Optoelectronic Materials and Devices
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Module - 04
Optoelectronic Device Physics
Lecture - 35
Microelectronics Processing

Today, we will talk about processing of p n junctions, so far we have looked at the individual devices, a p n diode, its applications, its device characteristics and where all it can be applied, but having a good device is not the only reason for success. Today, we have electronics in our life, it has become part of our life style to use. So much electronic products because, there has been as a hand in a hand development in the manufacturing of microelectronics and hence today's lecture, I am devoting to understanding how we fabricate microelectronics.

In this, I will start with the processing a simple discrete device p n junction and show you how it is very important for a material science engineering student to know about this field. It opens a new career path, you can think of a career in semiconductor processing industry.

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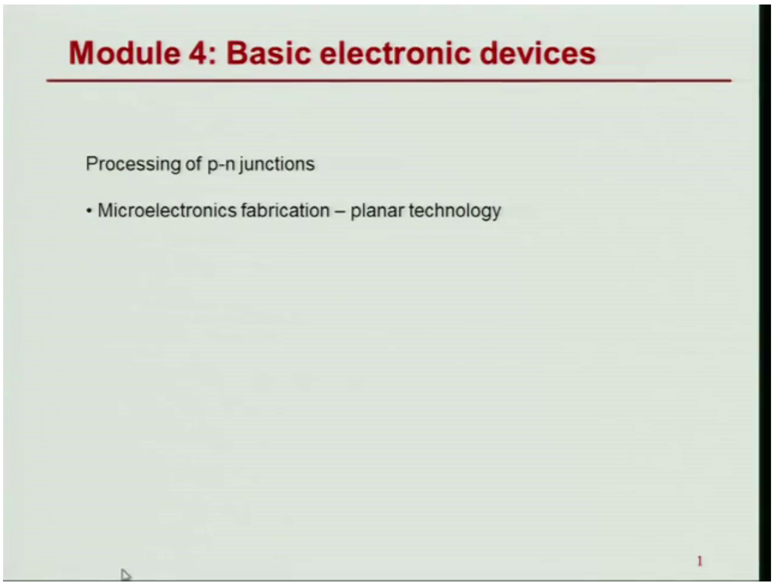

Module 4: Basic electronic devices

Processing of p-n junctions

- Microelectronics fabrication – planar technology

So, let us start with p n junction processing and the various processing, it leads to how we do the microelectronics fabrication.

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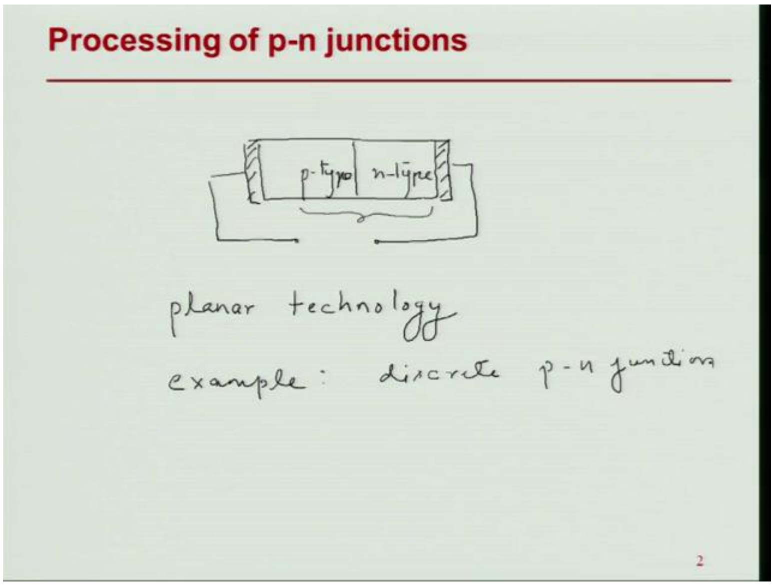

Processing of p-n junctions

planar technology

example: discrete p-n junction

So, I have been describing a p n junction to you, in which the p n junction is consisting of p part and the n part. Then we will make a metal contact to the p and n side and while describing this junction we said that the contacts are ohmic and so we did not look at its characteristics. Basically, we focused on the characteristics of a p n junction and looked at the device characteristics. Today, we want to see if I need to fabricate this p n junction, how will I do that?

How can I make this p n junction? Of course, a very simple metallurgical solution would be: you make the contact, you make the p type, you make the n type semiconductor, you make the p type and you try to join them by using some conventional joining technique. But immediately you know from your knowledge that is not possible because in a device it is not only these four components which are important, but the interfaces between these components have their characteristics.

That requires a very special processing for microelectronic devices. So, this is what we are going to learn and the advances in this fabrication processing are what have made electronics so cheap today. So, I hope you will appreciate that part in the coming slides. So, if I want to make a p n junction in the semiconductor processing fabrication I normally use a technique called planar technology. The name will become clear as we describe this process. We are taking a example of a discrete p n junction to describe the process.

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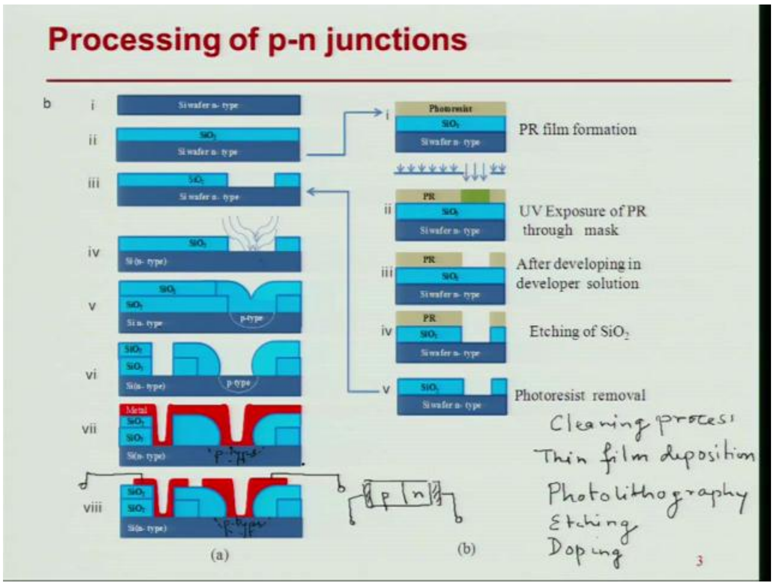

Processing of p-n junctions

PR film formation

UV Exposure of PR through mask

After developing in developer solution

Etching of SiO_2

Photoresist removal

Cleaning process
Thin film deposition
Photolithography
Etching
Doping

Now, in this process, we are going to start with a silicon wafer and I am going to start with the n type silicon wafer. How do we get this wafer? We are going to get this wafer from growing a single crystal silicon boule, which is then cut into small wafers, which are about 500 micron thick. Their size can be anywhere from 2 inches to 12 inches, 2 inches was very early period of semiconductor technology when people started making devices and today they are making very large wafers.

So, this silicon is n type and I am just giving you an example of how to make a single p n junction. On this n type silicon, I am going to deposit silicon oxide. How am I going to deposit this silicon oxide? I am going to use a technique, which is a thin film deposition technique which can be either chemical vapour deposition or thermal deposition, thermal oxidation and by that I will grow a required thickness of silicon oxide on this. From there, a thin film deposition process. I am taking a detailed process called photolithography by which I open a window in this silicon oxide.

Now, what is this photolithography process? Let us look at various sub processes in this process which is the first one is we deposit a photoresist and short form called P R, this we can spin coat. This is a polymer in certain solvents and additives. After spin coating it, we normally pre bake it to get certain amount of hardness there. Then, we expose it to UV light, this is a light coming through a mask. So, the portion where there is no mask, the light will come through and where there is a mass the light will not come through.

Now, the property of this photoresist chosen is such that, in this particular case wherever the light has come through, its chemical properties have changed. So, that portion is exposed and wherever the light is not there, that portion is not exposed, so what do we have now after we develop? After we are done with the exposure, when we develop in certain chemicals or developer, then the part, which is exposed is removed.

So, as a result what I have done, I have taken a flat film and I have created a pattern in this and that pattern is created only in the P R at this point, but what I wanted to do was I wanted to create a pattern in the silicon oxide. So, I need to follow it up with the etching process, so after opening the window in the photoresist, I will etch and I will use a etchant for silicon oxide. By that process, I will fetch a window in the silicon oxide and then I will remove the photoresist. What I have done is the initial film, which was a blanket silicon oxide film, has a opening in this particular area. Now, this whole sub process is called photolithography and we can generate any type of pattern by designing a particular mask by using this process. Now that I have done this, what I am going to do is, I need to create a n type p type here, because I started with the n type substrate, I need to create a p type here.

Now, for that I need to bring in a p type dopant and I can bring it by two processes: one is called diffusion and the other one is called ion implantation. Diffusion can be through a gas phase or using a solid phase and ion implantation is through energetic ions. By any one of these two processes we bring in the p type dopant here. Now, that you have the p type dopant here, you would finally go through a annealing process and create a region here which is p type.

So, what we have done is, we had a n type a semiconductor in which we have created a p type region. Now, I need to make the metal contacts to it, so what I do is I do again a silicon oxide deposition, just similar to the earlier one. Now, keep in mind, in this case I can use oxidation in this part, but above the silicon oxide, oxidation might be a little bit slow. So, some sort of chemical vapour deposition might be required and in any case I create another film here and then I go through the same sequence of sub processes to create two windows, one here and one here.

So, what I have done, I have opened a window which will make a contact to n type and I have opened a window which will make a contact to p type. So, I did the first photolithography step, here then I am doing the second photolithography step to open the contacts. In between, I changed the property of n to p type and now I need to make contacts. So, I do another thin film deposition process which is to deposit the metal, now once I deposit the metal and if I have not used a mask it is the blanket deposition. Then, it will basically short the p and the n type.

There is a n type here, there is a p type here. So, to avoid the shorts between the n and the p type, I need to further photolithography making of the contacts so that only the contacts are in the p and n type. So, I do another third masking photolithography step to open this area, so that there is no shorting of the p and n contact and this of course, p type remains. As it is here now, if you see this if I can make contacts to the outside world, this is a p n junction, this is an outside contact through a metal to the p going to the n going to the p type.

Then again a metal contact so this is a p n junction it looks very much different from what I had made earlier, but it has a same electrical characteristics this is p type n type as then what I wanted to draw or what I have discussed earlier. So, it looks different, but it has same I V characteristic that this particular structure will have now, this technology is called planar technology, because everything that I am doing is within few microns of the top layer its almost in the same plane.

I am working to make this device and what are the processes that I have used, I have used thin film deposition. I deposited silicon oxide photoresist and metal I have used photolithography. Wherever I needed to pattern my film, I have used etching because I need it to etch number of times, I etch the silicon oxide, I etch the metal in order to separate out different box. I also used doping to change the semiconductor property from n to p type. In addition to this, there is the process in semiconductor manufacturing which is basically between each process.

Then, I take it from one machine to the other machine, my wafers are getting contaminated and this is another requirement for semiconductor manufacturing. Because as I said each of this interfaces has its own characteristics and if it is contaminated, you may lose it and that is the requirement of clean room. If I do not have a clean room then, I do not make good devices and that requirement then also makes it important to clean the substrates between each process. So, almost between each of these processes, there is a cleaning process which is to make sure that no contamination goes from one tool to the other tool.

So, these are the main processes by which I complete the fabrication of a single simple p n junction diode and this has many advantages. The biggest advantage it has is that I am making contacts to the device both from the top side. Now, it allows me to make many such devices on the same wafer and make contacts to them. So, I can integrate many devices together and that leads to the advantages of this planar technology which has led to the revolution of electronics.

