Polymer Assisted Abrasive Finishing Processes (Surface Morphology and Surface Metallurgy)
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Lecture – 06
Polymer Pad and Chemo-mechanical Polishing

Now, we are studying the conventional abrasive processes where in we have seen the grinding process, honing process, lapping, super finishing, sand blasting micro blasting, vibratory finishing and tumbling processes we have seen. Now we move on to the pitch polishing.

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Introduction to Conventional Abrasive Processes

- Introduction to
  - Grinding Process: Grinding and Belt Grinding
  - Honing Process
  - Lapping
  - Super finishing
  - Sand Blasting and Micro Blasting
  - Vibratory finishing and Tumbling
  - Drag finishing
  - Ice bonded Abrasive Finishing
  - Pitch Polishing, Pad Polishing

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The pitch polishing is one of the good process for the lens polishing as well as for the mirrors polishing applications. As you can see here this is the lens basically which is polished by the trailer and error methods of the operator normally which is one type of polymer along with the abrasives which you and this type of a pads there will be some pads will be available where you can use this pitch and you can do it by trial and error method. Normal it is started with trial and error method nowadays this also can be this is automated technologies are there which you can see in the upcoming slides.

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Introduction to Pitch Polishing

- Similar to Lapping Process but here special type of Pitch is used
- Optical pitch polishing process has been used for more than 300 years to obtain high quality optical surface finishes with little subsurface damage.
- Polishing with pitch was first introduced by Sir Isaac Newton in the 1700's and has since been used to produce high quality optical surfaces.
- Pitch is usually a dark color and is viscoelastic at room temperature. For polishing, a mixture of wood tar pitch and colophonium (a type of resin) is used.

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This is a similar to lapping process, but special is nothing, but here in the pitch is used which is slightly different from lapping fluids. Optical pitch polishing process has been

used more than 300 years to obtain high quality optical surface; that means, that this particular process is hugely used for optical industry for the lens polishing.

Assume that I want to polish this type of lenses or something lenses. So, you can use this type of pitch polishing techniques. Pitch polishing pitch was first introduced by Sir Isaac Newton in the 1700 and has since been used produced in high, high quality optical surfaces finishing applications you can use. Pitch is usually in the dark colour which is a viscoelastic at room temperature ok, it will have viscous component it will have elastic component. Viscous component can help you in moving along the direction of motion that is given by their external source.

At the same time elastic component we will try to move perpendicular to it so that you can get the finishing. This viscoelastic effect and other things you will see whenever I am teaching abrasive finishing processes in advance level; that means, that advanced abrasive finishing processes whenever I am going to deal there one of the processes is abrasive flow finishing process there you will observe what is this viscous effect what is this elastic effect and how this viscous and elastic effects are going to help the abrasive particle to finish in a nano scale that those things you will clear this basics in that particular process ok.

Time being you whatever I explained you that viscous component of this pitch will move along the direction of external energy; that means that in the previous slide the operator is moving like this. So, if at all I want to move like this that my pitch viscous component move try to move in this direction and elastic component moves perpendicular to it. So, that it will indent and this will create the shearing.

So, that you can remove the surface peaks and you will get a mirror surface finish and this can be used for optical applications.

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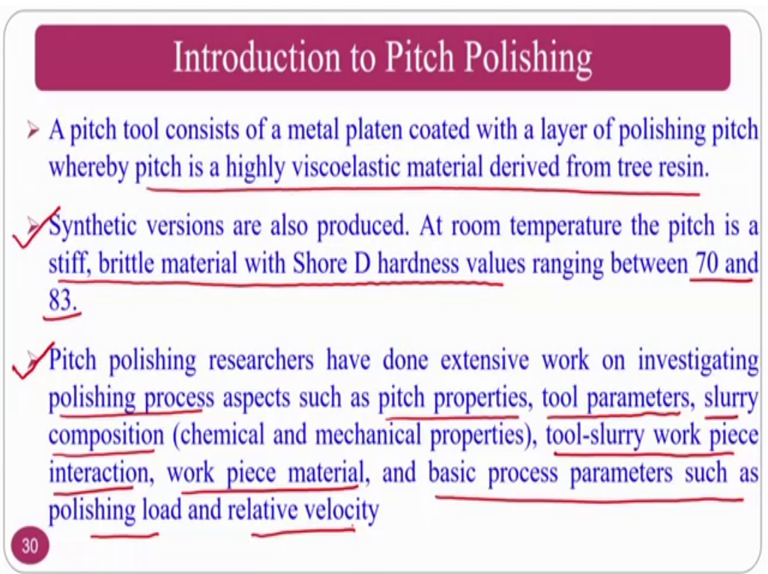

The pitch tool consist of metal pattern coated with a layer of polishing pitch whereby a pitch is highly viscoelastic material derived from the tree resin. Normally, this is naturally taken material. There are 2 varieties; one is a natural pitches another one is a synthetic pitches there. So, natural pitches are like taken from the tree resins. Synthetic versions nothing, but synthetic pitches also produced at room temperature this are stiff brittle material with the shore d hardness values ranging from 70 to 83.

That means the shore hardness normally used for measuring the hardness of very soft materials like with rubber, elastomers and other things. So, normally this pitch shore hard d hardness ranges from 70 to 83. The pitch polishing researchers have done extensive work on investigating the polishing process aspects such as pitch properties because pitch properties play a major role we have. In order to understand those it is itself is a very big study. So, tool parameters, tool also pitch tool also is the another input parameter and slurry composition and slurry interactions and other things.

Chemical and mechanical properties of also play a major role. Tools slurry and work piece interactions will also play a major role, work piece material pitch type of a work piece material when I am whether I am using fused silica for as a work piece material whether I am using a polymer lenses as my work piece material that will also play a major role because the hardness of this will of this materials will drastically changes from fused silica which is a ceramic to a polymer and basic process parameter such as

polishing load and relative velocity will play also major role; how much load that you are giving at the same time how fast you are rotating. If you are rotating by a manual method then you cannot rotate at cassia speed for that purpose people nowadays are going for automatic machines ok.

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Experimental setups these are some of the experimental setups, that are available and you can see the lenses many lenses are there and you can do it for mass finishing applications.

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Pitch Polishing: Principle

- Pitch is adhered to a polishing tool which is the inverse of the radius of optic being polishing. The tool with the pitch will be placed on the optic and rubbed together, much like the grinding process.
- As the polishing process continues, the pitch will slowly conform to the shape of the optic so that the surface of the optic is smoothed out, but its overall radius is not changed.
- To aid in removing debris, grooves are cut along the pitch to allow slurry to flow more readily between the tool and the optic.
- A hole is also cut in the pitch at the center of the tool since pitch will flow toward the edges and center of the tool during polishing.

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Pitch polishing principle; pitch is head to the polishing tool which is the inverse of the radius of optic being polish. The tool with pitch will be placed on the optic and rubbed against which much like a grinding process. You just take the lens that is if you take a pitch tool and you put the slurry as well as the pitch, then you do the operation by applying certain load and your required speed. This will act as a grinding process also because basic thing that we have as a mechanical engineers which we see the basic thesis as a grinding process.

As the polishing process continues the pitch slowly confirm to the shape of the optic. So, that the surface of the optic is smooth out and it rural radius is not changed. That means that this pitch is a initially at the room temperature it maybe bit high viscous. As you increase the temperature sensitive less will increase normally this all viscoelastic material. I cannot say all, the most of the viscoelastic materials and which comes this pitches this whatever the pitch polishing techniques which uses a pitch also comes under viscoelastic materials. Most of these pitches are temperature sensitive with respect to time the temperature goes up. If the temperature goes up this get low viscous and it confines to the complete area.

And to avoid removing debris grooves and cut along the pitch to allow the slurry to flow more readily between the; normally this pitch you can give some of the scratch. Normally if you see that polishing tool will be like this where in pitch will be there. In the pitch they will make this type of grooves ok. So, this type of grooves are there. Whenever these grooves are provided on a pitch what will happen? The chips which are there are something. Assume that this particular cross section if I want to take, so, it will look like a like this ok, this is the pitch where there and whatever the chips that are coming out may embody here so that it would not disturb the finishing process. For that purpose the grooves are provided you.

I think you may see this type of pitches in the upcoming slides. The hole is also cut in the pitch at the centre of the tool since the pitch will be flow towards the edges and centre of the tool during the polishing; that means, that there will be a hole. So, what I mean to say is that the pitch try to move out towards the edges are pitch try to move towards the centre or edges for that purpose you will have a hole at the centre.

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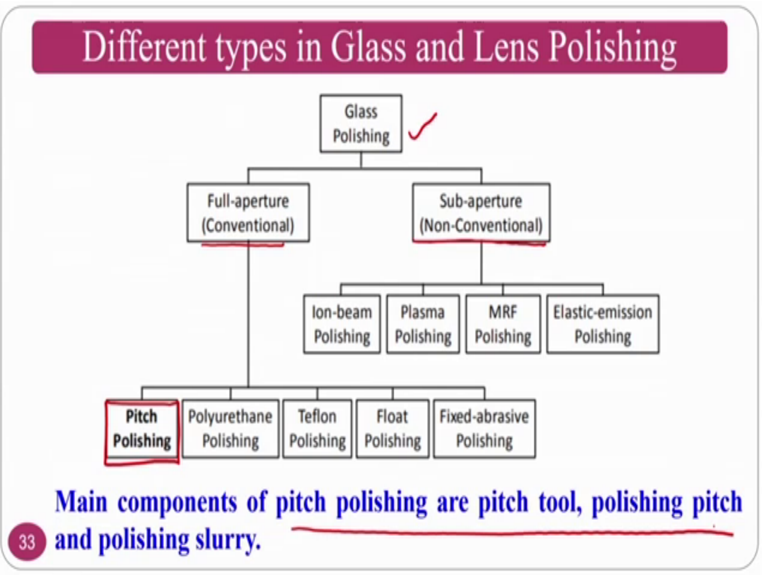

Different types of glasses and lens polishing; if you see the glass polishing techniques there are full aperture that is conventional methods and sub aperture non conventional methods. In the conventional methods there is a pitch polishing is one of the technique that is commonly used then there is a polyurethane, Teflon polishing, float polishing, fixed abrasive polishing is these are the techniques which are used in a conventional way. At the same time in a non conventional way, ion beam polishing, plasma polishing, MRF polishing, elastic emission polishing will be used.

So, these are the there are 2 varieties; one conventional and a nonconventional then we are seeing the conventional type. The main components are pitch polishing or pitch tool pitch polishing pitch and polishing slurry these are the 3 varieties.

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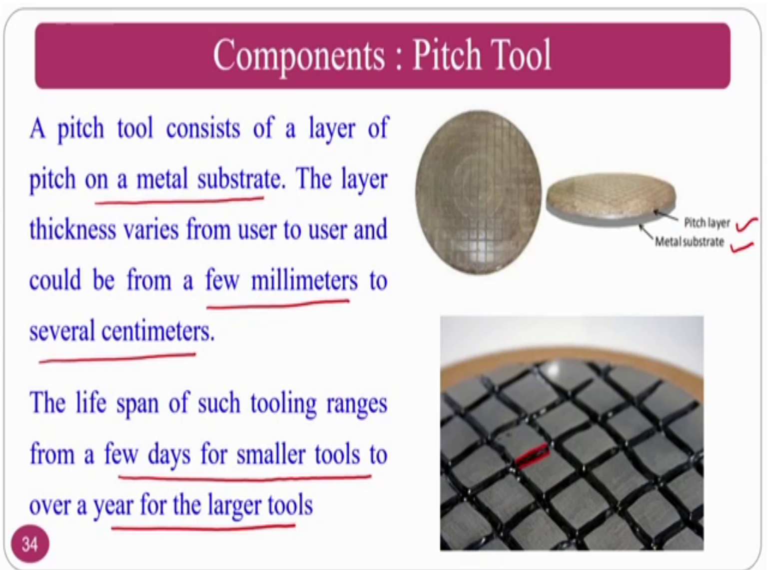

And the pitch tool as I said you will get the pitch layer at the same time metal substrate will be there on which the load will we applied. As I was telling you there will be a grooves are generated so, that the chips that are generated micro chips or nano chips will go and occupied this grooves. So, that it would not disturb the finishing process which tool consists of layers of pitch and on a metal substrate.

This layer thickness varies user to user and could find few millimetres to several centimetres. So, and the lifespan of such tooling ranges from few days to for smaller tools for few years for a larger tools; that means, that this thickness gradually decreases with respect to number of components that you want to finish at the same time what is the load that you are applying another things.

