Soft Nano Technology

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Lecture - 12
Photo Lithography – 1

Welcome back, we are now essentially moving on to the next module, though I am not really following it in a very structured way.

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Course Content

1. Introduction:
    - What is Nano? What is so unique about it?
    - Specific Coverage in the Course
    - Nano Patterned Surfaces
    - Stability of Ultra thin Films
    - Applications of Nano Patterned Surfaces and the Associated Science
2. Some Basic Concepts
    - Surface and Interfacial Tension: Components
    - The Wetting Regimes: Young's Equation
    - Wetting on a Nano Patterned Surfaces ;
    - Hydrophobicity: Cassie and Wenzel State of Wetting
    - Laplace Pressure and Young Laplace Equation

But if you look in to the content, we sort of had a pretty exhaustive discussion on introduction and certain questions like; what is nano? What is so unique about nano? What is the application of nano patterned surfaces? These things we have looked in to some that of detail. Stability of thin films is something that I am keeping for the aim I mean we need to have some more concepts before we can talk about it. Then we tip talk about application of nano pattern surfaces and in certain cases the science associated with it.

Particularly we have discussed the wetting behaviour of the pattern surfaces and do you now know about structural super hydrophobicity. You now know about issues like Cassie and Wenzel state of wetting etcetera. Then we moved on to discussing some of the basic concepts and you now know surface and interfacial tension you know the individual components. You know about the Young's equation. So, wetting on nano pattern surface, what I talked here and you also know about the Laplace pressure and Young Laplace equation.

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Course Content *continued*

3. Patterning Techniques:
  - Nano Fabrication Methodologies
  - Top Down, Bottom up ....
  - Self Assembly, Introduction to Surfactants
  - Brief Introduction to Photolithography
  - Discussion on Soft Lithography
    - Nano Imprint Lithography
    - Capillary Force Lithography
    - Micro Molding in Capillaries
    - Micro Contact Printing etc.

If you look in to the content, we are essentially looking back at the content. The next thing we needed to discuss was nano fabrication methodologies that also we have in fact talked about briefly about the top down and the bottom up approaches we already have had an introduction to surfactants and may be one example of self assembly. So, this is also done. You now know what is CMC? What is a Micelle formation? What is yours Micelle and stuff like that?

So that also we have discussed. What we are going so the next in that comes up is photolithography and in the introductory slide itself I had given you an introduction a sort a dreams of why photolithography is important, because though we talked about several application areas of pattern surfaces like super hydrophobicity, structural colour, nano biotech application even meta material. We finally, I finally, told you that the most significant user of nano patterning is actually the microelectronic industry and the significant progress in nano patterning is attributed.

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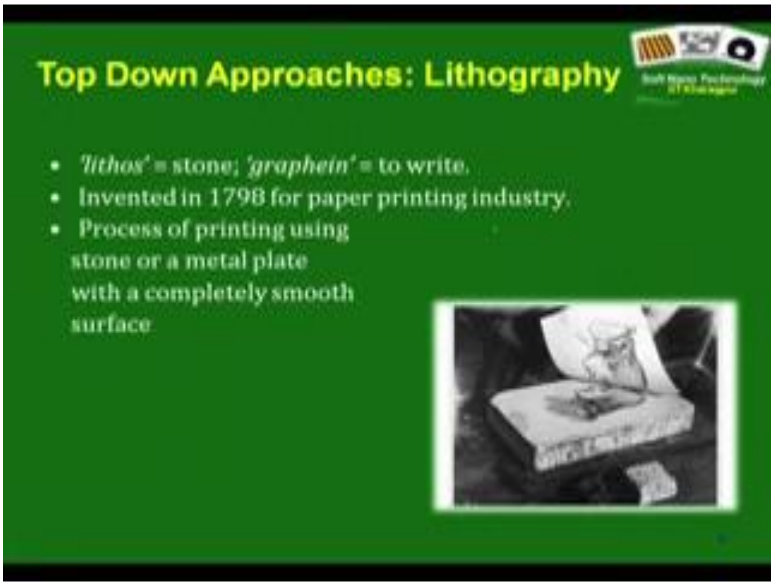

