Nanoelectronics: Devices and Materials
Prof. S. A. Shivashankar
Centre for Nano Science and Engineering
Indian Institute of Science, Bangalore

Lecture - 38
Nanowires and other nanostructures

Hello. This is the next session of segment 3 of this course on Nano Electronic Device Fabrication and Characterization. And we have recently dealt with nano crystal growths.

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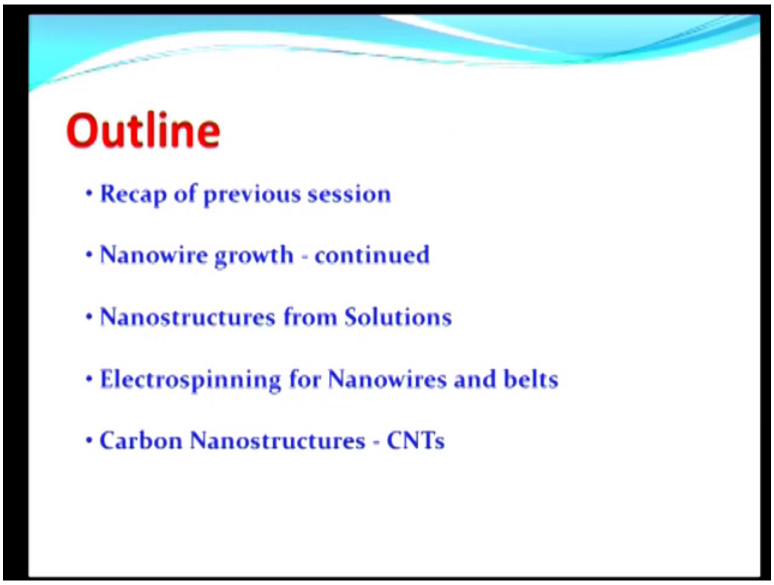

And in particular we talked about. The growth from solutions of compound semiconductors, metals and last time we also dealt with sol gel processing for the preparation of oxide nano particles nano crystals. We also learned about polymer stabilizers and the role they play in the growth of nano crystals of all of these types of materials, metals, semiconductors and also oxides.

We then went on to deal with the continued the discussion on the vapor liquid solid process for the growth of nano crystals are nano wires in particular of semiconductors and what we where we left off last time we were discussing the growth rate an arrhenius plot of the growth rate that is the logarithm of the growth rate on the temperature inverse temperature.

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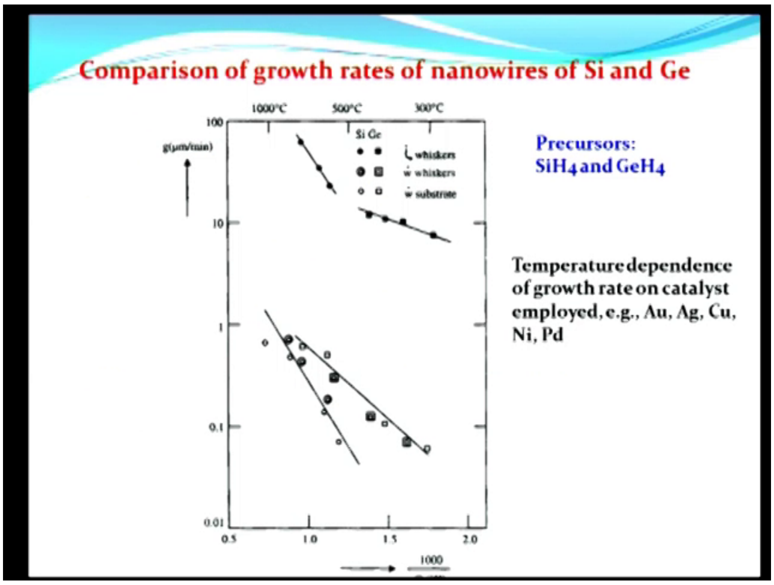

So, we have inverse temperature on the x axis and the logarithm of the growth rate on the y axis and what we showed was, how greatly the growth rates of silicon and germanium nano wires respectively from silane gas and germane gas using gold as the catalyst, actually a number of catalyst can be used gold silver copper nickel and palladium and so forth. So, how greatly these rates can vary depending on the conditions that actually employed for the growth, notice that these on log scale.

And therefore, there can be a difference in the growth rate of as much as two orders of magnitude. That all that shows us that a great deal of control can be exercised over the growth of nano wires of semiconductors from the VLS method.

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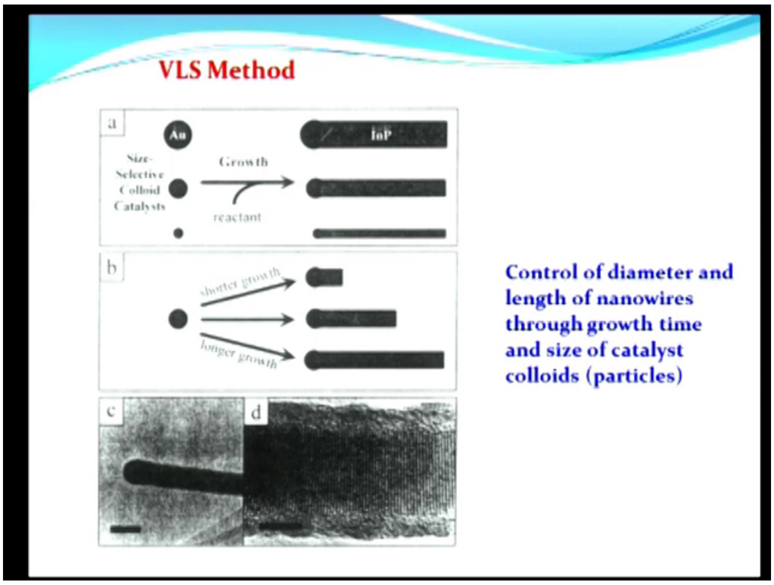

Now, in particular one can control the size of the wires that is the diameter of the wires you can see here illustrating the growth of indium phosphide wires of different diameters based on the conditions that are grown used for the purpose. We can also change the length of these things that is we can have short wires longer wires and much longer wires notice that in each case there is a bead at the front of the nano rod and that represents the catalyst that moves along the growing nanowire.

So, that the growth species become a part of this bead forming a eutectic that allows the growth process to continue as long as we have the growth species fed continuously. In this case in the vapor phase through the vapor phase, and the tm images here at the bottom the image d in particular shows this is a lattice image of the nanowire, I have a nanowire of indium phosphide and the regular distribution of these lattice planes shows how perfect these crystals can be these wires can be these nano crystals can be.

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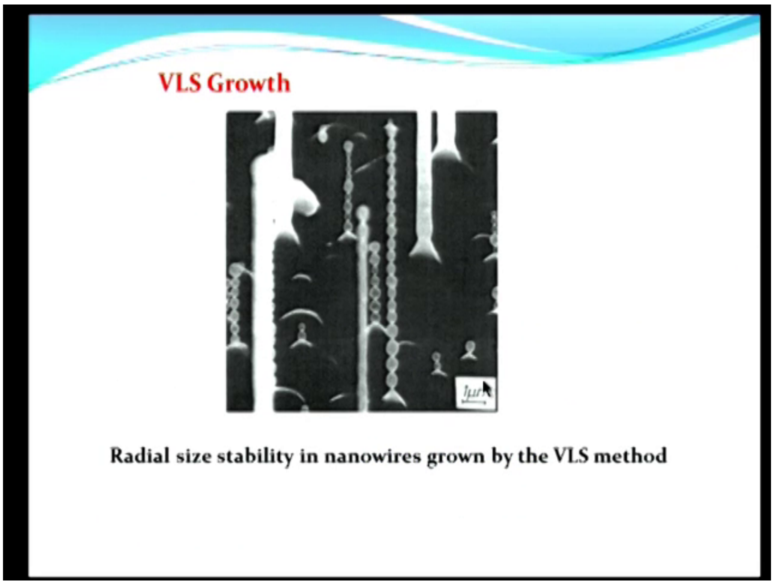

Now, this image actually this SEM image shows how stable the radius of these nano wires grown through the VLS process can be. So, these are actually illustrations a silicon wire that is being drawn and one you know you can see how for example, from the top to the bottom the radius of these structures are essentially invariant.

So, that speaks for the great deal of control one can exercise in the VLS growth method, over the shape and size the diameter and so forth of the semiconductor nano crystals that are grown and just to reinforce the idea I just want to point out that apart from elemental semiconductors like silicon and germanium. We have shown the illustration of how indium phosphide for example is grown here using gold as the catalyst.

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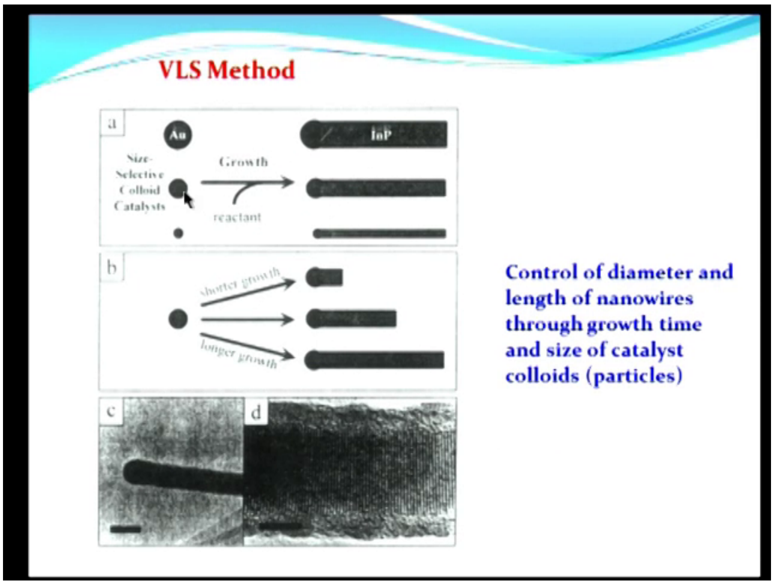

So, it applies also to compound semiconductors now we have.

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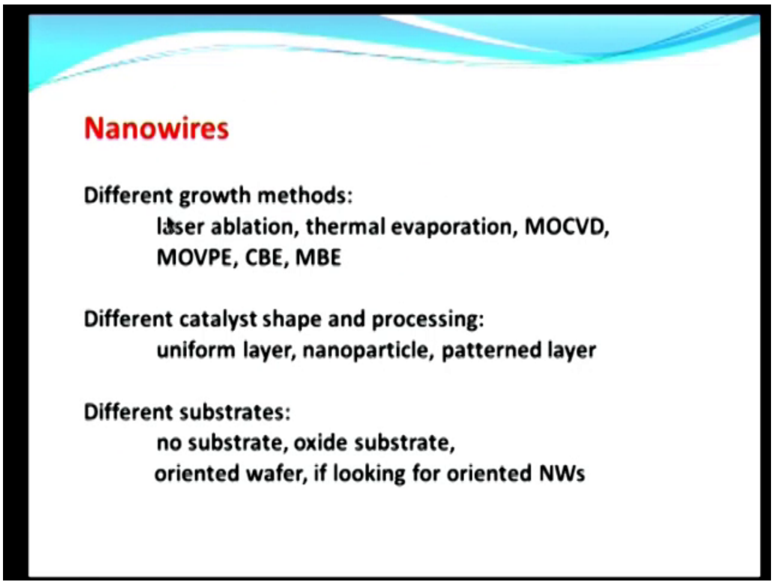

So, far dealt with the VLS method there are different growth methods for nanowires as shown here laser ablation thermal evaporation and so on so forth and employing different catalyst shapes in the VLS method we have used basically a droplet of a metal like gold, but you can have different shapes of the catalyst itself; namely you can have a uniform layer of it nano particle a patterned layer of the catalyst and so forth that way one can have an additional degree of control of the growth of the process as well as the configuration in which these wires are grown.

For example in the pattern layer different substrates also. So, one can use no substrate at all that is one simply tries to draw these wires out using a bead of the catalyst, one can use an oxide substrate, one can use an oriented crystal as a substrate if one is looking for oriented nano wires a let us say a cluster of oriented nano wires, that can be obtained for example, by patterning as shown here a silicon substrate with gold dots in a uniform array and that would give you one oriented for example, silicon wires in a two dimensional array.

So, all these variations are possible that allow us to grow nano wires of various materials, semiconductors in particular and this one here illustrates a laser catalytic growth of silicon nano wires what is done here is to incorporate the catalyst namely iron into a solid target.