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Components : Polishing Pitch

- Pitch is primarily derived from either pine tree (natural) or petroleum based products.
- The petroleum-based pitch is commercially named as Cycad™, and the most common wood based pitch is sold as Gugolz™. The synthetic versions are also available and are sold under the trade name Acculap™.
- For natural pitch the basic properties slightly vary from batch to batch and with preservation time. The reason for possible variations includes the evaporation of the solvents added to the natural pitches to control its hardness values.
- The synthetic versions developed in the laboratory are more stable, consistent, and resistant to chemical attack, including high temperature oxidation or degradation

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Polishing pitch primarily derived from the pine tree which is a natural source. The other things are that you can also generate from the petroleum based pitch which are commercially named as Cycad. And these are the commonly for the wood based pitches like that glucose and this synthetic versions also available and should be under the trademark of a Acculap. These are the companies that it will produces the different types of pitches.

For natural pitch the basic properties slightly vary from batch to batch because if you are taking out in a winter if you are taking about in a summer then the properties slightly will vary ok. At the same time the possible variations include evaporation of solvent added to the natural pitches control the hardness value; that means that you have to add some of solvents to the natural pitches so, that you can vary the viscous and elastic components and other things.

And if the elastic component is more normally the hardness will be more. The synthetic versions developed in the laboratory are more susceptible and consistent because the synthetic ones are developed as per your requirement. I know this much elastic component required I know this much viscous component is required. So, that you can develop your own, but naturally available you have to take the natural what are the properties that have, but only thing that you can use some other solvents to modify it that

is all, but you cannot decide whatever the you required whatever you the properties that you require.

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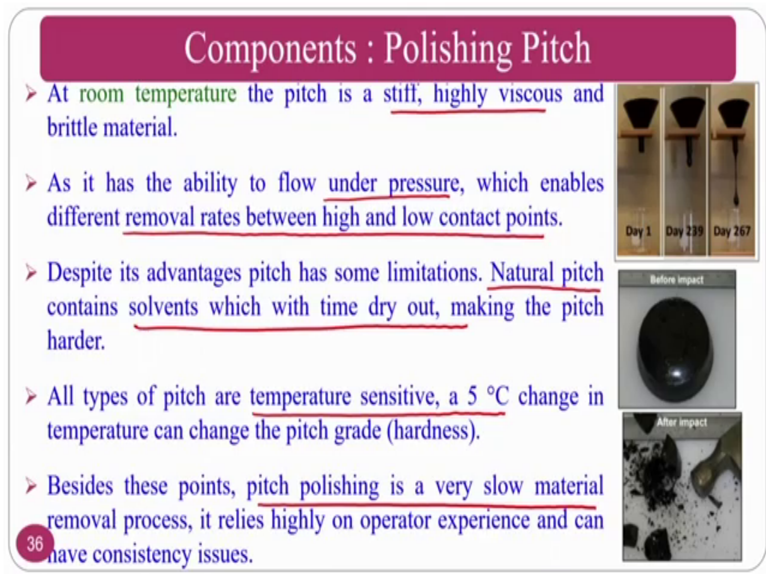

These are the polishing pitches. If you see that the room temperature pitches are stiff highly viscous another things, which are act as a brittle materials and it is ability to flow under the pressure and which enables different removal rates between a high and low contact points. Because if you are applying certain load what will happen? If it is very brittle the stiff if the pitch is very stiff, then it will causes material higher material removal rate. And despite advantages of some limitations also is there. Some of the natural pitches contain solvent which may dry out with respect to time because the temperature will increasing the temperature increases what will happen that solvents will goes off then the pitch will become more stiff.

So, the material removal rate will be very high and the roughness will increase; that means, that nano polishing you may not get. All types of pitches are temperature sensitive; that means a 5 degrees change in temperature can change the pitch grade; that means that the hardness as we have seen in the grinding process the pitch grade also will change. Beside this pitch polishing is very slow material removal for; that means, that specific energy requirement for this pitch polishing will be very high.

The material removal is very slow, but the input energy is very high this is also one of the drawbacks of polishing pitch.

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Components : Polishing Slurry

- A **polishing slurry** consists of an abrasive - liquid mixture. Water is typically the base liquid used.
- Different abrasive particles are used in pitch polishing process depending on workpiece material and required surface finish.
- Cerium Oxide (ceria), Aluminum Oxide (alumina), Iron oxides, Zirconium oxide, Silicon Carbide, Cubic Boron Nitride (CBN), and diamond are the most common abrasives used in polishing process.
- Ceria is a very popular polishing compound for a variety of optical materials. For a workpiece material like fused silica, ceria based slurries can provide the best removal rate when compared to other abrasive types. Ceria is a rare earth oxide that can be acquired, purified and processed for commercial use.

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Now, we go to the second component that is a polishing slurry. Polishing slurry consist of abrasive liquid mixtures normally water typically is a liquid. Different abrasive particles are used in a pitch polishing process depend on the work piece material. Commonly used are cerium oxide compared to other abrasive particles like Al 2 O 3 that is alumina iron oxide, zirconium oxide, silicon carbide, cubic boron nitride, diamond other things, but commonly for the lens polishing applications people will use cerium oxide which is nothing, but ceria will be used and ceria is very popular polishing compound for a variety of optical materials.

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Components : Polishing Slurry

- As abrasives chemically react with workpiece material, their chemical composition can have a profound influence on the polishing process and process outcomes.

Table 2-2: Some physical properties of pure CeO_2.

Property	Value (unit)
Density	7.22 g/cm^3
Melting Point	2477 °C
Youngs' Modulus	1.65×10^{11} N/m^2
Hardness	Mohs Hardness 6
Crystallography	Cubic, face centered
Solubility in Water	Non-soluble

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And you can see the properties of this ceria here. The density and melting point, Young's modulus, hardness crystallography, solubility of water with this is, it is a insoluble one and you have a better properties of a cerium oxide for lens polishing or the glass polishing applications.

At the same time this up. So, chemically react with work piece material that their chemical composition have profound influence on the polishing process and process outcomes; that means, that the if at all you are using this type of a ceramic particles these are stable and this may not react, but the pitch which you are getting synthetically developed or which you are getting from the plants or wood these all have their own chemical properties which influence the finishing process.

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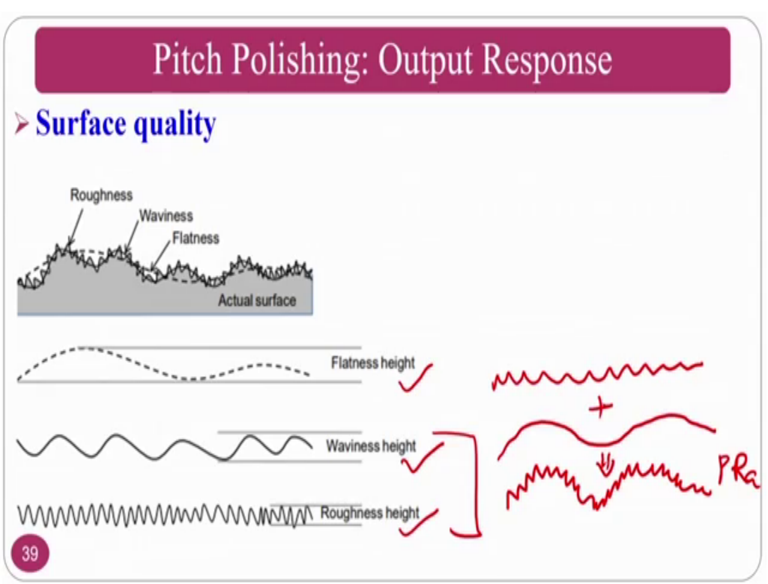

The output responses; if you see the surface quality this particulars thing I will explain you in deep in the upcoming slides. Normally the profile roughness will be there. If you see here this is the roughness and this is the waviness and this is the flatness height. Normally if you see these 2 your surface will be like this; this is called profile roughness that is normally represent by P R a which you can divide into waviness and you can divide into roughness ok. So, these 2 gives raise to profile roughness. These are all things I will explain you in the upcoming classes where the surface properties you should know all these things in the upcoming slides.

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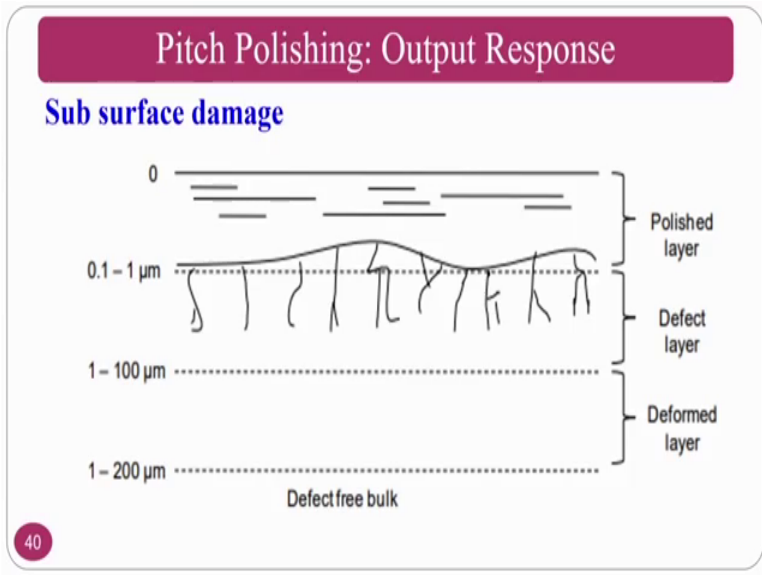

Sub surface damage; the subsurface damage if you want to see this is a surface and normally there will be if you are going for the grinding applications and other things what will happen? The forces are very high. If the forces are very high then there will be a subsurface damage cracks and other things, but in the pitch polishing this things may not happen. In the pitch polishing this may not happen because the interaction forces are very less.

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The other process that you can use is the pad polishing. You can use the abrasive slurry here and you can use for slightly applications like polishing or buffing applications you can use the pad polishing.

Now, we move on to the pad polishing after the pitch polishing. There are 3 basic finishing processes that we are looking at; one is pitch polishing, pad polishing and hybrid version of the pad polishing that is called chemo mechanical polishing. So, even though you directly go to the chemo mechanical polishing, but; however, just we will give you some of the glimpse because the pad polishing and CMP approximately similar. Only thing is that CMP is slightly advanced version or the hybrid version of pad polishing.

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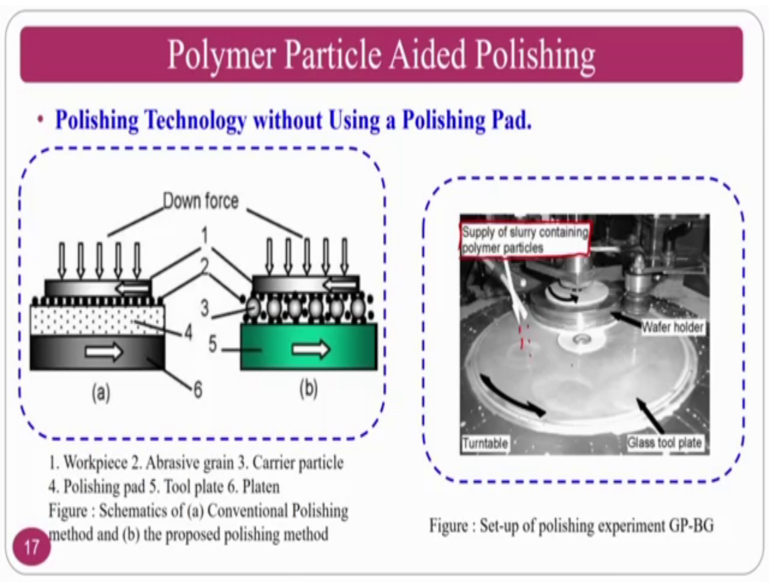

So, the polymer particle aided polishing here you will have a pads, but you do not have any soft pad. You will have a particles which are used along with the polymer then you can do the finishing operation. You can see this supply of the slurry containing the polymer particles. You just supply the polymer particles then your disk will be there at the bottom, the pad will be there and then the finishing will takes place.

