Nano structured Materials-Synthesis, Properties, Self Assembly and Applications
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Module - 4
Lecture - 40
Concluding Lecture

Welcome back to this course on Nano structured Materials, Synthesis, Properties and Applications. Today is the concluding lecture of this course, which spend over 40 lectures in 4 modules, so today is the 12th lecture of Module 4 and the 40th lecture of the overall course on nanostructure materials. And in this course we have covered various aspect of nano technology from synthesis to applications. So, module 4 we are referring today to module 4, lecture 12 and this is the concluding lecture, the last lecture on this course of nano structured materials, synthesis, structure and properties. So, what did we learn in this course? We learnt that what is a nano material?

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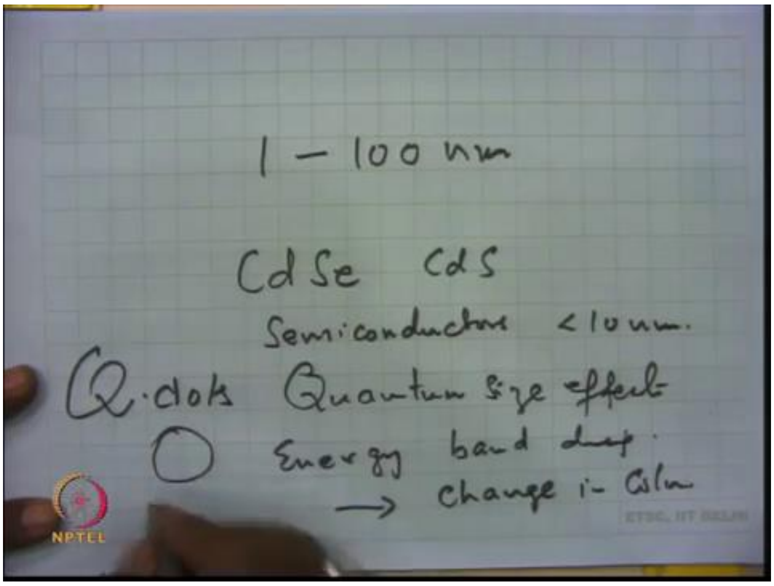

So, for example we define a any nano material having size between 1 to 100 nanometer, this is consider to be a region, where any particle, any object having this size we refer to that as a nano material. Now, with that size there has to be some change in property, in the type of property may be a magnetic property, an optical property, etcetera, so what are these different properties which occur at this nano scale. For example, we learnt that a gold if you reduce the size of gold, it can have different colors depending on what is the size.

So, gold is normally yellow in color, it can be red in color or green in color depending on the size of the particles of gold. So, this is the optical property of nano particles and example of a metal nano particle. Similarly we looked at optical properties of semiconductor nano particles for example, quantum dots. So, what are quantum dot for example, we studied quantum dots like cadmium selenide or cadmium sulfide if you make particle of such semiconductors, which fall in the dimensions of less than, say 100 nanometer.

Then you can see quantum size effects and quantum size effects lead to changes in the energy band diagram. And this change in the energy band diagram leads to change in the color, so based on that we call them quantum dots if they are spherical; however, we can also discuss nano particles not only in three dimensions, but in one dimension or two dimensions.

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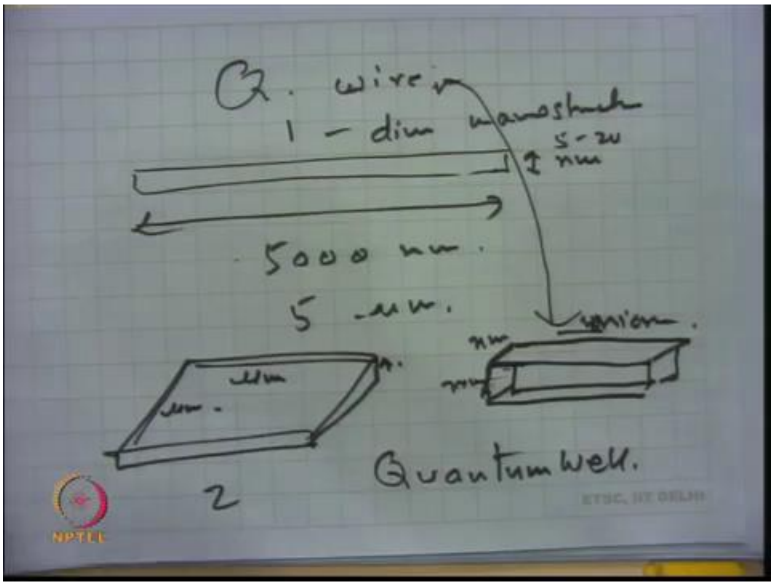

So, in one dimension for example, you have a long wire, now this may be a few nanometers say 1 or 5 to 20 nanometers or 30 nanometers. Whereas, this is like 5000 nanometers, which is like 5 microns, then this will be called quantum wire or this is a one dimensional nanostructure. So, different types of nanostructures we studied, they can be zero dimensional like, quantum dots one dimensional, like quantum wires or they can be a plate like objects, which are like two dimensions are in nanometer scale and you can have the length and breadth.

For example, you can have something in nanometer dimensions in this direction and in this case you have this large in say micron dimension. So, in a plate when I have a nano dimension, but you can also have a kind of quantum wires, where you have these two dimensions are in nanometers, where as this is in micron sized. So, this is the quantum wire we are referring to, so two dimension are in nanometers and it is one dimension is very large.

So, this is a quantum wire is called one dimensional nanostructure and this is like 2D or you can have what is called a quantum well. So, many such properties in nanostructures we learnt lead to the quantum region, so lot of properties will change when something goes to the quantum region. This one important thing is we learnt and we look at the several such materials, including semiconductors and metals and even something like, organic nanostructures, like carbon nano tubes, etcetera.

So, carbon nano tubes are like 1D nanostructures, but it is made up of carbon and not metal of semiconducting, inorganic semiconductor of course, you can have metallic, carbon nano tubes as well as semiconducting carbon nano tube, so you can have different type of nanostructure that is the basic thing.