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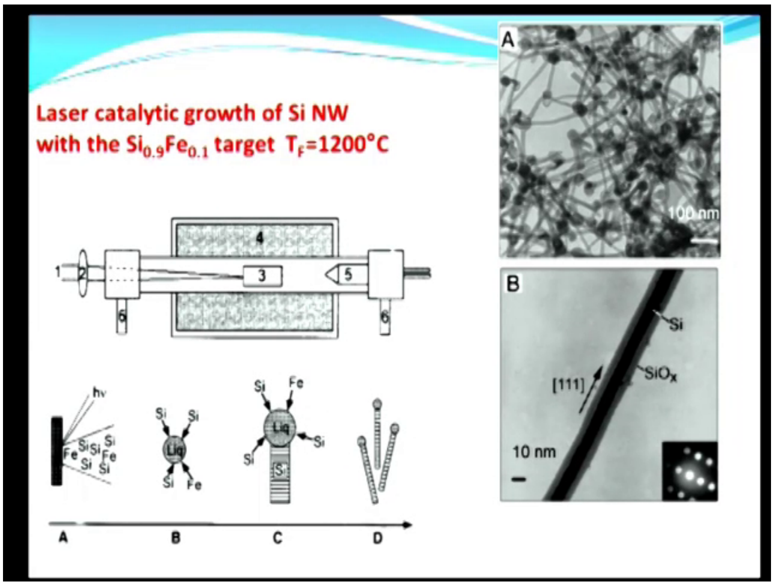

One makes a an alloy of silicon with iron and makes it into a solid target 3 over here and that one is then bombarded with lasers in a furnace at a temperature without 1200 degrees.

So, what happens as a result of that is that one can collect as shown here in the s e m micrograph, one can collect nanowires of silicon in this kind of a essentially shapeless consideration because no particular effort was made to have this in some pattern what is happening here is silicon and iron or being blasted out of this target into the hot surface I mean hot furnace. And we have iron silicon forming a eutectic this. Therefore, this is a liquid droplet and out of that catalyzed by the presence of iron silicon begins to grow as crystals.

So, you have these pencils small pencils with the metal bead at the top illustrating the growth of nanowires by this so called laser catalytic method.

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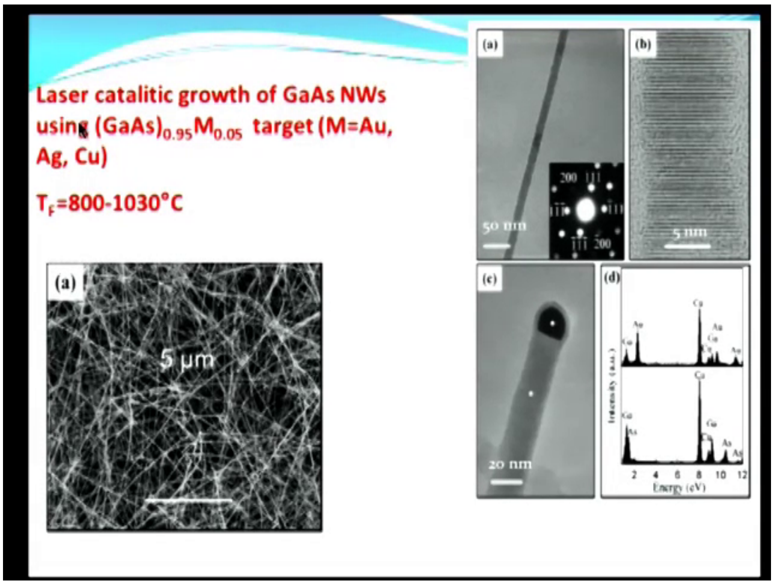

The same method can be used for the growth of gallium arsenide, once again the catalyst metal gold or silver or copper is incorporated into the target just as in this image over here. So, this target would be made of gallium arsenide mixed with gold or silver as the catalyst material. And as it is bombarded with lasers evaporating the material into the hot furnace into the ambience of the hot furnace then through this same process and analogous process the growth of nanowires of gallium arsenide takes place.

Once again the tm image for example, this selected area electron diffraction pattern this one over here, this one because it consists of dots well ordered dots as opposed to rings what this illustrates is the is that this nanowire over here of a diameter approximately 20 nanometers or there about this nanowire of gallium arsenide is a single crystalline nanowire as illustrated by this s a e d patterns and as confirmed by the tm image the lattice image of this wire. So, through this process which takes place somewhere between

800 and 1030 degrees. So, over here in this particular process one can get nanowires of gallium arsenide through a process that is laser catalytic process.

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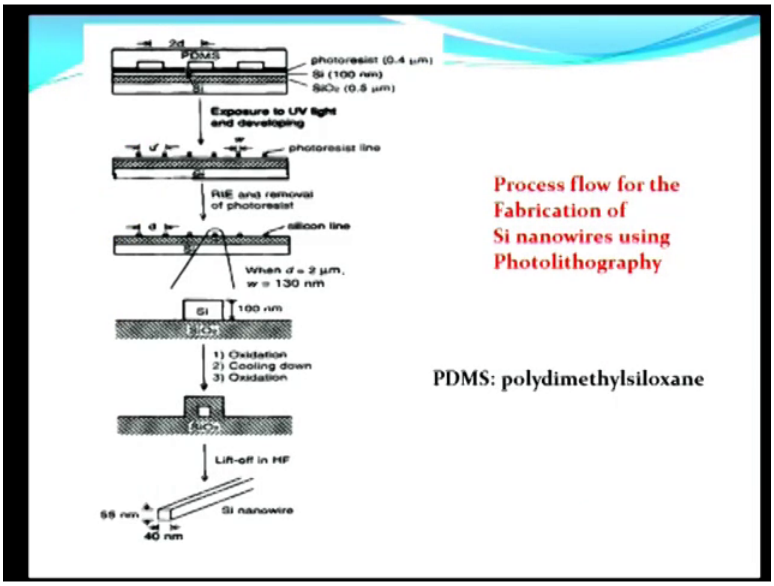

Now needless to say lithography optical lithography, which is a process that you are all familiar with already from earlier parts of this course, that can be used to pattern silicon into nanowires as shown at the bottom of the micrograph. For example, this nano wire over here are silicon that is obtained through a multi step patterning and releasing process then one obtains a nanowire of silicon from a single crystal silicon substrate. Therefore, we have a single crystal silicon nanowire with a rectangular cross section of 40 nanometers versus 55 nanometers as shown in this case.

In other words the familiar processes of lithography that are used in all kinds of patterns for semiconductor industry, can be deployed to obtain nanowires because high resolution photo lithography is possible today therefore, nano metric wires of great uniformity in shape and size and so forth can be obtained through this top down process. Let us remember that all these processes that we showed earlier the VLS process and so on are really bottom up processes. So, one can deploy the top down process to obtain nano crystals or nanowires with great degrees of control.

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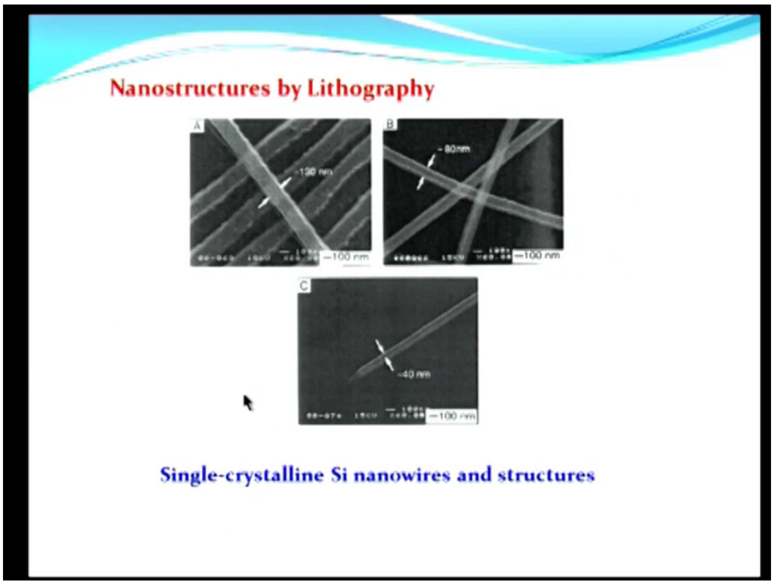

So, this show again images of silicon nanowires and you know patterned nano structures over here for example, there is a crisscross pattern over here of silicon obtained through photolithography of a silicon wafer in a multi step process. So, junctions for examples can be patterned and so forth. So, really there is a great deal of possibility for using photolithography to obtain these things, with a much greater degree of order than for example, this forest of nanowires that comes out of the laser catalytic growth process.

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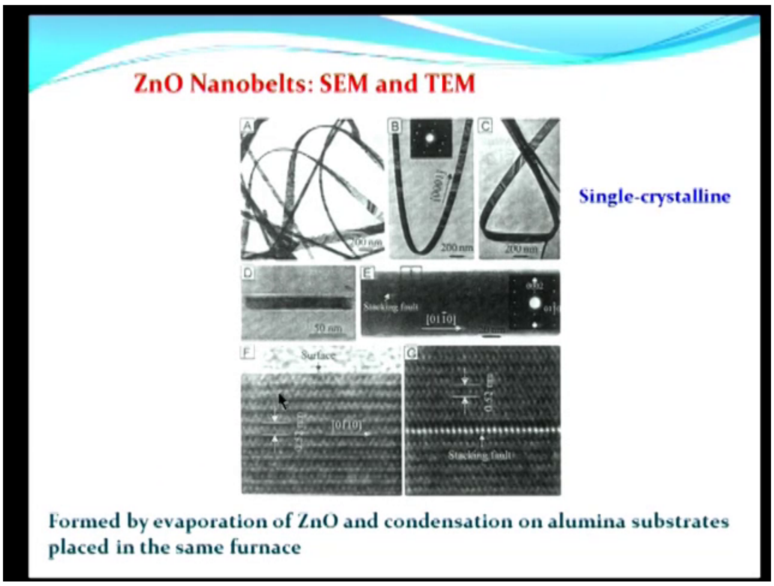

Now, zinc oxide which is a broad band gap semiconductor of great interest today. So, zinc oxide is an oxide semiconductor of much interest and so called nano belts of zinc oxide have been obtained these are single crystalline nano belts as shown by the tem micrograph over here, which shows the lattice image.

So, zinc oxide nano belts of this sort have been obtained by evaporating zinc oxide and condensing zinc oxide on to alumina substrate placed in the same furnace that is one evaporate zinc oxide out of a boat kept in a furnace at a an appropriate temperature. And then one collects the evaporated zinc oxide on a substrate like alumina. And when that is done with appropriate temperatures and other conditions, one is able to obtain these kinds of rather spectacular belt like single crystalline growth of zinc oxide.

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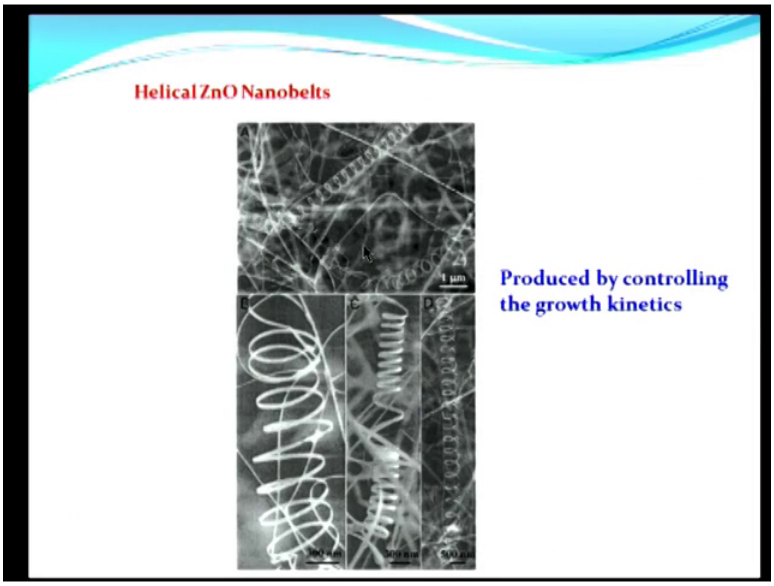

Now, these same authors then went on to control the growth kinetics; that is through process control namely temperature and the vapor pressure of zinc oxide in the chamber and the flow rate of organ, which is used as the carrier gas and so forth. By controlling this growth kinetics they have been able to obtain these spectacular spiral structures of zinc oxide very regular spirals and so on. So, these are helical zinc oxide nano belts and such very interesting structures can be obtained through the simple process of evaporation and condensation, which we discussed last time evaporation condensation.

