Fundamentals of Semiconductor Devices

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Lecture – 58
Microelectronic fabrication

Welcome back. So, in the last class we have taken up some of the topics fabrication for discussion including oxidation and doping like ion implantation and diffusion. I told you that we should be just be basics of the fabrication should be aware to us so that we know you know how the device is actually fabricated. So, today's class we shall try to wrap up most of this.

So, we will go ahead when we will discuss about deposition photolithography and etching as time permits. So, there will be after that we will have a couple of lectures remaining maybe a one or two lectures in which will we shall try to wrap up some of the practice problems.

We can try to solve some numericals and other things from previous years question papers and so on. So, let us come through a white board and continue where we have left in the last lecture.

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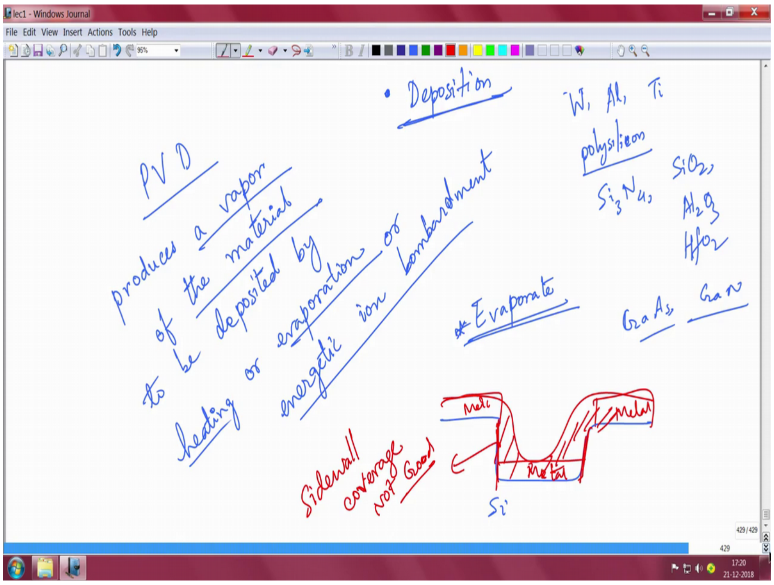

PVD produces a vapor of the material to be deposited by heating or evaporation or energetic ion bombardment

So, we have done oxidation diffusion and ion implantation today we shall study about deposition I am giving a very brief you know overview not going in to much details. Depositions you want to deposit metals like say it maybe tungsten maybe gold; gold is not used so much in CMOS process it is not used. So, tungsten for example, aluminium maybe titanium and so on metals you can put in many of the applications you need this in CMOS fabrication MOSFET fabrication.

You might want to put polysilicon polysilicon gates are used by the way, these are highly doped polycrystalline silicon that can behave as sort of metals and I use that gate metals actually polysilicon you might onto deposit dielectric electric like silicon nitride. Silicon dioxide also you know aluminium oxide whatever hafnium oxide sort of things you can also. So, there are many ways you know to deposition, technically they are divided into two categories one is physical vapour one is chemical vapor deposition ok. So, first lest talk about physical vapor deposition, physical vapor deposition or physical processes you can say those processes that will produce a vapor of the material.

It will produce a vapor of the material to be deposited; it will these processes will produce a vapor of the material to be deposited by heating either by heating or evaporation or evaporation or by energetic ion bombardment of some material. So, what essentially is happening is that, you produce a vapor of the material that you want to deposit and you get by basically heating or evaporation or energetic and ion bombardment ok. This is called physical vapor deposition and you might have say for example, evaporation ok, you might have to evaporate a metal.

This is typically no longer used in silicon I c industry because you do not evaporate metal you do something call sputtering and an etching I will come that and evaporation of metal is typically done in compound semiconductor like gallium arsenide, gallium nitride industries. We will do this kind of evaporation of metals because evaporation does not give a good step coverage, what I mean is that if we have the feature like that this is suppose silicon.

And you want to deposit you know you want to deposit metal all over then it is a silicone this thing. Then a metal that you deposit will not be it will sit here this is metal for example, the metal will come here this is metal the metal will come here, but this sidewall this is called sidewall know.

The sidewall coverage is not very good the sidewall coverage is not very good; the sidewall coverage is not good. So, that is why it is called poor step coverage, you know the step you will not get the metal done ideally you want the metal to go like this everywhere right. So, in some you know there is a chances you want to fill. So, this evaporation is not very widely used in silicon its used in gallium arsenide gallium nitride because they use it in another way call lift of actually and evaporation is mostly used for metals; so in a way I will come to this point again.

