UNIT – IV NANO FINISHING PROCESSES

In order to substitute manual finishing process and to meet the functional properties such as wear resistance, power loss, due to friction on most of the engineering components, we go for advanced machining process. This finishingprocess is carried out at micro and nano level. This process is called as advancednano finishing process.

Nano finishing is the only operation which can make rough surfaces in nanometers range. The ultimate precision through finishing will be where processed where there is a change in size of sub nanometer.

It offers batter accuracy, higher efficiency, economic and consistency. Some of the nano finishing processes are

1. Abrasive flow machining
2. Chemo mechanical polishing
3. Magnetic abrasive finishing
4. Magneto rheological finishing
5. Magneto rheological abrasive flow finishing

4.2. ABRASIVE FLOW MACHINING

4.2.1. PRINCIPLE

In abrasive flow machining process, the semisolid abrasive media acts as deformable grading wheel; which helps to remove small amount of materials.

The abrasive media is given larger force or velocity by hydraulic or mechanical means to push the media into the areas in which conventional finishing process cannot be performed.

4.2.2. CONSTRUCTION AND WORKING OF AFM

The schematic arrangement of abrasive flow machining is as shown in figure.

The main elements of AFM are (*i*) Machine (*ii*) Tooling (*iii*) Media (iv) Workpiece.

Machine

- The machine consists of two opposing hydraulic cylinder with piston rod and base plate.
- The two opposing medium charmless are hydraulically clamped together with the workpiece in between them.
- When hydraulic pressure is applied in the media containing the abrasive particles moves over the workpiece surface and removes the peaks the surface.
- Pressure and temperature control devices are provided at appropriate setup in order to monitor the pressure and temperature of the media.
- Replaceable inserts are provided at various points in experimental setup. It is made of nylon, Teflon and other materials which is used for restricted flow of media. The inserts can be replaced on worn out conditions.

Tooling

- The tool used in AFM process is the media.
- It consists of organic polymers and special hydrocarbon gel. This gel along with the abrasives is present at the base of the setup.
- Tooling design in AFM permits or block the flow of media in or out of the work surface.
- Tooling is selectively and controllably used in areas were material in the workpiece is removed.
- Tooling holds the media, it confines and allows the flow of abrasives to the desired size into the workpiece surface at desired force or velocity.
- The machining rate depends on the stiffness of the media and the restriction to the flow of media.

Media

- ❖ The media consists of the base and abrasive grits.
- ❖ The base contains organic polymers and hydrocarbon gel. It exists in semisolid form.
- ❖ The abrasive grits used along with the base are Aluminium oxide, silicon carbide, boron carbide and diamond.
- ❖ These abrasive grits are mixed with the base by mechanical means to forma semisolid laden putty.
- ❖ The abrasive grits with the base is called the media. It is used to abrade the surface of workpieces, when it moves through restricted areas and resist abrasive action.
- ❖ The composition and mechanical mixing determines the stiffness of the media.

Workpieces

- ❖ The material such as metals and metal alloys are used as workpieces. These workpieces are flat or cylindrical in shape.

Working

- ❖ The hydraulic rams are those which alternatively compress and extrude the abrasive medium from the bottom cylinder to the top through the workpiece.
- ❖ The pressure of the extruding medium is in the range of 0.70 to 0.22 MPa or 100-3200 PSI.
- ❖ Abrasive grit size are 8 to 700 mesh, which enable quick cutting action. Fine grit size are 300-700 mesh for the medium to increase the stiffness.
- ❖ The medium may be mixed with hand or cycled 20-50 times through scrap parts. On repeated action, the medium loses its cutting ability more abrasive or base can be added to reconstitute the mixture.
- ❖ The excess medium is removed from parts using air or vacuum. Also solvents are used to dissolve and destroy the base.

