Nanobiophotonics: Touching Our Daily Life
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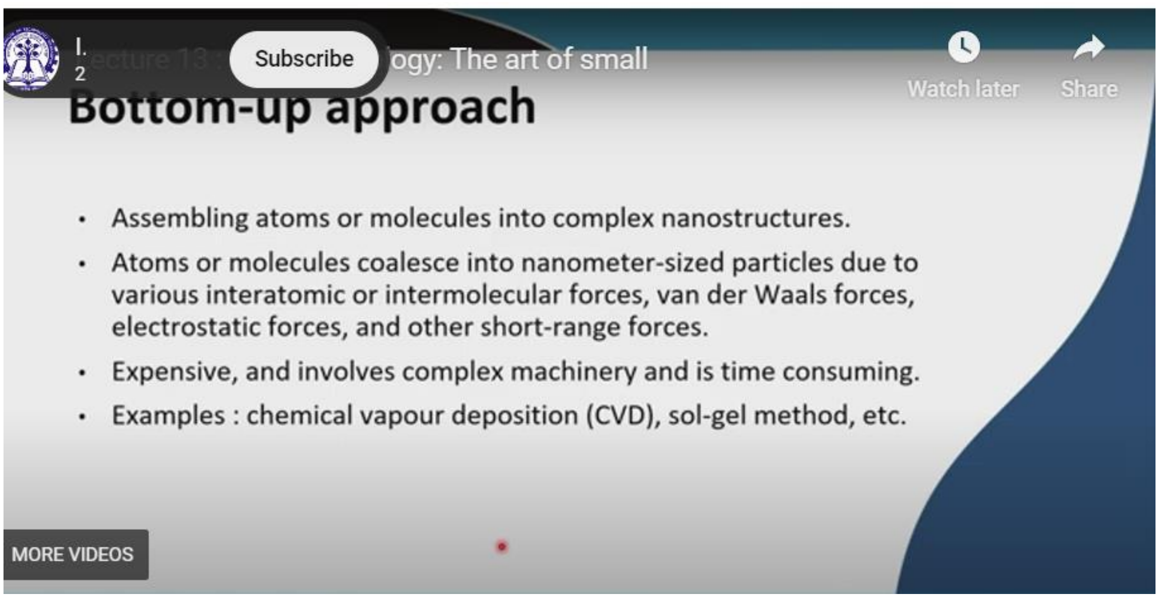
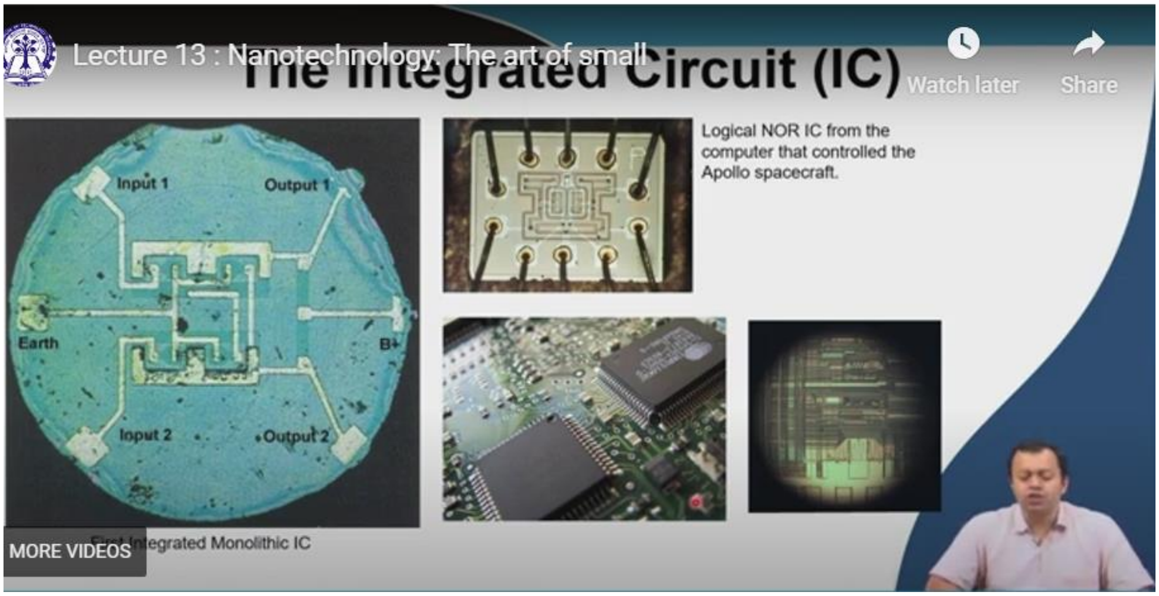
Lecture No. 13
Nanotechnology: The art of small

Welcome back. In the previous lecture, I gave you a very very brief introduction to the nanotechnology. Today again preliminary nanotechnology in photonics, we will briefly discuss how do we make materials at a nanoscale level. We have previously seen that certain properties can come up, we can manipulate matter at a nanoscale level, certain properties change as compared to their bulk counterpart. Today, we are going to discuss how to make materials, how to make anything at a nanometer scale level. So, there are two basic approaches in which materials at a nanoscale can be created.



One is the bottom up approach, which we are going to discuss today. The other is top down approach, which we will discuss in next class. The bottom up approach is where you assemble atoms or molecules into complex nanostructures. It is like Lego, anybody who had played Lego, those Lego blocks you take some atoms from this material, some atoms from this material, combine them together, make some kind of a localized chemical bond nanochemistry you can say, where the chemical reaction takes place at a very very nanoscale level and form something which then bulks up.

And these atoms of molecules combine together coalesce into nanometer size particles due to inter atomic intermolecular forces, Van der Waal forces and they form nanoscale materials. They are quite expensive, it involves complex machinery and they are indeed time consuming.