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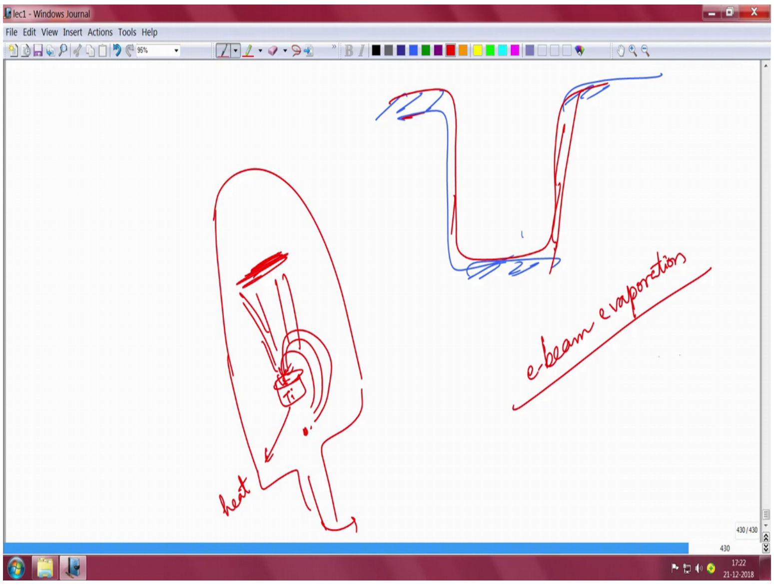

So, you know if you have the strands like that a poor step coverage will mean that you know you have a metal that comes here and a metal that comes here and a metal that comes here sometimes you might want to get metal here and then you might want to get a metal on the other side.

So, you know that was step coverage you ideally want like to have like this and then metal should form like this right. So, that step coverage is difficult to obtain in evaporation. So, people do not do it so much, but you know people used to do something called e-beam evaporation; e-beam evaporation in (Refer Time: 05:06) compound semiconductor in conductor industries still we will do e-beam evaporation.

So, essentially you have a giant chamber in which you put a substrate here and then you have a source that you actually you know, you have a source there in a metal say you know you have a titanium or aluminum here.

And you use an electron beam that is magnetically deflected and electron beam will come like this and a electron beam will heat up the this you know this metal it will heat up and it will melt sort of thing and the species will come here and they will deposit the coat the substrate, that is call the e beam evaporation ok. That is e-beam evaporation and the whole system under vacuum of course. So, the all the junk and other things are pumped down you want to better quality, but this process is only used in compound semiconductor in conductor industries I told you.

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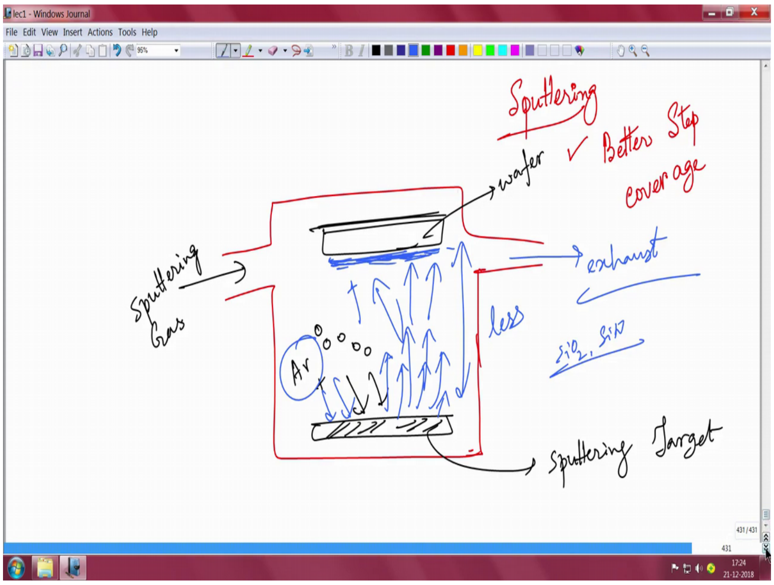

Its not so, much in use in silicon industry, what silicon industries also do is called sputtering; it is also a physical process by the way it is called sputtering sputtering is mostly used in silicon I c fabrication in MOSFETs and other things because it gives you a better step coverage or better you know sidewall coverage you can say better step coverage ok. It gives you a better step coverage, it is also better at depositing layers of alloys right its high density of ions can strike the target and continuing the material will deposited. So, what happens is that you have a chamber like that right you have a chamber like that you have a chamber ok.

So, maybe I use a different colour here. So, you a plate form here, this is called the sputtering target this is called the sputtering target and you are using a sputtering gas of course, here sputtering gas and then you have your wafer here right this wafer and which you want to deposit the metal by sputtering that is your thing right. And essentially you have high energy argon ions, this high energy argon ions will bombard and I release this target material whatever sputtering maybe silicon nitride metals. Something it will sputter and it will release and those will go and basically this deposit the metal, the film will grow here to whatever film you want to do grow here and a exhaust the byproducts of that will whatever junk eventually will be stressed out.

