Nano structured Materials-Synthesis, Properties, Self Assembly and Applications

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Module - 3
Lecture - 27
Nanocomposites – I

Welcome back to this course on nano structured materials synthesis, properties, self assembly and applications. Today, we are in the module 3 lecture 13 and we will be doing 2 lectures from today on nano composites, a nano composites lecture 1 starts today and this is the thirteenth lecture of module 3. Now, a nano composites the term as you can understand is a composite, which has a nano sized ingredient. So, for example commonly composites are made up of 2 materials which are mixed and they are not forming a compound within specific stoichiometry, but you can vary the stoichiometry of two components two materials which are say immiscible in each other.

So, you can have a mixture of say sodium chloride with titanium dioxide and when you mix them together you get a composite. Now, if you have one of these materials is nano size, for example nano particles of titanium dioxide mixed with sodium chloride will form a nano composite. Similarly, nano particles of titanium dioxide mixed with a polymer will also form a nano composite. So, nano composites as such if you take an x ray pattern will not give you the x ray pattern of a particular compound, but it may give you x ray pattern of two or more compounds, so that is what a composite is and if one of the materials is a nano particle or a nano rod or a nano wire, then that will be this mixture of material is a nano composite. The 2 ingredients or 3 ingredients all of them need not be nano sized even if one of the ingredients is of nano dimensions, then its mixture with another material which has say micron sized particles will still be called a nano composite.

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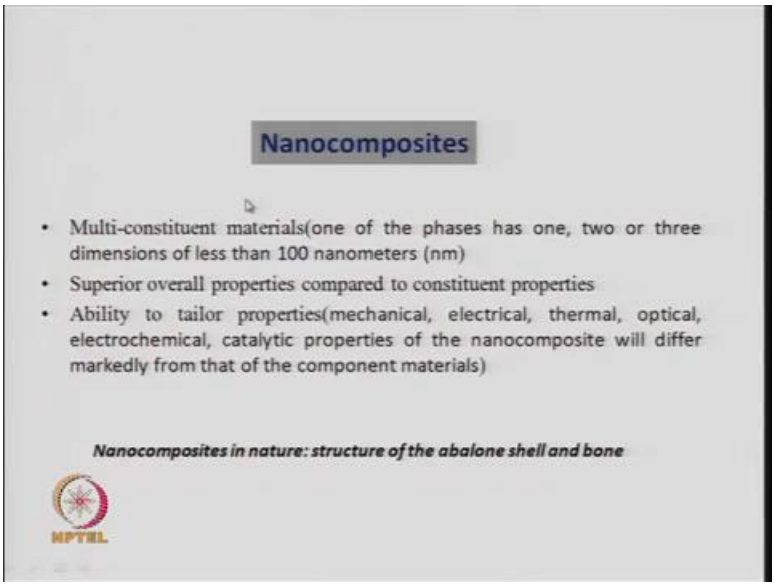

So, what are nano composites as I first explained what are composites, what are nano composites are multi constituent materials one of the phases has 1, 2 or 3 dimensions of less than 100 nanometers. So, that means one of the ingredients is a nano material it may be a nano particle, it may be a nano wire or it may be a nano plate. So, the mixture of that nano sized particle with some other material which has got say micron sized particles or which is may be a polymer which may not be at all a crystalline material will be called a nano composite.

Now, why nano composites are important because it will have superior overall properties compared to the constituent, so you have 2 constituents a and b. Now, one is a nano particle and b can be a nano particle or not a nano particle if you measure the property of a and say the property of b then individually their properties have some values. But, when you make the composite and you measure the same property it may be a electrical property it may be magnetic property or it may be an optical property. So, any of the property of the composite is better than either the same property in a or b, hence such nano composites will be better and superior. So, in their properties of their compare to their individual components hence you are interested in nano composites the ability to tailor properties.

But, whether mechanical, electrical, thermal, optical, electrochemical or catalytic properties of the nano composite will differ markedly from the component materials, so

you will be having the ability to tailor properties, because adding a to b is in your hand. So, if you control the addition of a to b and the properties are changing, hence you can control or tailor make the properties as you choose. So, there is an ability to modify the properties by judicious choice of the amount of the 2 components a and b to give you the resulting property.

So, in nature there are many nano composites available which we see in our daily life made in nature by natural phenomena. Now, example is like abalone shells, abalone shells are like found in marine animals those found in the sea and you can see many of them have shells and these shells are made up of a mixture of many times calcium carbonate. Now, may be a polymer which may be a biopolymer and this is a composite which has a nanostructure of say calcium carbonate or it may be calcium phosphate.

So, along with a biopolymer and these are known as abalone shells found in marine animals, similarly bones which is there in almost of the vertebrates. So, these bones are made up of calcium apatite and it has got other fibrous material and this makes the composite. So, bone is a composite of calcium apatite and some polymer which is above a polymer and it can be a mixture of biopolymers. So, it is a natural composite, so these are 2 examples we see there are many other examples of nano composites in nature.

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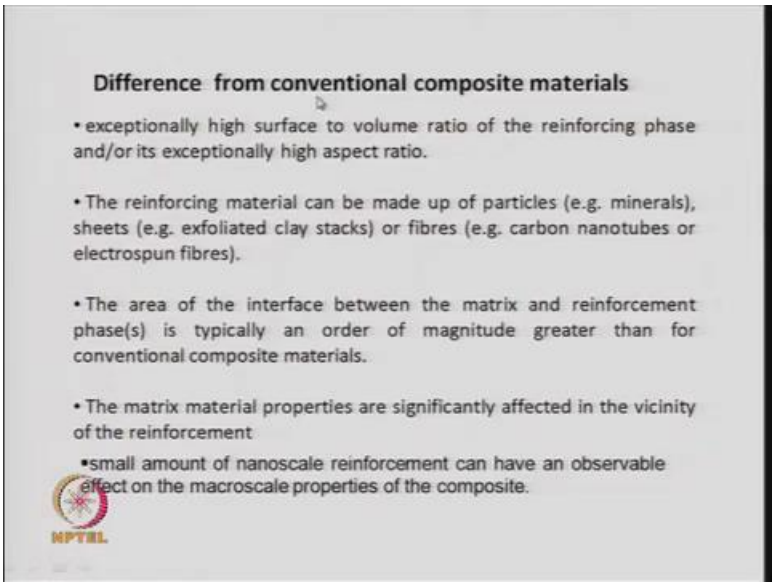

Now, the difference from normal composites, so there are conventional composite materials, how are nano composites different from other composite materials the area of

composite materials is a very old. So, area in material science and in engineering materials engineering and has been studied for over 60, 70 years and has given rise to large amount of engineering materials. But, especially for the strength and controlling their ductility and malleability, etcetera, so composite materials are not new, so how are these new nano composites different from the earlier known composite materials.

