Advanced Neural Science for Engineers
Professor Hardik J. Pandya
Department of Electronic Systems Engineering, Division of EECS
Indian Institute of Science Bangalore

Lecture 13
Basics of Photolithography

Hello everyone, welcome to this lecture. This lecture is focused on a very important topic, which is called lithography. And why because lithography is the technique by which we can pattern several materials or whether it is metal or semiconductor or insulator. And what is the importance of pattern because we can fabricate different devices. Now, for example, the heater should look like a meander shape or look like a coil. How can we fabricate or design this coil from the matter.

So lithography in another terms is called the heart of microfabrication. So, let us try to focus on that, we will try to divide it into two parts. So that you understand, digest and we continue from there. In the last lecture, we talked about the physical vapor deposition and then I told that let us see the chemical vapor deposition as the next part, but before we go for CVD, let us first understand how the photolithography works. And lithographic itself, the name comes from Greek and litho means from for single stone lithos, and graphics means to carve, so carving on single stone, right, that is how the lithographic term comes.

Now, for photolithography in particular, what I want to teach you is the process steps and process steps and then we will understand that how we can design or develop certain devices. So, let us start with the with the process, the important step in a lithography here we will be focusing on photolithography there are x ray lithography, there is an electron beam lithography, but we will be looking at photolithography and in photolithography, several steps are there, but in those steps also we use a term called mask and we use a term called photoresist.

Now just term is photoresist but actually there is a chemical which is called photoresist and photoresist are of two types. So, let us see the screen and start from them so it becomes easier for you.

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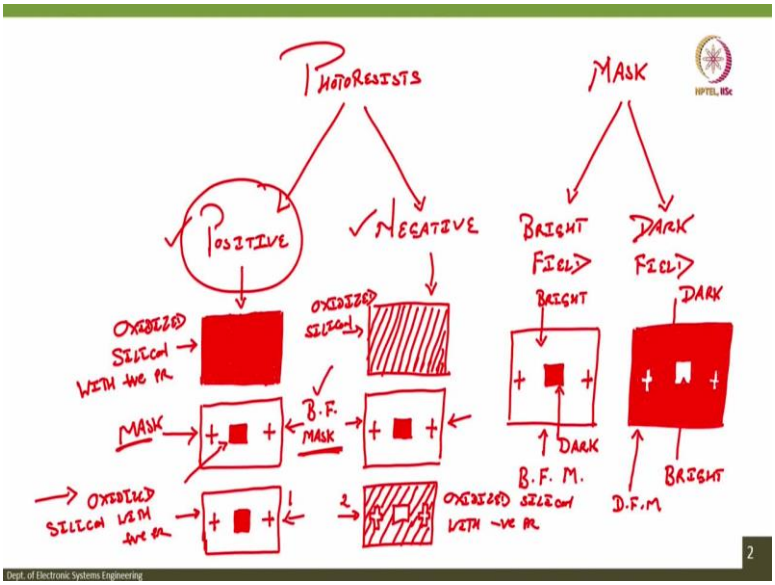

We say photo and resist, photoresist and photoresist are of 2 types one is positive and one is negative. So photo and then I will write down resist here resist all right? Photoresist two types positive and negative. Now, what happens when we use positive photoresist and what happens when we use negative photoresist.

Let us simultaneously understand mask, term called mask, mask again out of two types bright field mask, bright field and dark field. So I will show it to you the type of mask bright field and dark field. So, if you take and then the material is either Fe_2O_3 or soda lime glass or it is a chrome mask. So, if I have this structure, which is very simple structure I am drawing which is your square box on the glass, then this is your we have something called mask alignment marks.

So we just put plus here just for reference. So, this is your bright field mask, bright field mask. Why? Because the field is bright you see here the field is bright. And the pattern which is this pattern is dark. The field is bright, easy, this is how the bright field mask looks like. But if I want to see the dark field mask, then it will be opposite of bright field so let us have, and the entire mask the field should be dark. So, the field is dark and the pattern is bright, as you can see, the light can pass through the patterns. But it cannot pass through the field, because your patterns are bright or transparent and our field is dark. So, this is your dark field mask.

