Nano structured Materials-Synthesis, Properties Self Assembly and Applications
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Module - 3
Lecture - 28
Nanocomposites – II

Welcome back to this course on nano structured materials, synthesis, properties, self assembly and applications. We are in the module 3 and this is the last lecture of module 3; the twelfth lecture. And we are discussing nanocomposites the subject of the nanocomposites we started in the previous lecture. And today is the second lecture for nanocomposites. So, briefly we discussed in the last class that composites are a mixture of 2 or more metals or ceramics or metal ceramics which do not form a single compound or a solute solution. They are separate entities, but mixed a very vigorously and intimately to give you a structure where if you look at the x ray diffraction patterns.

Then you should be able to see the different phases, which form the composite. If the phases, which are making the composite are crystalline then you will see all the phases in an x ray diffraction pattern or even under electron micrographs. However, if you have a polymer and one crystalline material forming a nanocomposite then you can you may be able to see a broad hump of the polymer and a sharp lines for the crystalline material, which is forming the nanocomposite. So, there are different types of nanocomposites which we studied which can be one metal in a ceramic like an oxide. It can be gold in T i O 2 or silver in a S i O 2 or it can be a polymer with another polymer or a polymer with a ceramic or a polymer with metal nanoparticles.

So, wide variety of a composites are possible and it is not only 2 materials that can be mixed to form a composite, you can have 3 4 different materials to form a composite. And we discuss that why composites are important, the most important part is that composites give multi functionality. So, if you have 3 in the visual components making the composite then you get 3 different properties are possible to be present in the composite which you make. And specifically when you talking about nanocomposites, how is it different than a normal composites? Is that one of the in gradients should be in the nano dimensions? So, when you are taking 2 or 3 different materials one of the material has to be either a nanoparticle or a nanowire or a nanoplate. So, one component of say binary mixture of components or ternary mixture of components yielding the composites should be nanosize then you get a nanocomposite. So, today, we continue on the second and final lecture of nanocomposites.

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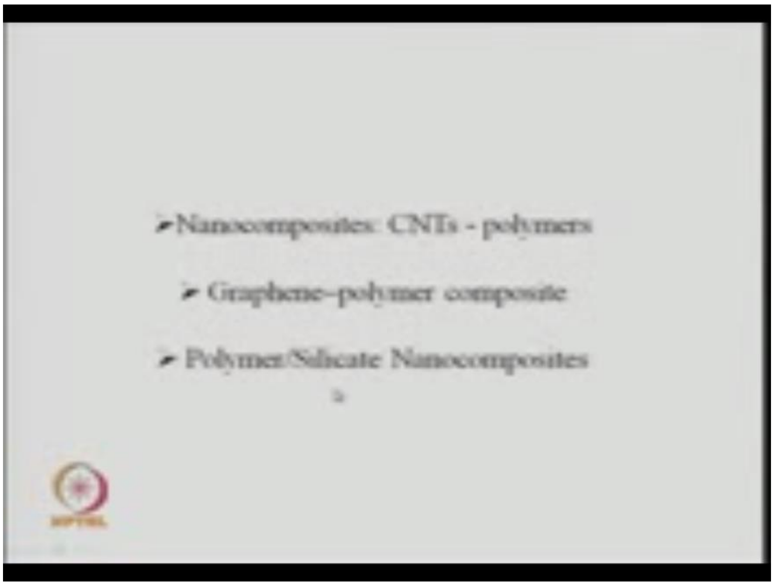

So, today we will discuss some composites which are made of carbon nanotubes and polymers. A carbon nanotubes as we have discussed earlier in this course are can be of different kinds they can be single walled multi walled. And basically they are nano in a two dimensions the third dimension can be very large, because it is a nanotube. So, it can be 100 micron, 5 micron, 10 micron and certainly more than a 50 to 60 nanometers. Whereas, the other two dimensions of carbon nanotubes depending on the number of nanotubes in a bundle can be of few nanometers to 20, 30, 40 nanometers.

So, when you mix these nanotubes of carbon with polymers different types of polymers you can get different properties depending on whether this is a semiconducting nanotube. Then you will have semiconducting property incorporated in to the nanocomposite with the polymer. And the polymer will be giving it strength or ductility etcetera for applications. So, combinations of carbon nanotubes either semi conducting, or metallic carbon nanotubes with polymers or known and they have different properties as we will discuss. Then a very fascinating material, which is of interest in recent times is grapheme. Graphene is one layer of graphite if you take graphite, which has got several layers made of carbon hexagonal rings of carbon and the layers in between have very weak Vander Waal forces.

So, this layered structure of graphite if you can remove one layer from graphite then you get graphene and graphene is very exciting. Because of its high mobility of electrons and it graphene is known as a dirac solid and it is it has got tremendous applications. So, people are trying to make graphene polymer composites so here graphene is a 2 dimensional sheet. So, it is like a nanoplate or nanosheet, because one dimension in graphene is in nanometers. So, it may be one nanometer or 2 nanometers it that depends on how many layers of graphene you have.

So, graphene polymer composites will give you a the functionality of conductivity of graphene and many other properties of graphene in the polymer. And the polymer is basically to stabilize this graphene and the nanocomposite becomes mechanically robust then you can have polymers with silicate materials. So, there are several silicate materials some are a naturally occurring some are manmade large number of ores of silicon are basically silicate materials even zeolites are alumino silicates. There can be many many silicates based on magnesium strontium etcetera, which are available in nature. And which can also be synthesized in the laboratory and when you mix these silicates with polymers you get different types of nanocomposites.

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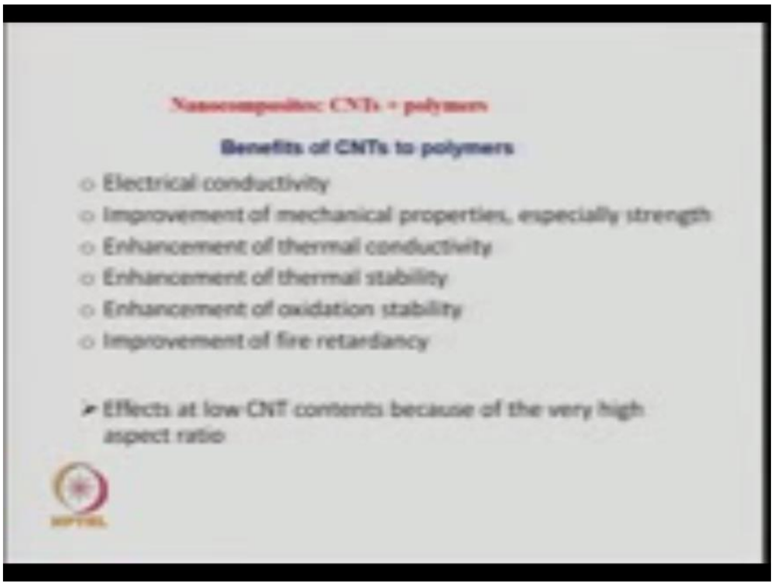

So coming to the first class of nanocomposites, which we are discussing today is a blend of carbon nanotubes and polymers. So, what are the benefits that carbon nanotubes can give to this nanocomposite? As I mentioned some of the carbon nanotubes a are highly conducting. And those carbon nanotubes are metallic and they give high electrical conductivity a. So, the nanocomposite made with such carbon nanotubes will show such high electrical conductivity then you can improve mechanical properties. The mechanical strength you can improve thermal conductivity; you can enhance the thermal stability by making composites with polymers enhancement of oxidation stability. And it can be used as fire retardant when you mix nanocomposites of made from carbon nanotubes and polymers of you chose the right polymers.