So, how did it all start? I would say the advent of nanotechnology has to have a particular application, particular purpose. It simply is not a proof of concept, some kind of equation written, it has to have a particular concept. For me, the advent of nanotechnology, I know physics people and chemistry people will disagree with me, but as an electronics engineer I think the advent of nanotechnology started when in 1958 the first IC, the first integrated monolather integrated circuit was created.

The first IC technically was made by Jackson and K. L. B. at Intel in 1958, he even got the Nobel Prize for it, but technically the actual integrated circuit was made by Robert Noyce, Bob Noyce in 1958-59 which is this particular structure in which all electronic component, all part of an electronic circuit, every single part of an electronic circuit, the resistors, the wires, the capacitor, the transistors, all of these components were integrated onto a single piece of silicon. A single piece of silicon was previously being utilized and this different area of a single piece of silicon defined different circuit arrangement.

Prior to that germanium has been used by Kilby and he made a bipolar junction transistor connected with three resistors and one capacitor combined together, but actually and which has been connected externally with gold wires etcetera. But the first integrated circuit the actual IC 1958-59 by Robert Noyce, this is the particular structure, this is the particular material, this is the particular integrated circuit, every piece every single piece of the circuit element was on a monolithic silicon chip ok. To the best of my knowledge this is silicon, but check if could be germanium as well to the best of my knowledge it is silicon, but I could be wrong because prior to that they did germanium and then they shifted to silicon that I know whether it was silicon for the very first IC, but then again there is controversy which is the very first IC noises or Kilby's, Kilby got the Nobel Prize, but the actual monolithic IC was this whether the monolithic IC was Germany or silicon, but let us go with silicon. This is the first integrated circuit which is made up of a single piece of semiconductor. One area of the semiconductor determines input, one area determines output, one area determines the transistors, one area determines the capacitors, one area determines the resistors and all of that.

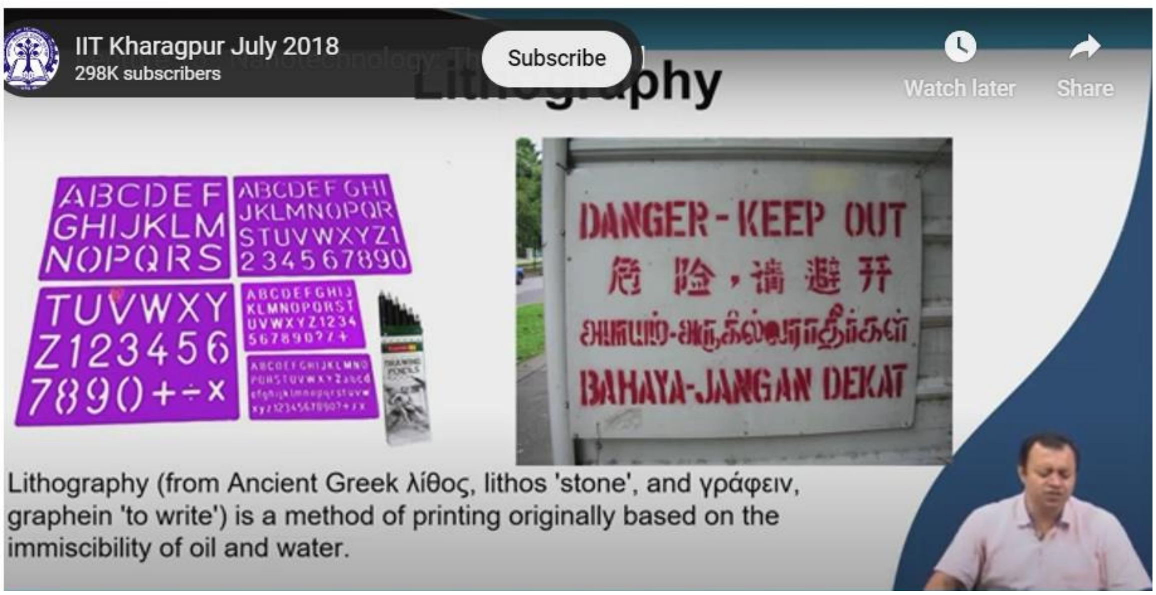
The overall circuit this is the first integrated circuit you will ask what it is the first integrated monolithic IC made by Noyes, Robert Noyes in 1959 was a flip flop circuit. What is a flip flop circuit? I am not asking physics or electronics student, I am asking the other guys. What is a flip flop circuit? A flip flop circuit is a circuit that can store information one bit could be stored one bit it is a digital circuit which can store one bit either 0 or 1 could be stored. What do you call that stores information? Memory you use USB sticks, you use memory devices meet its great great great great grandfather. Since then it is not only storing information it is also processing information and this this thing has basically created the entirety of electronics industry it is created these processors these processors that is making your computer or laptop or mobile phone run through via which you are able to see me understand this particular lecture.

So, this is what all started 1958-59. So, comparatively think about it not not very far away right not not not ancient information it is still you know 60-70 years old. So, this for me was the advent of nanotechnology where in a very very small piece of silicon different elements of circuits were made and that was a functioning circuit that was able to perform a particular function.

