Nano structured Materials-Synthesis, Properties, Self Assembly and Applications
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Module - 3
Lecture - 20
Metal and Metal Oxide Nanowires – III

Welcome to this course on nanostructured materials. We are in the module three and today is the sixth lecture of module three, and we are discussing nanowires, and the method of synthesis and their properties of nanowires, which are basically one dimensional systems. That means they have a long length along 1 axis while the 2 other axis are in nanometer size much smaller. The longer axis can be in micron sized may be 100s of microns depending on their applications. So, the today is the third lecture of the nanowires, which we are discussing that is metal and metal oxide nanowires, we can also be extrapolating this kind of study to other materials like sulfides or phosphate nanowires. So, earlier we were discussing in the previous lecture the synthesis of nanowires…

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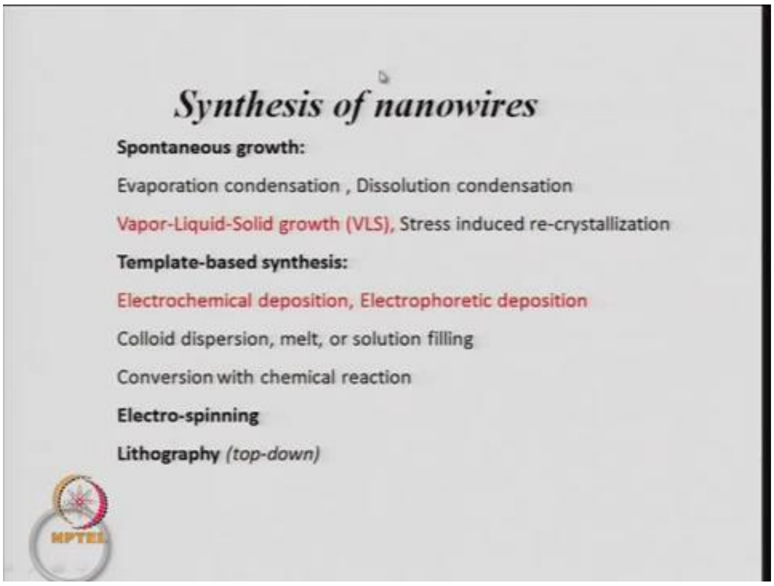

In which two major techniques we discussed, one is the spontaneous growth methodology, which includes evaporation, condensation, dissolution, condensation, vapor liquid solid growth, and stress induced recrystallization methods. And also CVD type of methods, out of which we discuss to a larger extent, the vapor liquid solid growth or also called the VLS growth mechanism of making nanowires. These all form under the spontaneous growth of nanowires, however we can also synthesize nanowires based on templates, which is called the template based synthesis.

And in the template based synthesis, we have discussed two main techniques. one is the electrochemical deposition, while the other is the electrophoretic deposition. And the two techniques are little different, this is mainly for metallic nanowires whereas, electrophoretic deposition we can make nanowires not only of metals, but also metal oxides, that is with nanowires which are non-conducting. Whereas, those which are conducting can be made by electrochemical method as well as electrophoretic method. There are other techniques which we have not discussed to much greater detail like a colloid dispersion or electro-spinning.

And there are of course, many techniques of making nanowires using the top down approach, that is taking a big chunk of material and then slowly removing material from that using some lasers or using electron beams or ion beams. Such that, ultimately you get fine wires, but we are not discussing those techniques, which are called lithography techniques or top down techniques. The techniques in which we have concentrated for the synthesis of nanowires are the chemical based techniques and the 4, 5 techniques which we have interest.

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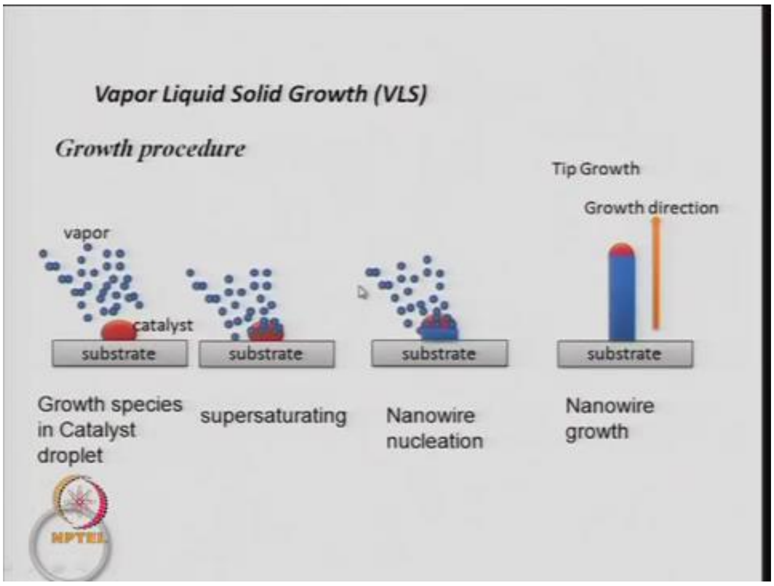

I will just recollect with you, the vapor liquid solid growth which we discussed in which, you have the presence of a substrate on which there is a catalyst which is a metal and that metal catalyst is in the form of a globule. So, it is in the liquid state, and we, the material which we want to grow as a nanowire is in the vapor phase. So, you somehow make that material form a vapor that means, either high temperature or through some other method and those molecules in the vapor phase get into the metal globule.

And then when there is the concentration of the material which are to be form the nanowires, goes beyond some value when this globule gets saturated ok, with these gaseous species. And then the nanowire starts forming on the substrate and the catalyst which is the globule moves on top of this nanowire, and so further deposition in this manner will increase the length of the nanowire. This is typically the vapor, liquid, solid mechanism which we discussed earlier.

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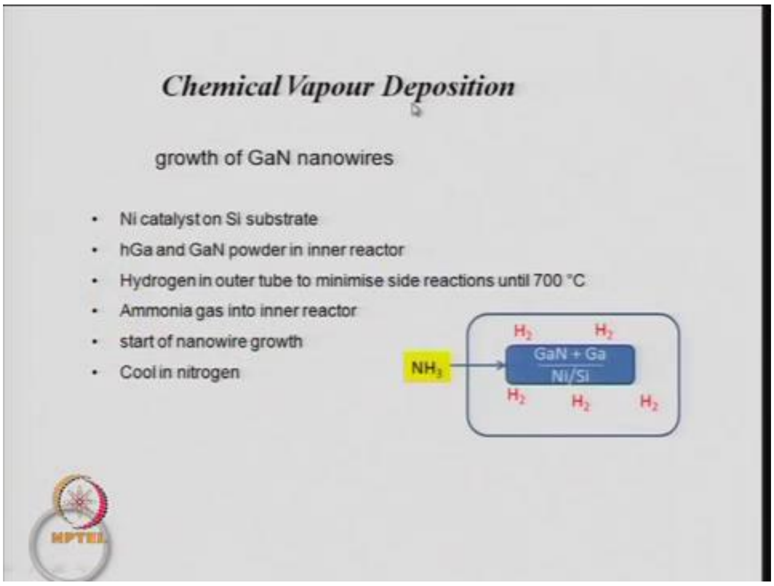

The other technique, which is of importance was the chemical vapor deposition and here for example, I have shown you the growth of gallium nitride nanowires, very important material where, you have a nickel catalyst on a silicon substrate. So, you have a nickel catalyst on a silicon substrate, and you have a gallium, and a mixture of gallium and gallium nitride powder in the in a reactor.

So, you have nickel catalyst on silicon substrate, and gallium, and gallium nitrate mixture on top of that, and this is in a tube around that there is a space in which you have hydrogen gas. So, that hydrogen gas keeps the chamber under reducing conditions, and then you have a furnace around this, which you heat at around 700 degree centigrade and if you do not have the hydrogen this will get oxidized. So, the hydrogen prevents that and then you pass the ammonia in the inner chamber.

