Biophotonics
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Lecture 52
Processes of Nanotechnology

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Welcome back. We were discussing about nanotechnology and today I am going to give you a glimpse on the different types of processes that we utilize in nanotechnology. Now, remember in the last class we discussed a little bit about the cleanroom. The cleanroom is this environmentally controlled environment, the environmentally controlled area, where the total number of particles, i.e. dust particles, total number of foreign particles has a particular concentration.

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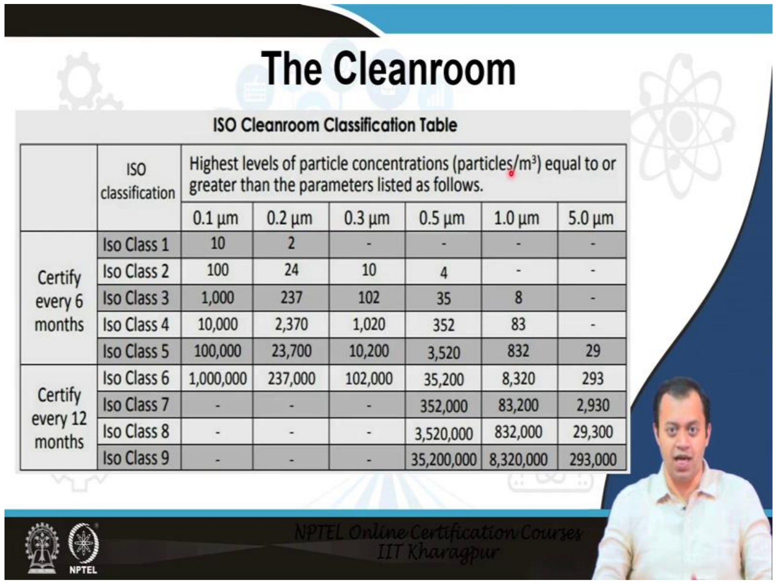

So, the ISO classification, International Standardization Organization, they have divided the different classes of cleanroom according to the highest number of particle concentration. And remember these particles are mostly dust particle or foreign particle, particle which does not belong there or should not belong there in a nanofabrication process. Now, remember, we have to be absolutely, absolutely clear about the dust.

We need to be absolutely, absolutely clear about the dust. Why, because the circuit that you are trying to make, the chip that you are trying to make, the transistor, the devices that you are trying to make are or could be or should be rather at a size smaller than the dust of a grain, smaller than the grain of a dust, beg your pardon. So, take a sand particle from anywhere, sand particle or dust particle, how small is it.

Our devices are smaller than that. So, just like any electronic equipment, if you cover it with some kind of an insulating material, it will stop working. Similarly, if something is that small, if your devices are smaller 10 times, 100 times smaller than a single grain of sand, a single dust particle that dust particle if it falls onto that circuit, that chip, that device, it destroys it. It will stop functioning. Why, because it has been insulated. It has completely been covered.

So, the total number of particles per meter cube, the average size of the dust has to be less than 0.1 micrometer or around 1 micrometer. And if there are at a times around 10 of such particle floating in the air, I take some amount of air at one time, any random time, a volume of air, some meter cube of air and I analyze at this present moment in this air a meter cube of the volume of the air how much dust particles are floating, it has to be less than 10 for a dust particle of size 0.1 micrometer, then only it will be considered as class one.

And so, on and so forth for class two, class three, class four, class five. There has to be absolutely, absolutely dust free environment with the minimum amount allowed in a meter cube is 0.1 micrometer. So, not more than 10 particles of size 0.1 micrometer should be floating at any random time instance in a meter cube of the volume of the air of that room. Think about it. Give it a pause, return back and rewind what I just said.

This is how ultraclean; the cleanroom has to be. And yes, I know what you all are thinking that we can do biological experiments here as well. Just the nomenclature is slightly different. Instead of class one, class two, class three cleanroom, the biological things are biosafety level one, biosafety level two, biosafety level three and biosafety level four.