Now, these nano composites have exceptionally high surface to volume ratio of the reinforcing phase and or it has exceptionally high aspect ratio. So, because you are putting nano particles as one or both of the components or more than 2 components if it is made up of 3 materials, the addition of any nano particle or a nano wire increases the surface to volume ratio.

So, that is a difference from normal composites the nano composites will have a higher surface to volume ratio. So, it may also have exceptionally high aspect ratio especially if you take nano fibers or nano wires then the reinforcing material. So, that is one of the components which is the reinforcing material which normally is the nano particle can be made up of several particles.

So, example minerals sheets or clay stacks or fibers like carbon nano tubes or electro spun fibers and the area of the interface between the matrix the matrix is the larger material. So, larger component normally the matrix may be ceramic or it may be a polymer and the reinforcement phase is normally the nano particle or a nano plate or a nano wire. So, the interface between the matrix and reinforcement phase is typically an order of magnitude greater than for conventional composite materials. So, this since the particle size is small, so surface to volume ratio is high and the area of the interface.

So, the connectivity between the matrix and the added particles, which is being called the reinforcement phase. So, the area of the interface is an order higher in these nano composites compared to normal composites which may have micron size particles. But, the matrix material properties are significantly altered in the vicinity of the reinforcement, so wherever the reinforce particles are present around them if you look at the region just around those particles.

So, they will be modified to a large extent compared to the material the matrix material much farther away from those nano particles or farther away from the reinforcement particles. But, the matrix material as mentioned will have will be significantly affected in

regions where the nano particles are present small amount of nano scale. So, addition can have an observable effect on the macro scale properties of the composite, so what it means is that if you add even a small amounts of nano particle as reinforcement materials.

So, say you add some silica nano particles in a bulk or ceramic silica then you can observe some changes which you can measure by microscopic measurements. So, you can measure say the yield strength or the a thermal expansion or things like that which you can measure in the macro scale that means on dimensions which are of the size of say millimeters centimeters etcetera. So, this property which is being changed due to the nano material being added will be reflected in the macro scopic property on a large sample of say millimeter or centimeter size.

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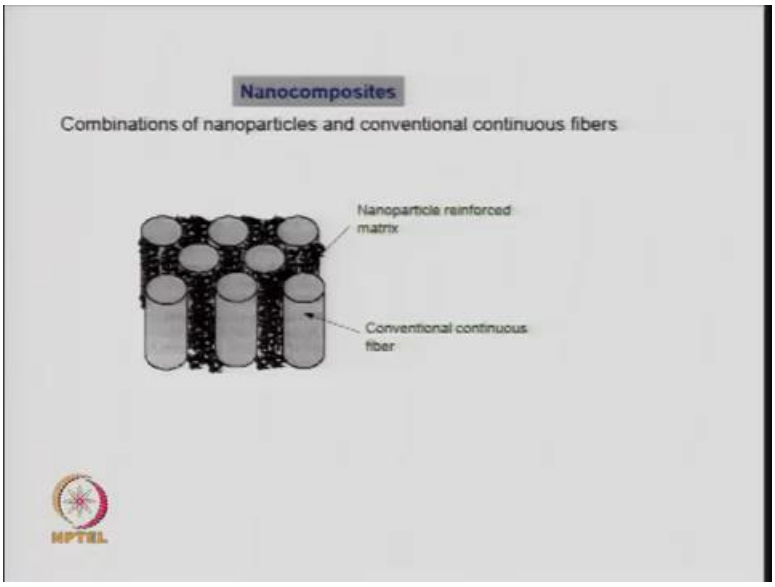

So this is typically a nano composite of particles which are nano dimensions, so these are nano particles along with fibers. So, the matrix here is the fibers and the nano particles is the phase which we are calling as the reinforced reinforcement particles. So, together this nano composite is a nano particle reinforced matrix this is the fiber and as you see in between you will have these nano particles which are reinforcing these fibers.

So, the strength of this composite is going to be enhanced because of the presence of these nano particles compared to a system where there are only the fibers and no nano

particles. So, this enhancement in the property gives you the interest to study and investigate and design new nano composites.

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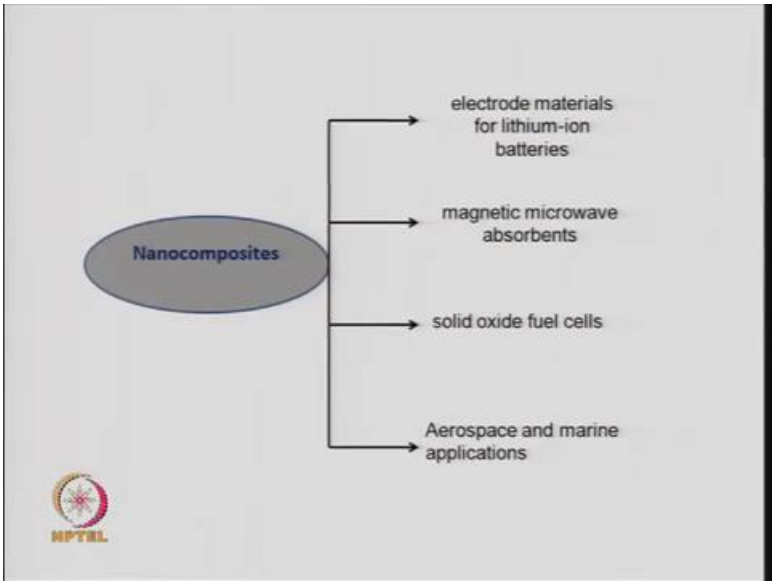

So, what are some of the applications of nano composites, so here we are we have listed some 4 major applications for which nano composites have been used and the first example is as electrode materials for lithium ion batteries. Now, one of the most important areas of research and development and applications in industry for and also for domestic purposes is the development of batteries which have long shelf life can be used for several 100s or 1000s of cycles. So, such batteries are based on lithium ion intercalation and de intercalation and the electrode materials for such lithium ion batteries are being developed based on nano composites.

So, this is a major area of industrial scientific and industrial research where nano composites are being developed for electrodes. Then another area is where you are looking at microwave absorbing materials magnetic microwave absorbing materials, especially these materials are of use in the defense in space in communication systems.

So, there is a large market and industry is very important, these materials are very important for industrial applications. Then another area of research again related to energy like the lithium ion batteries related to energy and here solid oxide fuel cells is also related to energy where you get clean energy.

So, that means there is no pollutant produced as a function of the energy being produced unlike many thermal and other types of fuel energy generation in fuel cells. So, you basically use hydrogen and oxygen at two electrodes and generate energy and water which is non pollutant is produced as a byproduct. Now, when you have solid oxide as the electrolyte then it is called as solid oxide fuel cells and many nano composites are being used as electrodes in these solid oxide fuel cells.