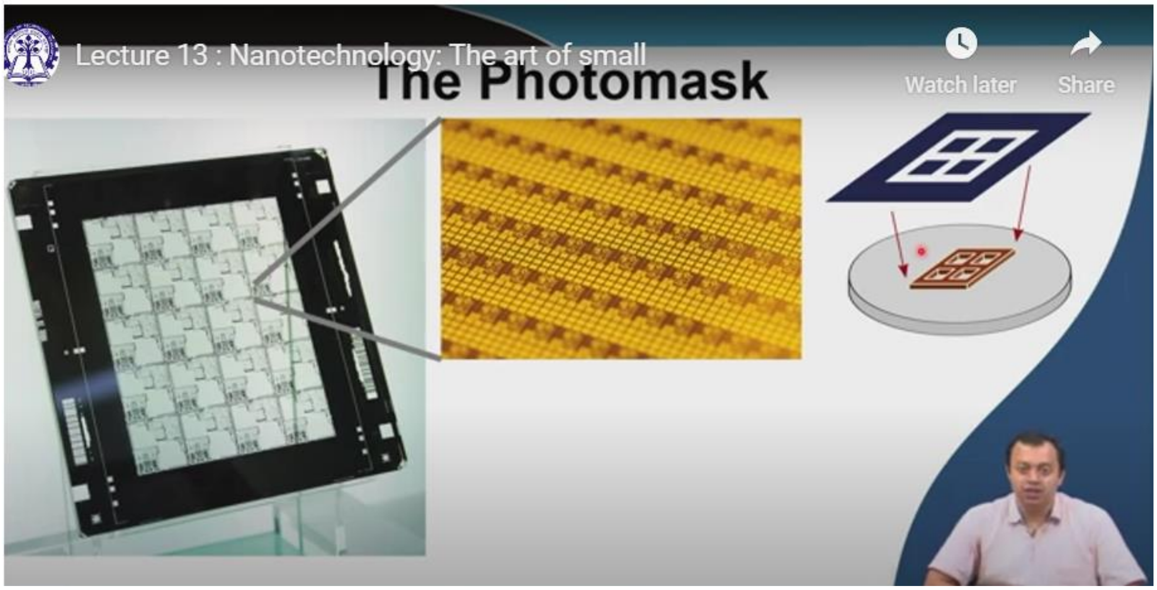
Where do you make these circuits? Where do you make these kinds of integrated ICs or similar structures? You made it in specific areas called clean room these nano devices are made in certain areas called clean room. This clean room have this beautiful yellow light

I used to work in this yellow yellow light and miss it dearly.

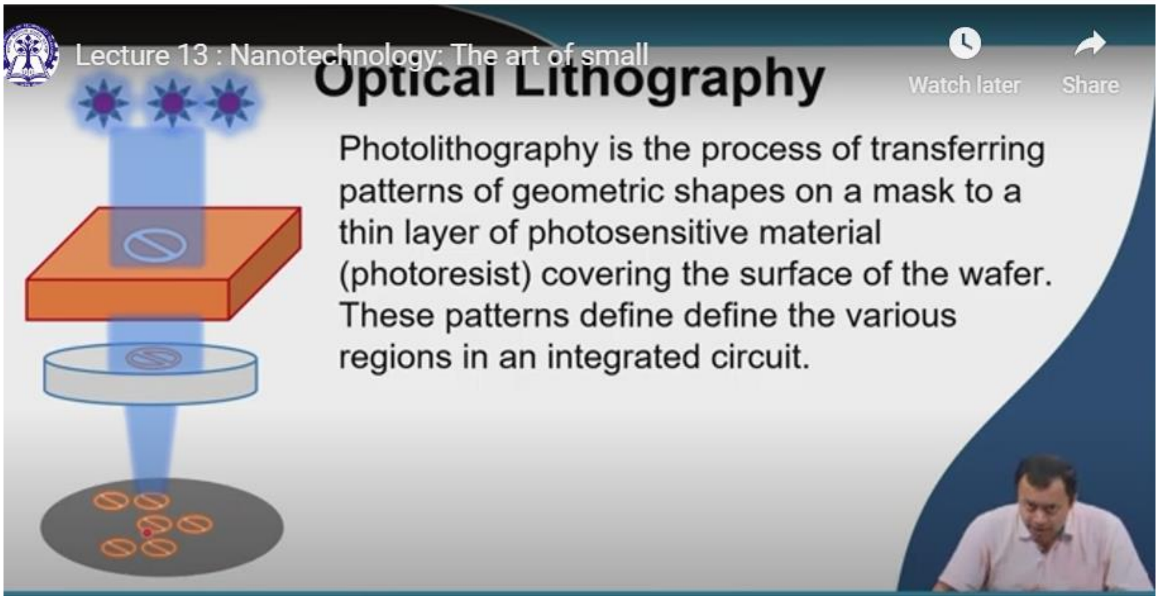
I will tell you why exactly this yellow light is there the yellow light does not affect a particular chemical that we use regularly that are called resist photosensitive materials we use we have to use these kinds of PPE personal protective equipment and the temperature pressure humidity of this particular chamber this particular room is controlled to the number of particles floating at any time per centimeter cube. The number of particles any particle should not be below 100 or below 1000 at any time in any particular area and that determines whether it is class 100, class 1000, class 10,000. What does that mean? Meaning that it has to be ultra clean the dust particle should be very very much controlled one grain of dust falling onto your circuit can destroy the entire circuit because your circuit is smaller than the size of one grain of dust one grain of sand can destroy the entire circuit because your circuit is smaller than its size. So, we create ah nanodevices in a particular room which are called clean rooms at temperature pressure humidity all of those are controlled most importantly we control the number of particles floating in the air number of particles when consider dust or anything else we control it completely. So, that our devices are error free, right.



