Advanced Ceramics for Strategic Applications
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Lecture - 30
Solid Oxide Fuel Cell
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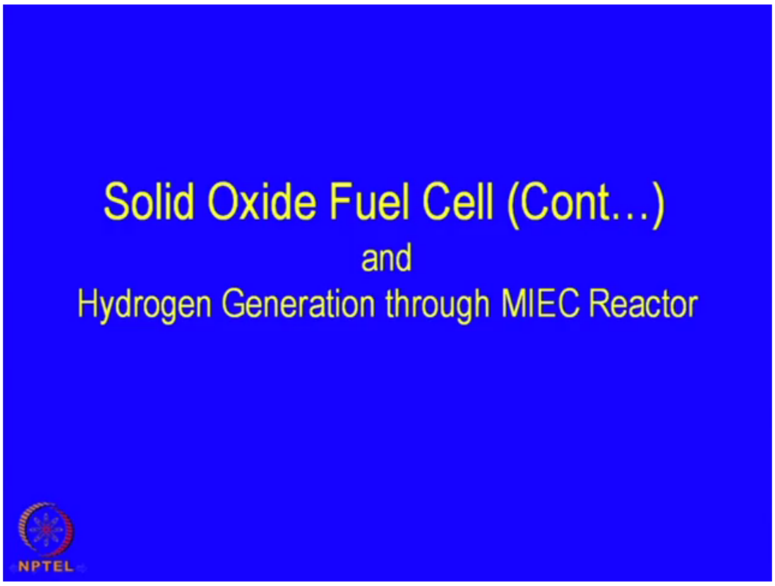

Today's topic is also Solid Oxide Fuel Cell, which we have been discussing for the last couple of lecturers. In addition, we will also talk about a something related topic it is Hydrogen generation through MIEC Reactor, we will discuss what is the MIEC Reactor later on. To start with will let us talk about the Solid oxide fuel cell once again.

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The thing which we have discussed earlier is the following; this was the anode supported single cell. It is basically a plate like structure, a sandwich structure, the basic support structure is anode, a very thin layer of electrolyte which you cannot see on the surface is actually almost like a transparent material, and then on the top the black layer what you see is actually a cathode layer. The bottom layer is actually the anode layer. So, this has been prepared in CGCRI it was prepared in CGCRI and had some of the pictures of that.

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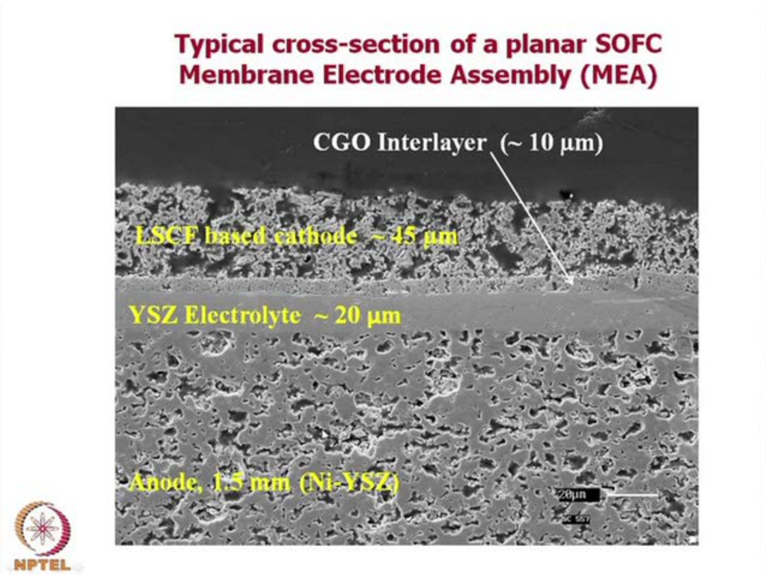

So, this as shown you earlier, this is the typical microstructure of the cross section as we have discussed earlier that the anode as well as the cathode is a porous structure in between you have a dense electrolyte, YSZ electrolyte. In this particular case, it is about 20 micron thick in addition 4 th layer here which is called the cathode functional layer. In this case is about 10 micron thick and it is a basically a gadolinium doped cerium CGO interlayer.

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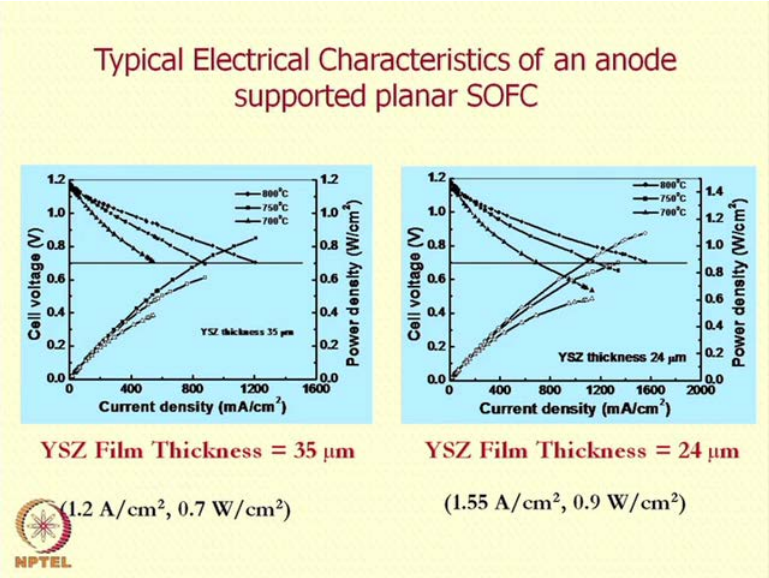

So, this is the typical structure and of course, it is single cell, and then we also discussed about their electrical characteristics two typical structure, two typical current voltage plots have been shown here. One is the YSZ or the electrical electorate thickness about 35 microns other one still less is 24 micron. And this is typical curve this is the open circuit voltage it is slightly more than 1 volt about 1.1 volt very close to 1.2, but that is when the current is zero that is, no current is being drawn and as soon as the current is being drawn current increases and current is on this cell. Current increases and the voltage drops that are the typical characteristics or the normal characteristics of any fuel cell as soon as the current drawn from this cell the open circuit cell voltage this is not the open circuit voltage. But the voltage drops and the somewhere here we actually get the maximum not the maximum this is a standard practice that at about 0.7 volt whatever the current is drawn that is operating current.