So, a lot of applications exist in the aerospace and marine industry and this is an area which has tremendous market because the aerospace industry always uses lot of composites. Now, people are trying to make nano composites, which would replace the composites being used in the aircraft industry. So, the aircrafts have to use properties like the same materials should have high strength, but at the same time should be light. Similarly, when you need a material which has two or more properties then composites are of great importance and in this area composites have been developed for a long time for aircraft parts for aircraft wings.

Now, nano composites are being tried out in the applications in the aircraft industry similarly, for marine applications many nano composites for making light weight shapes for making nano composite coatings. So, as antifouling agents which can be painted on the outside of the surface of the ship such that with long usage the skin is not fouled by marine organisms and salt water etcetera. So, there are tremendous applications in aerospace and marine industry based on nano composites.

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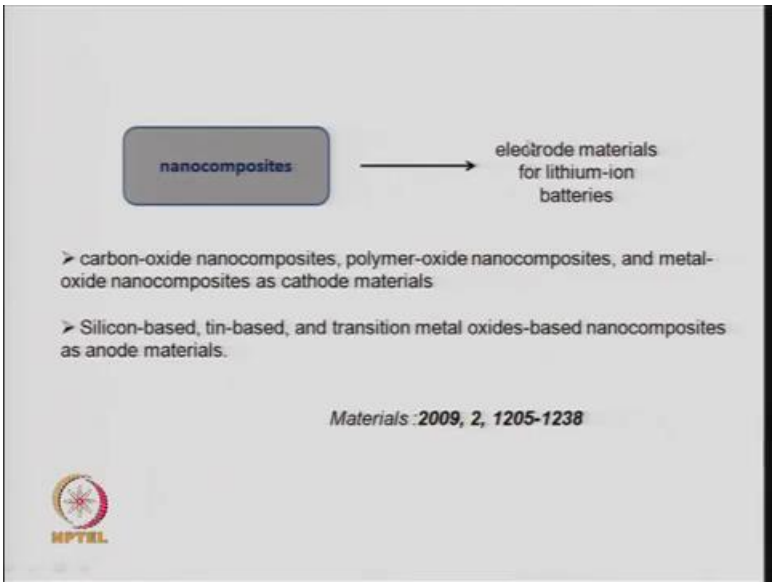

So, if you emphasize on one of the applications that is electrode materials for lithium ion batteries and look for nano composites for acting as such electrode materials then people have investigated carbon mixed with oxide particles. So, some metal oxide and carbon particles together people have studied as nano composites, so people have made use of nano carbons. So, it may be carbon nano tubes or it can be fullerenes with some metal oxide retaining the properties which you require for a good electrode material like good conductivity and good recycling properties and low thermal expansion etcetera.

So, you design composites keeping in mind the application and hence keeping in mind the properties that you need and may be two or three properties need to be optimized. Hence, you mix components such that one component gives the conducting property the other component may give the mechanical strength and a third component may give the property of low thermal expansion.

Similarly, you can have other properties, which are interlinked and you can get a resultant material by mixing 2 or 3 properties materials of different properties. So, such that the resultant material gives an outstanding combination of those 2 and 3 properties, so you can have carbon based particles mixed with metal oxide particles to give you nano composites.

But a polymer mixed with metal oxide nano particles will also give you nano composites and you can have metal particles like copper metal, copper nano particles, cobalt nano

particles, nickel nano particles mixed with metal oxide nano particles. So, that will also give you metal oxide and many times such composites made of a metal oxide with a metal particle are called cermets because the metal oxide is a ceramic. But, which is a non conducting material high temperature refractory material and that ceramic with the metal is typically will be called cermet.

Now, of course if one of them is nano size then it will be a nano composite or a nano cermet and these combinations have been used to act as cathode materials in lithium ion batteries. Similarly, silicon based tin based and other transition metal based oxide nano composites have also been designed and developed and investigated as anode materials. So, their efficiency as anode materials has been measured by making cells and studying the current as a function of the properties as a function of the dopant which is the nano particle.

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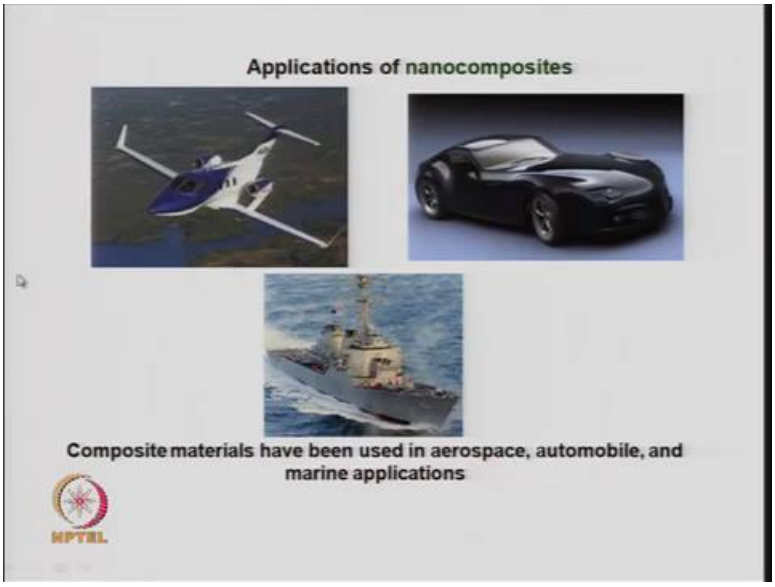

Now, you can also, these are some of the applications of nano composites, which you can see in the aircraft industry in the automobile industry and in the marine industry. So, we just discussed that you have lot of applications in the automobile in all kinds of transportation industries. Now, in the of course the properties have to be different depending on your application in an aircraft light weight is a being light weight is a major property for the nano composite.

So, the material has to be light weight in a aircraft in a car the property that you need mostly is that you need a scratch resistant coating. So, that this surface is coated with a nano composite suspension which gives you a very good shine and also is scratch resistant and it may also have properties like it mechanically of very high strength. So, you make a nano composite depending on the application for the marine industry the property again you needs the material which has high strength light weight.

But, if you are making the structure of the marine vessel with that nano composite, however if you are using a coating on the surface then you need a coating. So, that has a property such that that material does not get allow, does not allow the corrosion of the structural material and does not get allow fouling of the ship or the marine vessel. So, there are different applications depending on the what is your target industry whether it is the aircraft industry or whether it is the marine industry or whether it is the automobile industry.