You can have composites which are fire retardants the, a very high aspect ratio of carbon nanotube a leads to properties at very low concentrations of carbon nanotubes. So, with very low dopant of carbon nanotube you can get excellent properties, because of the very high aspect ratio of these nanotubes. The aspect ratio is basically the, if you take the ratio of the length and the breadth of the nanotube then that is called the aspect ratio. And the longer the tube and thinner, the tube you will have a higher aspect ratio and the high aspect ratio allows you to add very small amounts of carbon nanotubes as dopants but the nanocomposite have has very enhanced features. And properties which have been listed here and discussed like electrical conductivity thermal conductivity, etcetera.

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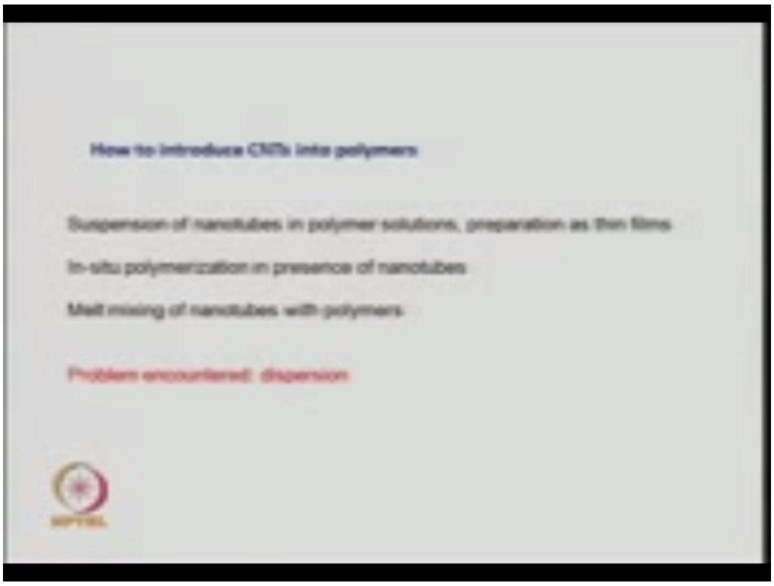

Now, how do you introduce carbon nanotubes into these polymers? So, one of the methodologies is that you suspend these nanotubes in polymer solutions and then you can spin code them to make thin films. Of course, there are various other methods of making thin films, but this is a simple methodology you suspend them in nano the nanotubes in solution and spin code them or dip code them on substrates of your choice. A variety of substrates you can use and depending on your spinning speed and the concentration of the nanotubes in polymer. You can vary the thickness of these thin films this is one methodology otherwise you can do in situ polymerization. So, you have nanotubes and you start with monomer in the solution mixed with a nanotubes and then you do the polymerization in situ in the presence of the nanotubes.

So, then you will have a good mixing of the nanotubes in the polymer the other is you do a melt mixing of nanotubes you take nanotubes and take an polymer. And then you melt them and then allow it to cool and that is called melt mixing of nanotubes with polymers. And one of course, you have to optimize the best nanocomposite will be those where the dispersion is very high. That means the carbon nanotubes has to be dispersed a very well throughout the polymer metrics and the method chosen depending on your polymer. And depending on your concentration will make this dispersion will be dependent on these. The dispersion will be dependent on the methodology and the concentration, which you choose. So, because this is a generally a problem how well or how homogeneously you can distribute the carbon nanotubes on in the polymer? That is a key point. And you have to optimize methodologies such that you have high dispersibility of the carbon nanotubes in the polymer metrics.

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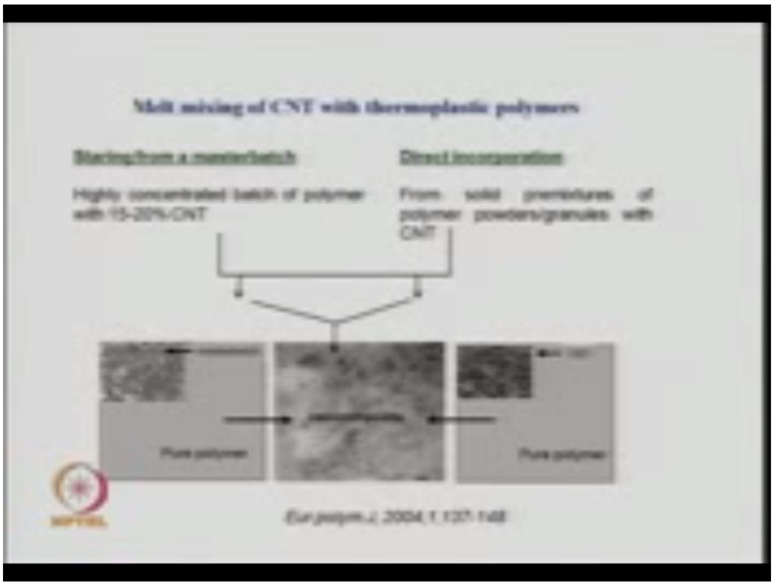

So, this is an example of melt mixing of carbon nanotube with a thermoplastic polymers. So, you start from a masterbatch of a polymer which is a highly concentrated a polymer with fifteen to 20 percent of carbon nanotube and you can. And then you directly incorporate from solid premixtures of polymer powders and nano granules with carbon nanotubes. So, and then you melt it so when you melt it then you get this nanocomposite depending on the masterbatch here is the masterbatch that you have. And if you start from a pure polymer you have this kind of features of the pure polymer.

And these are the carbon nanotubes so depending whether you are starting from a masterbatch which is a highly concentrated batch of polymer a mixed with carbon nanotubes. You get this kind of which has this kind of S E M picture of the masterbatch and this is a pure polymer and this is the nanocomposite that you get here. You have started with C N T and solid premixture of polymer powders. And these are the C N T tubes and this is the nanocomposite that you get. So, a melt mixing of carbon nanotube with thermoplastic polymers can be made in the this way. And this is the nanocomposite these are scanning electron micro graphs of nanocomposites.