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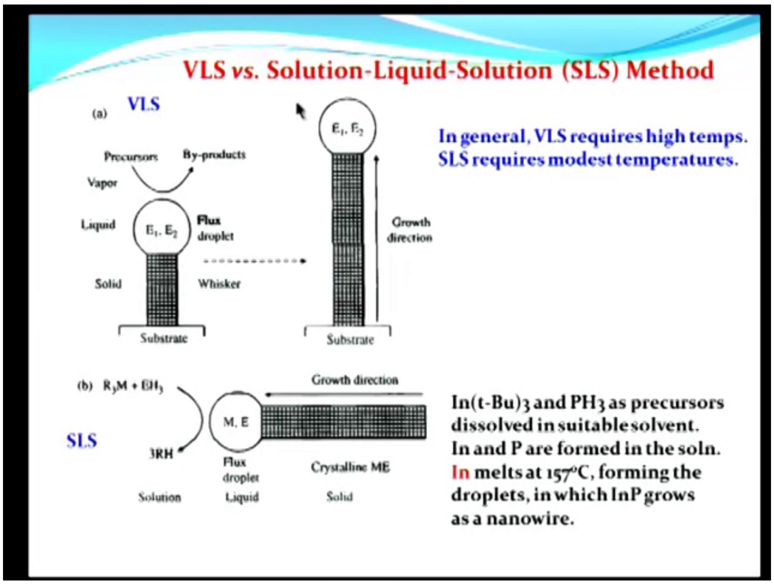

Now there is also now so far we learned about the vapor liquid solid process, there is all that is the VLS process there is also an SLS process SLS method solution liquid solution method solution liquid solid method sorry solution liquid solid I am sorry for the error.

So, solution liquid solid method SLS method is illustrated by the figure at the bottom over here what is done for example, what we are trying to do here is to grow single crystals or nanowires of indium phosphide, which is a semiconductor compound semiconductor to do that a compound of indium tertiary butyl indium over here and another precursor which is really a toxic gas phosphine PH 3, these two are dissolved in a suitable solvent often an alcohol methyl alcohol for example.

So, these are dissolved this indium compound and the gas actually phosphine gas or dissolved in a suitable solvent and one then heats this appropriately. In the solution then what happens is indium metal is formed indium melts at a rather low temperature of 157 degrees Celsius. So, indium metal is formed and what you now have is a liquid droplet there is a flux for the growth; this is the flux out of which the growth of indium phosphide takes place there is the indium metal itself which is one of the components of indium phosphide.

Phosphorus is released from PH 3 by the high temperature and therefore, catalyzed by the rest of the indium that is present in this dropletm then indium phosphide begins to grow. So, what we have therefore is the steady growth of indium phosphide from out of this liquid droplet that contains one of the constituents of the compound semiconductor through this solution liquid solid process. So, this is a variation that can also give high quality single crystalline wires nanowires of compound semiconductors.

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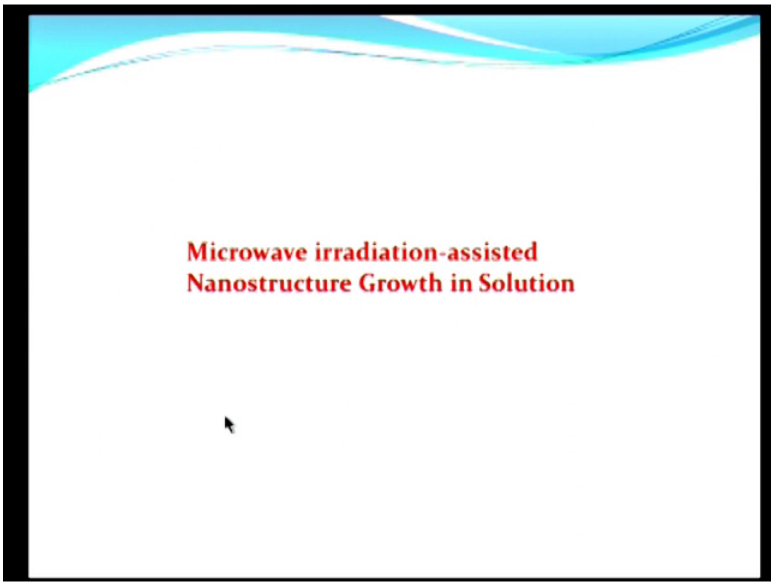

I would like to also discuss a rather simple very practicable method for the formation of nano structures from a solution, using microwave irradiation that is microwave irradiation used to assist chemical reactions taking place in a solution that would give nano structures of different materials, and in this particular case we will discuss oxides.

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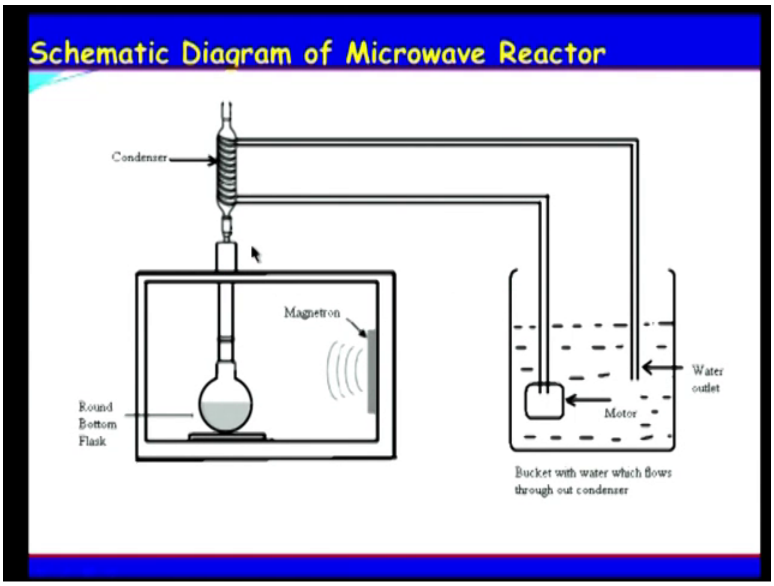

So, what this is really a simple arrangement a an ordinary so called domestic microwave oven is sufficient for this purpose, and one takes a certain solution which we discuss here in a round bottom flask and one has a condenser over here this the solution often contains a low boiling point solvent such as ethyl alcohol. Therefore, as it begins to boil out of this we do not want to lose it. So, there is a condenser. So, this condenses the alcohol and brings it back into the solution.

So, this is a way to collect the boiling and evaporating alcohol which is a solvent in this case and that happens when microwave radiation is turned on, which is absorbed by the solution and therefore, it gets heated just as in the kitchen when one cooks using microwave radiation. So, this condenser collects the solvent back. So, this is simple arrangement now how does one use this to make nanostructures.

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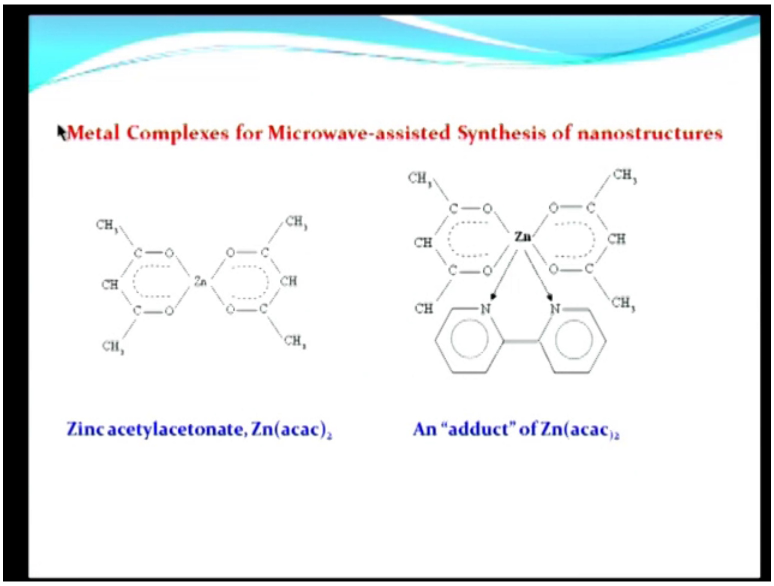

One uses appropriate metal complexes what is shown here, is the schematic diagram of the structure of a compound at a complex called a Zinc acetylacetonate. So, you can see that there are hydrocarbon groups over here. So, is a metal organic complex what we have here is a direct bond between zinc and oxygen at the core of this complex, and then there are these terminal groups which are hydrocarbon groups.

So, this is a metal organic complex and here is a variation of the same something known as an adduct that is another group is added to this structure. So, this is also zinc acetylacetonate with an adduct over here. Now both of these dissolve readily in solvents like ethyl alcohol, hexane, benzyl alcohol and so forth. So, one takes.

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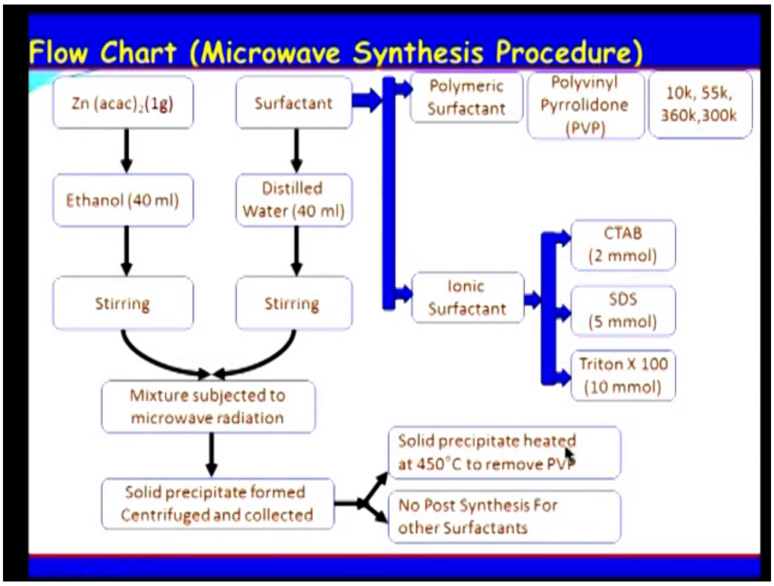

So, here is a flowchart for the procedure from which one can get zinc oxide nanostructures. So, one takes is alcohol rather the complex dissolves it in ethanol or ethyl alcohol, stirring and then subjected to microwave irradiation well when you do that nothing really happens why it turns out that it is necessary to add something known as the surfactant, which is analogous to the polymer stabilizer we talked about. So, this surfactant which is something that we discussed last time addition of polymers into solution that would aid the rather that would prevent agglomeration of nano particles are created and also enable the formation of nano crystals of specific shapes and so on.

So, it turns out that it is necessary to add a surfactant into this solution and when the surfactant which is water soluble is added into the solution and then you subject that to microwave radiation then it turns out that you do get a solid precipitate. So, there are different surfactants polymeric surfactants ionic surfactants and so on all of these affect the surface tension of the solution of the solvent over here. And as I said they prevent agglomeration and direct the growth of nano crystals in solution in this case through microwave irradiation. So, there are you know for example, this PVP which we met last time in our discussion. So, this is polyvinyl pyrrolidone which is a well known surfactant is a polymer and therefore, it is available in different molecular weights 10,000, 55,000 and 360,000 and so forth.

So, one can get PVP in different molecular weights to see how this can affect the growth of crystals of zinc oxide in this process and then there are differences of different surfactants which we shall not go into right now. So, a solid precipitate is formed when one of these is used and that precipitate is heated in air at about 450 degrees to remove the polymer otherwise it becomes remnant part of the precipitate, so to get the polymer out of this one heat sitting here at a rather modest temperature.

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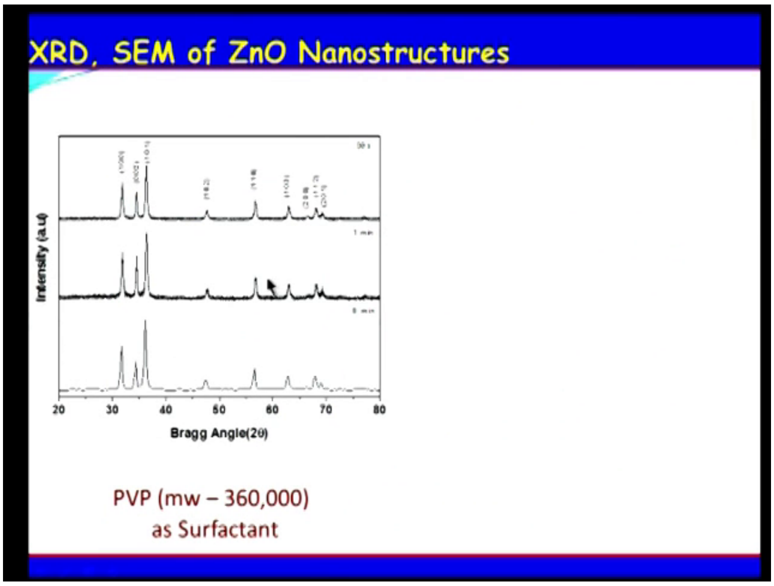

So, one gets a powder material and when x ray diffraction is conducted it is found that a crystalline pattern is formed and this pattern can be shown to be that of through databases one can show that this is zinc oxide zno which has a hexagonal crystal structure.

So, what is shown here is a sequence of x ray diffraction patterns for samples that are obtained after as little as 30 seconds of exposure to microwaves. So, 30 seconds 1 minute and 5 minutes. So, what you can see here is that even exposure of as little as 30 seconds results in the formation of crystalline zinc oxide in that solution after microwave irradiation is conducted. I want you to note that this is a very short period of time compared to what is generally required in the absence of irradiation in solution based processes, I mentioned earlier for example, growth of single crystalline nano crystalline material, nano crystalline metals and so on from solution for example, gold nano particles and so forth and then silver and platinum and so on.