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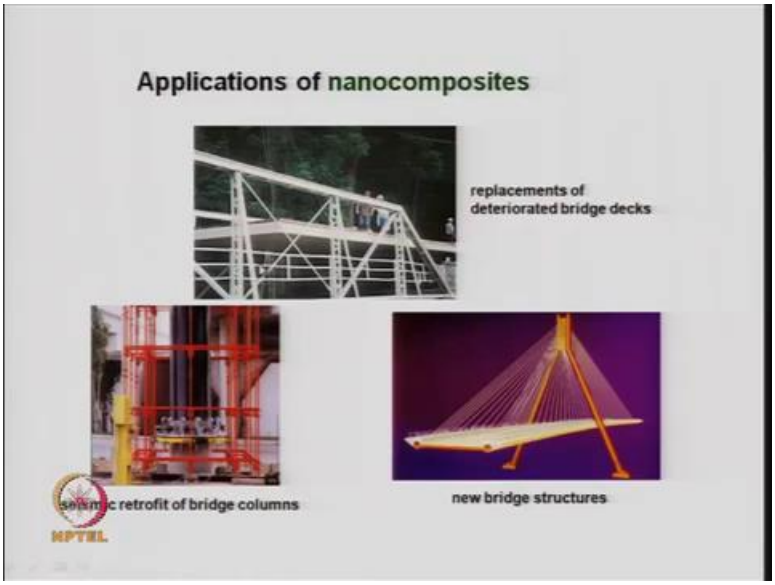

So, if you extend those arguments, so if you extend those arguments, if you want to make lot of composites have been used in structural materials, for example in bridges on the decks which form in the bridge. But, there can be retrofitting of bridge columns using composites and various kind new types of bridge structures with modern composites have been developed which are again very light weight. But, of immense mechanical

strength and then you can design bridges with new structures, new type of structures as shown here.

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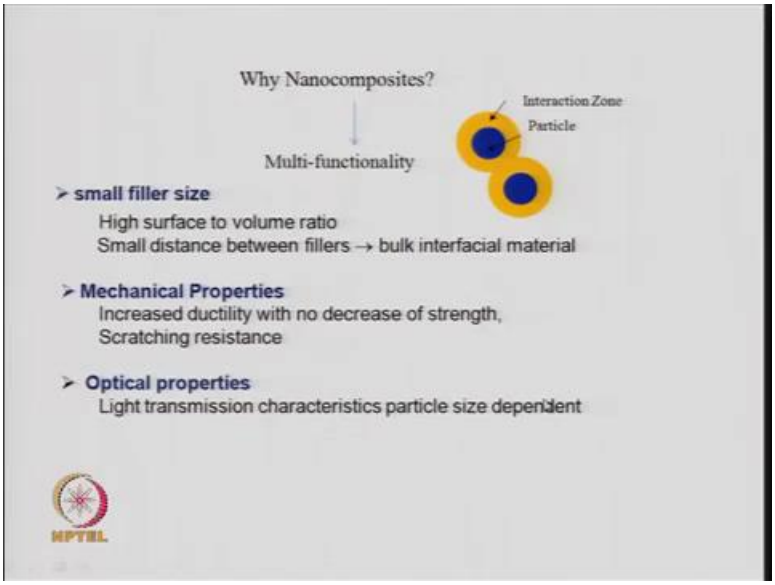

So, why, now we come kind of summarize that why we need nano composites and as we discussed because you need two or more properties in the same material. So, you need multifunctional materials, so when you mix two materials then 2 materials bring their own properties and the composite has 2 functions. So, it is a multifunction if you bring together 3 materials and make a out of it then you get a multifunctional material with may be 3 optimal properties.

So, typically you can have particles where some of the, you can have composites with particles such that one of the material forms the core the other the shell. However, you can also have composites where the particles are all separate, but compacted together. So, you what when you use nano composites the properties one is that the properties of interest are there in F composite.

Now, second you need small filler size because the surface to volume ratio is very high and between the 2 particles acting as fillers you have small distances, so you get a bulk interfacial material. So, you have small filler size the mechanical properties increase, so you increase the ductility with no decrease of strength and you increase the scratch resistance and these are mechanical properties.

Now, one wants to enhance in a material for industrial applications or for construction materials then for optical materials you can have light transmission which is particle size dependent. So, if you have a composite and your adding some nano particle you have a choice of adding 20 nanometer particle, 40 nanometer nano particle.

So, you can vary the size of particles by varying the size of particles in that composite you can vary the amount of light which is transmitted through the nano particle. Hence, you can modulate the optical properties, so this is another application why nano composites are useful apart from that they are multifunctional materials.

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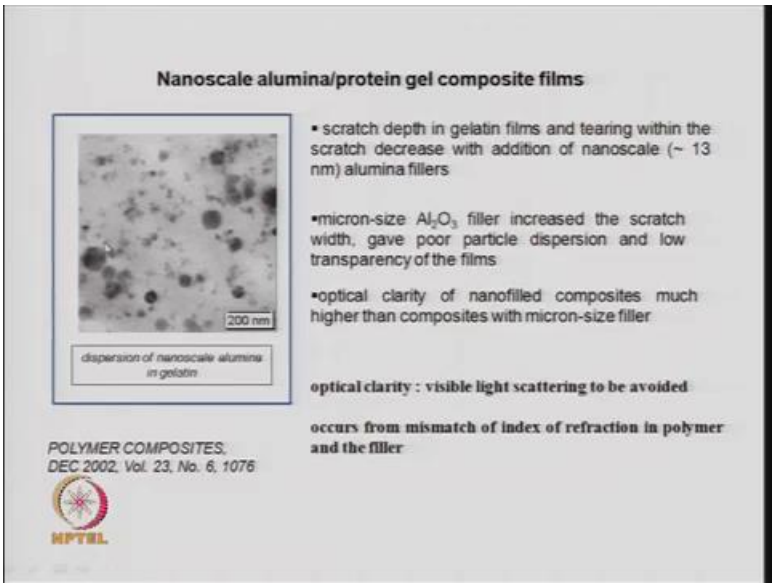

So, this is an example of nano scale alumina that means alumina in nano size particles and the matrix, here is a protein gel. So, when you have nano scale alumina particles in a protein gel, so you get a composite and if you make it as a film. So, you have a nano composite film now this is a T E M picture where you can see the continuous material which is the protein gel. So, you have these particles which are nano scale alumina which is dispersed in the protein or which is gelatin here. So, the protein is gelatin and these alumina A l 2 O 3, the A l 2 O 3 nano particles are being used as filler, so this kind of a composite film has its own advantages.

So, one of the advantages is the scratch depth and that is in a gelatin film how much depth you can scratch that will decrease when you add nano scale alumina fillers. So, for the same amount pressure you can reduce the amount of depth of the scratch in films

with nano fillers. So, if you have less of this scratch resistance then if you compare with a micron size alumina filler compared to nano sized alumina filler you will find that the scratch resistance is larger in the nano scale film which has nano sized alumina.