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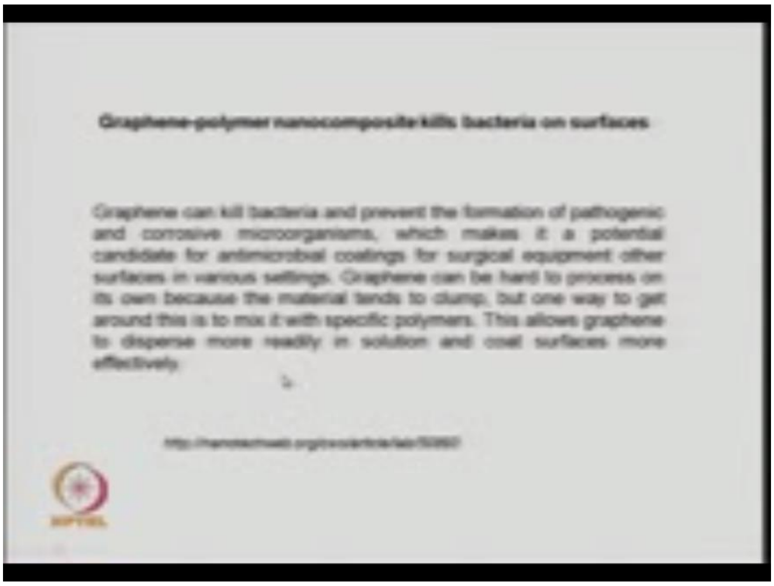

Now, this is an application of graphene with the polymer to form a nanocomposite and this kind of nanocomposite has been shown to kill bacteria on surfaces. So, graphene can kill bacteria and also prevent the formation of pathogenic and corrosive microorganisms. And so it is very important material or candidate for antimicrobial coatings for surgical equipment and various kind of tools which are used in hospitals. And especially where there is going to be a contact with a either blood or an organ where there is probability of infection if bacteria is present. So, these graphene a polymer nanocomposite coatings do not sustain bacteria.

And hence they if they are coated on top of such surfaces of blades etcetera which are used in surgically equipment. Then it provides that security against bacteria and a graphene can be hard to process on its own because graphene tends to agglomerate or clump together. And hence one of the ways of getting around this problem of aggregation of or formation of these clumps is to mix the graphene with polymers. And you have to choose specific polymers choice is such that the dispersibility is high. So, you want to disperse the graphene very readily in the solution and then coat the surfaces effectively.

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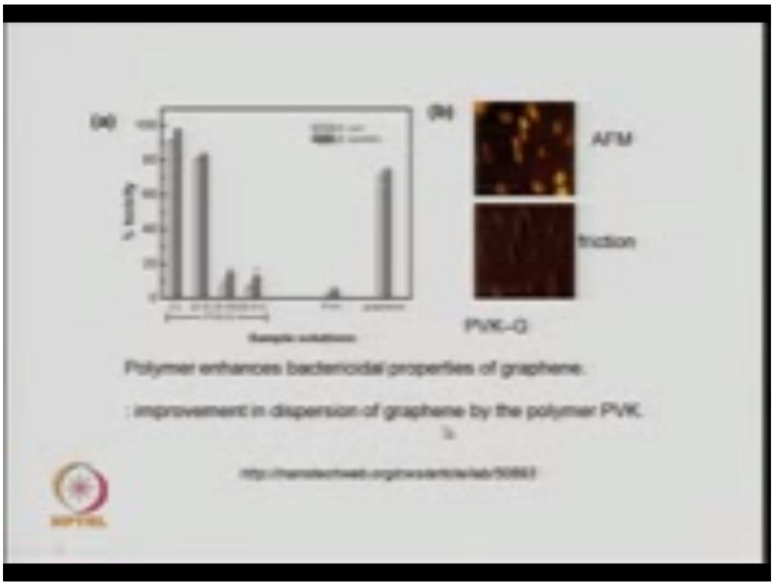

So, that is the choice has to be optimal to get very good coatings of this graphene nanocomposites on surfaces. So, this is a proof of the enhanced a bactericidal properties of grapheme. So, the polymer is enhancing the properties of the grapheme. So, if you look at a pure graphene that is somewhere here and the pure graphene acts on e coli. And you can see that is around 70 percent toxic to e coli the toxicity is there whereas, for another microorganism b subtilis that is little higher now you can add sample solutions. So, you have different types of sample solutions so and you will see that there is an improvement in dispersion of graphene by the polymer PVK.

And you see the toxicity levels come down when you have certain concentrations. So, if you have P V K this is the pure polymer right it has a it is not toxic to the bacteria and this e coli and subtilis graphene has toxicity of around 70 percent. Now, when you have this mixtures of PVK and graphene so that is PVK G and these are different sample solutions. So, you see that for certain solutions the activity is very high nearly 97 percent that means this mixture one of P V K that is the polymer. And graphene is 97 percent toxic which is higher than pure graphene which is like 70 percent toxic.

So that toxicity towards these microbes has been enhanced when you coat graphene when you mix graphene and P V K together, individually P V K is a very poor material. The polymer is not toxic to these and graphene is toxic, but with the a toxicity level of around 70 percent. Now, you also see that when you make the polymer graphene composite P V K G composite. You can see that the a A F M shows you the kind of dispersibility of graphene a in the polymer its quite uniform. And this is friction measurements on the surface of this composite which also shows quite uniformity in this and homogeneous surface. So the optimal coating of graphene with PVK a polymer can lead to much higher toxic levels for these microbes and which is helpful for applications in a medicine.

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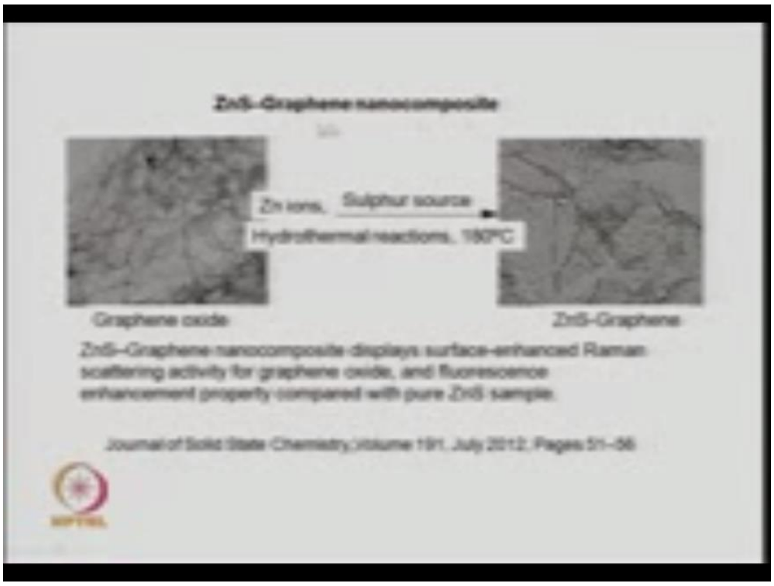

This is another example of nanocomposite of graphene with an inorganic material. So, this is zinc sulfide and zinc, sulfide, ghraphene nanocomposite can be used for several properties especially optical properties. So, here this is the a t e m the microscope picture of graphene oxide and zinc sulfide graphene nanocomposite. So, from graphene oxide you add zinc ions. So, a solution of zinc and a sulphur source and then this graphene oxide is mixed with these sulphur source and zinc ions in a hydrothermal bomb at 180 degrees. When you heat hydrothermal bomb, which is a kind of Teflon container you have inside a stainless steel bomb and then you close the lid.