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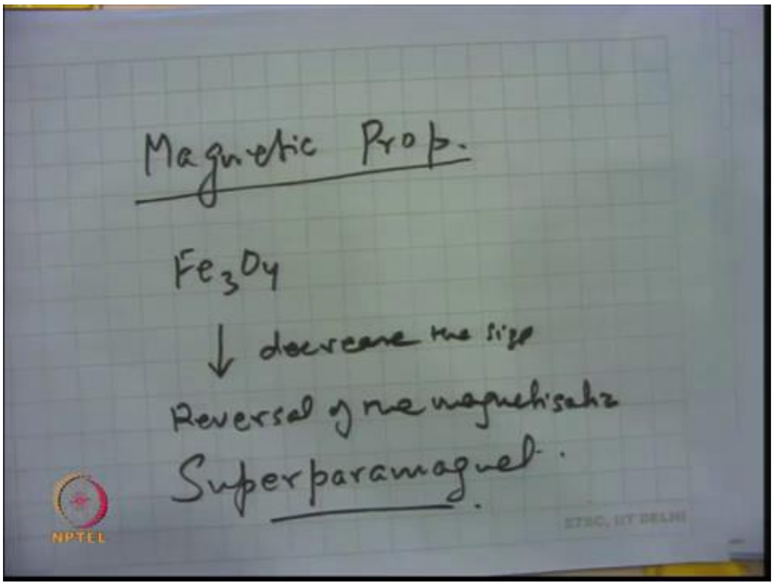

Now, looking at properties we looked at optical properties we looked at magnetic properties for example, main change which happen when something is magnetic. So, when you have something like iron oxide, which is magnetic, magnetic here means ferromagnetic and when you a decrease the size, what is the key chain in this property.

So, what we get is the reversal of the magnetization, so you have a material, which is a ferromagnetic and as you decrease the size of the particle, the magnetization changes over from ferromagnetic to you get a less ferromagnetic, so the magnetization is much less or it may become anti ferromagnetic. So, there is a reversal in the magnetization and you also result in something called a super paramagnet at a particular when you make small sized magnetic particles. And then we also looked at what are the application of such magnetic nano particles and their huge applications, especially in drug delivery etcetera.

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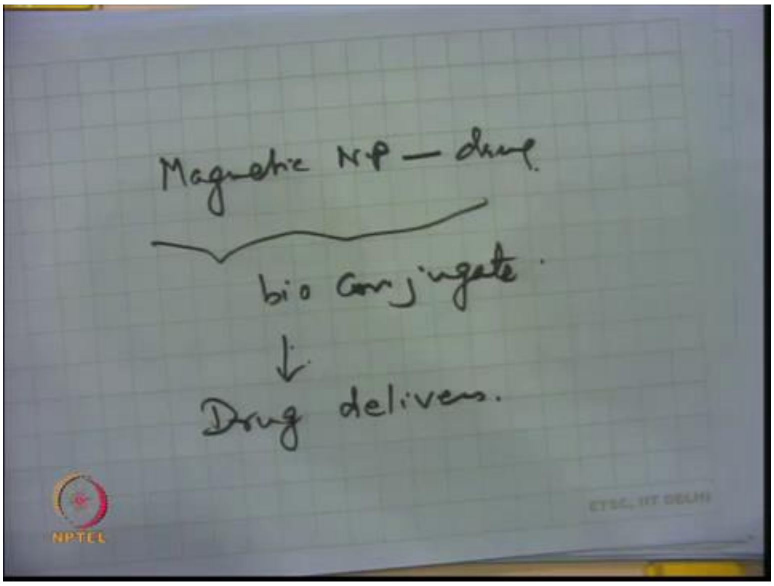

Where, if you make conjugates of the magnetic particle say you have a magnetic nano particle and you make a conjugate with a drug. So, this will be called a bio conjugate and this can be used to for drug delivery, since you can guide the drug, which is attach to the magnetic nano particle based on a magnetic field. So, since the magnetic nano particle will move as you guide it with the magnetic field and along with that it will carry the drug particle and take it to the place, where the magnetic nano particle is being guided to...

So, that is the way you can make drug delivery possible using the magnetic property of nano particle. So, this is another key important property we studied in nano dimensions, where it is use in medicine and drug delivery has been discussed in this course. However, in the magnetic nano particle being use for drug delivery, the size of the nano particle is not critically low like required for observation of quantum phenomenon.

So, you can use large sized nano particle for example, 100 nanometer particle can be use for drug delivery, it need not be 2 nanometer or 5 nanometer, etcetera, which is essential to see quantum effect. But, that is not necessary that size is not necessary for looking at the magnetic properties of nano particle for in drug delivery or in nano medicine. So, these are some simple differences, when you do nano particle for various applications, you have to keep in mind that if you are looking for an application, which is depends on the quantum effect of nano particles.

Then you have to work with very small particle of the range of 2, 3, 4, 5 or 10 nanometers. Whereas, if you are looking for an application involving some bio molecule or conjugation to a drug molecule, then that size can be larger can be 40 nanometer, 50 nanometer. Then it will depend on some other properties like, what is the size of particle which will penetrate across a cell wall is it important, those or which will remove across a membrane in a living system. Those will be concern, which are of more interest, rather than the quantum effects of the nano particle. So, one has to keep in mind these things, so we certainly discuss optical properties and magnetic properties and there are other effects of nano dimension materials, which we discussed.

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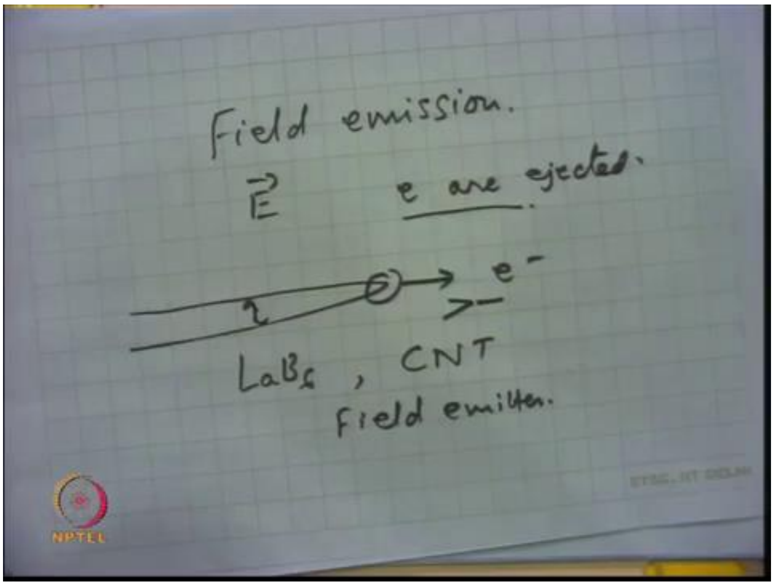

For example, you have something like a field emission, so field emission means, you apply an electric field and you get electrons. So, you apply an electric field and electrons are ejected out of the material, so if you have a nanostructure with a fine tip, then it is easy for electrons to came out. So, many one dimensional of nano structure of materials like, lanthanum hexa boride or carbon nano tubes have been used to make field emitters.

And here the dimensions of these rods and specially at the tip, what is the diameter that is very important a sharp tip will be a very good for the electron emission. And so these properties again field emission depends a depends a lot on how you have created these nanostructures. So, there are several techniques on the synthesis, so few of these particles I just went through, now the synthesis we also discussed in very elaborate fashion.