- While tooling, maximum machining takes place when there is a maximum restriction in media or flow of abrasives.
- The media stiffness is also used to determine the stock removal. If media has high stiffness, it will result in a flow patterns of pure extrusion process.
- If the media has low stiffness, then media flow in the centre is faster than along the walls.
- The pressure and temperature inside the media is determined and controlled.
- The force acting on the media are the viscous components assist to exert axial forces and tries to move along the direction of applied extrusion pressure.
- The elastic component assists in exerting radial force which presses the active abrasive particles into the workpiece surface.
- The viscous and elastic components are used in removing the material in the form of micro nano chips.
- For effective movement of the chips, the axial force should be greater than the required force because it increases the depth of penetration and remove the material.
- The surface finish obtained by this process is 0.05 μm.
- The force and velocity diagram in AFM are as shown in figure. 4.1.

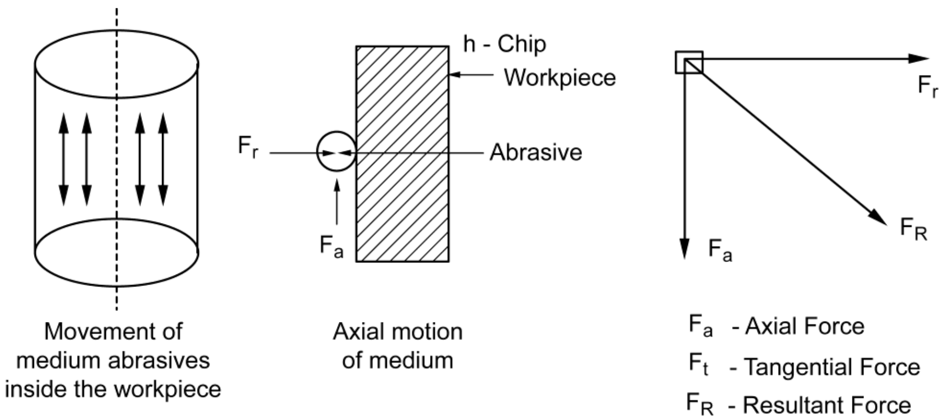

Fig. 4.1. Force diagram of abrasive flow machining

4.2.3. TYPES OF ABRASIVE FLOW MACHINING

The types of abrasive flow machining are

1. One way abrasive flow machining
2. Two way abrasive flow machining
3. Orbital abrasive flow machining

1. One Way Abrasive Flow Machining

The abrasive processing pushes the media in one way flow as shown in figure.4.2 The abrasive media passes in one way processing through the workpiece and exit freely from the other part.

The Advantages of One Way AFM

- ❖ The process is faster and easy to clean up small holes in turbines.
- ❖ Machining of larger parts can be done.
- ❖ Temperature control of the media is not required.

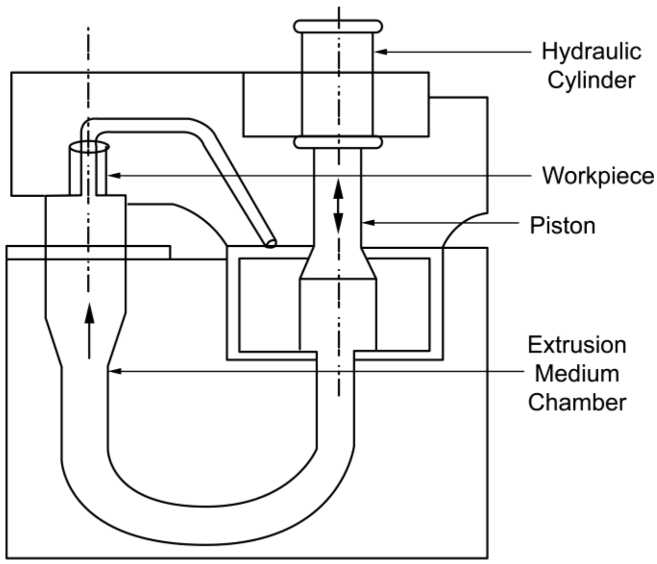

Fig. 4.2. One way abrasive flow machining

2. Two Way Abrasive Flow Machining

The two way AFM process uses two vertically opposite cylinders to extrude the abrasive media in backward and forward direction through or around the passage formed by the workpiece and tooling.