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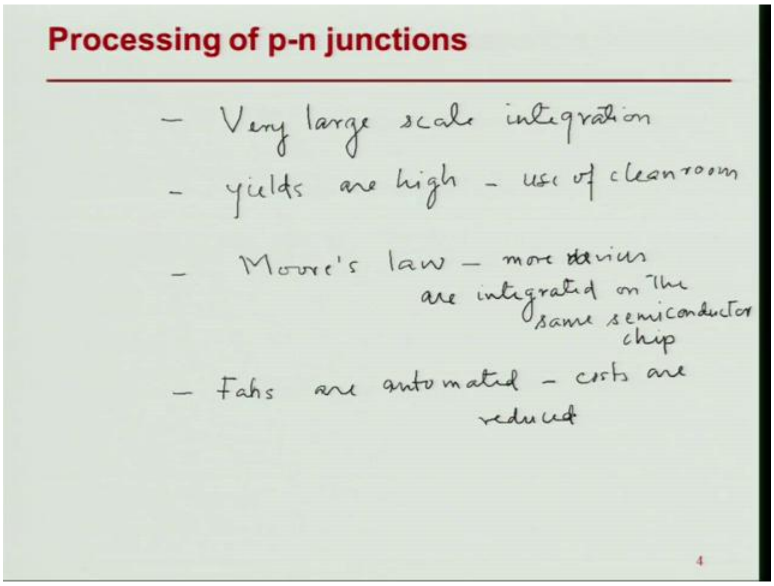

Processing of p-n junctions

- Very large scale integration
- yields are high - use of cleanroom
- Moore's law - more devices are integrated on the same semiconductor chip
- Fabs are automated - costs are reduced

The first one of that is it allows for very large scale integration, which means you can make large number of devices on the same silicon wafer and then contact them. In addition to that, by ensuring the cleanliness of the devices generally when we make these circuits, the yields are high and this is because we use clean rooms and further the development has been enormous. We know something called Moore’s law, which basically states that the development in the processing technology of microelectronics has been almost to double the number of devices in per unit area of the microelectronics chips.

This means, every year the processing technologies has developed enough to put more devices in a small chip and they have that law has been continued for almost half a century very successfully. So, following the Moore’s law, we have more and more devices are integrated on the same semiconductor chip almost up to the point that, today when we are reaching almost the physical limit of trying to put more devices on one chip people are going towards quantum devices. All the device physics we are learning, is going to fail if we go to even very small devices in the nano range and that is leading to a new field called nano electronics.

But, in the last fifty years the development has almost followed Moore’s law and if you want to continue with Moore’s law you need to think of new kind of devices. The conventional devices will not work, so these are the reasons why we have had a very successful revolution, a silicon age in last fifty years. It allows you to have very cheap P C’s and all sort of electronic gadgets that we can use today. The final point is the fabs which of course, have a very high clean room, their fabs are automated to ensure that the yields are high and we have costs reduced because of these measures.

So, this planar technology has played a very important role in deciding overall how we have being manufacturing electronics. In last fifty years, there have been many innovations in the materials and devices to bring out new and better devices. At the same time, the processing technology has kept up in order to make more and more devices at a cheaper cost by putting large number of devices together.

So, the development in the two phases has been almost hand in hand and that is why, this very successful industry will continue to grow in coming years. So, having introduced to you the planar technology let me summarize from materials point of view what are we looking at.

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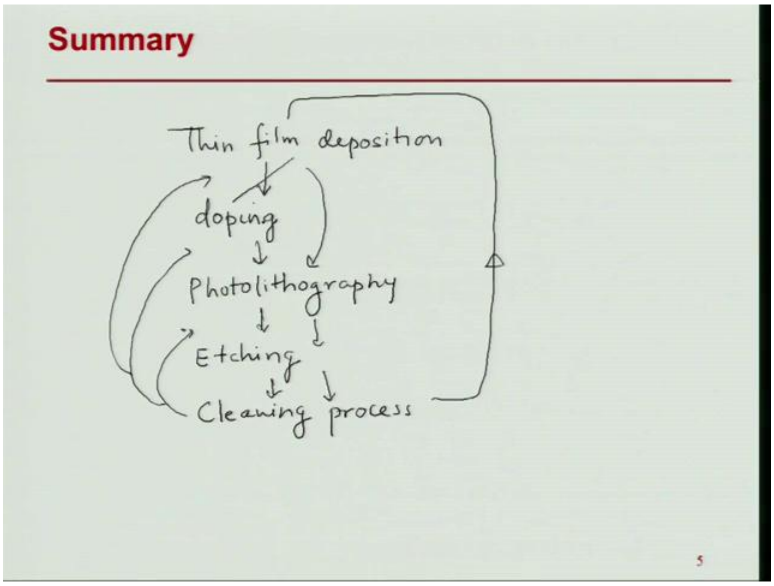

Summary

You can think of fabrication of any microelectronic devices in terms of four steps and the first one is thin film deposition, the second one is when we change the characteristics of a semiconductor, doping photolithography because we need to pattern. After patterning, we need to etch each layer, so etching and the cleaning process. So, any indicated circuit fabrication is basically repetition of these unit processes again and again. You saw in a very simple p n junction, we had to do the photolithography three times the if you count each process it would be more than forty process to make a simple p n junction.

So, if you are thinking of making microprocessors, you can almost think the complexity of a microprocessor. There will be number of steps are going to increase and keeping the yields high after all those steps is a very difficult task which is feasible only with the very clean processing and high accuracy processes. So, basically the fabrication can be thought of these four steps being repeated. The cleaning process is actually repeated many times after every step again and again in a loop until you get the final device.

So, you can think of it as a building block, you are making each layer, you are patterning it. How you want to pattern it? Etching it and then making another layer, patterning it and etching it until you have the final device form. We just saw a p n junction how this device form works, so having understood this microelectronics fabrication principle, we want to now go for basic materials processing of each of this step which can be used for making any particular device. It is not necessary that the thin film doping is following. It could be along with thin film deposition or doping.

So, it should be seen as thin film deposition or doping after photolithography or etching, either you will do a thin film deposition like we did in the case of metal or if you want to go from p to n it could be doping. So, this need not necessarily be a sequence, one can always have sequence which is going in this manner. You can skip doping if it is not required, its only or instead of thin film deposition, you could have only doping. So, let us look at each of this process in detail. The thin deposition which is used in the microelectronics industry is basically depositing material using its vapour phase on a substrate. Throughout all this fabrication, it is important to maintain the cleanliness of each interface and in thin film depositions which are mainly used in microelectronics industry are used in vacuum for this reason.

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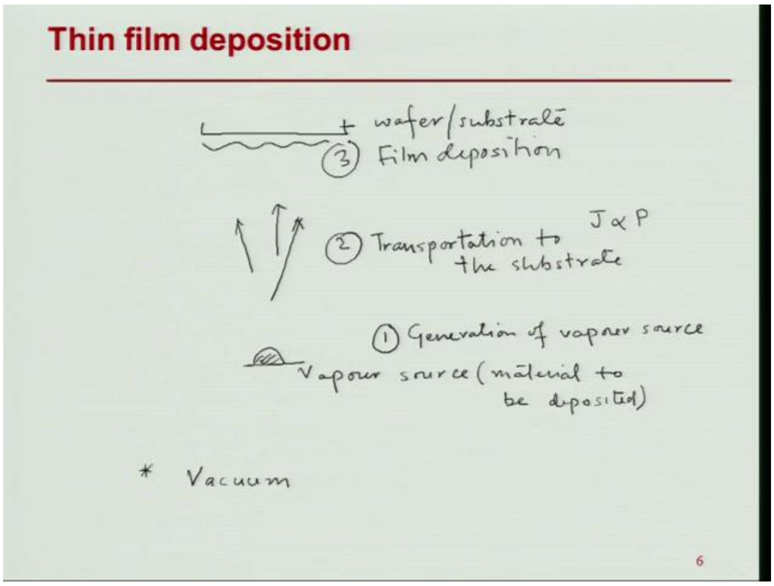

Thin film deposition

wafer/substrate

③ Film deposition

$J \propto P$

② Transportation to the substrate

① Generation of vapour source

Vapour source (material to be deposited)

* Vacuum

So, if we look at the thin film deposition here, thin film deposition is a process by which we will use the wafer on which we want to do the deposition and we also call it sometimes substrate. We will use the vapour source and that is deciding the material you want to deposit. So, there are three steps in thin film deposition, first is generation of the vapour source and depending on how you generate the vapour source each technique is called a different name.

For example, thermal evaporation if you are heating the material to generate the vapour source, sputtering if you're using a plasma to generate the vapour source or simply chemical vapour deposition if you're just putting in different chemicals to generate the vapour source. The second step is related to the transporting of the vapour source to the substrate. The third step is film deposition on the substrate. Now, these are the basic steps, which are required to make a film, now in all these steps, vacuum plays a very important role.

If I am making a vapour source, it is easier to create a vapour source. If I emit low vacuum I need a lower temperatures to get a high enough wafer pressures. If I am going from in the step two transportation to the the substrate, if i have vacuum then process of contamination is less because you know that in the in this step the flux is related to the pressure. The flux of the species is related to the pressure is proportional to the pressure if I have high pressure in a vacuum chamber, my deposition of the source is competing with the ambient pressure of the chamber.

If I reduce that pressure, the contaminants become less and I am depositing more pure film and for that reason when I am depositing semiconductors where purity is very important because you know that doping can change quite a lot. You normally use high vacuum and if I am depositing metal or something may be moderate vacuums are sufficient in that case. So, the pressure, the vacuum is important for the second step and also in the third step at the interface if I do not have high vacuum.

I will create contamination layer because the contaminants from the vapour phase which are existing in the chamber can deposit on the surface. So, most of the thin film deposition techniques which are used in microelectronics are vapour phase based, where you are going to create a vacuum depending on your requirement, middle medium level to a high level vacuum to deposit a film. So, vacuum requirement is important, now let us look at how do the film deposit on the substrate and what are the parameters that are important.

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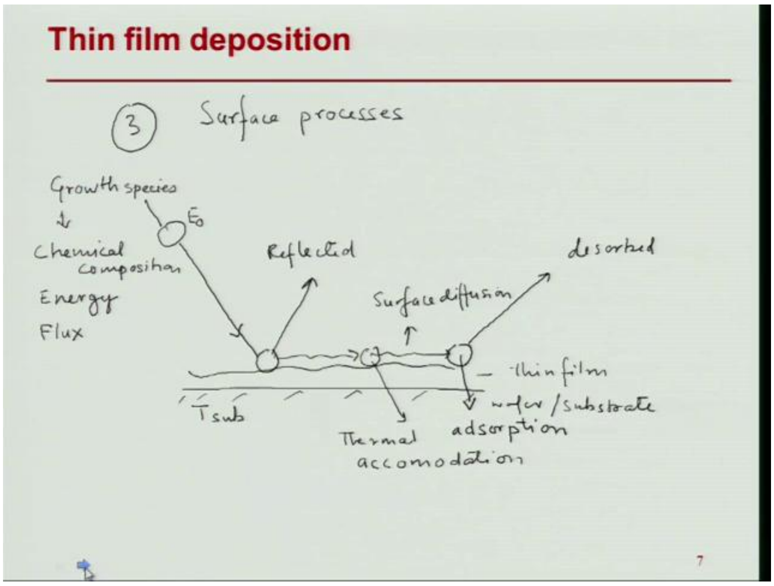

Thin film deposition

③ Surface processes

So, let us understand first in step three the surfaces, surface processes which lead to different film growth mechanisms that will be responsible in creating different layers which could be. They are semiconductor, insulator or metal depending on the device that we are making. So, what are these surface processes we are going to deposit on a wafer a thin film, how are we depositing this thin film we are depositing it by bringing in a vapour phase species.

