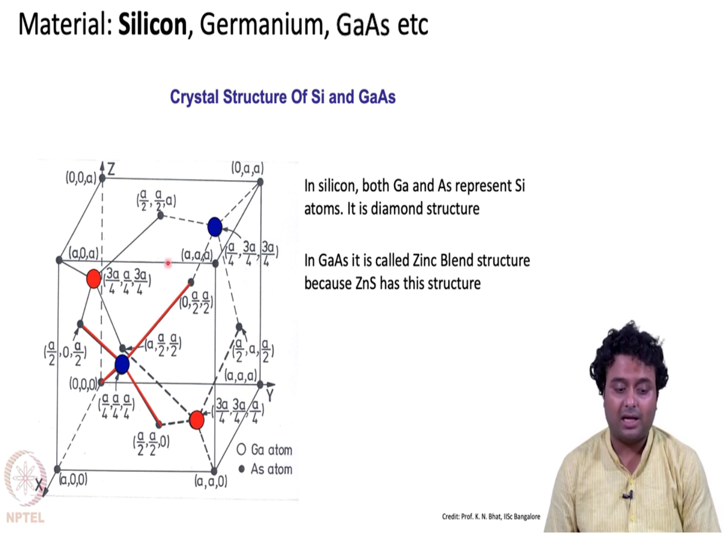

So, before going to micro fabrication, I would like to spend some time on the material. So, what are the material we use? So, mostly we use silicon, because silicon is a very well known and already very popular material for electronics. And, while we are making some kind of MEMS device then we have the mechanical sensor also and the electronic part also is there for signal processing or other requirements.

Now, the silicon is one of the popular semiconductor. And what are the others? Others are like germanium, gallium, arsenide etcetera. But, as the silicon microfabrication industry are already very much established because of the micro electronics industry. So, MEMS also had has adopted the same micro fabrication technology and the good things about silicon is it has a very standard mechanical properties like its Young's modulus etcetera are very much well known and also the electronics properties are also known.

So, while we are talking about let us say cantilever or membrane, which are the mechanical parts of the MEMS sensor; that can be made with the silicon as well as, we can make a silicon semiconductor conducting by doping some material like 3 valency or 5 valency material in silicon we can make it p type or n type semiconductor. And accordingly, we can change the conductivity of the silicon which is useful for electronics part of the sensor. Now, to understand the micro fabrication; we have to first understand that how this silicon structure is.

Now, while I am talking about the structure; I am talking about crystal structure. Now, what does it mean crystal structure? Crystal structure means that in an atomic arrangement all the atoms are arranged in a periodical matter, periodical pattern right. So, and this kind of structure can be called crystal structure which is part of some different course. So, I am not going into that details that what are the crystal structures and all.

So, but here what I am showing is how silicon are arranged in a single crystal silicon wafer or single crystal silicon block. So, the important point to note here is that the silicon and gallium arsenide have the same kind of crystal structure and that is called Zinc Blend structure because, this is also the structure of zinc sulphide or more popularly known as zinc blend.

In zinc blend structure or this kind of silicon or gallium arsenide structure they are, if you takes this cubes then there are at all the corners like in a cube there are total eight corners right. And in all the corners there will be one atom.

All these corners have one atom and then this is also called FCC or Face Centered Cubic lattice. Why? Because, in all the face also center of every face also there will be one atom. So, as you can see here, this is the center this is 0 0 0, there will be one atom then a 0 0, a a 0 like that, you will have 4 atoms at the bottom four corners then you have top four corners also four atoms ok.

And then at every face at every face means; like this cube has six faces right. And in that six faces you have six atoms and each at the center of that particular face, like if you see this atom this atom is a by 2 0 a by 2; that means, in along the X axis, it is at a by 2, along the Y axis it is at 0 because it is at exact plane. So, the Y distance is 0 and then along the Z axis also it is a by 2. So, similarly, you will have all the other faces also you will have 1 1 1 atom and then there is 1 atom from a particular distance from each corner ok.