And other difference is usually in a cleanroom environment, in a nanotechnology or microelectronic or nanoelectronics base environment like an Intel chip or a processor chip, we try to ensure that the outside environment does not come inside, i.e. we have a secured area, we have made a room, which is made ultraclean. We have put vacuums etc. So that dust particles have been completely sucked out and we have insulated so that the outside dust materials cannot invade, cannot come inside and thereby destroy my sample.

In biological laboratories, BSL 3 probably now, it has been made very famous because of the pandemic, here I want in biological laboratories, ultraclean environment, everything fine, everything fine, but whatever I am making in my laboratory should not go outside, because it might cause a pandemic. And maybe that has what has happened.

Some kind of a living material has gone out. For microelectronics industry that is not much of a problem, because if a piece of silicon goes out worst case scenario it destroys or if we pack it, we have to take it out anyways, because it will be part of a processor in some mobile phone, some tablets, some laptops. We have to take it out anyway, but we want to take it out in a controlled manner.

As long as the dust particles from outside is not invading us, that is the cleanroom, that is the microfabrication industry, we are fine. In biology, it is the other problem. Whatever we are making inside should not go outside. If by any accident or deliberately it goes outside it can cause mayhem. So, that is where the classification of cleanroom comes.

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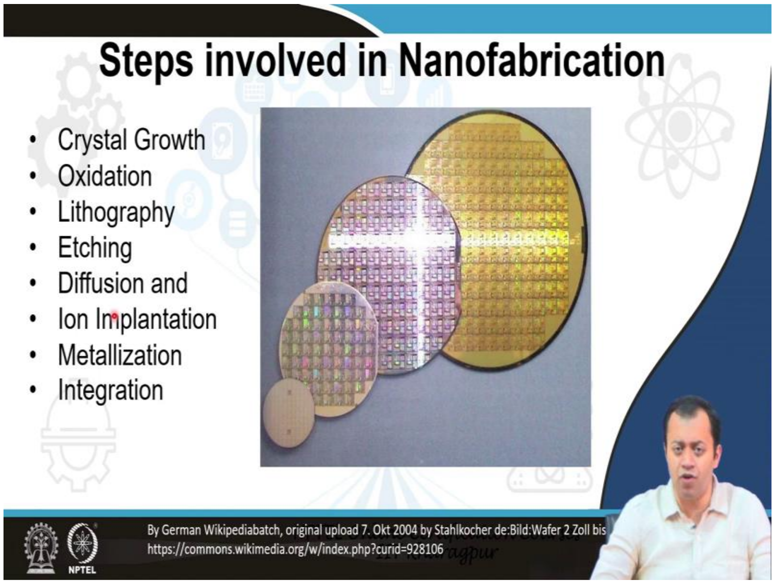

So, let us try to see what are the different processes involved in nanofabrication. These are the several different process of nanofabrication and they are but a typical example. We start with crystal growth, i.e. growth of a silicon chip. Then we oxidize, so that silicon becomes silicon dioxide. We have lithography which is patterning, etching.

These are diffusion, so that you put some sort of dopant and then metallization and integration and you get several of these silicon chips with several, you have made the pattern and you have made circuits out of it and entire chip and entire wafer contains different areas, each having their own function. And inside that if you look with a microscope, they will have the individual elements of the circuit few billions, few millions of them and a piece of this, a piece of this, a piece of this, you cut it off and put it in a processor.

You cut it off this square piece, this square circuit and put it in a processor. So, you can understand if each of these represent a processor of say couple of billion different circuital element, how many laptops you can make out of each, how many mobile phones you can make out of each. So, let us understand, try to see what are the different processes involved.

So, these are the list of some of the processes that we do under no means they are the only processes and under no circumstances all of these processors are always used, all of these processes are always used, all of these steps are always used and no means that is correct. We would try to see some typical examples. And remember, till now I am still keeping you into the realms of integrated circuit, because that is the basic or that is the precursor.