So, there is a autogenous pressure which develops and that is called a hydrothermal reaction. And in that reaction zinc sulfide is formed and it spreads homogeneously on the surface of graphene oxide which becomes graphene under these conditions. So, both zinc sulfide forms these particles as you see and this layered material which shows this kind of crumpled nature is grapheme. And this is a nanocomposite of zinc sulfide and graphene and the property which you are interested in this kind of nanocomposite is the optical property.

And, so you look at surface enhanced Raman scattering for graphene oxide and with pure zinc sulfide and this nanocomposite. So, you compare the surface enhance Raman which is S C R S surface enhanced Raman scattering is a very important technique. And there you see that the nanocomposite displays a enhanced scattering and you can see fluorescence enhanced property compared to pure zinc sulfide. So, the sers activity you compare with graphene oxide and for the nanocomposite it is much higher than for graphene oxide and the fluorescence enhancement. You compare with zinc sulfide again for the nanocomposite the enhancement is much larger.

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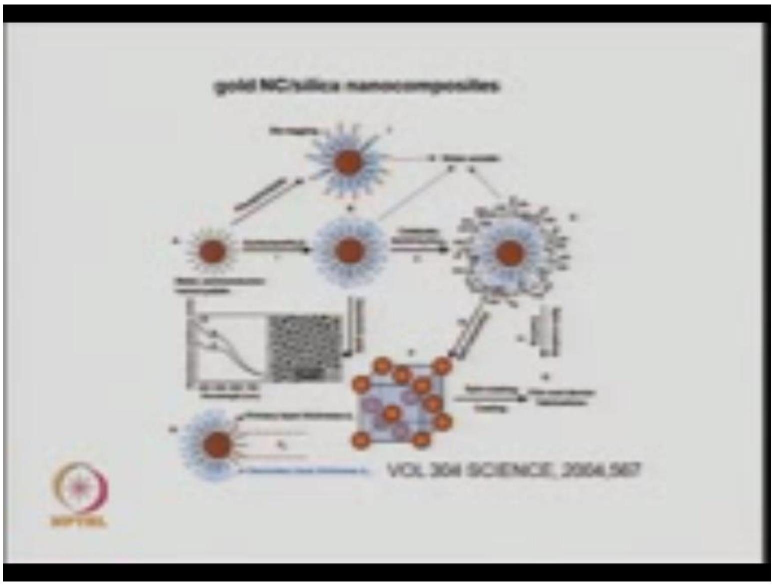

Now, this is another example and this is an example of a gold nanocrystals on silica. So, here the nanoparticles are of gold. And they are crystalline nanoparticles and you the metrics is silica that is S i O 2 and together they form nanocomposites. And so what you do is you start with your gold which can be metal here we are discussing with metal and you can have different processes to get different properties. So, here you can see that phospho lipids have been coated gold nanoparticles assuming a is gold nanoparticle. You have phospholipids on that and phospholipids are water soluble similarly, you can have these gold particles capped with surfactants.

And that is what it shows and then you can use catalyst to make a silanol layer on top of it. So, the silicon hydroxyl groups you see they are on top of it what these do is they make this nanoparticles water soluble. So, these are water soluble and here also you make the water soluble etcetera. The other thing is that you can make this silanol group capped in a gold nanoparticle and into a film using spin coating and you can make devices out of them or you can self assemble them and make a inorganic solid. So, you can have inter lattice of these particles using self assembly. So, different processes are there which have been shown here of gold silica nanocomposites.

So, silica is formed on top of gold starting from this silanol groups and when they self assemble you can get this kind of particles. And here also you can do self assembly and get these particles which you are seen of gold particles and since gold has a Plasmon resonance you can measure the absorbance in u v region visible region. So, this is an absorption around 500 nanometers and that is why you will see gold nanoparticle give coloured solutions. So, it depends on what is the size of these gold particles you will have the absorption maxima at different parts in this region.

So, it can be absorbing at 500 or higher wavelengths or lower wavelengths and hence the colour which you see of gold particles will be changing with the size of these particles. So, you can make gold silica nanocomposites by several methods and so the primary layer is the gold which has the particular thickness d p. And then you have a secondary layer which has thickness d z. So, these thicknesses define the thickness of the core and the shell if it forms like a core shell. If you can make not only core shell particles, you can also make simple nanocomposites of gold and silica.

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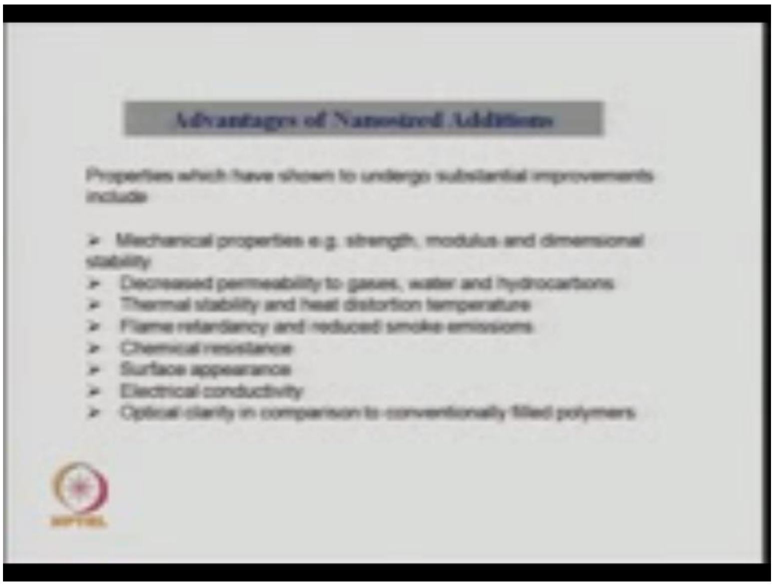

Now, what are the advantages of nanosized additives? There are all the properties that you can think of can be improved and it has been seen substantial improvement are there. For example, in the mechanical properties of nanocomposites, because you have these nanoparticles which are in a metrics and these metrics can be of a polymer or of a inorganic or a ceramic which is a inorganic solid. The strength of the composite will become much higher when you compare with the strength of just the bare particles put together. So, the metrics gives it certainly several properties, but the most important property most of the matrices give is a, is the mechanical strength and the stability. So, the mechanical properties, the strength, the modulus and the dimensional stability; all are enhanced when you make nanosized additions to a metrics.

Then the porosity is decreased and because of decrease in porosity the permeability of gases water and hydrocarbons is decreased. So, and this is very important when people are trying to make films for packaging. So, if you want to make food packaging or any other kind of packaging. When you use films to a keep materials fresh or to keep materials secure from microbes or temperature variations or p h variations. You need some kind of a surface, which protects that material and such nanocomposite films are a big applications say big huge industry of nanocomposite films for all kinds of packaging. Especially in food packaging and in making coatings in bottles which have to keep especially medicines and food.