So, usually these require lengthy processing although the temperature is low which is really desirable to control the growth of these nano crystals metal nano crystals what we have shown here is that a much shorter period of time is sufficient when microwave irradiation is used to assist the formation of zinc oxide from the zinc metal complex. So, as little as 30 seconds.

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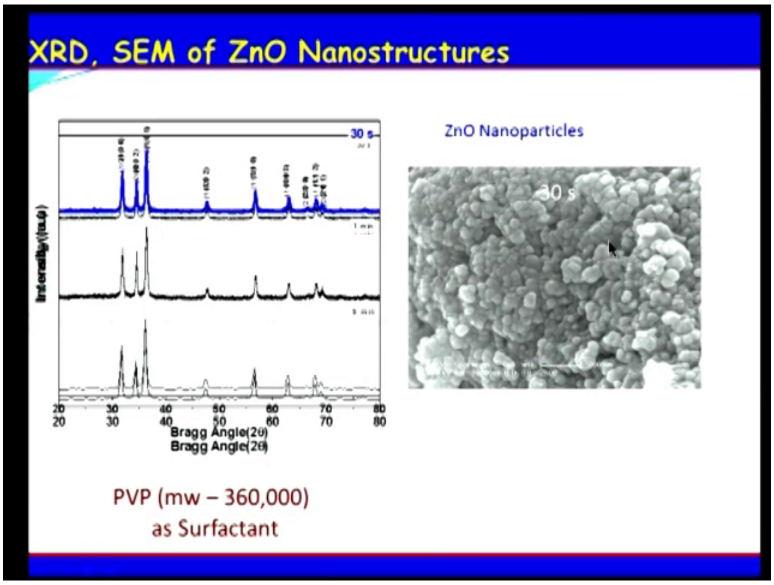

So, at the end of 30 seconds what we get is this zinc oxide crystalline material you know measuring about 30 to 40 nanometers in size. So, one gets so called powder material zinc oxide powder material crystalline powder material.

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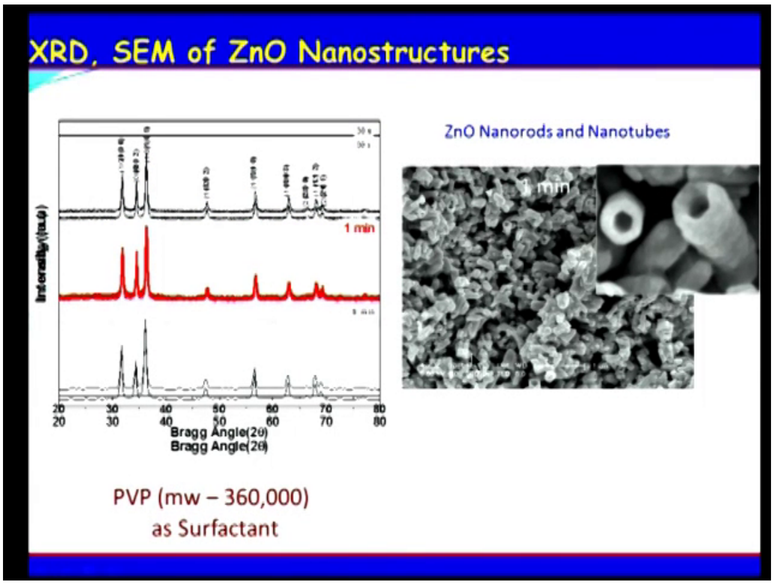

If it is done for one minute then the formation of hexagonal nano tubes and nano rods over here hexagonal nano rods characteristic of the crystal structure, the hexagonal shape is the characteristic of the crystal structure of zinc oxide they begin to emerge in as little as 1 minute.

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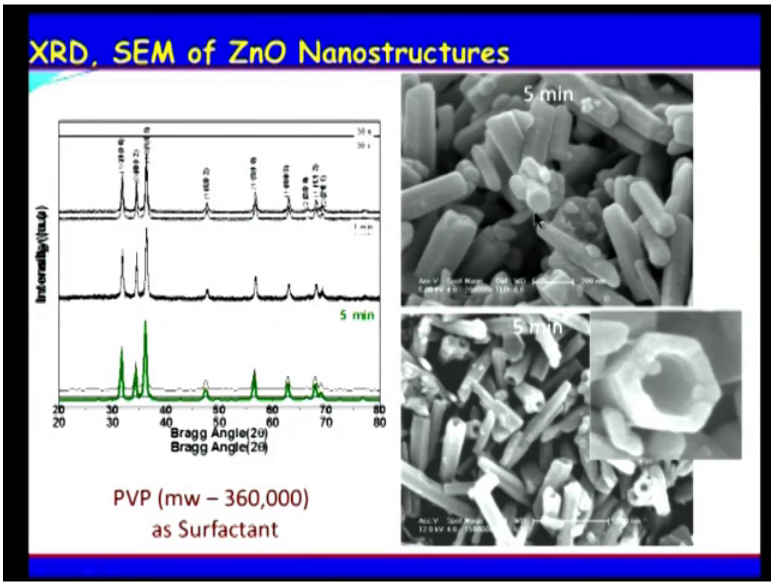

And when this is continued to 5 minutes you can see very well formed facets of hexagonal zinc nano rod zinc oxide nano rods and again very well formed zinc oxide nano tubes as shown here, diameter of the order of 60 to 80 nanometers. So, what this shows is that when a suitable surfactant such as PVP is used in this case of a molecular weight of 360000 then excellent nano structures by the way these structures.

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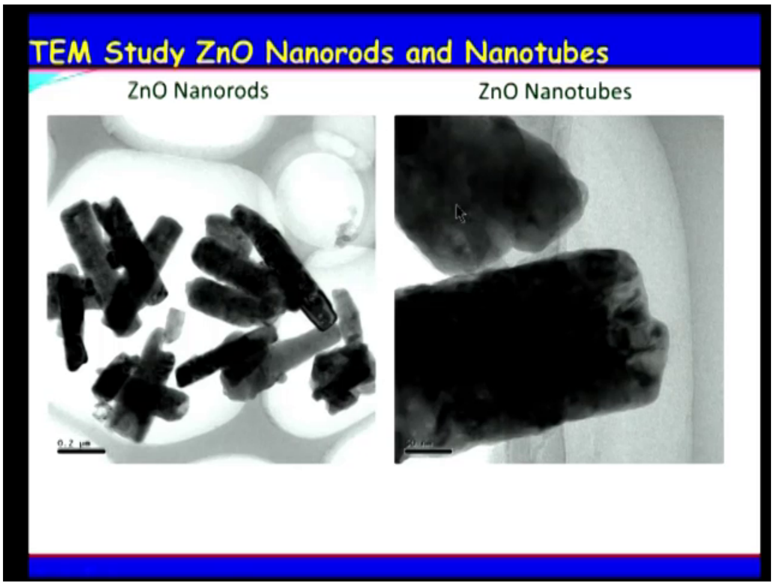

As I know this is these are transmission electron micrographs of zinc oxide nanostructures showing the dimensions, but more importantly.

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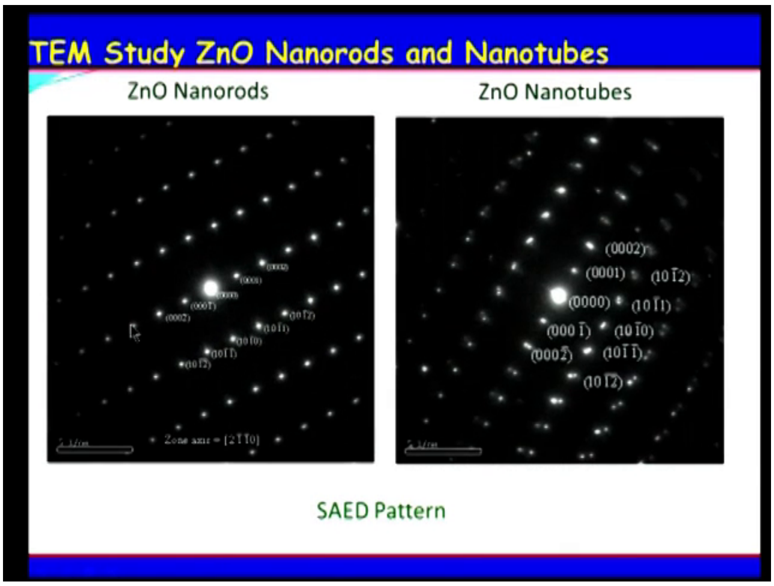

When one does selected area electron diffraction one gets these this spot pattern, which is indicative of these nano crystals nano rods and nano tubes and so on being single crystals.

So, these rods over here each one of them is a single crystal of zinc oxide of a pretty high degree of perfection. So, what is shown here?

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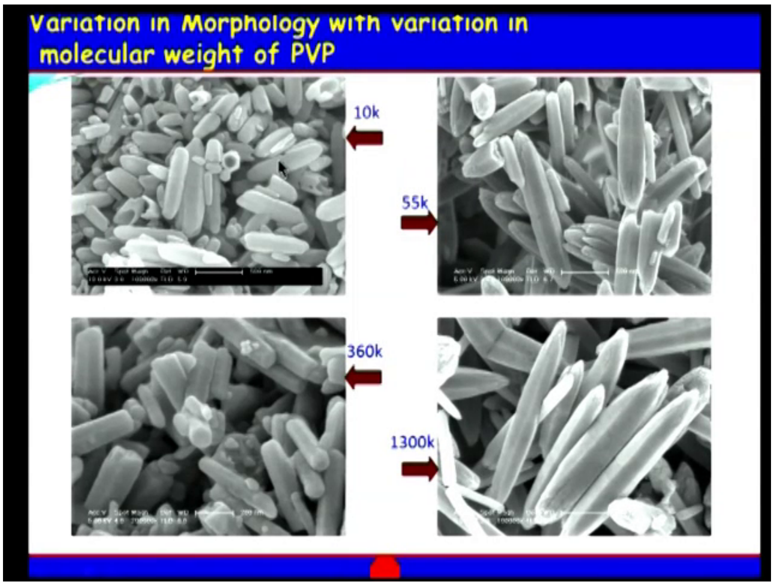

In this series of micrographs is how the shapes are this zinc oxide nanostructure is altered by changing the molecular weight of this PVP which is a surfactant. So, you have 10 k, 55 k, 360 k and 1300 that is one million 30000 k. So, what this is showing is the formation the shape and deformation of these different nano structures depends on the molecular weight of the surfactant.

Now, remember what is one of the things that the surfactant does one of these polymers one of the things that these polymers in solution do is to form a coating on the growing nano structure. Therefore, the growth process is affected by the polymer and naturally therefore, the molecular weight of the polymer which is indicative of the physical extension of these polymer chains that affects the formation of these nano crystals through this microwave irradiation assisted process.

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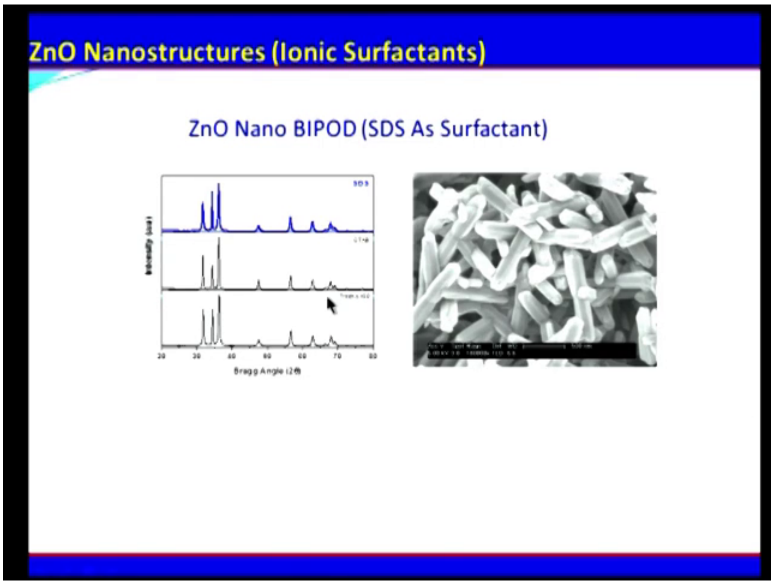

Now different kinds of by using different kinds of surfactants, SDS is one of the surfactants what is shown here is the formation of so called bipods, what I want you to note here is that when SDS is used as a fact end then each nano rod is really sort of welded pieces welded in the middle. So to speak, you can see that there is a symmetrical division of this nano rod around the center. So, we are calling it a bipod two pieces welded together in the liquid phase.