So, high density of argon ions for example, you produce this plasma sort of thing the high density of argon ions just strike the you apply appropriate bias of course. You will high density of argon ions will strike the target containing the material to be deposited and the substrate this distance is very less actually so that you know its if this argon species will bombard and will release the metal it is called sputter, it is like physical remove that you know.

And then you have to have this cathode and anode system you have bias them properly so that the metal that are sputtered the atoms will go and deposited on the film and you have this deposition that is done which was a better step coverage. You can also deposit silicon nitride, silicon oxide all these things you deposit with this also. So, widely used in industry this is called sputtering ok. Now these are physical processes that are used to deposit.

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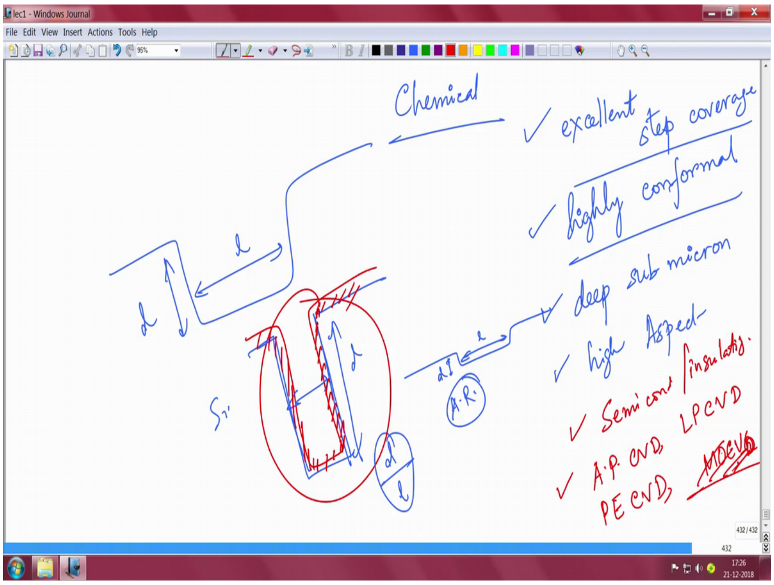

There is also chemical processes, now the best thing about chemical processes are there they give excellent surface a step coverage; excellence step coverage. And many of them in fact, are highly conformal highly conformal which means any step you know you can mimic the step very well, they are very highly conformal they are suitable for deep sub-micron when I say deep sub-micron I mean like 100 nanometer 200 nanometer extremely small scale dimensions.

And also they are suitable for high aspect ratio; do you know what is high aspect ratio? Aspect ratio is this so you have a trans for example, this is silicon. So, this is a depth you know this is the depth and this is the lateral width of the trans that you created or by etching or something else. The high aspect ratio would be like this ok, and a low aspect ratio will be something like this. So, this depth by l is d by l is very large typically you know maybe 10 or whatever its a high aspect ratio and if this depth by lateral resolution is not very large its very low, that is why the low aspect ratio its called AR aspect ratio. So, for high aspect ratio sort of this kind of structures you want to very conformal deep sort of a thing.

With lateral evaporation and all you cannot get that, with its physical process is very difficult. So, CVD can deposit that very well its highly conformal because its a chemical process and it can be used to deposit semiconducting and insulating layers also; semiconducting and insulating layers also.

They have many types of chemical vapor deposition CVD you can have atmospheric pressure CVD, you can have low pressure chemical vapor deposition, you can have plasma enhanced chemical vapor deposition then there are special techniques like metal organic chemical deposition MOCVD that is used from mostly like semiconductor film growth and all not for silicon so much. So, let us now talk about that here so much.

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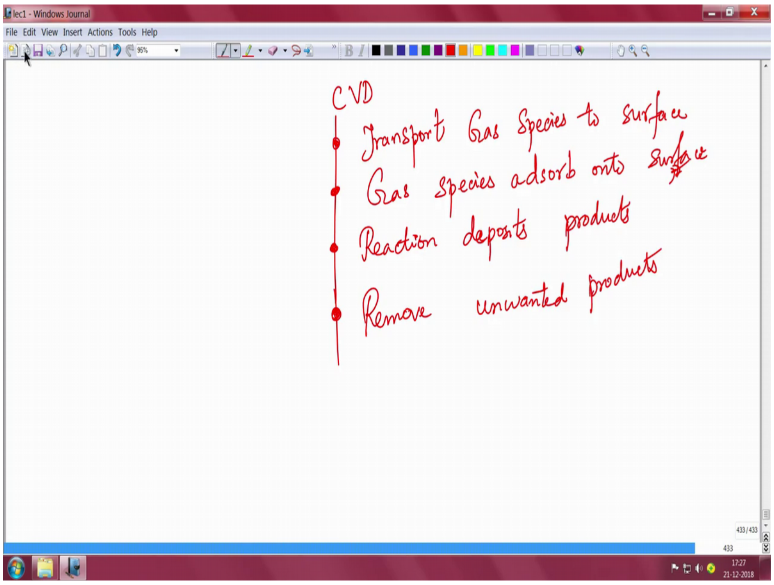