After this we start adding chemistry and physics and several different things. And this swells up to nanotechnology and that nanotechnology we can utilize, some part of that nanotechnology we can utilize in making our own optical transducers or our own fluorophores or our own chromophores or a laser device or anything of that matter an optical fiber.

Optical fiber, the code and cladding are slightly of different refractive index. We do diffuse or put some sort of a dopant material there so that their refractive index changes. We diffuse the impurities there. So, these things are either individually or in a combination are utilized in several biophotonics applications. So, try, let us try to see how some of these are done or what these actually are. What do I?

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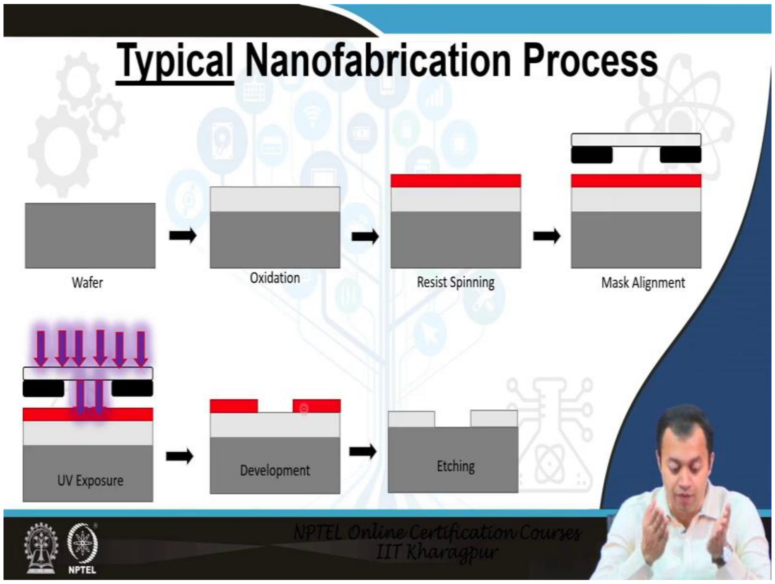

So, we start with some kind of a wafer. Wafer is basically a piece of silicon which has been polished. How do we make, it is a pure piece of silicon? Usually, silicon, but it could be glass. It could be gallium arsenide. It could be other exotic materials. It starts using with a wafer. Wafer is the starting piece, the, what we go for microfabrication. How this wafer is made?

How this ultrapure? That is part of metallurgy. And maybe if I have time, I will come to that how silicon is actually extracted from silicon dioxide. How, what are the chemical processes, the Czochralski process, how those things are done. We will be discussing if the time permits at a later stage. But let us say that I have given you a piece of silicon, just a simple piece of silicon, intrinsic silicon, i.e. it has not been doped. It is pure silicon.

Somehow, I have found. Something I have extracted from mine and then it has gone through several different metallurgical processes. And after that the ore which is basically glass, silicon dioxide or sand that has been purified and silicon has been extracted out the oxygen has been done. There are different processes that we can do. First, we can oxidize it, so that a very thin layer of glass, a thin layer of silicon dioxide can form over it.

Again, these are typical example. I put an underlying mark. Not necessarily all of these steps need to be followed or all of these steps will be useful in every single nanofabrication process. It depends on what you are trying to make. These are a typical example. So, you start with silicon. You grow a very, very thin layer of silicon dioxide.

The good thing here is why silicon has got popularity is that, you start with glass, silicon dioxide, you convert it into silicon and then you reconvert it back into glass. All of these three processes are more or less smooth or more or less easily done. Secondly, glass and silicon, silicon dioxide and silicon have good enough thermodynamically stability, good enough compatibility, so that they can stick to one another without destroying or without changing each other's property too much.

They are strong enough to stick to one another. This interface is strong enough and they are not that much that they had interjected inside each other and thereby changing their property. If you want to know why this is important think about rust, the rust that we get in iron. You might have iron grills or iron bars in your windows, think about it.