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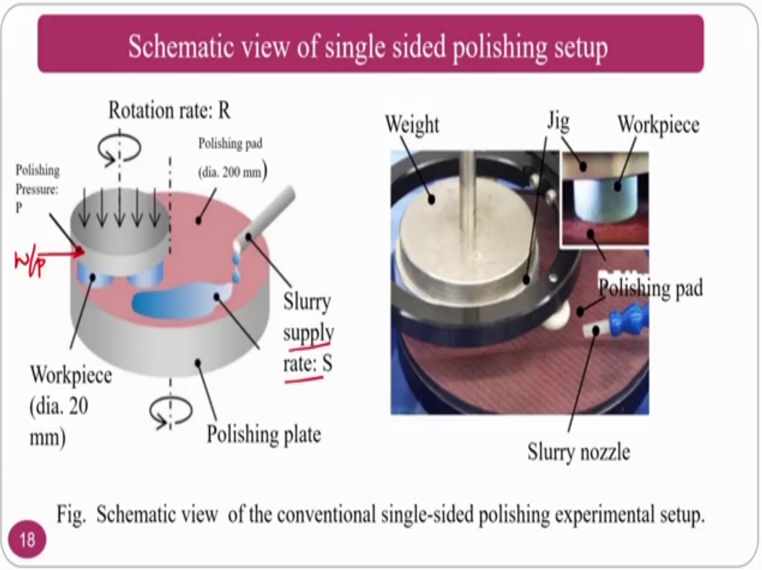

Originally later what is developed is the pad polishing. Pad polishing this is the one sided pad polishing where you have the polishing pad at the same time you have the work pieces and you have the pad slurry supply and other things, only thing is that you have to give some relative motion with respect to work piece and the pad cost of the supply of the abrasive slurry.

The abrasive slurry will has to be always paid to the pad polishing so that the finishing will takes place in a better way.

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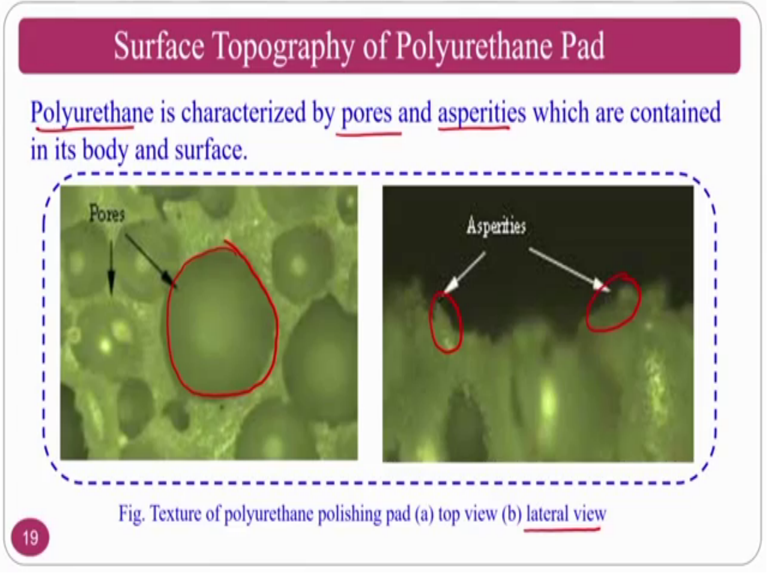

You can see here the surface morphology of polyurethane pads. Most commonly in pad polishing or chemo mechanical polishing polyurethane based pads are used. Why this polyurethane pads are used and other things regarding the characteristics we will see in the upcoming slides. Polyurethane is a characterized by the pores and asperities which are connected in the body surface. These are the pores which are there on a polyurethane, at the same time if you take a cross sectional lateral view we can see the asperities.

This asperities and pores will host the abrasive slurry and whenever you apply certain pressure and do the polishing operation normally the abrasive particles which are superfine enough, they will do the polishing operation using this pad polishing on the work pieces.

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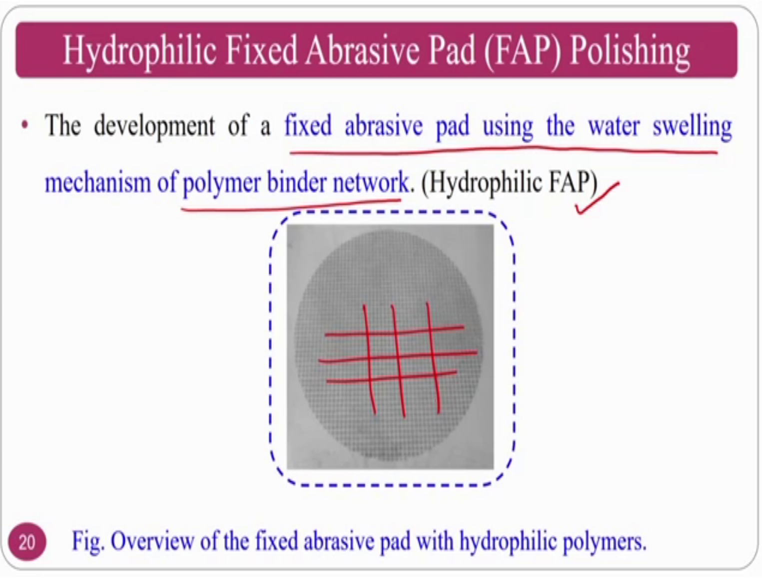

So, another variety is hydrophilic fixed abrasive pad polishing process. The development of fixed abrasive pad using the water swelling mechanism of the polymer binder network is done they said that is why it is called as hydrophilic fixed abrasive pad polishing. This is the overview ok.

You can see lot of striations are there where in you can hold the abrasives and do the finishing process.

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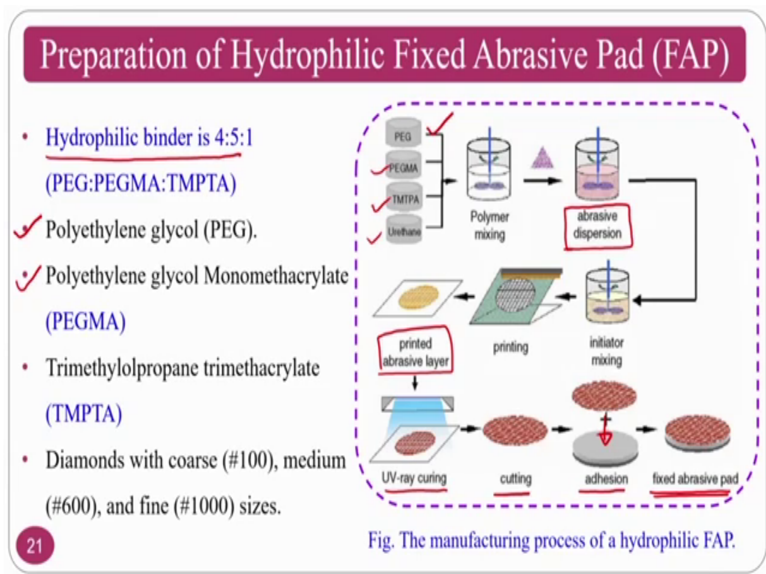

Fig. The manufacturing process of a hydrophilic FAP.

The preparation of hydrophilic fixed abrasive pad; how this can be prepared? You will have the PEG; Poly Ethylene Glycol. Then you can see the expansion of this one. Normally hydrophilic binder you will use 4 is to 1 5 is to 1, this is the commercially available and you will have polyethylene glycol monomethacrylate that is second one also is there then trimethylolpropane trimethacrylate it is there.

Then you have can also use urethane and the polymer mixing can be done then you can add some of the abrasive particles also and you can just put into the stirring system then you can print this mixed polymers along with the abrasive particles that gel on a sub printing that means, that you will have a desired shape of the print so that you will get a specified printed abrasive layer. This printed abrasive layer is in the gel form.

Now you how to cure the you can do the UV curing. Normally, the UV curing do the cross linking and other things so, that you will get a sample of the hydrophilic fixed abrasive pad. This cutting you can do then you can do the adhesion to the substrate.

Then you can do adhesion to the substrate, now fixed abrasive pad is achieved. This way the fixed abrasive pad can be developed. This is a just a raw procedure in trick a details may be much much bigger. So, some people who are interested they can go through the original documents.

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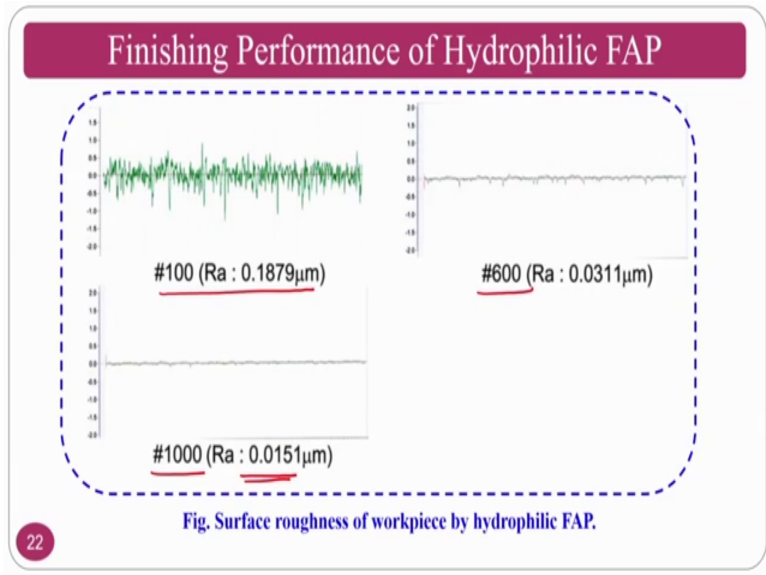

Fig. Surface roughness of workpiece by hydrophilic FAP.

And you can see the surface roughness abrasive particle hash 100, 600 and 1000 as you increase the mesh size. What will happen? The particle size will reduce and you are going to get a super fine surface using hydrophilic fixed abrasive pad. Now we are moving into a another pad polishing technique which is a hybrid version. Till now just a glimpse of pad polishing I have given there it is just a conventional slurry.

You have some oils or water along with the abrasive particles you will add, but in the chemo mechanical polishing you will use some of the passivating chemicals along with the abrasive particles also.

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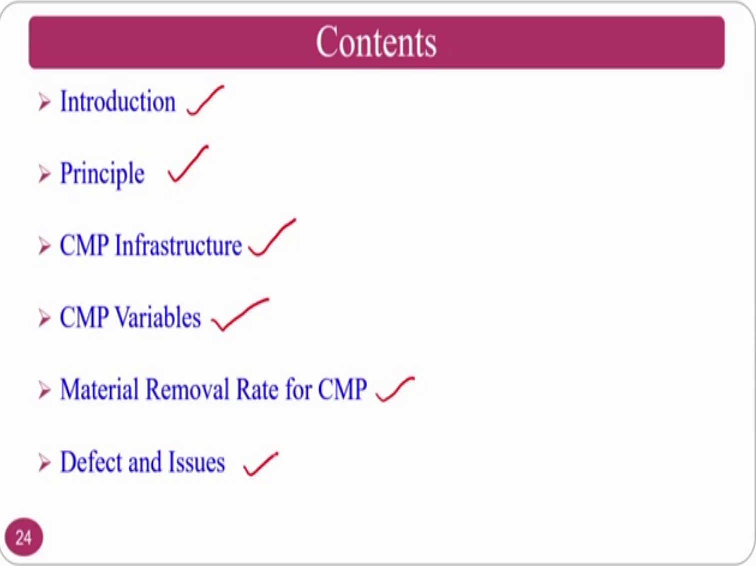

Now, the contents of this chemo mechanical polishing; you can see here introduction to chemo mechanical polishing principle, what is the infrastructure required, what are the variables, material removal rate and how the mathematical relation will be there between the chemo mechanical polishing process and materials and defect and issues what are their using the chemical polishing process and applications.

Normally this is used in mostly in electronic industry.