So, with this consideration 1 gets about 1.2 amps per centimeter square at 0.7 watt per centimeter square. If it is multiplied ampere to voltage you get that if you reduce the thickness of the electrolyte which is a very important criteria of any fuel cell decrease sorry decreases the thickness there is a possibility of drawing higher current 1.55 amperes and the same voltage and you get 1.9 watt per centimeter square that is the current density or power density one can expect from this kind of single cells. Of course, this is not it depends on the type of application technique depends, on the interest characteristics, depends on many different parameters as porosity force and distribution the interface characteristics and so on so forth. So, there are many different parameters to be controlled optimized to get the best possible results.

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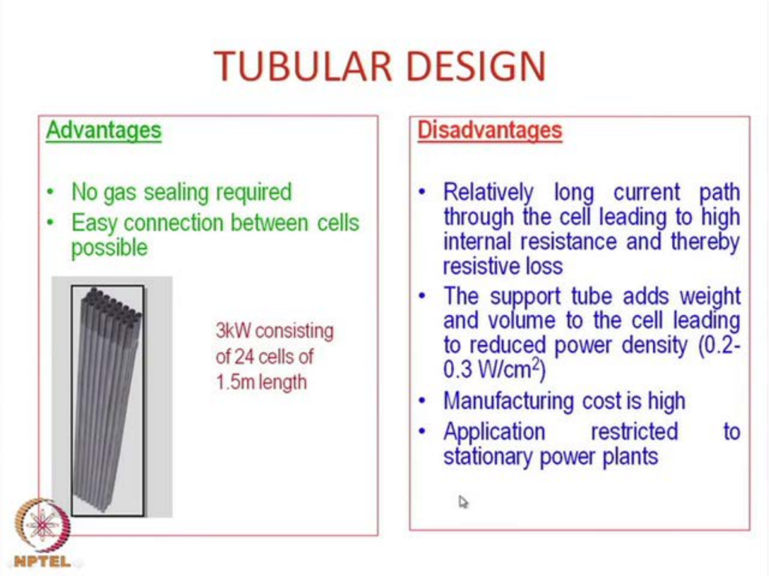

With this background, let us go to the advantages and disadvantages of the two designs we have discussed so far. The Tubular design advantages are like this. This is the typical stack large number of tubes, one unclosed loops that use can be as long as 2 meters long and about 2 centimeters in diameter. So, no gas sealing is required because the two chambers are already separated by the tube wall. So, there is no special effort needed or separating the two chambers easy connection between cells possible.

With this kind of technology are already pilot plants, on the demonstration plants been applicated and demonstrates that up to 3 kilowatt in fact their much larger plans have been erected up to 150 kilowatt, but it 3 kilowatt stack would consist of 24 cells of 1.5 meter length. So, this is a typical dimension and the volume of material used.

There are quite a few disadvantages of course, disadvantages are like this relatively long current path because the connection is only on the one end. So, any current generated or a oxygen being transported here are the end it is to the electrons to come all the way this. So, the current path is too long a little higher resistance path and therefore, the cell leading to high internal resistance and thereby resistive loss. So, even though the film thickness the electrolyte thickness itself is very small maybe up to 20 micron, but the current is to pass or trouble through a longer distance because the length of the tube. And therefore, this is relatively loss or the internal resistance overall internal resistance is relatively high.

The support tube adds weight and volume to the cell leading to reduced power density. One of the driving force for fabricating or developing the technology of cell is basically high-power per unit mass. However, here the tube the cathode particularly support tube is relatively thick and when you are making 1.5 meter long tubes the strength the tube is sufficient and therefore, need sufficient amount of material so that increases the weight and the dead weight of the material. Because as such the cathode is not taking part in the except the interferace the rest of the material is not taking part in the electrochemical reaction.

So, it is about 0.2 to 0.3 watt per centimeter square that is more or less power density gets manufacturing cost is high, because it needs a CBD thin-film depositing technique and quite elaborate fabrication technology is required for fabrication of this tubular structures. So, the application is restricted to stationary power plants primarily, because that has been designed or district particular technology has been designed only for the stationary power units or absolute power units or the captive power units like that. So, that is one of the, may be one of the limitations one can get much larger capacity of power plants.

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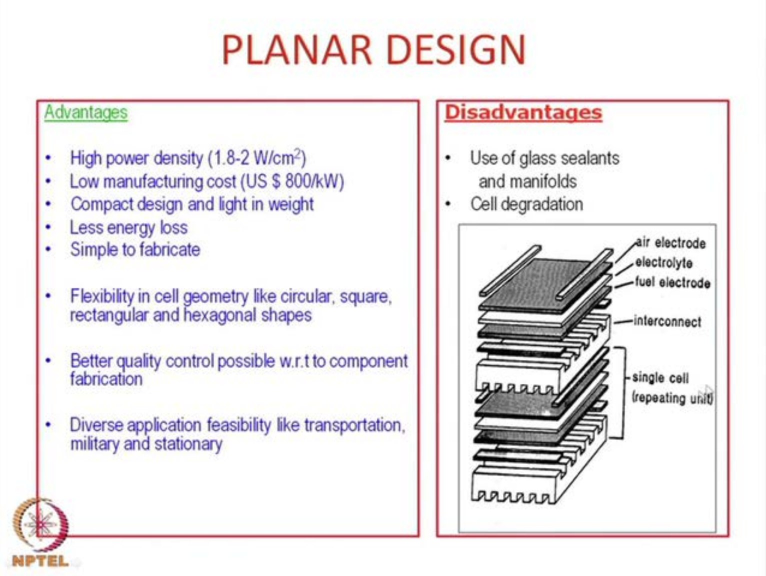

Next to come to the planar design what are the advantages and disadvantages of that compared to tubular design, because the tubular design practice by certain company certain research labs a whereas, the planar design is being partial to buy a separate group of researches. High-power density one can gets much larger power density are up to about 2 watt per centimeter square of course, manufacturing cost relatively low on giving this dollar about 800 kilowatts. But it still not sufficient for commercialization, the target is it about less than 400 US dollar per kilowatt that will be the ideal situation under which this kind of technology and economic on the current economic condition.

The compact design and light in weight as a mentioned compared to the tubular design it is a relatively compact and little light in overall act, less energy loss because the current percent limited current percent relatively short so less energy loss. Simple to fabricate and because it is not a tubular construction basically plate like construction so generally it is assumed that it is relative a simple to fabricate the ceramic structure. Flexibility in cell geometry like circular square rectangular hexagonal shapes so one can make different kind of geometry super is the surface area is concerned. So, one in order to make it a much more compact structure one can make either a timeless rectangle cross-section or a hexagonal shapes.