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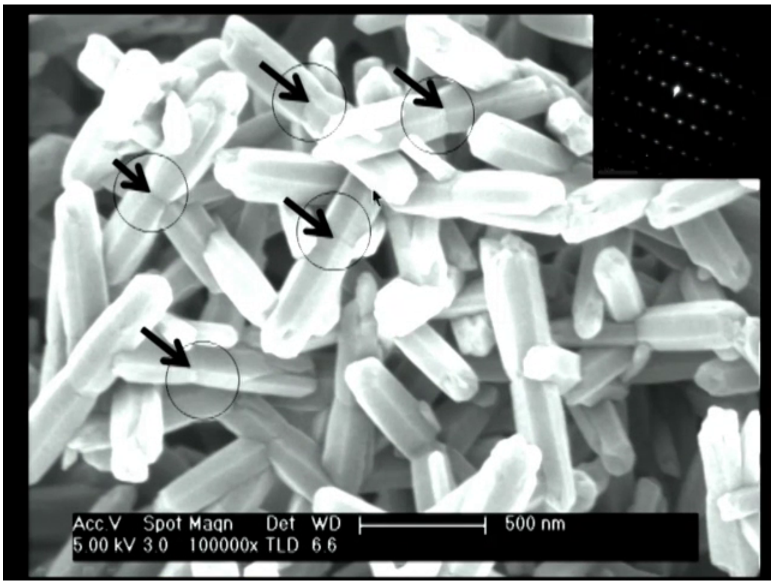

And that is shown in a close up here where the fusing of two crystals growing in opposite directions is very clearly seen when we use a different surfactant.

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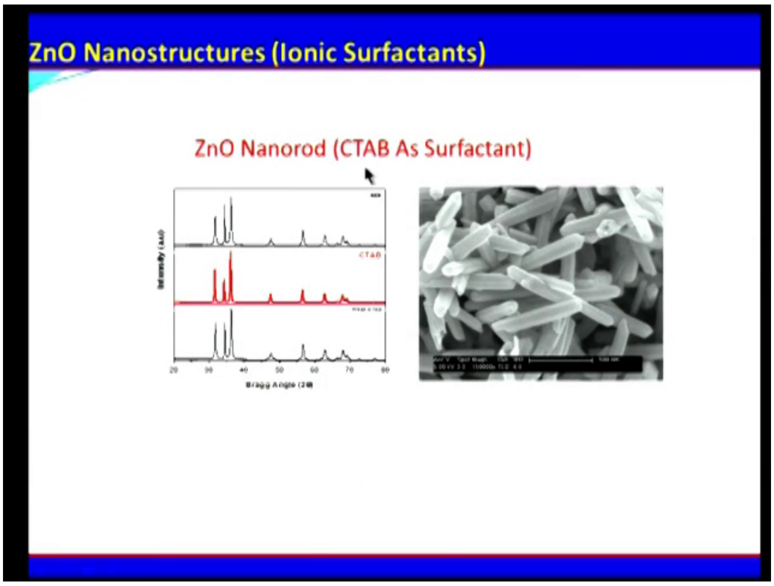

Known as c tab ctyl trimethyl ammonium bromide CTAB is one of the surfactants are used very commonly in nano structural growth. So, what we are getting here are zinc oxide nano crystals that have a high aspect ratio higher than previously. So, they have thinner and longer. So, this is what happens when a different surfactant is used.

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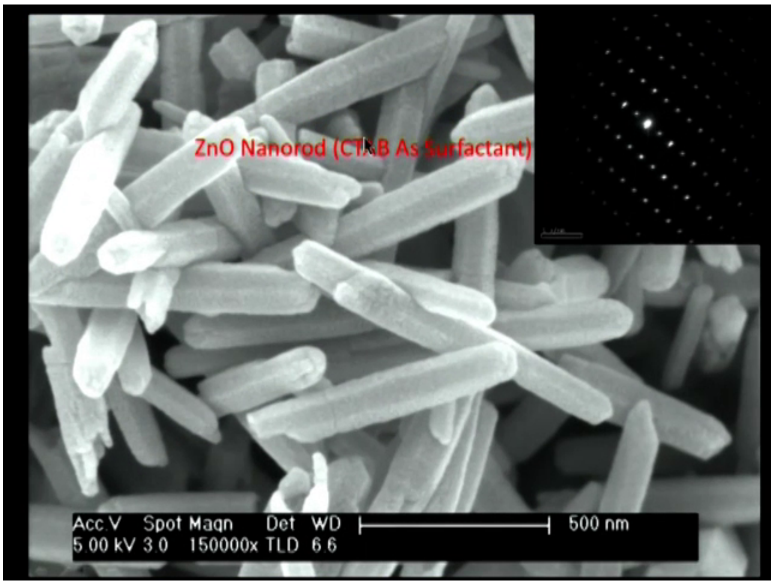

And you can see a close up of that.

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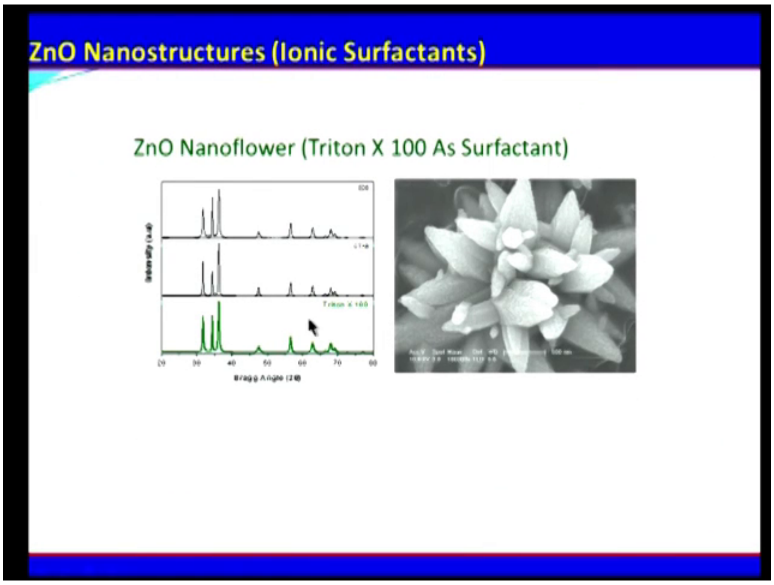

And a very different thing happens when a surfactant called triton x 100 which is a trade name actually. So, this is a different polymer when this is used altogether different nano structures are formed a flower like structure is formed in the same in the solution.

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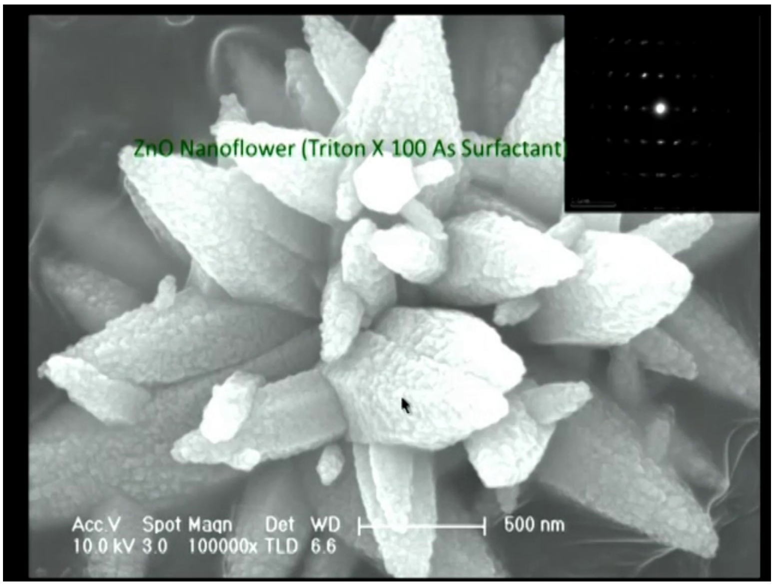

Now, you can see a close up of that. Each of these petals each of the petals of this so called flower is made up of zinc oxide nano particles that are all assembled in this petal like formation. It turns out that each of these petals even though it is assembled from nano particles of a much smaller size, each of these petals behaves like a single crystal of zinc oxide through a process known as oriented attachment.

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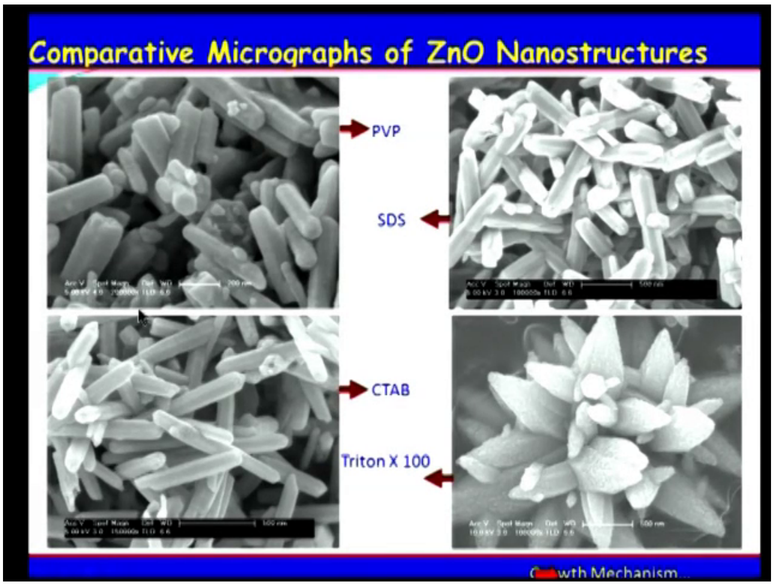

So, what is shown here is comparative micrographs of zinc oxide nanostructures obtained by using different polymer surfactants added to the solution in ethanol of zinc acetylacetonate, and then subjecting that solution to microwave irradiation for short periods of time.

So, what this illustrates is the ability to obtain nano crystals high quality nano crystals as indicated by electron microscopy and other measurements, high quality crystals at a within a very short time compared to other methods that are that use basically temperature as the control as opposed to microwave irradiation.

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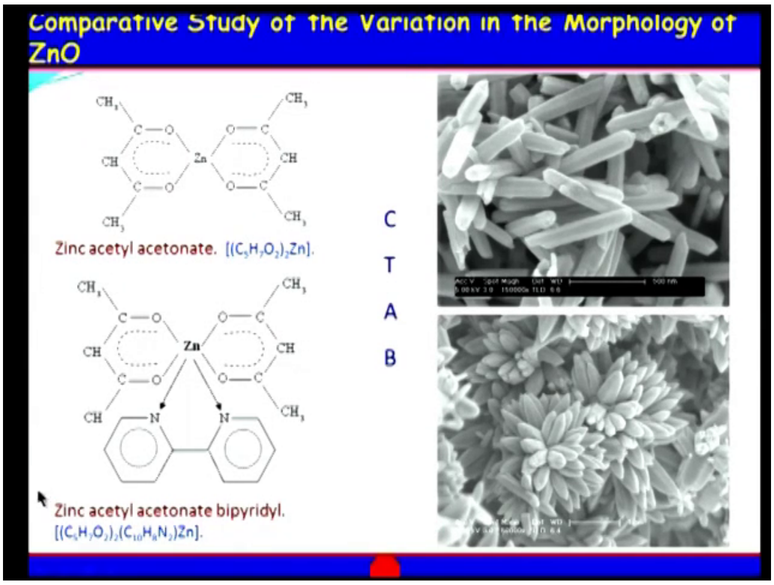

Now earlier I showed this molecular structure of an adduct so called adduct of zinc acetylacetonate. So, this adduct has a cap. So, to speak this molecular structure is capped by something known as the Bipyridyl Ligand over here. So, it is a chemically different precursor. So, this again goes into solution and then is subjected to micro irradiation in the presence of this CTAB, CTAB as the surfactant when zinc acetylacetonate is used as shown in the top micrograph one gets nano rods of zinc oxide, but when this adducted zinc acetylacetonate is used one gets an altogether different kind of a structure this flower like formation in solution each one of these being a single each of these petals being a single crystal of zinc oxide.

So, what this shows is that why suitably altering the chemical composition of the precursor material as well as by changing the surfactant using these as parameters in the process for the formation of nano rods or nano structures, it is possible to greatly alter the structure of the material that is derived from this microwave irradiation process for the formation of zinc oxide nano rods zinc oxide nanostructures.