I will take a minute because it is important for you to understand how the mask looks like, because depending on the type of mask, we will be patterning several substrates. So, it is very

important that you understand this terms and the way it looks like directly. So, just you need to have patience, patience is something that we learn when we get old, but if you are young and if you learn how to be patient, then you will be in a better place, lot of things in life requires you to have a lot of patience. Even in the fast moving world, we have to have our patience intact.

So, what I am trying here is a field which is completely dark you can see completely dark and the pattern that we have is bright, almost there. So, here this is dark and the pattern, this pattern is bright. So, this becomes your dark field mask correct? We have bright field mask, we have dark field mask, in this the pattern is bright in dark field mask, in the bright field mask the pattern is dark, in bright field mask the field is bright, in dark field mask the field is dark, easy.

So, now, if I have bright field mask and if I have dark field mask, why I have shown you the mask while talking about photoresist is that depending on the mask and depending on the photoresist your patterns will be determined. So you have positive photoresist. Now, let us say that you have your wafer, you have your wafer I just trying wafer as a square it actually you know how they looks like I have shown you in the previous class, right? Like this correct. I am just trying for a reference okay here.

So if this is your substrate, the substrate which is let us say your oxidize silicon, this is also your oxidize silicon and this oxidized silicon if I quote with positive photoresist let us say this is my positive photoresist, just drawing some patterns. Assume that this is your positive photoresist and then if I coat the wafer with negative photoresist if I coat my wafer with positive or resist, and if I coat my wafer with negative photoresist and if I use bright field mask on this particular wafer, which is coated with photoresist and then there are a process called pre baking or soft baking and then exposure and then development and then you get some better but just quickly to understand the same thing here I have negative photoresist.

So I am just trying some different patterns. So as to make you understand that the positive photoresist is different than negative photoresist, it is not like these lines. It is also similar to this whole dark block that I have drawn. Now, you have this oxidized silicon wafer on which you have positive photoresist and you have negative photoresist. If I use bright field mask for both the cases, if I use a bright field mask in both the cases where the wafer is coated with negative photoresist and refer is coated with positive photoresist my mask is like this, bright field mask.

You can have several patterns and just drawing it for ease of understanding, so, you have your wafer like this with this pattern, this is your bright field mask. So, if I have oxidized silicon wafer coated with positive photoresist and if I have bright field mask my final pattern so, if I develop the photo, if I expose the wafer develop it then my final point in the photoresist will remain in the center like this. This is my oxidized silicon wafer with positive photoresist.

So, if I use bright field mask then I have oxidized silicon with positive photoresist it looks like this. But if I have negative photoresist then my wafer will look like this. What is the difference here between this one and that is one and this one too because here the mask is same bright field mask, the mask is same, right? But the patterns that we get finally on the oxidized silicon wafer with positive and negative photoresist. The final pattern that we get on the oxidized silicon wafer with positive and negative photoresist is different, right?

For positive photoresist it is the same as your mask. Right? Correct. This is your mask. So if you see the positive photoresist this case, we have the final pattern, which is this one. The pattern is similar to the mask in the case of negative photoresist which is this case for the mask, which is right over here. The final pattern that we get is opposite to that of the mask right?

You see the mask, this is the dark area here it is brighter in the final pattern where the plus is dark here the plus is bright. Correct. So, for positive and negative photoresist we have different patterns for the same mask. What we understand from this, can you see what we understand from this that if you use positive photoresist then the area which is exposed gets weaker you see positive photoresist, the area which is this area when you use this mask with this oxidized silicon wafer with positive photoresist the area which is exposed gets weaker right the field. The area which is not exposed which is the, this pattern gets stronger the area which is not exposed get stronger.

So, that is how the positive photoresist works, but if you take example of a negative photoresist what you can see on the screen that the area which is exposed as you can see on the screen the area which is exposed gets stronger and the area which is not exposed gets weaker, is not it, easy?