Not at exactly each corner rather two reciprocal corners means other than the corners, other than all the eight corners and six faces also we have atom at the opposite at a certain distance from the opposite corners. And what does it mean? Means, see this blue atom here, this blue atom here is from this 0 a a corner at a distance at a certain distance from 0 a a corner and its coordinator a by 4 comma 3 a by 4 comma a by 4 right. And then, the other atom is at the just the opposite corners. So, this 0 0 a corner or this a a a corner; there is no atom there is no atom at at this vacancies ok.

But, at this corner vacancies which is a tetrahedral vacancy actually; there will have 1 1 atom. And at the bottom side also we will have similar atoms, but just at the opposite diagonal, the corner of the opposite diagonal right. So, this side; if you take then this 2 atoms the top 2 atoms are at the certain at along this diagonal right, along this diagonal; that is, connecting a 0 a and 0 a a. Whereas, the bottom 2 atoms which are at the tetrahedral vacancies that is at the that is at this diagonal which is opposite to the top diagonal; that is, connecting 0 0 0 and a a 0.

Now. these are called tetrahedral vacancies; Because, if you considered the face like the face centered atoms and the corner atoms then it can it can form a tetrahedral vacancy like this tetrahedral vacancy like this. So, we have this 4 atoms also which are at a certain distance from that particular opposite corners. So, this is for gallium arsenide where the big atoms or the biggest size atoms out of gallium and the smallest size atoms out of arsenic.

Now, for the silicon structure; it is same exactly only the all the gallium all the gallium and arsenic atoms will be replaced by silicon atoms. So, for silicon atoms for silicon crystal structure; all the atoms are of same size right. Because, like in gallium arsenide structure gallium atoms are higher in or bigger in size as shown in the picture, but in and arsenic as a smaller, but for the silicon crystal structure will have all the atoms of same size.

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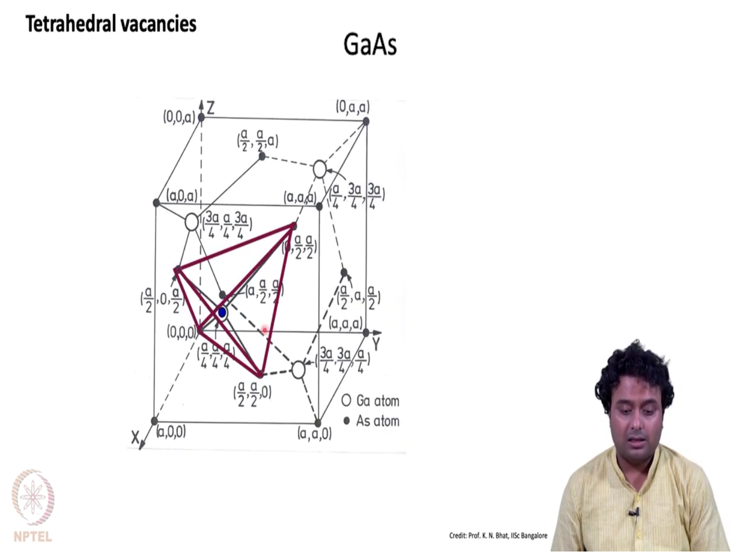

And as I was saying in the last side that; if you if you consider this corner atoms and face centered atoms then it it it can form a tetrahedral vacancy. And these 4 atoms which are at a certain distance from the corners are actually at this tetrahedral vacancies. But, all the tetrahedral vacancies are not filled up. As you can see in this atomic structure; there are total 44 plus 4 total 8 tetrahedral vacancies.

Whereas among the four tetrahedral vacancies at the top only 2 vacancies are filled with the atoms and at the bottom also with there are only 2 vacancies which are filled with the silicon atoms or gallium atoms right and the other vacancies remain vacant.