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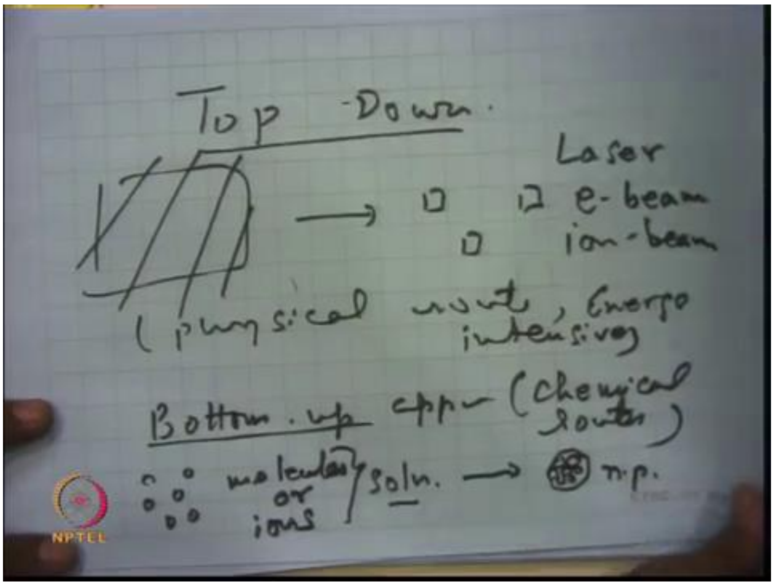

For example, you have the top down method and where you have a large particle and then you slowly break it into small particles, many small particles. So, this the top down approach and this is also called the physical root and it is highly energy intensive, but the bottom up approach is also called the chemical roots, where you start with small you know these are say in molecules or ions. So, this are say in solution and from that you build them, so you assemble these particles, such that this becomes a nano particle.

So, this is the chemical root, where you are taking small sized objects and assembling them. So, you have top down method and you have bottom up method, these are physical method, energy intensive you may need lasers or you may need electron beam or ion beams. So, high energy situation, whereas here you do work with solutions and chemistry, etcetera.

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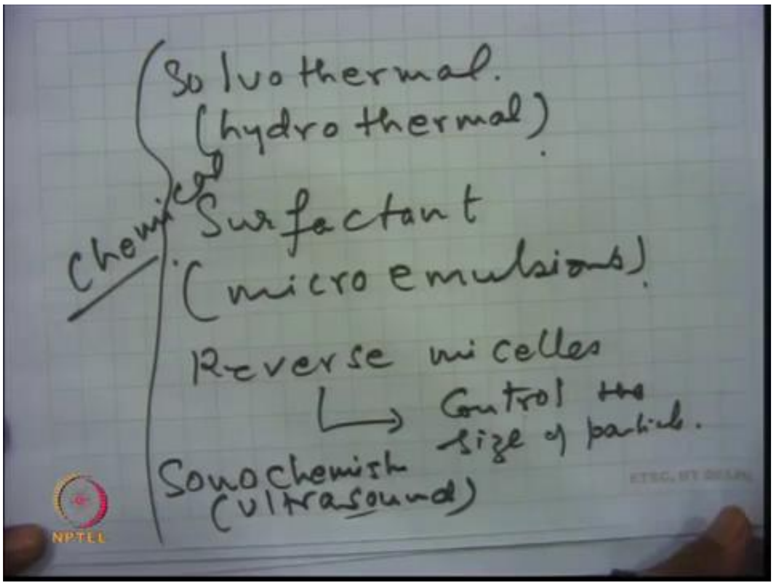

And some of the important chemical roots, we discussed or for example, the solvo thermal roots. And then which of course, includes hydro thermal if the solvent is water, then it is the hydro thermal root and you also we discussed surfactant mediated roots. So, you can use surfactant as templates and you can also use surfactant to micro emulsions and using micro emulsions, especially reverse micelles, we can control the size of particles is very effectively.

So, apart from that you can work with for examples, sono chemistry where we use something like ultra sound. So, various methods have been use and this are all we can consider as chemical roots, all though so no chemistry you are using ultra sound, but again you are putting them in a solutions. So, and there the control in this of the size and shape of the particles is quite effective, and that we discussed in great detail, so you can make bulk particles.

That means, powder particles, which are nano crystalline both by physical methods, which are the top down methods and the chemical methods, which are uses the soft root at low temperatures, solution based methods. In which you add some time templates like, surfactants to control the size and shape of particles, now these are polycrystalline samples and you can make powders. So, but suppose for applications you want to make devices etcetera, then you may need to make nano structured films, so that also we discussed.

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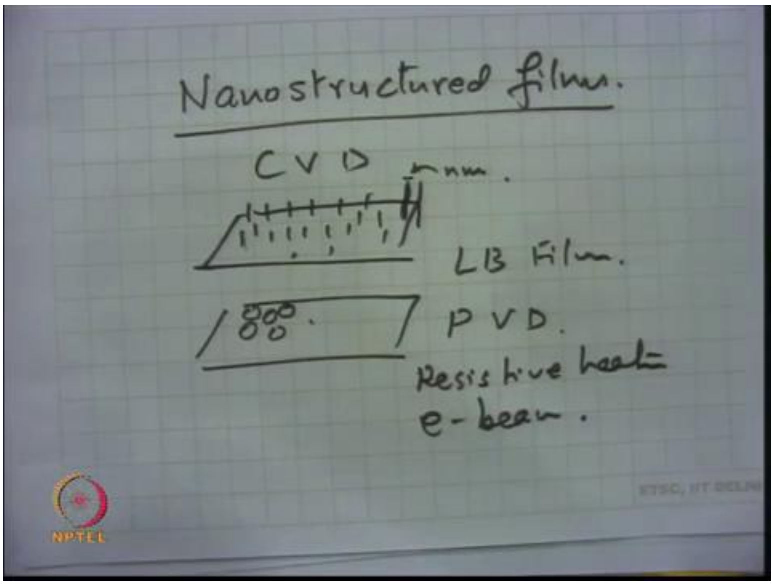

So, nano structured films if you want to make, then you have to use some other techniques. So, typically you have a substrate and on that substrate you want some structures, which are grown on the substrate and how you do that, you can do by what is called a common chemical vapour deposition root. So, on this substrate you can have pillars of or wires of nano structures and here the wires themselves may be long, may be micron size, but there diameter is nanometer diameter.