So, if you use micron sized alumina then you can go to larger depths with the same pressure, so the scratch resistance is lower when you're using micron sized alumina. But, that will give you low transparency of the films, so when you have easy scratch resistance that means the transparency of the film will be poor and this is what is seen. So, when you have micron sized alumina instead of nano sized alumina, so coming to optical clarity, so the optical clarity will be higher in composites which have nano filled particles. Now, nano particles filled composite films and this optical clarity that means where the visible light scattering has to be avoided.

So, wherever the scattering is less that will give you more optical clarity and the scattering is basically when you have a mismatch of the refractive index in the polymer which is gelatin and in the filler and the filler here are the alumina particles. So, when the refractive index mismatch is lower then you will have more optical clarity, so this is one example how you can improve a property. Here, it is the optical property of the film along with the scratch resistance of the film, which has been improved using alumina nano particles.

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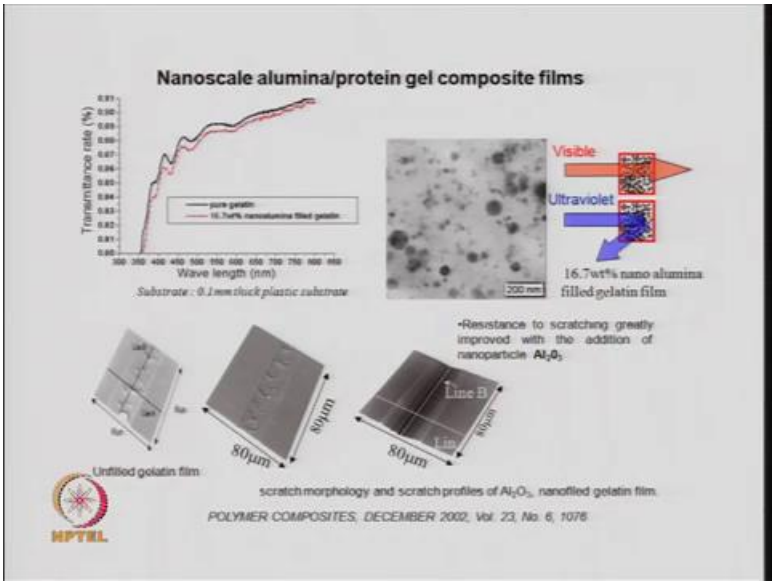

So this is the measurement to show that you have this is the optical property, so the transmittance and the transmittance is as you see here you have the black one is pure gelatin. So, when you add nano alumina filled gelatin it is nearly the same, so there is hardly any reduction in the transmittance. Whereas, if you use micron sized films then you have tremendous loss in transmittance, so the optical clarity will reduce much more if you use micron size alumina instead of nano alumina.

But, this is a diagram to show that visible light is being passed, so in this nano particulate film it allows visible radiation to go through. Whereas, the ultraviolet radiation is scattered back which you want, so in many applications you do not want the U V rays to be going through the film and only the visible rays are going through. So, you can design a composite film based on nano particles which has this property of allowing visible light.

So, it is clear optically clear or optically transparent for visible radiation, whereas it is optically opaque or which means that it does not allow the U V radiation to pass through it this is the scratch resistance test. So, this is an these are a f m atomic force microscope pictures of a film on which there is a scratch and this is a film with of pure gelatin there is no nano particle on this film.

Now, if you add some nano particles and then do a scratch test you see the scratch, now is less visible than in the film where there was no nano particle. So, if you increase the amount of nano particles in the film then you see that you can hardly see any scratch on this film where the amount of nano alumina has been increased. So, there is no nano alumina and here you add some nano particles there are more nano particles and the scratch resistance has increased dramatically as seen by this a f m pictures. So, the surface roughness which is a measure of this scratch resistance the surface roughness, but roughness will be very small in this case because it is scratch resistant and you can measure the surface roughness using atomic force microscope.

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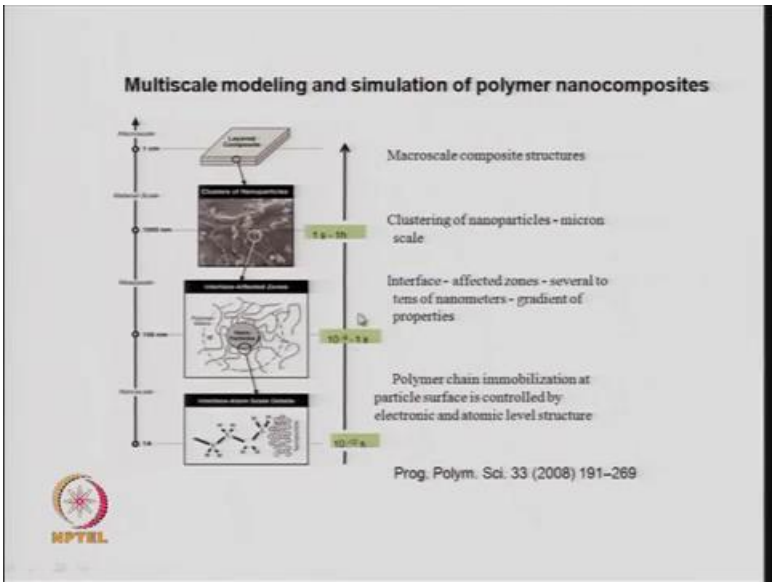

Now, these are some experiments you can also do modeling theoretically a computational modeling and simulation of polymer based nano composites. But, where you have one of the components is a polymer to which you add some nano particles and you can model and simulate. So, what would be its properties what will be the mechanical properties of a particular composite, which has so many amounts of nano particles in a matrix of a particular polymer? Now, this kind of computational modeling is of use when you want to design a new material for a particular or specific application.

So, the scale here what is shown here is to explain to you why people call this multi scale modeling it is called multi scale modeling. So, because the modeling takes into care small this variation in properties due to small changes in distances, which are at the nano region. So, the your talking of nano scale where the distances are between two atoms it is in the sub nano scales region which is the atomic dimensions. Hence, you see you are here it is the in inter atomic distances which become important and as you go to the hundred nanometer size.

Now, you have got these fragments or oligomers of polymer and you have nano particles of say 10, 20, 30 nanometers. So, these are atomic scale distances which are inbuilt in the particles which are of say 100 nanometers along with some chains of polymers which are may be few monomers. So, it is a, it may be a oligomers and then you go to larger scale

so from smaller scale you are going to larger scale. So, you put many of these together and you are in a scale which is at a micron level so you are looking at 1000 nanometers.

Then, finally you come to objects which we can see with our naked eye in the macro scale something which we can see with our eyes like 1 centimeter long substance. So, this final layered composite if you take a small region and look under the microscope you will be seeing regions which are of the order of microns. But, if you take a small region in this micron sized object and you look deeper then you see objects which are in the range of few 100 nanometers.