CVD

- Transport Gas Species to surface
- Gas species adsorb onto surface
- Reaction deposits products
- Remove unwanted products

Ah there are four steps of chemical vapor deposition actually, CVD has four steps ok, number 1 step is that you transport it is a chemical reaction essentially it is a chemical reaction that will deposit a material you transport the gas species to the surface. There are many other steps involved within each step, but primarily four steps you transport the gas species the reacting gas species to the surface of the vapor.

Then you allow the gas species whatever gas molecules and species have gone to absorb on the surface; absorb on the surface of the vapor semiconductor whatever right. And third is the reaction we will now deposit, the reaction deposits the products chemical products right.

And the fourth step is that you remove unwanted products, you remove the unwanted products and leftover reactants, you remove the unwanted products and the leftover reactance.

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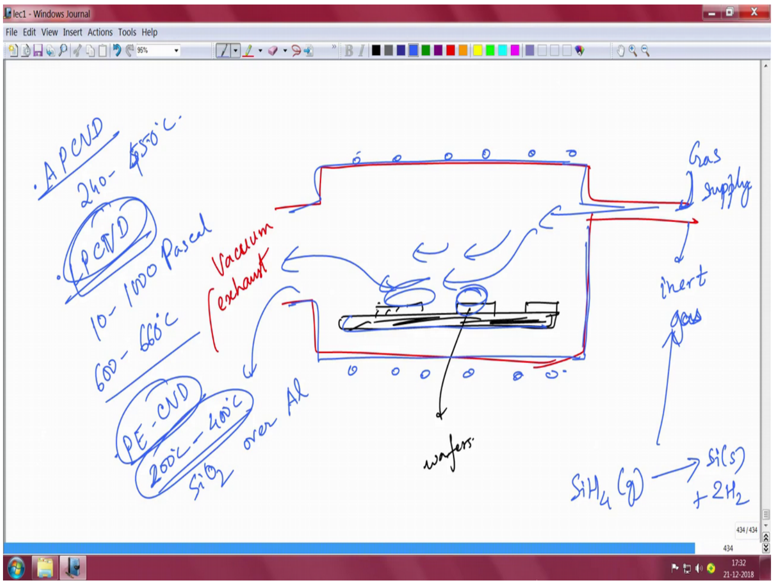

So, how do you do it? So, what you have essentially is that again its very simple, I mean at least some paper it is very simple practically it may be very difficult. So, if this is a vacuum you can pump out you can put a pump. So, as to make an you know pump the things down.

So, you have your susceptor; susceptor is essentially the plate from which you actually place the wafer you can place it horizontally you can place it vertically. So, suppose if you place it horizontally. So, it will refers it will like that horizontal susceptor you can also place them vertically sometimes in some susceptor these are wafers ok; these are wafers.

Then there will be heating coils, there will be heating coils there will be heating coils there will be heating coils that will heat up the things right then you will have gas supply you will have gas supply [FL]. So, essentially this whole chamber can be maintained at low temperature in which, but the substrate will be heated, if the whole chamber is maintained at low temperature you call them cold wall, if the whole chamber is maintained at hot temperature you call it hot wall that is the different things ok.

Each step in chemical vapor deposition is very complicated in terms of kinetics and thermodynamics to understand, its a very very complicated you will have to read multiple text books multiple courses we cannot go into that.

In the basic principle is that when you supply the gas you also have an inert gas inert gas to carry the primary gas inside ok, as they come here they will get absorbed and exhausted right. For example, silicon silane if you use a silane gas you are using a silane gas here, the silane gas will react you know on the surface of silicon to give you silicon solid plus 2 H 2 gas like that is the gas right as the decomposition of silane in CVD chamber in to amorphous this thing right. So, I told you know this will come here they will react from the products here and then the exhaust will go away right.

That is what happens, it is a chemical reaction chemical reaction takes place and forms this thing, it has to absorb on the surface it is a very complicated process we will not going to that, but this is a chemical processes are highly conformal process and there are many variations I told you. Atmospheric pressure CVD for example, in atmospheric pressure CVD you maintain atmospheric pressure, you can get very large reaction rates so fast deposition very thicker films can be grown very short time.