So, there is a tremendous industry of packaging where such nanocomposite films or plastics are important and essential. So, we mentioned about permeability of gases water hydrocarbons very important for storage of food and liquids for edible purposes or medical use. Then thermal stability and a variation of heat this is again fusing the right nanocomposite film you can maintain a high degree of thermal stability then flame retardancy. So, material which will not catch fire that kind of nanocomposite film or coating has to be put on surfaces. Where the environment may reach temperatures, which are above the ignition temperature of the material and you may lead to fire.

So, you code these kind of nanocomposite films then you can have flame retardancy. And you can also have reduced smoke emissions if you are having the right kind of films to control the carbon particles which are coming out with the smoke. You can design nanocomposites which are highly resistant to acids or alkalis you can give a different finish to surfaces. This is especially important in the automobile industry where they are coming up with newer and newer coatings on the surface of vehicles to give a very fine finish. Apart from a very fine or shiny finish they also want to make these nanocomposite coatings on these automobiles such that the surfaces are scratch resistant.

So, scratch resistance is a very important thing in automobiles and for that several nanocomposite films have been developed which enhance the scratch resistance. And those are very important in automobile industry then in certain applications you need highly conducting surfaces. So, you have a nanocomposite film say of carbon nanotubes which are conducting carbon nanotubes on a polymer. So, you have a polymer carbon nanotube composite nanocomposite which is highly conducting. And such coatings or such materials are required wherever you want electron transfer or current carrying capabilities. You need such coatings to be made on those surfaces finally you have in some cases to need optical clarity.

For example, if you are making certain lenses and you need optical clarity or you are making some prisms for optical data collection. So, in those cases optical clarity is very much required that means the transmittance has to be very high and a many conventional or normal polymers filled with certain normal cheap materials which are used or which are there in the industry have been shown to lower the transmittance. And so there are now many new nanocomposite materials of nanoparticles mixed with polymers which form materials of great optical clarity. So, you can really have improved optical properties based on nanosized additives.

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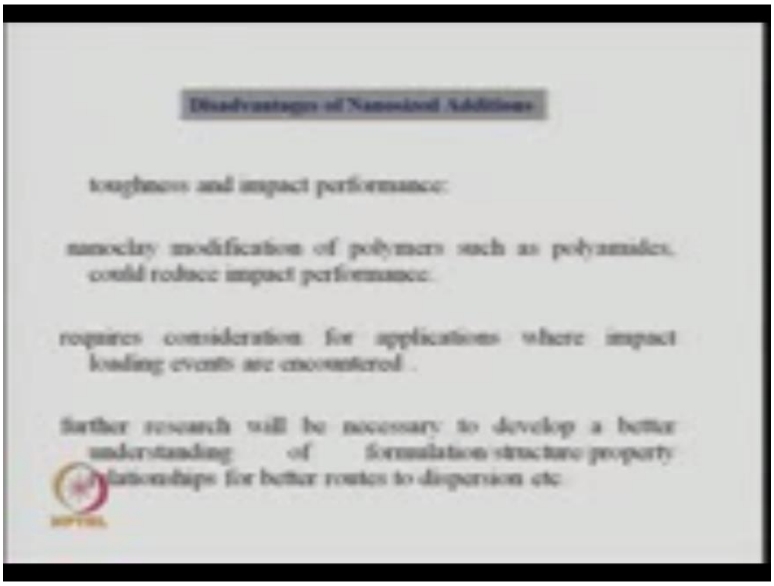

Now, what is the disadvantage of nanosized additions? The toughness and impact performance for example, nanoclay modification of polymer such as polyamides in some cases have been seen to reduce the impact performance. So many polyamides if you use it like for a coating, which will resist any sharp attack by a shrapnel or a bullet. Then it has been found that nanoclay modification of those polymers can reduce the impact performance. That means when a projectile hits this nanocomposite then what is the impact of the polyamide which is the polymer several polymers are known which are very tough.

And have been used for making bullet proof vests etcetera, now it is a possibility that some of the nanoclay modified polymers can have lower impact performance. Then the nanosized addition or nanocomposite formation for application where you have impact loading. There also you have seen people have seen events where there is a reduction in the impact loading. So, there are possibilities where although many properties improve due to nanosized addition there may be few properties which are kind of at a disadvantage when you add a nanoparticles.

So, one has to choose the optimal solution and has to priorities which properties are more important for a particular industry. And according to that one has to optimize whether somebody is ready to forefeet some of the advantages of keeping the polymer as such without adding any nanoparticles. Or you gain a lot in some properties which is beneficial to you by adding that nanoparticle. So, you have to see the application for which the nanocomposite is required. And then you design whether you need to add nanoparticles to the metrics.

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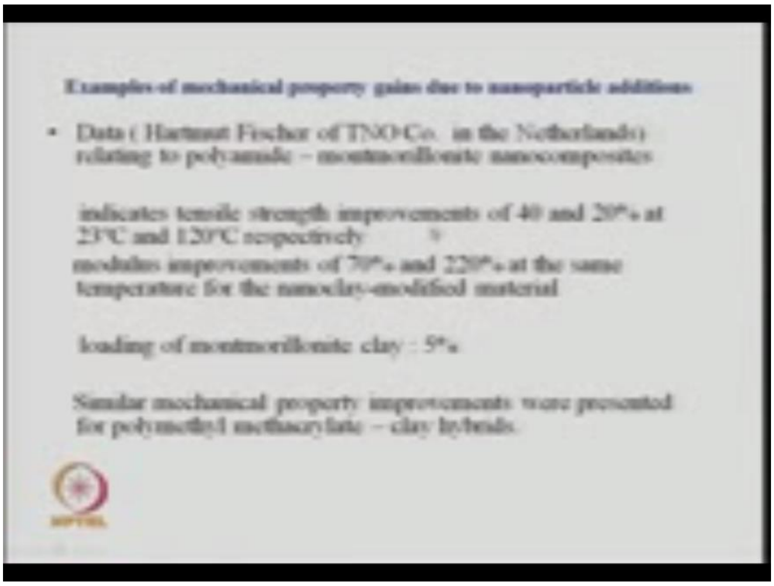

Now, this is an example of a material which has been made in a company called T N O Company in the Netherlands. And this data is related to polyamide montmorillonite which is a clay. So, it is a polyamide a polymer clay nanocomposite now in this polymer clay nanocomposite there is tremendous improvement in the tensile strength. So, this report of this company assured that the tensile strength improves nearly by 40 percent at nearly room temperature. And if you increase the temperature to say 120 degree Celsius then the improvement is still there however it goes down from what it was at room temperature. So, from 40 percent at room temperature it becomes 20 percent at 120 degree Celsius.

But still it is much higher tensile strength then the polyamide by itself if you do not add this clay nanomaterial. So, this montmorillonite clay and is here the nano dopant here now it will also been seen that modulus improves by 70 percent and 220 percent at the same temperature for the nanoclay modified material. So much improvement of modulus can be find for this nanoclay modified material then the loading of one clay is only very small amount. You need a 5 percent loading to see these kind of improvements in the properties. And similarly, in another polymer p m m a that is the short form of polymethyle methacrylate. When you mix this polymer with a clay and make this polymer clay hybrid or composite. Then mechanical strength improves just like in this case of polyamide montmorillonite nanocomposites.