So, that maybe tightly fitted into one another better quality control possible with respect to component fabrication business they are relatively smaller in size and therefore, uniformity of the properties will be better diverse, application feasibility like transportation military, and stationary in addition to stationary we have seen in tubular the primary application a year is stationary power plant, whereas in case of one can think of one can think of other possibilities also a particularly the transportation impact some companies have already fabricated what they call APU auxiliary power unit for the automobile sector.

So, in addition to the motive power basic power is a once again the IC engine, but in addition today's automobile industry or a particular car means lot of electrical for running many electrical electronic gadgets. And therefore, that electronic power can come from the fuel cells. So, that is what we call the auxiliary power unit and that auxiliary power and demonstrated with solid oxide fuel sets this has not been possible with the tubular designs.

Of course, there are few disadvantages, the main disadvantage is the non-availability or the requirement of a glass sealants because a separation of the two chambers becomes quite difficult in a tubular configuration, it is quite easy whereas, in a any planar configuration is not that easy. So, need to separate these two chambers of the fuel chamber and the oxidant chamber of the chamber through some salient high-temperature sealant and the only option is a high-temperature glass. Unfortunately, you the same amount of several glass compositions are available, but this kind of purpose, but none of them are quite fully satisfactory, either there is a breakage because of the cycling thermal cycling or there is some reactions between the components. So, that problem still exists, but lot of development is really taking place under one can use some of the glasses available.

So, many of these glass compositions can be attempted by different glass companies including short from Germany while that is the structure of the planar configuration which you shown earlier. So, it is basically these are the two advantages only the glass seal and the cell degradation, cell degradation is also a problem and that means the overall life is little limited. So, these are the two disadvantages so far as planar designs is concerned.

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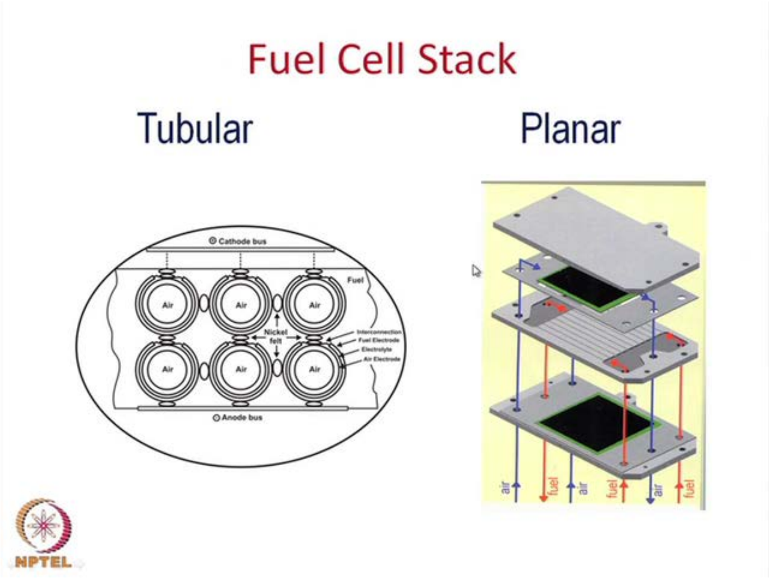

Next we have so far discussed about the single cells how it performs, how it depends on the different geometry how depends on different materials and what are the different structures available to us both in the tubular form as well as the planar form. Now, as I mentioned earlier the overall, open circuit voltage of each single cell is nearly little more than one volt and is normally operates at about 172.8 volts. So, that is not useful so far as the power plant (( )) concerned or a power unit is concerned. So, we need stacks, stacks up several such single cells and these are the kind of stackings one normally uses this is for the tubular cell are the cross-section of the tubular cell, these are 6 tubular cells put together here and as I have mentioned earlier in the last class possibly this is the interconnect material. So, in the interconnect protrude interconnect actually it connects the cathode on this side and anode on this side.

So, the internal surface is connected to the external surface of the next (( )). So, this is vertically it is a series circuit were as vertically is series circuit horizontally is basically a parallel circuit because the anode is connected to the anode and here also anode is connected to anode. So, battery overall power system will consist of a large number of series and parallel connections of individual tubes and that is how actually a stack is produced. In fact a fuel cell stacking here once the single cells single tubes are fabricated stacking is relatively easy in this case, and in between you have the connections high-temperature contacts basically a number, generally it is actually nickel felt some kind of nickel felt which also acts as the vibration absorbers.

So, it is uses as a cushion and on this side you have a cathode bars and other side anode bars. So, this bars is connected to the anode all the anodes and this is connected to the cathode of individual so that is how a stack normally generated in fact next picture will show a another view of that.

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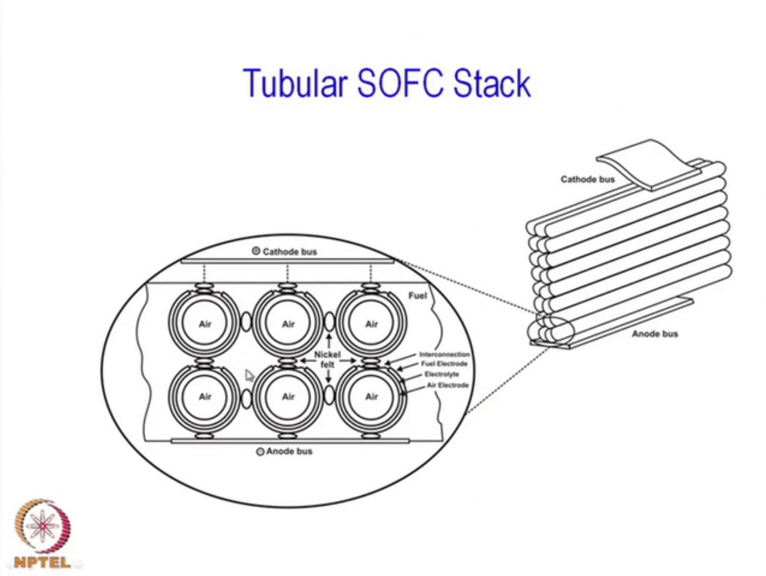

This is actually the magnified view of this particular region, but in general it look like this a large number of tubes just at over one another and that is the normal way one can put a stack. So, stacking is relatively simple and of course, you have gas connections which is not so here and there will be manifolds for gas inlets as as well as outlets from one of the ends will result are normally. Close the end tubes, so gases to come from the other side and then go outside. So, those manifolds have to be put in place. Well, going back to the planar design, planar design of course, the stack allocation is little complicated sorry this is the single cell, and this is what we call the interconnect.