Again repeating for the positive photoresist the area which is exposed gets weaker you see the final thing in the positive photoresist this area this field area right the photoresist from the

field area is gone the photoresist on the area which was not exposed is still there, that means that for the positive photoresist the area which is exposed via the mask right gets weaker the area which is not exposed which are your patterns gets stronger.

In negative photoresist the area which is exposed which is this field area right here in bright field gets stronger the area which is not exposed gets weaker what will happen if I change this mask to a dark field mask then what do we have we have a bright field mask, but if I change this mask to a dark field mask what will happen let us see.

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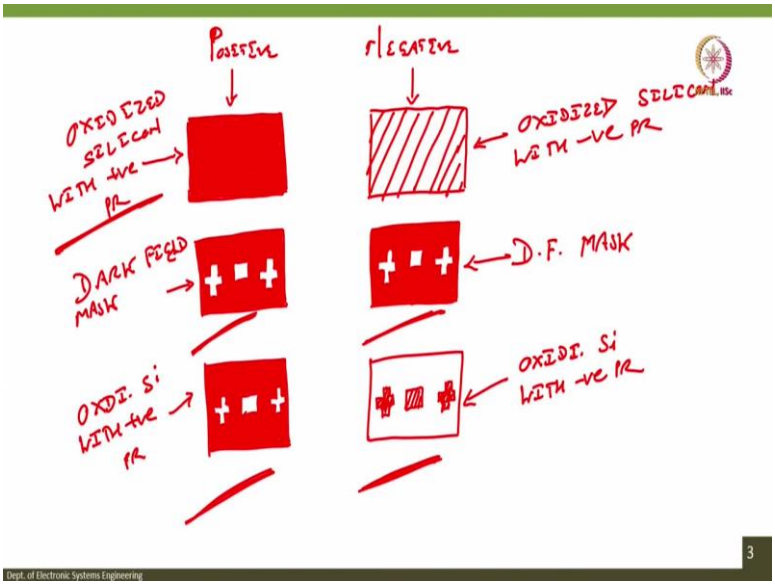

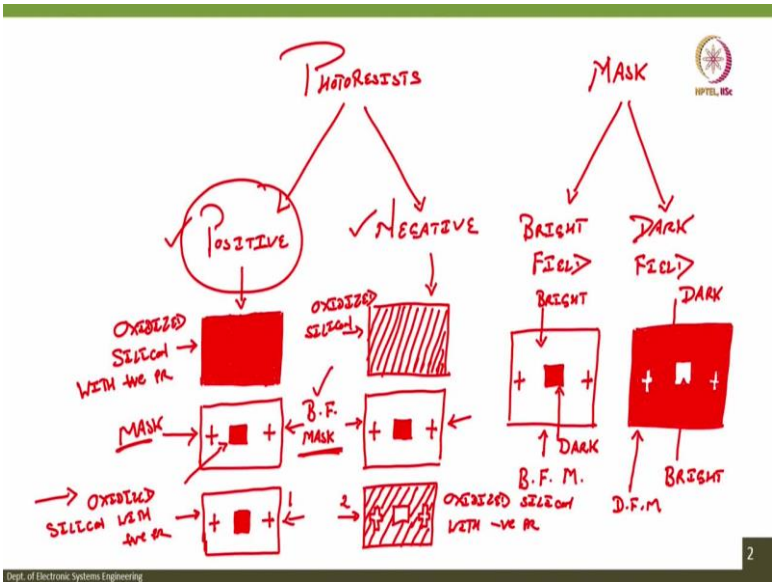

So, I have my silicon wafer coated, oxidized silicon wafer, coated with positive and negative photoresist in now case in the next case we are using a dark field mask. So, this is your negative photoresist. And we are drawing a dark field mask field should be dark and pattern

should be transparent. So, let us draw a dark field mask where the field would be dark and the patterns would be transparent, it takes little bit time to draw the schematic or representation of the mask, but when you have a proper drawing right, you will be able to easily understand what is the reason of using the bright field, what happens when we go for dark field? Does it have any effect actually or it all depends on the photoresist that you use? That is the reason of me taking a little bit more time for drawing these things, because I want to make sure that you understand the concepts clearly.