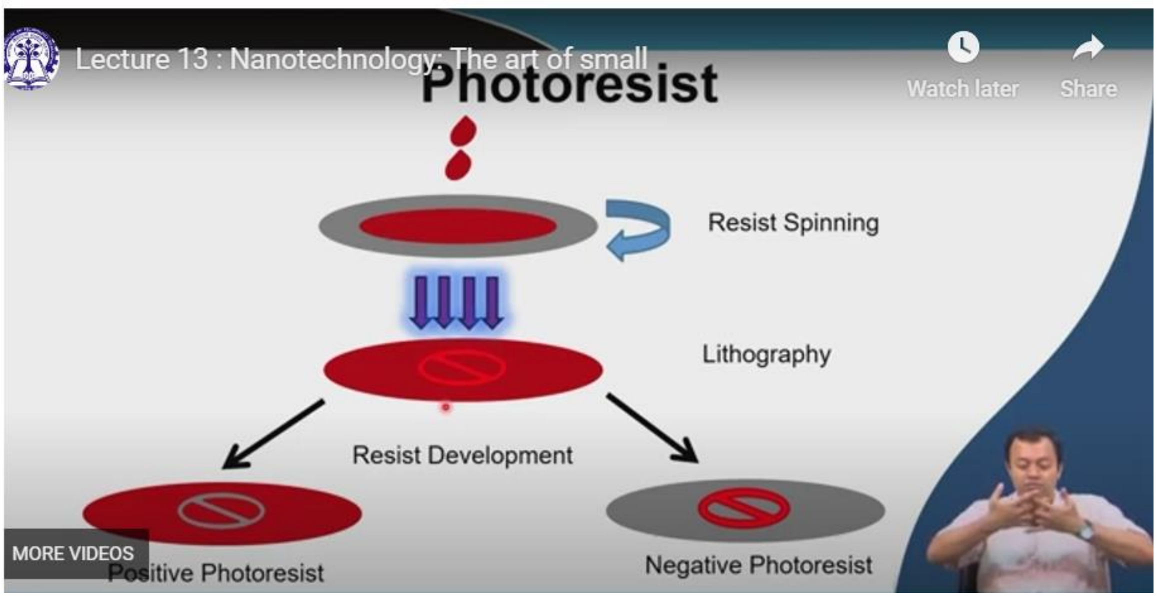
So, one very ah typical example of how we actually can make such small designs designs such as this entire structure within a small piece of silicon within a small piece of silicon with nanometer scale dimensions we can make a transistor inside capacitor inside is by the process of lithography. What does lithography means lithography simply means writing all of you have used these kinds of stencils you have used stencils and you have if you like this if you have spread paint over this stencil some paint will go through this particular hole some paint will you know stick outside and depending on how you have do it how you have how you have utilized this particular stencil you can make writing you can make something written as it is. Basically, taken from the Greek word ah stone ah writing basically stencilized structure such as these were used. So, that particular alphabets particular images particular characters can be simply written simply written by selectively throwing by selectively allowing certain ah ink or paint or graphite in this case of pencils to pass through it and selectively blocking it, yeah that is exactly what happens. You take this and you you know spray paint all over it the purple area will block it the gap area will pass it through and if you have used it judiciously enough you can make a meaningful sentence out of its right stencil.



We do that in making circuits by sending light we call it optical lithography. Our stencils are these photo masks structures geometrical structures are written here they are made up of chromium ultraviolet light is being passed through it chromium some specific type of chromium with particular thickness absorbs a specific wavelength of ultraviolet light where there is no chromium just like this where there is no purple matter the light passes through and the entire particular design is imprinted just like a particular design a particular character is getting imprinted onto the substrate. So, this is your silicon this is the stencils you have used the photo mask made up of chromium and instead of sending ink you have sent light ultraviolet light.

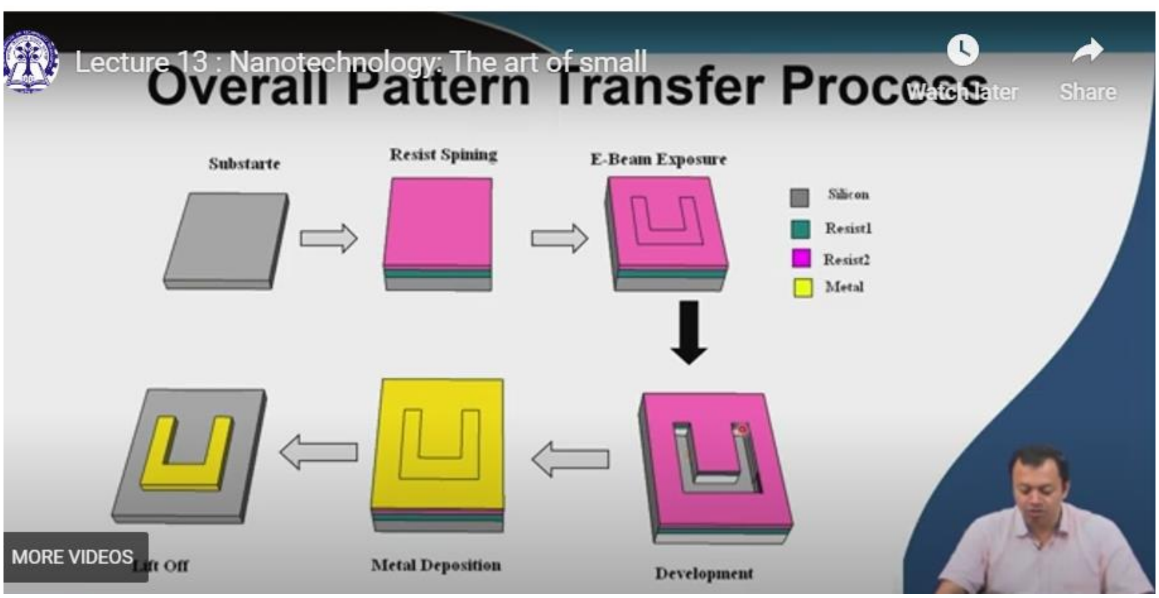


So, the entire process is called optical lithography or photolithography is also quite common what you do your ultraviolet light it needs to pass through a mask this stencil is called the photo mask. Mask as in it allows certain light to pass through these areas certain lights are blocked which then passes through some sort of a condenser condenser condenses the light like a lens and you are making these patterns create on some kind of a silicon substrate.