Top Down Approaches: Lithography

- *'lithos'* = stone; *'graphein'* = to write.
- Invented in 1798 for paper printing industry.
- Process of printing using stone or a metal plate with a completely smooth surface

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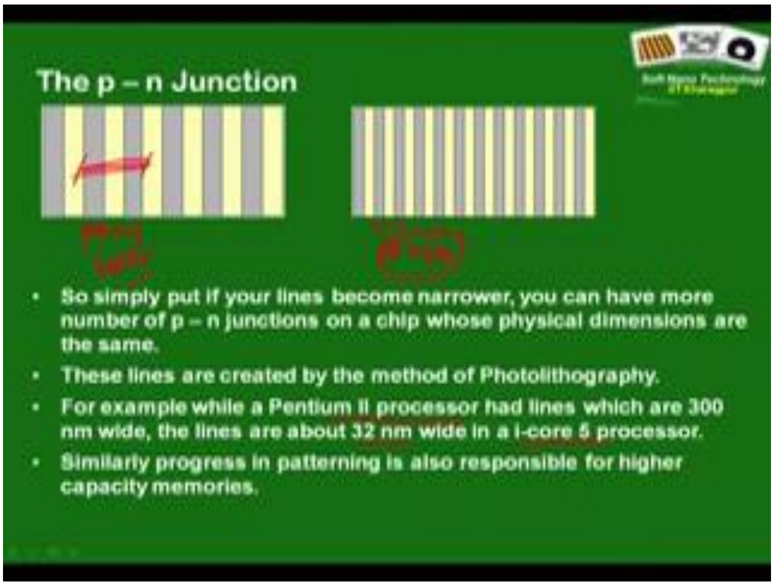

The p – n Junction

- So simply put if your lines become narrower, you can have more number of p – n junctions on a chip whose physical dimensions are the same.
- These lines are created by the method of Photolithography.
- For example while a Pentium II processor had lines which are 300 nm wide, the lines are about 32 nm wide in a i-core 5 processor.
- Similarly progress in patterning is also responsible for higher capacity memories.

We discussed this also very briefly, significant progress in the microelectronic industry; particularly in the form of faster processor higher clock speed is achieved due to tremendous progress in field of nano patterning. Now I will not go in to the details of the exact physics of what happens? But we understood that for example, there was an example some numbers were written. So, Pentium 2 processor had lines which were 300 nanometre. So, periodicity was of the order of 600 nanometre and now you understand for a I 5 core processor, line which is down to 32 nanometre. So, the periodicity 64 roughly it is 60. So, in roughly 10 years were the same area where you could put 1 p n junction. You are now able to place 10 objects.

Chip size remaining same, you are now able to increase the number of p n junctions and this is the heart of the basic fundamental that leads to the significant enhancement in the top speed of the processor speed.

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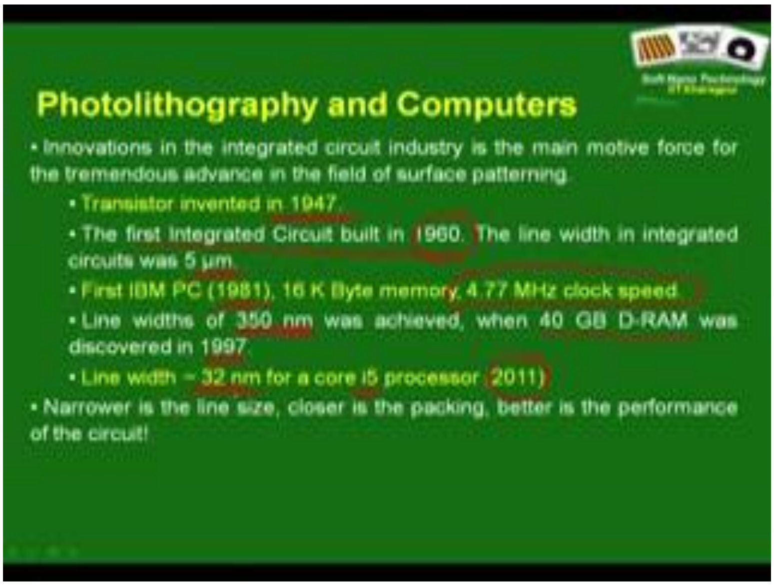