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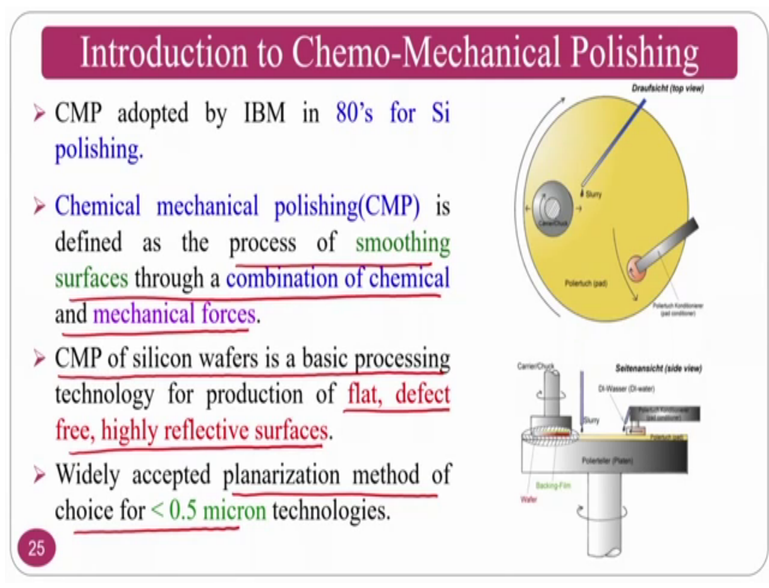

So, introduction to chemo mechanical polishing; you can see here. CMP that is acronym for the Chemo Mechanical Polishing is adopted by IBM in 80's for silicon polishing basically. Chemical mechanical polishing or chemo mechanical polishing is defined as a process of smoothing the surface through the combination of chemical and mechanical forces. That means, that you are going to use some chemical for making a chemical reaction on the surface, then you are going to use the abrasive particles for upgrading the surface. So, that material removal will be improved along with the super fined surface also.

Chemo mechanical polishing of silicon wafers is a basic process of technology for production of flat, defect free, highly reflective surfaces. Normally, as I said this particular process is basically uses for silicon industry and widely accepted planar method. Normally, this CMP stands for chemo mechanical polishing or chemical mechanical polishing or the another name also given by some other people that is called chemo mechanical planarization or chemical mechanical planarization, instead of polishing they may also called as planarization processor. So, CMP stands for chemo mechanical polishing or chemo mechanical planarization.

Why if this name is given is because planarization method of choice approximately for less the 0.5 microns technologies; that means, that you need a very good planarization surfaces or the plane surfaces that is why this process also called as chemo mechanical planarization.

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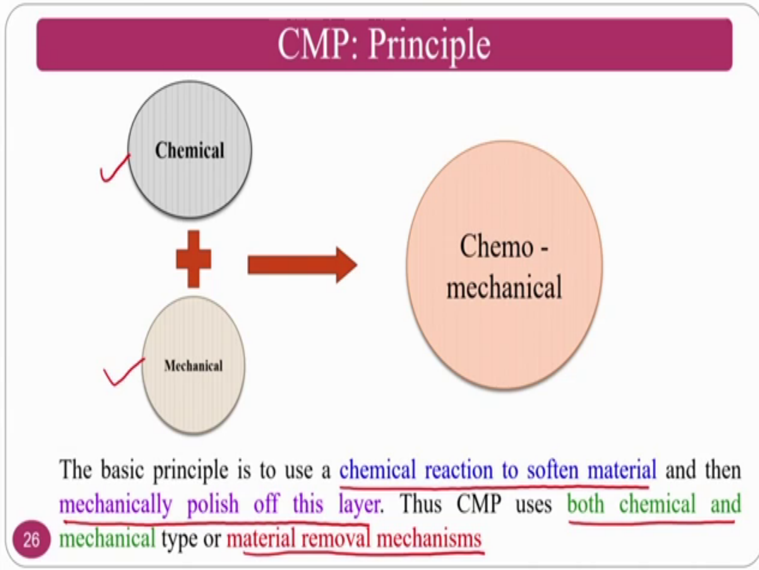

You can see the principal of chemo mechanical process or the chemo mechanical polishing. You have a chemical technology, you have mechanical technology then it will lead to chemo mechanical technology.

How it is leading? The basic principle use as chemical reaction to soften the material. This chemical is going to make the surface smooth. The surface layers of your substrate will become smooth because of the chemical reaction that is taking place between this particular chemical and mechanical action will be further followed because you have the slurry, this slurry will have abrasive particles and this will do the polishing process. So, that you will get a better surface and mechanical polishing will be done by the abrasive particle. Thus CMP have the both chemical and mechanical type of material removal mechanisms. That means, that it has a 2 positives; one is a chemical another one is a mechanical.

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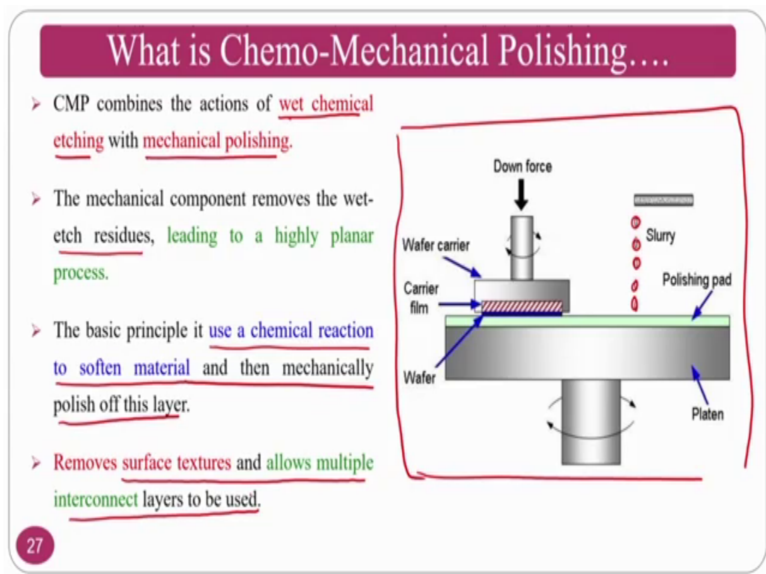

So, what is chemo mechanical polishing, how it looks like? This is the chemo mechanical polishing set up where in you have a wafer, normally wafer will be polyurethane wafer and you can have the work pieces and slurry will be continuously fed so that abrasives will be there and this slurry will also contain the chemical. The CMP combines action of wet chemical etching with mechanical polishing; that means, that 2 individual processes was there that is called chemical etching and mechanical polishing. These both are combined then called as a chemo mechanical polishing. The mechanical component removes the wet etch residues leading to a highly planar surface.

That means that what it will do is your chemical that is used in the chemo mechanical polishing will do the etching and make the surface soft. Use of chemical reaction to soften the material and then the mechanically polish the layer and removes the surface texture and allows the multiple interconnect to be used; that means, that what is meaning is it can only passive at the surface layers. So, that it the abrasive particles can remove the surface.

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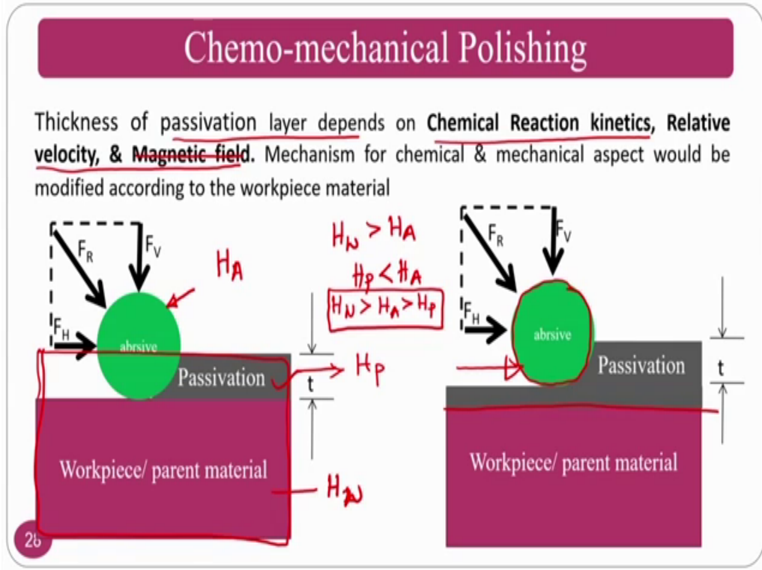

And how this will be done and other things; there is a some animation also will be there in the upcoming slides, I will show you. Thickness of passivation layer depends on chemical reaction kinetics and relative velocity and magnetic field.

Sometimes you can also use the magnetic field based chemo mechanical polishing. You will see one of the slides at the last where you can change or you can add chemo mechanical polishing with respect magnetorheological finishing also. So, currently you just forget about magnetic field and you can see here passivating field. I have a work piece surface of this much surface. Whenever I am adding some chemical to it what is happening? It is making a passivating layer. This passivating layer will become smooth. Assume that my work piece hardness is H 1 and the work piece hardness is H 2. H 2 hardness of the work piece let me take in good ways; abrasive.

Now, work piece hardness may be higher than hardness of the abrasive particle. In that circumstances finishing is not possible because the convention of basic metal cutting or basic abrasive processes will say that you are tool should be harder than your work piece material. Then what will happen? You are going to use a chemical so that you will get a passivating layer. Now this passivating layer will be hardness will be H P. H P will be less than H A; that means, that your abrasive particle will only take away the surfaces which are smooth enough; that means, that your H W is greater than HA greater than H P. In that circumstances your work piece hardness is higher than yours abrasive hardness.

So, abrasive cannot cut the original parental material, it can cut only the passivating layer that is clearly evident from this particular picture. So, you can see this is only cutting a passivating layer and in one go. In another go it will remove the passivating layer and makes the surface super finished that is how the chemo mechanical polishing works and this animation shows you that only abrasive particles aim is to remove the passivating layer, it cannot do the original surface. If it cannot touch or it if it cannot remove or intent the any surface of the parent material; that means, that there would not be any scratch marks on the surface.

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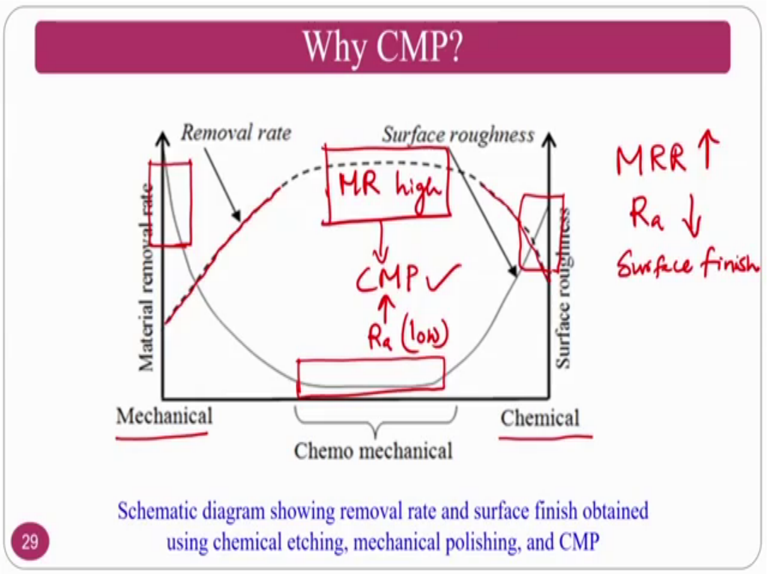

So, why CMP? You can see here mechanical polishing process and chemical etching process and you see the material removal the material removal is less here, but material removal is less in this region, but the surface roughness values are low in the chemo mechanical polishing, but the surface roughness values are high in chemical as well as in mechanical. If you are going to use only the abrasive particle; obviously, the feedbacks will be there. So, surface roughness is high. What your main aim is your material removal rate should be high that means that you have to remove the material per unit time in a high, but surface roughness value should be low.

That means that surface finish will be better. So, both things are achieved in chemo mechanical polishing. Your surface roughness is low; your material removal is high because this started curve represent the material removal. Both things are achieved in the

CMP process, chemo mechanical polishing process; that is why chemo mechanical polishing can be a good alternative compare to individual mechanical process or individual chemical process. That is why this is considered in this particular super finishing processes.