So, this is the 2 reactor, 2 cylindrical reactors with the, with the outer furnace and this ammonia in the presence of gallium nitride will lead to growth of nanowires of gallium nitride. And ultimately when you cool, you remove the hydrogen through an outlet and flush in nitrogen, so that the system cools in nitrogen, and then you can get pure gallium nitride nanowires.

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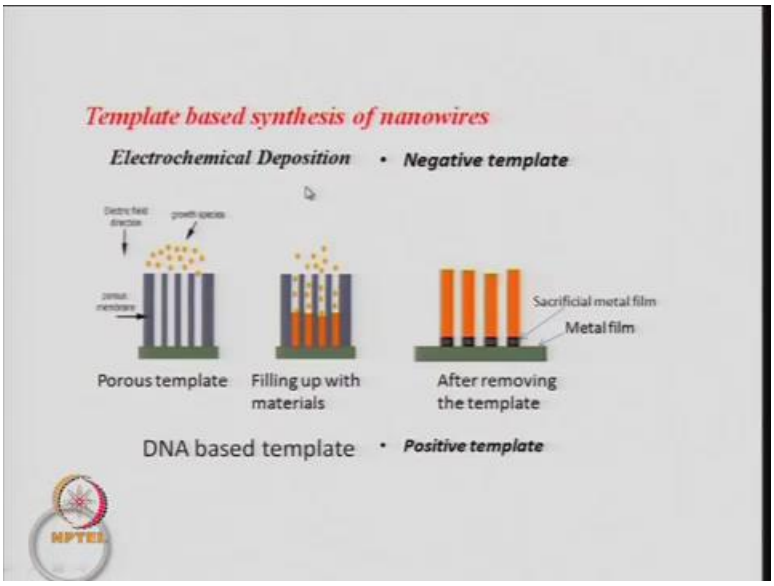

There are other methods which is the template method we discussed, where we use the electrochemical methodology of deposition, this is a negative template method. That means wherever the template is there so this grey one is your porous membrane which acts as a template so the voids get filled with the growth species which you want to make nanowires.

So, ultimately what you get, are these nanowires which are shown in this orange color which are forming in this voids of the porous membrane. And when you remove this template, the grey color template then you are, you will get only these orange nanowires. And if you have another metal at the bottom which is called a sacrificial metal, then you have to have that metal before you start growing these nanowires. Then you can have free standing nanowires because, you can remove this sacrificial metal and then these nanowires will not be connected to the substrate.

So, basically this is called a negative template because the nanowires are growing where you had voids. You can also have positive template methods, that is you grow the nanowire on top of a template, and that normally happens for example, in DNA based templates, where the nanowire grows on the DNA itself, not in the voids like in this case. So, that is why it is called a positive template. So, here is the case of the positive template method which we discussed earlier based on DNA. Now, if you go to another method these, all these methods we discussed many of them are for metallic nanowires.

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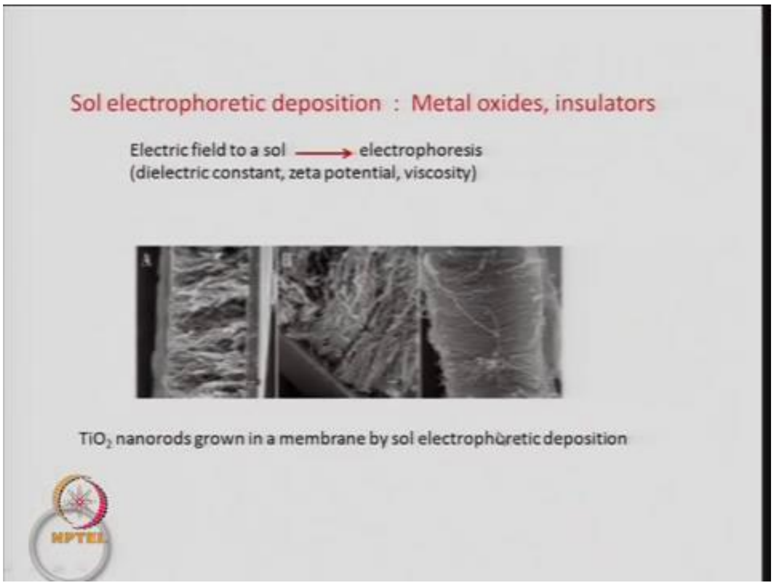

Now, if you have to make nonmetallic nano wires like for oxide like, titanium dioxide or zirconium dioxide, etcetera, then you cannot use the electro deposition method. Then you will have to use the, what is called the sol electrophoretic deposition, where you have, you apply an electric field to a colloidal solution and you that undergoes electrophoresis. And in this system, you do not need the material to which is going to form the nanowires to be metallic because you are going to move some species under an electric field. And it depends basically on the dialectic constant, the zeta potential that is the surface charge, and the viscosity of the medium.

So, these factors control these movements under an electric field of these charge species, which then deposit in the porous membranes to give you these wires. And this is an example of titanium Nano rods grown in a membrane. So, these were some of the techniques we have already discussed in our previous lecture. So, today we will start some other techniques like, the laser ablation catalytic growth.

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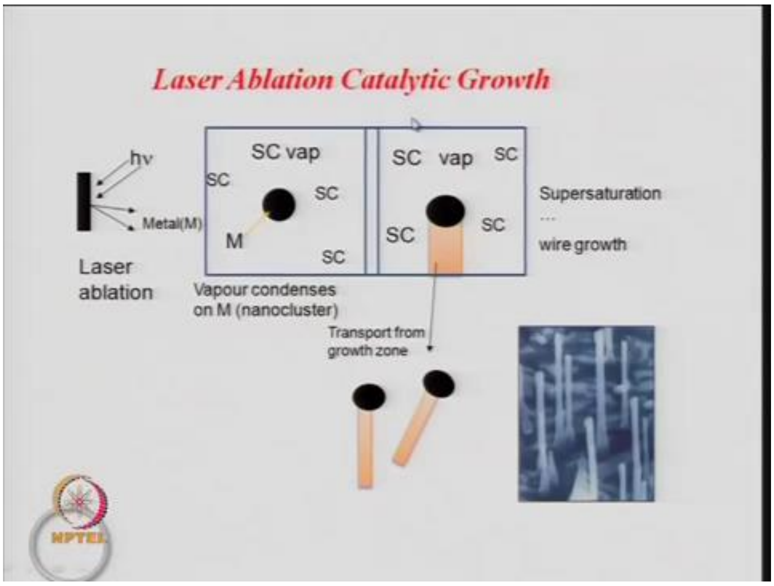

So, in this technique as the term laser ablation means that, you have a metal target and you shine a laser beam with some energy, and you will have these metal atoms coming out of these materials. So, these metal atoms will form a cluster, they can be atoms or clusters which will come out. And these clusters of metal atoms, when they are surrounded by the material, the semiconducting material around it, then these semiconductor materials will then dissolve in this cluster, and then when it reaches a point of super saturation. So, when the semiconducting material crosses a certain concentration within the globule, then it starts forming these wires. So, then you have to have a mechanism by which you remove these wires away from the growth region. So, these nanowires of the semiconductor with the metal on the tip and this is called tip oriented growth, tip mediated growth of nanowires. There are two types of growth of nanowires, one is the route mechanism of growth of nanowires where the metal cluster will remain at the bottom.

But here the catalyst which is the metal cluster, goes to the tip and the nanowire forms below, this is called the tip growth mechanism for nanowires, and that is what is happening in this laser ablation catalytic growth. And you can you can move these nanowires away from the growth zone and if you deposit them on a substrate, this is a TEM picture of, this is a STM picture of these nanowires which have formed by the laser ablation catalytic growth mechanism. So, the catalyst is always some metal particles which have been removed from the substrate using a laser and this is a common method now a days to make nanowires.