So, these lengths can be long or sometimes even the length can be nanometer dimension, so you can have these kinds of columnar or you can have particles, which are assembled on the top of the substrate. So, one of the method in CVD, but again you have various other techniques, you can do what is called LB film techniques, ((Refer Time: 18:47)) Blodgett film techniques as a chemical root or you can do physical vapour deposition roots, which include either resistive heating through a wire or you can use electron beam etcetera.

So, many of these nano structured films can be prepare and all kinds of nanostructure are now known, which can be prepared in the large quantities. And one of the most important materials in nano technology is carbon based nano structures and that has been studied to great extend, how to grow good quality carbon nano fibers on top of substrates and use them for different applications.

So, growing nano structured films is gain very important method because, ultimately to make a devise, typically you need films and the substrate can be change depending on your application. So, synthesis of nano powders synthesis of nano crystals and nano structured films both been covered in this course in great detail.

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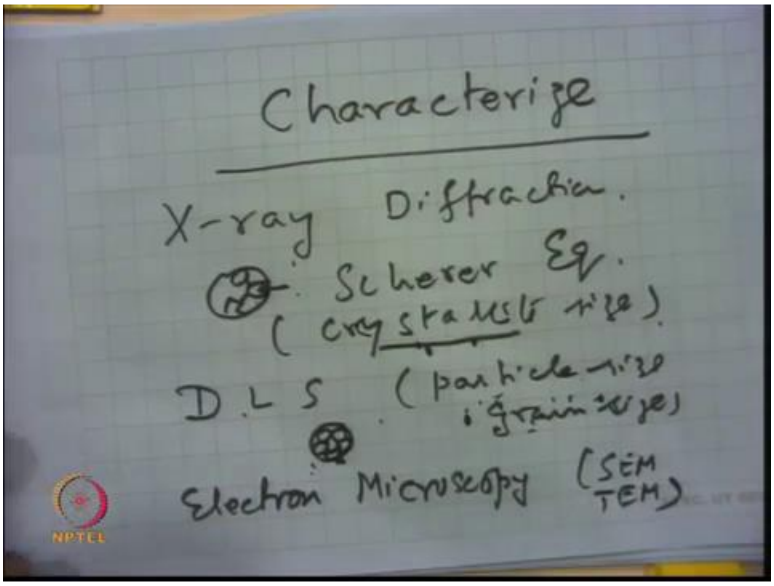

Now, if you want to study a characterize, so one is looking at how to make them, then after making them you want to characterize. So, we went into all the techniques that are commonly used like, X ray diffraction, how to find the particle size, etcetera, so you use what is called Scherer equation for finding the crystallite size. And you can also used what is called dynamic light scattering, where you use a laser light which scatters and finds the size of the particle, but here it is call particle size or grain size.

And it is different from crystallite size, particle size and crystallite size will be same only if this particles are single crystals. Because, X ray finds out using the Scherer equation the size based on assuming the each crystal whereas, in light scattering you it will find an object, which is diffusing at a particular velocity. And from that try to calculate using the stoke science and equation about the size of the particle, so it does not look at only whether it is single crystal not, it finds a particle and the particle can be made of 4, 5 crystals together.

So, then you will get a overall size in DLS, whereas in X ray even if you have these kind of agglomerates, you will get only the size of a single crystal which is forming the agglomerate. So, that is why normally crystallites size will always be smaller whereas, light scattering will give you particle size, which is larger and the two will be same the crystallite size and the particle size, only when these particles are single crystalline, then these two sizes these are an important difference between crystallites and particle size.

So, you characterize the size using X ray or light scattering or using electron microscopy, so microscopy is a important technique in nano technology. And you can do scanning electron microscopy or transmission electron microscopy and we have discussed them in great detail to look at the particles.

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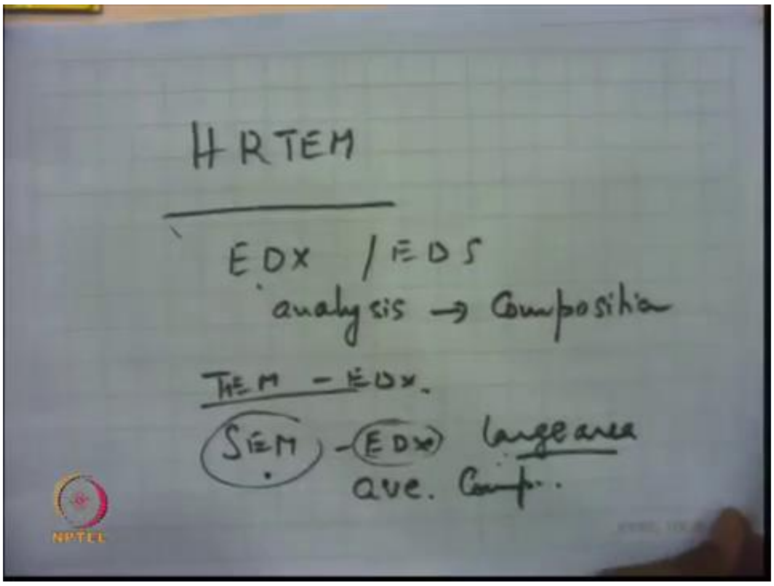

If you are very small particles and you want to see high resolution, when you do what is called HRTEM. That means, you need a very high resolution and careful study, where you can then look at and array of particles, array of atoms and sometime you can go atomic resolution. And so you can find out exactly what is the size of your particle and also the phases which you are seeing, so HRTEM is nothing but transmission electron microscopy, but you are doing in the high resolution mode.

And apart from that you can find the composition of the particles, etcetera using electron microscopy by doing what is called the EDX electron diffraction energy dispersive, X ray analysis or sometimes it is also called EDS is a same thing, which is basically analysis is a analysis of the material and it gives you the composition. So, if you have an

EDX attach to TEM you can do what is call tem EDX and it is more precise because, you are looking at very small grains, but if you are doing with SEM, EDX.

So, the EDX the detector is attached to the scanning electron microscope, it looks at a much larger area and not individual grains in a SEM and so you get a average compositions. So, average composition over many grains you get in a SEM whereas, TEM you can get more precise composition of single grains at which you looking at, so these are methods by which you can finds the composition of the nano particles. So, these are for characterization you do X ray diffraction, light scattering and electron microscopy to get the size of the particle, the shape of the particle, the composition of the particle.