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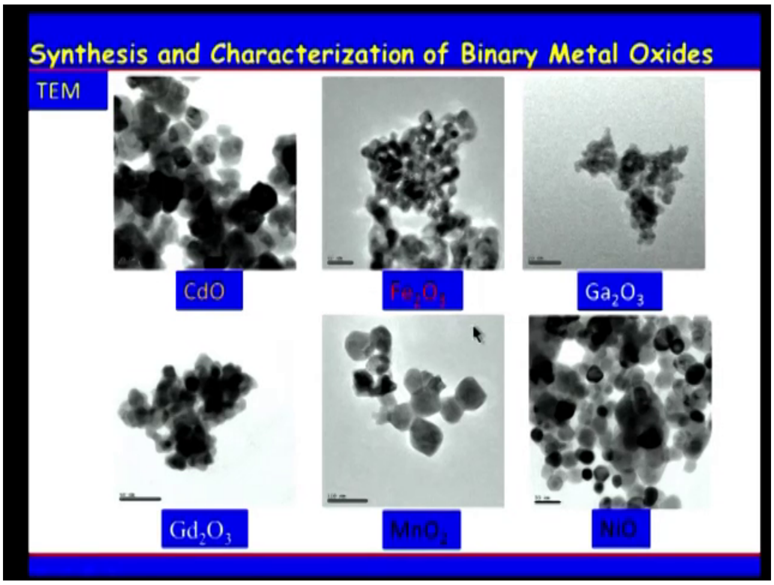

What is shown here is that the same thing can be extended these are transmission electron micrographs of cadmium oxide, iron oxide, gallium oxide, gadolinium oxide manganese oxide and nickel oxide each of these is produced using microwave irradiation starting with an appropriate complex of the respective metal.

So, by doing that it is possible therefore, to obtain the nano crystals of a number of oxides metal oxide from the microwave irradiation process all of them within a short period of time; typically a minute or two for the reaction to occur to produce or to obtain nano crystals of the metal oxide in question.

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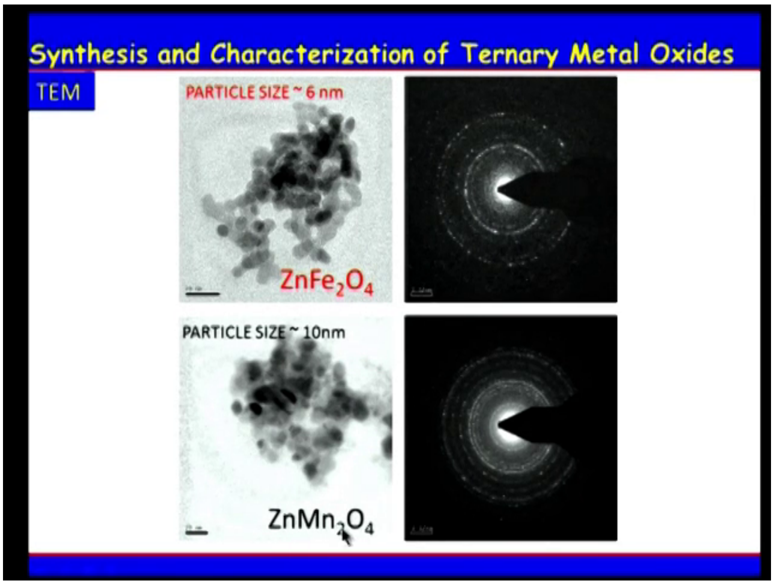

Now it is also possible to synthesize you see these are so called binary oxides that is one metal and oxygen binary oxides. It turns out that a similar procedure can be employed to produce complex oxides such as a ternary oxide which in this case is zinc ferrite ZnFe2O4 and then Zn M n 2 O4 zinc manganate.

So, these are ternary oxides. So, by taking one molar proportion of zinc complex and two molar proportions of iron complex in the solution typically an alcoholic solution and subjecting it to microwave irradiation it is possible to obtain zinc ferrite in this case zinc manganite in this case. And these patterns the ring patterns from the transmission electron microscope show that these are well crystallized this, this ring pattern as opposed to spot pattern shows that it is not a single crystal it is a so called poly crystalline material where each of the crystals that is shown in tem micrograph has a different orientation.

In a single crystalline formation then all of them have the same orientation crystallographic orientation, but these are all oriented differently leading to a spot pattern in the scanning electron microscope. So, this illustrates the versatility of the microwave radiation based process in solution in producing nano crystalline material of a number of oxides.

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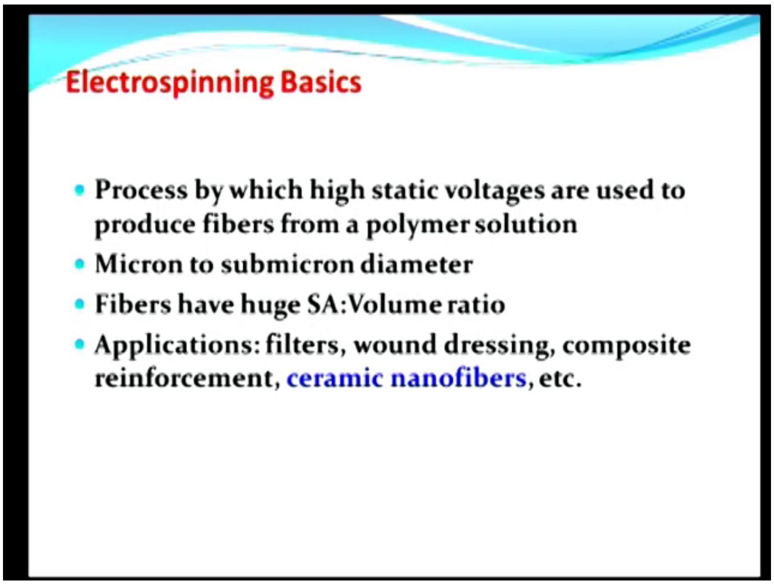

We jump now after having gone through the solution based process for the formation of oxide nano particles nano structures we go to add different technique for producing nano structures called electro spinning which has become a widely used technique for the formation of nanowires nano structures.

Now, this is a process whereby from a polymer solution fibers are produced when a high static voltage when it is subjected to high static voltage and you know it is these polymer solutions are drawn out of an orifice in a jet. So, we will come to that. So, this is capable of producing fibers of microns or diameter as well as sub micron or nanometer nano metric sizes in diameter, these fibers very thin fibers have a large surface area to volume ratio as you can expect out of nano structures and these fibers have numerous realized in potential applications as filters wound dressing composite reinforcement ceramic nano fibers and so forth. So, this rather simple electro spinning technique is becoming a very useful technique for the formation of nanostructures.

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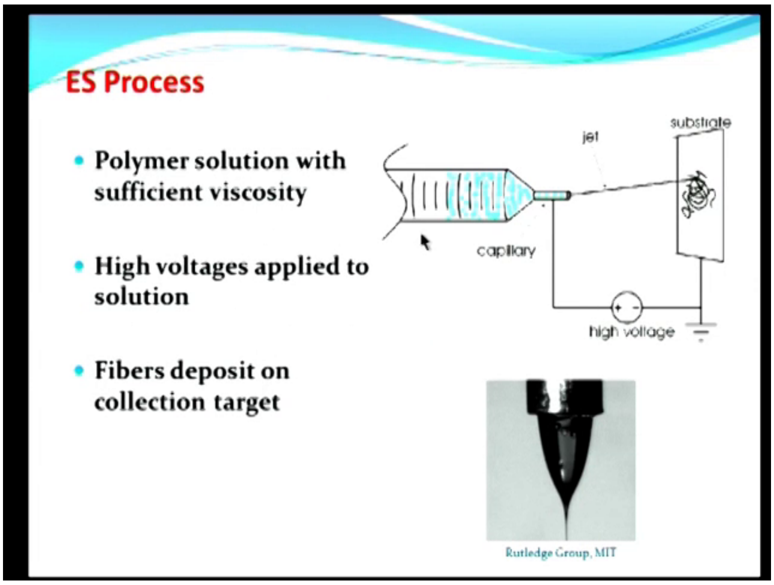

So, the schematic of that is shown here a polymer solution of sufficient viscosity is taken in this syringe like entity and a high voltage is applied high dc voltage is applied to this solution and this solution is then you know there is there is a there is pressure applied that draws out the solution out in a jet, and then this jet is collected on some substrate. So, what is shown here is image of this capillary through which this jet is formed and the fibers that are drawn out of this are then deposited on the collection substrate or target as you might want to call it.

Now, there is a you know because one has to push this jet out then there is a.

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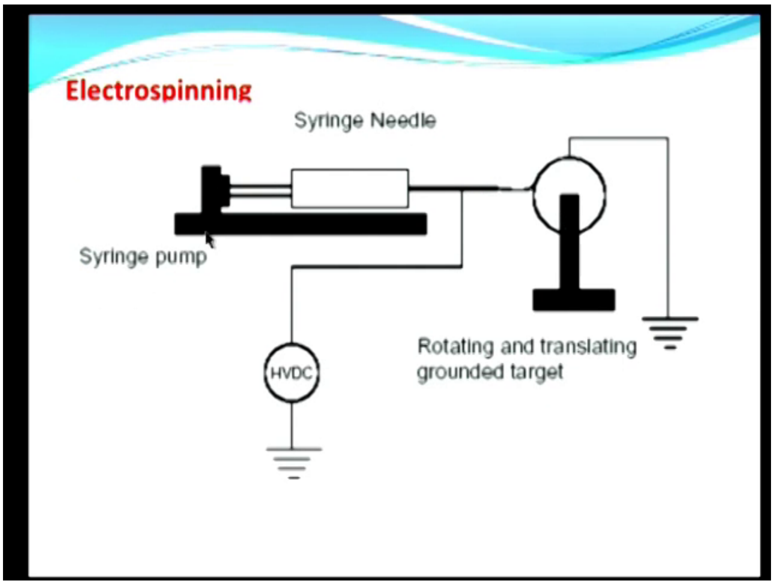

Syringe pump that pushes it out and then you can have for example, a rotating target. So, that you can draw the fiber out in some kind of a spool for example. So, different kinds of arrangements are possible for this collection of the electro spun material.

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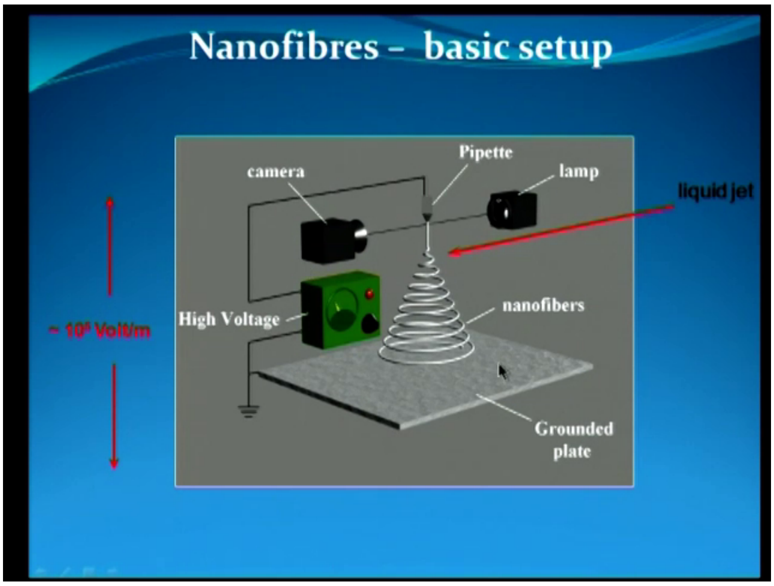

So, here is a cartoon that shows that. So, out of this capillary or a pipette comes this fiber out and you can see that it comes out as a helical spool and collected on this grounded plate remember this solution polymer solution is at high voltage high dc voltage and that potential to which it is applied rather the field that is applied to that either the order of a million volts per meter.

So, pretty high electric field dc electric field is applied to that as a result of this this spiral like fiber formation can be drawn out from the syringe.

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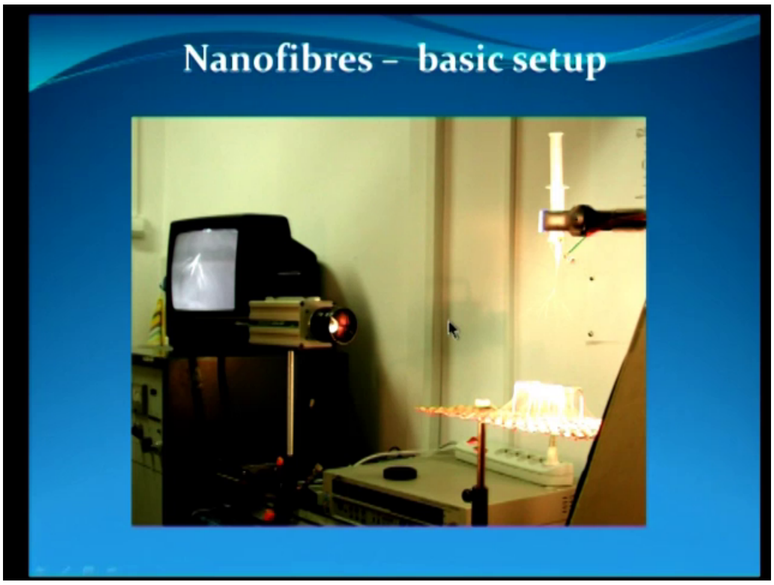

So, this is an actual photograph of this process you can see that the fiber is coming out as filaments and being collected on this plate down below. So, here you have the syringe out of which the fiber is being drawn out now.