But the uniformity may not be great and which is used for like low quality dielectric, very thick dielectric temperature that you use is typically say 240 450 degree Celsius right you can grow thick high the very low quality very thick semiconductor might be needed in some applications all this things are done right.

Then there is low pressure CVD where you have to use a little low pressure, you have to pump it down pressure could be the range of 10 to 10 10 10000 1000 Pascal, this is the low little low pressure in atmosphere. What happens is that you get the mass transfer velocity the velocity which you are transporting mass is actually lower than the reaction rate. So, you know reaction velocity. So, you get better uniformity, purity, homogeneity and control used widely used for polysilicon deposition like deposition of high quality oxide or silicon nitride and so on critical temperature could be around 660 degree Celsius for in case of silicon technologies temperature is very important here.

You know what happens in l LPCVD is that you put the substrate then you would evacuate the tube then you flow the process gas and increase the pressure to thousand pascal or so; you let the reaction perform and remove the substrate. So, that is LPCVD then there is plasma and a CVD, this is a very simple again a similar process where you have a plasma. You also this advantage of plasma and CVD is that it may not give you as high quality as LPCVD which is gives you better quality. But its a low temperature process so you can deposit at around 200 to 400 degree Celsius.

So, you know in some cases you cannot take the wafer to a higher temperature in that case you have to use a lower temperature. So, you cannot use LPCVD then you can use plasma and CVD, what happens is that you know this is useful things like for example; you want to do silicon dioxide over aluminium metal. Suppose you have an layer of aluminium metal over which you have to put silicon dioxide. Now aluminium melts at 660 degree Celsius, you cannot do LPCVD aluminum will melt so you have to use PECVD at 400 or 200 degree Celsius. So, that aluminum doesnt melt and you can put silicon dioxide.

So, essentially a plasma chamber, all of you know what is plasma chamber you have the reactive gas is there and you have I f voltage cathode and anode to accept that. You know have ions that ions will bombard the ions will bombard the surface and provide energy and you will deposit the material on the wafer that you want ok. It gives you higher information high field density, chamber can be easy to clean and all, but you can generate lot of toxic gases that are should be you should be aware of that you should be aware of any toxic gases that are generated in this case. So, also CVDs can be done for metals I told you metal CVD.

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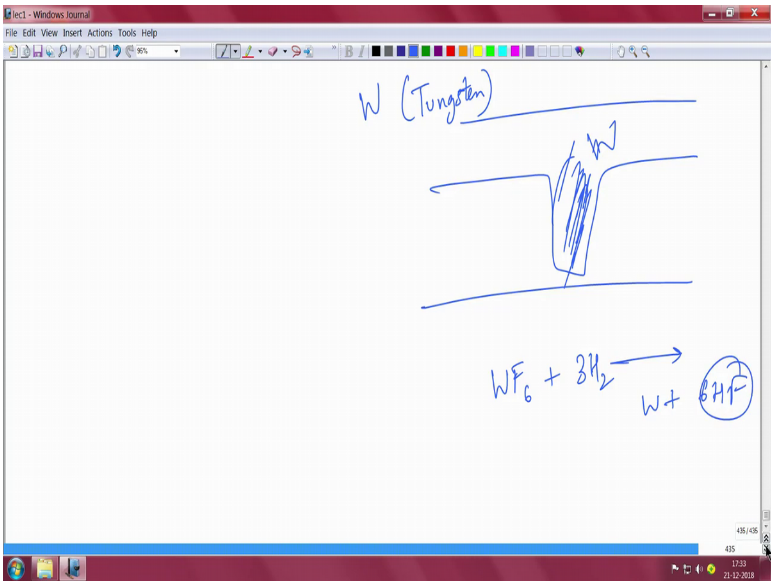

W (Tungsten)

W

$WF_6 + 3H_2 \rightarrow W + \boxed{6HF}$

They are not LPCVD or PECVD they are the metal CVD for example, Tungsten tungsten is which was is a plug metal plug for example, you have this layer of metal here and then you have to connect another metal. So, you fell tungsten as a plug this tungsten plugs are used, tungsten can be also done by CVD.

So, you take this compound of tungsten, then you put hydrogen gas heat and then you get tungsten plus 6HF. So, these are you know this is also careful by the way all this things. So, you can use CVD for different types of metals also you know titanium nitrogen so on.