So, it is basically a stacking of several plates are unlike students the general plates this particular single cell single cell is fixed on a in this case steel plate steel plate grouped properly so it is exposed on both sides this is the cathode side and that bottom side is actually the anode side. So, exactly the dimensions have to match the dimensions have to match and they should not be a leakage of the fuel or the air and therefore, this has to be sealed with some glass cells so that is one thing.

The other thing is, this is your interconnect that means I have shown you earlier. That there are groups on both the sides this is one kind of group and below also there will be another group. So, that group may be crosswise or parallel moves, but on one side it the fuel passes through the groups on the other side air which passes these groups. So, these of course, we have expanded you expanded view the vertical direction ultimately it actually has to be sit over one over the other. So, it will be a compact configuration and there are some vertical holes see these vertical holes coincide with each other and finally, they form the manifold.

So, one of those holes in the fuel comes and comes on the surface the top surface because the bottom here is the anode and the top of the the black surface is actually the cathode. So, this top surface on this plate is actually the channels for the fuel and the bottom surface on this plate is actually for the air, that is what is happening here the blue lines actually comes and goes the top side of this, the single cell and it is end plate. The end plate which actually a encloses the air channels and so all these plates are stacked over there are another and between the very small channels this parallel channel designs are of course, also very, very important. The channels can be designed in many different ways when discussing here, but one can design it in different ways, but the depth of the channel the width the channel and whether it should be uniform or it can be little tapered and so on.

So, forth, because as the fuel enters fuel or the gas enters on the on-site and it immediately reaction on that site and less and less amount of the gases are regular at it flows across the channels. So, the channel dimensional have to be very important to flow rates have to be uniform and the conjunction of the gases are also have informed over the whole area of the electro electrolyte or the plate of the single cells show those utilization of the gases fuels are also very had to be fully utilized. And therefore, and channel dimensions a channel design is a very important and therefore, one has to have a lot of possibilities in such cases.

So, this is a stack and these are only two single cells have been shown here, but one can have a large number of stacks large number of single cells up to hundred cells. One can imagine, so that they are all and such cells such cells it again can be these are all series connections and that kind of stacks can be put together in parallel connections. So, this is slightly complicated and the stack design in case of planar disk planar concept is planar configuration slightly complicated than the tubular concepts or the tubular design or the tubular configuration. So, stack design in case of tubular configuration is simple whereas, stack design in case of planar little more complicated and fabrication is little difficult that you have seen earlier.

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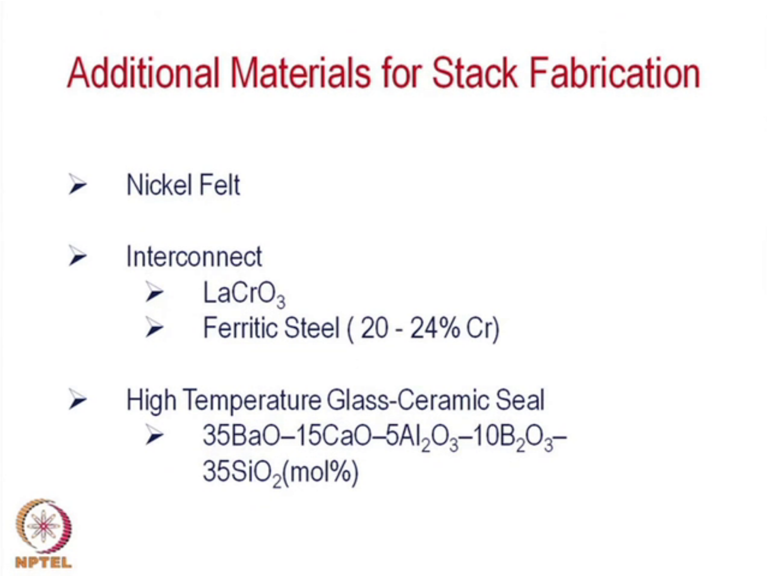

Now, when you are talking about stacks, you need in addition to the anode, cathode electrolyte and we have also discuss some materials used as cathode functional layer or anode functional layer in addition to all these materials two more important materials are also have to be used for stack design or stack fabrication. As just shown you earlier, slight nickel felt is just a simple thing which one can use between the tubes in case of a tubular design, in case of stacking up tubes only need additional material what is needed is a nickel felt. So, that can be that is the only thing on one need in addition of course, the other chambers of the manifolds and so on. Some metallic are also needed for supplier gases or taking out the exhaust gases, but otherwise it is a simple nickel felt for the tubular design.

Whereas, in a planar design you need to important materials two groups of important materials one is the the interconnect which I have shown you earlier this is the interconnect material is plates, these plates are actually interconnect material and this material is one additional material. In addition to cathode and anode and electrolyte and the other material is which also been mentioned is the sealant high-temperature cell these are two to groups of material and there are various different materials are being tried out. I will give you more details of this a another slide and but this one so far as the high temperature seal is concerned I mention that there was a high-temperature glass or glass ceramics them a after cooling actually gets crystallized some extent and forms glass-ceramic seals.

One of the major problem here is the Thermal expansion match, matching of the Thermal expansion between the metallic interconnect if it is a metal is used as the interconnect material, and the ceramic electrolyte plate or the anode plate anode cathode plate. So, one aspect is to match the thermal expansion coefficient between the through 3 active materials like electrolyte cathode and anode and then active or inactive passive materials like the interconnect has also to be matched.

The expansion coefficient of that has also matched the overall a membrane electrolyte membrane electrode assembly MEA any and there are sealing material also had to be properly and thermal expansion coefficient of also properly matched for the sealing material that MEA. As well as the interconnect material. So, all of them have properly adjusted and therefore, the composition is of great importance here composition also is important so far as the softening part is concerned or the glass transition temperature is concerned. So, since the operating temperature is about 700 to 800 degree centigrade so, the softening point has to be relatively high otherwise there will be leakages.