After some time, due to air and moisture, the iron in your grill, in your window panes that convert into rust, ferrous oxide, ferrite oxide etc. whatever, ferric hydroxide et cetera. That rust is powdery material and that does not remain stick to the piece of iron. If you rub it, it will fall. Not in case of silicon. Silicon is a semiconductor. Silicon dioxide is an extremely good insulator very, very high band gap.

So, if you have a silicon, which is highly doped, it has a very high conductivity, the top part you have oxidized by heating it into a temperature by putting localized heat that can act as a coating to your silicon wire, an insulated coating to your wire that will remain stick and that insulating property will not affect the underlying semiconducting property of the silicon unlike the iron oxide that forms on top of iron upon rust upon oxidation. It falls off.

It drops off. So, we oxidize a bit, then we cover it with some kind of a photosensitive material. We cover it using some kind of a photosensitive material. The photosensitive material a, we put some kind of a stencil on top of photosensitive material. This stencil is called a mask. You know what a stencil is. Stencil is some kind of a perforated or a particular design.

It has a particular design. You can, you must have seen what stencil is or what a mask is, it is like a sheet with certain holes in it, with making a particular design, a mask basically, the mask that you wear in children's parties or something like that or a stencil, where a particular a, b, c, d can be written, a particular design can be made because it has a shape, because it has a particular design. On that photosensitive material having a mask, we expose UV light.

So, if it is a mask, i.e. it has perforation, some of the light that is passing through the stencil, some of the light that is passing through the mask will be selectively blocked, this area, the black areas, and some of it will pass through. So, you are exposing a certain area of the photosensitive material to UV light. A certain area of the thin polymer, photosensitive polymer that, we call as a resist with UV light.

Not all area, some of them are taken and some area has been exposed just like your stencil, where you put some amount of powder or some kind of a color paint or something like that and only a particular pattern comes out at the end, because rest of them has been covered. Only the holes remaining, the holes in the shape of a design, only there the color or the paint can come down. You know what I mean. Just look into a stencil.

So, wherever the UV light has hit, the photosensitive material, the photosensitive material undergoes some kind of a chemical change. I will discuss this photosensitive material in next class in detail, but suffice is to say now that there could be two different kinds of reaction depending on the type of photosensitive material that you have. Either, in the first case, that is positive photoresist.

The UV light causes some kind of a photodissociation in the molecular chains. So, the photosensitive material is a polymer which is a chain like structure upon UV light this chain breaks down and they become very weakened. This is positive photoresist. The negative photoresist is where the UV light is causing cross-linking and they become hardened.

They strengthen up. Both could be possible. In this particular example, I have taken a typical example of positive photoresist, i.e. the part where the photoresist is exposed to light is weakened, that part which has not been exposed to light remains as it is strengthened. The weakened part is then removed and thereby you make some kind of a pattern on the photoresist, some kind of a pattern, i.e. selectively opening up the certain areas of the wafer which has, which may contain silicon dioxide.

And then you remove the photosensitive resist altogether. You can simply remove it. And the area which was exposed is eaten away by some sort of an acid or some sort of a gas. So, remember this, acid usually do not attack polymers. This is a polymer. Polymer would not be attacked by this. It can go below. But if you are clever enough and if you have quickly made your timing, this area is where which is exposed which will be attacked fast and attacked first.

Before it goes and start eating away these areas, if you take it out from the acid bath, you have a nice little hole, nice little hole of a particular dimension etched into your oxide layer. You put either gas through it, some sort of a fluorine-based gas, fluorine can eat away silicon or you again put it into some different kind of acid, that acid will not be harming glass, but may harm silicon selectively silicon dioxide or glass is kind of strong.

And you have got yourself a pattern or a trench or a hole on to your silicon wafer. Only thing that you have to remember here is that this bio, is this photosensitive polymer is very, very sensitive, and any small exposure to light results in its weakening of bond. Meaning, even if the spot size of the light is few nanometers, few micrometers, that will be able to define a particular set of patterns.