Then if you go further down within the nano particles you will see atomic distances, so different length scales are involved you have atomic length scales which are sub nanometer. So, you have nanometer sized length scales you have micron sized length scales and then you have a 100s of 1000s of micron length scales which is visible to the naked eye. So, since so many length scales are involved in the same material the same material which is the final layered composite can be understood at different length scales, hence it is called multi scale modeling.

So, all these different lengths scales are build when you try to understand theoretically or computationally the properties of a composite, especially polymer nano composites where the matrix is a polymer. So, you have nano particles being embedded in that which is acting as a filler and then if you do a simulation at these lengths scales then you do a multi scale modeling. Now, you can come up with some final properties which these polymer nano composites will have this is an area which is of lot of interest in the current computational materials science.

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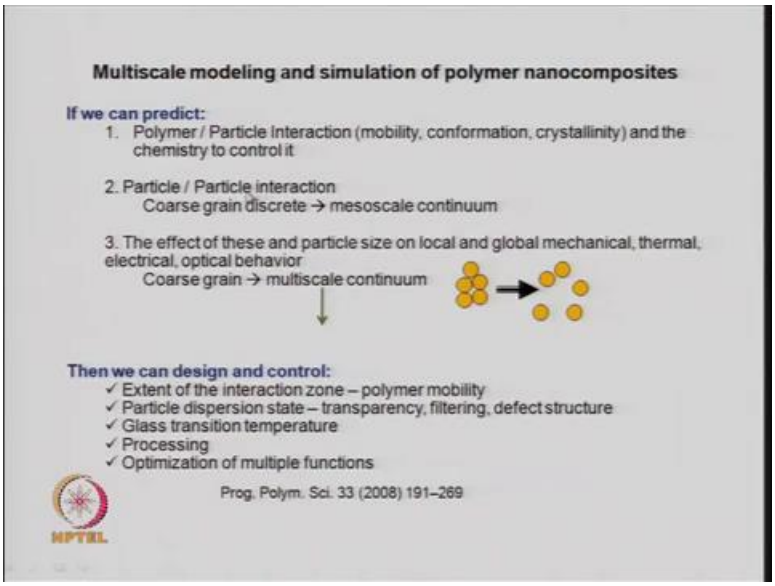

So in multi scale modeling and simulation what we can do what can be predicted if one does multi scale modeling of polymer nano composites. So, you can try to understand the mobility after understanding the interactions between the particle and polymer, so there are polymer chains and there are particles. So, you try to understand the interaction that means you try to understand the mobility the conformation of the polymer chains the crystallinity.

Now, how do you control the chemistry to control the conformation and crystallinity, so this can be predicted if we can predict this then we can design and control these nano composites. So, we have to predict these interactions using multi scale modeling and simulation apart from polymer particle interaction particle, interaction has to be understood. So, there what people do is what is called a coarse grain theory where you go from me, so scale to the continuum and then the effect of these interactions and particle size on the local and global properties.

So, that is the, such as mechanical properties thermal electrical and optical properties can be should be predicted and so you one goes from the coarse grain theory to the multi scale continuum. Then once you know you are able to predict these then you can design and control the composite by the extent of the interaction zone and the polymer mobility. So, the particle dispersion state, the transparency, the structure of the defects the glass

transition temperature which is the temperature at which you have a glass amorphous solid.

So, which a polymer behaves like an amorphous solid, hence the transition temperature which is called the glass transition temperature. So, it is very important to understand the glass transition temperature to understand many of these properties of these polymers. But, if you can predict all these things then you can optimize the processing conditions and you can optimize the various properties or functions of these nano composites or polymer based nano composites.

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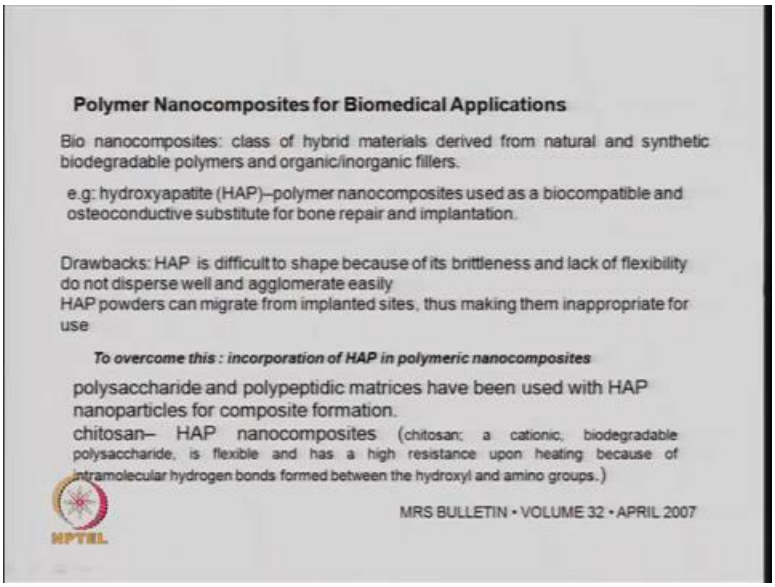

Now, that was a multi scale modeling of a polymer nano composites, now why are people interested in polymer nano composites one of the major areas for the interest on polymer nano composites is in the area of biomedical engineering.

So, applications in biomedical engineering a biomedical science for example you can design and synthesize bio nano composites. So, what are bio nano composites this is a class of hybrid materials that means combination of materials derived from natural and synthetic biodegradable polymers and organic or inorganic fillers. So, you can have a natural or manmade that is laboratory synthesized polymer which is biodegradable because ultimately you want today.

So, one wants biodegradable polymers that means polymers which can be naturally degraded over time by appropriate bacteria etcetera, so you want biodegradable polymers. Now, you may be having some nano particles as fillers they may be organic or inorganic and these kinds of bio nano composites are important in several biomedical applications. So, an example is hydroxyl apatite polymer nano composites which are used as a biocompatible and osteo conductive substitute for bone repair and implantation.

So, this is a synthetic material, it is a substituent for bone and so people use this combination of hydroxyl apatite and polymer nano composite for bone repair and implantation. Now, the there are certain drawbacks of this material because hydroxyl apatite is difficult to shape that means difficult to make it in a particular shape because it is very brittle that it breaks very easily. So, when you want to machine it to make it into a particular shape because it has to fit into some part of the body then it has it is very brittle and it is not very flexible it also does not disperse very well and agglomerates.

So, these hydroxyl apatite powders they can migrate from the site because of their ability to agglomerate they can move from their site where it was implanted. Thus, hydroxyl apatite as such is not very efficient for the purpose for which it is planned that is as a substituent for bone or bones either implantation or for bone repair. So, to overcome this instead of using pure hydroxyl apatite you incorporate this hydroxyl apatite in a polymer to make nano composites.