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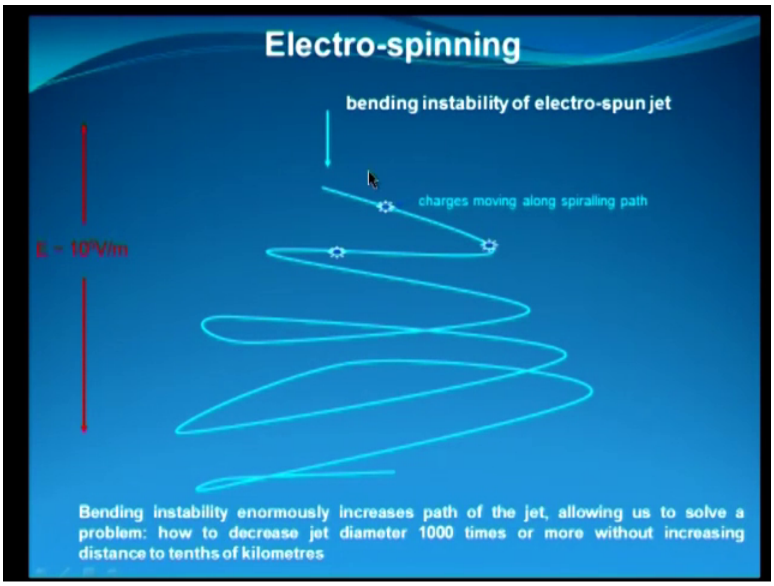

There are charges moving along the spiraling path this is the fiber that is being pulled out pushed out I should say something known as bending instability of this electro spun jet takes place, that is this cannot this cannot bend in sharp turns that is why as shown here there is this spiral like shape to that.

So, as a result of it is possible to obtain it is possible to decrease the jet diameter 1000 times more than without the distance that is because of this jet formation one can have great lengths of this. And therefore, a high aspect ratio without having to draw out very long fibers ordinarily very long fibers would be required fibers measuring tense of kilometers in length to get this high aspect ratio, but because of the bending instability it turns out to be possible to get these long fibers or very very small diameter fibers without making them very long. So, this is so called something called a tailor cone.

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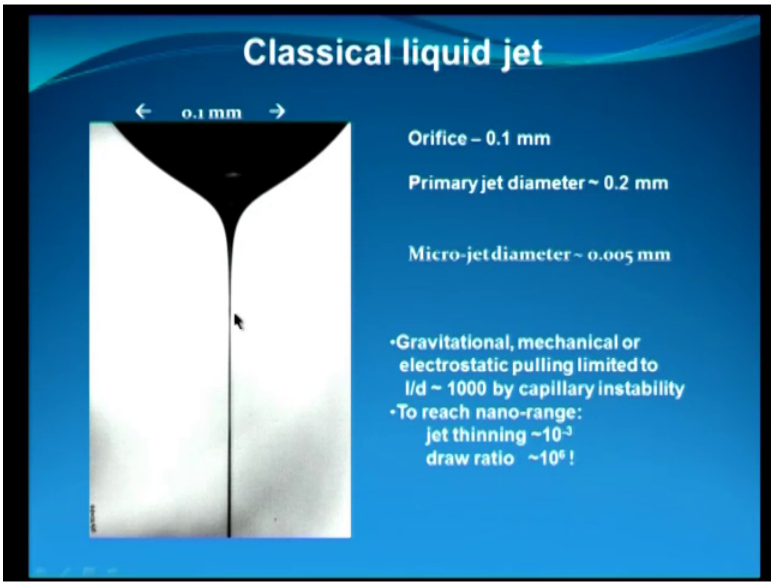

So, this is close up of how the jet comes out and you can see that the nozzle is very narrow, because here you have a scale of 100 micrometers. And you can see that this jet that comes out how that is the orifice it comes out of measures a micron or less.

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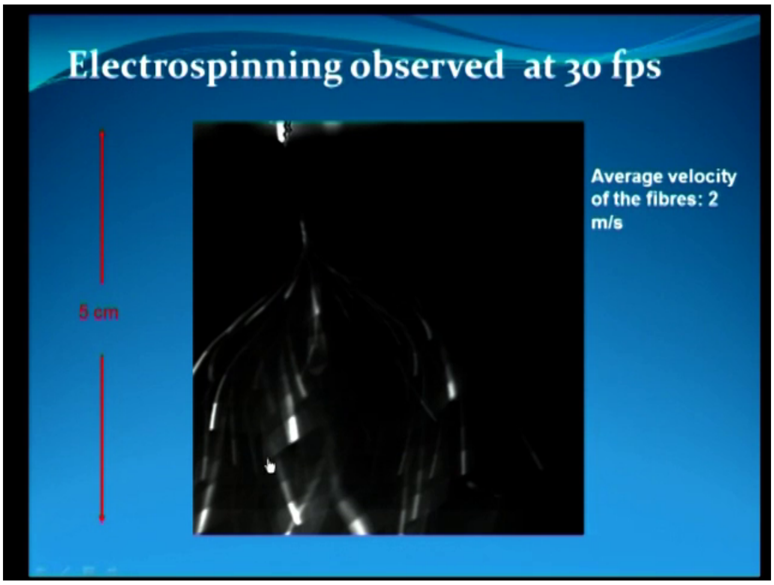

Another image a photograph of the fiber being drawn photograph taken at 30 frames per second and the average velocity of these fibers that are drawn out is about 2 meters per second.

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Again another photograph, because the high voltage is a discharge; and therefore you can see the fiber that is lit by the discharge.

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More of the same.

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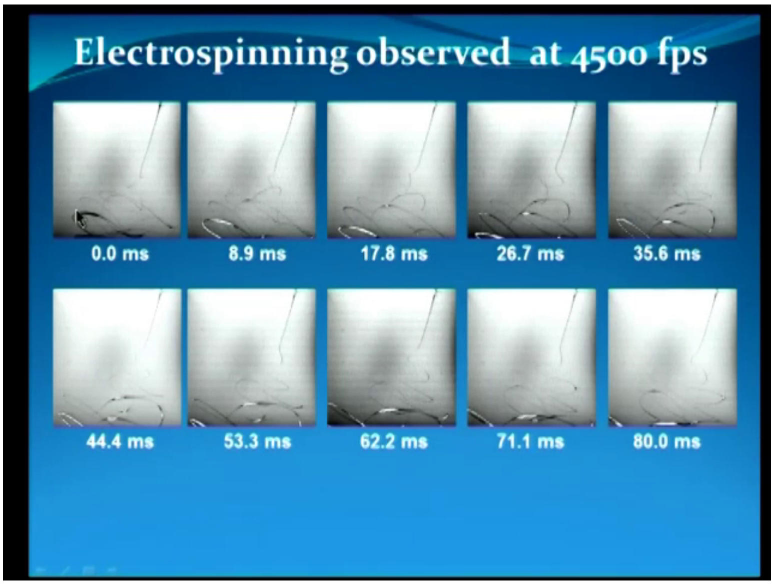

And this is a series of photographs taken at intervals of a few milliseconds as the fiber is being draw out. So, this is a high speed photography 4500 frames per second of how the fiber is drawn out from 0 milliseconds from starting point to about 80 milliseconds. So, this is just a an illustration of how the fiber is formed.

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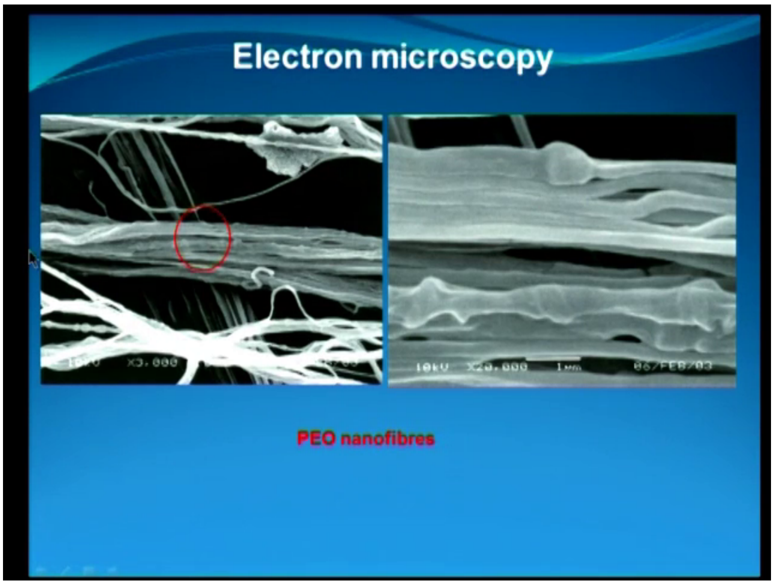

Micrographs of polymer fibers actually drawn out.

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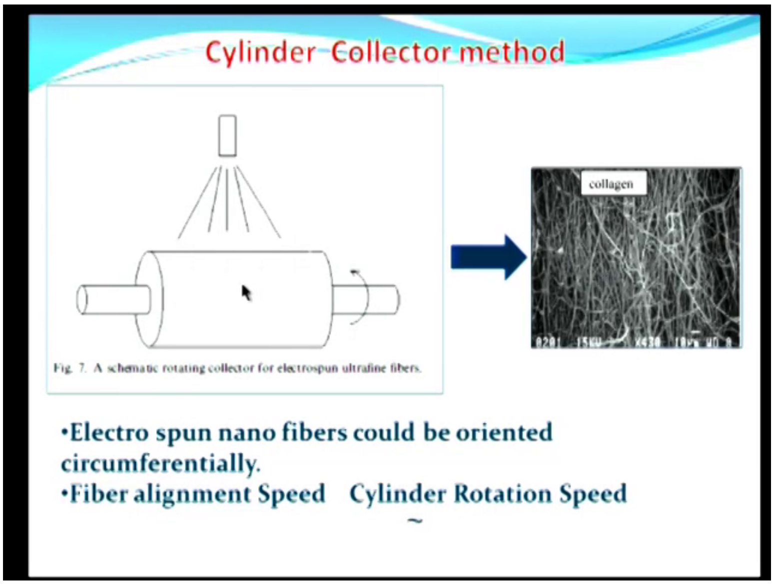

Now, one can have a cylinder that collects the fiber as it emanates from the jet as a jet. So, one can have these kinds of fibers that are then collected on a rotating cylinder. So, you can have some kind of a spun a weaving of this.

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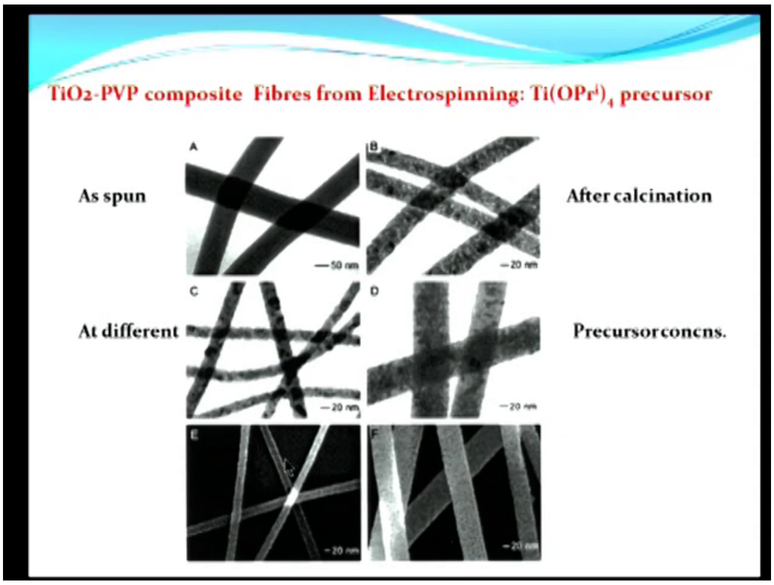

Now what is really of interest in the context of non polymer materials non polymer nano materials is that the polymer solution can contain a precursor for example, for an oxide. So, what is required is that you have a polymer solution, now if we dissolve for example, in this case a precursor to titanium oxide titanium dioxide especially titanium dioxide of a polymorph called anatase is a very important catalyst material and catalyst materials are desirable when or rather it is desirable to have catalyst materials with large surface area.

So, naturally if you had a nano fiber of a catalyst like TiO 2 then it will be useful as a catalyst material. So, what is done is to dissolve a precursor typically a. So, called alkoxide of TiO 2 and then make a composite with the polyvinyl pyrrolidone which we met while ago in the context of zinc oxide. So, this polymer is then subjected to electro spinning. So, as spun one gets these fibers are shown in this micrograph A, but what you want is really the oxide. So, if the right conditions are chosen, the right conditions are chosen for this then it would be possible to heat this in air and so that process is called calcination and therefore, essentially drive out the polymer to retain the oxide in the form of a fiber.