Photolithography and Computers

- Innovations in the integrated circuit industry is the main motive force for the tremendous advance in the field of surface patterning.
  - Transistor invented in 1947.
  - The first Integrated Circuit built in 1960. The line width in integrated circuits was 5 μm.
  - First IBM PC (1981), 16 K Byte memory, 4.77 MHz clock speed.
  - Line widths of 350 nm was achieved, when 40 GB D-RAM was discovered in 1997.
  - Line width ~ 32 nm for a core i5 processor (2011)
- Narrower is the line size, closer is the packing, better is the performance of the circuit!

How it is done? Few interesting facts about photolithography and computers, in fact the development in the field of microelectronics is significantly attributed to development in photolithography. The transistor invented in 1947, this is just for your knowledge. This is do not have to remember any of the dates because we are not learning history. I was particularly bad with all dates and things like that.

First IC, the Integrated Circuit was built in 1960, line width was 5 micron. First IBM PC with 16 kilo byte memory and 4.77 mega Hertz clock speed was developed in 1981. Line width of 350 nanometre was achieved, when the 40 GB D RAM was discovered in 1997. Presently not presently in fact, is 2011 data line width in I 5 core processor is down to 32 nanometre. So, narrower is the size closer is the packing and better is the performance or faster is the clock speeder; faster is the processor.

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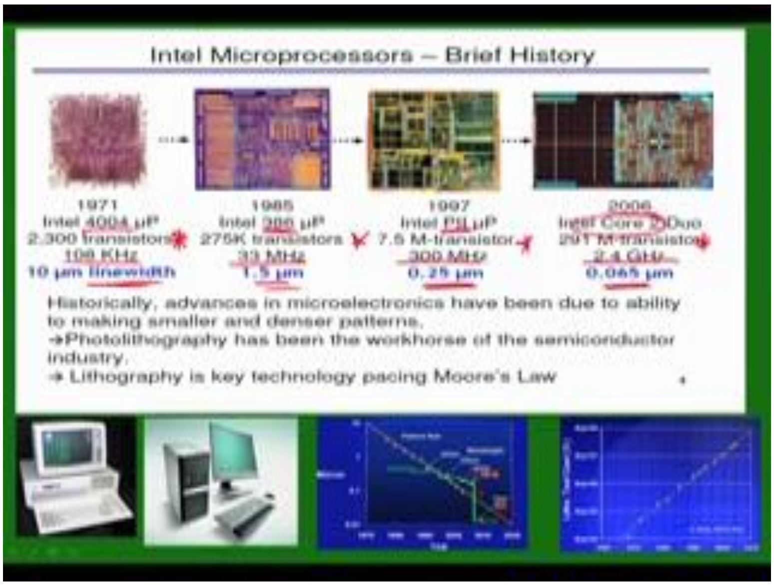

Intel Microprocessors – Brief History

1971	1985	1997	2006
Intel 4004 µP	Intel 386 µP	Intel PII µP	Intel Core 2 Duo
2,300 transistors	275K transistors	7.5 M-transistor	291 M-transistors
108 KHz	33 MHz	300 MHz	2.4 GHz
10 µm linewidth	1.5 µm	0.25 µm	0.065 µm

Historically, advances in microelectronics have been due to ability to making smaller and denser patterns.
→Photolithography has been the workhorse of the semiconductor industry.
→ Lithography is key technology pacing Moore's Law

Here are, again sort of another way of representing the same data. So, 1971 you have Intel 4004, 85 you had the Intel 386. PCs 1997, the Pentium 2 and 2006, this is the I core 2 processors. So, you see that there are this is the clock speed. This is something you all looking to, what are the speed of the processor you are going to have? There are two additional in formations.

1 is the number of transistors and you see that and how exponentially a number of transistors have grown and there is another information that is given here and that is the line width and I am sure, now you are already able to follow what is meant by line width? And now you all understand, it is this line width, the width of the p type and the n type domains on the semi conducted chip or on the silicon chip, that is actually responsible for all the fantastic performance, enhancement that you observe.