Once you understand and digest these concepts, believe me you can pattern many devices not one, many many devices. So, this is my dark field mask is easy for me to directly you know copy from the book and show it to you. But when you do this, this kind of examples right? It is much more easier for you to understand when I draw it and that is why instead of just taking it from some literature, or from some papers right or some images I preferred to draw it even it takes a little bit more time and energy because then this given this example this should stay with you for your lifetime that is what I want to make sure that the concepts that we learn in this class and any other class right try to understand thoroughly do not miss anything.

And believe me it is very easy once you understand it becomes very, very easy then you should start teaching your juniors right or if you are already a faculty, then your students right because microfabrication whether you talk about this neural science course or you talk about any other course where there is a fabrication involved whether there is a silicon involve whether transistors involved right you have to learn these techniques because these are all techniques that are used even for the transistor fabrications like MOS transistors right if you want to have source sensors right then also a wave guides even wave guides on silicon we had to learn the fabrication.

So, it is very important anyways almost there, so, what we have we have the dark field mask, we have the dark field mask with us correct and one more thing left, this is our for oxidized silicon wafer with positive photoresist. And, if you see the positive photoresist which we will be showing it to you in the experiment labs it exactly looks like a reddish in color, looks a little bit red in color negative photoresist does not look like the pattern that I have drawn okay just a representation, great, we are ready all right.

So, what is this? This is oxidized silicon with coated with positive photoresist. This one is oxidize silicon with negative photoresist. What are this, dark field mask and I have my final

wafer, I have my final wafer. Now, what will happen if I have dark field mask? See in this case again so that we do not forget, we have positive photoresist, we have bright field mass, we have the same pattern. Where negative photoresist we have bright field mask we have opposite pattern. What do you think if we have positive photoresist with a dark field mask, what kind of pattern you are assuming what I taught you for positive photoresist and for negative.

The area which is exposed in positive photoresist will become weaker and the area that will not be exposed will become stronger. That is what we have learned. Right? So that is what will happen. The area which is exposed will become weaker. So the positive photoresist from this wafer, the area that gets exposed will get weaker, and the area which is not exposed will get stronger.

So the final pattern that we get will be the pattern similar to our mask in case of positive photoresist, the final pattern that we get is a pattern similar to our mask is it correct? Right, easy, this is absolutely the same pattern that we have on our mask. Why? Because in case of positive photoresist, the area which is not exposed, gets stronger, and the area which gets exposed gets weaker.

So the area in the mask which is exposed is the transparent area that got weaker and the area which was not exposed is a field area will get stronger. Now when you say exposed, exposed with what right? Exposed with UV rays that is why this photolithography is UV lithography, ultraviolet rays lithography. So exposed to ultraviolet light, I will tell you how this process works process step works, just wanted to first quickly tell you the way the positive and negative photoresist work. So that becomes easier for you when we talk about the fourth process steps.

So, this is how we get when we have the this is your final oxidize silicon with positive photoresist. Here what will happen? The area which gets exposed right will be stronger, the area which is exposed will be stronger and the area which is not exposed will be weaker. So, we get this pattern, this is the oxidized silicon with negative photoresist. Now, let me tell you the easy way of remembering this.

First I made it complex. Now, let me make it easier. Whatever the pattern is there on the mask, the opposite pattern will come in negative photoresist whatever the pattern is there on the mask same pattern will come on positive photoresist you see whatever the pattern is there

on the mask, same pattern we get on the photoresist like oxidized silicon wafer, when we expose it and develop it.

When we use negative photoresist whatever the pattern is there on the mask, the rivers will get on the wafer, the rivers that we get on the wafer easy. So, now what we are seeing we are seeing positive photoresist, negative photoresist, positive with an example of positive photoresist with bright field mask, negative photoresist with bright field mask, then we have taking an example of positive photoresist with dark field mask and negative photoresist with dark field mask.