Abrasive action on the workpiece takes place, when the medium enters and passes through the passage as shown in Figure. 4.3

The Advantage of 2 Way AFM

- The process control is excellent
- The process is used to finish the internal ends and outer diameter of the components
- Radiusing is done effectively
- Fully hydraulically controlled system
- Factor changeover of the media

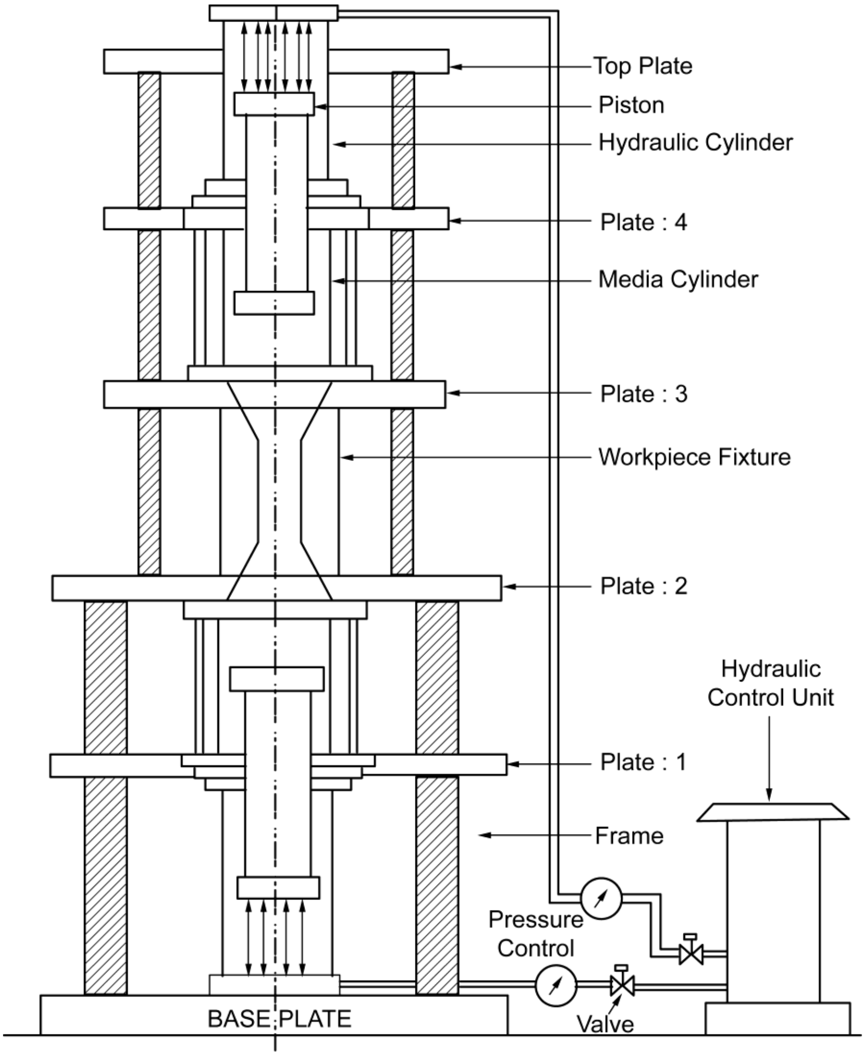

Fig. 4.3. Arrangement of two way abrasive flow machining

3. Orbital Abrasive Flow Machining

This machining process is done by rapid. low amplitude, oscillation of the workpiece relative to self forming elastic plastic abrasive polishing tool.

The tool is a pad or layer of abrasive laden elastic plastic medium.