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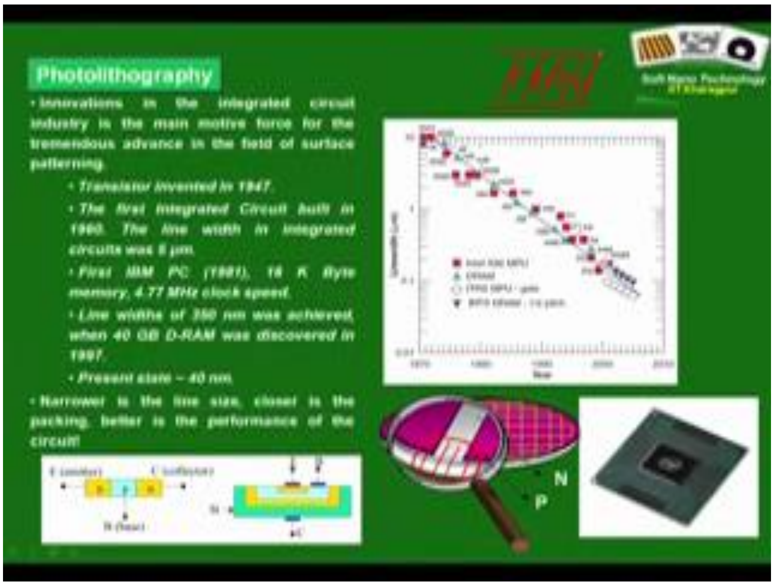

Photolithography

- Innovations in the integrated circuit industry is the main motive force for the tremendous advance in the field of surface patterning.
  - *Transistor invented in 1947.*
  - *The first integrated Circuit built in 1960. The line width in integrated circuits was 8 µm.*
  - *First IBM PC (1981), 16 K Byte memory, 4.77 MHz clock speed.*
  - *Line widths of 350 nm was achieved, when 40 GB D-RAM was discovered in 1997.*
  - *Present state – 40 nm.*
- Narrower is the line size, closer is the packing, better is the performance of the circuit!

There are lots of these graphs and Moore’s law and stuff like that are available. Moore just is business or a management guru or something like that, he predicted that the processes number density of processor will double in every 5 years and microelectronic industry sort of has grown exactly following that road map so that what makes Moore’s law very very famous. So, as we had already discussed in the introductory slide. This is the heart of a microelectronic process of this array of p and n type domains and the basic the technique that makes this or lets us make this is nothing, but a patterning technique and its photolithography.

That is what we are going to learn in a very simplistic way. So, that irrespective of what background you are from, whether you are a chemical engineer, mechanical engineer or some other engineering or you have a science background with some basic high school physics knowledge, you are able to understand what it is.

Let me also tell you photolithography is a very very complicated process. It is a multibillion Dollar industry. So, all the chip makers have their own photolithography setup. Things are kept in an extremely secretive manner, even patents are not filed. So, they are more like trade secrets of a company. So, everything that comes in the open literature is bid dated. So, nobody actually tells what is the present state of Act and I also have and it has significant inputs from various areas like electronics, chemistry, everything is required, but we will take a very simplistic feature and only try to understand the very basic steps that are associated with photolithography.

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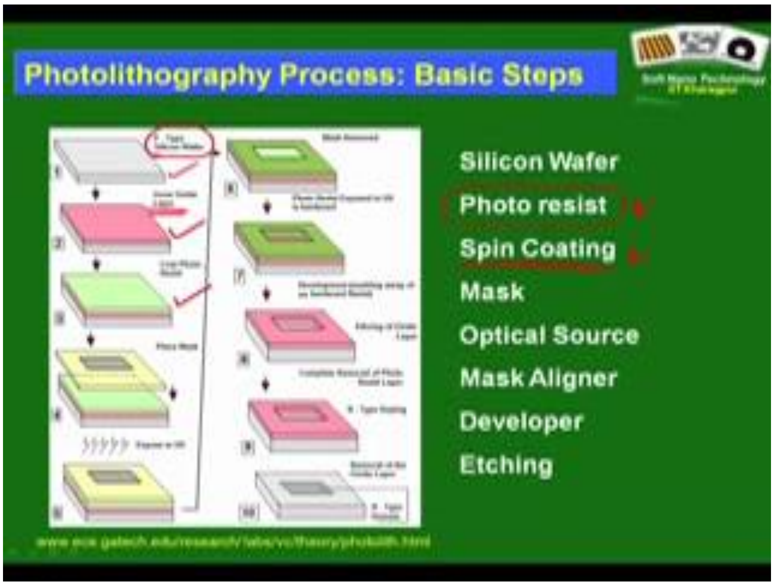