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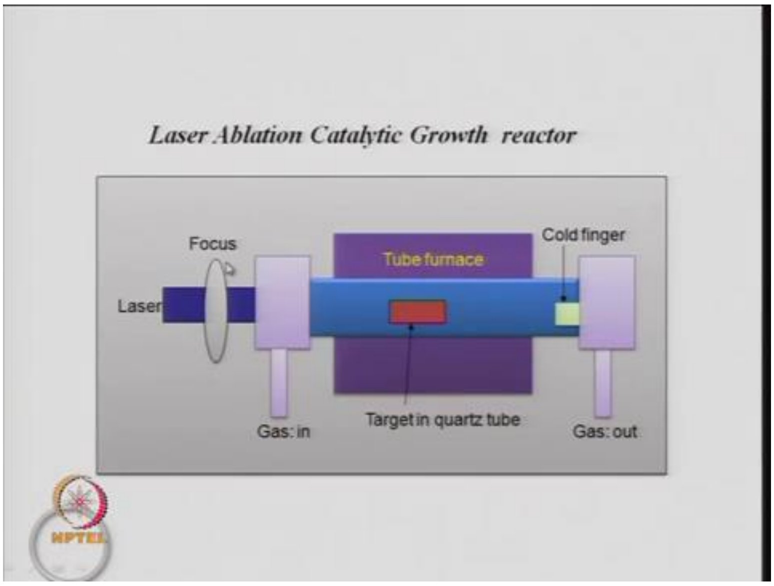

This is the setup which you use for the laser ablation technique. So, you have a furnace and you have your material on which the laser has to be focus so your target is in a quartz tube and you have the gas, which is the semiconducting gas which is going to be around that target.

So, the laser beam comes there hits the target and you have the metal particles with the gas here and then this gas will be flowing out here and the Nano rods, or nanowires will be deposited on this cold finger. So, in this region the temperature will be high because there is a tube furnace which heats this region, and then this will be some metal plate which we call the cold finger. Since, the temperature on here will be less than inside these nano rods, nanowires which you get will deposit on the cold finger. So, this is the setup used for the laser ablation catalytic growth mechanism.

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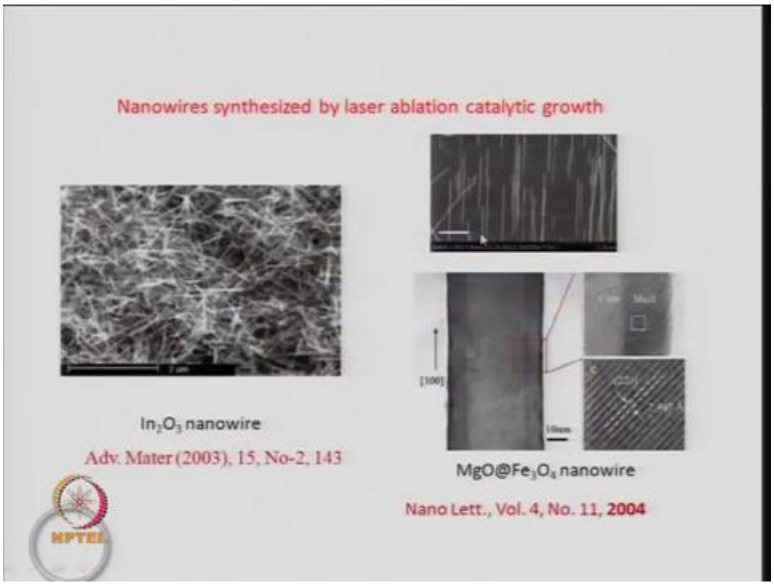

Now, these are some examples of nanowires grown by this laser ablation technique, and you can see different types of nanowires can be grown, this is an indium oxide nanowire. So, in this technique also you do not need that, you do not have this restriction of the growth of only metallic nanowires, but you can grow both metallic as well as oxidic nanowires, which are insulating or which are semiconducting. So, the indium oxide nanowire is shown here is quite uniform, and in this case what is shown is a core shell type of nanowire, that means there is a magnesium oxide wire which is surrounded by iron oxide Fe 3 O 4.

So, this kind of core shell nanowire can be seen in high resolution, this is the TEM picture along 1 axis, which is the 1 0 0 axis and this nanowire is going growing along the 1 0 0 axis. And if you zoom into this region of this TEM picture, which has a scale of around 10 nanometers, if you zoom here and enlarge this, you can see clearly the contrast between the core material and the shell material. So, you have this is magnesium oxide and this is the Fe 3 O 4, and then you can do of course, high resolution of this region. So, the shell material if you do high resolution, the shell is iron oxide F e 3 O 4 and you can clearly see lattice fringes corresponding to the 2 2 0 reflection of the iron oxide material.

So, this is a very good a uniform nanowire showing the cores shell structure so you have two materials magnesium oxide and iron oxide, and one on top of the other, this is like a cable. So, you have like a copper cable on which you have an insulating layer this is similar to that, you have a magnesium oxide nanowire which is clouded by or surrounded by F e 3 O 4 a material in the form of a hollow wire inside which MgO is embedded. So, these have lot of applications.

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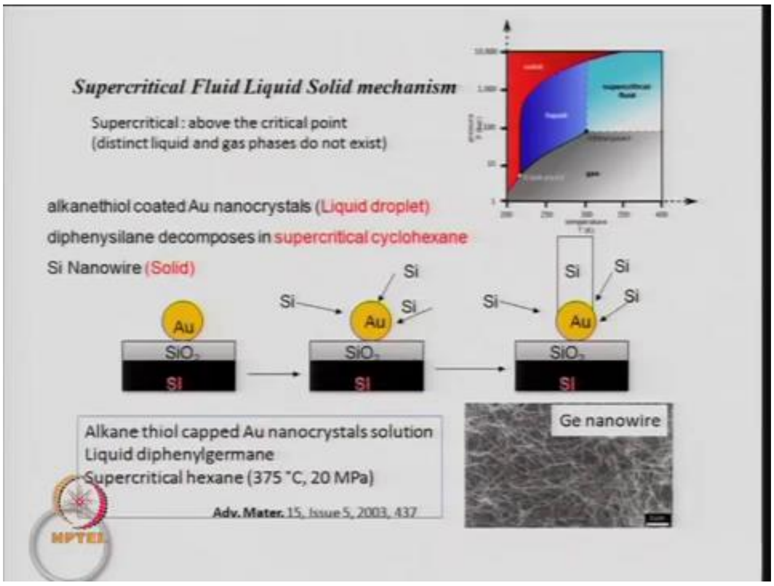

Now, going into another methodology of making nanowires, this is called the supercritical fluid liquid solid mechanism. So, supercritical fluid, what are supercritical fluids? So, basically anything in physical chemistry or chemical engineering, you may be aware that liquids which cross a certain critical point in the phase diagram.

So, this is suppose a phase diagram of some gas, or which has under some pressure, and some temperature, shows this phase diagram how that gas goes into a liquid and in a solid, in that system if you come to a point, beyond this point. Since, this curve is not extending, you cannot differentiate between the gas and the liquid. So, long as you have this curve, you can differentiate that in this region the system whatever be maybe it is oxygen or whether it is some other gas, will remain like a gas. However, if you cross this region, that means if you increase the pressure beyond certain value at a certain temperature, you will, it will become a liquid.

But if you are somewhere here it is a gas, now you keep increasing the pressure it will become a supercritical fluid because, now it has no boundary, it is neither a gas nor a liquid or you do not have distinct liquid and gaseous phase. So, that point beyond which liquid and gas phases do not exist separately is called the critical point. So, if you cross that critical point either in temperature or pressure such that, you are in this region, then that is a called supercritical fluid. So, if you have supercritical for example, carbon dioxide, you can have supercritical carbon dioxide, you can have supercritical hexane. So, you can create or do reactions which are otherwise not possible.