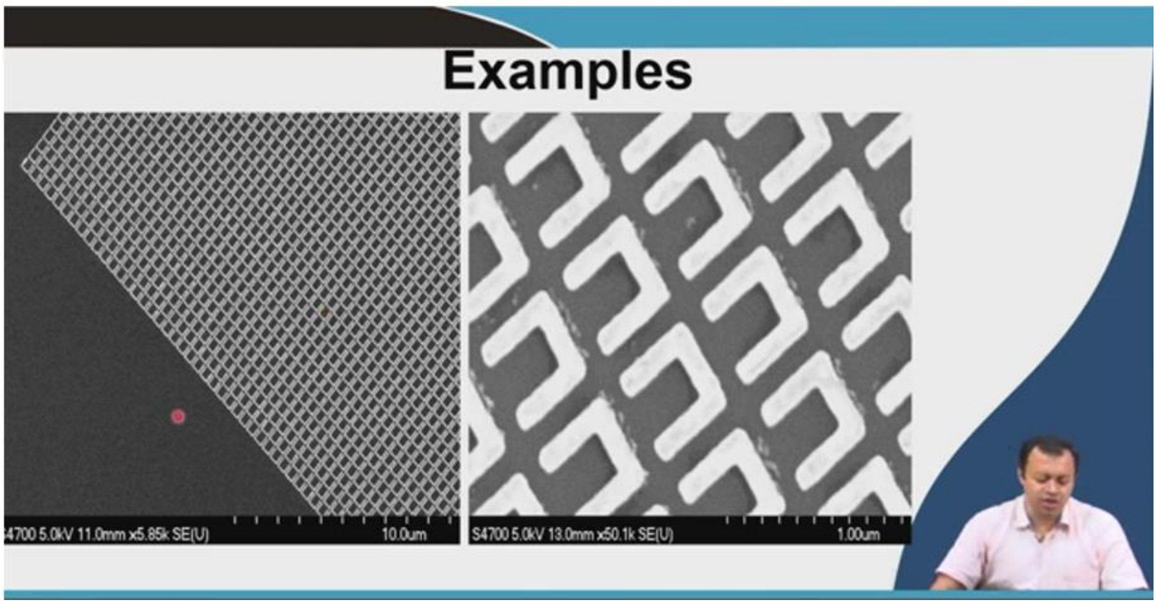


How do you create this pattern? This substrate is covered with photosensitive material this photosensitive material is called resist. When light falls onto it depending on the resist the ultraviolet light falling onto it either either makes the molecules wherever the light has formed joined together make it stronger or wherever the light falls the molecules that are coming in contact with light the light is breaking down electron absorbs that light goes to higher orbitals and thereby breaking down the bond and become weaker. You then put it into some kind of a developer some kind of a chemical that eats away the weakened part in positive photoresist the light has weakened wherever it has fallen the weakened part is dissolved in negative photoresist light has fused the area where it has fallen the weakened part is removed however you pass light ultraviolet light can be confined at a nanometer scale region why not you pass through condenser you pass through lenses they can focus at a very small area and you have this kind of chemical photosensitive material called resist that are very sensitive to light at a very specific areas. We use the yellow light the yellow light is there so that the photosensitive material is not affected by yellow light white light or any other light closer to ultraviolet light may destroy it. So you pass first you cover the entire thing with photoresist you simply spin coat it photoresist resist chemical or a polymer material which is photosensitive then this entire process takes place this entire process takes place where ultraviolet is made to pass through a mask which is then made smaller using a condenser using some sort of a lens which falls on a photosensitive material the photosensitive material makes these patterns.

Once this patterns is made you can then selectively dissolve these area of the resist these area of the substrate usually silicon putting some sort of a gas or some kind of an acid etch it down give it pattern give it geometrical shape size structures dope put some other chemicals other atoms in this particular area rest of them which will fall on to the photoresist can then further be removed. So, this area might have a different resistivity then the other area there by making different parts of a transistor bipolar junction transistor or field effect transistors so on and so forth.