Even if the spot size of this light that is falling onto the resist is of few nanometers, only few nanometers will be weakened, which can then be developed and thereby this whole, this size, this strange, this pattern that you are getting could be of nanometer scale as well. You do not have to expose it for a long period of time this much area. You can just simply send a light beam of spot size few micrometers, few nanometers even if you can, and you will get some sort of a pattern, some sort of a whole developing on to your silicon substrate, on to your wafer.

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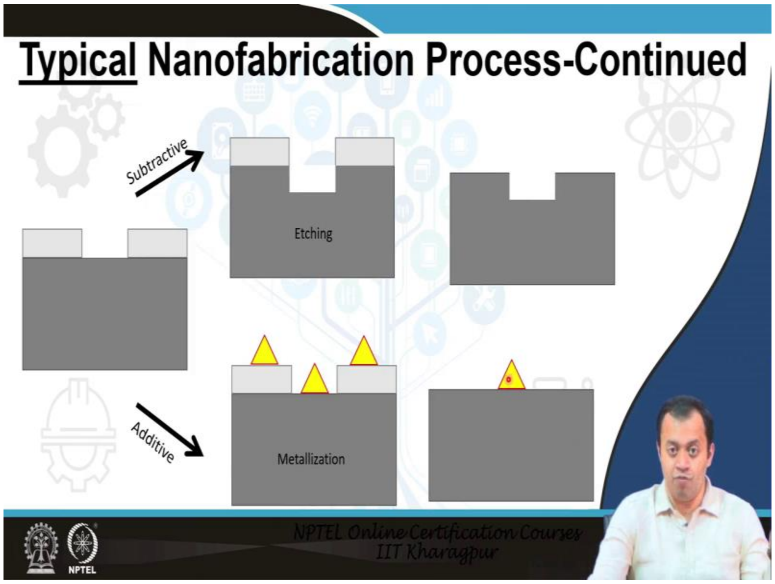

What next? Well, there are two processes. Either you go for subtractive, as I said. You eat away the silicon part and make a hole in the silicon. Remove the glass altogether. And now you have a patterned silicon. Or additive, where you put some sort of a metal in those trenches.

Remove the glass part. And you have a nice little pyramidal shape gold patch in a nanometer scale area on a silicon wafer. You, from looking at these two, you know why this is called subtractive process and this is called additive process. You can look into it and you can understand. Why do we do this, specifically for nanophotonic, where have I utilized this?

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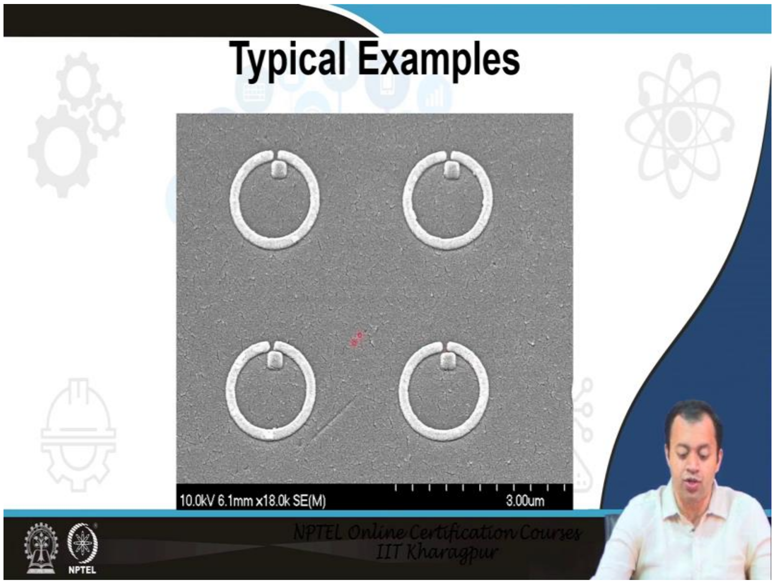