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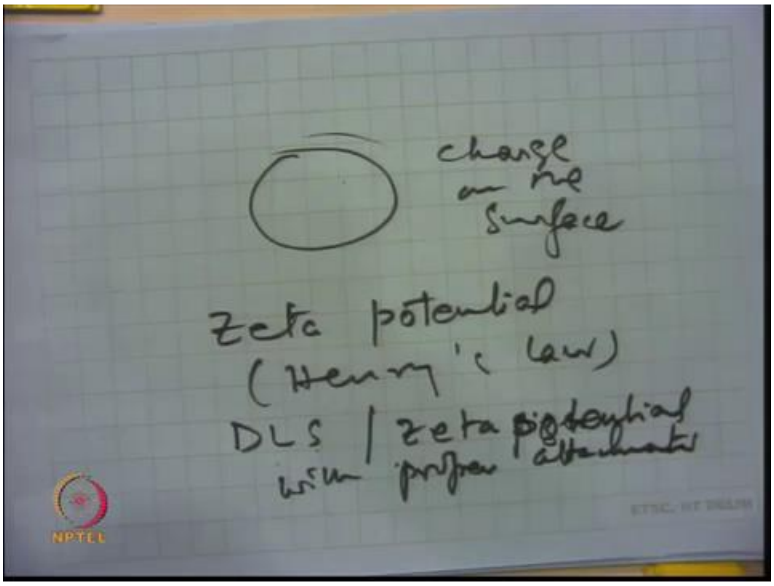

Now, if you want to look at what is the charge on the surface of the particle, so what is the charge on the surface. Then you do what is called a zeta potential measurement and this zeta potential is related to what is called Henry's law and the instrumentation that is you use basically comes along with a light scattering machine. So, a DLS machine is attached with you can analyze using what is called zeta sizer or you can analyze the zeta potential using a light scattering machine with proper attachments.

And you can also study variation of the zeta potential as you are changing the p H of the system. So, it is possible to study, which is an very important study to understand how the p H is controlling the surface charge, so that kind of work is possible in modern day equipments, where light scattering and zeta potential both can be measured. And also measured as a function of change in the p H of the system, so these are some techniques by which you can measure the particle size shape and surface charge of the system. Now, the two main equipments we change the face of nano, because of which nano technology became very important or very the famous or the AFM and the STM.

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So, the discovery of AFM and STM by Binnig and Rohrer who got the Nobel prize along with Ruska, who had discover the electron microscope long back. So, three of them got in the Nobel prize, but this was in around 1985, 1986 that these two were discovered and hence nano technology became very important after 1985, 1986 in the 1980's. And the atomic force microscope can measure all type of samples whereas, STM measures mainly conducting samples, so here tunneling current is measured.

And here force is important, what is the force felt by the cantilever when it comes close to the surface. So, they the two are different measurements they tell you a lot about the nanostructure present and these two probes have been expanded two introduced many, many new methodologies. For example MFM, which is the Magnetic Force Microscopy you can map out in a sample regions of high magnetization, low magnetization, etcetera. These are nothing but how the AFM has been modified the tip has been modify with the magnetic probe, which looks on to the surface.

So, all types of techniques you can have what is call the scanning electrochemical microscope. And like that many, many microscopes are possible, all together they are called SPM, which means scanning probe microscopy, so scanning probe microscopy is the common name for this whole lot of techniques, which is the corner stone of nano technology. And one comes across measurements using some form or the other of the scanning probe microscopy in this area of research of nano science and nano technology.

So, the basics of AFM, STM, etcetera we have discussed in length and we had looked at the images that they generate and how to understand nanostructures using scanning probe microscopy has been dealt in great detail in this course. Now, apart from these X ray techniques, microscopy and scanning probe techniques, what are the other techniques that people are using.

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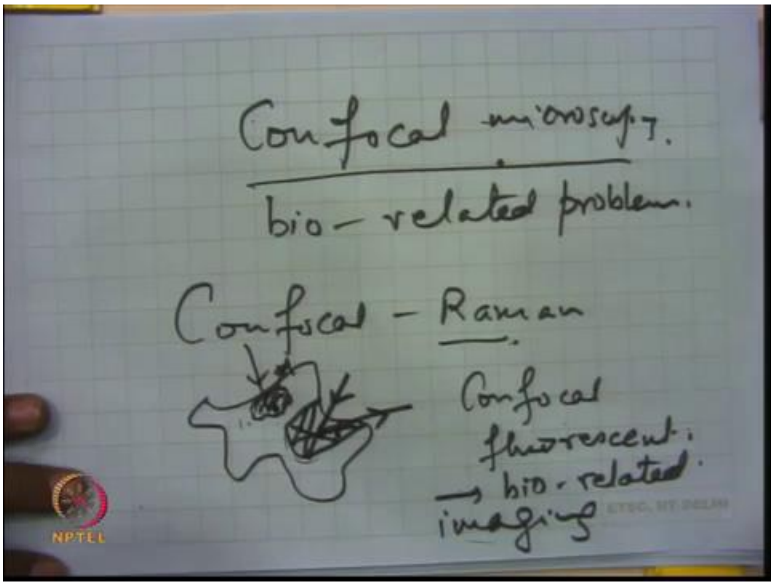

Now, this AFM a people also use in conjunction with what is called confocal microscopy. So, now days you can look at an object and especially in bio related problems of nano science, you can make use of confocal microscopy to a great extent. And then you can also do what is called confocal Raman as a technique to understand the Raman's signals, which are coming from specific regions from a sample. So, if you have a samples here, nano particle like this and you want to study is small portion is of this and there is another portion, which has a different kind of feature.

So, you have say looked at this using scanning probe techniques and this is looks different then this and you want to look at, whether the Raman active modes here are different from that. So, you can use a confocal Raman microprobe to understand, what is happening when you a pass light beam and understand the scattered radiations, which are coming out from this point and you can also focus at this point. So, you can do confocal Raman at different positions and from the signals that they gave, you can understand the differences of the region here and the region there.

So, confocal Raman is a very, very important technique to understand the different types of phases, which are present in nano structures. More importantly confocal microscopy with florescent markers is very important in bio related problems, so you can study the florescence of a dye, which is entered into some cell under the confocal microscope and you can understand how it is present and whether it is migrating somewhere, etcetera.

And you can also do spectroscopy at different points and together this technique of confocal microscopy, confocal imaging it gives you an image of these nano structures with respect to especially, which are related to bio or a cellular objects. You can understand many of the processes, very important processes using imaging in a confocal microscope. So, is confocal microscopy is again kind of become a basic tool like the AFM the confocal microscope basic tool of a any lab, which is working on nano science or nano technology.

And especially, if you are working any biology related problem, then this confocal microscopy becomes very important. The confocal Raman of course, is more important for people you are working on nano materials, the carbon based compound nano structures for that the Raman spectroscopy is very important. And hence if you could can do confocal Raman, then you can look at the Raman's signals from different parts of the same material within nano structured a domains. So, this is a great advancement in the technology that we have today to understand nanostructures.