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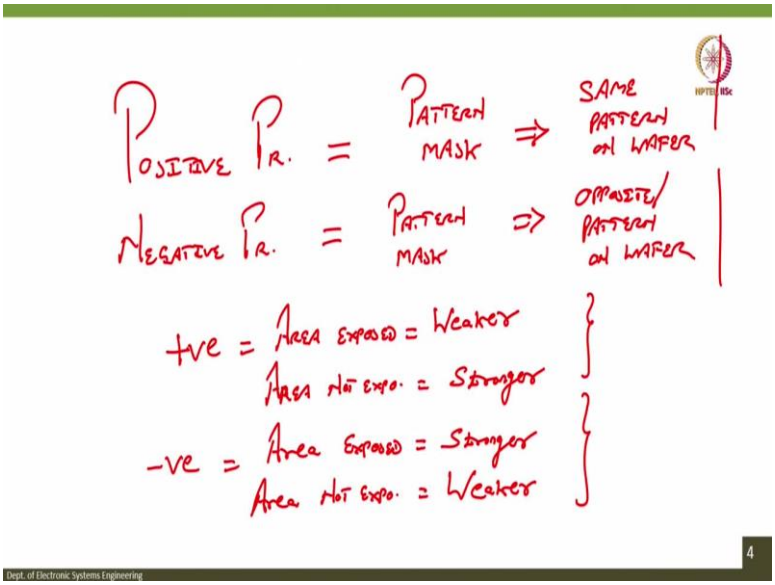

Again just to repeat, for positive photoresist and negative photoresist, whatever the pattern on the mask same pattern on wafer, whatever the pattern on the mask opposite or opposite pattern on wafer, easy, easy mantras, positive photoresist you can replicate the same pattern in the mask negative photoresist it will be opposite of the pattern on the mask, but the book says that in case of positive photoresist the area that is exposed will be weak weaker, the area which is not exposed will be stronger in case of negative photoresist, the area which is exposed will be stronger, the area it is not exposed will be weaker.

This is same thing what I have mentioned here right, super easy all right? So, let us now see how the mask looks like. And then we will stop and then I will continue in the next lecture. So, I will first show you the bright field mask. Now, as I told you, there is an attire to work in a cleanroom because I wanted to show you the mask. I have brought the mask with me. But still I not hold it with my bare hands. At least I will wear gloves, right? And I like magic.

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See, today can we see, today we can see the mask, you can see my gloves. Yesterday you were not able to see know why, right? You should ask the question why? What happened? These are old masks, but let us not worry about it. You see, you can see the area transparent right and then there is something in the center. Right? You see there is something in the center and the remaining area is transparent.

What is this mask, bright field mask the field is bright, the pattern on the mask is dark, the pattern on the mask is dark, the field is bright, bright field mask easy, right? What is the size? Is for 5 inch mask for 4 inch wafer we had to use 5 inch mask I have not taught you the aligning right now. So I will be teaching it to you as a part of this photolithography.

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But if you say how the dark field mask looks like? Then you see this one, the whole field is dark, the patterns here are transparent. Right? The whole field is bright, the patterns are transparent. So it is very easy to identify how bright field mask looks like compared to the dark field mask.

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And if I hold both the mask together, then it will be even easier for you to recognize which one is bright field. And which one is the dark field mask, easy see. Bright field, know right dark field and this is bright field, field which is bright, bright field, field which is dark, dark field. The pattern of bright field is darker. The pattern in the dark field is brighter or

transparent. Easy, easy, dark field, bright field, dark field, bright field. You cannot forget this right? And I cannot teach you better than this. This is the limit. Right?

Everybody has his own limit of teaching, this is my limit of right online mode. This is the best I can do for you who have not seen the mask. Do not worry about it right. When you understand these concepts clearly and when you enter the laboratory, automatically your life will become easier. That is the reason you do not have something in your university does not matter. At least you know the concept is more important, right you can learn right? But if you do not know at all, very difficult.