The medium used here are higher in viscosity. The medium is pushed from one side with the piston through cylinder as it passes through the workpieces and machining takes place when abrasives passes through the workpiece. The detail is shown in figure 4.4

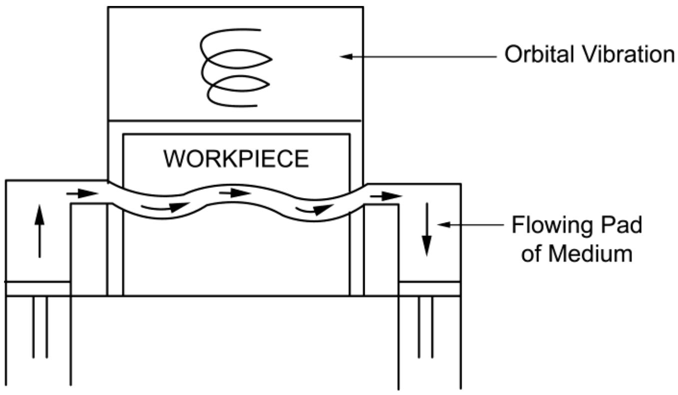

Fig. 4.4. Orbital abrasive flow machining

4.2.4. PROCESS PARAMETERS IN ABRASIVE FLOW MACHINING

The metal removal rate depends upon the following parameters.

1. Addition of plasticizers
2. Extrusion pressure
3. Number of cycles

1. Plasticizer Vs Change in Surface Roughness

- In process addition of silicon carbide percentage increase the surface roughness of the components.
- This graph shown at 15% addition of SiC in the Plasticizer has the maximum surface roughness value.
- The maximum surface roughness value is obtained at 15% addition of SiC and maximum at 10% ωt of plasticizers.

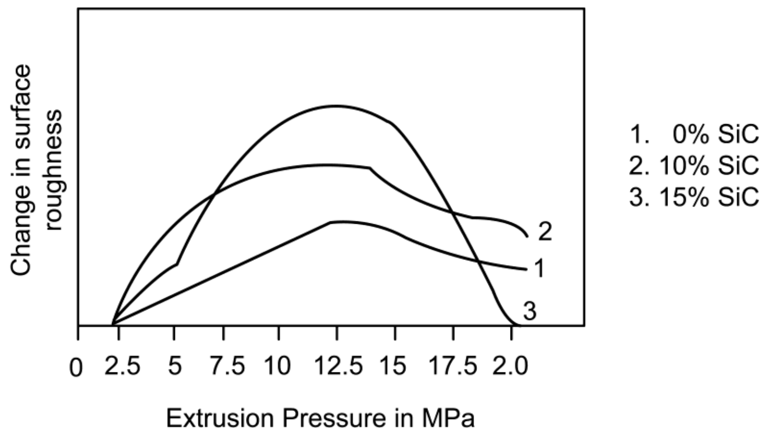

Fig. 4.5.

2. Extrusion Pressure Vs Change in Surface Roughness

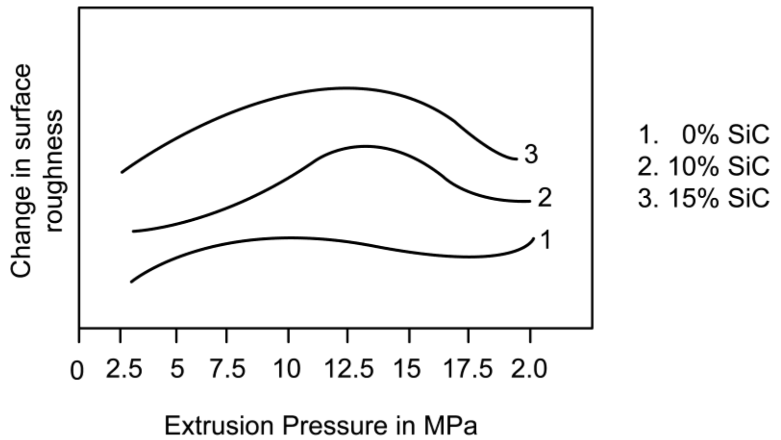

Fig. 4.6.