Photolithography Process: Basic Steps

- Silicon Wafer
- Photo resist
- Spin Coating
- Mask
- Optical Source
- Mask Aligner
- Developer
- Etching

www.ece.gatech.edu/research/labs/vc/theory/photolith.html

That is somebody is talking about photolithography you at least know what are the things that are going on, let me get started with this particular schematic which sort of tells what are the steps you do, but before that let me just tell you about the photolithography why you do that.

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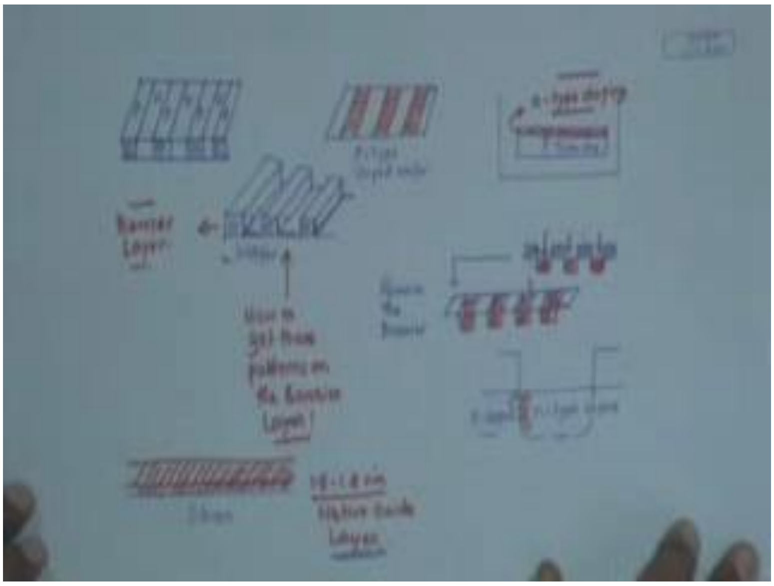

You as we have already talked about, you would like to have these type of arrays of let us say p and n type dope domains and as I have briefly mentioned during the introductory discussion that they are done on a single piece of silicon. It is not that you bring in strips of p and n type silicon and then try to stitch. It is going to even more combustion and that it is going to significantly enhanced resistance of the interface.

So that is not the desired thing. You would like to have p and alternative domains of p and n type doped areas on the same piece of silicon. So, what you do? You actually start of so I hope this is clear if not please refer to the text or discussion we have. The basics of photolithography or referred to my NPTEL lectures, whatever you want to do. So, the idea is that how you achieved? You start of and for the example we will be giving I will show that you start off with a p type dope wafer. I am just showing a section of the wafer. The wafer is typically circular in size, but that does not matter and what you try to achieve is you try to do some doping, n type doping in a periodic specially varying manner by putting the wafer inside a doping or a reactance chamber.

Now, issue is if you put the whole wafer in to a reactant chamber, you will not get structures like this. What you will get even if you take a p type doped wafer, you put it in the reaction chamber and you have strong reactions that sort of do some surface diffusion and you get n type doping. You are going to have a layer of n type domains across the entire way.

The whole purpose is in fact lost. So, how can you do that? You can achieve it in a way that if on your wafer, you have some patterns like this of a material, some material what material is it? I tell that prevents the diffusion of your n type doping and the wafer is open only at these locations, other areas it is (Refer Time: 12:18) it under this barrier layer. It is actually called a barrier layer.