So, what these microwave micrographs show here apart from the as spun fiber that contains titanium dioxide precursors, then what is shown here are fibers that are obtained for different concentrations of this precursor which is titanium isopropoxide so called isopropoxide. So, this one is dissolved along with PVP under at different concentrations and after suitable calcination or heating in air, one obtains these fibers of TiO 2 and a close examination will show that these fibers are made of extremely fine crystals and in this case this happened to be the polymorph namely anatase which is an important catalyst oxide.

So, this process of electro spinning therefore is capable of giving us fibers with large surface area that is large specific surface area specific surface area means how much surface area the material has per unit mass. So, many meter squared of surface area because these are nano crystals, which large surface area for each single each crystal over here each crystallite over here that forms the fiber, because of that the specific surface area of this fiber can be very large. So, one can obtain nano fibers nano metric fibers of a number of materials such as these oxides through the use of the electro spinning technique, which is really a rather simple technique and a versatile one because one can employ them for other than polymers.

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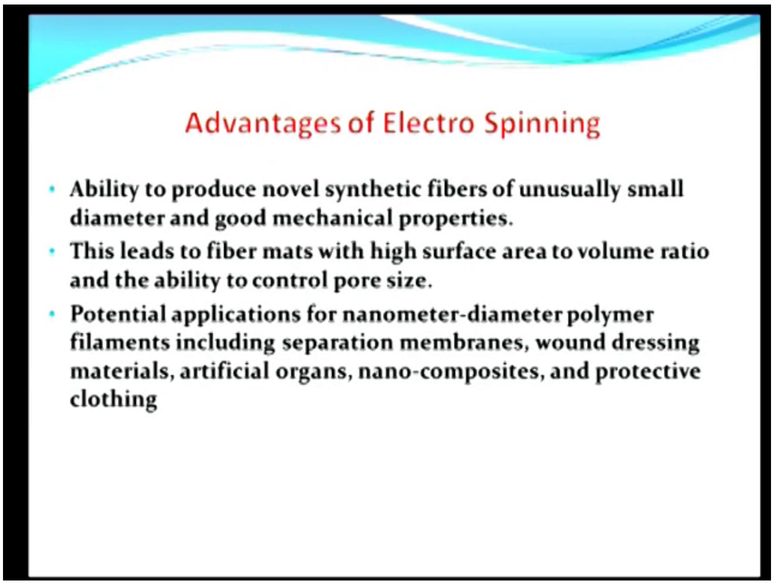

Now, electro spinning as shown here is clearly advantageous because one can get novel synthetic fibers of very small diameters and good mechanical properties by choosing the solution properly and so forth one can adjust these properties of this high specific surface area and numerous applications you know what is mentioned here is not just for oxides, but also for polymer fibers that is pure polymer fibers.

So, separation membranes in chemical engineering, medical applications wound dressing and so forth making of artificial organs through controlled a formation of fibers nano composites and so forth. So, there are numerous applications for electro spinning.

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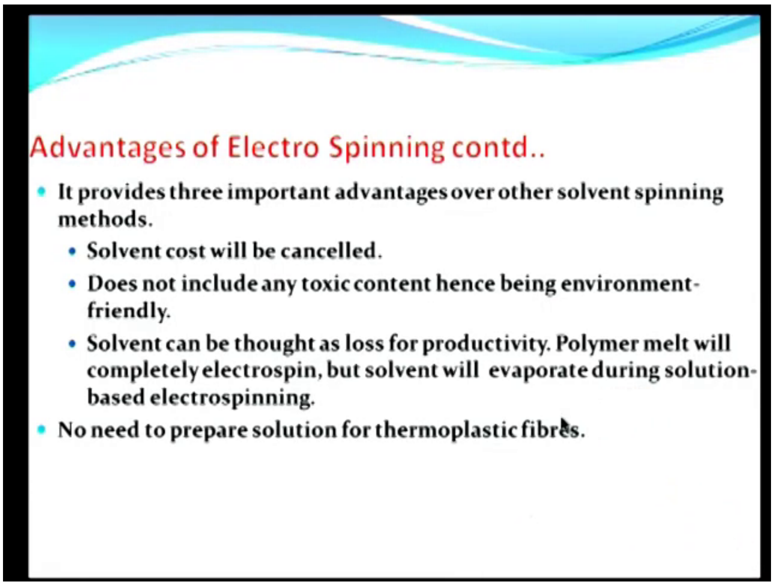

The one of the specific advantage is that there are solvent based techniques for formation of these fibers, but here we do not really have that. Therefore, the cost of solvents is removed does not include any toxic content this process is simple. Therefore, it is a an environment friendly process.

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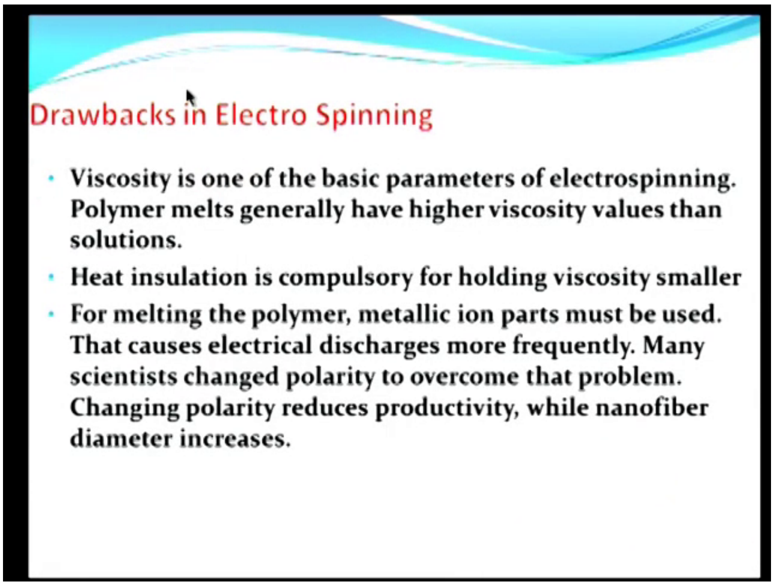

But there are also certain drawbacks to the electro spinning technique, viscosity is one of the basic parameters for electro spinning, now polymer melts generally have higher viscosity values than solutions and therefore, heat insulation becomes compulsory for holding viscosities to be small, if viscosities are very high then the process is less controlled called less controllable.

So, to hold the viscosity high the temperature of this syringe and the fiber as it is drawn out better that temperature has to be low. So, that the viscosity is reasonably high to control the formation of the fiber. So, heat insulation is important therefore, there are a number of parameters one has to attend to in having a well controlled formation of fibers from the electro spinning process. There are other drawbacks for example, the formation of beads along this fiber.

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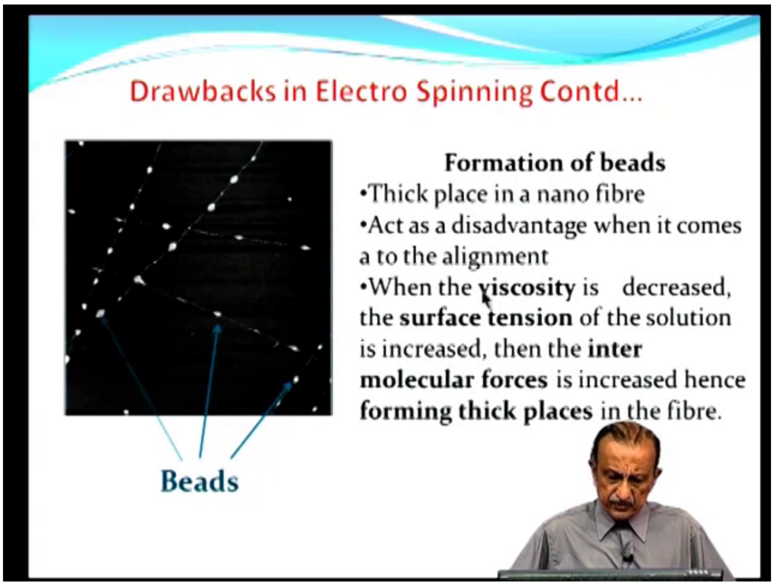

So, what is micrograph illustrates is the essentially periodic formation of beads of the polymer as the fiber beads being run out therefore, this clearly affects the properties of these fibers, it can affect severely the mechanical properties of these fibers. So, these things have to be controlled by controlling the surface tension of the polymer solution that is being spun out. So, there are these advantages disadvantages that one has to deal with.

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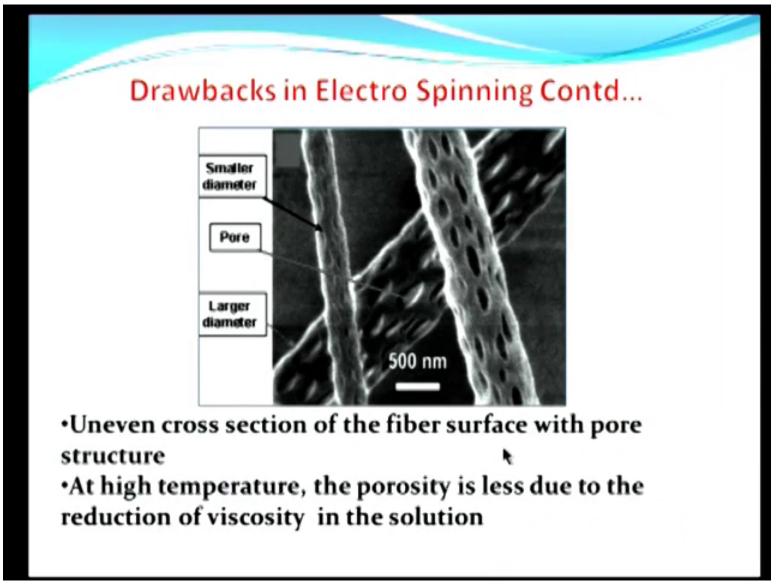

There are also uneven cross section as shown here and porosity and so forth uncontrolled porosity. Now if you want to control porosity then high temperature is beneficial because that reduces the porosity. So, what all of these indicate is that careful control of the electro spinning solution and the electro spinning process are necessary to make sure that the advantages of electro spinning stand out while suppressing the different disadvantages that have just been briefly reviewed.

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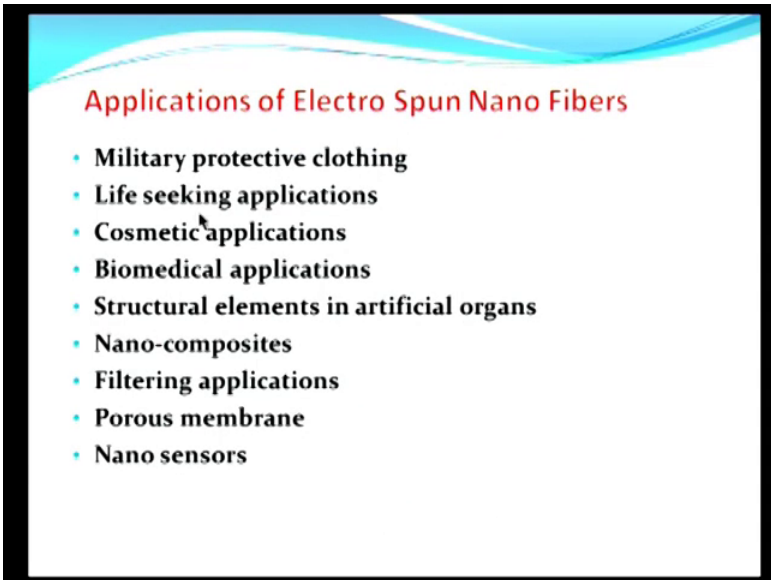

As I said there are numerous applications and you know for example, these porous membranes there is shown here filtering applications, nano composites these are all the kinds of applications that could involve oxide materials nano sensors catalysts are usually also good sensors. So, one can have fibers are contain appropriate oxide as sensing material therefore, this simple technique of formation of fibers through the electro spinning method has numerous possibilities and therefore, it is a an important part of the technology for one dimensional nanostructures.

So, we will in there we will return next time to the consideration of carbon nanostructures what we have done this time is to look at the process of VLS and the SLS methods for the formation of nanowires of semiconductors, subsequently we learned about the solution based microwave irradiation assisted process for the formation of oxides and oxide nanostructures of high crystalline quality, and how that method can be used to form single crystals single crystal nano structures of zinc oxide. Similarly one can obtain nano structures of various binary oxides and the method can also be extended to the formation of complex oxides, turnery oxides such as zinc ferrite zinc manganite and so forth.

Then we went through the formation of nano fibers through the electro spinning technique. And in particular even though the technique has been largely used or developed in the context of polymer nano fibers, how that can be deployed to obtain nano fibers of oxide materials such as that of TiO 2 really there is no restriction to TiO 2 it is just a good illustration of an important catalyst material that is an oxide.

So, as I said we will end there and we return to the rather when we return we will deal with carbon nanostructures and the properties of carbon nano tubes and so forth.

Thank you.