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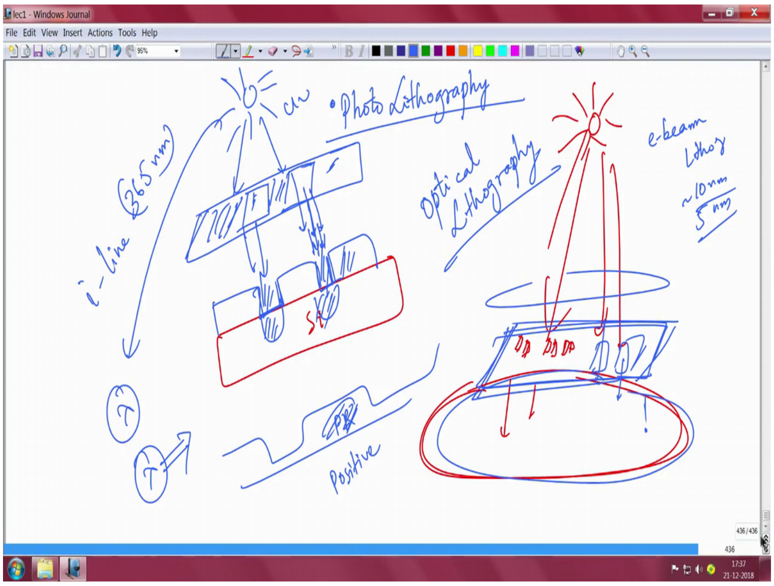

So, the next step that we should study is photolithography; photolithography is the process or the art of transferring in the pattern whatever source do in whatever you want to do the pattern is to be transferred to the wafer I told you.

So, you have a mask and that mask will transfer the pattern to the; so essentially you have a mask right on the mask you have this pattern may be sourced in sourced in pattern tiny patterns you can define this is call mask writing you can write the mask and keep it, on below you have a wafer and which will transfer the pattern. So, you will have a UV lamp here UV lamp and your shine ok; you shine the lamp what happens is that you coat the silicon wafer this is a silicon wafer, you coat the silicon wafer something call photo resist.

A photo resist is a complex organic compound and there are many kinds of photo resists I will only talk about one kind for example. So, what happens is that you can pattern it, you can pattern it and make sure that photo resist is only you know. So, so if the mask for example, this is a photo resist so for example, sorry. So, this is a ligand, this is a photo resist that is spin coat you know you can deposit that by spinning and coating it is very easy. Now suppose you have a mask on top there is a mask on top here the mask has suppose an opening here, an opening here so which means and everything is opaque.

Now, you have shining UV lamp three sixty of nanometer; so some UV lamp. So, UV will come, but it will block everywhere except this. So, the UV lamp will rays will come here UV rays will come here, what will happen is that the photo resist will get soften here and soften here and if you dip it in a particular solution this parts will go away rest all part will remain.

So, what happens is that the photo resist will now look like this, this part it has been dissolved away this, part has been dissolved away because that UV rays came and hit this part and so that became the cross linking of the polymer became soft. Actually it is a polymer, the cross linking became soft you dissolvable you dip it in the particular solution call developer which is basic not acidic.

And then that part will go away so you have a pattern like this. So, you can now put some metal here or whatever you know so that you can get this patterns you can get this patterns you can also etch away the silicon from here I will come etching little later you can etch away under some plasma ok; so this kind of thing is called lithography and because you are using a light source its call optical lithography, its optical lithography.

And what is the minimum dimension of the feature that we can write? That depends on the wavelength of the light we are using typically you know many of the industries and academy institutes you something call eye line of UV which means you are using a using 365 nanometer of UV lamp.

So, the critical dimension that you can define will depend on the lambda, the more shorter wavelength you use the better resolution of smaller features you can get. There are many types of lithography’s, the one who had a mask can be in contact with the wafer call heart contact when where the mask can be little bit away from the wafer one who have a mask you know has many lenses to project the image and all projection lithography. There are many ways many techniques of lithographys to essentially transfer the patterns and lambda if you use a smaller lambda you can get better smaller features and smaller and smaller features ok.

So, there are limits and the mask that you use this mask actually is nickel chrome um. So, anywhere you know you will have transparent features where the light can come through, you have everywhere is opaque this mask is printed separately that we should know. Photo resist that I have talked about photo resist PR profile that photo resist is a radiation or UV sensitive compound a polymer sort of thing, once you expose you know it become soluble in those areas.

This type of photo resist is called positive photo resist there is also negative photo resists such that wherever the UV light has shown illuminated that becomes become part become hard and rest all part become soft and can be that is called negative photo resist.

So, this is in a basic in about the lithography, you can also apart from light you can also use electron beam to define features. So, electron beam lithography is very expensive and very we can go up to like 10 nanometer 5 nanometer features you know because electron beam will have better resolution high energy and so on; so other things are there.