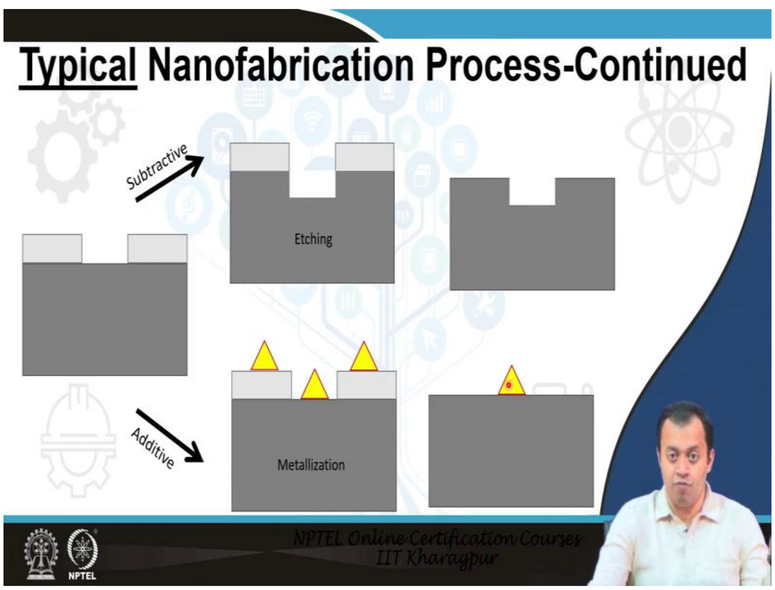

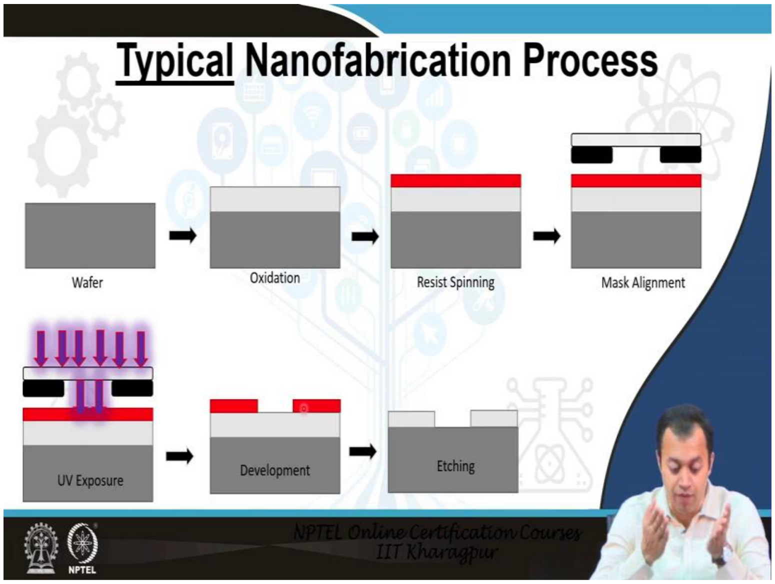

Here, this is gold ring which is acting as biosensor, optical biosensor. This has a particular resonance of its own. When excited by light, they resonate. And these are some sort of a polymethyl methacrylate nanoparticle. You can look at the overall scale from this. This is my picture. This is what I myself personally have done.

This is 3 micrometers. So, the total area is 3 micrometer, total scale. From this you can understand what big is this size and what small is this size. I tried to give you my images rather than asking permission and copyright from several other people. I have, can you tell me whether this process is additive or subtractive or a combination of both, where this polymer has existed. Rest of the polymer has been etched away.

And this gold nanoparticle, this gold ring has existed and both of them have been combined together to form some sort of a structure such as this. So, the PMMA, the Polymethyl methacrylate polymer is acting as some of my analyte. You know this image. You have seen this in previous classes. This is acting as an analyte that I am trying to detect.

This is a proof of concept that this much small area, 200 nanometers by 200 nanometer can be detected by these kinds of gold ring resonator structure. These are electron beam, electron microscopy images. Hence, this is black and white. You cannot have color. Well, you can have color. You have false color. False color is a separate thing. This is something that I took. This is something that I made. If I can, so can you.