So, this is my growth species. Now, growth species what it is, its chemical composition will decide what I am trying to deposit, how I have created this growth in a species. In step one will decide the energy and finally, how much is coming per centimetre square per second. The flux will also be decided by the how I am creating these growth species. Once they come to the substrate after being transported through the chamber, this particular atom ion or molecule is going to be interacting with the surface. Now, it has two possibilities, it might have enough energy E 0 that it gets reflected back.

So, if something is reflected back, it is not becoming part of the film and it is not good for you. The other possibility it has is that it loses all its momentum in the vertical direction stays on the surface, but it is mobile on the surface because of energy in the parallel to the substrate. Since it is mobile on the substrate, it goes to a second point and there in the mean time it loses its energy and becomes thermalized with the substrate.

This is known as the thermal accommodation, at this point the growth species coming in is part of the film, but it is not has not form a bond with the film as yet.

This can now surface diffused because there is some temperature at which we have our wafer, the t substrate temperature which is a temperature of the substrate or wafer here. This would be the surface diffusion and at the end of it would either be adsorbed on the surface adsorption and later it can also be desorbed due to thermal activation. So, out of all these processes, the atoms which remain adsorbed on the surface will become part of the film, anything that is reflected or desorbed is not part of the film.

So, the final film structure that you are getting is a combination of how many are absorbed, what is the surface diffusion process and how many are thermally accommodated. Based on this, one can create different structures and properties of the different films that we want in the device which again in turn affect the device characteristics. So, having understood this kind of process, let us look at what are the ways by which we can control the growth flux or different deposition techniques.

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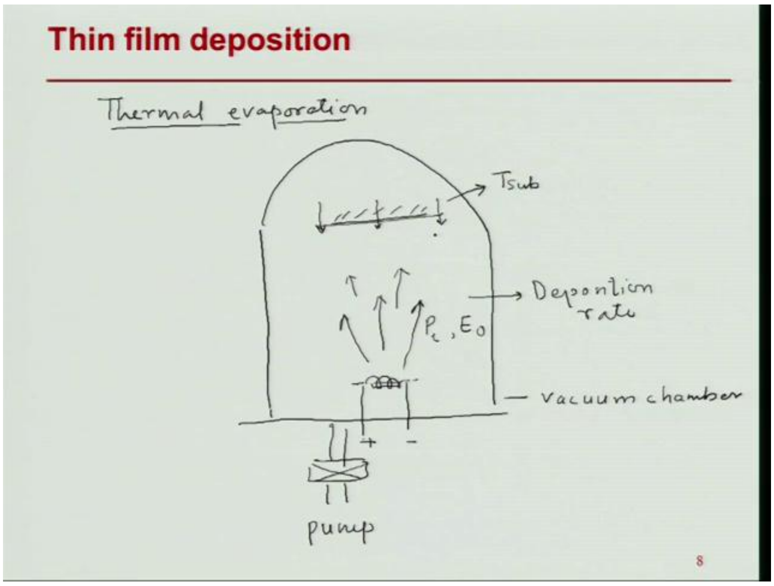
Thin film deposition

So, the first one that comes to our mind is thermal evaporation, which is the simplest and the oldest thin film deposition technique. As we said that in thin film deposition vacuum is necessary for all the three steps of the film deposition especially from microelectronics where you want good interfaces and low contamination. So, we will be making all the deposition in a vacuum chamber and depending on our requirement, we will have different kind of vacuum levels. Here, this goes to a pump, in thermal evaporation, we have two electrodes which have a cross, which we will put a heating element. Whatever material we want to evaporate, we will put in this heating element.

The heating element need not be heating element, it could also be a crucible and by using the electrical power, we are heating a resistive element using that heat to melt whatever we want to deposit. Since there is a low vacuum pressure here, there will be evaporation of the element that the material we have put and there will be a partial pressure of that material which is going to be transported to the substrate that we keep over here. Now, the things which are important here is that we should not have any contamination due to evaporation coming from the element itself and that is why we use high melting point materials like molybdenum tungsten as a heating element.

We sometimes even coated with the ceramics so that there is no evaporation of the element or electrodes. Once the material is getting evaporated, we have an energy associated with it which is decided by the thermal energy of the element to approve which point we have heated that element. The kind of things which are required in such a process is how well can you control the temperature. If you can control the temperature of your heat of your vapour source very well, that means you are getting a constant flux of the vapour coming to the substrate in a crude equipment in the laboratory.

Generally, that is not there, but once we go to the fabrication floor, the temperature control on the source material is very well so that you can control the growth flux throughout the process. The other point is the distance from the source to the substrate and then that dictates that the film is not uniform throughout the substrate. So, that is important, because I am making a device assuming certain thickness whether my device is here or my device is on this part of the substrate. So, if the thickness of the layer is not same, all the processes get affected.

So, one of the requirements in processing is that the thickness across the whole wafer should be within certain specification. Of course, from the materials properties point of view, the film should be of a certain quality which can be controlled by controlling source processes vacuum. Also by controlling the surface processes by looking at the substrate temperature which is an important parameter. So, you have substrate temperature, you have how you create this source and how you create this source processing parameter becomes deposition rate.

Creating the source to at a high rate or a low rate will decide what would be the characteristics of the source and that will decide the final film property. So, this is a simple thermal evaporation equipment, it normally gets less used in the commercial set up for the reason that it has some issues with the non-uniformity on large areas or many devices.

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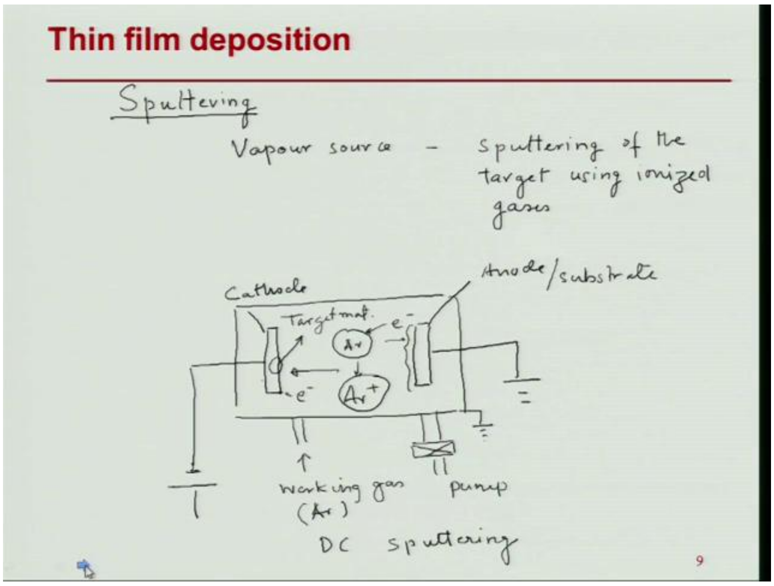

Thin film deposition

Sputtering

Vapour source - sputtering of the target using ionized gases

DC sputtering

The second process which is very common in the industry is the sputtering and the technique gets its name because we are creating the vapour source by sputtering of a target using ionized gases in its simplest form. Sputtering technique can be used, it can be seen as a D C, simple D C sputtering technique, in which again I have a vacuum chamber, I am pumping it down and in order to create the plasma, I am going to inlet some working gas which is generally a inert gas. Argon is a favourite source for this and I am going to apply a voltage across two electrodes anode, which sometimes is grounded or I can even apply a bias to it and a cathode across, which I apply a negative voltage.

Generally the chamber body is either grounded or left floating. Now, when I put in the argon gas and I am applying the voltage as you know that at certain point there will be plasma created because the electrons are going to be generated at these high field points. These electrons are going to ionize the argon gas when they collide with each with each other that generates argon ions. Now, what is the situation in this part? Electrons are going to be attracted to the anode and the ions are going to be attracted to the cathode. Eventually, we will come to a point of voltage, where this processes get stabilized.

You have a source of argon ion to the cathode and electrons will be going towards anode. Now, this argon ion has high enough energy because it is getting accelerated by the cathode voltage to come to the sub surface and sputter off whatever the target atom I am putting here. So, this becomes my source, so this would be my target material, so the argon ion or a sputtering of the target material. This is now my source which is coming to the anode and I put my substrate at the anode. So, I have a deposition of the target material on the anode.

Now, the advantage of sputtering over evaporation is: one is that I can have the choice of making the target very large and hence that issue of uniformities are better in case of sputtering. There are other considerations as well; in addition to that it changes the properties of the material to a large extent. Why does it change? Because, earlier I just heated the material and the energy of the growth flux was decided by the temperature up to which I heat the material, it is thermodynamically decided.

But now, I have a voltage and the energy by which the target atom comes out is decided by what energy I am going to accelerate the voltage. I am going to accelerate the argon ion towards the target. Hence, I can control the energy of the target material and depending on what is the energy of the target material, the processes which are occurring at the substrate while I am growing the film can get affected and which effect the film property.

So, that is the advantage on the sputtering, which we get our independent control on the energy of the growth flux by using sputtering. Just to mention that this is this, I am discussing only D C sputtering. There are other versions of a sputtering in which we can use R F sputtering of magnetron sputtering which help the process in terms of deposition rate or making it more efficient.

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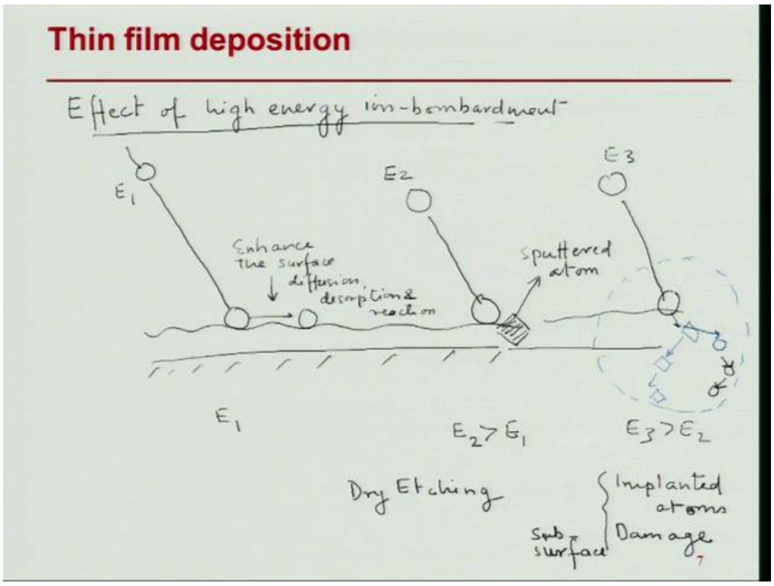

Thin film deposition

So, now let us look at the effect of high energy bombardment in case of a sputtering of thin films. So, earlier we looked at the surface processes in terms of surface processes with the atoms which are coming with thermal energies of the source material to whatever extent I have increased the source materials temperature. The energy of the incoming atom was up to that point, but when I go to sputtering. Now, I have that is additional voltage which will increase the energy of the incoming atom.

Based on that, I can talk about some processes, so if I have a atom which is coming at energies something like E 1 and I am looking at the processes which I saw when I was looking at processes due to thermal evaporation. This additional energy is going to do what it is going to enhance all the surface processes, additional energy is going to give more energy to all the enhance a surface diffusion desorption and reaction.