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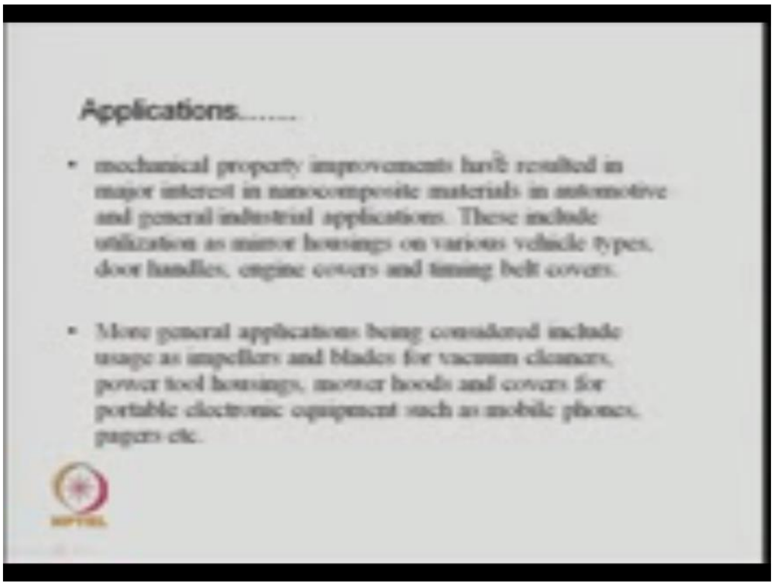

Coming to some other applications so mechanical properties we discussed further in automotive and general industrial applications also. Many of the auto parts are nanowires now made of nanocomposite materials and these typically are used as mirror housing. So, if you see on the rear view mirror the side view mirror. There is a kind of a cover on which in which the mirror is kind of placed so that material is normally a nanocomposite in the better cars today. And those mirror housings then door handles engine covers and timing belt covers. Most of these people now a days are using nanocomposites to make these materials in the automobile industry. In the home appliances sector also many traditional materials are being replaced by nanocomposites.

So, for example, you have blades of various types of blades are there fan blades are there blades for vacuum cleaners a blades for power tool you have this power drill that has a housing. So that out outer casing of the power drill is made of nano composite which is very high strength and durable. Then lawn mowers you have your lawn mower and they have a hood and this hood. Now, a day’s is coming with nanocomposites similarly, covers for portable electronic equipment like mobile phone pagers etcetera. They have this cover which is not metallic which is mainly nanocomposite today earlier it could have been a polymer or a metal. Now, a day's most or a composite now, you we have nano composite which give you high strength may be lighter to make housings or covers for electronic equipments.

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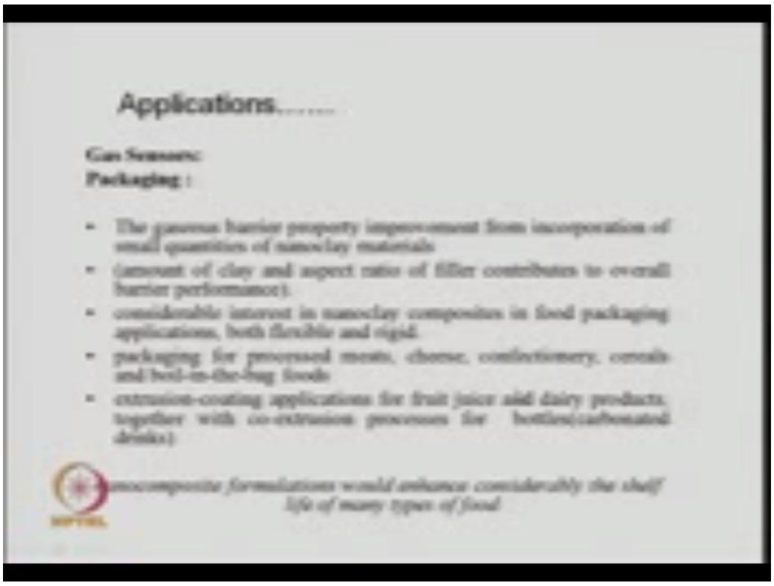

Now, further applications 2 important applications of the nano composites one is the gas sensors and second is packaging, because this also to do with transport of gases in a package where inside some materials is there depending on the material. You want either no entry of gaseous or you want selective entry of certain gaseous. So, this permeability of the polymer film or the membrane is very essential to be controlled in packaging industry. Similarly, in gas sensors you have to control you have to have maximum sensitivity and for a particular kind of gas so the gas barrier property improves. From incorporation of small quantities of nano clay materials there are several nanocomposites which have been found where you have this kind of packaging. And as is said in packaging in the food industry it is very important for covering say processed meats, cheese, confectionary, cereals, and many items. Where you have the raw material inside the bag and you just boil the bag and then open it.

So, in this kind of cases there has to be certain property of the membrane which is outside the material which helps in keeping this processed food intact safe without attack from a microbe. And if it requires certain environment say it needs a nitrogen atmosphere then that remains intact. So, all these things are very important for the meat industry, cheese industry, milk industry, for fruit juice industry, for all kinds of dairy product for carbonated drinks. The bottles have to be coated with something's you have this kind of a nano polymer bottles and they can be made of nanocomposites. So, this are great applications for nanocomposites and food packaging is an industry which has tremendous growth. And is of tremendous importance where nanocomposites play and will play a very important role.

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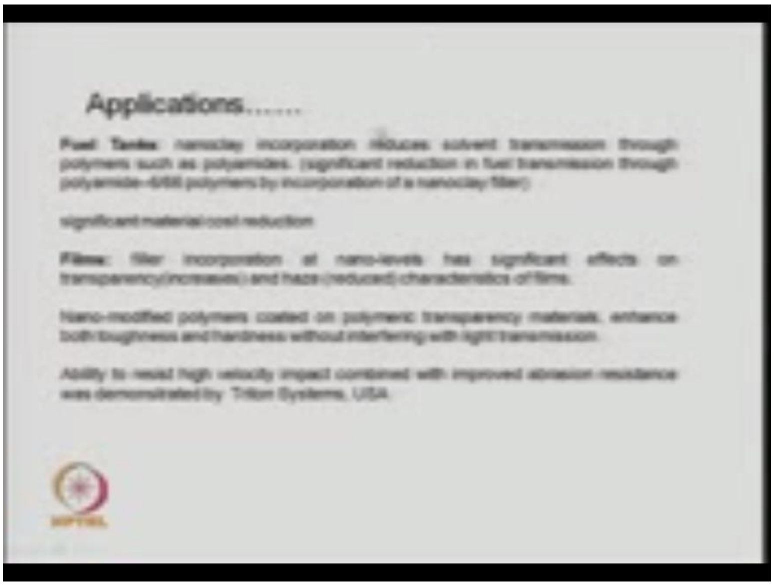

Now, there is tremendous application of nano composites in the fuel tank industry for example, in automobiles you have this fuel tanks. And you can make nano composites a where you have incorporated nano clay in a polymer network. Now, these kind of nanocomposites have been shown to reduce solvent transmission through the polymers a many of this polymers which are normally use are polyamides. And the incorporation of nano clay is as fillers reduce the solvents transmission through them. And so they retain this solvent of the fuel for much longer time. And this kind of a nano composite where you have a polyamide 6 or 66 polymer with a nanoclay filler like montmorillonite. Or other nanoclays bring about a significant cost reductions due to the the economy being safe, because of the solvent being less transmitted through the fuel tank.