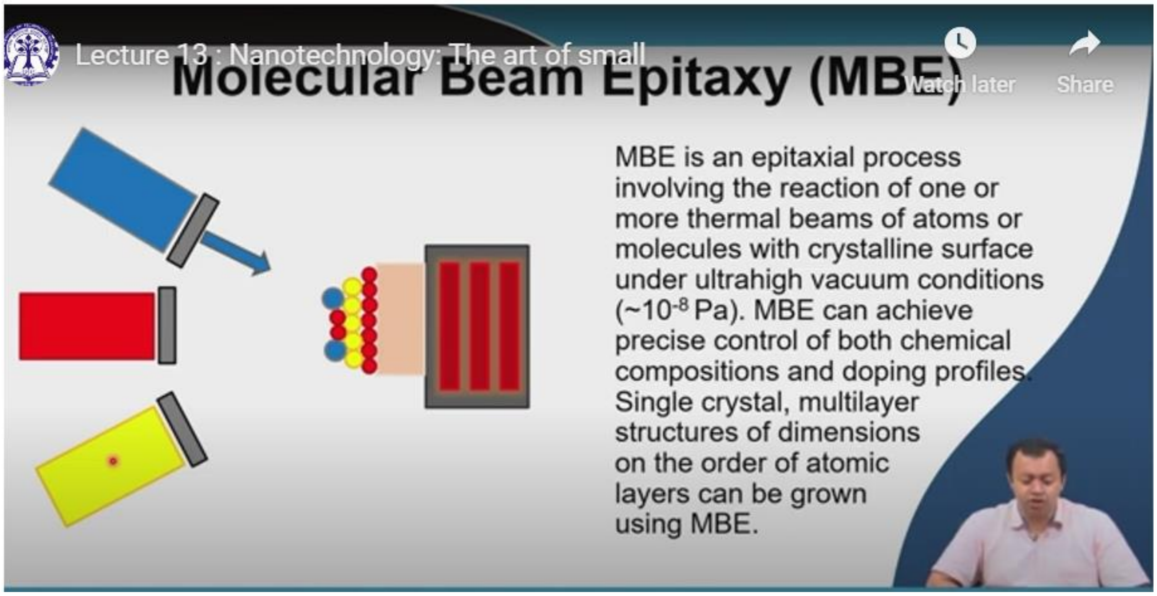


This is one such pattern which I did my own work in which a substrate was covered with different types of photosensitive materials a pattern was created the weakened part was eaten away making a hole just like here making a hole into the photoresist the substrate remain as it is I covered the entire part with gold will come here gold will go inside the trench inside the hole as well as on to the surface and then I put this entire material into acetone, acetone usually dissolves acetone is present in your nail polish remover varnish. So, that acetone removes this photoresist acetone usually eats away anything organic does not touches anything in organic. So, the gold that was above here is also washed away the gold which is in direct contact with the substrate not in contact with the material not in contact with the photoresist stays rest of it removes

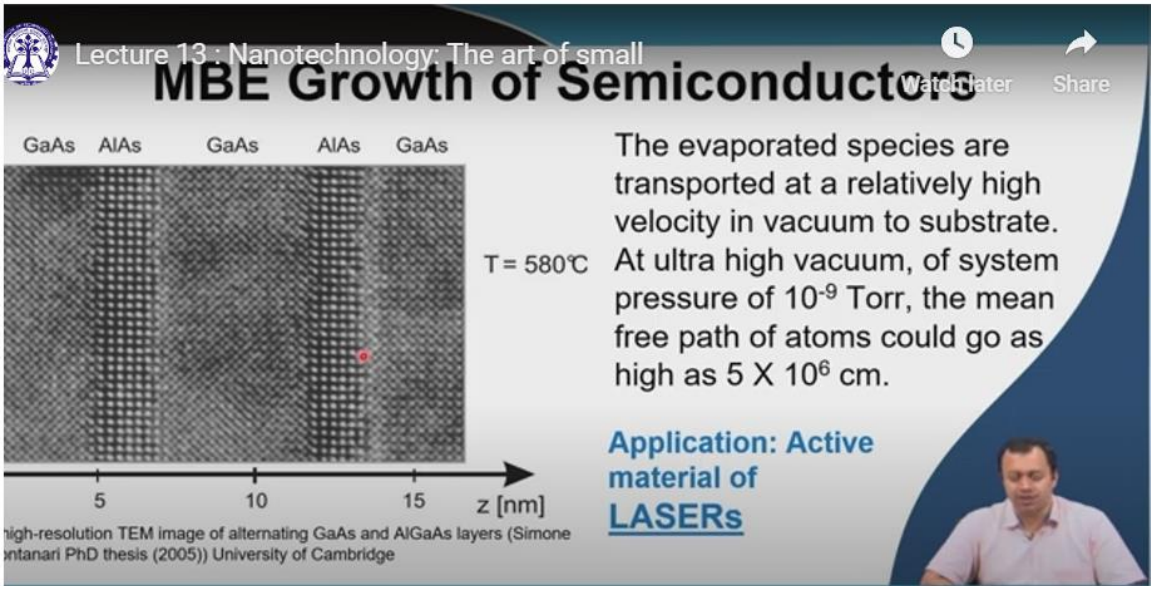


this was the image this was the structures that I created you can read the scale from here this entire area is this entire scale is 10 micrometer this is 1 micrometer this entire scale is 1 micrometer.

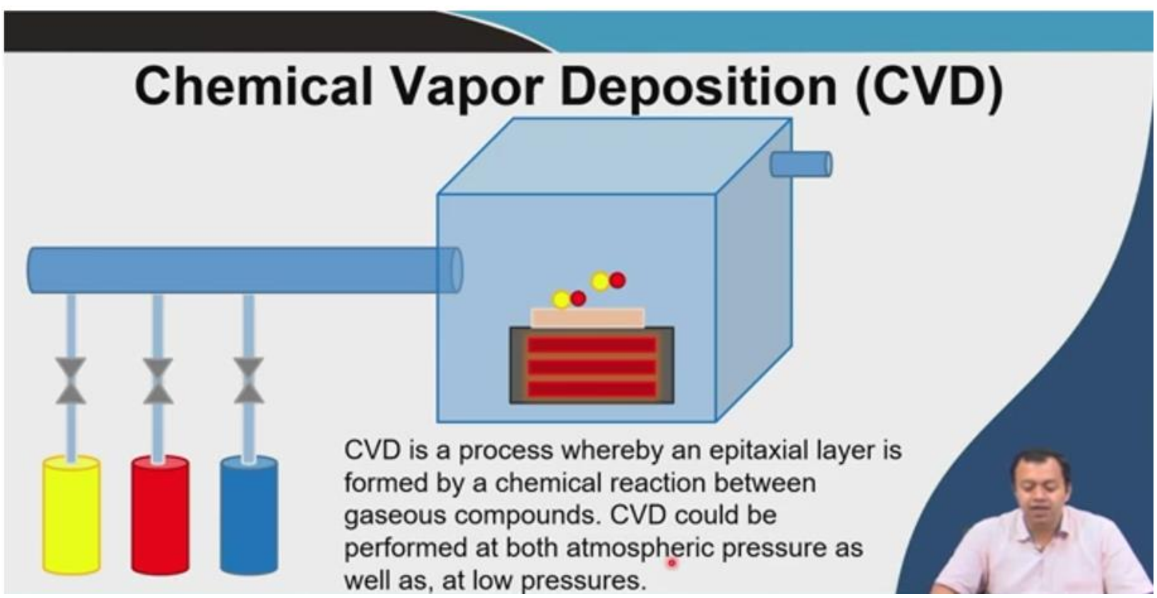
So, you can say whether this is a nano scale material or not these are gold nanostructures on silicon substrate I made it these are my structures if I can make it you can make it do you know what these are what these are they are not transistors we will learn about them we will learn about them. So, these are structures of lithography these are structures of lithography bottom up you create one then you create thousands and you bring them up nanotechnology material forms.