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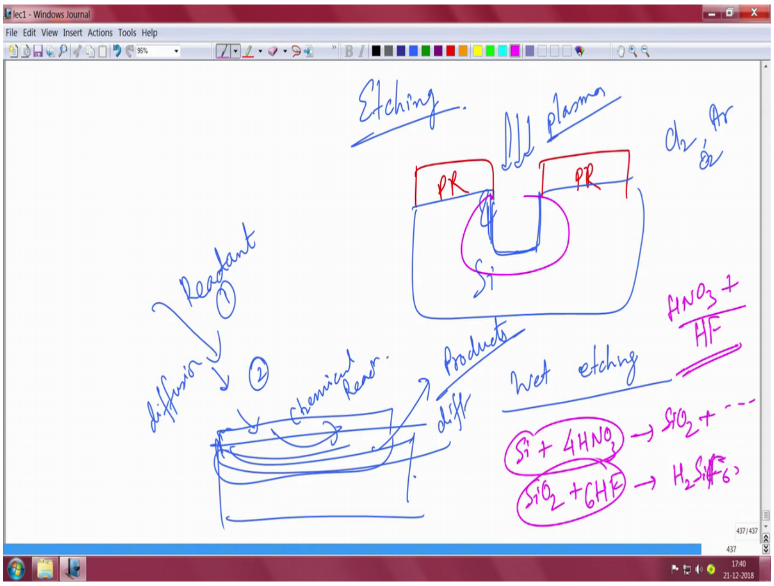

And finally, for this you know module you know this fabrication thing the one thing that is last remaining is actually etching ok, the one thing that is last remaining is etching.

Etching is removal of a material for example, you have a silicon wafer and this is silicon and then you have photo resist; you have patterned photo resist.

And you want to remove silicon from here. So, you can actually do a wet etching; that means, you can be dip it in some acids some solutions at specific solutions at temperature or you can do a dry etching when dry etching which means its plasma bombardment ok.

So, if you do wet etching for example, if you do a wet etchings are isotropic. So, if you dip it in a specific solution that can attack silicon chemically and it will give you like a like a etching like this profile like. So, it will = remove like that, it will be an isotropic profile like that you are etching you are removing silicon like that. And if you are using a bombardment then you will have an isotropic profile an isotropic profile you can near exactly like this silicon ok.

This is a plasma bombardment ok, like just like an implantation here you are actually etching wet ion silicon. So, high energetic ion bombardment that you are actually using this plasma can be chlorine plasma you know argon plasma and oxygen plasma and so depends on the chemistry that you are using essentially.

So, wet etching; wet etching as I told you it basically dipping the wafer with some particular specific chemicals that will attack, it is used extensively in semiconductor processing. Is useful for blanket etching like whole area etching of not only silicon, but even dielectric like oxides, silicon nitride, polysilicon metals also you can etch actually certain chemicals will attack the metal and metal can be wet also essentially again.

So, wet etching the same thing will happen your reactance, a reactance species its a chemical thing sort of thing here reactance species will you know diffuse; reactance species will diffuse to the surface and then the surceases the first step. The second step is that at this surface your chemical reaction will a take place chemical reaction will take place and the third step is that the byproduct will come out and give it carried away and they will diffuse out ok.

So, this is how your film will get reduced layer by layer whatever is basically you are removing the as a silicon it can be silicon nitride, it can be oxide, it can be metal can you think this is a wet etching.

Is very isotopic nature, its also dependent on the temperature using the solvent you are using and so on. So, it gives you a profile like a very as I told you it gives you a like an isotropic profile like that. So, it goes in all direction there are many examples for example, silicon if you dip it in nitric acid then it will give you silicon dioxide plus some products and all. The silicon dioxide, now if you use in combination of nitric acid and hydrofluoric acid right you use a combination of hydrofluoric acid you will get some product like that. So, essentially you can etch the silicon away in the combination of nitric acid, combination of nitric acid and hydrofluoric acid.

So, different materials will have different chemistries that can attack them right. So, this is silicon wet etching [FL], then there is dry etching dry etching in dry etching we use high power plasma to remove the silicon from this pockets.