So, in this case what has been done, this is a particular example where supercritical cyclohexane has been taken. And in supercritical cyclohexane people have added diphenylsilane, now diphenylsilane is a precursor for silicon. So, what happens when you take diphenylsilane in supercritical cyclohexane it decomposes to give you silicon vapors. So, those silicon vapors are then surrounding your some nanocrystals, where, on which the growth will take place.

So, basically in this particular experiment, the, you take gold nanocrystals to act as a catalyst, like in the earlier cases we have studied nanowire formation. You always used a metal catalyst whether it is laser ablation or VLS method etcetera. In this case also, you have to have a metal catalyst on which the nanowire will grow.

So, here we choose at the particular example shown here has gold nanocrystals which forms a liquid droplet and this gold is passivated on the surface of this gold, you have got alkanethiols, these are like chain like molecules and as an alkanethiol has a sulfur at the end of the chain, and that sulfur binds to the gold. So, alkanethiol coated gold crystals will always have gold with some sulfur at the end and this droplet is then passivated we say, and then you bring it close to the diphenylsilane in supercritical cyclohexane. So, diphenylsilane will decompose, give you silicon that will be around the gold globule which will act as a catalyst, and all this is being done on some substrate and that substrate here is silica on silicon.

So, there are some reasons why silica is chosen on top of silicon, but main the point of interest to us is in the growth of this nanowire. And this growth of this nanowire in the presence of a supercritical fluid, which is cyclohexane and that enables diphenylsilane to decompose to give silicon. Hence, silicon grows on this metal catalyst to form this silicon nanowires. Now, the another example, instead of silane, if you take the precursor as Germaine, Germaine and silane the only difference is, instead of silicon you have, you have germanium, which is Ge.

So, if you take diphenyl germane instead of diphenylsilane then obviously you will have germanium nanowires, you will not have silicon nanowires. So, you get germanium nanowires in this system again you have got gold nanocrystals has catalyst. And you are now using supercritical hexane at certain temperature and pressure so you understand that under this temperature and pressure, hexane is in the supercritical region. So, it will be in the supercritical fluid region in the phase diagram, of its phase diagram not necessarily this phase diagram. And so from this you will get not silicon wires, you will get geranium wires and the TEM picture here shows germanium nanowires grown using the supercritical fluid liquid solid mechanism.

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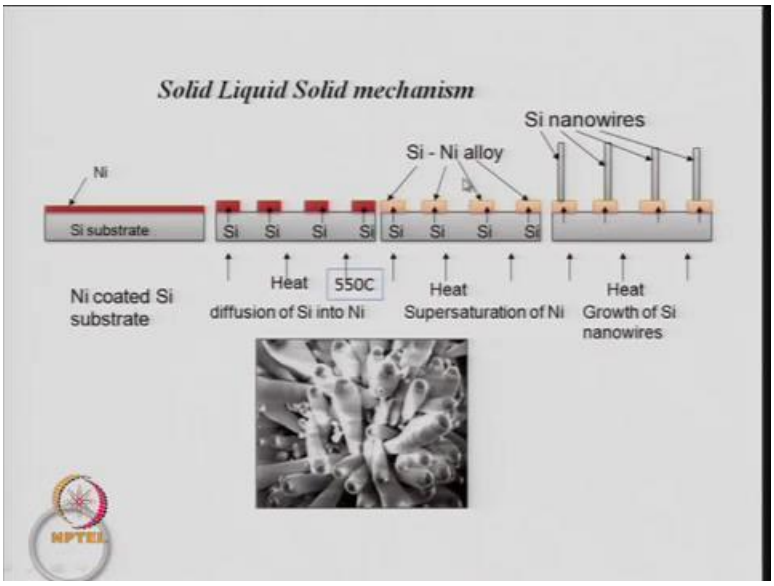

Now, coming to another technique, this is the solid liquid solid mechanism of growth of nanowires. So, you have silicon substrate on which you have another solid which is nickel, so you have coated nickel on silicon substrate, then you make through some technique it can be through e beam lithography or something, you remove some of the regions of nickel. Right now you can see that the entire surface of silicon is coated with nickel, but you remove part of this nickel so that is there alternately you will have nickel, and then no nickel, and then nickel, and no nickel, like that.

So you made this kind of a design using either an ion beam or an electron beam or any other method by which you can h away which means, remove some of the nickel in a particular manner. Once you have this set up that means you have silicon at the bottom and nickel at particular places, you heat this system to around 550 degree centigrade. When you heat this system, the silicon will start defusing into the nickel.

So, soon when silicon goes into nickel from the substrate to these places, you will no more have pure nickel, but you will have silicon nickel alloy. And when the quantity of silicon becomes larger than a critical concentration in the nickel, then the growth of silicon nanowires will start. The concept is quite similar to many of the methodology we studied earlier that, where you have a metal in which the material which is going to form the nanowire diffuses in. And then reaches a super saturation and then the nanowire growth starts. Same thing is shown here except that, you start with a solid and then the solid you heat and then diffusion takes place so you have a solid liquid solid mechanism.

Because this silicon nickel alloy will have a lower melting point than either silicon and nickel, and then from that melt you will have the growth of silicon nanowires, and this picture is a TEM picture, showing the growth of silicon nanowires. So, this another method by which we make nanowires of different materials.

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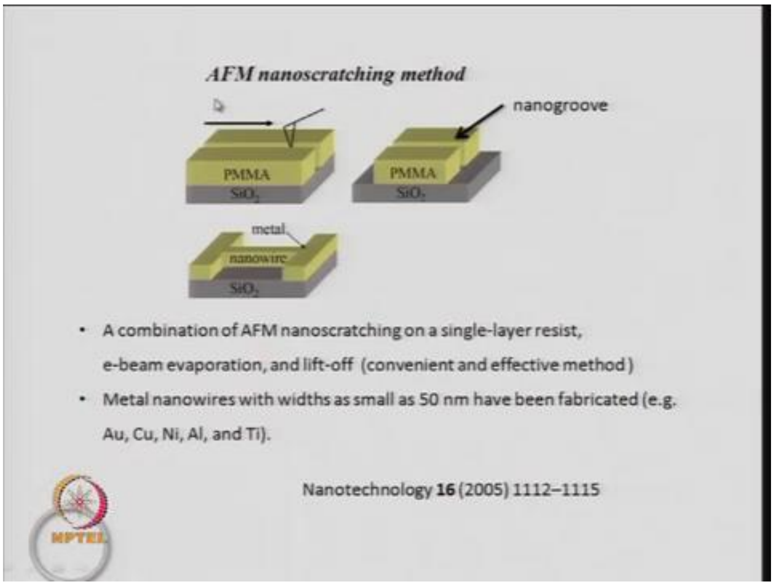

Now, another method is using an atomic force microscope. So, in atomic force microscope you know that there is a cantilever, and at the tip of the cantilever you have this kind of a tip, which is normally made up of either tungsten or platinum or iridium. There are lots of different types of tips which are available.

Now, this cantilever I can move wherever I want using and x y z positional stage, and I can make a touch the surface of any material by controlling the movement of the cantilever. If I put pressure on the cantilever I can also make a scratch on the surface depending on what kind of surface it is. If it is a very hard surface I need special tips to make a scratch, if it is a soft surface the one chosen here is a polymer and so it is a soft surface.

So, it is a easy for me to make a scratch with normal tips so this is PMMA is polymethyl methacrylate. It is a polymer and that polymer is coated on a substrate, which is silica or quartz, and you make a pattern on top the way you want the nanowire to grow.