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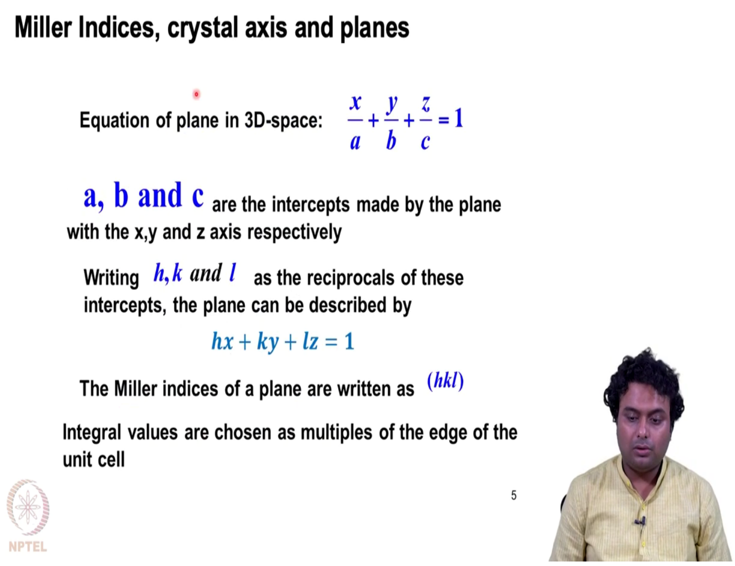

So, to explain crystal structure; we need to get held from the coordinate geometry. And in coordinate geometry; we can write equation of a plane in 3 D space, like x by a plus y by b plus z by c equals to 1. Where a b c are the intercepts at x axis y axis and z axis like if this is a plane then where the if this is the three axises and this is the plane then this a b and c are the intercepts at the with the plane and the axis right now a b c intercepts are made by the plane with the x y z axis respectively.

Now, we can write this new terms h k l as the reciprocal of these intercepts. And in that case the plane can be described as h x plus k y plus l z equals to 1. And this h k l are which are actually the reciprocal of the particular intercepts are called Miller indices. And a plane can be called by its Miller indices. So, if I say like 1 0 0 plane then; that means, h equal to 1 k equal to 0 and l is equal to also 0.

So, k equal to 0 and l equal to 0 means the intercepts at y axis and z axis are at the infinity or we can say the plane is uh parallel to the y z plane right parallel to the y z plane and at the x axis the intercept is 1. So, the plane is at the x axis intercept is 1 and while it is parallel to y z plane.

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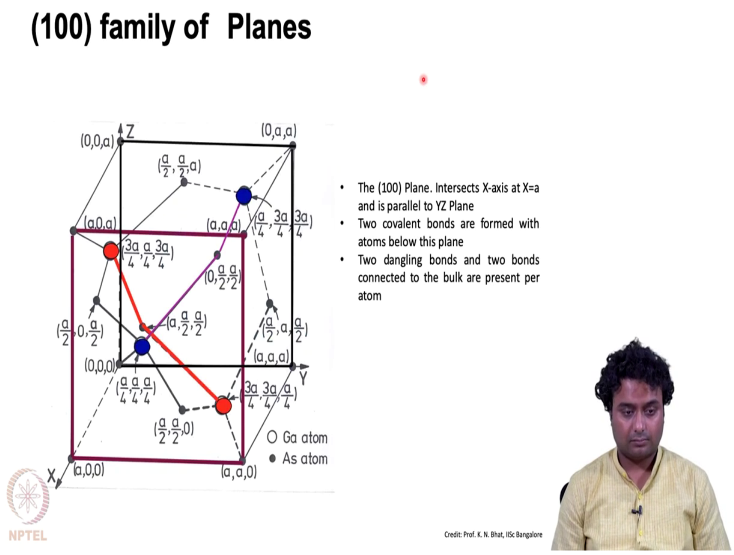

Now, let us see this 1 0 0 family of the plane for silicon crystal structure or gallium arsenide crystal structure. And here we can see that this is the cubic lattice and this is my X Y Z axis and then I have drawn the 1 0 0 plane or you can right as a 0 0 right. We can take a common and this is ultimately 1 0 0 plane or a 0 0 plane. In this plane actually, this intercepts the X axis at a or 1 right.