So, it is retained in the fuel tank for much longer period of time. So, this is one of the major applications in the fuel or the tank industry. And it can be used for storage tanks it can also be used for many other types of tanks not only in automobiles. So, you can use such nano composite coatings on even overhead tanks where in industries where they are retaining certain solvents. And specially large industries in the petrochemical industry where they have very large tanks to store solvent, you can protect the solvent transmission by having nanocomposites as a coating. Now, several films like in the packaging industry you can make nano composite based films; you can also make films where the importance is in the optical transmission.

So, you can add fillers at nano levels which has significant effect on the transparency of the film. So, you increase the transparency of the film by increasing the content the by adding nano dopants. And you can also reduce the haze in the film and several film are required where you need high transparency and reduced haze. Now, nano modified polymers coated on polymeric transparency materials, you can also enhance their toughness without interfering with the light transmission. So, you want to make the film much more stable much more mechanically stronger.

But you do not want to effect the optical transmission and such nano fillers are known where you can add them to those polymers. And you get both the properties of enhance strength without cutting down on the light transmission. Now, similarly, can have other applications using nanocomposites for example, you can have a duel property of high velocity impact resistance combined with abrasion resistance in the same nano composite. And this was demonstrated by a company called triton system in USA where they showed how that nanocomposite can prevent a high velocity impact and also prevents abrasion.

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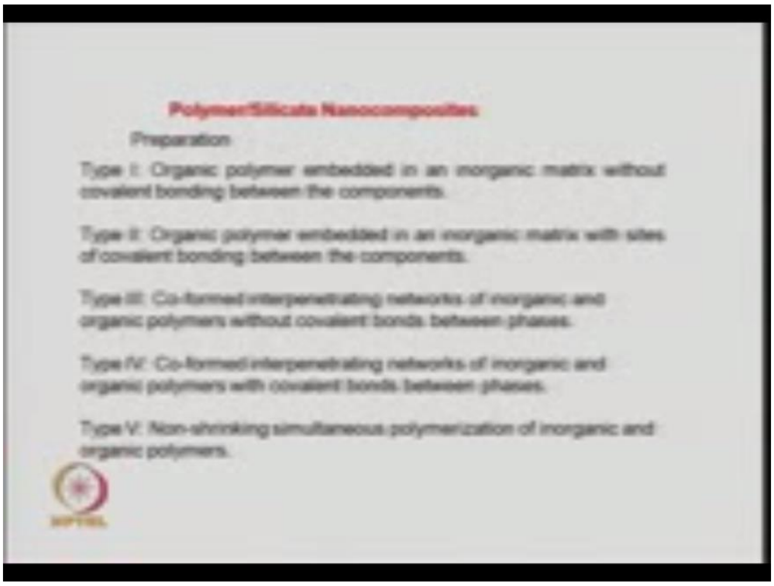

Now, a another class of nano composites is the polymer silicate nanocomposites. So, you have a polymer and you have a in organic material like a silicate. There are many many types of silicates both man made and naturally occurring. And hence they can be very economical to make nanocomposites with. Now, if you have an organic polymer embedded in an organic matrix without any covalent bonding between the components. Then you can have one kind of nanocomposite however, you also have a organic polymer with inorganic matrix where you have covalent bonding between the components. So, that also possible similarly, there is another class of polymers silicate nanocomposites where you have co formed interpenetrating networks of inorganic and organic polymers without covalent bonds between phases.

Then in this case there is no covalent bond then you can also have the other way where you have covalent bond now, with between the phases between the interpenetrating networks of inorganic and organic polymers. So, you can have with covalent bonding and without covalent bonding these nanocomposites and the, you can have non shrinking simultaneous polymerization of inorganic and organic polymers. So, both normally we think that you make organic polymers by polymerization we can also make inorganic polymers. And if you can simultaneously do the polymerization of the organic and inorganic polymer then you get another type of nanocomposites or you can get nanocomposites through another methodology.

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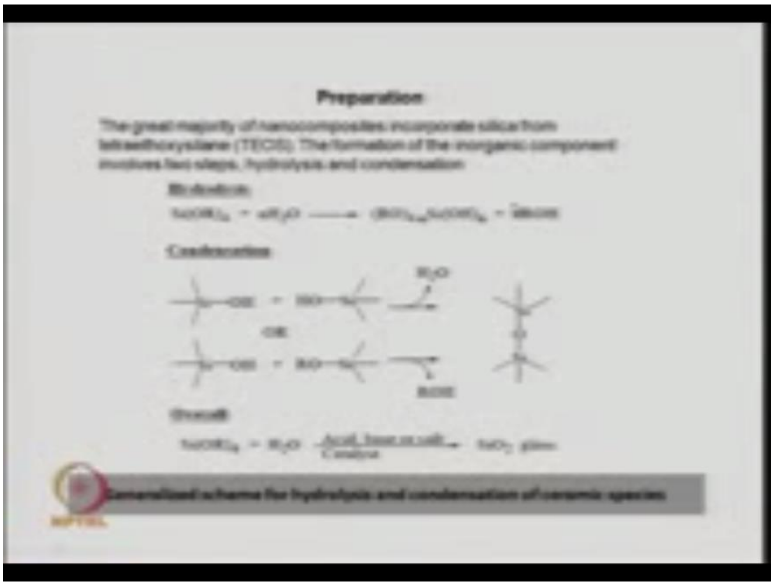

Now, simply speaking this making nanocomposites of silica based nanocomposites or many other titania based nanocomposites they all go through a 2 step reaction. The first step is the hydrolysis and the second step is the condensation. This is a large majority of the nano composites which use alkoxides as their starting reagents like in this case one wants to make silica as the inorganic component of the nanocomposites. So, you want to incorporates silica. So, you start with the alkoxide which is tetraethoxysilane, so when you use tetraethoxysilane first step is the hydrolysis. So, you can have a basic hydrolysis acidic hydrolysis depending on the process and you get this kind of a silanol group.

And then these silanol groups loose water molecules to form S i O S i linkages. So, that is a condensation of 2 silanol groups and water molecule is ejected and you get this kind of S i O S i linkages. So, this is the condensation process the overall process can be written as this tetraethoxysilane with water in the acid base or salt as catalyst. And then you get silica or silicates depending on other metal ions present. So, these are general scheme for hydrolysis and condensation and has been used largely for making silica nano composites or titania nanocomposites. And also in recent days on other type of nanocomposites niobium, and tantalum, etcetera.