So, first you can see that this cantilever the tape is making a cut on the PMMA surface, then it removes makes a cut on this part so what you see is on these edges, the polymer is not there and in the center the polymer is not there. So, it makes what is called a nano groove at the center and at the edges also you see there is no more polymer and the silica is visible here. Now, if I add anything on top of that, that will grow on the silicon on the sides and the silica which is in the nanogroove, because there is no PMMA there.

So, what I do is now I grow the nanowire, whatever metal I want on that groove and then I remove this PMMA. So, now wherever the PMMA was there, that is blank and that silica surface is now seen and so you now have the structure like an i. Because wherever there was a gap, now you have the metal coating. And so now you have two metal contacts, in between you have a nanowire. So, this is another way using the AFM nano scratching method that you can make nanowires and you can also make simultaneously metal contacts on sides.

So, if you want to do some measurements of say current voltage and other kind of measurements, you can make nanowires like this. And it is possible to do this using an e beam lithography setup, where you can do e beam evaporation and then you can lift off, that means takeout the PMMA. And also after the nanowire is formed, you can lift it using a robotic arm and place it wherever you want. So, using this technique many metal nanowires with thickness as small as 50 nanometers, have been fabricated of many kinds of metals.

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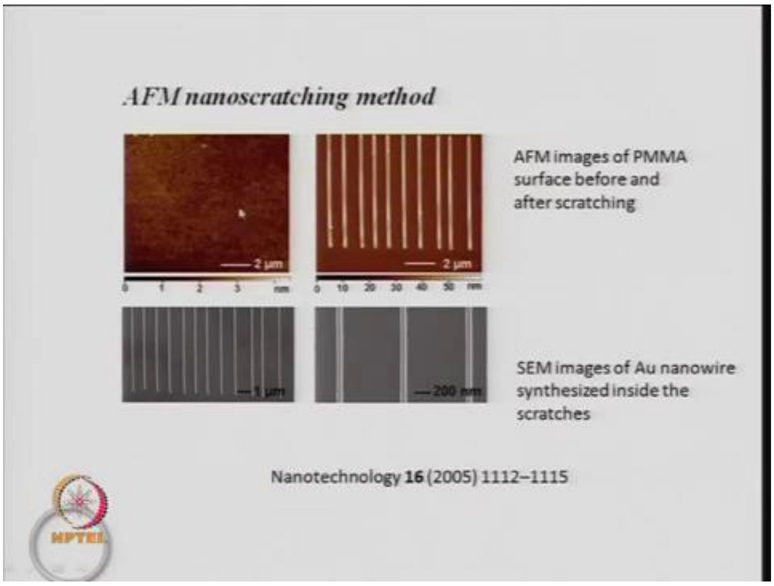

This is one example, so this is the top surface, this is the PMMA surface, the polymer on top of that, that is seen here in a picture which is a typical AFM picture and then you make the AFM scratches. So, this scratches as seen on the AFM picture, and then you can put your nano say here it is gold nanowires. So you have deposited gold on top and this is then SEM picture of the nanowires which have been deposited in the nano grooves, and if you take a closer look. So, you come close to this 1 or 2 nanowires, you can easily find out and you can do an EDX analysis, and see that this is typically gold which has been embedded in the system.

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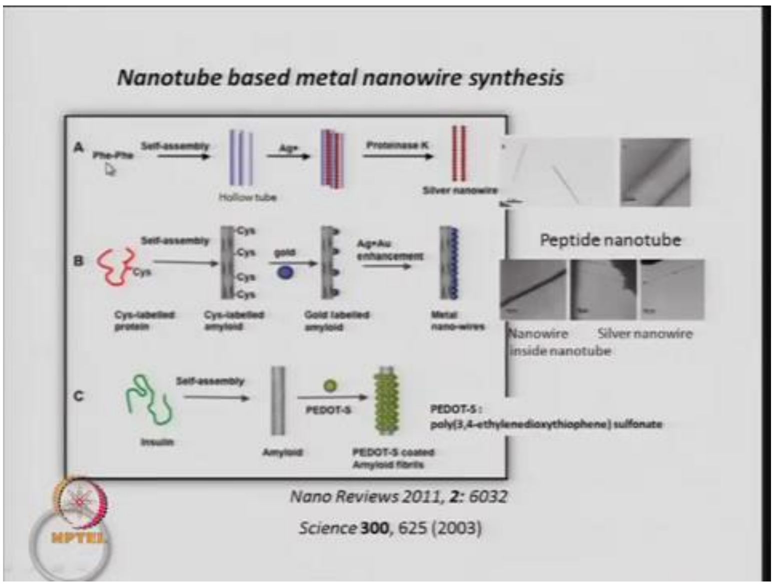

Now, coming to some biological methods of making nanowires, you can also use peptides to make nanowires. So, this is very interesting, a lot of chemistry and bioorganic chemistry is involved in thinking and designing, how you will make hollow tubes of peptides and make nanowires inside them. So, here you see this is you start with a dipeptide, you have this phenylalanine type of dipeptide, and then itself assembles to form these hollow tubes. And then you add silver ions which get reduced on them, and you get the silver particles embedded inside the hollow tube of this biopolymer which is basically a polypeptide tube.

Now, knowing that this polypeptide chain can be cleaved using certain enzymes, we add this enzymes which is Proteinase K, which cleaves this polypeptide tube. So that polypeptide tube then will get dissolved in the solution and what you will be left behind are the silver nanoparticles arranged as a nanowire. So, the silver nanowire will be remaining behind and the hollow tube has been dissolved because the Proteinase K has cut the peptide chain.

This is another example where you have a protein, so this red wire kind of thing is a protein which is a long polypeptide chain, and it has got some cysteine labeled protein. So, that means cysteine is amino acid and that cysteine will help you in attaching metal particles.

So, when this protein self assembles to form a tube, then this cysteine moieties, you can see here the cysteine moietie,s and cysteine is an amino acid which all of us know has a sulfur at the end. And sulfur is known to be aerophile, that means it likes to be attached to gold nanoparticles. So, wherever you have a tube with cysteine labeled and you bring in gold solution, then this gold will get deposited wherever the cysteine is there because the sulfur of the cysteine will attached to the gold. And so you will have these gold nanoparticles on the polypeptide chain. You can further add more gold and more silver and complete this chain to get metal nanowires.

So, this is another method where we have used our knowledge of cysteine in polypeptide chain and cysteine known to be aerophile will attach to gold wherever it finds. And that is how you first make the gold clusters on the polypeptide chain, and then you can enhance it by adding more gold nanoparticles or silver nanoparticles. This is the third example of this biopolymer based nanowire synthesis.

So, this is insulin which you know is secreted in your body, and this insulin is again a biopolymer itself assembles to form this tube which we in biology we called amyloids. So, here you have cysteine leveled amyloid and this is an amyloid, and on that we add a polymer, this polymer is called PEDOT-S, and the full name is given here poly 3, 4 ethylene dioxythiophene sulfonate. And when you add the PEDOT-S, then that attaches itself to this amyloid and forms this kind of change. So, there are several biopolymer based methods by which you can get metal nanowires. Now, coming to the properties, metal oxides as you know have a wide range of electrical properties.

So, they can be super conducting, they can be metallic, they can be semiconducting, and they can also be insulating. The difference between semiconducting and insulating is basically dependent on the band gap. If it is low band gap say 1, 2, 3 electoral volts, we normally call them semiconductors, when the band gap is high say 4, 5, 6 electoral volts, then we call them to be insulators. Where, when is something a metal, something is a metal if you heat it its resistance increases, if you cool it its resistance decreases that is a metal. And typically and then what is a superconductor, a superconductor behaves like a metal till you come to a certain temperature.