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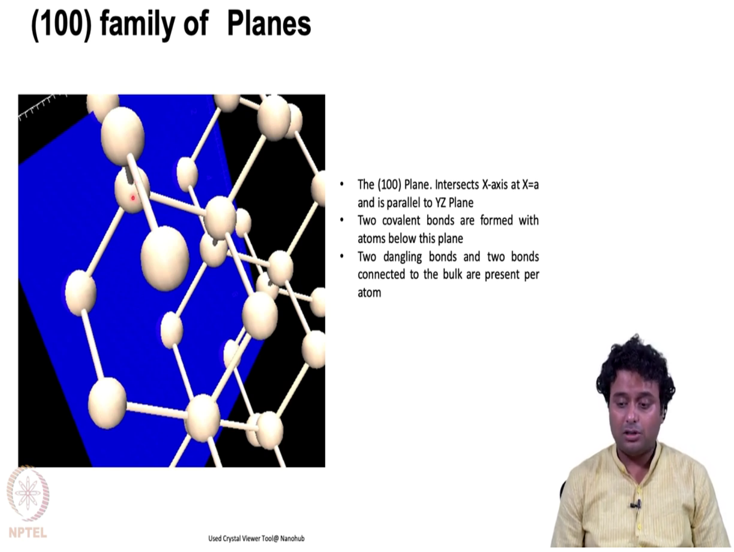

And from the next picture; we can see that there are two covalent bonds which are formed which are formed with the atoms below the plane right. And there are 2 dangling bonds. So, so, this is the plane I am talking about and on this plane these are the 4 atoms. Now, how these 4 atoms are connected to the how these four atoms are connected to its neighboring atoms. So, you see there if I take this atom let us say then this is connected this is connected to this atom through in the bulk ok. So, this side is the bulk and on our side on your side is the above the surface ok.

So, see that this is the bulk and in the bulk it is connected to one atom and then the another atom is there which is also connected in the bulk right with this atom also this is connected. Now, there are 2 bonds which are not drawn here. So, those are the dangling bonds which are above the surface.

So, if I if you can assume this as a cube cubic structure then, what I am talking about is this plane ok. The, let us say this is the plane. So, this is the plane I am talking about and then, if you go to the next picture what you can see is I am seeing it from the bulk perspective. So, I am at the bulk or we are at the bulk and then if you see that this plane like this plane is connected to 2 atoms inside the inside the material which is at the inside the bulk right and then this atom is connected to two more atoms which are at the out of the surface right

So, those are called dangling bonds, because surface is cut here. So, this is the surface and these 2 bonds are not satisfied; they are just dangling. So, these 2 bonds are not satisfied and another 2 bond are connected to the bulk.

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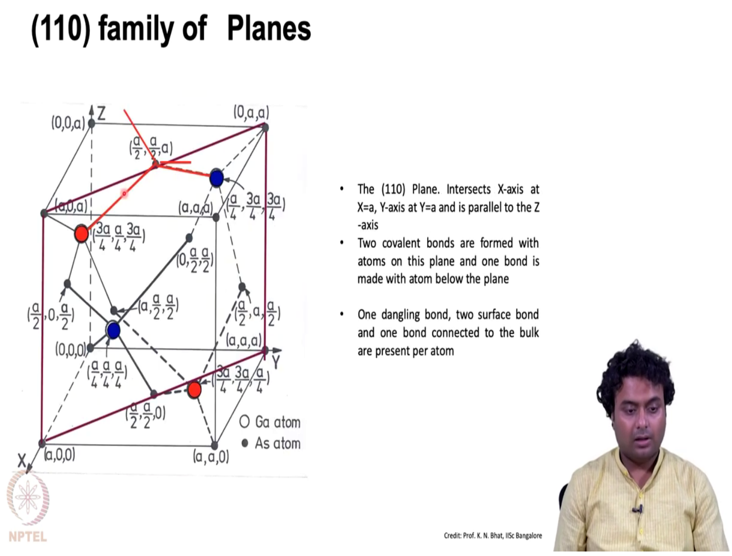

Now, let us see the 1 1 0 plane. So, 1 1 0 means that; it will intercept the X axis at 1 or a and Y axis also at 1 or a and with Z axis it will be parallel right or the intercept is infinity. So, this is the plane we can draw.