From this figure 4.6 the graph shows the maximum change in surface roughness. When 15% of silicon carbide is added to medium and moved in optimum extrusion pressure.

3. Finishing Cycles Vs Change in Surface Roughness

- The surface roughness of components increases with maximum number of finishing cycles.
- As the finishing cycles are increased from 100 to 400, the surface roughness also increased and good surface finish is obtained.
- The number of finishing cycles are controlled by mechanical counter.

4.2.5. ADVANTAGES OF AFM

- ❖ Operations such as deburring polishing and radiusing can be done.
- ❖ This process is more suitable for batch production
- ❖ It is faster than manual finishing
- ❖ It can finish inaccessible areas in one single movement.

4.2.6. LIMITATIONS OF AFM

- ❖ It has low finishing rate compared to other nano finishing process.
- ❖ The process involves high production time and high production cost.
- ❖ There should be repeated replacements of poly abrasive media that is used in AFM process.

4.2.7. APPLICATIONS OF AFM

AFM is used in finishing of

- ❖ Extrusion dies
- ❖ Nozzle of flame cutting touch
- ❖ Air foil surfaces of impellors
- ❖ Accessory parts like fuel spray, nozzle, fuel control bodies.

4.3. CHEMO MECHANICAL POLISHING

4.3.1. INTRODUCTION

Chemo mechanical finishing or CMP was adopted by IBM in 80‟s for Si polishing.

Chemo mechanical polishing is a process of smoothing and planning surface with the combination of chemical etching and free abrasive polishing.

CMP of silicon wafers is a basic processing technology for production of flat, defect free, highly reflective surface.

This planarization method is a choice for < 0.5 micron technologies.

4.3.2. PRINCIPLE

In chemo mechanical polishing, a chemical reaction is used to soften the material and then mechanical polishing is done on the layer. The polishing action is partly mechanical and partly chemical.

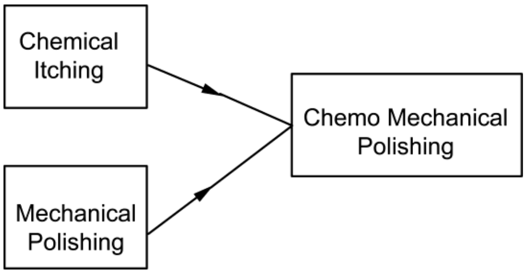

Fig. 4.7.

The chemical reaction that takes place soften the material and the mechanical element of the process applies downward pressure.