So, below that temperature its suddenly loses all its resistance, and then its resistance is more or less 0. We cannot measure the resistance, it is beyond our capability to measure the resistance of a superconductor below a certain value. And so we say that the resistance is 0, and this state of a material when the material goes from the metal to a superconductor is a, we call it a metal superconductor transition and there are many other properties associated with it.

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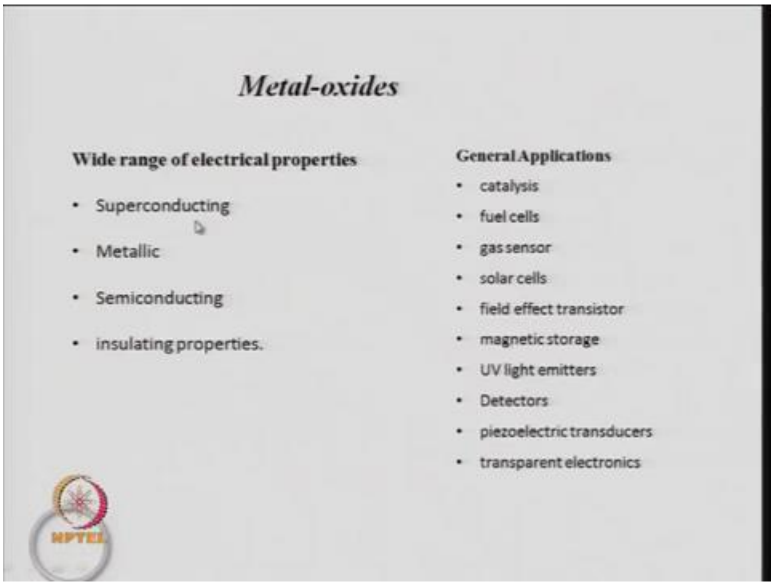

So metal oxides can have different electrical properties and their wide range from insulators. An insulator can have a resistance of 10 to the power say 8 ohms whereas, a metal like copper or aluminum will have a resistivity of 10 to the power minus 8 ohm inverse centimeter meter inverse. So, there is an order of 10 to the power 16 order change from a insulator to a good metal, like copper, or gold, or silver. Now, with all these wide ranging electrical properties, you can make use of them in many-many applications.

So, there are general applications of metal oxides as catalyst, as fuel cells, gas sensors, solar cells, field effect transistors, magnetic storage systems, UV light emitters, detectors, piezoelectric transducers in transparent electronics. Many-many applications and metal oxides are something which are very widely used in all our day to day life, and in the entire world. Now, if you come that what we discussed here are general properties, electrical properties of metal oxides, we have not discussed about nanowires as such. And these are general applications of metal oxides either in their bulk forms or in the nanostructured form.

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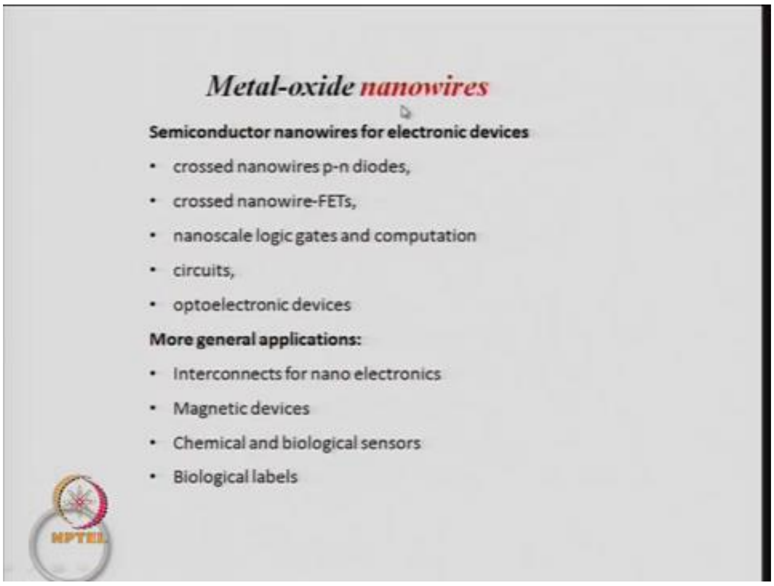

But when we come to nanowires, metal oxide nanowires have some specific applications. For example, if you are talking about metal oxides, which are semiconductors, then they have some specific applications like they can be used as p-n diodes, where you have nanowires which are crossing each other. So, crossed nanowires which can act as diodes, which we normally study in simple electronics p-n diodes, or it act as a field effect transistor FETs are effect transistors, very important in all kinds of electronic circuits. And you can use FETs using nanowires, what we currently or earlier used to use using simple copper wires or other types of conducting material or semiconducting materials, that you can use using semiconductor nanowires. So obviously you will have very small FETs, and so your circuits will be very small, and your applications will enhance because you can put more number of FETs in the same space. Now, you can also make nanoscale logic gates, other general circuit and optoelectronic devices using semiconductor nanowires.

So, all these applications which we mentioned p-n diodes FETs, logic gates are with semiconducting nanowires. If you go to general nanowires may be metallic or magnetic, then you add more number of applications for example, as magnetic devices you can use nanowires, as sensors in chemical and biological sensors you can use nanowires, you can use them as biological labels. That means they can find out something, which belongs to a particular biological system.

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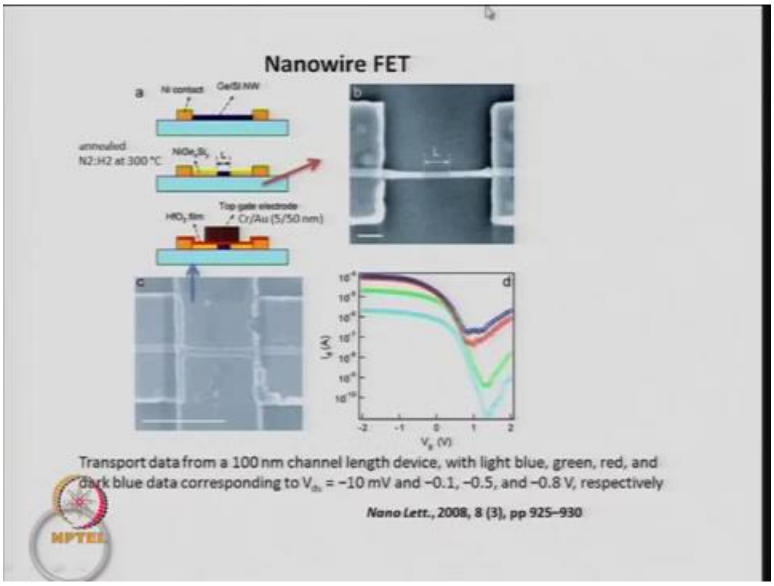

Now, this is an example of a nanowire field effect transistor. So, what is this here as you see you have got a nickel contact on a silicon surface and then you have a germanium silicon nanowire here, right. So, you have a germanium silicon nanowire and this is, these are nickel contacts and when you anneal this around 300 degree centigrade, then part of the nickel will diffuse in the germanium silicon nanowire. So, you will have some region where you will have nickel germanium silicon. Nickel will diffuse from this side from the left side, as well as nickel will diffuse on the right side. And if you control the diffusion then in between you can retain a space where there is no diffusion, only their diffusion is here and on this side.

So, now your composition of your nanowire is no more the same. You have germanium silicon nanowire at the center, and you have nickel dope germanium silicon on the left and on the right. Because of the change in the composition their property will be different and now this will behave as if a nanowire with nickel germanium silicon on either side.

So, if you look under microscope, then you can see that these are the two contacts and this is the small region marked L is actually the germanium silicon nanowire and this is nickel dope germanium silicon nanowire. This is also nickel dope germanium silicon nanowire and so this corresponds to this schematic diagram. However, if you want to make a device you have to put a gate on top, so on this what you do, you make a hafnium oxide film, this red one is the hafnium oxide film.