So, when you have additional energy with which you are your growth flux is coming, you enhance all these processes. So, in some sense, whatever is however you making the film, it is becoming bounded by more energetic processes and this would be then, help in making the film properties better. Sometimes, you can have another case where this energy is atom is coming with much higher energy. In this case when E 2 becomes even more than E 1, then you can have a case where this atom comes and it takes an atom on the substrate.

It rather than sitting there only by itself, it sputters off the atom on the substrate. So, basically what is happening when I increase the energy which is slightly larger than the E 1? In addition to becoming part of the film, that atom is actually sputtering off the film. So, in rather than depositing the film, it is etching the film. Now, this process is used for dry etching. It is what you use in ion etching, when you hit a surface with the high enough energy at ions.

It is going to or atoms it is going to sputter off the film and you will etch away the film and this is used as a dry etching process. Now, I can take this energy to even further E 3 such that E 3 is greater than E 2 and this atom, when it comes here. Now, it has much more energy and it does few more things than just being part of the film. What does it do? It can go in and I am enlarging this area now because I want to show some processes. So, this is the film area I am showing in enlarged form. What is happening in this film? The incoming high energy atom can come and have a collision with the atom of the film, this whole area is just showing the film now and as a result this atom will get displaced from where it was.

The incoming atom which was coming here will also get displaced depending on what was the collision kinematics the incoming when it is going on the other direction and the atom of the thin film is going in this direction. Now, I have two energetic particles, one is the incoming atom and the one which is being displaced inside the film. So, this will further have collisions and it can create again damage and it can go to some other place. So, if I continue this process eventually it will lose all its energy in different collisions. This atom is going to may come to rest at some point deep in the film.

The incoming atom and the same time, the atom which is displaced inside the film will also come to a rest after losing its additional energy. So, what it has done I have implanted the incoming atom deep into the film and I have created the damage in this film. Now, this damage can work both ways, either can change the properties and it can be used can be annealed out later. It is changing the structure of the film than what it was if I was just thermally growing on the surface. So, sputtering then leads to either etching, which is dry etching or it can lead to implanted atoms damage and this region in which it is happening we call it sub surface because this is below the surface these processes are happening on the surface.

So, with the help of sputtering I am changing my film deposition method by adding more energy to the incoming atoms and that has some beneficial effects on certain films and sometimes it is a not so beneficial and that comes only by experience. The applications that one is looking at, so we have discussed thin film deposition by two techniques, thermal evaporation and sputtering and both are physical vapour deposition. I am using a physical process to create the growth species and by that I am adding material to my device structure.

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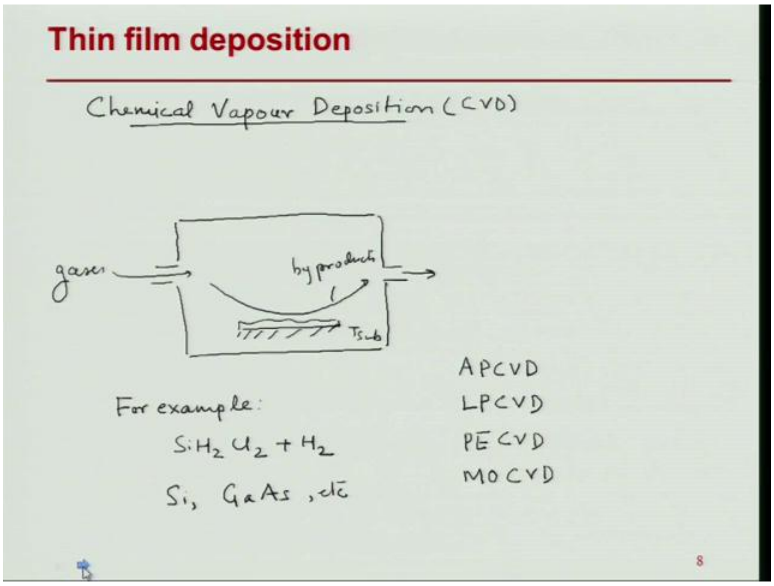

Thin film deposition

Chemical Vapour Deposition (CVD)

For example:

$SiH_2Cl_2 + H_2$

Si, GaAs, etc

APCVD
LPCVD
PECVD
MOCVD

Next, we discuss a technique which is using chemical vapours to deposit the material and that is known as the chemical vapour deposition technique. In chemical vapour deposition technique, we do not create the species by a physical process; we use the chemical gases, react them on the substrate to get the film in a very simple schematic. I can think of the chemical deposition process in which I have the substrate or wafer I am bringing in some gases here this could be at a higher temperature.

These gases react here and the by products are taken out and I deposit a film by reaction of the gases on the surface. Now, this is basically decided by the again thermodynamics and the reaction rate at the substrate temperature and what gases I am using in order to deposit a film. For example, if I wanted to deposit silicon I will use dichlorosilane gas plus hydrogen to deposit silicon on this substrate. The by-products H C L plus different compositions of silanes or chlorosilanes will come out as by product here, substrate temperature would play a very important role.

Now, chemical vapour deposition technique is a good for many materials because the controlling step there is no damage here as in a sputtering and you can control different gases and substrate temperature to get a very uniform film. So, this is generally used for making a silicon gallium arsenide and many semiconducting materials by C V D technique. There are certain versions of again this technique, we are talking about very simplest form of it, which is known as in this technique. I do not need necessarily a vacuum process, it can be a atmospheric pressure C V D.

So, this stands for C VD, I can have a atmospheric pressure C V D without vacuum, but if I want higher purity and better control I will go for low pressure C V D. I can have different techniques called plasma enhance C V D, by which I can reduce the substrate temperature at which I am depositing the film that has some beneficial effects in terms of overall processing of semiconductor devices. So, one can go on and look at several techniques. There are also metal organic chemical vapour deposition, which is very common for depositing 3, 5 semiconductors. So, that is one technique finally, another technique which is very common in the microelectronics processing and that is.

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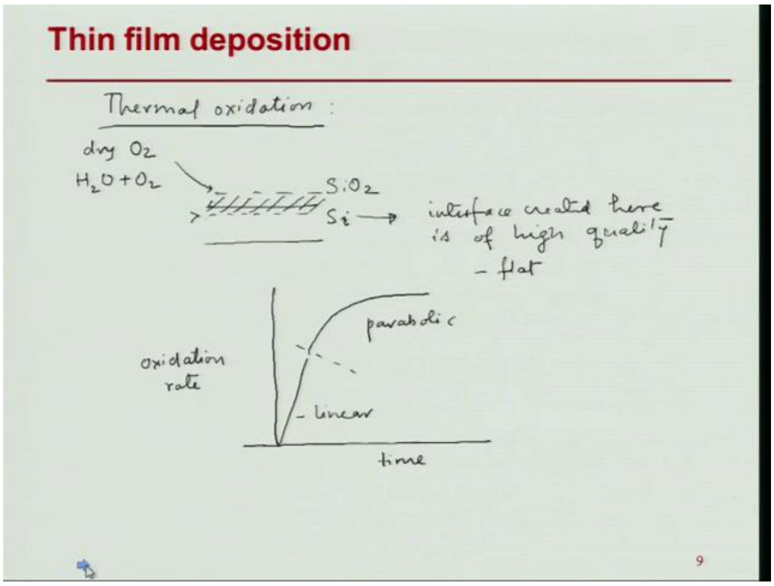

Thin film deposition

Thermal oxidation :

So, that is one technique finally, another technique which is very common in the microelectronics processing and that is thermal oxidation of silicon. So far, all the techniques of thin film growth that we have seen, we brought the material from outside and deposited on a substrate. But, in case of thermal oxidation we bring only oxygen and we oxidize the surface of silicon to convert it into silicon oxide and that is why many times, it is known as silicon oxide growth rather than deposition. Deposition is because some part of the film of the substrate is being used while we are making the film.

Now, in thermal oxidation, basically we use it is used most in the case of silicon processing where we start with silicon substrate, we are bringing either dry oxygen or sometimes we bring water vapour plus oxygen. That is known as wet oxidation, so dry oxidation or wet oxidation and this then reacts with the silicon and forms a silicon oxide. I am using this changing interfere between silicon oxide and silicon because I have used some of the silicon. So, that interfaces the moving interface, now this process has some very nice properties and that has that is one of the advantages that silicon has. As we oxidize silicon and make silicon oxide.

This interface remains flat the interface created here is of very high quality. It is flat; there is no roughness at the interface, if you have cleaned the surface very well. Then, even the defects can be reduced to a large extent and as well as the oxide that is created by thermal oxidation is of the highest quality. Normally, when we end up depositing oxides by bringing some sort of silicon oxide, both cursors from precursors from outside, we compare it with the properties of the silicon oxide. The thermally grown silicon oxide has the best dielectric constant compared to all the different thin film deposition techniques.

So, this thermal oxidation that why it is a very important process in microelectronics of fabrication of silicon related devices. This property of silicon oxide and silicon interface makes possible many of the devices that we use today especially, M O S transistor that that has these specific properties that come from its properties. In case of a silicon oxide, one can talk more from materials point of view, how the oxidation takes place? It is important to know that when you when the oxidation initially starts, it is being governed by the kinetics of the interface reaction.

But, once you start growing little bit of film, it gets governed by the diffusion of the oxidizing species through that oxide up to the interface, because a reaction takes place at this interface which is moving. So, if one plots oxidation rate for the thermal oxidation as the function of time, then in the beginning of the oxidation when the oxygen directly comes to the interface, it is just the reaction rate that controls the thing. It is almost a linear dependence on time, but once you start growing a little bit of thin oxide, it is the species which is diffusing through this oxide layer comes to this interface where it is reacting.

That decides the reaction rate and the deposition oxidation rate becomes parabolic in nature. So, there's a linear region and there is a parabolic region here for oxidation of silicon and it is a very important process in the thermal in the microelectronics fabrication of silicon related devices. In the end we have discussed some very key thermal deposition processes, sputtering processes, C V D processes and thermal oxidation, but there are many more variant I just gave a glimpse of it and it is not possible to cover it here, but from the microelectronics fabrication point of view what are we looking at, we are looking at in the film.

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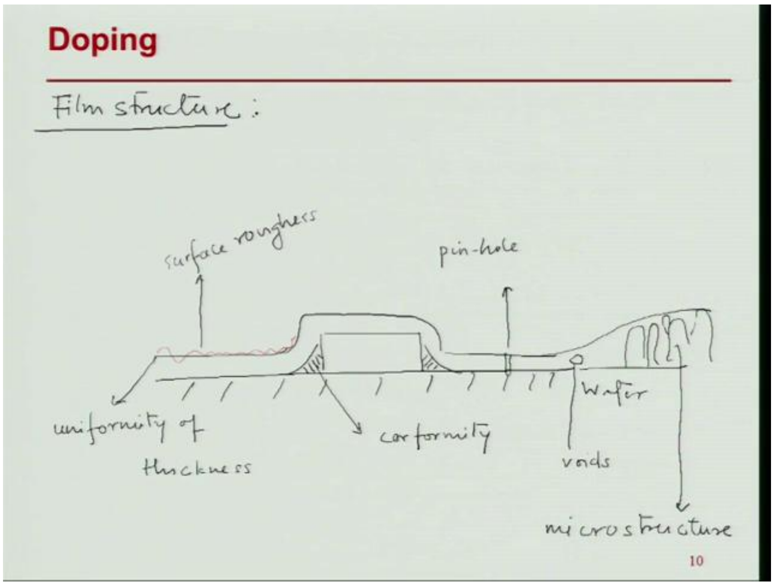

Doping

Film structure:

When I am making it a film on a wafer or a substrate, the important part I have, as I was showing you, we pattern each layer and then we deposit another layer. So, I may have some sort of pattern layer on it and I am trying to deposit a film on this. One thing I would like to see is that whatever I deposit has good thickness uniformity. So, uniformity of thickness is one of the criteria's. The other which is important is when I am growing it on some sort of features it is not a flat surface, then it is possible that at these features I may have some voids here. The film does not confirmedly grow on the whole feature, but it leaves some voids and that is, we call it conformity and this could be a problem when certain type of devices where the contact to this feature is important.