So, people have tried various types of polymers, for example polysaccharide and polypeptide matrices have been used with hydroxyl apatite for composite formation. So, one of the polymers people have chosen biopolymers is chitosan and chitosan with hydroxyl apatite. So, you get nano composites and this nano composite is has lot of important properties very much useful for bone replacement and that is one of the properties is it is highly flexible.

Now, it has a high resistance on heating because of intra molecular hydrogen bonds formed between the hydroxyl groups of hydroxyl apatite and amino groups in the chitosan, which is the biopolymer. And so this kind of nano composite can be used as a substituent for bone.

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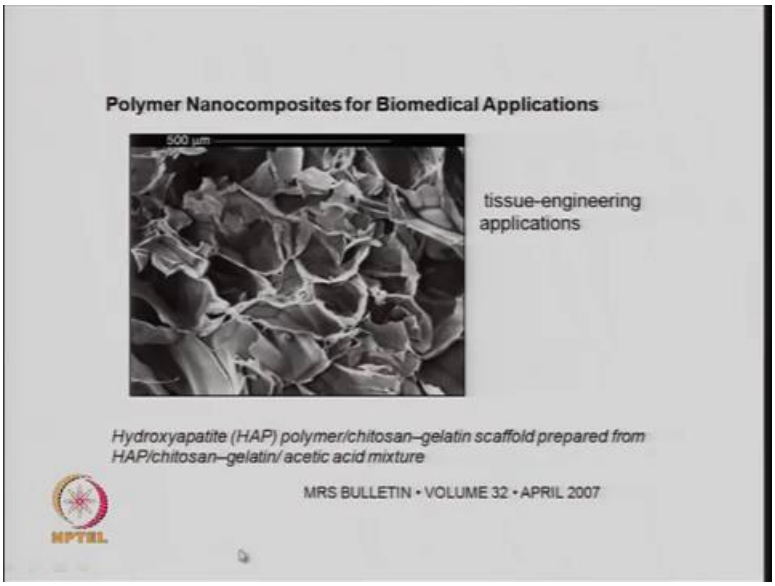

Now this is a S E M picture of a polymer nano composite between hydroxyl apatite and chitosan with a gelatin scaffold and you see these kind of features. So, these features are around 500 micron or more and it shows away highly compacted structure and this has applications in tissue engineering. So, there is lot of work being done on polymer nano composites especially for biomedical applications and chitosan is a important biopolymer which is being used in the presence of hydroxyl apatite for these applications.

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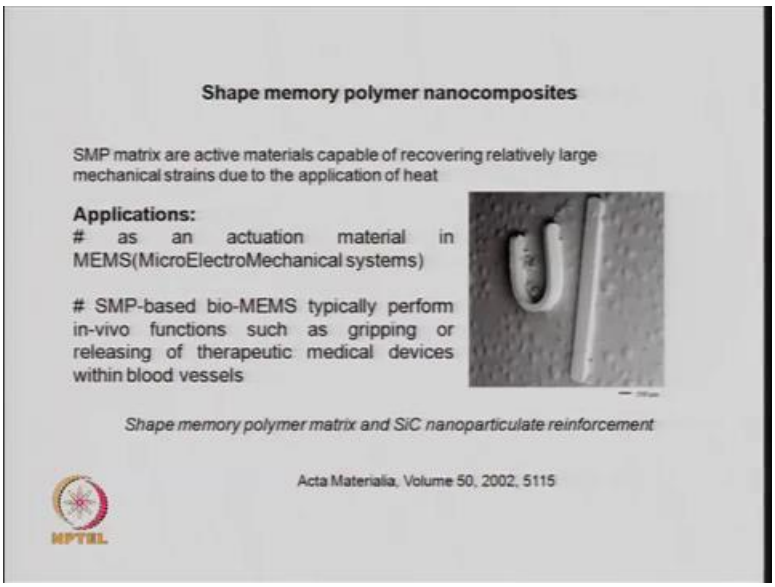

Now, people have also used other type of polymer nano composites and in that shape memory composites are very important. Now, what is this shape memory polymer matrix these are materials which can remember their or retain their shape after a mechanical strain has been remove. So, suppose you take an example where this material this shape memory polymer matrix is heated when it heats. So, when you heat there is a large mechanical strength which develops and this polymer nano composite may bend itself.

Now, when you remove the strain that means you cool the substance it goes back to its original shape, so it is as if the polymer remembers what was its original shape it is a polymer nano composite. Hence, it is called a shape memory polymer nano composite because once you remove the external force or the external stimuli in this case that is temperature because you are applying heat.

So, due to that there is a development of a strain you remove the heat and that strain goes back and this structure changes to the original shape. Now, this can be used for mems devices and what are mems, mems is micro electromechanical systems, similarly today the next generation of mems is called mems that is nano electromechanical systems.

So, here this can be these type of shape memory polymer nano composites can be used as actuators an actuation materials where the application of a particular external stimuli changes the shape. So, removal of those external stimuli brings it back to the original shape and so this kind of devices used in for in vivo functions that is inside a living system living cell. So, it is called bio mems because you are doing a application in biology or in life sciences and this kind of shape memory polymer nano composite based bio mems have been performed in vivo.

But, they can hold like gripping or releasing of medical devices within blood vessels, so you make this to hold some vessels or within the blood vessels to hold some particular organic. Then removing the external strain it goes back and releases whatever it was holding, so such bio mems based devices have been used for gripping or releasing of medical devices.

So, a medical device can be a small surgical implant or it can be a drug or it can be a capsule, so depending on that such kind of devices have been made in the area of bio mems. So, this is the example shown here is basically of a polymer nano composite where you have a shape memory polymer matrix with and a nano particle. Now, in this

particular case it is silicon carbide nano particles which is a high strength material and this silicon carbide with the shape memory polymer forms a composite and has shows a variation in its shape depending on temperature.

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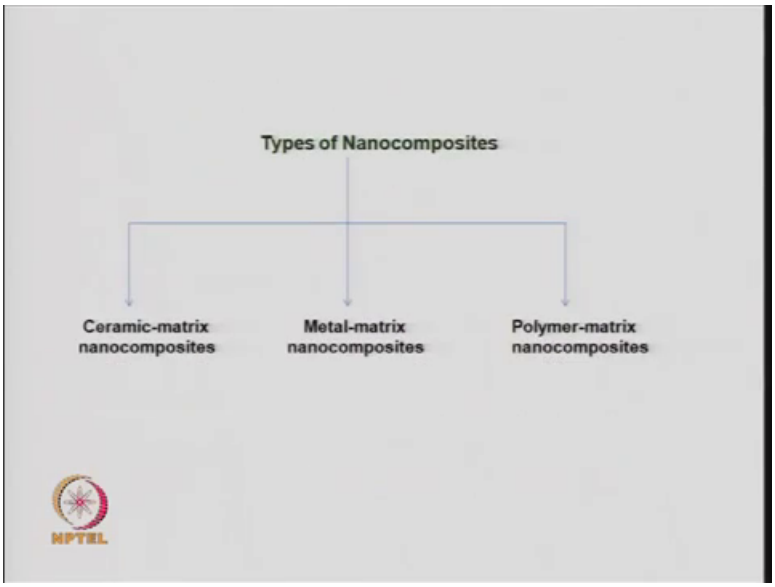

Now coming to different classes of nano composites you can have ceramic matrix nano composites where you have ceramic like oxide nitride chalco genides. So, these are called ceramics mainly oxides nitrides and fluorides are called ceramics because they are stable at high temperatures. But, normally materials which are stable at high temperatures are called ceramics especially those which are metal oxides or metal nitrides or metal fluorides. So, if you have one material which is a ceramic with another nano particle then it is called a ceramic matrix nano composite.