Now, can you think what you are going to achieve when you put this wafer in to this reactant chamber? What you are going to achieve is instead of a flat wafer, now you have a wafer that contains some barriers and therefore, if this barrier is adequately thick to prevent the diffusion of this n type dopants, the doping reaction will take place only at these locations. So, within a p type matrix you will have localised domains or n type domains. So, at I will just draw an exemplified picture, amplified picture. So, this is how it looks like. So, this is now n type doped this was anyway p type initially. So, in the process what you do is, at each of this interface you create p n junction.

However, that is the whole idea, I hope it is clear. So, you have some structures on the wafer, I will repeat it because it completely new concept. You take a p type doped wafer you put some structures on the wafer and then you put it for this doping I will not talk about the doping reaction at all in detail because that is not something that is associated or related to this course. But these structures, these patterns allow the doping to take in a periodically varying manner and therefore, your wafer now has periodic patches of p and n type domains which leads to the p n junction.

Of course you need a flat wafer like this for fabrication of microelectronic processor, but you have the barrier layer or the structure barrier layer. So, that is anyway another step where you actually need to remove the barrier after the doping is achieved. So, that is a simple thing. So, if you can remove the barrier then you is left with something else and this cartoon what I have drawn you just to try to take a view it should match with what I have shown here.

Now I think you should be able to correlate has to what we are talking. So, this is exactly what we wanted to have and you see you can do that, but there is some. So, there are processes that are associated. One of the process of course, is to remove the barrier layer that is a not a very important, not a very difficult thing, but the more critical thing is how to get this patterns on the barrier layer and what is the barrier layer for that matter. So, with this much amount of knowledge let us see how we can start understanding photolithography. So, you start off with a or I have a sort of a copy of the same thing which I will be using here. You start off with a p type dope wafer as I have already mentioned.

Then you grow and oxide layer on top of it. If you remember that we are talking about silicon and one of the examples in one of the earlier classes while talking about spreading coefficient I gave is that silicon has very high surface energy. So, the moment you take out silicon and expose it to atmospheric oxygen, what happens is if you expose silicon to atmosphere, the oxygen present in the atmospheric air immediately attacks this silicon and on the silicon surface it forms a very thin native oxide layer and its thickness is of the order of 1.5 to 1.8 nanometre a native oxide layer.

You may already start to correlate that what happens during this stage, where you want the doping to take place and you have a doped native oxide layer. The answer is that well the native oxide layer is going to prevent your diffusion dopant diffusion. You need to get rid of the (Refer Time: 18:03) at this stage, but simultaneously this oxide layer, the oxide is actually used as the barrier and therefore, you also understand that in order to get this you eventually need to patterned the oxide layer.

But 1.5 nanometre is too low a thickness, to prevent the dopant so over these areas. So, what you first grow is on top of native oxide layer, you first grow some more some thicker oxide. That is a very simple step, you just take your wafer in to a oxidising (Refer Time: 18:42) and heat it for some time.

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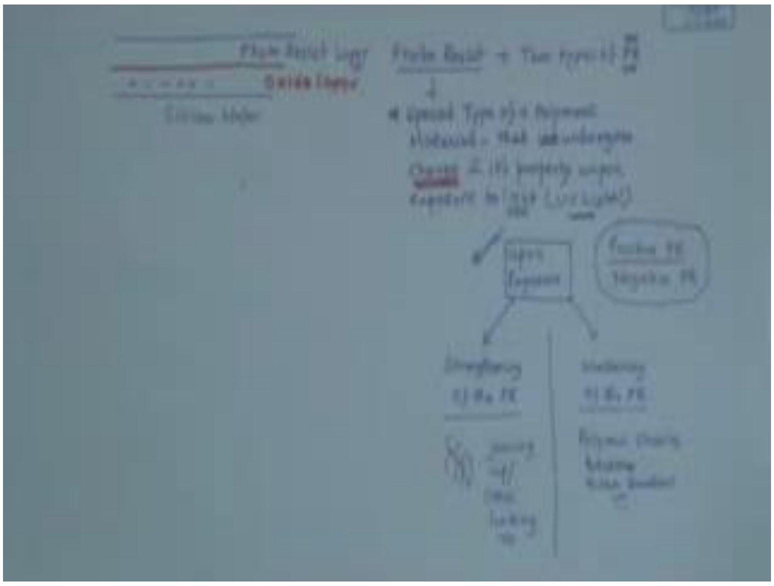

And this is a chip so, this is the wafer. First thing you do is you do an oxide layer. So, that is what is shown in the first and second stage.