The other kind of problems that can happen is that the thickness may not remain same it might become very large at certain areas. So, in uniformity of thickness is issue some other issues come up. Sometimes, you end up getting holes in these films this could start because there was some contamination as we pointed out throughout the microelectronics fabrication, cleanliness is very important because our feature size are very small. Each thing they are making is in microns, some microns and now going into nanometre range.

So, even a small dust particle can create a defect which is known as pin hole and they can have their impact on the device characteristics in some sense. Sometimes, you can create voids inside the film that could be a problem and in all this sometimes you may have roughness on the surface that could be a problem. So, these are the macro structure. Macro structural features on the film which are important in addition to that you have some microstructure of the film which is you might have some grains here, might have voids here. It might be amorphous in nature and that will affect the film property.

So, overall no matter which deposition technique we use, finally when we incorporate it in a device, it is its macrostructures and the microstructure is what is important to us. So, by using controlling our deposition technique, we are controlling the film structure. So, film structure is what our ultimate goal is? Getting the right film structure by whichever technique we choose to use and that also sometimes decide which technique we are going to use.

So, we have covered the one aspect of microelectronics fabrication which is how do we add material and we use one of the film, thin film deposition techniques and what are our requirements in that thin film deposition technique. Next, we will take up how we change the conductivity of the material by using a doping mechanism? That is a second requirement because we want to create p n junctions or M O S transistors in that case. So, what we just saw was how to make a p n junction using a planar technology and we can divide the processes that we have discussed in type of processes.

One is to add a new material which is a thin film deposition process and to change the characteristics of a material by incorporating dopants in it. The second type of processes when we pattern the layer that we have added and that is incorporating photolithography and etching and by using these two processes in different sequences, we can make any structure we want in three dimensions.

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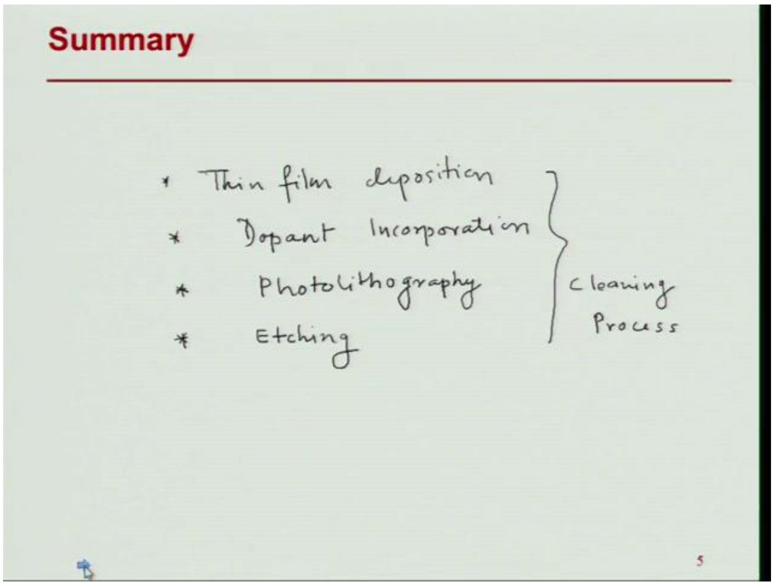

Summary

- Thin film deposition
- Dopant Incorporation
- Photolithography
- Etching

Cleaning Process

So, this is what we can say that main unit processes in case of microelectronics fabrication are thin film deposition. Second being dopant incorporation, photolithography, etching and then throughout these processes, we have intermittent process which is extremely important to maintain the yield of microelectronics fabrication and that is the cleaning process. By using these processes in a certain sequence, we can make any structure that we require. Next, we will be discussing the doping process, dopant incorporation.

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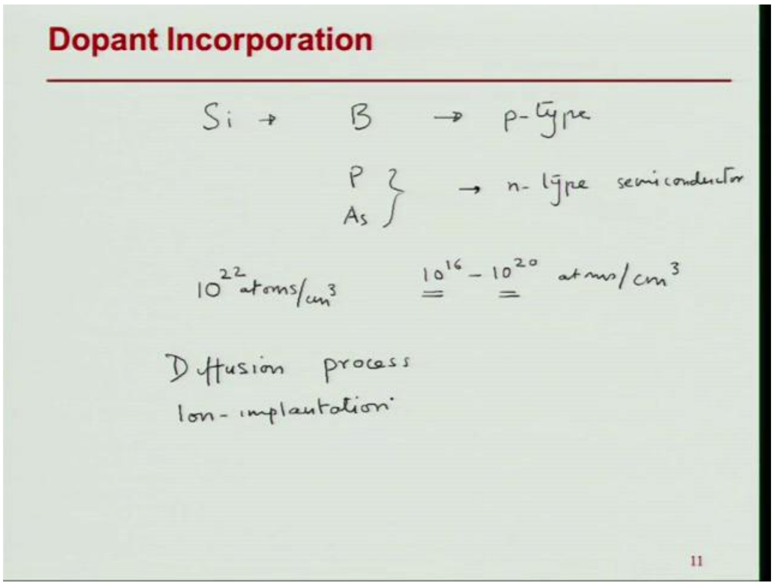

Dopant Incorporation

Si → B → p-type

P, As } → n-type semiconductor

10^{22} atoms/cm^3 $\quad$ $10^{16} - 10^{20}$ atoms/cm^3

Diffusion process

Ion-implantation

The dopant incorporation in the material changes its electrical characteristics. We already know and since we are taking the example of silicon, if I take Silicon and dope it with some p type dopants, our example being Boron, then I can make it a p type semiconductor and that is what is required for my devices. If I take, I put phosphorous or arsenic, then I can make it an n type semiconductor and we saw in p n junctions. That how much dopant I put basically decides on, what type of device characteristics we get.

So, controlling how much dopant I put to what extent, to what thickness I put is important in this particular process. Just to remind you again of the kind of the amount of the dopant that we are going to put in this silicon has roughly about 10 to the power 22 atoms per centimetre cube. Depending on the device requirement, what we are making we are going to put in the range of about 10 to the power 16 to 10 to the power 20 atoms of dopant per centimetre cube in silicon in order to make a device the low end is used for making p n junctions and the high end is used for making ohmic contacts.

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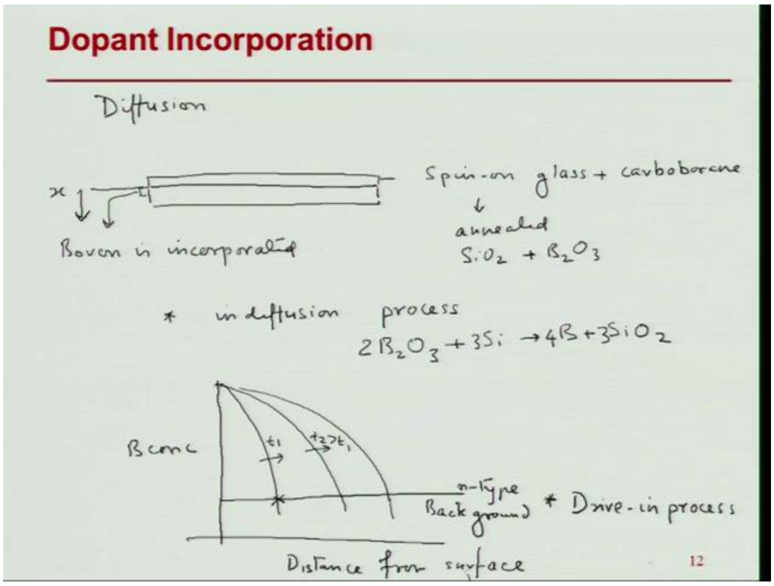

Dopant Incorporation

Diffusion

Spin-on glass + carboborene
↓
annealed
$SiO_2 + B_2O_3$

Boron is incorporated

* in diffusion process
$2B_2O_3 + 3Si \rightarrow 4B + 3SiO_2$

* Drive-in process

Now, we have two ways of incorporating this dopant and the first one is the diffusion process the second one is ion implantation. In the diffusion process, we can start with putting in the dopant material in the wafer in two ways. The first one is, we take the wafer on which we want to incorporate the dopant we put a spin on glass on top of this wafer and dope it. Whatever we want to dope for example, spin on glass is a silane derivative and we put corbo borene in it and spin coat a film on it which is further annealed and this gives me silicon oxide plus boron oxide.

Now, this boron oxide is depending on what concentration I want in this film. I can control the amount of it after that I have a thermal annealing process which is called in-diffusion process. In this thermal annealing process boron oxide reacts with the silicon to give me boron and S i O 2 and I can balance this equation to give me 4 boron atoms and 3 silicon oxide molecules. Now, this free boron will get incorporated because I am to putting at a thermal annealing. In this region boron is incorporated in the first top two layers.

Now, this incorporation is because of diffusion of borons from the spin-on glass into the silicon layer and one can do the analysis of the diffusion equation and figure out how much boron will be incorporated. If I look at the distance from the surface, starting from x down the boron concentration, then the surface concentration is going to be decided by the equilibrium of this reaction at the interface. Depending on for how long I have done the in diffusion process I will have a concentration gradient in which this is for time t 1 time t 2 which is greater than t 1.

So, depending on how far I want to take this diffusion, I can do the in-diffusion process for different timings. Generally, it is done for a very short time because I want certain amount of dopant incorporated and after that I will do a second process which is called drive-in process to decide exactly at where I want a junction. Normally, I would have some background doping of the material and whatever dopant I want. Let us say this was n type.

Then, wherever the n type doping is equivalent to the p type doping that is my junction depth and depending on my device requirement I can decide for how long I need to diffuse to change this junction depth. But at this point, I have only introduced some amount of dopant inside if I keep on the dopant source there then if I heat further to change the junction depth. I will put a lot more dopant, so normally at this stage the second process which is done is removal of the spin on glass.

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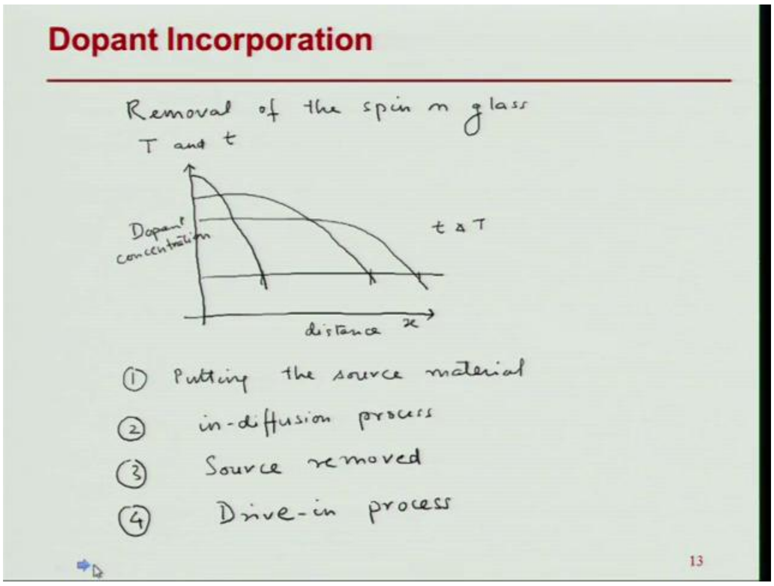

Dopant Incorporation

Removal of the spin on glass

T and t

① Putting the source material

② in-diffusion process

③ Source removed

④ Drive-in process

Now, I have my substrate and some in-diffused dopant which is constant and I have removed the source of the dopant. If I do a thermal annealing for certain at certain temperature and time whatever I had put in the first process of in-diffusion will further get diffused in and that solution is normally Gaussian because my amount is fixed. So, if I have initial dopant in diffusion process this. If I heat it this is going to be further diffused in depending on the time and temperature. My junction can be controlled by looking at the dopant concentration and distance in x direction. So, for different time and temperature I can control what concentration.