So, these are the normal are oxides used for making these glass compositions and this typical glass composition, but there are many different glass compositions have been tried out. One important aspect is there is no alkali here, alkali is normally a normal glasses alkali basic components which reduces the melting point or the softening point of glasses, in this case there no alkali is allowed and that makes the melting as well as processing of these glasses are quite different. So, typical composition here is about 35 percent mole percent barium oxide 15 mole percent calcium oxide aluminum oxide 5 mole percent and borate borate and silicate 10 mole percent of B_2O_3 and 30 mole percent of SiO_2. So, this is a typical composition. But there are a lot of variations a lot of different things can be added to this sometimes, Titanium or Zirconia can also be added. So, that they become crystallized and by crystallizing actually change.

So, the crystallizing properties important are controlled so that one can control the thermal expansion and coefficient. We will discuss about the interconnect later on a slightly details.

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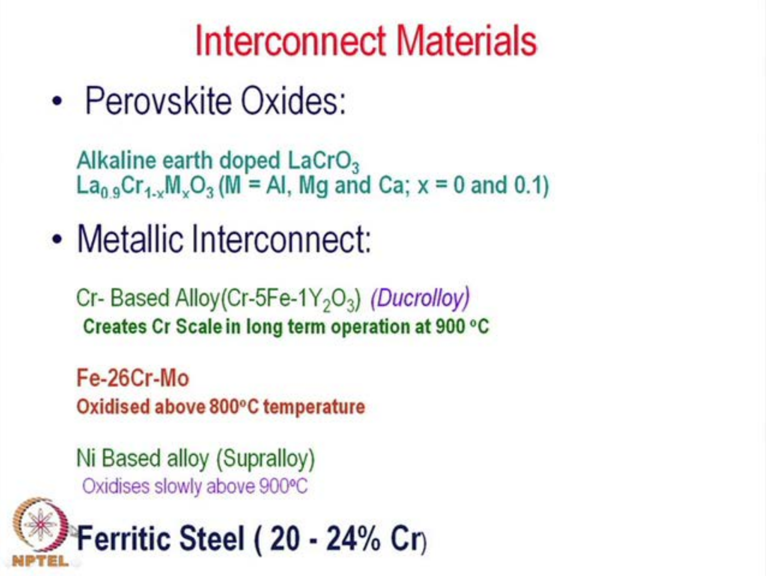

So, these are the different kinds of interconnects people tried over the years one started with the perovskite oxides because the since, the most of the other materials are basically oxides or ceramic materials. So, natural choice to find out a a high-temperature oxide which is electronically conducting and one can find out this kind compound again a perovskite compound Lanthanum chromite. So, lanthanum chromite is a fairly high melting point and at high-temperature it is very good electronic conductivity so what is needed here of course, is to separate the two chambers the fuel chamber, and the air chamber. These are to be separated out physically, that is one requirement and other requirement is it has to electronically connect the cathode side the anode aside of the next cell.

So, electronic conductivity also a very important the temperature the electrical conductivity is low that means you lose lot of power. So, electrical power will lost the electrical conductivity is not good enough therefore, Lanthanum chromite has been found out is one of the good electronically conducting material and also also it is a high melting higher melting point so it with stands does not really make any undergo any changes at the operating temperature of 800 to 900 degree centigrade.

It is not only pure Lanthanum chromite, but some dopant's can also be used for the purpose of sintering aid or because it is to be like the electrolyte this material also have to be density are vehicles were now here assess there should not be molecular diffusion through this material between the two chambers to enclosed this. So, one needs a very high density material and to proper densification some of these dopants can also be used and the general formula is Lanthanum 0.9 slightly, deficient in Lanthanum oxide that makes the simply in better and chromium. Chromium can be replaced by metals like aluminium, magnesium and calcium are its only about 0.1 mole percent this is what materials prepared.

However, this is not a current level of thinking or currently lanthanum chromite is not being used more because one of the reason why the lanthanum chromite is not being use in the later versions or in the current fabrications that is the in the chromium diffusion. When chromium comes in contact zirconia or the cathode material or the anode material chromium diffuses in and that creates ageing problem. So, deteriorates the cell characteristics so that is one of the reason why lanthanum chromite is not the normally preferred material at this point of time.

Instead, as we will go for metallic interconnects large number of different high-temperature metals and alloys being tried out a for example, chromium-based alloy, chromium, 5 percent iron and 1 percent yttrium oxide it is actually a oxide dispersed alloy it is called Ducrolloy and creates chromium scale in long-term and operation. So, this also creates a infact chromium oxidation takes place on the surface and sometimes better it actually and stops further oxidation of the same metal, but once again the chromium creates problem so far as the cell components are concerned.

So, this is then another material also have been used which is oxidised again from about 800 degree centigrade and this is higher in 26 percent chromium molybdenum. So, many different alloy is being tried so far metal interconnect is concerned between the temperature operation of for the cells have also come down. So, earlier it was the normal operating temperature will 900 degree centigrade now it is less than 800 degree. So, that makes it possible to use other alloys like the best material, so far is actually ferretic steel, so instead many different alloy have been tried, but ultimately it would have settle down for the ferretic steel which is basically 20 to 24 percent chromium alloy.

So, these are also chromium containing alloy some or most of them chromium containing alloys, but this has a a better property and better oxidation resistance property than the other steel's or alloys and of course, the thermal expansion coeffecient matching is another very important aspect. So, in general in the alloys or metals have higher thermal expansion coefficient when compared to the oxides and that is one of the problems of course, but the current trend is to use ferretic steel instead of other exotic alloys mentioned above.

Well, let me change the topic some extent will we have not discussed the details of how the materials are prepared in the powder form and soon. Particularly although I mentioned briefly that these are any anyway ceramic powders weather it is zirconia or YSZ or LSM like lanthanum manganite or nickel YSZ. These are basically starting materials are always powder and they can be synthesized by many different techniques like the solid-state sintering is one of the oldest technique. One can use ceramic processing technique one can use basically, because they are mixed oxides. So, two of the oxides are concerned that can be put together are mixed together and put to the high-temperature.

So, there will high-temperature chemical reaction and mixed oxides will be formed or a solid solution will form just like YSZ and there are other of course, much better techniques were much finer powders can be prepared by either co-precipitation or by soluble technique or a may be a combustion technique. So, it is a high-temperature combustion or I did a solution combustion or gel combustion.

So, many of these techniques can be used to make fine powders of these mixed oxide and they can be when you talk about the anode is basically Nickel YSZ; where nickel and YSZ normally, normally YSZ powder and nickel oxide are put together or mix together and then heated to a high-temperature to make composite Nickel oxide YSZ powder and then during its use because it basically phases the hydrogen or the reducing condition.