4.3.3. Construction and Working of CMP

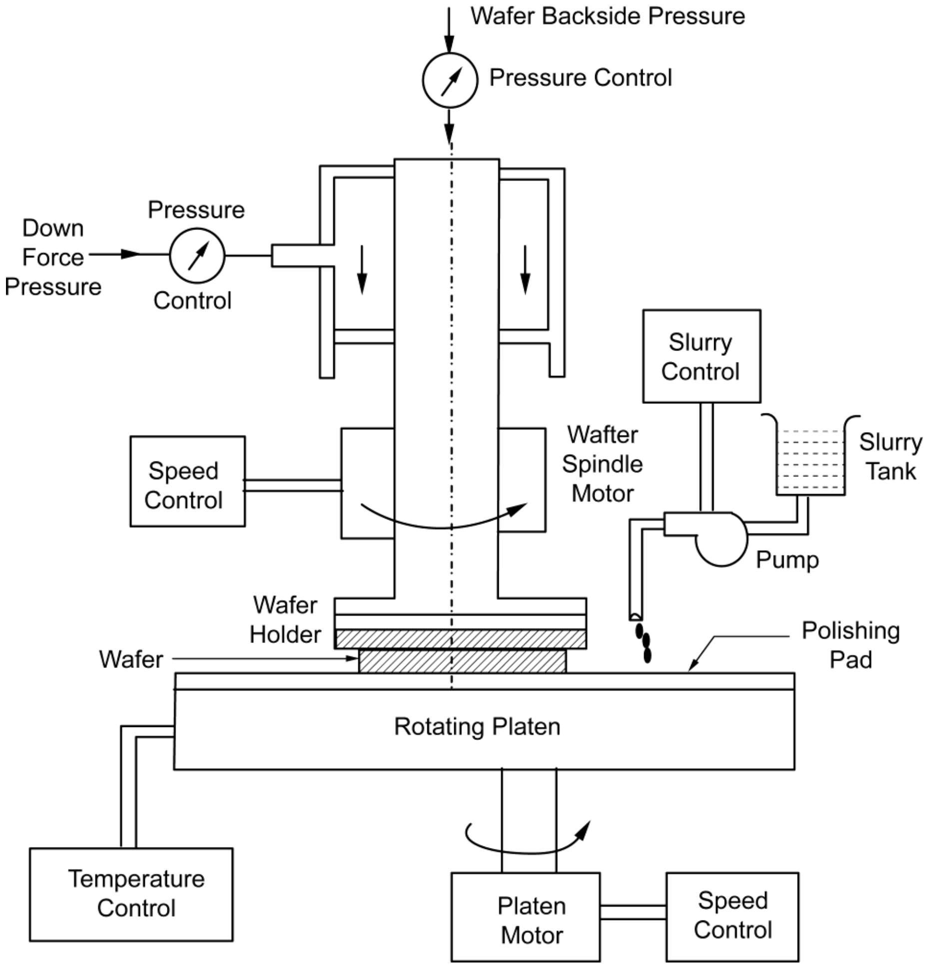

Fig. 4.8. Chemo mechanical polishing

The schematic arrangement of chemo mechanical polishing is as shown in figure 4.8.

CMP consists of the rotating platen. CMP polishing pad, workpiece, CMO slurry with abrasive, speed, temperature and pressure control system.

Rotating Platen

The experimental setup consists of a rotating platen which is controlled by motor and a controlling device. This platen is the place where the slurry flows and forms a thin colloidal layer.

CMP Polishing Pad – Material

CMP polishing pad consists of porous flexible polymer material made up ofmatrix of cast poly form with filler material to control hardness of polyurethane impregnated felt. The filler material improves the mechanical properties.

Properties of Pad

Polyurethane pad has a unique property of combining high strength, high hardness, and modulus combined with high elongation at failure.

The pad material should be durable, reproducible and compressible at process temperature.

Cells absorb polishing slurry and executes the polishing action and transmits the normal and shear force required for polishing.

Types of Pad based on its Hardness

The hardness is quantified by Young‟s modulus value.

- ❖ 2GPa – hard pad – good global planarity
- ❖ 0.5 GPa – medium pad – good local planarity
- ❖ 0.1 GPa – soft pad – good llocal planarity

Pad Asperities

Pores diameter – 30 – 50 µmPeak

to peak – 200 – 300 µm

CMP Slurry

Slurries consist of small abrasives of size from 10 to 1000 μm and specific shape suspended in an aqueous solution.

Function of Slurry

Chemicals in the slurry reacts with surface material and form chemical compounds that can be removed by abrasive particles.

Slurry mechanically abrade the wafer surface and remove surface material.

Additives in the slurry solution reacts with surface material or the particulates.

Able to achieve high removal rate, excellent planarization, good surface finish and lens defects.

Abrasives in CMP Slurry

There is atomic level interaction between abrasives and wafer surface. The types of abrasive used in slurry are

- Oxide slurry
- Metal slurry

Oxide Slurry

This slurry contains silica and Alumina (SiO_2+ Al_2O_3). Fumed silica oxidizes chloro silane in a flame reaction at 1800°C.

- The reaction involved is

$$SiCl_4 + 2\ H_2 + O_2 \rightarrow SiO_2 + 4\ HCl$$

- The process condition are

Flow rate - 250 to 1000 m*l* / min

Particle size - 50 to 250 nm

- Colladial silica used in this reaction are sodium silicate (Na_2SiO_3) and sodium metasilicate ($NaHSiO_3$).
- The process condition are

Flow rate - 50 to 100 m*l* / min

Particle size - 180 to 280 nm

- This is done by mixing liquid glass and water.