But then comes the question how to pattern this oxide layer? Is there a technique to pattern this oxide layer? And the answer is no. There is no step to pattern the oxide layer and here you essentially take help of a special type of a polymer which is called photo resist. So, see I have identified that some of the terms probably we will be hearing for the first time and one of them is indeed photo resist. So, photo resist as the name suggest is a special type of a polymeric composition material that under goes change in its property upon exposure light. Reality is, this is UV light.

It is not though it says I mean classical definition wise photo resist changes its property upon exposure to light. it is actually UV (Refer Time: 20:30) this is a very practical consideration because you do not want to work with a material that changes it is property when exposed to regular (Refer Time: 20:39) because you will be working in the laminated room or in the sun or whatever and if the material composition is such that; it changes property to light which has within the wave length of 400 to 700 nanometre.

Unfortunately during processing itself your material the photo resist layer or the resist layer will start changing its property and therefore, you cannot work with. So, what you want is that you want specific layer which will changes property only when you wanted to change that is you expose it with some UV light or specific wavelength light and then only it changes its property and that precisely what you do? But the second step is over the oxide layer you actually grow a photo resist. You deposit a photo resist layer and this is not done by any growth process like the oxide layer, this is done by another very simple, but very popular and powerful technique, which many of you might be hearing for the first time again, is what is known as spin coating.

We will talk about spin coating, then once you have this photo resist layer of course, what we will eventually discuss that there are two types of photo resist and what are the two types? In fact, there are several questions in the statement that I have made here one of the statement is, it changes under goes change in its property. So, what type of change does it under go upon exposure to light? And this change depends, I mean this change can either lead to strengthening of the photo resist or it can lead to weakening of the photo resist. So, there can be two different completely different types of materials. So, it is possible, these two possibilities are there.

Well some of you might know or might have already done a search that, there are two types of photo resist and this is called actually the photo resist tone and they are positive photo resist and negative photo resist. I am not trying to do any mapping of whether a positive, in a positive photo resist it is the one so in which strengthening takes place or this is the one in which weakening takes place because we will learn it in a slightly different way and therefore, you do not have to really mug it up but yes. So, new thing that we are learning, we are already learning whole lot of new things in this lecture is that there is a special class of polymer that is extremely, that is absolutely essential for photolithography.

For performing photolithography which are the photo resist and this photo resist upon exposure to UV light changes its property and this change in property can either lead to strengthening of the photo resist or lead to weakening of the photo resist. One can also ask what is strengthening and what is weakening? So, typically these are polymeric material. So, I would put strengthening as some sort of joining up or cross linking of bonds.

What will it do? It in fact increases the viscosity. So, if you now wash it with the solvent right it becomes difficult to this logic because the chains are now bulkier or they are sort of cross linked and what would be the chemical aspect of this so called statement weakening? Well, it in fact implies that the change, the polymer change becomes even smaller. It is something like change (Refer Time: 25:08) takes place and what that means, is that once you expose it again to a solvent and that is the step that is going to be very very important. We will soon realise it is easier to remove the polymer where, the chains have becoming smaller, chains have become smaller again because of this viscosity issues, viscosity is rather low.

Let us look back in to this schematic again. So, we now understand the starting point we now understand the utility of the growth of this oxide layer. We now understand the utility of this quoting of this photo resist, but then comes the question we have quoted a photo resist fair enough, but what do we do after all we wanted to create some patterns like this, but as of now we have not talked about any mechanism how to pattern it? So, in order to, this is something that I will continue in detail in the next class in order to make this patterns you need to bring in another piece of hardware element, which is known as the mask.

This mask in fact contains the structure you would like to create. They can have identical structure or some structures which are smaller or bigger, may be bigger not smaller and with the help of the mask you actually do the UV exposure to have this periodic variation in property in the photo resist layer first. So, that is what you do up to here.

In the next class we will understand each one of the process along with its nativity details and also the remaining part of the fundamental photolithography processes.

Thank you.