So, during its use the Nickel oxide gets reduced to nickel and finally, the structure remains as Nickel YSZ powder. So, I am not going to details of these powder preparation techniques, I am trying to concentrate on a particular technique of preparing a Nickel YSZ composite the Nickel YSZ sorbent composite which is used as a anode material. Now, I mentioned earlier that one of the reasons why nickel is used along with YSZ is it is facing a reducing condition very the extreme reducing condition like hydrogen and whatever, anode material we choose it is to be a chemically stable thermodynamically stable at this temperature and reducing condition.

So, nickel actually provides the electronic conductivity because YSZ at this temperature does not have any electronic conductivity, and it does not it produces fairly large register is until and unless this fabricated in a thin form for thin-film. Show that is the reason electrolyte the same material is can be used as electrolyte, but it is to be used as a very thin section whereas, anode has not that thin section and particularly the anode supported system anode supported structure read the uses about 1.5 millimeter, 1 millimeter to 1.5 millimeter thickness of the anode.

So, that itself is a very high resistance when you have YSZ as one of the components however YSZ is used primarily to maintained or to match the thermal expansion coefficient with the electrolyte. So, only nickel oxide or nickel cannot be used although it gives a good electrical conductivity, but it cannot used 100 percent nickel oxide 100 percent nickel cannot be used so nickel and YSZ both of them are required for two different purposes. The purpose is as much or the idea is the target should be as little of nickel is used. So, that the thermal expansion matching becomes easier or better because rest of the thing is YSZ.

YSZ has a good thermal matching with the electrolyte because the same material is also used as electrolyte as so our idea should be to use minimum amount of nickel and get the get good connectivity. So, far as there is a good electrical continuity that is an idea that is the kind of target that we should not use too much of nickel and in the system so that the thermal expansion coefficient goes away from YSZ. So, we should use very little off nickel and even then good electrical conductivity, so there must be a continuity that means the particles of nickel should be in touch with the each other. So, that is the peculation, peculation of charges and that is one of the targets.

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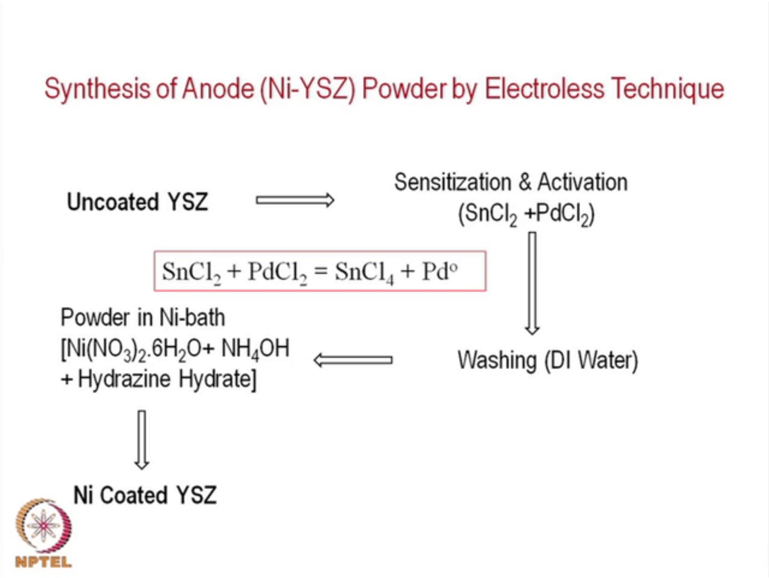

Normally one users nickel and YSZ just mixed together which may or may not be the right kind of connectivity here at a particular technique has been used which is called the synthesis of anode powder by electro less technique. Let me try to describe this process this very simple process where the YSZ powder is being quoted each of the individual YSZ powders been coated with nickel or metallic nickel right so that you get every YSZ is coated with nickel and whenever such nickel coated.

YSZ powder pressed together or put together or tip cost whatever the technique or fabrication is used are the nickel and nickel contacts only ensure this is a show that with this idea. This kind of electro less nickel coating has been used electro less nickel coating there is a technique by which and a metal can be deposited on a non-metal without any electrical emf. So, it is that is the reason it is called electro less technique and is very simple technique you take a YSZ powders it is put in a solution are called sensitization.

Sensitization and activation so these two purposes are served by stanic chloride a stanus chloride is essential to and palladium chloride. So, this actually at the activation and this acts as a kinds of sensitization so a one of the other just as essential 2 plus pcl2 this is the kind of reaction one expects so this forms stanic chloride and palladium metal palladium metal is deposited on the surface of the YSZ powders.

So, then of course, is washed with de ionized water and then finally, this sensitized powders that this kind of palladium coated powders are put in a nickel bath nickel solution bath nickel nitrate solution to nickel nitrate ammonium nitrate and some reducing agent like hydrogen hydrate. So, in such a bath of course, it has its a particular compositional to be used and such sensitized powders YSZ powders put in this kind of solution and the nickel coated and nickel coated YSZ powders available. So, one can instead of random mixing random mixing of nickel oxide or nickel normally as I have mentioned earlier it is the nickel oxide and YSZ is put is mixed together and then heated high-temperature center it to make a bonding between them and then nickel oxide is reduced in a hydrogen atmosphere.

So, the nickel is produced it of course, helps the develop the porosity is as once nickel oxide is reduced to nickel then oxygen goes out and it produces such an amount of porosity. That is also an advantage here we are not mixing randomly mixing the two phases together, but in a structured manner in a structured manner we are putting in the nickel coating only individual powders. So, that is it possible by this powder electro less technique.