However, if you have a nano particle which is, for example a metal, so here you can have a ceramic which is a nano particle with the matrix which is, for example a polymer or another bulk ceramic having micron sized particles. Then that is a ceramic matrix nano composite, on the other hand if you have nano particles of metals say copper silver gold etcetera.

So, a small particle of metal embedded in a matrix a matrix can again be a polymer or a ceramic then that will be called a metal matrix nano composite. Similarly, if you have a polymer with some other matrix then you can have what is called a polymer matrix nano composite, so these are different types of nano composites.

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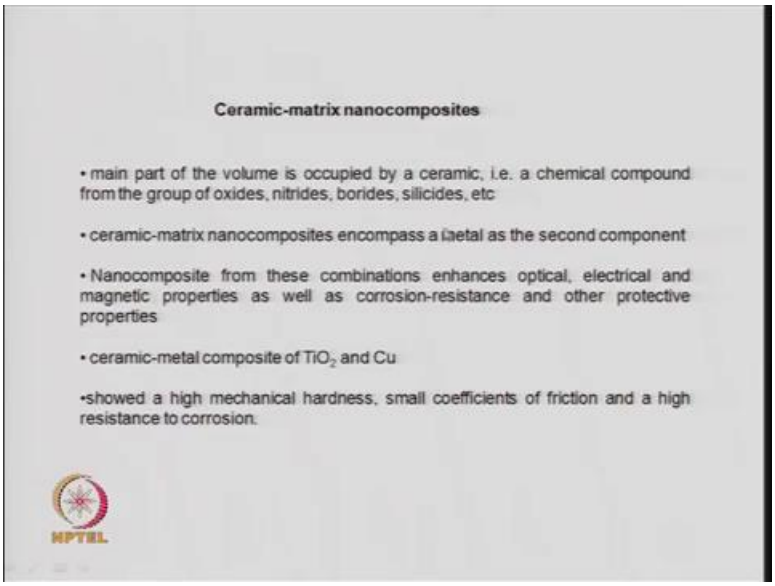

Now, ceramic matrix nano composites were the main volume that is the main, the bulk of the sample or the material that you have made is ceramic like an oxide or a nitride or a boride or a silicide. Basically materials which have high melting points that is they are refractory materials when this most of the bulk of that is this ceramic and you have small amount of other nano dopant or nano particles. Then those are called ceramic matrix nano composites, and these ceramic matrix nano composites typically can encompass metal nano particles.

So, the metal nano particles are the second component and that is embedded in this ceramic matrix, now if these nano composites can have different properties. So, depending on whether you are looking at optical electrical or magnetic properties or corrosion resistance you can see that these combinations of metal and these ceramic enhances those properties which you are studying.

So, it may be corrosion resistance or scratch resistance or optical efficiency, the intensity of some light which is being transmitted. So, there is always a enhancement of these properties when you optimally choose the metal nano particles with the right kind of matrix which is a ceramic.

So, an example of a ceramic metal composite is titanium dioxide and copper nano particles, so titanium dioxide is the matrix here it is the bulk phase here and in that you have incorporated small amounts of copper nano particles. So, then that becomes a

ceramic metal a composite nano composite and this nano composite shows a very high mechanical hardness it shows small coefficient of friction and a high resistance to corrosion.

So, this is an example titanium dioxide is micron sized forms the matrix is the bulk component in which small amount of copper nano particles is embedded impregnated or dispersed. Now, this combination of copper nano particles with titanium dioxide gives rise to a very important properties and an enhanced properties like large a mechanical hardness small coefficient of friction and lot of high resistance to corrosion.

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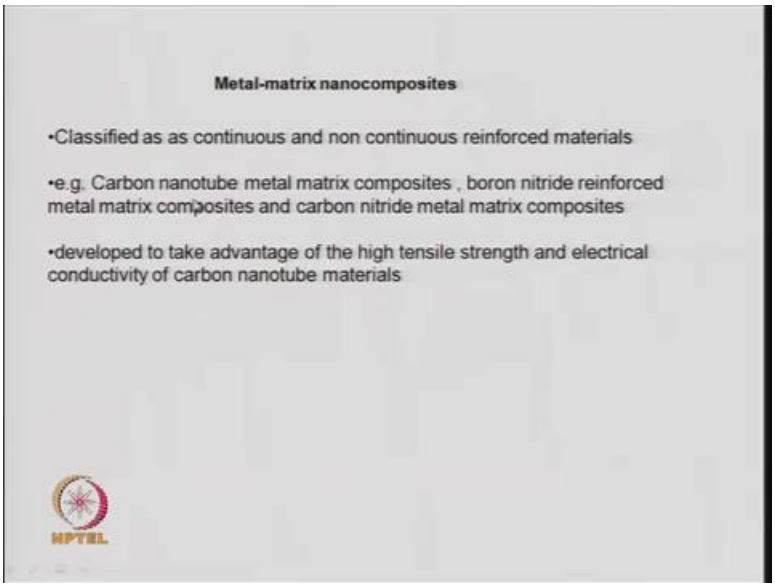

Then you can have metal matrix composites and they can be continuous and non continuous, for example can have carbon nano tube metal matrix composites. So, you can have carbon nano tubes and in a metal matrix, so then carbon nano tubes here is the dispersed phase it is the phase which is in small amount and the metal is in the large amount. So, you can have carbon nano tube based metal matrix composites or, similarly you can have boron nitride nano particles in metal or you can have carbon nitride in a metal matrix. So, these gives rise to very high tensile strength and electrical conductivity of the carbon nano tube materials, so we have discussed many classes of nano composites.

Especially, polymer nano composites metal ceramic nano composites and various nano composites based on their properties and functions like mechanical strength optical

properties magnetic properties etcetera. So, today we conclude the lecture here and we will have the second lecture of nano composites will be our next lecture and that would be the last lecture of module 3.

Thank you very much and look forward to meeting you again.