And look at the scale, is this not nanoscale. Remember what was the size? What was the dimensions required? You can calculate it with your own leisure and try to see if this has been done or not. So, although, the point that I am making here is, although this is a microfabrication process mostly, we have been able to utilize it in making a biophotonics application, i.e. some sort of an optical biosensor, some sort of an optical biosensors.

So, these are the type of examples that I will utilize. In the next class, I will be discussing how this lithography, how this patterning thing, i.e. this UV exposure part, this part. This is called the lithography. What this is, because this is the heart and matter of nanofabrication processes. This I will do. At the same time, I will try to see, if I can give you examples, when none of these are required.

We just do some kind of a chemical reaction, a self-assembly method, where you put a bunch of chemical A, chemical B onto the beaker. Some kind of reaction happens. Things evaporate, exothermic, endothermic, different types of reaction happen. And finally, the final product is saying some kind of a precipitation and the precipitation is of a nanoscale level which forms a thin layer on a piece of glass or a piece of semiconductor.

So, these are the several different procedures. So, this is called a recipe. We call it recipe, because it represents like a cooking. It represents like a cooking formula. We add different things. You then heat it up, cool it down, so that the final product comes out. And we will be discussing a little bit of this, this nanofabrication process, these nanotechnology-based things. Remember, there is not one single process.

The analogy that I would like to give you a is say, for example, the mathematics problem in trigonometry that you used to solve where left hand side was equal to right hand side. Remember, in I think high school you used to have these solutions needs to be, given these mathematical problems were asked to be solved by you. So, left hand side equation has to match right hand side. There was not one single formula.

There was sets of formulas. Sometimes you add them, sometimes you use more than one formula, sometimes none of them formula used, you simply something else. So, this is exactly like that. There are several formulas, several steps, several processes, you mix and match depending on what you are trying to make. If you are trying to make a biosensor, certain steps need to be followed.

If you want to make a microprocessor structure, certain other steps need to be followed. If you are making a device, optical transducer whose property changes, different processes need to be done or if you want something very cheap, very quickly, less accurate, different processes need to be done. We will try to look a little bit of each of them to the best of my capacity, knowing fully well that several of them cannot be completely covered in just two and a half hours of lecture.

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So, these are the typical concepts that I discussed cleanroom, typical nanofabrication processes, typical examples.

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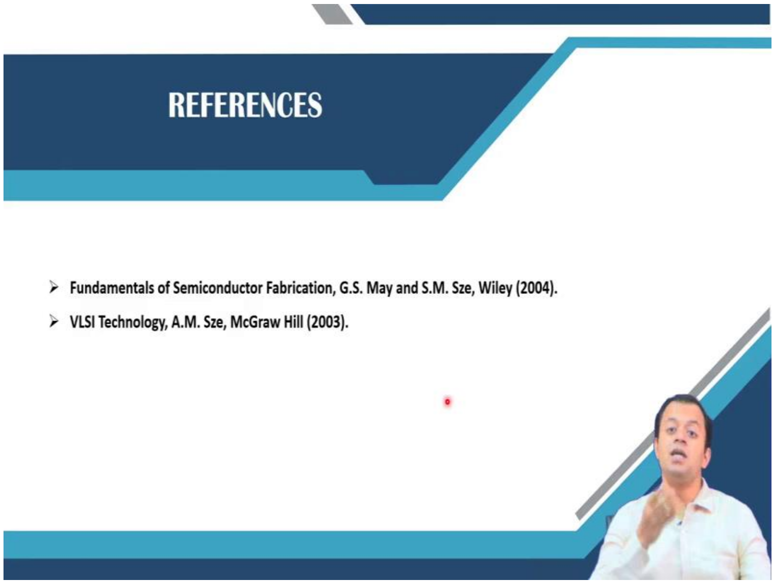

And these are my lectures, references. You are welcome to look through them. And I will see you in next class. Thank you. Thank you very much.