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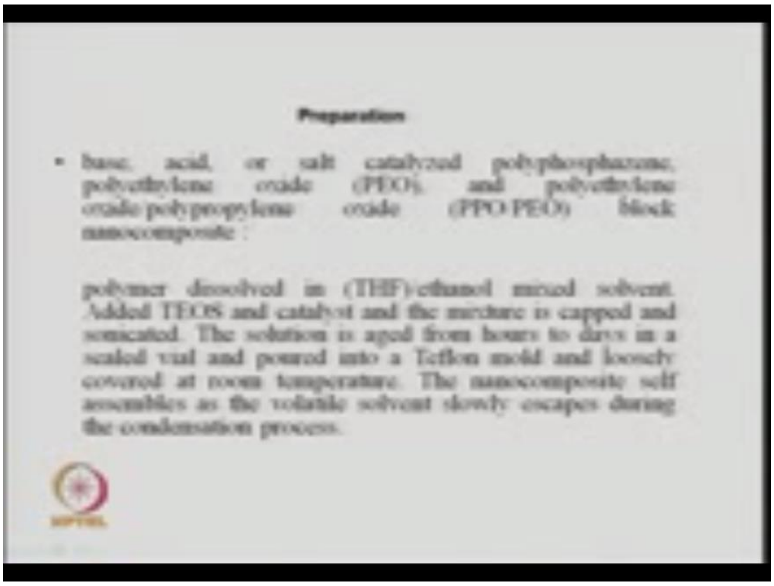

Now, this is another mode of synthesis of nanocomposites, where you take this base acid or salt catalyzed polyphosphazene, this is an example or polyethylene oxide. So, these are the polymers and then you dissolve this polymer in THF and ethanol THF is tetrahydrofuran. And you take a mixture THF ethanol is this mixture is the solvent and the polymer is dissolved in the solvent.The polymer can be one of this above polymers or something different. And then once you add this TEOs the silane precursor the silicon precursor and the catalyst to cause the polymerization to cause the reaction the hydrolysis and condensation. Then the mixture is capped and sonicated and the solution is aged from hours to days in a vial and poured into a Teflon mold. And it is loosely covered at room temperature when you do that since it is loosely covered the solvent will slowly escape. And the nano composite will form by self assembly it will self assemble and the solvent will escape during the condensation.

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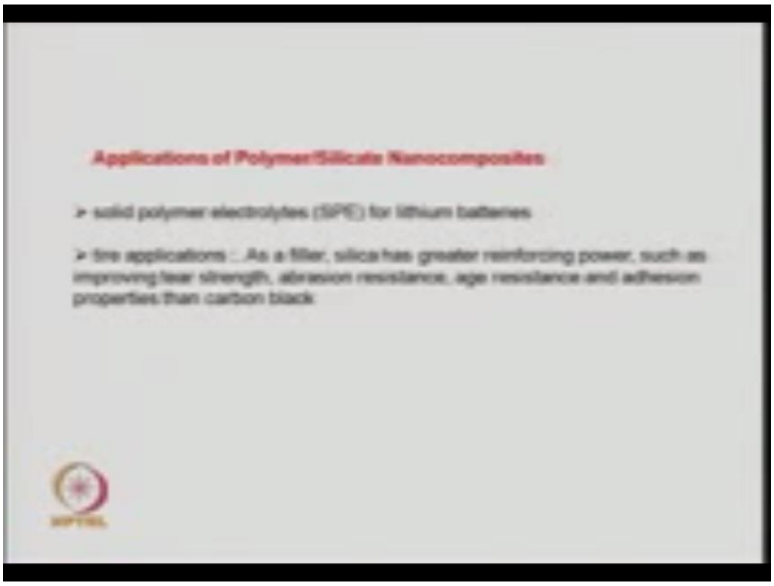

Now, the silicate polymer nanocomposites that we are talking about, so we are talking of basically silicates here because we are talking of silanes as the precursor. And so this is a process you started with TEOs, so you are looking at silicate based polymer nanocomposites. And so the applications of these polymers silicate nanocomposites 2 major applications. One in lithium batteries which is you know one of the most important areas of research and development for the industrial world, because of the energy crisis. So, lithium batteries is very important area and solid polymer electrolytes are required for lithium batteries.

So, this is one of the rich area where these polymer silicate nanocomposites are required and are used as electrolytes in another application in the automobile or the transport industry in tire manufacture. You require fillers where these nano silica or nano silicates have great reinforcing power. They are added in the to substitute carbon black normally carbon black is added as a filler. But these nanocomposites have much better properties they give much better properties to the tire like improved tear strength improved abrasion resistance. They go for much longer time and they have much better addition properties than carbon black. So, there are 2 industry one is in the energy sector and the other is the transport sector where these polymer silicate nanocomposites are of great use.

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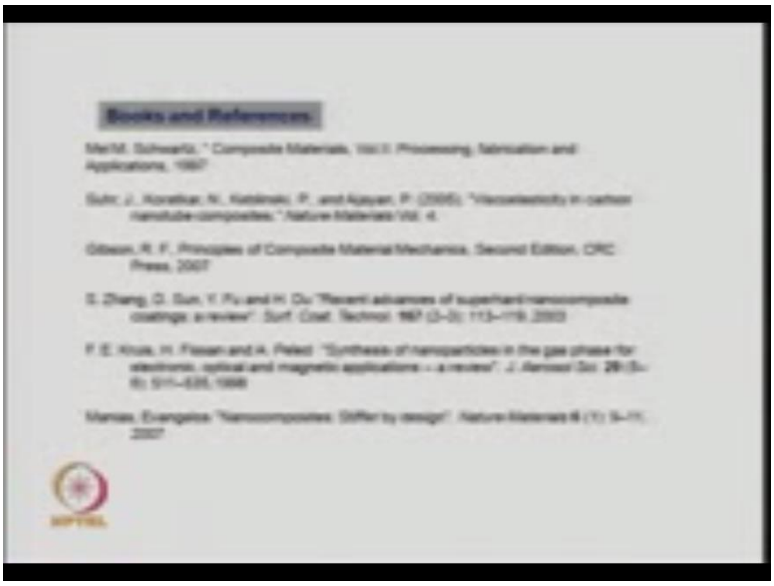

Now, so with this we come to the end of today's lecture that is a lecture 2 of nanocomposites. And with that we also came to an end to the module 3 and you may look for the last 2 lecture into these references. And these references the some recent work in journals have been given and some books which are books. And like this these are books and these are review articles which give you some idea into what is being done in the area of nanocomposites over the last 20, 30 years. And with this we come to an end to this our lectures on nanocomposites. And we will start with module 4 where we have 2 lecture and where we have 14 12 lectures. So, we have finished 28 lectures with module 3 and we have 12 lectures remaining to be done in module 4.

So, thank you and we meet in our next lecture.