Metal Slurry

The various types of metal slurry used are

- $Fe(NO_3)_2$ – based
- H_2O_2 – based
- KJO_3 – based
- H_5IO_6 based slurries having oxidizing ability

CMP Tool

The dielectric with suspension of slurry along with pH adjuster and oxidant with its local flow controller controls and mixes to form the CMP tool.

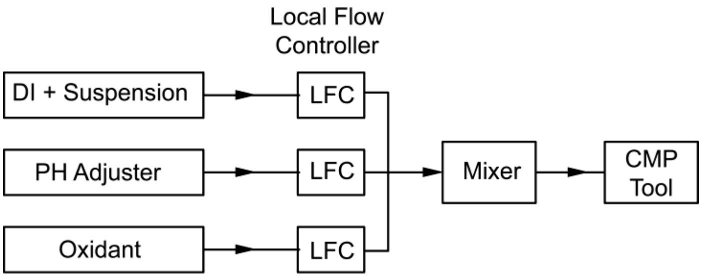

Fig. 4.9.

Working

In chemo mechanical polishing, the pressure is applied by down force on the carrier. The force is transferred to the carrier through the carrier axis.

The gas pressure is loaded on the wafer. The higher points on the wafer are subjected to high pressure and the removal rate are enhanced.

The wafer face is mounted upside down.

The carrier is pressed against a moving plates containing a polishing pad. The carrier also rotates.

The slurry is supplied from above the platen. The slurry may be oxide or metal type.

An abrasive containing aqueous slurry is dripped onto the table and centrifugal force distributes the slurry across the pad.

This forms a thin colladial layer of slurry which saturates the pad.

In aqueous solution, oxide form hydroxyl and hydrogen bond between slurry particles and wafer.

The silicon dioxide bonds are formed by releasing water molecules. Thus chemical reaction occurs and the silicon bonds also brakes when the slurry particles move away.

The combination of mechanical effect and chemical reaction results in material removal from the surface of the wafer.

The material removal is more or less in atomic level.

The process is explained in two aspects

1. Chemical aspects of material removal
2. Mechanical aspects of material removal

Chemical Aspects of Material Removal

The process uses a chemical etching to soften the workpiece surface and the mechanical polishing off the layer takes place.

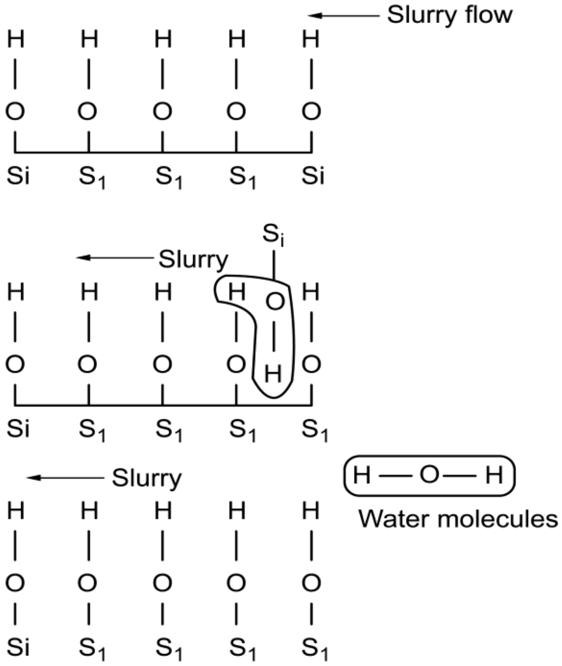

Fig. 4.10.

The chemical reaction removes surface texture and allows multiple interconnected layer to be used. This process of softening the material is called passivation.

The thickness of passivation depends on chemical reaction kinetics and relative velocity.

The chemical behind the chemical aspects in slurry with pressure forms a reaction of film to soften the surface of material.