I want and to up to which depth this is the drive-in process. So, basically diffusion in this process is four step, the first one is putting the source material. Second step is the in-diffusion process in which the amount I want to put in the silicon in-diffuse that process then I remove the source otherwise a very large amount of dopant will go in source is removed. In the third process and in the fourth process I have the drive-in where I control the time and temperature to get the required concentration of the dopant and the required depth of the junction. Now, this spin-on glass is not the only way we can introduce the dopant source there are other ways of introducing the dopant source one can have a gaseous source.

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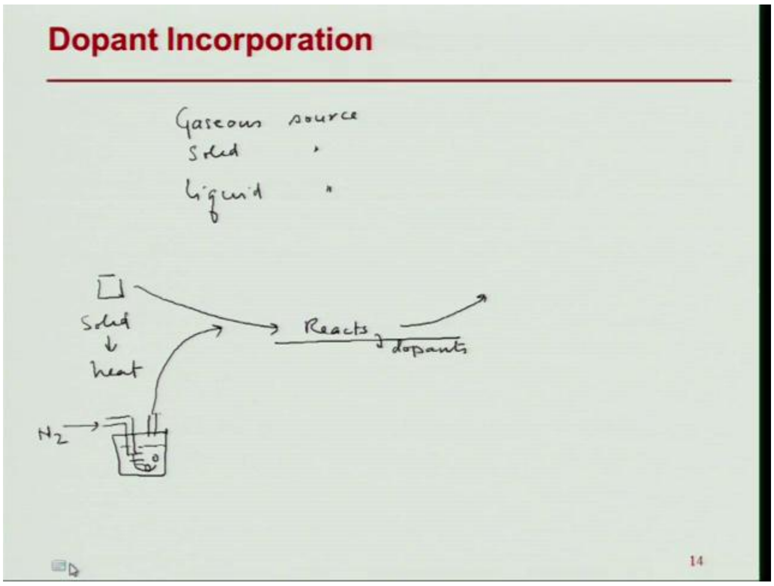

Dopant Incorporation

Gaseous source
Solid "
Liquid "

So, I have the wafer here a gaseous source comes and reacts and leaves the dopant at the surface I can have a solid source, but solid source also works in the manner that the gaseous source work. I start with the solid source and heat it to get the vapours which react with the surface, I can have a liquid source also of the dopant material again it works often in the manner that I will use a liquid source. I will pump in the carrier gas which could be nitrogen a noble gas and then this carrier gas bubbles through the liquid source carries with it some amount of the liquid source and then it its brought in to the contact with the surface.

So, spin on glass is not the only way of incorporating the dopant, I could use any of these three sources to react with the surface for certain amount of time so that I put the required amount of dopant in the film and then in the drive-in process. I can control the temperature and time to figure out to what depth I want to control the junction the next process this was used quite a lot in the earlier semiconductor industry. But diffusion has certain limitation because the amount of a dopant we are putting in is controlled by the thermodynamics it is. What is the reaction between the source and the silicon? But later on when a higher control was required we wanted to put very less amount and have very shallow junction and that was not possible to control using diffusion.

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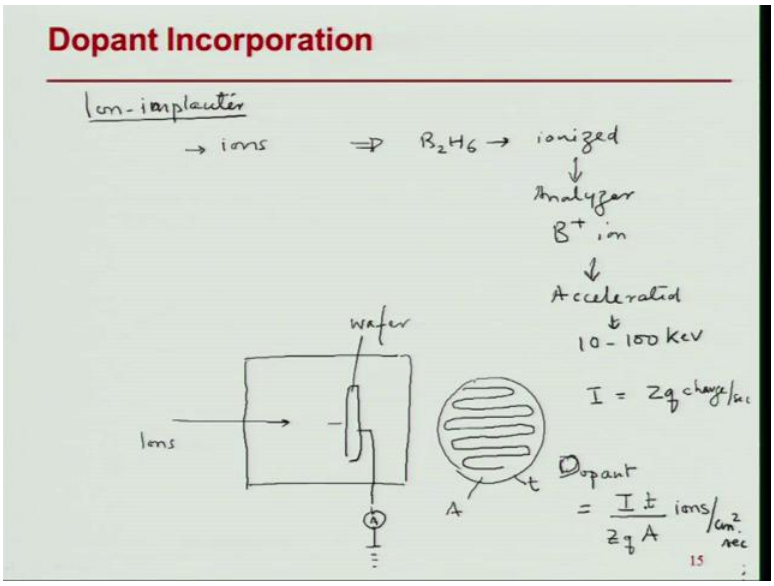
Dopant Incorporation

Ion-implanter

→ ions $\Rightarrow$ $B_2H_6 \rightarrow$ ionized

↓

Analyzer

B^+ ion

↓

Accelerated

to

10 - 100 keV

$I = Zq$ charge/sec

Dopant $= \frac{It}{ZqA}$ ions/cm^2.sec

Hence, a new process was borrowed from the from the nuclear physics community and that is known as ion implanter. So, in an ion implanter the dopant incorporation is done by introducing ions, how do we get these ions? These are normally the source gases like diborane in case of boron this is ionized the gas is ionized which means I have boron ion and some hydrides in there. Then it is further put through a analyzer to separate out only the b plus ion and these ions are then accelerated to the energies up to 10s to about 100 kilo electron volts.

So, you have by this process very high energy ions coming to the surface and you can incorporate it in the film as oppose to diffusing it from a different source. So, in this technology in semiconductor technology this part is used from the accelerator physics to how to create the ions? So, the process by which we control how much dopant is put in is like this we bring the ions through the accelerator and this is the wafer this wafer is generally grounded and since we are bringing in the ions we are able to measure the current.

Since, if you have grounded it the electrons must be coming to neutralize the wafer, so we can measure how much ion current is coming per second. Then this ion is rostered on the wafer so in the sense since ion is not going to be the size of the wafer we will put the ion beam is rostered across the wafer for a certain time and it is putting the dopant inside the material. Now, how much dopant it is putting let us say if the current for the ion beam is I current is nothing but charge per unit area charge will be decided by what is the valency of the ion.

Let us assume it is z, I have taken the case of boron plus, but it could be something else and then the charge for the electron that is going to be the current and per second how much of it is coming. We will decide this is a charge; that is going to be the ion current. So, let us say it takes me about time t to roster through the whole wafer then how much dopant have I put in the amount of the dopant incorporated is going to be the total current multiplied by the time for which I am rostering. It divided by the charge that gives me the ions if I divide it by z times q it gives me a number of ions coming per in the total time t.

Now, this number of ion is distributed in the area of the wafer because I have a rostering through the whole wafer, so per unit area this is the number of ions coming per second. So, this is the incorporation using a ion source this will be the number of ions coming per unit area per centimetre square per second. So, this is the way one will incorporate the dopant or whatever amount I want by controlling the current and the time now. Generally, how would I do this procedure is, it is difficult to monitor the current of the implant, so rather than monitoring the current I am going to monitor the total current coming through this meter here.

How much is being received by the surface, so this I can integrate, so normally I will have a reading of current here as a function of time. And I will integrate that current over the total time that I implanted and that gives me the total dose this is what I will call the total dose. I have put in my wafer and that will give me the total amount I have put in my wafer, so if I know how much total I have put and the next thing I want to know is where has it gone.

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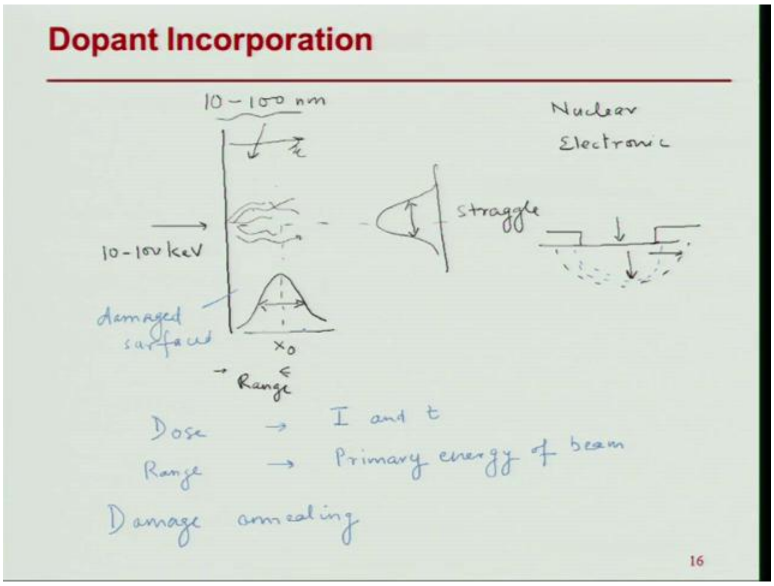

Dopant Incorporation

Dose → I and t

Range → Primary energy of beam

Damage annealing

Now, in case of most implantation I am going to put the dopant about 10 to 100 nanometres below the surface. So, if I look at the distribution of the dopant that I put in by the ion beam the distribution of the dopant is normally it is a statistical process because the dopant comes into the surface. It is going to be stopped by the substrate atoms where it is going in, there are two type of mechanism by which it is getting stopped. One is the nuclear stopping and the other one is the electronic stopping nuclear stopping is basically the dopant ion coming in and interacting with the atom on the surface.

An electronic stopping is that it coming with high energy and interacting coulombically with the electrons. But eventually this atom is going to lose all its energy it is just come up with something like 10 to 100 k e V and it is going to lose all of its energy at some point. And since this is a statistical process how it stops some of them are going to stop here, some are going to stop there it is going to be a range at which it will stop. So, this the average of the atoms the large number of dopants that we have put it is called range and there will be a standard deviation to this range.

So, this is the how much into the substrate I have put in my atoms and that is generally in the range of 10 to 100 nano metre. Now, since it is a statistical process and each ion is following a trajectory and I am taking averages of that in addition to in the x direction. I am going to also have a straggle in the y direction I have put the beam here, but there it is going to be a standard deviation in the y and z direction and that is normally called as a straggle. But interestingly this is less than what you would get the amount of variation by diffusion in diffusion.

It is a same process by which I am getting the same mechanism by which I diffuse in something and the same mechanism by which I will diffuse in the y and z direction. So, the amount of diffusion in the lateral direction is quite a lot in ion implantation the straggle is still much, much smaller compared to the range. So, one has a good control on the area in which I have diffused the material basically what we are saying is, if I have put in a mask window opened a window and I wanted to diffuse a dopant through a diffusion process. The diffusion process will give me dopant going in the x direction as well in the y or z direction.