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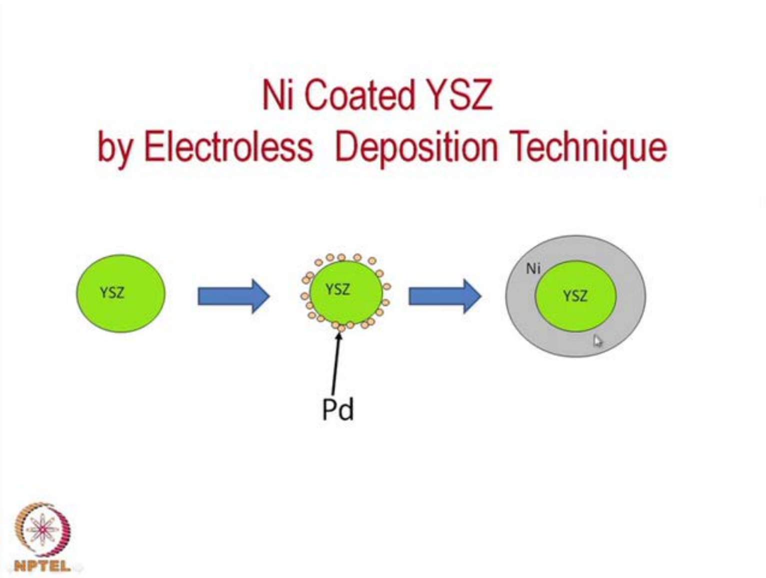

Yes, this is kind of a pictorial representation of what actually happens this is bayer powders. YSZ powders than you put a the palladium sensitization. So, far palladium particles actually gets adhere to the surface of an YSZ and then after the electro less solution it makes a is put the electro less solution the nickel a good coating of the nickel oxide and nickel metallic nickel. Now, this is not nickel oxide this is metallic nickel produced over YSZ.

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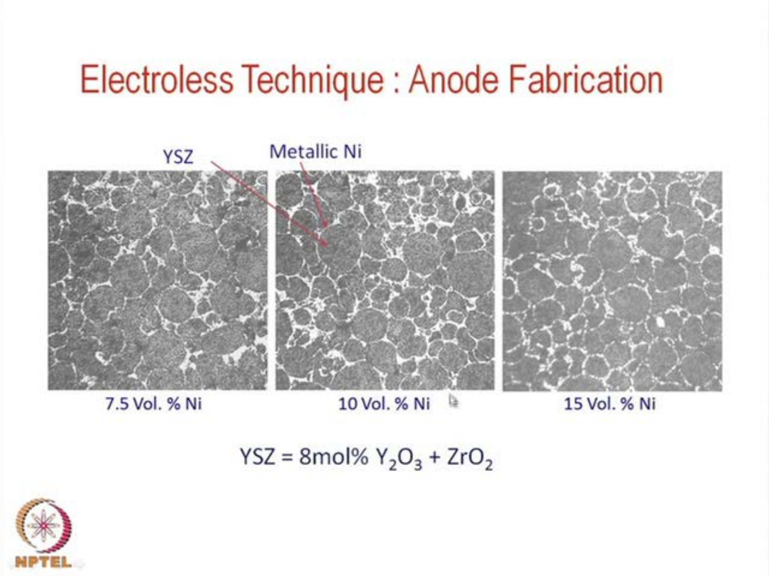

So, this how actually on get in nickel coated pouts and once centered that you get a distinct boundaries all the nickel metallic nickel are at boundaries is surrounding the YSZ powder far as the black YSZ powder. And the white regions are actually nickel and you can see very nice network forms as soon as you get the at a nickel coated YSZ powders. So, these are different volumes volume percentage as nickel has been used and has increases as the volume percent thicker and thicker layers are formed. So, 15 percent volume you can see much content much heat grain boundary phases and they are all forming continuous network and YSZ is it usual electrolyte material that is a 8 percent Y2O3 plus ZrO2.

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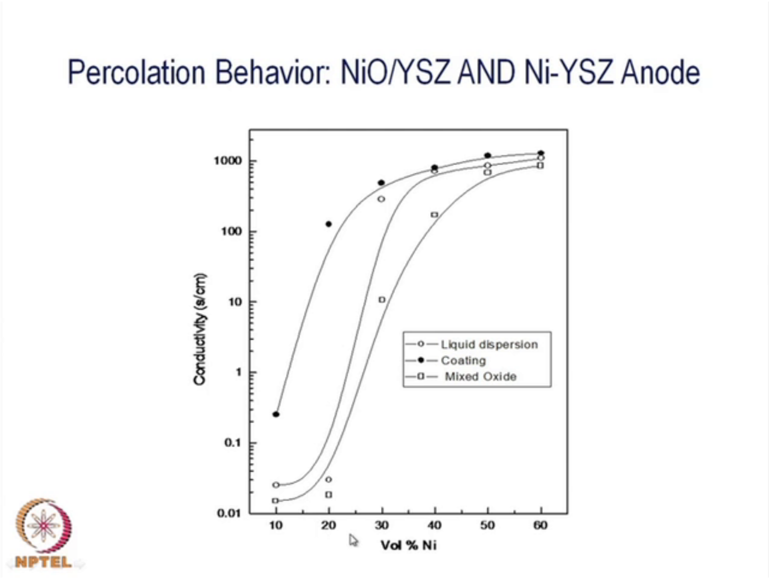

Now, the advantage of this kind structure is important and one can see from this particular graph where we have plotted and compared the conductivity electrical conductivity of differently prepared a nickel YSZ mixtures are there are three different types of mixtures have been prepared by different techniques. One is a normal solid-state mixing that is mixed oxide technique that nickel oxide and YSZ is mixed together centered and then reduced in hydrogen atmosphere. Then you have a liquid dispersion technique and instead of solid-state dispersion and uses liquid dispersion what the dispersion becomes better distribution also becomes better.

And the third one is in between the coating technique that is the limit electro less coating technique. So, what do have plotted here is the nickel volume nickel percent against the conductivity. So, you can see this was a much lower conductivity for the same volume let us say if you are talking about 20 to 30 percent, 30 volume percent of the nickel and can see the conductivity is much lower for the mixture prepared by the solid-state mixing. The samples been prepared by solid-state mixing is a much lower conductivity whereas, the liquid dispersion technique has a slightly higher conductivity and the coating technique which have discussed just now as a much lower much higher conductivity and that is a very interesting observation.

Because you have a continuous network in any other cases we really do not get a continuous network there are nickel dispersion's, but the continuous network is not a available their so and you can see here is quite effective so far as the this volume percentages is concerned. So, we get an this kind of conductivity is available at a much lower concentration of nickel oxide or nickel metal distortion nickel and that helps to match the thermal a thermal expansion coefficient of the electrolyte much better. So, this is the technique which is been developed as cgcri. So, this is the advantage of a electro less nickel deposition on YSZ powders.