In aqueous solution, oxide forms hydroxyl. Hydrogen bond in formed between the slurry particles and the wafer. Later Si_2O bonds are formed releasing water molecules.

And this Si_2O bonds breaks when the slurry particles move away. The reaction that occurs in polishing of metals are

In Si polishing it forms

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

In copper

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

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

In tungsten

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

Thus this reaction softens the material and then mechanical aspects come tomaterial removal.

Mechanical Aspect of Material Removal

When abrasives are present in the slurry then substantial material removal takes place due to abrading, but when there is no abrasives in the slurry the material removal purely takes place due to mechanical friction and result of pressure down force applied.

Polishing takes place when fine abrasives produce brittle fracture on the work surface. The materials are removed in step by step process by means of plastic deformation and finally produce a smooth mirror surface.

The process detaches material from the surface in a relative motion caused by protrusion of fixed and free abrasives between opposing surfaces of the polishing pad and workpiece.

The polishing technique consists of both mechanism of 2 body or 3 body abrasion, but dominance of either of them depends largely on the polishing condition during the process.

The six possible two way interaction are

- Fluid and workpiece
- Workpiece and pad
- Workpiece and abrasive particles
- Abrasive particles and pad
- Pad and fluid
- Fluid and abrasive particles.

Also four possible three way interaction are

- Workpiece, fluid and abrasives
- Work[piece, abrasives and pad
- Fluid, pad and abrasives.

The process parameter involved in CMP process are

- Process : 10 to 50 kPa
- Platen / carrier rpm: 10 to 100 rpm
- Velocity – 10 – 100 cm/s
- Slurry flow rate – 50 to 500 m/min

Typical material removal rate

- Oxide CMP – 2800 A° / min
- Metal CMP – 3500 A° / min

Some of the other process parameters are particles slurry, abrasive particle surface coating and abrasive particle size and concentration.

The mechanical material removal rate was given by person. This is called perston equation.

$$R = k_p \times P \times \Delta V$$

The equation works good for the bulk film polishing processes

where P - is the polishing pressure

k_p - perston coefficient

ΔV - relative velocity

4.3.4. FACTORS AFFECTING PROCESS PARAMETERS

The factors affecting process parameters are

- ❖ Temperature in the polishing pad
- ❖ Conditioning of polishing pad.

Effect of Temperature on Polishing Pad

Due to fractional forces at solid to solid contact, there is increase in temperature.

- ❖ The temperature rise of 30°C takes place on local healing of the pad.
- ❖ When the temperature increases beyond the limit the mechanical, physical and chemical properties of the pad will get changed.
- ❖ In order to avoid any additional pressure on the pad, the temperature range of the pad should be within its coefficient of thermal expansion which is zero.

Effect on Conditioning of Polishing Pad

- ❖ When the CMP pad is used in polishing process, the removal rate begin to decreases rapidly overtime. The pad becomes smoother due to the polishing.
- ❖ The conditioner of the pad is that the slurry used for machining is removed and the surface is supplied with fresh slurry.
- ❖ The pores of the pad is closed and delivery of slurry is not proper causing it unstable and lower material removal of rate. This can be avoided by pad conditioner which opens the pad by forming micro scratches on the pad surface.

4.3.5. ADVANTAGES OF CMP

- It is used to polish metal like Aluminium, Copper, Silver titanium etc.
- It can also polish insulators like SiO_2, Si_3N_4.
- Ceramics like SiC, TiN, TaN can also be polished.

4.3.6. LIMITATIONS OF CMP

- Cleaning of platen surface in a difficult process.
- Embedded particles, residual slurry are to be removed very carefully.
- Due to residues min scratches are also formed on the surface of the platenand the pad.
- Surface defects such riping out and dishing are formed on the surface.

4.3.7. APPLICATIONS OF CMP

- It is used in fabrication of semiconductor devices
- Oxides are deposited on the wafer in from of shape trenches
- Flat panel display
- Microelectronic mechanical system
- Magnetic recording head and CD writing