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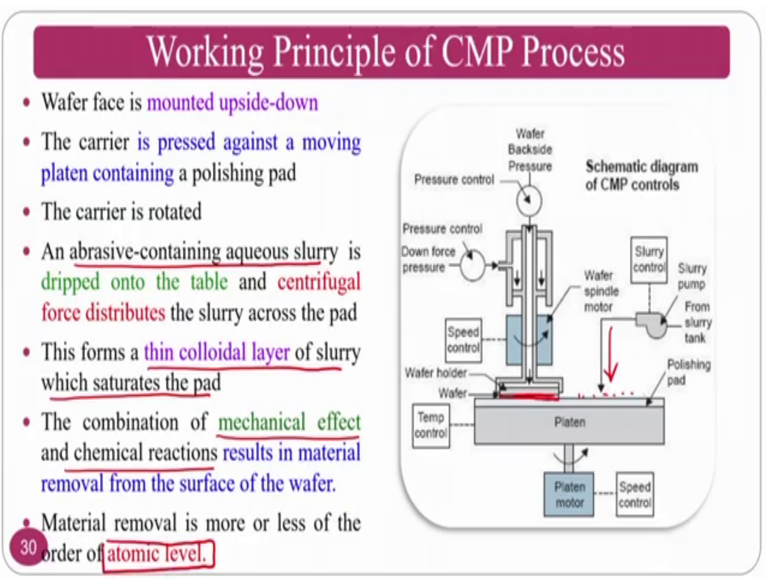

The principle of chemo mechanical polishing, how the chemo mechanical polishing; you can see the wafer is mounted on upside down this is a wafer. It is upside down it is mounted on this one then the carrier is pressed against a some moving platen.

Career means you have a polishing pad will be there and the career is rotated and abrasive containing aqueous slurry will be continuously poured. So, that it will stay on the surface and the polishing action will be taken care. And the thin colloidal layer of the slurry which solute the pad which its forms because what will happen whenever you are putting a slurry your pad is rotating because of the centrifugal action the slurry will be distributed basically. The combination of mechanical effect and the chemical reactions results in the material removal it is also a material remover more or less will be in a order of atomic.

Because why it is says atomic level is nano level or atomic level it will be always there because you are going to release or you if you going to remove only the passivating layer; that means, that original surface will be properly will be there and you will get a nano surface to atomic surface level.

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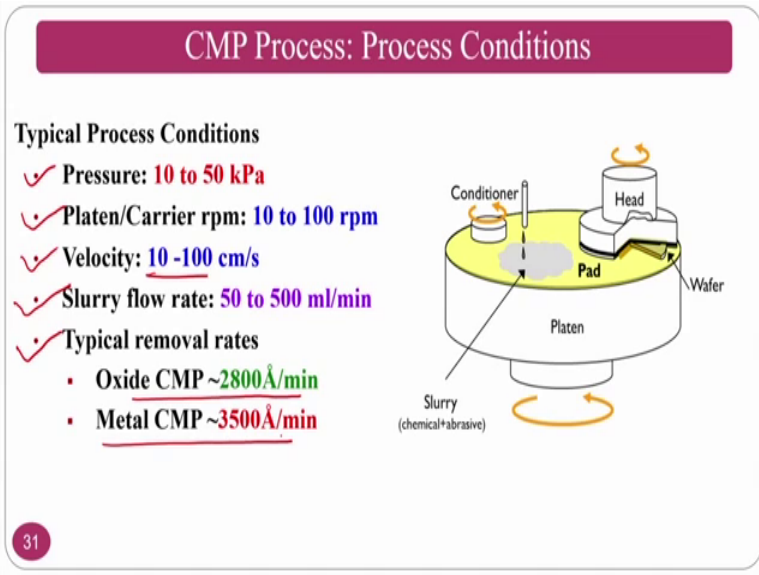

The CMP process conditions if you see normally the pressures 10 to 50 pascal will be there. Carrier rpm it will be 10 to 100 rpm will be there, velocity 10 to 100 centimetres per second, slurry flow rate will be there.

Typical removal rates for oxides 2800 Armstrong per minute, for metal CMP it is 3500 because metals are softer compare to the oxides.

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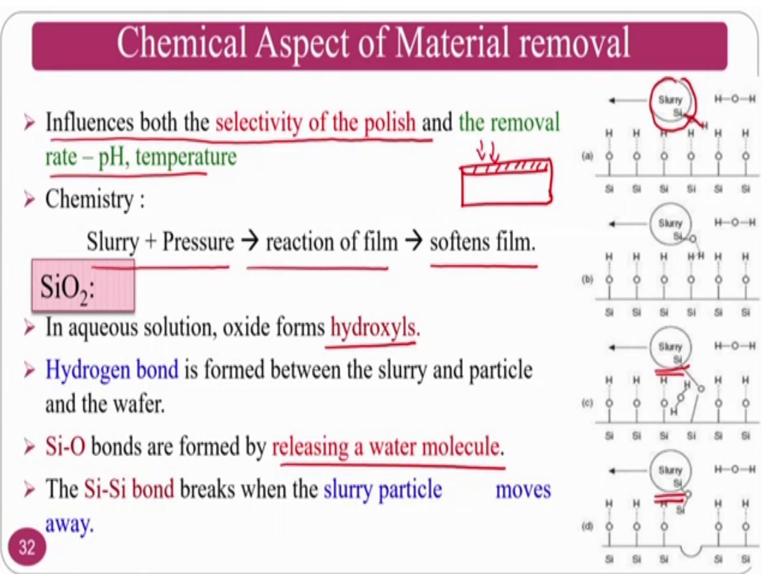

Now, we will see chemical aspects of material removal, what is the chemical structures of this chemicals, how this chemical is going to remove the material or how the chemical

is going to make the surface passivate. Both influences both selectivity of the polish and removes rate the temperature also. The chemistry; slurry pressure, reaction of the film will takes place and the soften the film; that is what the passivating layer. I have said when you have this work piece whenever you put some chemical and tough what will happen? There will be a passivating layer.

So, normally SiO 2 will be used. In aqueous solution oxide will form, hydroxyls hydrogen bonding is formed between the slurry and particle and the wafer, SiO bonds formed by releasing the water molecule and S i S i bonds break when the slurry particle moves away; that means, that you have a slurry is there this will form the bonding then this slurry will take away the S i particle that mean that the atom by atom or molecule by molecule the material removal takes place that is why the surface roughness normally achieve is Armstrong level.

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Chemical Aspect of Material removal

- Si Polishing:

  $Si + 2OH^- + H_2O \rightarrow SiO_2^{2-} + 2H_2$

- Copper:

  $Cu \quad Cu^{++} + 2e^-$

  $2Cu^{++} + H_2O + 2e^- \rightarrow Cu_2O + 2H^{++}$

- Tungsten:

  $W + 6Fe(CN)_6^{3-} + 3H_2O \rightarrow WO_3 + 6Fe(CN)_6^{4-} + 6H^+$

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Silicone polishing we will see here. Silicon normally it will be done using a chemical, but that is commonly available chemical that is called water base chemicals or you can also use water also and the copper normally copper will be done again with water based and you can do the this one and the tungsten normally FeCN whole power 6 and water based it will be done. So that means, that these are the chemical reactions for silicon polishing, copper polishing and tungsten polishing. These are the common materials

among that commonly used materials for the electronic industry silicone. So, this particular process is tremendously or enormously used in terms of electronic industry.

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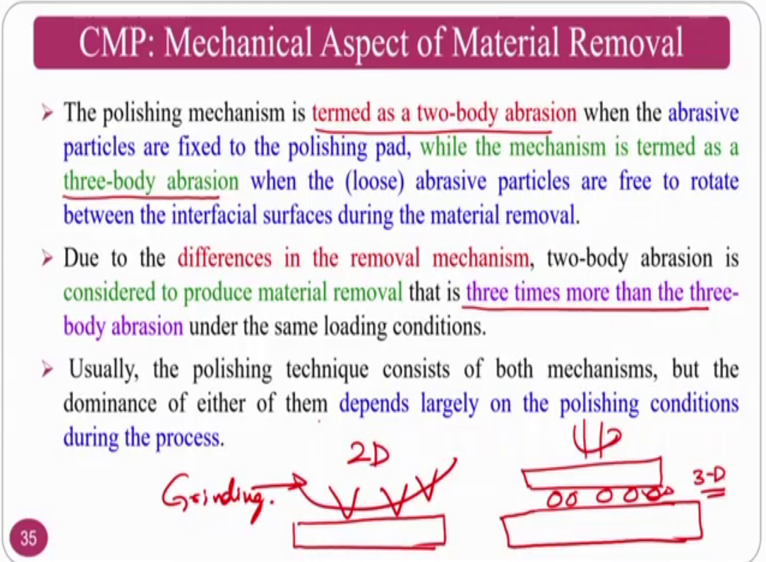

Mechanical aspects of material removal when the abrasive particles are present in the slurry then the substantial material removal takes place due to abrading. Basically what is mean by a abrading mean, it is just a rubbing action of the abrasive process that you have seen in the grinding process. And when there is no abrasive particle present in the slurry normally the mechanical aspect of the material removal lies purely in the mechanical friction present as the result of pressure; that means, that you have a upside down plate will be there work piece and you have the pressure will be given from the carrier. So, abrasive particles are there, pressure plus abrasive particles will take part in the finishing process. .

If there is no abrasive particles because of the friction because of the load that is given will decide the finishing. Finishing is carried out without letting the abrasive particle generate the brittle fracture and the work surface. While removing this material minute steps by means of plastic deformation finally, produces mirror surfaces; that means, that some of the passivating layers will form, this passivating layers might fracture and then come because if your work pieces are brittle in nature. This process detaches the material from the surface in the relative motion because relative motion is provided to the substrate work piece substrate with the pad also because one is stationary and another

one is rotationary then in this circumstances the polishing will takes place at the same time relative also will be there.

In one direction the pad will be rotating and another direction your work piece also can be rotated. So, this is again the mechanical aspect. The polishing phenomena is termed as a 2 body abrasion. Normally if your abrasive particle is fixed and it is not rotating about its own axis then it is called 2 body, if it can be rotated about it is about its axis normally CMP comes under 3 body abrasion. So, 3 body abrasion means your abrasive particle normally this is your pad your abrasive particles are there and your work piece will be there. So, if you are rotating it what will happen? This abrasive particles also rotate about its own axis that means that this is 3 body abrasion.

So, in terms of grinding process; your grinding process what will happen? Your abrasives are fixed that is whenever you do the work piece against this one, what will happen? This is called 2 body abrasion or 2D abrasion. The difference in removal mechanisms of this is would normally the 2 body abrasion will have 3 times higher material removal rate compares to 3 body abrasion; that means, that 3 body abrasion is normally for finishing applications and 2 body abrasion is you can use for material removal application that is why grinding basically will be currently used as a machining process.

Usually this polishing technique consist of both mechanisms of either 2 body or 3 body depend on the polishing conditions. If you are going to give more load what will happen this abrasive particles will stay at the location because there are pores on the pad polyurethane pad there are asperities this may obstruct the relative motion of this abrasive particles and they may stay at particular location. So, if your input conditions are very high it is called 2 body abrasion, if your input conditions are low then it is can be called as 3 body abrasion.

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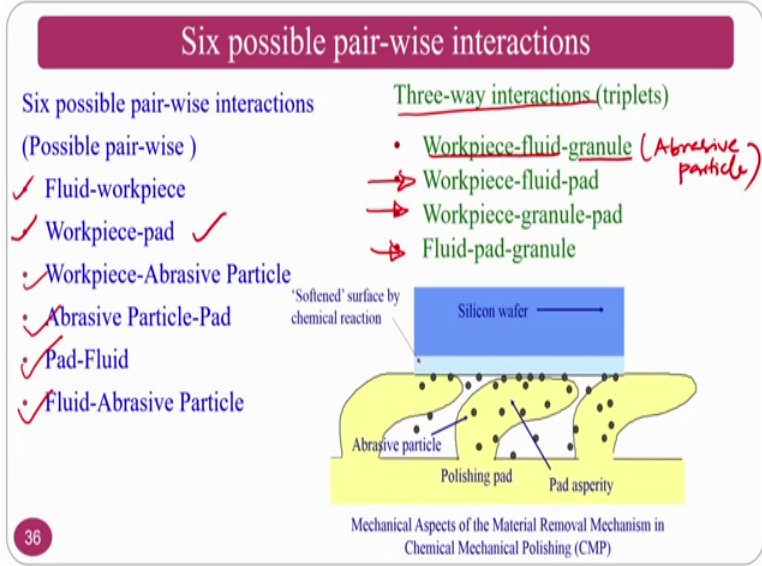

Six possible pair wise interactions if you see here. So, fluid work piece, work piece pad, work piece abrasive particle, abrasive particle pad, pad fluid, fluid and abrasive particles can be and everything is here you can see and the three way interactions will be work piece will interact with the fluid as well as abrasive particle granule means abrasive particle.

And work piece fluid and pad can interact, work piece abrasive particle and pad can interact and fluid pad an abrasive particle can interact. These are the 2 way connections some are there and the 3 way connections are there. So, this particular process is a random. If your finishing process is more and more random you will get a better and better surface finish.