And that film actually separates the germanium silicon nanowire, the blue nanowire from the top gate which you now put in, you coat chromium aluminum on top, which is of the order of 5 to 15 nanometers. So, this is called a top gated FET, top gated field effect transistor and then if you look at the under the microscope. Now, this picture will change like this picture where now you have got hafnium oxide on top, and on top here above what you have got L, this was pure silicon germanium nanowire. Now, this region if you do EDX will actually show from the top chromium gold.

So, the chromium gold is on top here, and on the left and right you have got hafnium oxide film, and then underneath you have got the substrate. So, now you can a plot or you can measure currents I d is the current measured at the drain and V g is the voltage applied at the gate.

So, this is the gate, so the gate basically controls the flow of the charge carrier across the two electrodes which is the source and the drain. And then you can see that depending on the gate voltage how the current is changing, and not only how the current is changing with respect to gate voltage. You can also see that depending on what kind of the voltage you apply at that drain and source, the curves will start changing. So, if you have a very high negative bias.

So the high negative bias is a minus 10 mili volts between the source and the drain if you apply, then what is the current that you get a different gate voltages that is given by this plot. And if you keep decreasing the negative value that means you increase the voltage between the drain and the source. If you increase the voltage from minus 10, the negative bias is now decreasing to minus 0.8 volts, you move slowly from away from 0 gate voltage towards, the shifting towards 0 gate voltage.

So, you see that the current at the drain you can control, you are changing the current value by changing the gate voltage as well as changing the voltage between the drain and the source. So, this kind of filed effect transistors have already been made using nanowires and this is typical system with germanium silicon nanowire is a semiconducting nanowire based FET. Now, this is another example.

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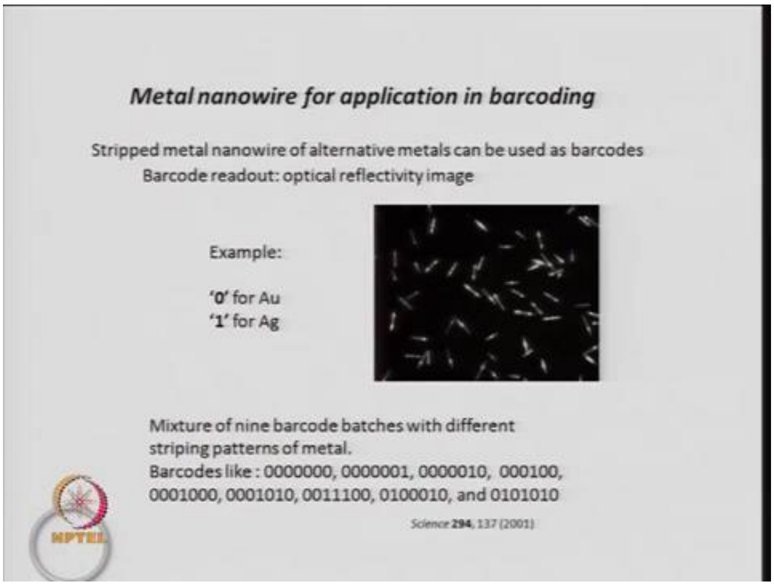

A bit different, this is an example of metal nanowires, which have applications in bar coding. Like you have several materials, you in the shopping, which are coded. They are magnetically coded and then when you take it out slip on which the magnetic code is written in the form of a barcode is slided over a magnetic reader. Then it displays all the information of that material, the price etcetera. Similarly, you have optical coders by, you have to have optical reader, and when the barcode is placed on the optical reader it tells everything what is the information stored about that material.

So, here is an example of a metal nanowire being used for application bar coding. So, this metal nanowires which you are seeing in a TEM picture. You can see different this is a optical micrograph, not a TEM picture in which you are seeing this different black and white spots, actually are coding for 0 and 1, like you this are made up of gold and silver. So, this entire rod is made up of gold and silver and we can write or code depending on say we want a code 0 1 0 1, then we have gold, silver, gold, silver.

So, like that if we have 2 nanometers of gold, and then 2 nanometers of silver. If we can design like that, then when we read using optical spectroscopy, it will tell us that this is made up of gold and silver in this ratio and then we can kind of understand what is the material based on the bar coding. So, bar codes like this can be made.

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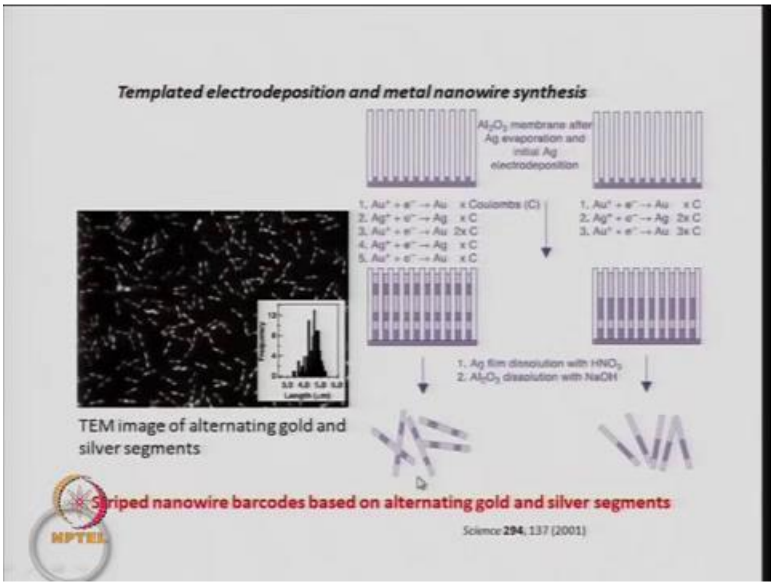

And how they can be made, this is easy to see in the optical microgram, but how do you make such nanowires, where you have alternate elements to make a particular pattern. So, the way it is done is what we studied earlier, it is a template method using electro deposition. So, you have a template, so this is your template, it is alumina oxide membrane, porous membrane, and then you grow gold or silver within this template. So, this is a negative template because you are going to grow wires within the spaces. So, what you do in a particular case.

For example, if you, in your first step you do an electro deposition with gold ions, then first gold will deposit. The amount of gold will depend on how much charge you passed during the electro deposition. So, if you want to control the length of your gold because your diameter is fixed, if you pass more charge the length will increase. So, as you see here, if you pass a gold and the charge is say C coulombs, you get some deposition and that is corresponding to this.

So, this one is your first step, you get gold here then you put silver corresponding to C coulombs, you get next silver on top of gold. Everywhere you get silver on top of gold. So, two layers have now been deposited on the bottom layer, then the third step you again put gold, but now you pass twice the amount of charge.

So what you will get, you will get gold, but now gold will be twice that amount. So, like that you can continue. So, you will have different amount of gold, silver, gold, silver, depending on which ion you are deposition depositing and how much charge are you passing. If you want a larger length of a particular metal, you pass more charge, so more amount of that metal will be deposited, since the diameter is fixed only the length will change. And that is how you see the bar codes are generated. So, this is one example, this is another example where there are only three steps. So, initial the first, let me clarify, the first layer is already there, when you make your template the first player is already there.

So, actually this light grey is then yours first step here gold. So, this light gray is gold, then this dark one is silver, and then again you get gold, but now twice the amount of gold and so this light gray is twice. In this case, this template first has this dark gray spots, so that is basically made up of your first metal which you have already put in your template. But now you are adding as your first layer gold and so that forms here the light gray is gold, then you pass twice the amount of charge of silver. So, you get length which is more than what you get earlier, now it is more than this. And then you pass three times more than this, so you get even a larger length of gold in this case.