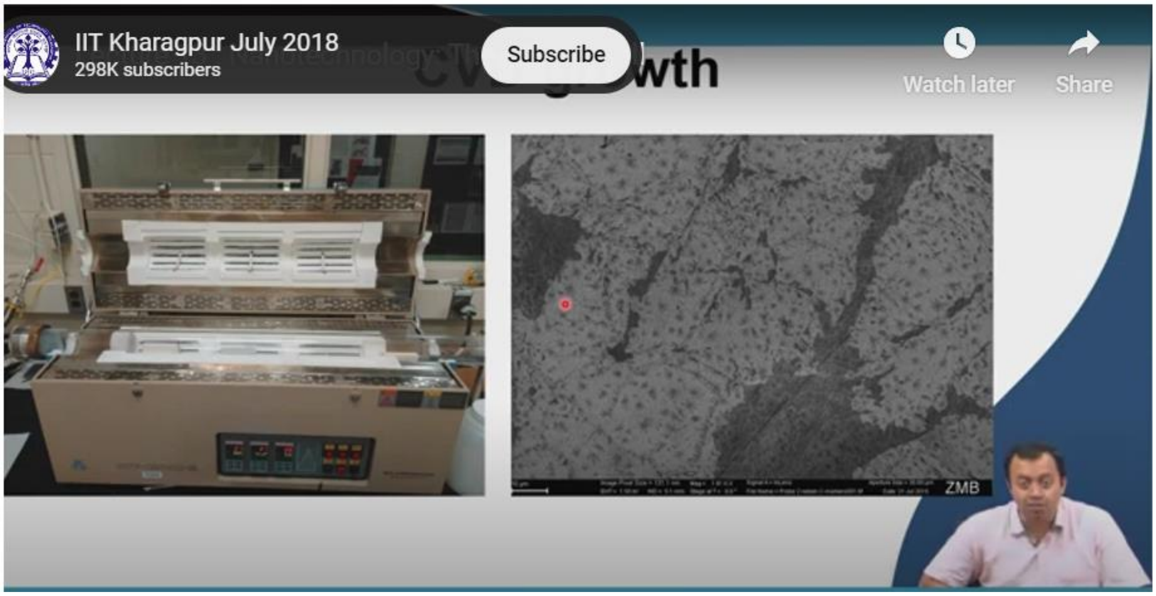
Another very expensive way is molecular beam epitaxy molecular beam epitaxy is where you put ultra pure ah compounds ultra pure say gallium or arsenic or these things in chambers you heat them up break them into molecules put them in an entire chamber at a very very ultra high vacuum conditions 10 to the power minus 8 Pascal right and then you have a substrate here you selectively open one part understand inside the chamber there is very high pressure this entire thing is put in an ultra high vacuum. So, outside is very low pressure here there is very high pressure inside the atoms are agitated here it is ultra high vacuum this is very very low pressure. So, what happens when a very high pressure opens inside a chamber which has very low pressure you have watered garden using a pipe have you not sometimes you pinch or press the mouth of the pipe what happens the water jets out previously it falls like this, but now you have pressed or pinched the mouth of the pipe the water goes further you have done that same thing here the mean free path i. e. the path before collision becomes few meters and atoms from here straight away straight away start forming on to the substrate. Atom by atom I told you I give you the example of Lego this is exactly what you do you open up another chamber say it has this was previously gallium this was arsenic you make arsenic then you break it you send another thing and you create an artificial material atom by atom yourself very expensive needless to say you have to maintain it ultra high temperature ultra high pressure, but the result is you can create some kind of nano structure atomic scale structures like this is what nanotechnology allows us atom by atom manipulation creating Lego like structures with gallium arsenide and aluminum gallium arsenide layers one after another and you can utilize them for making lasers and what not which we will see in coming classes for making for utilizing nano lasers etcetera which will then be utilized for probing nano scale areas. So, molecular beam epitaxy growth of semiconductors MBE molecular beam epitaxy is where Lego like atom by atom create an artificial element which does not exist. Obviously, remember that you cannot simply put any atom here and any other atom here and expect them to bond or expect them to be you know combined with one another stability matters. So, usually when we are trying to create structure such as this the lattice imperfection has to be less than 1 percent.