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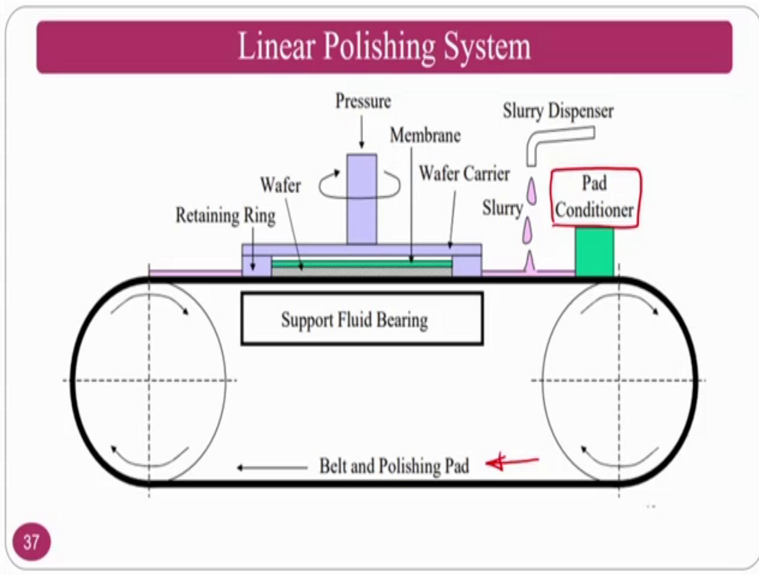

Linear polishing system is one variety where you will have a belt base polishing pad will be continuously moving and you can apply a rotational motion to the work piece and you can do the finishing process along with the slurry.

And you will have a conditioning pad also; you will have a pad conditioner also this conditioner will make the pad proper for the next round.

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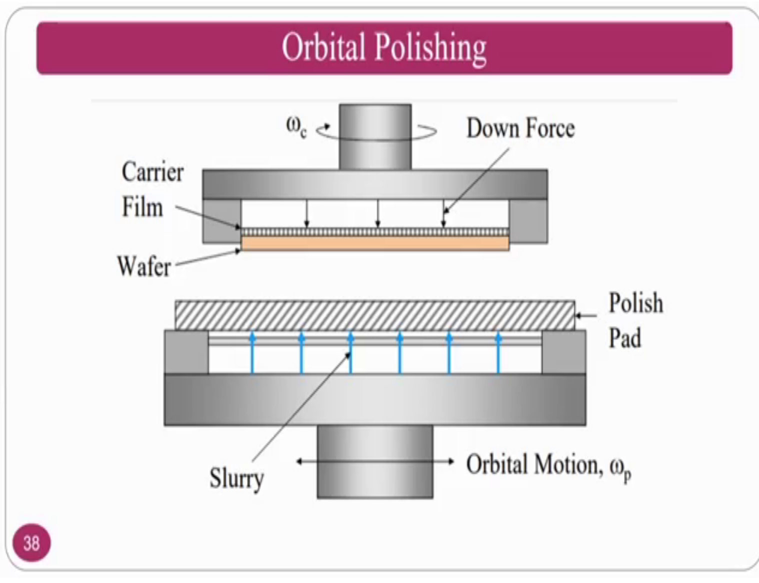

At the same time orbital polishing, it is normal what we have seen. You have a 2 disc and you will give the rotational motion to the work piece holding plate and the finishing will takes place.

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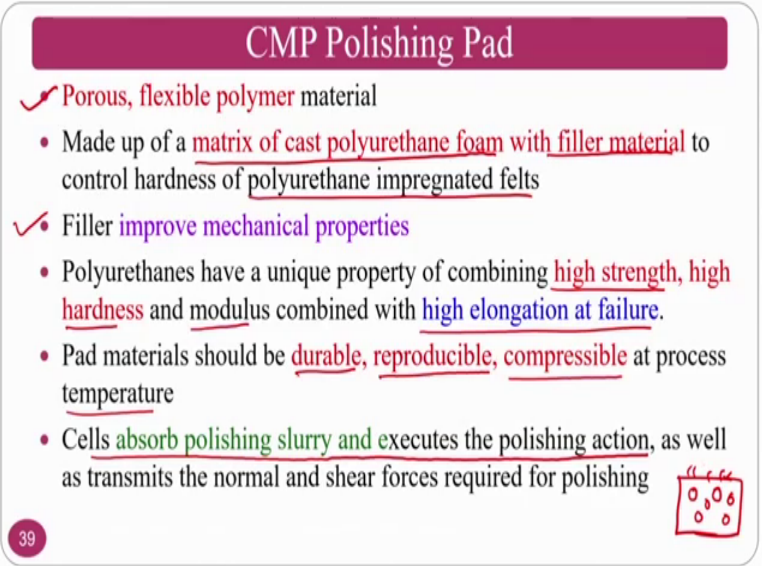

So, the polishing pad normally this will be porous flexible polymer. Made up of matrix of cast polyurethane foam with a filler material and controls the hardness and polyurethane impregnates and felts. The filler normally the function of filler is to improve the mechanical properties and polyurethane have unique properties of combining high strength, high hardness and modulus combined with high elongation failure.

That is why most of the cases polyurethane is used in the finishing process or pad finishing process or chemo mechanical polishing process also. The pad material should be durable, reproducible, compressible, process temperature and other things. Pad material should be durable reproducible and compressible at all the process temperatures and cells absorb polishing slurry and execute the polishing action; that means, that there are whites that you have seen on the surface of the polyurethane and there are asperities, some of the asperities will be there this should absorb the slurry and help this abrasive process to enhance its finishing and the chemical also should do the chemical etching process.

So, that the surface will become smooth and the polishing will be done by mechanical action.

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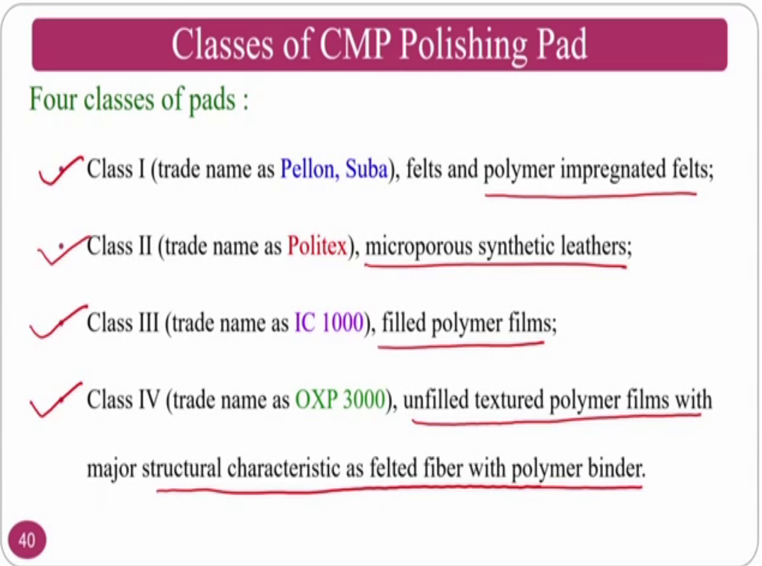

Four classes of pads are there; these are the varieties of classes. One is polymer impregnating felts, the second category is micro porous synthetic leathers this and the third category is filled with polymer films. Normally, your pad will have polymer films and you can also fill, the fourth category is unfilled textured polymer films with major structural changes as well as filled fibre in the polymer binder.

So, you have advanced polymers, since this particular course is about polymer assisted abrasive finishing process you can use polymers, you can use leathers in this case also at the same time, filled polymers also you can use that mean that you can fill some other things are whenever you fill the slurries, it can fill and you can do the polishing or advanced polymers also can be used in this process.

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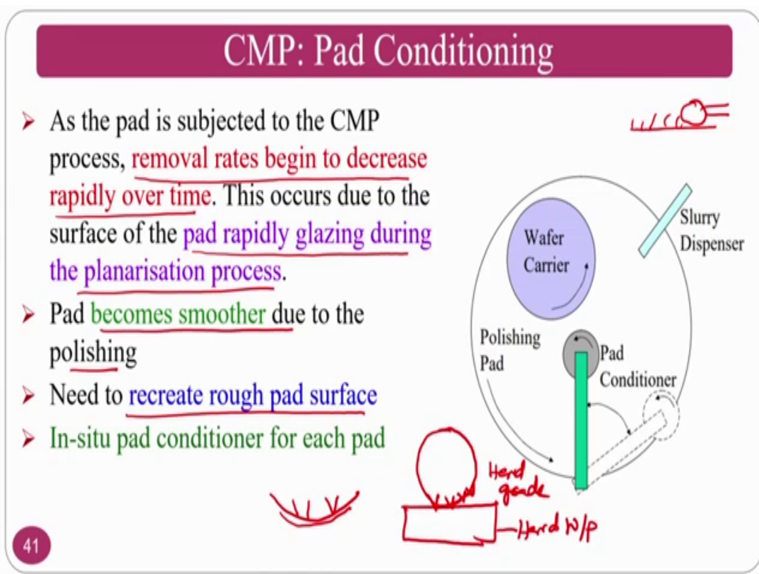

Pad conditioning; normally pad conditioning means you have to maintain its basic properties. So, the pad is subjected to CMP process, normally removal rate begins to decrease rapidly over the time; that means that this pad is constant one. So, you are going to use work pieces day by day. Assume that today we have this whatever piece tomorrow you are going to use another work piece like that if you are going to increase number of work pieces what will happen? Pad is constant. So, this start deteriorating.

Then what will happen? The glazing. Pad rapidly glaze during the planarization process; that means, that some of the BTech students who are watching they might have no this glazing work anyhow masters and PhD and faculty people may know what is glazing. If we have a grinding wheel whose grade; that means, that gripping of abrasive particle is very high with respect to a hard work piece. What will happen? Neither the abrasive will be dislodge from the grinding wheel nor it can remove the material removal as per the requirements of the manufacturer. In that circumstances abrasive particles will wear out.

What I mean to say is that this is my abrasive wheel, I have abrasive particles. If I am using hard grade versus hard work piece in that circumstances what will happen? Hard grade means it is held properly or tightly, So, it cannot dislodge mean that circumstances this will goes off; that means, your abrasive particles will goes off. These abrasive particles will goes off and it will stay inside some of the inside; that means, that this

surface will become smooth and glaze; that means, that it is looks very clean and glaze that is called a glazing.

The pad becomes smoother due to the polishing need to re create rough surface; that means that this pad is like a dresser in a grinding wheel process or the grinding process dresser will be there you use the dresser diamond dresser what will happen? The wheel will get the new abrasive particles again but the diameter in microns level it may reduced.

So, this pad also become very smooth glaze. For that purpose if you use a pad conditioner what will happen? This will make the surface rough because your pad have asperities like this. This asperities will goes off if you are using for longer longer time what will happen? Your asperities goes off. In that circumstances you are use a pad conditioner and again it will re generate to the lateral asperities.

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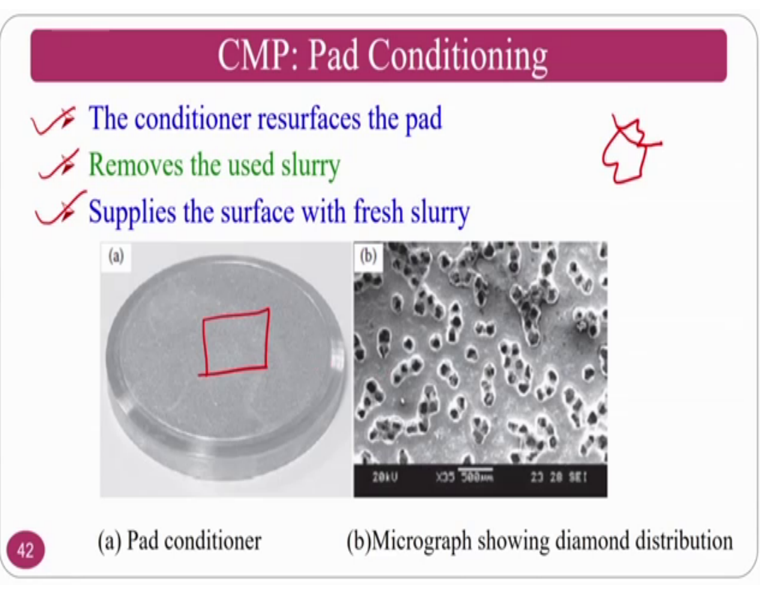

You can see the pad condition mean the conditioner this surface is the pad removes the used slurry and supplies the surface with a fresh slurry.