This variation the how much you go below the pattern is much more in case of diffusion. I can control it better if I do a ion implantation, this is going to be a lot better controlled process. The straggle is little less and that is the reason why when as the densities of devices went up people went from diffusion processes to ion implantation processes. Ion implantation has become much more popular compared to dopant incorporation by diffusion. So, this is one way of incorporating dopant where as the controls here I can control the amount of dopant which is known as dose, by controlling the current and by controlling the time for the dosage right.

I can control the range which basically decides how far I am putting in by controlling the primary energy of the beam which is this 10 to 100 k e V. So, if I have low energy it will be closer to the surface high energy, I can go deeper in so the primary energy of the beam can control the range now. But this is not sufficient because as we saw earlier in the thin film deposition when I am putting in implanting high energy atoms, I am getting a lot of damage. So, generally the ion implantation processes which are normally done at room temperature as oppose to diffusion processes which are done at higher temperature.

That is why they lead to a lot more straggle create a lot of damage which has to be annealed out, but the only purpose there is annealing and hence a shorter annealing is required as compared to diffusion process. So, one of the problems in this ion implantation is the damage annealing because as the ion goes in it creates a highly damaged surface which has to be annealed out. This annealing also then would change the profile, there will be some diffusion on what you have implanted. So, when you design the whole process one has to look at both the process the annealing process as well as the implantation process.

That will give the final junction that you want for the ion implantation. So, by this process then we have done is we have learnt how to control the dopant incorporation in a device by two different processes and both are necessary because just a simple semiconductor is not good. We always need a junction either a p n junction or some other junction to make an interesting device. So, now we come to the next process which is photolithography, now I described the photolithography the basic process earlier. Right now, I will talk about how it is done and what are the major requirements for it, so this is a process by which I am going to pattern the added layers.

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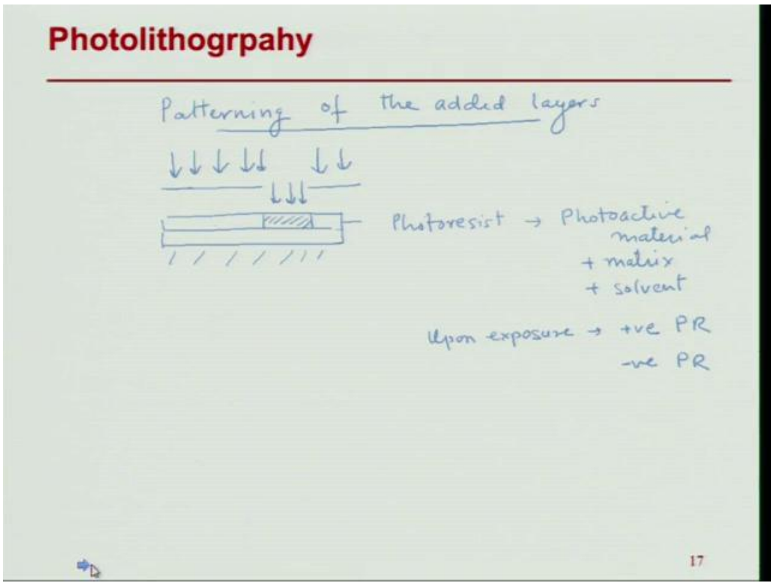

Photolithogrpahy

Patterning of the added layers

Photoresist → Photoactive material
+ matrix
+ solvent

Upon exposure → +ve PR
-ve PR

So, in this process what we do is we start with whatever layer I want to pattern and we will deposit a photoresist. Now, what is a photoresist? It is a polymer mix it has a photo active material plus a matrix plus a solvent many times if we are commercially getting a photoresist, one does not know the actual identity of the photoactive material, but a lot of information is existing in the literature to find out what kind of photoactive materials exist. Now, depending on the nature of the photoactive material, once I put the photoresist on the film.

I would remove the solvent that is known as the pre baked process and now I am left with only photoactive material. The matrix depending on what is the photoactive material if upon exposure it is easier to remove the P R film then we call it a positive photoresist. On the other hand if upon exposure this P R film becomes very tough and it is not possible to remove it then you will call it a negative photoresist. That depends on the photoactive material that is in there and it has its own applications related to that. So, if we take it further we then expose this layer to the U V light through a mask, so I have put the P R.

Then I expose this layer through a mask wherever there is a opening the P R layer is going to be exposed at this point. Now, if I am if I if this is the material I want to leave behind then that will decide what kind of P R, I am going to use. So if this is a positive P R and I am exposing in this manner what I will have in the end is a window here on the other hand if it was a negative P R. I was exposing it with a same mask I would have a small amount of P R left here rest will be removed. So, one can use the mask design and the P R in together to get the desired pattern, so if I were to summarize then all the processes which are important in the P R processing.

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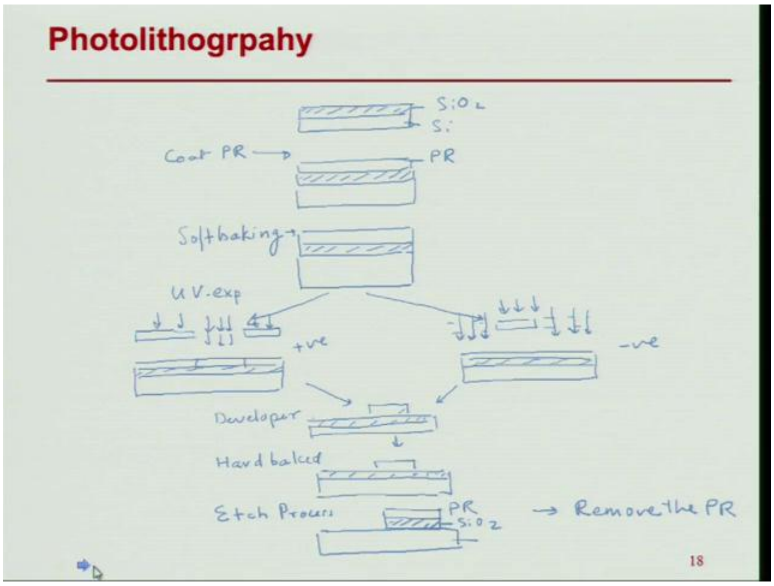

Photolithogrpahy

Initially, you will have the silicon wafer on in which the layer you want to pattern is there. Let us say I will start with silicon oxide and silicon here and this is the layer I want to pattern then the second step I will do is in the photolithography is coat with the P R and this is spin coating. So, I have got P R now, on silicon oxide and silicon and then there is a soft baking this soft baking is to remove the solvents from the P R and you are left with the matrix and the photoactive material. So, at the end of it you still have the two layers of the P R and the silicon oxide on the substrate.

Then I will expose it to a mask and depending on what kind of P R, I will design two different kind of mask for the for the positive P R. I will open a window here that will expose the P R layer for a negative mask I will do the other round. So, my window I will cover the region where I want to retain the pattern and the remaining will be exposed and here the light is blocked and the same I am going to for the negative P R. So, this is a negative P R and this is a positive P R at the end, when I develop it what will happen? If I have used it this part has become hard.

It will be left out after the after the developing if I have used this then this was already hard and what was developed will be removed. So, in the end whether I have used positive or negative since I change my mask I am left with the pattern of the P R which is this so this is after developing. So, developer is used to get this pattern and developer may be different for positive P R and for the negative P R. Now, this pattern will have to be hard backed because after this I am going to do some processes where I will either etch the silicon oxide and I do not want my P R removed I want that to be to be remaining there. So, I will do a hard baking after this process and at the end of it we will use what we learnt next the etch process that is to remove the remaining oxide.

So, in the end I am left with P R and the oxide which I want it to save because the remaining part I would have etched using chemicals like H F and the substrate and at the end then the last process is to remove the P R. So, this photolithography process has many controls that one needs to gather and the process is defined by what is the smallest feature I can pattern and today what I have talked about is the U V exposure here. But if I want to make large number of devices, I need to reduce this feature which means I need photolithography steps which can pattern even a smaller feature in order.

To do that I need to change the U V light to something which is either e beam or x ray that is why e beam is used for making finer or nano scale features. The process is basically same, but the mechanism change instead of U V exposure we are going to a different light. So, that is one part is to change the exposure to get finer and finer features and of course, the development in the P R so that you can define the patterns that you need to define. So, there is a lot of that development that goes on to a match up with the advances in the overall microelectronics industry in the case of photolithography. Next, we talk about the process, which is related to removing the part of the layer. Because finally, what we want it to do is, pattern each layer after we have added that layer we want it to pattern that layer. So, we have found the way of patterning the layer and we etched the film, so what we want to do is I talk about this etching process.

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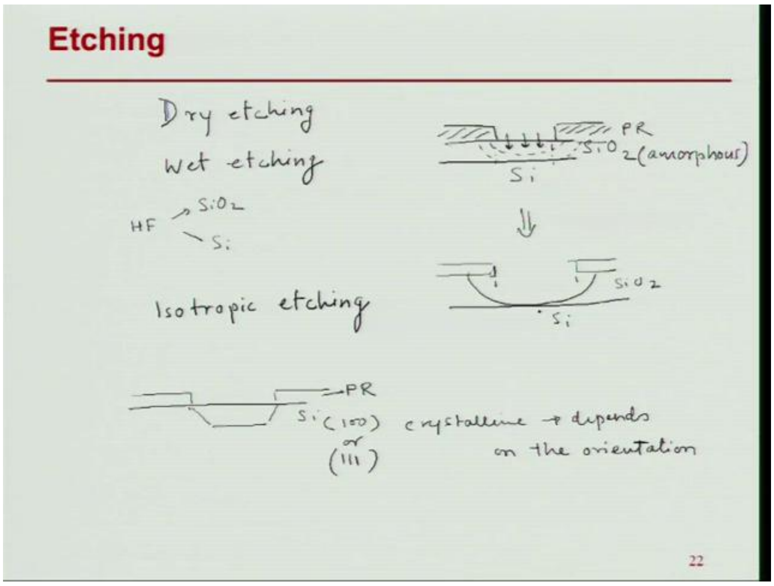

Etching

Dry etching

wet etching

HF → SiO_2
HF → Si

Isotropic etching

crystalline → depends on the orientation

Now, the etching process can be of two kinds, one is the dry etching and the other can be the wet etching process. So, taking example of again silicon oxide let us say if I had silicon and I deposited a silicon oxide layer by one of the thin film deposition technique then I wanted to create a window here. For my next process I did the P R and opened the window in the P R and I want to know etch away this region. So, one way to do is to do the wet etching and in case of silicon H F is a wonderful etchant because it etches silicon oxide at much higher rate compared to the silicon.

So, there is a differential in the etching rate of silicon and silicon oxide, so when I etch with H F it removes the silicon oxide, but it keeps the silicon. But there are problems with this kind of process silicon oxide if it is it is amorphous in nature and then if I am doing the etching by a wet etchant process then the etchant is not only etching in the x direction again it is etching in this manner. So, as you can see the final pattern that I get is going to have etching even below the window that I opened so if I look at this final pattern it is going to look something like this.

This is going to be the etched hole in the silicon oxide and these edges can be a problematic for the remaining process suppose I want to deposit a film then I would not get the film here, so these can be issues with the process. So, wet etching has this process because wet etching is basically isotropic etching, it is same in all directions. On the other hand if my if the layer I want to etch is crystalline now crystalline layers have a very unique feature because when I am etching those layers the etched rate of different planes are going to be different. So, if I take an example of etching silicon itself and I open a window in the P R then the silicon the way it etches depends on what is the orientation of the silicon is it 1 0 0 or 1 1 1.