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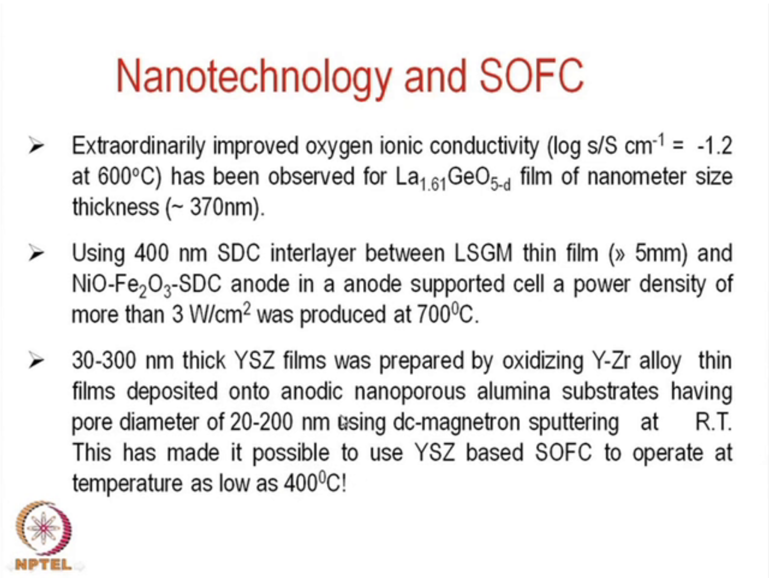

And finish discussion on a SOFC in couple of slides and is a nanotechnology and SOFC with the introduction or the development of the nano concept. It has a bearing on the SOFC also, SOFC performance and SOFC development also is I will just give you some statements some information are only two. Say that nanotechnology can be introduced and can be utilized of the concept of nanotechnology can very well utilized for the development of the SOFC or the improvement of the performance of the SOFC.

Extraordinary improved oxygen ionic conductivity this is log sigma of the order of minus 1.2 at 600 degrees has been is observed with lanthanum gallet. Lanthanum gallet film this is not YSZ . I mentioned earlier that are just like YSZ or a stabilize zirchonia another compound called lanthanum gallet which is a very high in general have a high conductivity at a much lower temperature, but if the same material is deposited in the nanometer size of the thickness of 370 nm you get a much enhanced conductivity at 600 degree which is much later than that of YSZ.

So, and if says the thickness is smaller both 370nm or one can get a much enhance conductivity. So, that is one advantage you get if you take just the concept of nanometers using 400 nm is SDC this is cerium interlayers interlayer between LSGM this is a stroncium and magnesium doped lanthanum gallet this is pure lanthanum gallet. Here, it is actually a strancium and lanthanum that improves of the expansion coefficient or the electrical conductivity as such and then thin one film 5.

I think it should be nano meter and nickel, nickel ferrite SDC as node and this is the electrolyte and anode supported are power density of 3 watt per centimeter squares was produced at 700 degree centigrade. So, these a interlayer of course, it is not used as electrolyte, but the interlayer by using the concept of nanometre sized particles nanometre sized films one can get a power density of 3 watt per centimeter square. Earlier, we have seen that the maximum power densities about around one watt or 1.2 w per centimeter square. Whereas, in this kind of a configuration or finer materials one can get almost double the watt power density are at a temperature of much lower temperature of 700 degree centigrade this is one advantage.

Similarly, this is for YSZ films 3 and 32 or 300 nm thick films normally the structures we are seen are 20 micron, but the in this case we're talking about much thinner about 30 to 300 nm YSZ films were prepared by oxidizing. Of course, this kind of film cannot be prepared this powder metallurgy to a powder represent techniques one is to do something different and that is why y yttrium zirconium alloy has been oxidized to form thin layer deposited onto a anodic nano porous alumina substrates having pore diameter about 20 to 200 nm. Once again, the poor sizes are also quite fine and using dc magnetron sputtering.

So, this is a little exotic processs as commercially will not be a it may not be economic to do that, but just to demonstrate what kind of effect what kind of advantages we get by thin films sputtering one can make at micro thin flms SOFC like this. So, this has made it possible to use YSZ based SOFC to operate at a temperature of as low as 400%. So, below 600 is very difficult, but on can get some this kind of exotic materials and exotic fabrication technology. So, that temperature operation as low as 400 degree centigrade.

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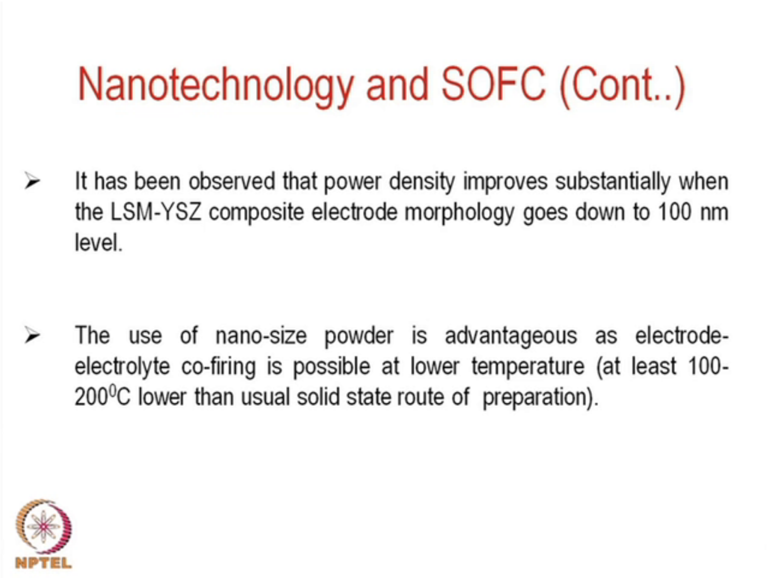

Extraordinarily improve oxygen, another two points to been observe that power density improves substantially when the LSM YSZ composites composite electrode morphology goes down to about 100 nanometers level. So, by reducing the morphology 100 nanometer level power density can also improve. Finally, use of nano sized powders advantages as electrode electrolyte co firing is possible lower temperature at least 100 to 200° lower than the usual selection. As the there is a co-firing technique for the anode supported here an anode supported fuel cells both were the anode as well as the electrolyte of cofired at the same temperature while we expect that the anode should be porous and the electrolytes should be a complete dense material.

So, cofiring has a very important role in fabrication of SOFCS. So, if you can reduce the cofiring temperature to a about by 100 to 200 degrees is that certainly proves to process and facilitates fabrication technology. So, by use of nano powders is of nano dispersions one can really make a much better or include technology not only in terms of the characteristics that electrical characteristics, but also the fabrication technology becomes little simpler .

So, by introducing the concept of nanotechnology one can have much better technology better performing materials. So, far SOFC is so this will come to the end of discussion on

SOFC have discussed various technologies various configurations and the fabrication technology and also their performance.

Thank you very much for your attention.