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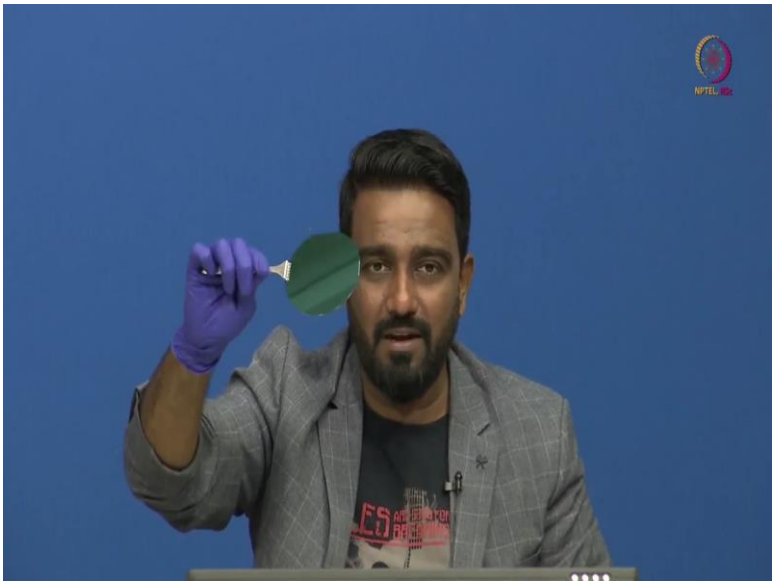

Now yesterday if you remember, we have seen the silicon wafer. And I told you that there is a tweezer that is required to hold the silicon wafer right, you see, this is the silicon wafer is it polished? Yes, it is polished, what is the other side, rough, this is the polish side this is the rough side right, I am holding with a tweezer okay, it is very important how to hold the wafer with a tweezer each wafer cost about 1500 to 1,800 rupees. 1500 to 1800 rupees and otherwise you cannot buy, but can we have a foundry that can make the silicon wafer for us, right.

So, we are looking to go towards that sometime. But, if I have a thermal oxide grown on silicon, how it will look like depending on the thickness of silicon dioxide, the color of the wafer would be different. So, if I show it to you this wafer you see is slightly greenish in color right I hope that you can see the color it is greenish in color right the backside, the front

side this is greenish and now, if I hold the let me hold the wafer because then I will not use it further just use it for demo.

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So, if you see the wafer now, this one is gray, this one is green, can you see the difference right this is silicon, this is oxidized silicon a thin layer of oxide is grown thin layer can be 1 micron also thin layer can be half micron also right. So, a silicon wafer oxidized silicon wafer right both are single side polished single side polished, Alright, this is how the wafer will look like 4 inch wafer. And now, let us see the mask again.

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So, I had to align my mask with silicon wafer or oxidized silicon wafer, so, that I can have a better patterning. So, let me just show it to you how it will look like, you see this, these are the pattern, there was some pattern on the glass, right this is how the alignment is done. So, for 4 inch silicon wafer, we have 5 inch mask. For 4 inch silicon wafer, we have 5 inch mask, this is dirty wafer and dirty mask, so, let us not worry about it, I am just showing it to you how this wafer can be aligned with a mask. This we do not use it anymore, this is just for the demo purpose.

But the idea of me to tell you about how to use the wafer wave mask is I have brought this mask and wafer here in the studio. And again do not get confused that why we are learning all these things, because as I told you earlier, this all techniques are useful for you to fabricate devices, implantable devices, that can be used for acquiring the neural signals.

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So tweezer right, mask, wafer, gloves. Once you are done, take out the gloves, wash your hand and you start the experiments, right or wear other gloves and do it. So we will stop here. So that you understand what we talked about. We talked about photoresist, we talked about mask. Two types of photoresist positive and negative, two types of mass bright field and dark field. If I go for positive photoresist, I can replicate the same pattern of the mask on the final wafer. If I use negative photoresist the opposite of the pattern that is on the mask will be on the wafer, right.

In the next class. I will teach you the process. What is the first process when you get silicon wafer? What is the next process so that we understand the process flow and then we will take it from there and understand how we can align the wafers, so when you have 1 mask versus

you had 2 masks versus you have 5 masks how the alignment process can be done and the same thing we will be also showing it to you in the experiment labs. So till then you take care I will see you in the next class. Cheers.