Depending on that orientation, you are going to get different type of etching profiles here and this is used in the M E M S it is not as much useful for microelectronics. But in the M E M S devices where you want to create cavities one needs to know what kind of cavity you want to create. So, when you have crystalline materials then the etching is not isotropic it depends on the orientation of the crystalline material. So, these are the advantages of wet etching that if you find a right chemical you can do the etching fairly easily. But a problem is in transferring the right dimension to the to the substrate so in order to solve that problem one goes to dry etching.

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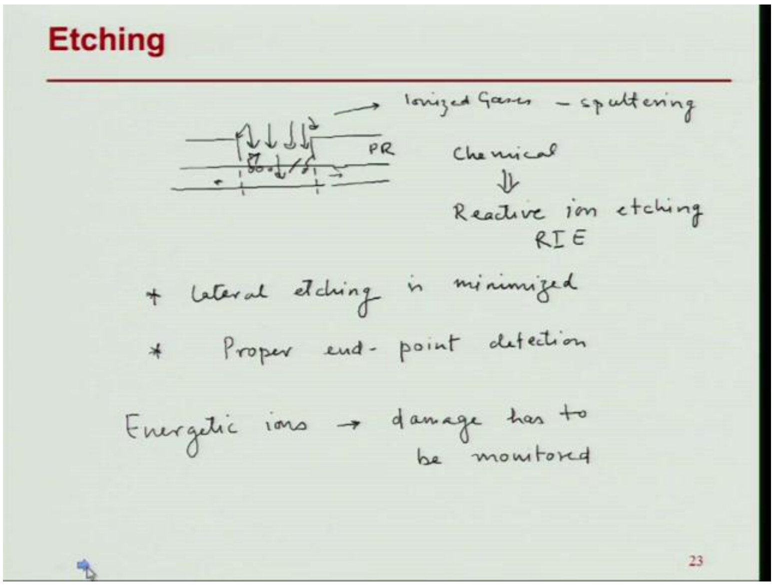

Etching

→ Ionized Gases – sputtering

Chemical

⇓

Reactive ion etching

RIE

* Lateral etching is minimized

* Proper end-point detection

Energetic ions → damage has to be monitored

Now, what is there in the dry etching, it is a similar process that we discuss in sputtering. So, if the layer that I want to remove, I want to make sure that I remove only this region and not in the lateral region then I can bring in some dry etchant what could be a dry etchant ionized gases that are accelerated towards the substrate. What do they do they will sputter off this material that is one way of dry etching. So, this is basically sputtering. Now, since I am accelerating these gases towards the substrate it is highly directional.

I do not have the argon ion or whatever the etching ion is going away in other directions. So, the etching is going to be done in only in the x direction there is very little y direction etching. Now, in to further enhance this sputtering process by which we are doing etching we can add some chemicals to it. And if I do that we call that reactive ion etching and we use a lot of fluorocarbons in this process, in which in addition to its sputtering the ion that comes reacts with the surface. And then the reactant product is removed so the r I etching is again a way of using the ions plus some chemicals which would react with the surface and then remove, get removed.

So, we have the advantage of dry etching is, it has very little lateral etching is minimized, but we need to use some controls in the case of wet etching what we had was that silicon was not etching by H F. So, it automatically stopped once you have removed all the silicon oxide there will be no more etching of the silicon. But in case of dry etching these ions and the reactions the ions do not know, whether I am etching silicon oxide or the next material? So, they can continue on and hence there is a proper end point detection that has to be involved.

So, one keeps looking at the by-products in the gases to figure out when the process has to be stopped, so there is a considerable amount of process development that goes on to designing these processes for each microelectronic device. So, there is a lot of process development that is required in these areas in this process of dry and wet etching, one can also talk about that is in the same manner the cleaning processes. So, the problem with dry etching processes is that we have energetic ions the energetic ions as we saw earlier in ion implantation as well as in thin film deposition.

We will go inside the layers which is below it and that can create problems with the device overall, so dry etching although is good from the point of view of dimension control is sometimes not good for the property of the underlying layers. So, one has to look at the affect of the drying etch dry etching on the device characterization it could affect the device properties by controlling the material properties. So, the damage due to the energetic ions has to be monitored so because of this both dry and the wet etching are prevalent in the microelectronics fabrication right now.

Now, we look at last process, which is cleaning process it seems to be a very benign process, but it is extremely important because as we said each layer interface is extremely important. Hence, when I do a process a flow in which I have number of steps I can add lot of contamination where can the contamination come from they can come from the materials that I am using they can come from the process materials.

If I am using a etchant the contaminants could be in the etchant or could be in the gases. Hence, between each process between two processes we will like to do a cleaning process where I remove the different type of contaminants, which have been introduced and depending on which surface I am cleaning.

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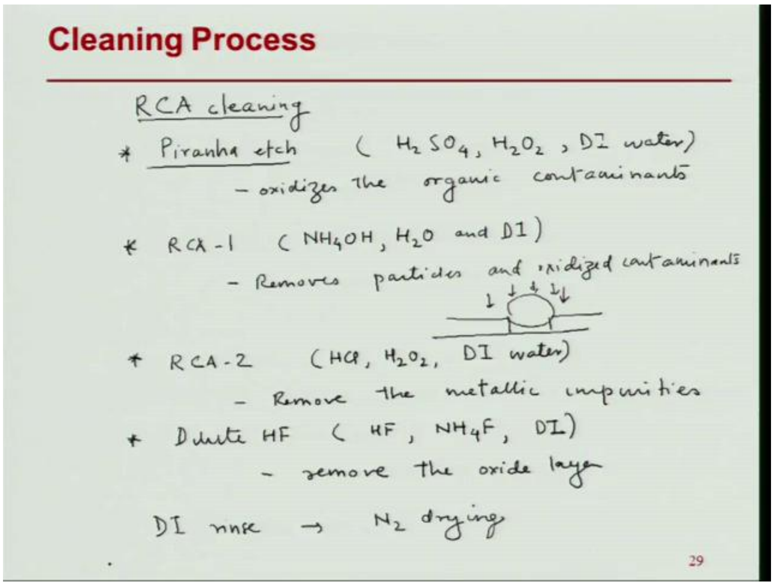

Cleaning Process

RCA cleaning

- * Piranha etch (H_2SO_4, H_2O_2, DI water)
  - oxidizes the organic contaminants
- * RCA-1 (NH_4OH, H_2O and DI)
  - Removes particles and oxidized contaminants
- * RCA-2 (HCl, H_2O_2, DI water)
  - Remove the metallic impurities
- * Dilute HF (HF, NH_4F, DI)
  - remove the oxide layer

DI rinse → N_2 drying

There are different chemistries, but there is one which is very well known and that is known as R C A cleaning. The name goes after Radio Corporation of America which first introduced it, now they have devised a good way of controlling silicon surfaces or silicon oxide surfaces. So, this is a typically for silicon oxide surfaces and in this cleaning there are several steps which are there designed for certain type of activity. The first one is known as the piranha etches, which is basically sulphuric acid hydrogen peroxide and D I water.

Its concentration and dilution people change depending on their need, what it does is? It oxidizes the organic contaminants this follows generally with the process called R C A 1, the R C A 1 consist of ammonium hydroxide hydrogen peroxide and D I water and in this process whatever has been oxidise earlier is removed. So, it removes particles and oxidize contaminants now I am talking a lot about particles because you would realise that all the dimensions we are talking about are very, very small and today in the range of some micron and nano range. So, even a small particle if I am making, let us say a window of this kind, which is in some micron range. If I have a particle sitting on top of it, it will not be able to do any further processing with this particular device. This device will eventually fail.

Hence, in all these cleaning processes, I have ensured by these two things that I remove all the particles on the surface. If I look at under a the microscope this surface I can actually see particles being removed after these processes this is then followed by a process called R C A 2 the R C A 2 consist of hydrochloric acid hydrogen peroxide and D I water. The main purpose of R C A 2 is to remove the metallic impurities. This you can understand in the context of what you have learnt about the different type of impurities and how they behave?

Since, all the chemicals do have some metallic impurity and if they get into the device performance in the device in at the interface these are creating traps, traps which would then have problems with the recombination of the charges or injection of the charges. Hence, metallic impurities are extremely sensitive for microelectronics fabrication and by doing R C A 2 you remove these metallic impurities that can affect your interface property. Finally, the last process which is comes in this sequence is known as a dilute H F process which of course has H F noises sometimes it is buffered H F by ammonium fluoride.

It can be used at different dilution and the purpose here is to remove the small oxidized layer. If you are doing cleaning of a gate oxide silicon oxide surface probably you will not do this last H F step because you would be removing the oxide, but if you are cleaning a silicon and you want to remove any oxide on top of it then this last dilute H F step is required. So, by doing these four processes if you have silicon surfaces where you want the silicon plus tin surface for making the next layer then these steps are generally used. Each has a certain purpose, it removes particle, it removes contamination of the surface, so your interface quality remains to be good.

You do not introduce additional traps and recombination centres in the structure. So, this gives feel of the cleaning processes today the amount of the chemicals that one uses or the D I water in the cleaning processes is very large. So, there is a trend to go for processes which are using a gaseous etchants and the idea there is these are gases can be recycled, so you can have reduce your consumption of the chemicals. So, there is a move go to go from wet cleaning processes to dry cleaning processes for the same purpose of removal of particles by using gaseous sources.

Now, in after doing all this normally one does a final D I rinse and a nitrogen drying to get the final surface. Now, this again seems to be a very benign process, but can be very important because if you do not do the proper rinsing and drying you may end up getting the water spots on the surface. When you are dealing with very fine resolution of the devices these waters spots can again destroy particular devices and reduce the yield.

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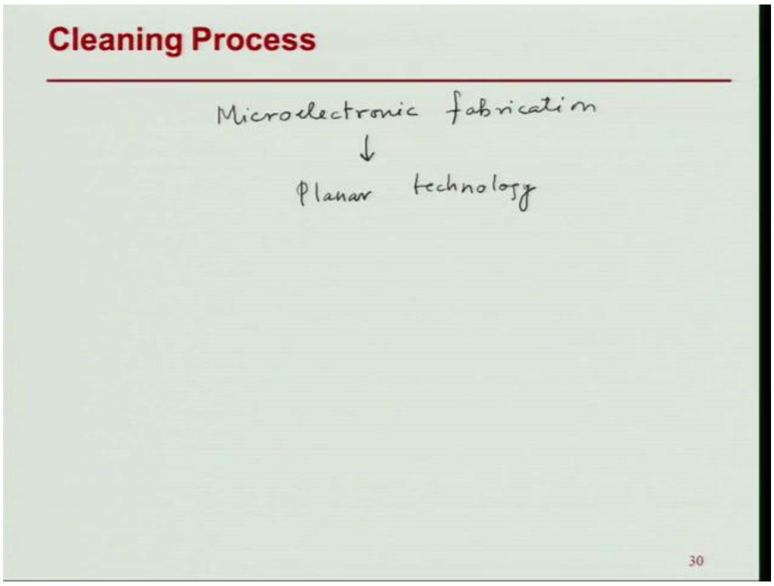

Cleaning Process

Microelectronic fabrication

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Planar technology

So, in the end what we have looked at is looked at the each process in microelectronics fabrication and we have seen how the fabrication has developed along with the devices and that has led to a very highly controlled manufacturing technology. The technology that we discussed is known as the planar technology and the advantage that it has, it drives the industry. There is normally before a new device comes the process development is going hand in hand with the new device to make the product. Hence, the development of semiconductor industry has been phenomenal in last 60 years starting from the first transistor, which was which came in late 50s to now. We have chips, which are absolutely cheap; we can enjoy the electronic devices at a very cheaper rate.

Thanks to the process technology along with the development of the devices.