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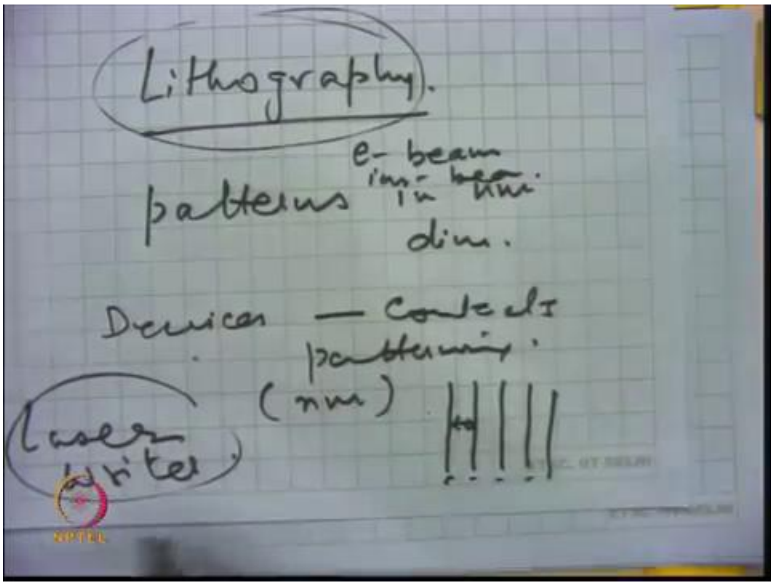

Then, we have lithography by which we can make patterns in nanometer dimensions, so this is very important, because you are trying to make ultimately devices, which will have contacts, and hence you need patterning with some material and this patterning should be as low as possible to make smaller and smaller devices and so how to achieve that. So, this lithography that is making kind of designing something using very fine beam of lasers or electrons or ions.

So, you can have ion e beam or ion beam or you can used what is called laser writer, so by doing this you can make patterns. So, you can make patterns like for example, you make lines like this, now if you want to make patterns regular lines and the dimensions you want to keep nanometer dimensions. And may be the gap is lightly more than few nanometer, this may be 5 nanometer, this may be 20 nanometer, this repetitive structure if you want you this patterning has to be done by a things like e beam and ion beam or laser writing etcetera.

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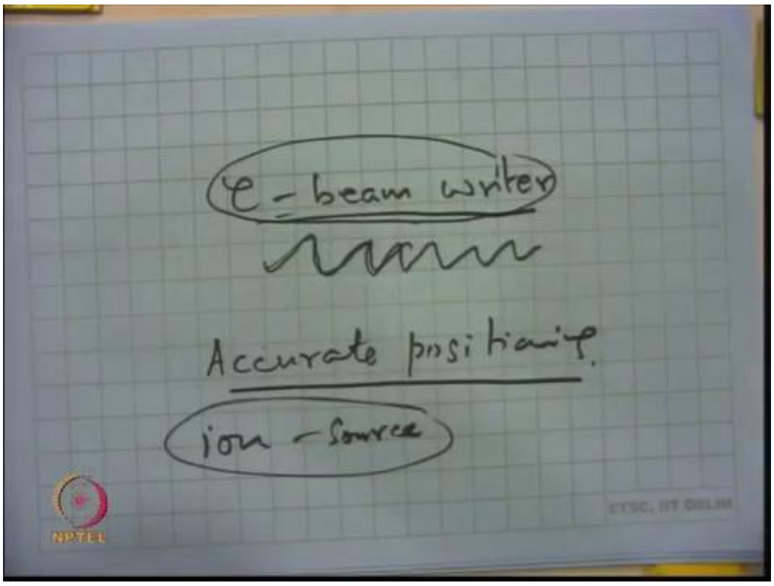

And, so we have now commercial e beam writers, so you can have like in electron microscope, here also you can have a source of electrons, but then that electron beam can be manipulated. So, that it can move like moving of a pen, so you can manipulate the electron beam like, you can manipulate the pen, so and hence it is called a e beam writer because, what you are writing here in ink, you are writing with electrons, so that is called an e beam writer.

So, you need to control the electron beam very carefully and commercial machines are available, where you can use e beam writing to make patterns, so and that is called e beam lithography. And you can even have robotic arms to move the samples within the e beam writer and place it such that, you do not a very accurate positioning of the sample can be done. So, accurate positioning of the sample is important because, otherwise you cannot make a patterns, which are nanometer dimensions unless you are very accurate positioning systems.

So, these are now available, so the technology has really move in finding out methods, how you can make finer and finer tracks or circuits based on some material. So, you can write with any atoms, so you can have use and ion source to pattern particular kind of element on top of the substrate. So, this is been people have doing for some time, like that we discussed many other methods, how you can make patterns on surfaces and e beam writing is one such method.

So, lithography is a big and challenging problem and also solution for nano technology, which requires advance laboratory, which requires clean rooms. And everything has to be dust free, you have instruments within clean rooms and you have a characterization facilities within clean rooms. Because, you are talking of very, very small dimensions and in such kind of e beam writing or ion beam writing, if there are dust particles they will scattered them and you will not get any accuracy.

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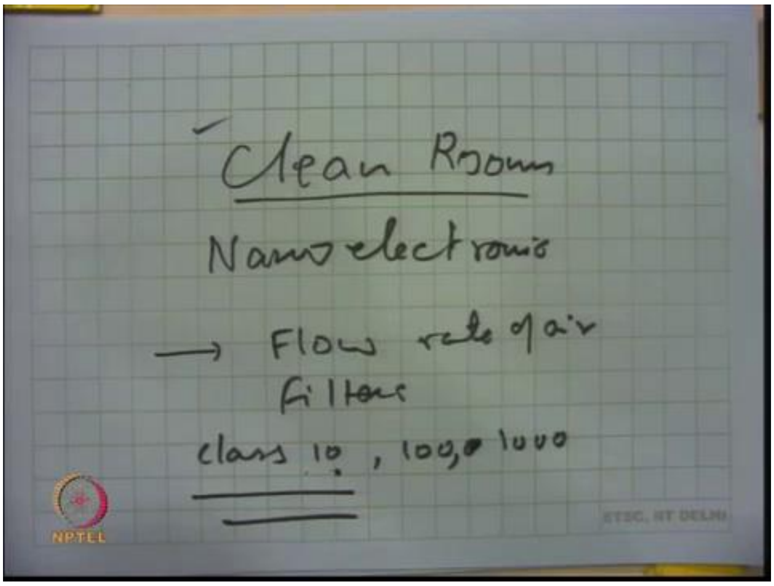

So, a very important thing in nano technology is especially, if you are working in nano electronics. Where you are trying to pattern circuits is you need very good clean rooms and these clean rooms are quite expensive, because you need to design this clean rooms with some particular conditions and flow rate of air and filters for removing particles above a certain size and based on these filters. And what size of particles cannot enter that room, you have what we call class several classes of clean room, so class 10 class, 100 class 1000.