That means that it is not only taking out the used slurry; that means, that my abrasive particle assume that this is my abrasive particle edges are gone. So, it is blunt in that circumstances what will happen? It has to be replace that pad conditioner try to replace the used slurry with a new slurry. At the same time it will also resurfaces, the asperities

to come up. You can clearly see the pad conditioner and micrographs and diamond distributions on the pad condition and other things.

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Pad Condition in CMP

- The pores of the pad become closed, reducing slurry delivery to the wafer surface and causing an unstable and lower removal rate.
- This can be achieved by pad conditioning, which opens the pores of the pad by forming micro-scratches on the pad surface.
- Typically, a diamond disk is swept across the polyurethane pad surface to obtain a stable process and maintain a consistent removal rate.

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The pad conditioning in CMP this pores of the pad become closed reducing the slurry delivery to the wafer and causing an unable and lower the material removal rate if you don't do the pad conditioning and can be achieved by the pad conditioning which open ups the pores because this become smooth means the pores are completely filled with a used slurry.

So, you have to take out that one then only it will do its original functions, so that you can pore the next phase of new slurry. Typically, diamond disk swept the across the polyurethane pad surface to obtain the stable process and maintain the consistent material removal; that means, that it will act as a dressing material.

There in the grinding wheel you have to use a diamond dresser so that you will do the dressing operation. Here also you have to use a diamond disk so that the pad conditioning will be done.

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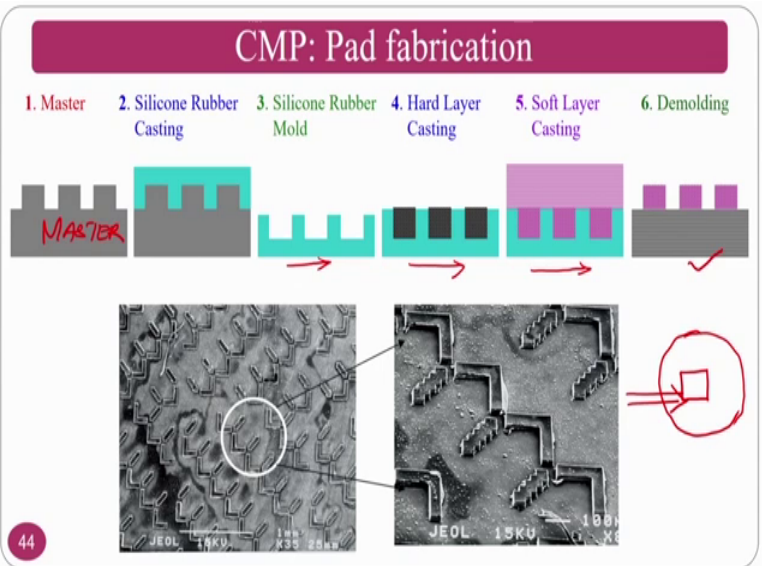

Now, how the pad will be fabricated? So, chemo mechanical polishing pad you take the master first then you put some silicon rubber casting in a gel form then you take out the silicon mould then you just put some hard casting layers on it then you followed by soft casting layers and now you can remove this one by demoulding process what you are going to get is some patterns this patterns. For example, if you see the fabrication of pad you will be there at the bottom. This is preparatory from company to company they will have their own different different patterns of the pads.

That is what you can see here on the scanning electron microscopy, but whenever you see in a naked eye it will look a simple nothing is there on the it. For a view of this pad and other things you have to zoom it up and you have to check then only you can see the surfaces and how the fabrication is done on the surfaces.

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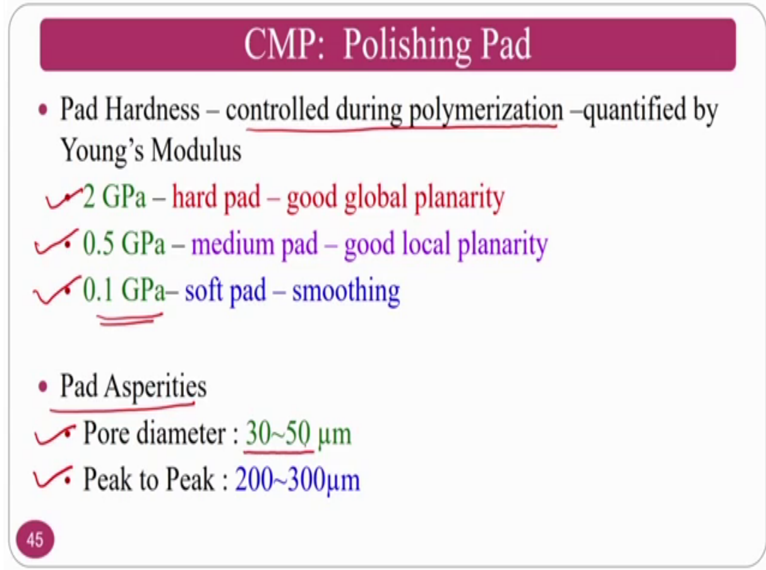

Polishing pad normally pad hardness control during the polymerization process and the qualified by the Young's modulus normally 0.2 GPa hard pad, 0.5 GPa medium pad, 0.1 GPa will be soft pad; there are 3 varieties and pad asperities you can also maintain the pore diameters. If the pore diameter is approximately 30 to 50 microns and peak to peak normally you will it will be like 200 to 300 in the polishing pad of chemo mechanical polishing.

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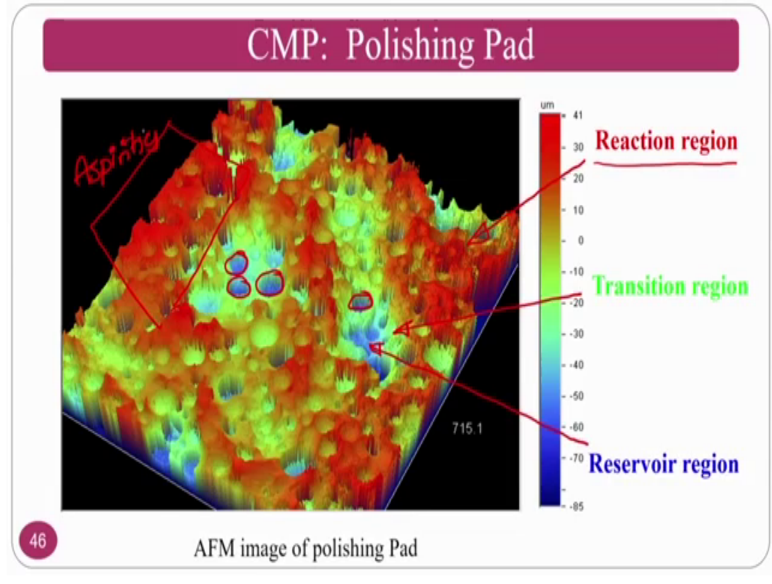

Now, you can see the atomic force microscopy image of the pad. So, there are 3 regions; one is a reaction region the red ones whatever the red ones which are visible that is called the reaction region, the green ones is transition region and the blue ones which are there is the reservoir region; that means, at your pad should do multiple actions and perform multiple jobs. So, the top layer will do the chemical reaction with respect to the work piece and the transition layer will always work between the reservoir and reaction.

If the chemical is incomplete or insufficient the reservoir will supply to the reaction region. At the same time what you have to observe here is how the surface is made here. Polyurethane surface having asperities as well as pits; these are the pits are there and some places asperities are there ok. This asperities and holes will hold the abrasive slurry which is also combination of the chemical. The chemical will do the chemical etching and abrasive particle will do the polishing action and the reservoir keeps the abundant amount that is required for the polishing action.

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Effect of Temperature on Polishing Pad

- Subjected to elevated temperature due to frictional forces at solid–solid contact
- Local heating of the pad leads to rise in temperature up to 30°C.
- The effects of pad heating are compounded if the chemical reaction between slurry and pad is exothermic.
- Mechanical, physical and chemical properties of the polyurethane material permanently or temporarily altered if heated beyond limit.
- Temperature averaged over the pad/wafer contact area. Local pad temperature during CMP may increase significantly, especially at the localized points of contacts between pad and wafer
- To avoid additional pressure, the pad is operated in the temperature range within which its co-efficient of thermal expansion is zero

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The temperature on polishing pad whenever it is subjected to a elevated temperatures due to frictional forces and other things solid; solid contact will be there and local heating pad may rises approximately up to 30 degrees which is may not be that much and the effect of pad heating is compounded if the chemical reaction between slurry and pad is exothermic normally depend on the chemical reactions endothermic exothermic will be there. Whenever exothermic reactions are there, it will produce and there will be a

problem in the pad. The mechanical and physical and chemical properties of the polyurethane mechanical permanently or temporary alter the heating beyond the limit.

So, the temperature average over the pad wafer contact area and may increase significantly especially at the localised point only; that means, that whenever there is a more and more friction what will happen is that will localised heat will be taken place.

To avoid additional pressure pad is operated with the temperature range below which its coefficient of thermal expansion is 0; that means, that normally polyurethane and other polymers are temperature resistive. So, they would not deteriorate that much fast. At the same time and the operator or a manufacturing engineer should be much cautious. They have to operate below the temperature where the thermal coefficient of expansion should not increase; that means, that it should be stable around 0.

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CMP Slurry

- Slurries consist of small, abrasive particles of specific size in the range from 10 to 1000 nm and specific shape suspended in an aqueous solution.
- Chemicals in the slurry react with surface materials, form chemical compounds that can be removed by abrasive particles.
- It should also be easily cleaned from wafer surface and cause no defects to the wafer surface such as scratches.
- Slurry mechanically abrade the wafer surface and remove surface materials.
- On the other hand, additives in the slurry solution react with surface materials or the particulates and dissolve the surface material or form other compounds that can be removed by abrasives particles.
- An ideal CMP slurry should be able to achieve high removal rate, excellent global planarization, good surface finish, less defects.

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Slurry; the slurry consists of small abrasive particles specified in the range of 10 to 1000 nano metres; that means, that it is the abrasive particles are very super fine and these are suspended in aqueous solution. As I said for silicon normally people use a surface solution. The chemicals that slurry react with the surface material and the chemical compounds can be removed by the abrasive particles and should be easily cleaned from the wafer surface.

That means that if you have abrasive particles held on the surface and other things what will happen? It means required tremendous cleaning procedures, but ideally the slurry should be easily cleanable. So, if it is water there is no problem. The slurry mechanically abrade the wafer surface and remove the surface material.

On other hand, additives in the slurry solution reacts the surface materials or particulates dissolve the surface material or as we have seen the passivating layer is it will develop a soft layer and forms a compounds and which can be removed by the abrasive particles. This is same that explained in a earliest slide whenever you have a chemical it will make a passive layer or it try to dissolve make smooth. So, that abrasive particle can shear it very easily.

So, CMP slurry could be able to achieve high material removal and excellent planarization, good surface and less defect. It should not react much with the wafer because wafer is the one that is directly in contact with the work piece and if the chemical it is going to destroy the wafer; that means, that there is biggest problem for the chemo mechanical process.

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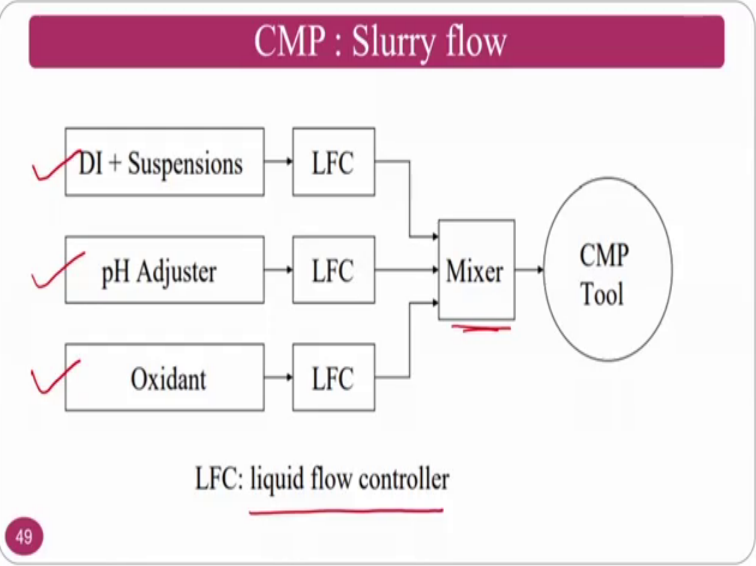

That is why slurry flow if you see DI arise water and suspensions; that means, that abrasive suspensions and pH adjuster and oxidant will all mix at the mixer then it will be submitted to the chemo mechanical polishing tool. So, these are all can be controlled by a liquid flow controller.