So, you can deposit different materials and different lengths and then you remove this and you get these free segments of the segmented nanowires. These are called segmented or strike nanowire based bar codes, which you can study using optical microscopy. And since silver and gold are easy to study, they are very popular because they have a surface plasmon which can be easily study using a UV visible spectrophotometer.

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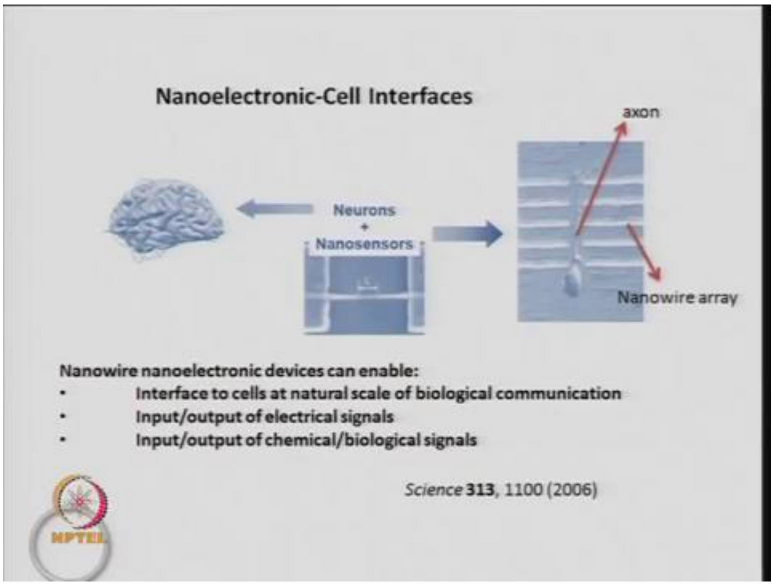

Now, you can also make nanowires, connected to nerve cells. So, this is an example where the nanowires have been corrected to neurons and this has been shown here. So, this is the nerve cell, this the axon, and these are nanowires. And then we can study their input and output.

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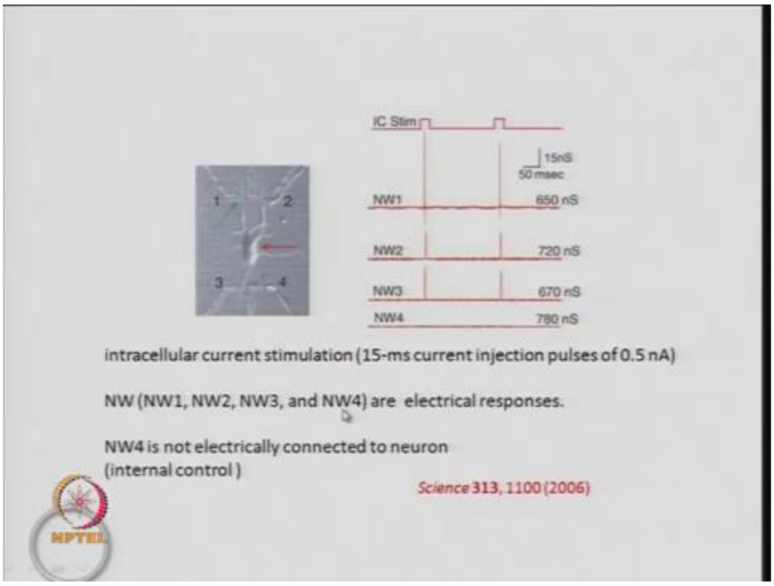

And that is what is studied here, there are 1, 2, 3, 4 contacts on a nerve cell and we gave a stimulus. So, the nerve we give a stimulus from outsides of electrical signal, and then we study what happens in nanowire 1, 2, 3 and 4. Note that nanowire 4 is not connected, so when nanowire 4 is not connected, we can see nanowire 1 shows us stimulus, nanowire 2 show us stimulus, and nanowire 3 is shows. But nanowire 4 does not show anything because it is not connected to the neuron, and this kind of studies are very important to understand the working of inside our brain, where nanowires are being connected to nerve cells and then studying how the nerve cells behave on that particular stimuli. Now, there can be many other studies have nanowires applications. For example, nanowires have been used to study the antibodies.

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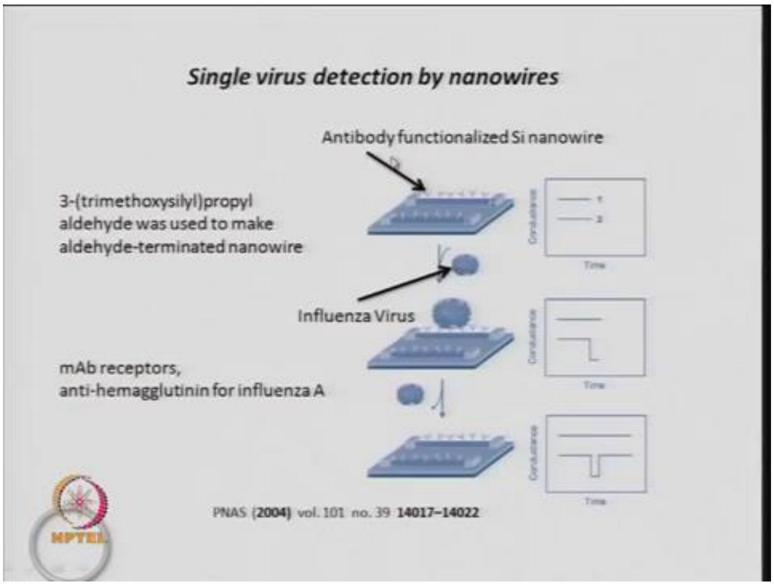

So, you have nanowires and if antibody are functionalized, then these antibodies which are specific to certain viruses will attract these viruses. And when that happens, there will be a change in the conductance and from the change in the conductance we can calculate how much virus is there in the environment. So this kind of single virus detection by nanowires has also been done.

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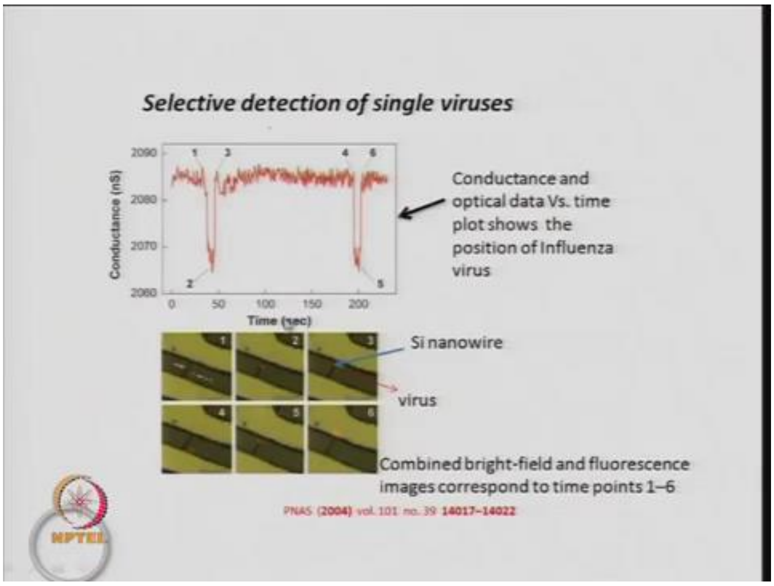

So, this is what is being shown by single wire detection by nanowires. So this is a silicon nanowire and there is this red dot is the virus. So, when that virus is on the wire that is the point 2, you get a signal when the nanowire is, the virus is not on the nanowire that is point 3 you do not have a signal. So, these kinds of things are very well known in now in the current age of nanotechnology and nanowires have played a very important role in this. By this we come to an end of our studies on nanowires, their synthesis, and their applications and we will continue this course on nanostructured materials.

Thank you very much.