So, these tell you that you cannot you have a room, which is class 10 means particles smaller than 10 microns cannot enter that room. So, you have filters which can fill, this will be very expensive and normally class 10 you normally have a small region in the laboratory, which may be a small hood or something which is class 10, ideally clean rooms are class 100 or class 1000 or class 10,000 a class 10,000 is like not that great for doing nano electronics works.

So, depends on what kind of work you plan to do in the clean rooms, what kind of lithography you plan to do in the clean rooms, that will tell you what kind of class of clean room, you must have. And making a clean room itself is a very challenging and technical problem which of course, has been develop and there are many companies which may rooms etcetera, so this is special if you are working in nano electronics etcetera.

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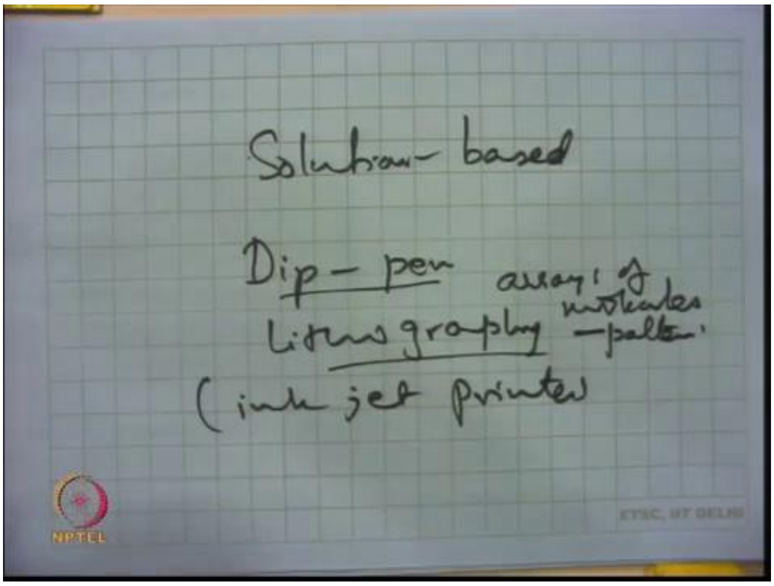

But, if you are working with the solution based techniques and you want to pattern something, then as a technique like dip pen lithography can be used. Where it use as a solution with molecules and this is based on like your inkjet prints on your paper like that, you can have dip pen lithography and you can have arrays of molecules of your choice and you can make patterns out of these molecules. So, this is solution based is less expensive does not need the types of clean rooms, which you need to do nano electronics and many any places such lithography is sufficient.

But, to do really high quality nano electronics, we need to have clean rooms of the best quality. So, these are several of the characterization techniques, which we have done or fabrication techniques, which we have discussed in various parts of the course and apart from writing on substrates, etcetera. We also discussed how people have worked on making devices like you can have a carbon nano tube and then join to a platinum wire.

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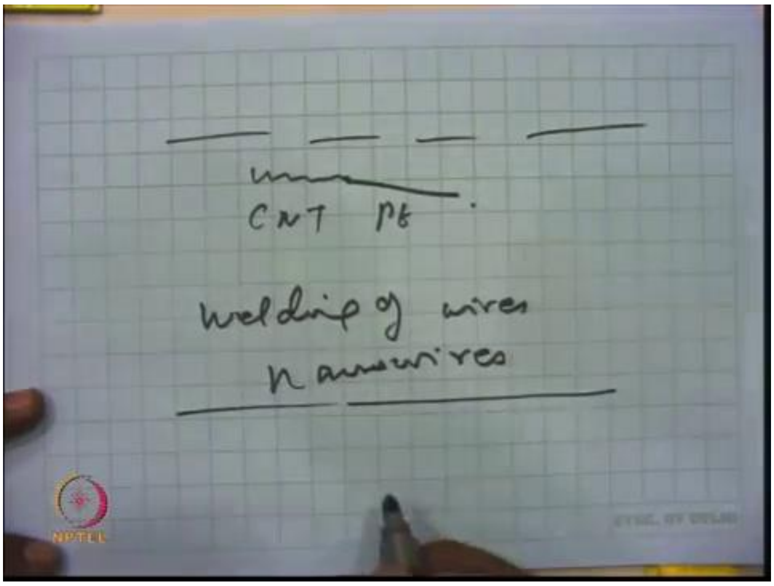

So, such kind of things people have done, this is like people welding to wires, so this kind of welding of wires here nano wires has been done by several groups in the world, we were discussed the kind of devices, which have been made out of these kind of welding of wires in some cases. Now, you can some of the very good applications, where nano science and nanotechnology are these nanostructure materials will be useful. Let me mention in conclusion that where are we going use these nano science and nano technology.

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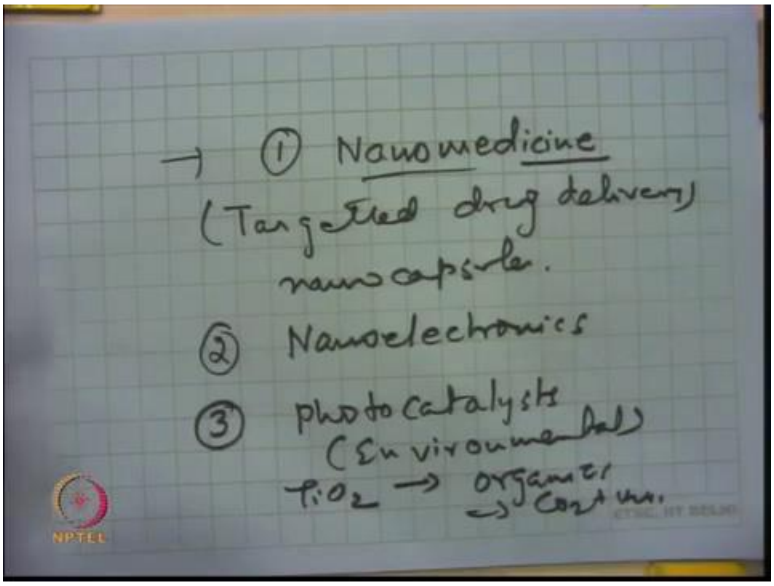

So, for example, one of the places which people really want to use the study of nano structured materials is in nano medicine. So, lot of research is going on targeted drug delivery or related aspects and also people are trying to make nano capsules with the drug inside. So, in nano medicine this tremendous hope, the other area of course, is a nano electronics, if you can make smaller and smaller chips and increase the memory of the devices, then a lot of interest is there in photo catalysis. So, make nanostructure materials, which are very good photo catalyst and this is from the environmental point of you. So, one of the most popular nano materials is T i O 2 and this is used to spilt organics to carbon dioxide and water, so why that you want to clean the environmental.