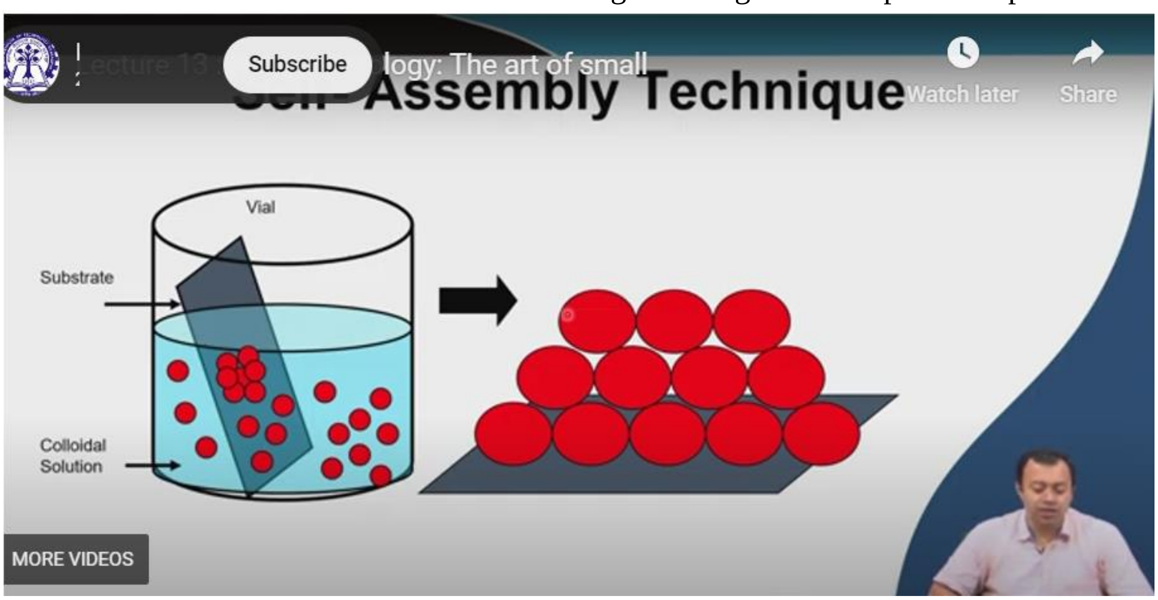
So, gallium arsenide and aluminum arsenide their lattices are very close to one another, but still stability problem will come. Moral of the story you cannot simply put hydrogen or uranium to combine together using MBE and think that something will happen carbon and platinum and this and that not everything can be very stable made using molecular beam epitaxy it has to be something very close the atomic size the orbitals etcetera has to be very close to one another.



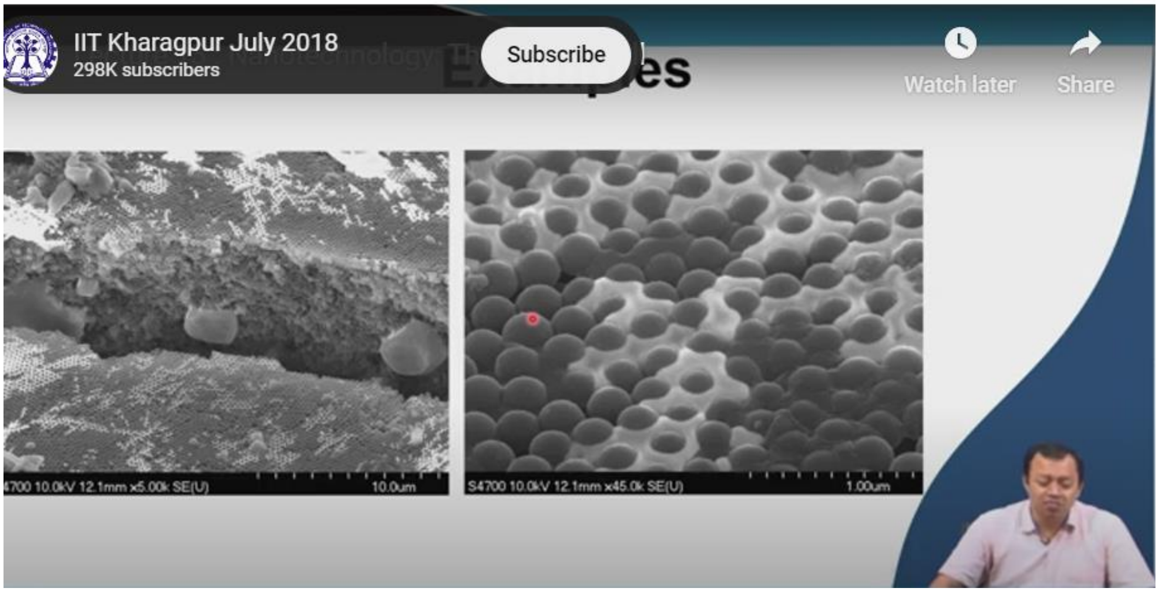
Another thing is chemical vapor deposition another bottoms up where different gases are being sent they combine together in this chamber the chemical reaction forms inside the chamber and then the final product gets inside the substrate falls on tops of the substrate and you have thin layers of these materials coming up thin layers of this.



A primary example of such a CVD growth system is graphene where argon methane and hydrogen etcetera are being sent they combine in the chamber final product is carbon these carbon gets deposited onto the substrate and you have layers of carbon 2-dimensional sheet of carbon is called graphene. So, these are ah bottom up approaches you nucleate you start from the bottom and go go top up ah.



There are also the self-assembly technique it is basically like making pizza if anyone you have seen how pizza is made you put a substrate inside some kind of a vial containing colloidal solution. So, like you mix salt in water and put a substrate and put that entire beaker in sun the water evaporates the salt stays and coats the part of the substrate that is self assembly technique not very accurate, but very easy can be done more or less with an oven and certain temperature pressure changes etcetera.



I tried to arrange some colloidal silica spheres ah by simply putting it in a solution and putting that solution inside an oven the solution dried out the silica ball somewhat stuck to my glass substrate because this is silica that is silica though the sticking part was not very good and then I infiltrated metal inside them to make some kind of metal dielectric nano structures these are the structures these are the sizes you can understand what what size it has happened and that can be that can also be cost effectively creation of some new type of ah artificial materials. So, these structures. So, these are basically ah bottom up approach where you start from bottom and you grow this up you nucleus and you start growing them up and this is a prime example by which you can manipulate matter at the nano scale and you can make nano devices structures whose sizes are less than nanometer why do you know need structures whose sizes are less than nanometer because it shows of interesting properties it shows a far interesting properties than their bulk counterpart.

So, these are my references this is very basic of nanotechnology perhaps almost all of you have known this already I was just refreshing them in the next two classes I will finish the preliminary. So, that we can go directly on to the topic of biophotonics. So, thank you very much.