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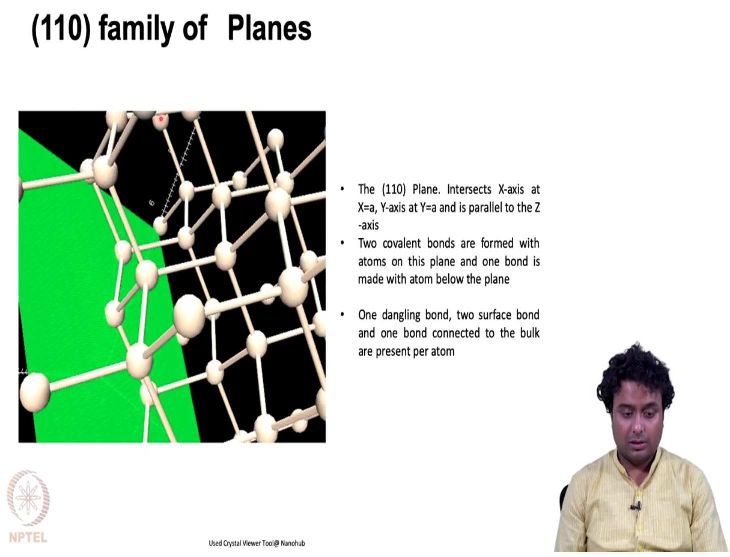

Now, if we see one atom in this plane then, we will see that one bond will be above the surface it is the dangling bond let us go to the next picture. So, this is this is the this is the atom which is at the surface right. Now, if you see here then 1 is there you can see only three bonds here, you can see only three bonds here right and in this three bonds, these two bonds; this bond and this bond ok. This bond and this bond are connected to the surface atoms, which are also available on the same surface.

So, this is the one atom and this is another atom right. And one bond is connected to the bulk one bond is connected to the bulk like this atom and there is another bond which is dangling or which is on the other side of the surface. So, that is dangling bond.

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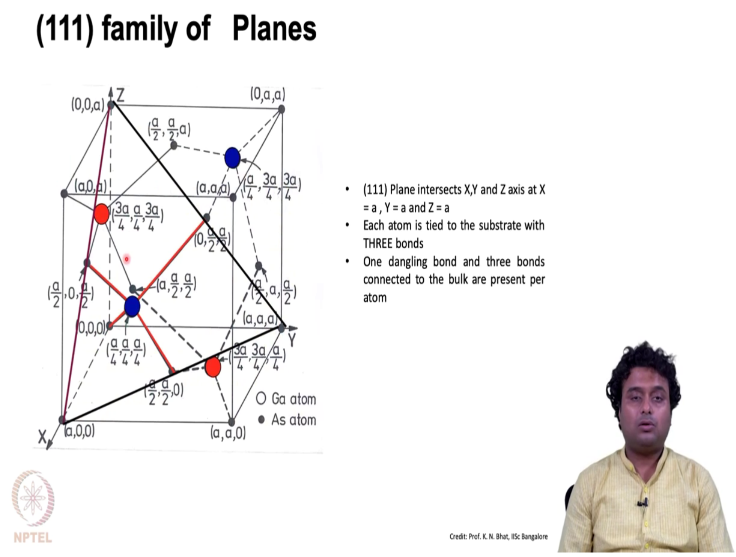