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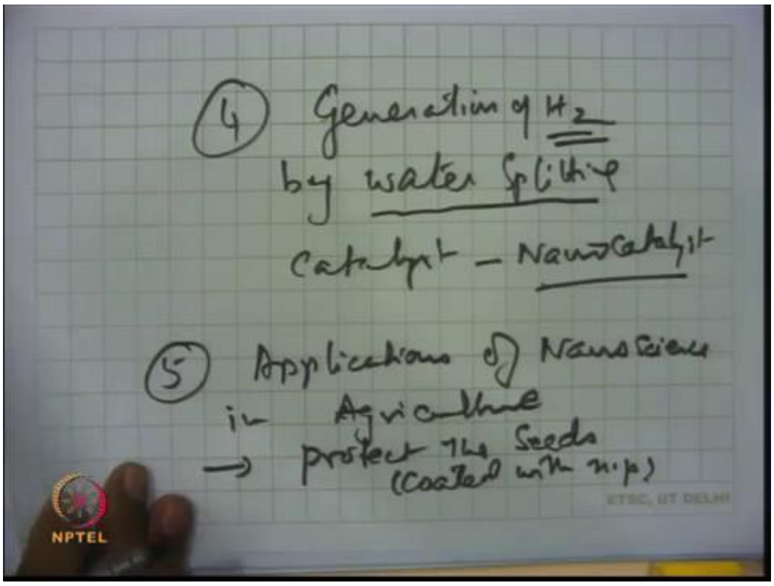

So, then 4'th thing is can be use nano structured materials for generation of hydrogen by water splitting. So, since fuel is becoming there is a lake of fuel on the earth soon, we will be a having no petroleum and even coal will finish by 2100 you need to have alternative sources of energy and hydrogen is being doubted as one of the areas with you can use hydrogen to generate energy.

But, how do you get hydrogen easily, one is by water splitting and what will do the splitting some catalyst and which catalyst you will choose your nano catalyst. And so there is lot of work in the type of nano catalyst for generation of hydrogen by water splitting, this is a very, very challenging problem. Now, we are discussing what is the future of nano science and nanotechnology and where it will probably the applicable, so nano medicine, nano electronics, photo catalysis for environmental purposes, then the generation of hydrogen, when lot of interest there, now in applications of nano science in agriculture. Say can you protect the seeds by giving some coating of coated with nano particles, so there are lot of interest in finding out applications of nano science in agriculture.

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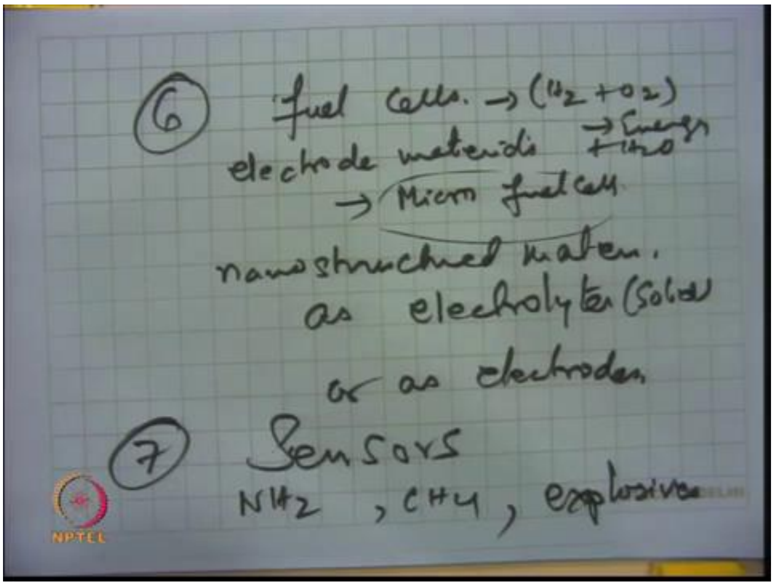

Then people are interested in making materials for fuel cells, so the electrode materials, which are applicable for fuel cells in the nano size to make if not a nano fuel cell, but you can think of what is call a micro fuel cell. So, fuel cell uses hydrogen and reacts with oxygen to give you energy and water, so the by product in a fuel cell is energy and by product is water. So, it is a very clean form of energy and lot of work is going on in trying fabricate, micro fuel cells using nano structured materials as electrolytes or very solid electrolytes or as electrodes.

So, varies such aspects of nano science and nano technology are there a very important applications is in sensors. So, lot of material in nano structure materials are been used for say sensor for a ammonia, for methane and to detect these type of gases and also sensors for explosive. So, lot of research is going on how to use nano structured material to detect explosive like, TNT or RDX, etcetera, there is lot of research already some work has been have has already come out different countries on these materials.

So, several such applications are there and what I went through are few of them, which we have discussed in the whole course. So, with this I would like to wrap up is course and I hope that you have gone through the whole course material by now and got a feeling for what nano structured materials are how they can be synthesized and how their properties can be measured, what are the key techniques which any buddy who is practicing nano science and nanotechnology has to have or has to find to do work on nano structured materials.

And what is the scope of applications, we see there is wide ranging scope of applications of nano structured materials right from medicine to agriculture, including electronics. And it will be an area, which will be more and more interesting for with people who are coming in future and it is a interdisciplinary subject. So, it does not matter whether you are chemist or biologist or engineer, nano technology has room for every buddy, the interest is to make a device using the properties of nano structured materials and the device should be miniaturized and it helps solve a problem.

So, most of the time to solve a problem to make a device, using nano structured materials you will have to have a interdisciplinary kind of approach. And you will have to interact with people of different origin, may be an electronic engineer has to interact with the biologist or a chemical engineer has to interact with mechanic engineer and a chemist to fabricate a device, through which say nano particles are flowing in a fueled and cooling something. So, I dint touch upon this too much, but there are thing called nano fluids by which you can heat exchange very, very much better than conventional cooling agents.

So, this is an area, which is important from the nano structured material point of view and also from the mechanical engineering point of view, where mechanical engineers are involved in designing heat exchangers. So, this is an example how to very different fields a chemist who is making nano material and a mechanical engineer who is designing a heat exchanger come together in an area called nano fluids, which once flowing through a tube can cool the environment around it.

Similarly, if you want to make a micro fuel cell, you need a chemical engineer who is the designing the fuel cell with a nanostructure materials person, who is making the electrodes made of nano materials. And this kind of overlap of areas is the hallmark of nano science and technology and nano structured materials full form, the key to many,

many applications in futures. So, with these words let me thank all of you for taking part in this course and attending this course and I hope you will be able to answer all the questions, which will given as a part of this course.

Thank you very much for you kind attention.