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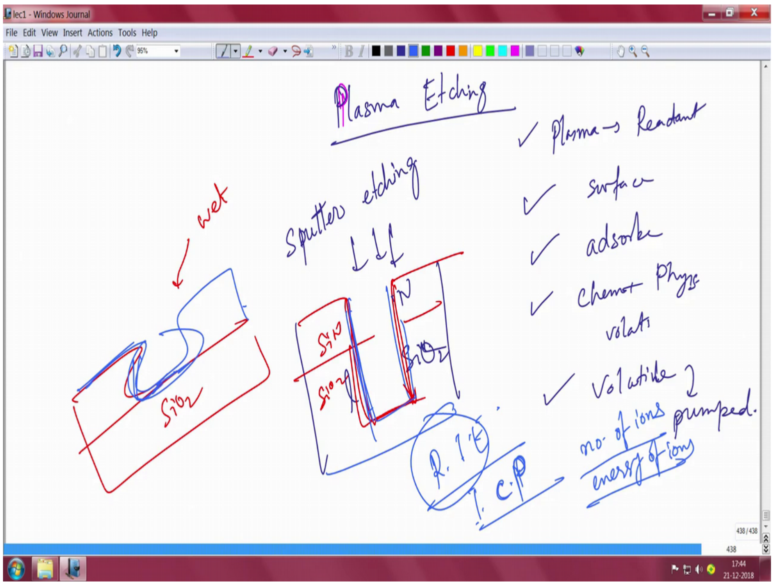

So, dry etching is essentially also call you can typically its called plasma etching, you use a plasma high power plasma to etch the surface away. It is a process in which a solid film is removed by a chemical reaction with the with a presence of a excited or a ground stage species ground stage species ok. This energetic ions will bombard in a gaseous discharge and you know enabled this plasma etching, the first step is that the plasma will generate the reactant species.

The second step is that the reactant species is transported by diffusion to the surface right, third step is that the reactant is absorbed in the surface right and the fourth step is that the chemical plus physical reaction will take place here. Physically you are bombarding and chemically also they might react on the surface to from volatile compounds and the fifth step is that.

The volatile compounds are pumped out volatile compounds are pumped out and they are you know that done that is done basically that is what happens in the plasma etching. So, plasma etching has a combination of both physical and chemical in a way because you are using high power plasma you can sputtered them physically away.

So, it is also caller sputtered etching and the physical component is called sputtered etching that gives you the an isotropic component of the of the etch at very high energy ions bombard the surface at high speed to give you an isotropic profile. But is has poor at selectivity which means if you have suppose layer A and some other layer B suppose this is silicon nitride layer and then this is silicon dioxide layer.

Because it is not you know if you use a sputtered etching physical and you bombard a very high energy then they will not select anything they will just etch everything away ok, which means you are not able to you are not do not know actually which layer is etched and everything etched here.

Whether it is silicon nitride or silicon oxide everything will etched away to a particular depth that you want ok. It does not have this if this is called etch selectivity in wet etching for example; you might use a compound that might only attack silicon nitride, but not attack silicon oxide. So, in that case in wet etching no matter what you do you will essentially get like wet etching like that you will not at silicon oxide because you are using a chemical you know species or a chemical reactant, but in dry etching if you have a very high power plasma it will etched away everything.

It will give an isotropic profile this will give you an isotropic profile, but the etch selectivity is very low in the etching. So, you also need to add a another degree call chemical degree. So, you also want to have the it is a chemical process that is in combination with the physical process, to give you better ion isotropic at the same time it gives you better at selectivity also so that kind of things are used. Typically this processes we call them Reactive Ion Etching RIE and you might have inductively coupled plasma that you might call ICP RIE to give a better degree of freedom in etching the you know the materials away.

So, it is chambers, this plasma chambers will be there wherever in anode and cathode its like a parallel plate system that you know even RF capacitive couple bottom electrode that will hold the wafer, large grounded area low pressure will be use like 0.5 or 1 millimeter. Heavy bombardment will happen and selective area can be improved by proper at chemistry here that is what it means, an ICP RIE chemistry of course, gives an additional degree of freedom. It will also help you control the number of ions, the number of ions that you are using the bombard and also the energy of the ions that you are use in to bombard both are important; both are important.

So, that brings us to the conclusion of this lecture, we are we will end the lecture here today we have studied most of the unit processes that are needed to understand fabrication of devices oxidation, diffusion and implantation physical and chemical vapor deposition the different techniques we have discussed etching, photolithography in mask and also on.

So, all these unit steps are used in a proper conjunction and a coherence in a sequence fashion to essentially get devices like MOSFET for example, silicon CMOS you know for implies source then you might want to do ion implantation, for gate oxide you might have to. So, thermal oxidation for some pocket you know doping you might want to do again diffusion or implantation you might want to etch oxide or silicon in certain areas.

So, all this process are used extensively and they enable the silicon MOSFET and subsequently CMOS fabrication process. So, we are done with this enough fabrication processes. So, we have maybe couple of lectures remaining in this module where we shall try to recap whatever we have learnt and solved previous years question papers and some mock practice questions numericals that will give you an edge and understanding.

And also I will give you some unique questions that are typically not asked in textbook that we will discuss to make sure that we are interact with the semiconductor course that we have studied. We have not memorized we will understand the concepts that what we will focus on in the questions we will see the next class. I will see you in the next class.

Thank you for a time.