Now, go to the next family of plane and that is 1 1 1 plane. And this and in this 1 1 1 plane, as you know that; the intercept will be 1 1 1 and with all the three axis. So, it will be like this if this is the block, if you take then this is like this, this cutting the block like this right. So, the X axis, Y axis and Z axis all has intercept as 1 1 1 or a a a. And now, let us see that; how the atoms are connected towards the bulk and also above the surface right

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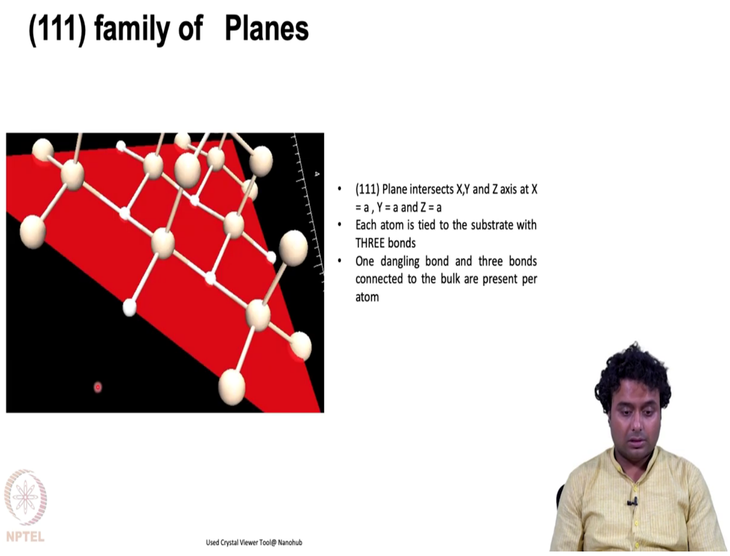

So, let us see this picture; here you can see, so this is the bond this is an atom which is at 1 1 1 plane. And in this plane; in atom 1 atom in this plane is connected to the bulk with three bonds. So, here you can see 1 2 and 3. So, these atoms are inside the bulk, because as I am saying while I am considering one surface, while I am considering one surface; I am seeing the picture from the other side, that is the bulk side right. And the surface as it is the terminating point. So, there is no other atom on the above the surface right.

So, on the other side of this surface there are some atoms which are not connected to, but this particular atom right and then you have 1 dangling bond. And this dangling bonds and this surface connected bonds are very much important. Why? Because, the more number of dangling bonds we have that atom will be more reactive ok. And while we are etching some while we are etching one particular material in one direction then, what happens is; the surface bonds very easily surface bonds very easily can get destroyed because, while I am attacking a surface then all the atoms in that surface will get destroyed.

So, if we go to the 1 1 0 plane as you see here there are two surface bonds. So, while this atom is attacked by some chemical this atom and this atom this will also will be attacked by the same chemical right. So, these bonds will also not be valid and the surface itself and the surface above the surface or the dangling bond is anyway unoccupied

So, ultimately there is 1 bond which is holding this atom to the bulk whereas, for 1 0 0 case, if we go to 1 0 0 case then, we will see that there are two atoms which are; there are two bonds which are dangling bonds. So, those bonds are anyway not satisfied. And if this plane is attacked then this atom will be hold by the by the atoms at the bulk and there are only 2 atoms to hold this in the bulk. Whereas, if we go to 1 1 1 plane, then we see that the there are three for to hold this atom this particular atom there are three atoms present. One this another this and another this.

So, there are 1 2 and 3 atoms which are holding this surface atom to to the bulk right. So, this is the most stable case where 1 1 1 1 1 1 face get attacked very slowly or the etching rate is very slow in 1 1 1 plane. Whereas, for 1 0 for 1 0 0 plane, there are two atoms; which are actually holding which are actually holding the surface atom to the bulk.

So, this is moderately aggressive or the etching rate is moderately aggressive in this plane. And if we take 1 1 0 plane and there is only 1 atom which can hold this atom to the with the bulk because the other two atoms are anyway of the surface, so these atoms are also not safe. So, this is the most aggressive case where the etching rate is etching rate is highest. So, next in the next class, we will discuss on different kind of etching.

Thank you.