Everything will have the liquid flow controller, how much I want whether 10 ml of D I plus suspension or 2 ml of pH adjuster or 5 ml of oxidant, how we require. Oxidant normally will do the oxidation process of the work piece surface because that is normally a metal then the polymer based polyurethane pad may not get oxidation because it is a basically polymer.

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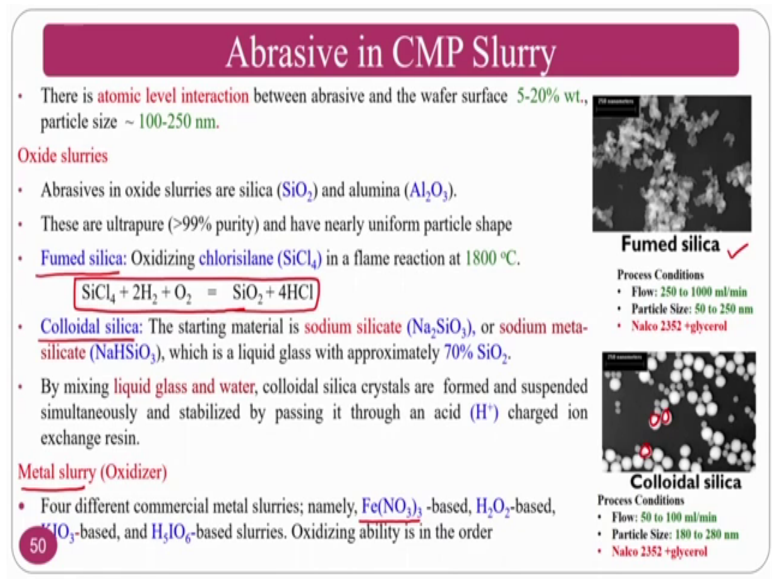

So, abrasive slurry basically there are 2 varieties of abrasive slurries you can see that is called oxide slurries and metal slurries. So, in oxide slurries we have fumed silica and colloidal silica. So, fumed silica is nothing, but the SiO 2 and it can form like this and the colloidal silica will be another variety.

Now, you can see the surface morphology of fumed silica; this will be not as spherical as the colloidal silica looks like that is why colloidal silica will give better results. At the same time you can also go for metallic slurry where your FeNO 3 and other based metallic slurry also can be used in a abrasive in a CMP process that is commonly used abrasive slurries are fumed silica as well as colloidal silica.

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CMP: Other Parameters

- Slurry flow rate
- Particle less slurry
- Abrasive particle surface coating
- Abrasive particle size
- Abrasive particle concentration

The other parameters of CMP; there are many many parameters. If I start teaching it will be big lecture basically. So, some of the people who are interested to know about this processes lot of papers are there which you can read. So, CMP itself will be one of the courses in particular semesters in abroad nations like Taiwan and US and other places. CMP process is a semester course. So, you can go through those courses slurry flow rate how much flow rate I have to use the abrasive particles along with the chemicals that can be controlled in the slurry flow and the particle less slurry whether I want to use along with the particle or I don't want to use.

If I am not going to use what will happen? The mechanical action will be slightly reduced and it will be depend on the friction between your pad as well as your work piece only. So, abrasive particle surface coating, whether if you want any advanced abrasive particles like a function lies in the abrasive particles and other things. And abrasive particle size; if you are going to use fine then you will get a better surface if you are going to use the core abrasive particle then you will get a rough surface. So, what is the surface roughness that you want according to that you have to choose the particle size.

Now, the particle concentration; if you are going to use more and more number of particles that mean if the abrasive particle concentration is high the finishing rate will be high and the finishing time will be reduce.

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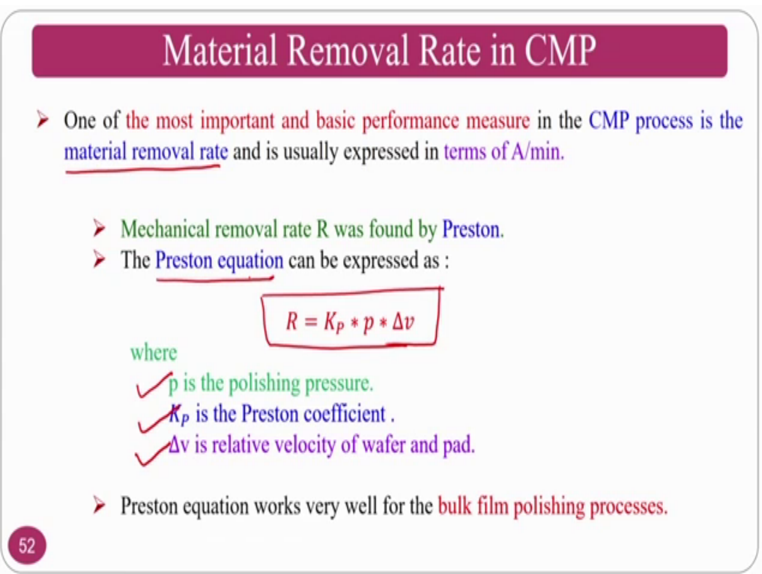

Material removal rate in terms of chemo mechanical polishing; one of the most important and basic performance measure in the chemo mechanical polishing is material removal rate. This is usually represented by this particular equation where R equal to K p rho delta v; where p is the polishing pressure, K p is Preston coefficient and delta v is relative velocity between the wafer and the pad. This normally represented as Preston equation. So, this equation represents the how much material is removed from the work piece in a chemo mechanical polishing, but every process will have its own issues.

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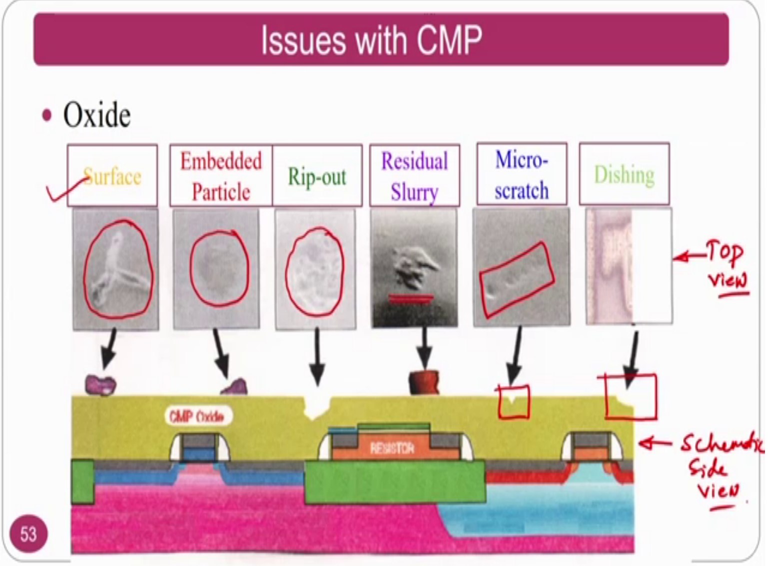

You can see here, surface some of the defects will be there m embedded particle; that means, that your particle can embed inside the polyurethane foam rip out. So, some of the material can come out at the same time residual slurry will remain on the pad itself even though the conditioning is done still there will be a some residual slurry will be there, 100 percent nobody can clean the surface.

Micro scratches you can see the micro scratches can be done on the pads which can reflect like this at the same time dishing. So, at the edges there will be some of the material that will goes off. Similarly the top view these are all shows the top view and this shows the schematic side view so that you can see the basic issues in the chemo mechanical polishing especially in the pad.

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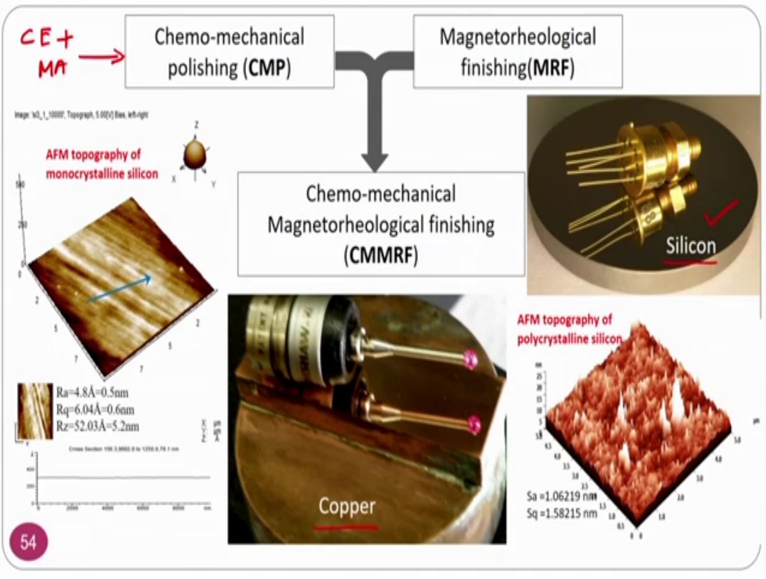

See this is what I want to tell you that whenever you understood certain process you should understand what is its applications. So, one of the hybrid chemo mechanical polishing itself is a hybrid. How? Chemo mechanical polishing is combination of chemical etching plus mechanical abrasion. Chemical etching plus mechanical abrasion; this will give the chemo mechanical polishing that is why chemo mechanical polishing itself is a one of the hybrid polymer based finishing process.

If you are going to add this particular process with magnetorheological finishing where you are magnetorheology where iron particles are there, regarding magnetorheological finishing process you will go through in the upcoming slides where I will just give you a

glimpse of 2 3 slides whenever you are going to study about magneto abrasive flow finishing process where magnetic field will be used for finishing along with the polymer abrasive medium.

There you will see the, what is magnetorheological finishing. If these 2 process are combined then you get a very super fine surfaces on metals especially soft metals as well as brittle materials also. Normally, finishing is very difficult in soft metals because indentation resistance is very low that is why getting a super fined surface and soft materials like copper aluminium is very difficult, but you can get very good surface on silicon and other hard and brittle materials. I am very thankful for this particular slide to Prabhath Ranjan as well as professor V K Jain and Dr. Balasubramanyam from Bhabha Atomic Research Centre to share the slide.

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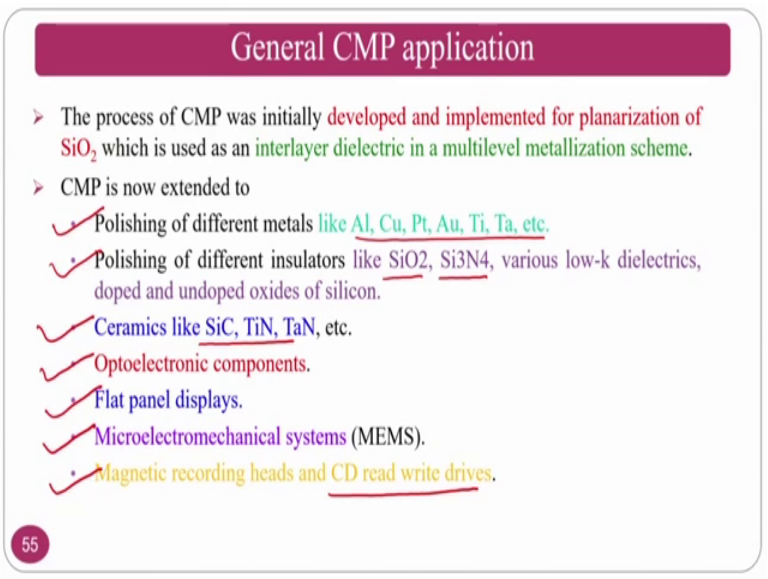

And general applications of chemo mechanical polishing; you can see that it can be extended to different materials like aluminium, copper, platinum, titanium tantalum and other things; polishing of the different insulating materials SiO 2, Si3N4 and other things. Ceramics also can be polished like silicon carbide and other, optical optoelectronic components, flat panel displays, MEMS, magnetic recording heads and CD’s; these are all can be polished using CMP. CMP process will have tremendous applications. If you can master in it and if you can make a CMP process that means, that you have a good market across the globe, ok.

Thank you for your kind attention for this particular class.